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

BRUNA DE RAMOS

RELAÇÕES ENTRE LIXO NO MAR, ATIVIDADES HUMANAS E FATORES METEO-OCEANOGRÁFICOS EM UMA ILHA COSTEIRA DE PERNAMBUCO-BRASIL

Recife

2025

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Tese apresentada ao Programa de Pós-Graduação em Oceanografia da Universidade Federal de Pernambuco, como requisito parcial para obtenção do título de doutora em Oceanografia.

Área de Concentração: Oceanografia Abiótica

Orientador (a): Dra Monica Ferreira Costa

Recife

2025

.Catalogação de Publicação na Fonte. UFPE - Biblioteca Central

Ramos, Bruna de.
Relações entre lixo no mar, atividades humanas e fatores meteo-oceanográficos em uma ilha costeira de Pernambuco-Brasil / Bruna de Ramos. - Recife, 2025.
96f.: il.

Tese (Doutorado) - Universidade Federal de Pernambuco, Centro de Tecnologia e Geociências, Programa de Pós-Graduação em Oceanografia, 2025.
Orientação: Monica Ferreira Costa.
Inclui referências e apêndices.

1. Lixo marinho; 2. Princípios FAIR; 3. Gestão costeira; 4. BeachLog; 5. Modelagem hidrodinâmica. I. Costa, Profa. Dra. Monica Ferreira. II. Título.

UFPE-Biblioteca Central

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Aprovado em: 03/02/2025.

BANCA EXAMINADORA

____

Profª. Drª. Monica Ferreira Costa (Orientadora)
Universidade Federal de Pernambuco - UFPE

____

Prof. Dr. Roberto Lima Barcelos (Examinador Interno)
Universidade Federal de Pernambuco - UFPE

____

Profª. Drª. Grasiela Lopes Leães Pinho (Examinadora Externa)
Universidade Federal do Rio Grande – FURG

____

Prof. Dr. Allan Paul Krelling (Examinador Externo)
Instituto Federal do Paraná - IFPR

____

Prof. Dr. Paulo Henrique Gomes de Oliveira Sousa (Examinador Externo)
Universidade Federal do Ceará - UFC

À imensidão do oceano.

AGRADECIMENTOS

Essa tese é um esforço coletivo e resultado de muita colaboração. Agradeço à CAPES pela bolsa de Doutorado e Doutorado Sanduíche, essenciais durante os quatro anos de formação. Ao DOCEAN - UFPE pelo espaço físico. Aos colegas da graduação e pós graduação em Oceanografia da UFPE. Aos professores pelas aulas e discussões, em especial Profa Tereza Araújo por compartilhar tantas experiências (malucas e perigosas) no gerenciamento costeiro e embarques, e ao Prof. Roberto Barcellos obrigada pelo acompanhamento e pelos valiosos comentários desde a apresentação do projeto no PPGO. Obrigada aos amigos que o PPGO me presenteou. Ágatha, obrigada pelos bares e conversas. Obrigada, Ellen, pelos encontros online, pelos desabafos (e fofocas), pelos conselhos, obrigada pela parceria. Um agradecimento imensamente especial à minha orientadora Profa. Monica que me acolheu na “caverna” em Recife, me orientou, escutou, apoiou e incentivou nas mais malucas e bizarras ideias que tive e tivemos em conjunto, cada ida à Itamaracá foi uma aventura diferente. Muito obrigada para sempre por todos os ensinamentos científicos e pessoais. Aos POGOs, muito muito obrigada pelo incrível ano do NF-CofE in Observation Oceanography Cohort 10 em Helgoland. Obrigada pelos jantares, cursos, envio de balões para a estratosfera, análise de dados de madrugada, e 300 mil apresentações. À Bärbel, Anna, and Eva, obrigada pela acolhida na ilha. À Vera e Dmitry, obrigada pelos ensinamento sobre modelagem e por me ensinarem tanto sobre o FESOM. Aos colegas do IOW, obrigada pela acolhida, pelos cafés às 9h30, compartilhamento de ideias, projetos e discussões. Gabi, obrigada pelas ajudas com a burocracia na Alemanha e pelas conversas no nosso Latin Team. Gerald, obrigada pela confiança e oportunidades. Finalmente, um obrigada gigante aos Queridíssimos, obrigada família por sempre me apoiarem e torcerem por mim. Cada vitória ou derrota sempre vem acompanhadas de palavras de afeto e incentivo.

El mar es a mi vida lo que al hambriento el pan; para saciar mi espíritu tengo que ver el mar.

El mar me da la norma y el ansia de vivir: su majestad es ciencia suprema para mí.

Palabras de los siglos, Obras de eternidad, ¿qué sois ante la inmensa Sublimidad del mar?
(Saulo Toron, escultura na praia de Las Canteras, Las Palmas de Gran Canaria - Espanha.)

RESUMO

A tese aborda a problemática do lixo no mar e explora abordagens inovadoras para seu estudo, com foco em dados científicos e soluções tecnológicas. Ao longo da tese, foram investigadas lacunas na disponibilidade e integração de dados sobre lixo no mar no Brasil. Os bancos de dados frequentemente não seguem os princípios FAIR (Findable, Accessible, Interoperable, Reusable), dificultando sua utilização em futuros estudos, políticas públicas e gestão ambiental. Ao entender a gestão de praias como um processo integrado, e o lixo no mar como um dos problemas ambientais presentes nos ecossistemas marinhos e costeiros, foi desenvolvido o BeachLog, uma ferramenta inovadora para descrição de praias, que permite mapear e documentar, por exemplo, características ambientais, serviços e infraestrutura sem classificações pré-definidas. A ferramenta foi aplicada em 14 praias brasileiras e foram identificadas lacunas em gestão e planejamento das praias. Foi dado enfoque em como o lixo no mar é abordado dentro de ferramentas de classificação e certificação de praias, ressaltando a importância do tópico na gestão de praias de maneira geral. Ainda no contexto do ambiente praial, foi realizado um monitoramento sazonal na Ilha de Itamaracá – PE em 2022. O enfoque foi dado ao lixo presente em áreas de banho submersas (0 a 3m) e em praias emersas na Ilha, observando-se maior proporção de incrustação em lixo submerso (87,73%) em comparação ao lixo emerso (10%). Destacaram-se diferenças significativas na composição e nas possíveis origens do lixo entre as duas áreas. Para conectar os dados produzidos na tese e entender o lixo do mar de maneira mais holística, propôs-se um banco de dados relacional que integra informações de coletas de lixo no mar em Itamaracá, dados do BeachLog e variáveis meteo-oceanográficas. O banco de dados pode ser replicado para diferentes realidades e foi desenvolvido com ferramentas open access. Por fim, utilizou-se modelagem hidrodinâmica e rastreamento de partículas para estudar a retenção de macroplásticos flutuantes em dois estuários do Mar Báltico. Apesar de focado em um contexto europeu, os resultados oferecem insights valiosos sobre o papel dos rios como reservatórios e sumidouros de lixo no mar. De maneira geral, a tese traz abordagens inovadoras que conectam ciência, tecnologia e gestão ambiental para o entendimento do problema do lixo no mar.

Palavras-chaves: Lixo marinho. Princípios FAIR. gestão costeira. BeachLog. Modelagem hidrodinâmica. Banco de dados relacional.

ABSTRACT

The thesis addresses the issue of marine litter and explores innovative approaches to its study, focusing on scientific data and technological solutions. The gaps in the availability and integration of data on marine debris in Brazil were assessed. The results suggested that often the databases do not follow the FAIR principles (Findable, Accessible, Interoperable, Reusable), hindering their use in future studies, public policies, and environmental management. Beach management is an integrated process and marine litter is one of the environmental problems present in marine and coastal ecosystems. The BeachLog tool was developed in this context, it is an innovative beach description tool that allows mapping and documenting for example, environmental characteristics, services, and infrastructure without pre-defined classifications. Applied to 14 Brazilian beaches, gaps in beach management and planning were identified. Marine litter was a focus topic and we analyzed how the subject is addressed within beach classification and certification tools, highlighting the importance of marine litter in beach management. In the context of beach environments, seasonal monitoring was carried out on the Itamaracá, PE island in 2022. The focus was on litter found in the underwater bathing area (0 a 3m) and exposed beaches on the island, showing a higher proportion of bio-fouling in the bathing area (87.73%) compared to exposed beach litter (10%). Significant differences in the composition and possible sources of litter between the two areas were highlighted. A relational database was proposed to integrate information from marine litter collections on Itamaracá, data from BeachLog, and meteo-oceanographic variables to link the data produced in the thesis and understand marine litter more completely. The database, developed with open-access tools, can be replicated for different realities. Finally, hydrodynamic modeling and particle tracking were used to study the retention of floating macroplastics in two estuaries of the Baltic Sea. Although focused on a European context, the results provide insights into the role of rivers as reservoirs and sinks for marine litter. In general, the thesis presents innovative approaches that combine science, technology, and environmental management to understand the problem of marine litter better.

Keywords: Marine litter. FAIR principles. Coastal management. BeachLog. Hydrodynamic modelling. Relational database.

LISTA DE FIGURAS

SUMÁRIO

1 INTRODUÇÃO

A preocupação com o lixo no ambiente marinho e costeiro ressalta a necessidade de soluções inovadoras baseadas em dados e tecnologia para sua mitigação e gestão. O plástico, devido à sua alta abundância e durabilidade, é um dos principais componentes do lixo no mar, persistindo no meio ambiente por longos períodos (ABALANSA et al., 2020). Ao longo das últimas cinco décadas, a literatura científica tem documentado extensivamente a presença de lixo em ambientes marinhos e costeiros (THOMPSON et al., 2009). No Brasil, estudos desde o final da década de 1990 têm enfatizado os impactos do lixo plástico em praias, destacando a importância de dados científicos robustos para entender e enfrentar esse problema (PóVOA et al., 2024; VIDELA; ARAUJO, 2021).

Essa tese de doutorado é composta por cinco produtos científicos (três artigos publicados, um manuscrito submetido e um manuscrito), além de dois datasets publicados em repositórios de acesso aberto. Cada produto científico dessa tese reflete uma abordagem para estudos com lixo no mar (Figure 1).

Os tópicos e produtos estão relacionados à coleta e disponibilidade de dados sobre lixo no mar no contexto brasileiro, desenvolvimento de uma ferramenta de descrição de praias (BeachLog), e o papel do lixo no mar. Também foi realizada a coleta de dados in situ em praias emersas e região submersa, análise e construção de base de dados relacional incluindo dados de uso da praia, previamente coletados no BeachLog. Como abordagem tecnológica e com objetivo de entender a contribuição dos estuários para o aporte ou a retenção de lixo, a tese apresenta um modelo de dispersão de partículas em regiões estuarinas do Mar Báltico, técnica que pode ser adaptada para o contexto brasileiro.

Existe uma lacuna na gestão, disponibilização e na integração dos dados sobre lixo no mar no Brasil (RAMOS; LIMA; COSTA, 2022). Tais dados raramente seguem o princípio FAIR (Findable, Accessible, Interoperable, Reusable) e estão dispersos em publicações científicas. As ciências ambientais dependem fortemente do uso de conjuntos de dados, e o compartilhamento desses dados está se tornando cada vez mais comum na academia e na gestão pública. No entanto, os registros de dados sobre lixo no mar no Brasil são escassos e difíceis de encontrar em bancos de dados globais e nacionais (RAMOS; LIMA; COSTA, 2022). O uso dos dados para o desenvolvimento e otimização de políticas públicas para o combate ao lixo no mar fica fragilizado com a escassez de dados que cumpram o princípio FAIR.

Figura 1 – Design conceitual da tese. Os números indicam os produtos científicos. (1) Where are Brazil's marine litter scientific data?; (2) BeachLog: A multiple uses and interactive beach picture; (3) What lies underneath: Comparison among beach litter in the underwater bathing area and exposed beach; (4) Marine Litter and Coastal Oceanographic Data for Usage in a Relational Database; (5) Retention of floating riverine macro-plastics in Baltic estuaries and coastal zones – A model study. Estrelas representam artigos publicados. Quadrado representa manuscrito submetido. Círculo representa manuscrito não submetido.

No contexto de gestão de praias, o lixo no mar é um dos vários problemas ambientais, que pode gerar conflitos entre os diversos usos e atividades que ocorrem no ambiente praial. Uma visão integrada que combine a descrição e a qualidade das praias com a presença de lixo no mar é essencial para uma gestão mais eficiente desse tipo de poluição (CORRAINI et al., 2018). A descrição detalhada de praias, incluindo parâmetros ambientais, serviços e infraestrutura, informações sobre segurança, planejamento e gestão, pode auxiliar em identificar mudanças e prioridades de acordo com a realidade local (WILLIAMS; MICALLEF, 2009). Inovações que utilizem tecnologia com uma interface amigável, sem índices ou scores como o BeachLog, podem ter aplicabilidade para os usuários de praia, gestores e cientistas em um contexto de gestão de praias que considera o lixo no mar como um problema crônico no cenário brasileiro (RAMOS; COSTA, 2023).

Além disso, é importante destacar que, no contexto do lixo em praias, algumas regiões do ambiente praial, como as áreas de banho, têm sido frequentemente negligenciadas (HAARR; FALK-ANDERSSON; FABRES, 2022). O lixo que se encontra submerso (no substrato ou flutuando) na área de banho (de 0 a 3 metros) muitas vezes é ignorado nos esforços de amostragem, tanto em pesquisas quanto em ações de limpeza. Devido às diferenças nos tipos de lixo e dinâmica entre os dois locais, as mesmas estratégias de mitigação podem não ser igualmente eficientes (RAMOS; COSTA; LIMA, 2024). É preciso atentar para as particularidades dos ambientes e das realidades locais ao desenvolver estratégias de gestão.

Abordagens inovadoras são fundamentais para lidar com a escassez e a diversidade de dados relacionados ao problema do lixo no mar. Nesse contexto, um banco de dados relacional se destaca como uma possível solução. Um sistema de banco de dados relacional que integra informações sobre quantidade de lixo no mar, fatores meteorológicos e uso das praias, permitindo uma análise abrangente da problemática, pode ser útil para gestores e cientistas.

A Ilha de Itamaracá no litoral norte de Pernambuco, Brasil, funciona como um estudo de caso interessante. Um banco de dados de lixo no mar para a ilha para o ano de 2022 está disponível (RAMOS; COSTA; LIMA, 2022) e os usos e atividades das mesmas praias para o mesmo período também estão disponíveis em repositório de dados (RAMOS, 2024).

Em se tratando de abordagens inovadoras, a modelagem hidrodinâmica associada ao rastreamento de partículas, tem o potencial de fornecer insights valiosos e ajudar a elaborar cenários para a gestão do lixo no mar (PIEHL et al., 2021). Além disso, ferramentas de análise de dados e ciência de dados podem desempenhar um papel fundamental no melhor entendimento e no combate ao problema do lixo no mar.

1.1 OBJETIVO GERAL

Identificar lacunas no estudo de lixo no mar e explorar abordagens inovadoras úteis para a gestão.

1.1.1 Objetivos específicos

Identificar lacunas nos dados sobre lixo no mar no Brasil (disponibilidade de dados e áreas pouco exploradas).

Entender a problemática do lixo no mar através de diversos tipos de dados (dados descritivos, meteo oceanográficos, quantidade de lixo).

Explorar a aplicabilidade de ferramentas computacionais (e.x: banco de dados, modelos hidrodinâmicos e rastreamento de partículas) para dar suporte à gestão do lixo no mar.

2 CONTEXTUALIZAÇÃO

A revisão de literatura ocorreu durante todo o processo do doutorado, principalmente em relação à banco de dados, gestão de praias e técnicas/ferramentas computacionais inovadoras que possam dar suporte ao combate do lixo no mar. O produto da revisão relacionada aos bancos de dados e disponibilidade de dados sobre lixo no mar no Brasil resultou no artigo intitulado "Where are Brazil's marine litter scientific data?". Este artigo investiga a disponibilidade e a distribuição dos dados científicos sobre lixo no mar no Brasil. Os aspectos chave discutidos no artigo foram (1) escassez de registros open access sobre lixo no mar proveniente do Brasil, com apenas um repositório global identificado e poucos conjuntos disponíveis no Figshare; (2) entre as iniciativas em andamento no Brasil, a Our Blue Hands está operacional, utilizando método padronizado e replicável para compartilhar dados; (3) identificou-se a interoperabilidade como ponto crucial, destacando a necessidade de repositórios específicos para dados sobre lixo no mar que possam conectar-se à outros tipos de dados e plataformas. O artigo é apresentado como Apêndice A e foi publicado na resvista Frontiers in Sustainability (ISSN eletrônico: 2673-4524), Volume 3, August 2022, Sec. Waste Management, 947343. doi: 10.3389/frsus.2022.947343.

Ao reconhecer a poluição por lixo no mar como uma preocupação na gestão costeira e marinha, uma ferramenta para múltiplos usos e descrição de praias foi elaborada resultando no artigo "BeachLog: A multiple uses and interactive beach picture". Destaca-se a necessidade de ferramentas que vão além da classificação de praias, abordando uma variedade de parâmetros importantes para diferentes aspectos e públicos alvo, como características ambientais e serviços e infraestrutura disponíveis na praia. Foram utilizadas ferramentas tecnológicas gratuitas e intuitivas facilitando a replicabilidade. Além disso, foi possível identificar o papel chave do lixo no mar na descrição e qualidade de praias. Este artigo foi apresentado e aprovado em fevereiro de 2023 como exame de Qualificação, um dos pré-requisitos para a obtenção do título de Doutora em Oceanografia no PPGO-UFPE. O artigo é apresentado como Apêndice B e está publicado na revista Marine Pollution Bulletin (Online ISSN: 1879-3363); Volume 193, August 2023, 115156. doi: 10.1016/j.marpolbul.2023.115156.

Ao realizar uma análise detalhada do ambiente praial e coletar dados sobre lixo na Ilha de Itamaracá ao longo de 2022, observou-se que a área de banho, era uma região sub explorada em termos de coletas científicas ou iniciativas realizadas por mutirões de limpeza.

A investigação dos dados coletados, abrangendo tipos de lixo, possíveis origens e uma auditoria de marcas, resultou no artigo "What lies underneath: Comparison among beach litter in the underwater bathing area and exposed beach". Este estudo compara a composição e distribuição de lixo em áreas de banho e na praia emersa, destacando diferenças significativas, especialmente em relação às possíveis origens do lixo nessas duas regiões. Destaca-se a contribuição de marcas locais no lixo presente na área de banho e proporções mais altas de incrustação foram encontradas na área de banho, 87,73% em comparação com 10% na praia emersa. O artigo é apresentado como Apêndice C da tese e está publicado na revista Science of The Total Environment (Online ISSN: 1879-1026); Volume 947, October 2024, 174661. doi: 10.1016/j.scitotenv.2024.174661. O banco de dados com os dados das coletas de lixo na Ilha de Itamaracá está publicado no Figshare (RAMOS; COSTA; LIMA, 2022), fornecendo acesso aberto e fácil aos pesquisadores e gestores interessados.

Integrando dados já coletados, apresentamos um banco de dados relacional aplicado à problemática do lixo no mar, conforme detalhado no manuscrito "Marine Litter and Coastal Oceanographic Data for Usage in a Relational Database". Este banco de dados engloba informações das coletas realizadas na Ilha de Itamaracá (RAMOS; COSTA; LIMA, 2022), juntamente com dados do BeachLog (RAMOS, 2024) e dados meteo oceanogrüafiocs provenientes de modelos globais para a regiäao. O estudo tem como objetivo armazenar, organizar e apresentar possibilidaes de interação de dados de diversas fontes e formatos para uma compreensão abrangente do problema e para o suporte a políticas de gestão eficazes. O manuscrito é apresentado como capítulo 3 da tese e foi submetido à revista Scientific Data em Outubro de 2024.

O manuscrito 'Retention of floating riverine macro-plastics in Baltic estuaries and coastal zones - A model study' é uma abertura para explorar novas tecnologias e insights sobre a poluição costeira. Embora não diretamente relacionado ao contexto brasileiro, oferece perspectivas sobre a retenção de macroplásticos flutuantes em estuários e zonas costeiras, contribuindo para uma compreensão mais ampla dos processos de transporte e acumulação. O manuscrito conecta-se aos demais e à tese ao propor soluções baseadas em ciência e tecnologia para o lixo no mar, além da possibilidade em se dialogar com iniciativas locais no Brasil (ANDREUSSI et al., 2024) e transposição para outros contextos. Além disso, processos colaborativos entre instituições podem fomentar um abordagem complementar às coletas e bancos de dados já existentes em território nacional. O manuscrito compõe o capítulo 4 da tese.

3 MARINE LITTER AND METEO-OCEANOGRAPHIC DATA FOR USAGE IN A RELATIONAL DATABASE

Bruna de Ramos[1 2],* Monica Ferreira da Costa[1]

[1] Departamento de Oceanografia, Universidade Federal de Pernambuco - UFPE, Recife, Pernambuco 50740-550, Brazil

[2] Research Unit - Coastal Seas and Society, Leibniz-Institute for Baltic Sea Research - IOW, Rostock, Germany

* Correspondent author: bruna.ramos@io-warnemuende.de

3.1 ABSTRACT

Marine litter is a multifaceted environmental issue requiring advanced data management systems to effectively integrate and analyze diverse datasets. This study presents datasets that have data about marine litter, beach use, and meteo-oceanographic variables. A relational database framework was designed to facilitate data access and future use. The data acquisition processes are detailed and linked to previous research, highlighting the interoperability of relational databases with various data sources, including beach use data from the BeachLog tool and meteo-oceanographic data from climate models. This enables detailed analysis and customized subsets of marine litter data. The relational database structure includes key tables such as Beach, Litter Item, Litter Survey, Survey Observation, Meteorology, and Beach Use, allowing queries using Structured Query Language (SQL). Data from Itamaracá Island, Brazil, demonstrate the database's ability to manage diverse data types and sources. This study emphasizes the importance of connecting different data sources in environmental research, offering a scalable tool that can be applied to various regions and research objectives.

Keywords: BeachLog, environmental data, SQL, beach surveys, data analysis, beach litter.

3.2 INTRODUCTION

Beach litter is a growing concern worldwide due to its negative impacts on the environment, economy, and marine life (WILCOX et al., 2016). Organizing marine litter data is crucial for understanding its sources and distribution. Integrating meteo oceanographic factors such as winds, precipitation and waves into databases and analyses could enhance comprehension of beach and marine litter dynamics (ONINK et al., 2021). Factors like beach activities and the presence of Marine Protected Areas (MPA) are also key to contextualizing beach litter data (RAMOS; COSTA, 2023).

Relational databases are commonly used in oceanographic studies to organize and store large amounts of data in a structured manner (ETIENNE et al., 2021). These databases store variables like wind speed, wave height, and water temperature, often integrated with time-series data for analysis. This allows for efficient querying and retrieval of data. Additionally, relational databases are widely used in the study of marine litter to store and manage data from litter surveys, including types, sources, and distribution patterns (CENTRE; LITTER, 2023). These databases can be integrated with oceanographic data to analyze the transport of marine debris. Databases that track beach usage patterns, including, types of activities, and waste management infrastructure, can provide insights into the impact of human activities on coastal environments (RAMOS; COSTA, 2023). This information is often integrated with other environmental factors in relational databases. In the context of marine litter, meteo-oceanographic factors, and beach activities, relational databases can store data related to litter surveys, beach usage patterns, and meteo-oceanographic data. The data could be retrieved from different sources, improving the interoperability process. Relational databases improve the interoperability of environmental data by allowing different systems to exchange and use data effectively. This is particularly important when working with diverse data sources.

Given the extensive and diverse data produced by marine litter surveys and management initiatives, effective storage and management systems are important, particularly within the scientific and management areas (ADDAMO, 2018). Relational databases offer a structured approach, enabling researchers and managers to effectively handle, subset, and analyze vast and complex datasets. Also, a relational database could facilitate data sharing and collaboration among multiple stakeholders, including scientists, government agencies, and non-governmental organizations. This can foster a more comprehensive understanding of the sources and distribution of marine litter and develop more effective management strategies.

Relational databases can also integrate data from multiple sources. For example, Oracle was used to integrate data from the ECOTOXicology Knowledgebase (OLKER, 2022), and PANGAEA uses a relational database for environmental data storage (DIEPENBROEK, 2002). Relational models have also been used for water resource management (HORSBURGH et al., 2008) and watershed monitoring (CARLETON; DAHLGREN; TATE, 2005). In the Philippines, MySQL was used to create a national marine litter database (ALINDAYU et al., 2023).

By incorporating variables like meteorological data, beach use, and litter surveys into a single platform, relational databases enable the identification of correlations and patterns that may not be apparent when analyzing datasets individually. This provides a more comprehensive understanding of marine litter dynamics. Together with Citizen Science initiatives, it can collaborate for the better use of already collected and open-accessed data (WU, 2023).

Several studies have utilized relational databases for marine litter research. For instance, Oracle was used to store data from necropsies and stomach content analyses to study biological interactions with marine litter (FRANEKER, 2011). Europe has led the way in establishing strong data management practices, exemplified by the pan-European beach litter database, built on PostgreSQL with PostGIS for spatial management. This database supports the EMODnet Chemistry beach format, enabling the integration of datasets from various protocols and reference systems for marine debris monitoring (CENTRE; LITTER, 2023; GESAMP, 2019; HANKE, 2019). In contrast, countries in the Global South, such as Brazil, still lack comparable frameworks for effective marine litter data management (RAMOS; LIMA; COSTA, 2022).

In this article, we presented datasets from beach uses and marine litter and developed a relational database. We provide a step-by-step guide for the database creation, aiming to spread this knowledge for future research. Our case study focuses on Itamaracá Island, Brazil, using consistent data on beach litter (RAMOS; COSTA; LIMA, 2024), beach characteristics and use from BeachLog (RAMOS; COSTA, 2023), and meteorological factors from the same timeframe. This case study demonstrates how integrating diverse datasets into a relational database can provide valuable insights into local beach litter dynamics.

3.3 METHODS

To develop a relational database for beach litter studies related to other variables, we followed the database modeling cycle (Figure 2). The first step involved understanding the problem that needed addressing: the composition of marine litter and its relationship with meteo-oceanographic variables and beach use, represented by the BeachLog data.

The next step was to create an Entity-Relationship (ER) model to represent the different entities, attributes, and relationships (e.g., a beach can have many litter data entries). Entities, defined as real-world objects or concepts, were represented as tables in the database (e.g., Beach, Litter Data). Each entity has attributes, or characteristics that describe it (e.g., beach names, litter types), which are understood as columns in a database table.

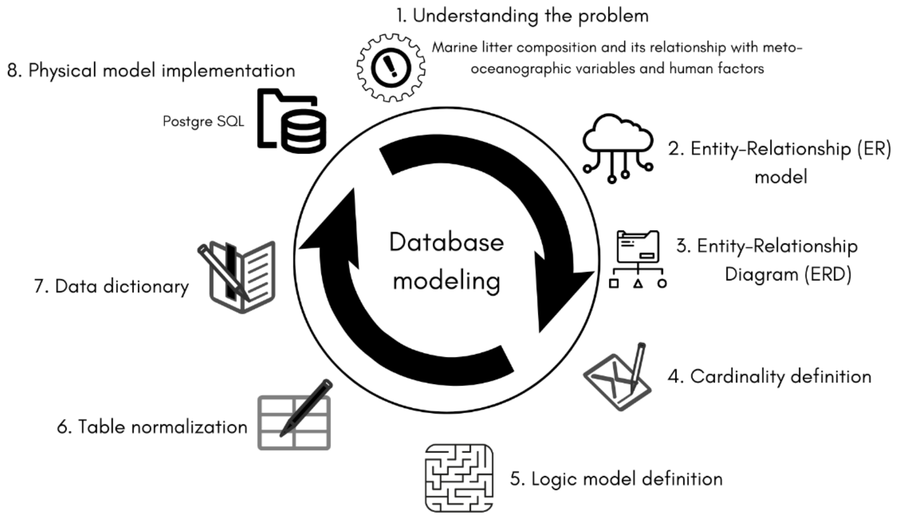

Figura 2 – Data modeling cycle. The methodological approach used for beach litter relational database construction.

Each attribute has a specific data type, such as text, number, date, or boolean, which will be explicitly documented in the data dictionary (Step 7; Figure 1). Entities can have relationships with other entities; for example, a beach can have multiple litter surveys. These relationships are visually represented in the Entity-Relationship Diagram (ERD) (Figure 3).

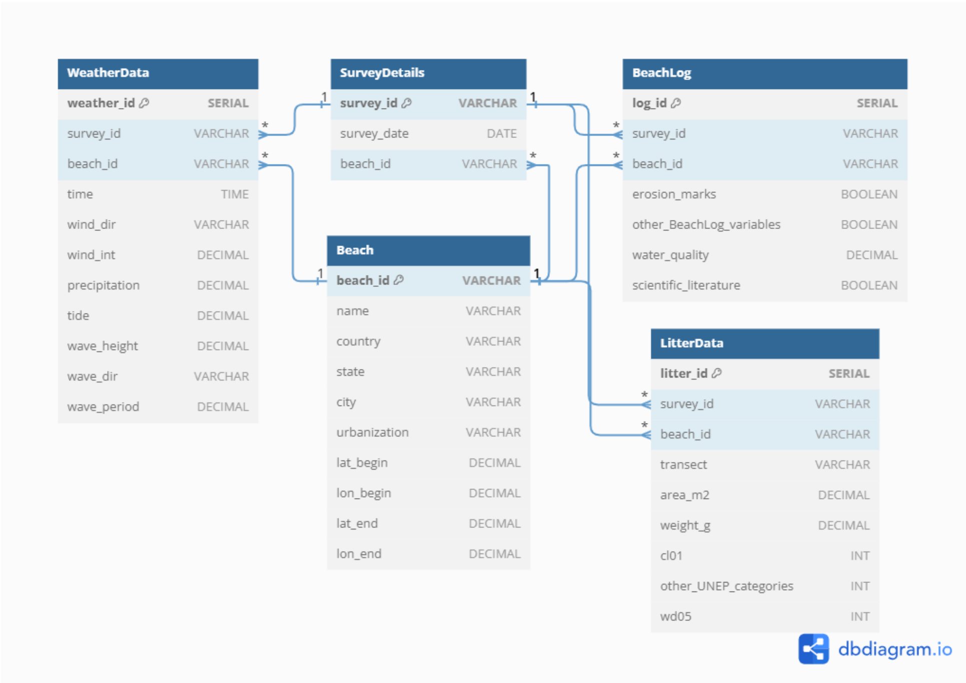

Figura 3 – Entity-Relationship Diagram (ERD) for a relational database about marine litter, meteo-oceanography, and beach use variables/attributes. Relationships are highlighted in blue lines connecting the tables/entities.

The fourth step involved defining the cardinality between entities, specifying how many instances of one entity can relate to another. For instance, a beach can have one or many litter surveys, which may record zero or many litter items. Next, we defined the logical model, establishing tables, columns, and relationships based on the ERD. Table normalization was then performed to optimize the database schema, minimize data redundancy, and enhance data consistency. We followed three rules to ensure table normalization:

- Each table must have a primary key column uniquely identifying each row.
- Each column should contain a single value, avoiding repeating groups or arrays.
- Each table should represent a single logical entity or relationship.

The seventh step involved documentation, creating a data dictionary to describe the structure and contents of the database tables, columns, relationships, and data types. This documentation is crucial for improving the database and ensuring user understanding of its structure and contents, the information about litter types is also available in (CHESHIRE et al., 2009).

The physical model was implemented in PostgreSQL using the pgAdmin interface and SQL (Structured Query Language). We created the tables, defined their relationships, and inputted data using a Python script linking the table structure to data organized in a spreadsheet (available in data repositories). Subsequently, queries were run to retrieve and manipulate the data. This worked as prove of concept and usage notes.

3.4 DATA RECORDS

The data collected for the database are divided into beach litter, meteo-oceanographic variables, and beach use data from three beaches on Itamaracá Island in northeast Brazil. The sampling methodology was based on United Nations Environment Programme (UNEP) guidelines for beach litter monitoring (CHESHIRE et al., 2009).

During each sampling period, the team walked along a 25-meter transect, collecting all visible litter found between the low tide level and the high tide range. All collected litter was separated, counted, and categorized based on UNEP guidelines (CHESHIRE et al., 2009) and possible source classification (ARAúJO; SANTOS; COSTA, 2006). Additional details on marine litter collection are described in (RAMOS; COSTA; LIMA, 2024).

Regarding meteo-oceanographic variables, tide data were sourced from the Brazilian Navy website, while wave, wind, and precipitation data were obtained from the Global Forecast

System (GSF). Beach use data were acquired from the BeachLog description tool (de Ramos and Costa, 2023) and the raw data can be accessed in Figshare (de Ramos, 2024).

3.5 TECHNICAL VALIDATION

We created five tables (entities) in the database: Survey Details, Beach, Litter Data, Weather Data, and BeachLog (Figure 3). Each table represents different aspects of the marine litter data for storage and analysis. The database can be reproduced in other contexts by adapting the table structure, accessible via GitHub: <https://github.com/ramos-bruna/MarineLitter_database>.

The SurveyDetails table provides information about the surveys conducted at the beaches and the dates. The Beach table holds details about the sampled beaches (Sossego, Jaguaribe, and Forte Orange), including unique identifiers (beach_id), names, locations, urbanization levels, and geographical coordinates. These two tables serve as central entities linked to other tables through foreign keys.

The LitterData table records litter data from surveys, uniquely identified by litter_id, linking each record to a specific survey and beach via survey_id and beach_id. The attributes include the transect number, surveyed area, weight of litter, and various columns representing different types of litter items (e.g., CL01, CL05, etc.), each recorded as integer counts. A data dictionary explaining the litter codes based on UNEP (2009) (Cheshire et al., 2009) was created as a .txt file.

Weather conditions during sampling are captured in the WeatherData table, with entries uniquely identified by weather_id. This table includes attributes like observation time, wind direction and intensity, precipitation, tide levels, wave height, direction, and period.

The BeachLog table logs various environmental and management features of the beaches. Each log entry, uniquely identified by log_id, includes the beach_id and date (same as weather data). Attributes include boolean conditions/features such as erosion marks, water quality, food services, beach cleaning, and others (RAMOS; COSTA, 2023).

The Beach table acts as the hub of the database, with other tables referencing it via foreign keys. The SurveyDetails, LitterData, WeatherData, and BeachLog tables are connected to specific beaches through beach_id, allowing for complex SQL queries to analyze the data.

Queries can answer questions such as:

- "Which beach had most fishing items such as lures, traps, pots, and fishing nets observed during surveys?" (Supplementary material - example 1), for this the answer was Jagaurribe Beach with 0.0051 items.m-2.

- "Which were the wind and wave conditions that happened in the biggest litter concentration on a beach?", that the answer was that on December 22, 2022, at the Forte beach, there was 0.62 items.m-2. The wind was coming from the east-northeast at 6.1 knots, while the wave height was 1.1 meters with waves coming from the east-northeast and a period of 13 seconds.

- "What are the data for beach wrack, food services presence, MPA presence, wind velocity, and light fragments concentration for September 2022, for all beaches?", for the results were the absence of MPA for all beaches, Jaguaribe beach had no wrack, but it did offer food service. The concentration of light fragments was 0.010 items.m-2, with the wind blowing from the southeast at 8.5 knots. Sossego Beach had wrack but no food service, with a light fragments concentration of 0.011 items.m-2 and wind from the east-southeast at 7 knots. Forte Orange Beach, featured both wrack and food service. The light fragments concentration was 0.0054 items.m-2, with the wind coming from the east-southeast at 8.5 knots.

As a proof of concept, we performed a query followed by a PCA (Principal Component Analysis) using data retrieved from the relational database, indicating the interconnectivity between variables and their influence on litter concentration on Itamaracá Island (Figure 4).

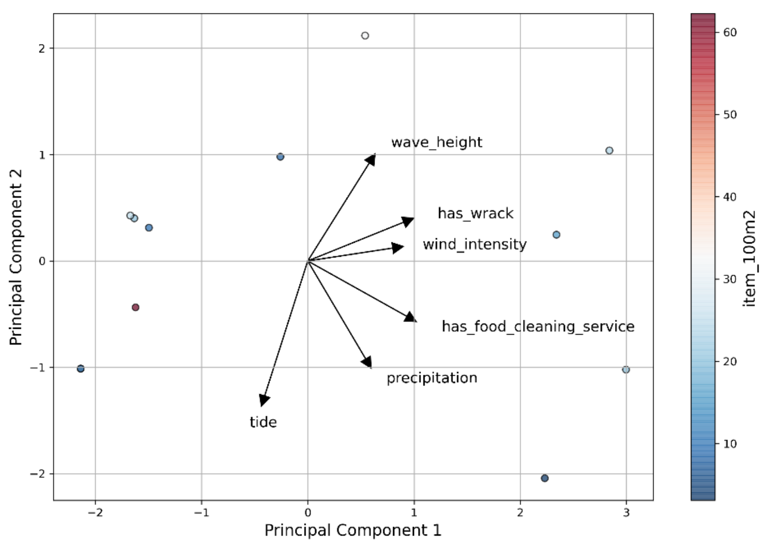

Figura 4 – PCA using retrieved data from the relational database.

The PCA enables the visualization of the relationships between meteo-oceanographic variables, beach use, and marine litter. In this example, variables like wave height and wind intensity show a strong positive correlation, suggesting their combined effect on litter transport/deposition, also the presence of beach wrack is associated with these two factors. This analysis helps identify the primary environmental drivers of marine litter accumulation.

3.6 USAGE NOTES

This database enhances the capacity to answer complex questions about the relationships between marine litter, environmental conditions, and beach use. By incorporating meteo-oceanographic data and beach use information, we can explore connections between these variables effectively. Users are encouraged to utilize the SQL queries available at <https://github.com/ramos-bruna/MarineLitter_database> to analyze and extract insights from the database.

Existing free tools, such as relational database management systems and SQL, have the potential to greatly improve the organization and analysis of marine litter data (ALINDAYU et al., 2023). These tools, along with good data management practices, support the efficient storage, retrieval, and handling of complex datasets, which are essential for advancing research and informed decision-making (ETIENNE et al., 2021; PARTESCANO, 2021; WILKINSON, 2016). Relational databases, in particular, offer clear advantages over traditional spreadsheets, especially in managing large, interconnected datasets and facilitating robust data management and sharing. This shift aligns with the growing emphasis on the FAIR (Findable, Accessible, Interoperable, Reusable) (TANHUA, 2019) and CARE (Collective Benefit, Authority to Control, Responsibility, Ethics) principles within the scientific community, especially in the global south where the data infrastructure relies on good willing, and free options (RAMOS; LIMA; COSTA, 2022; SALES, 2020).

Much of the marine litter research has traditionally focused on field data collection, monitoring, and assessment methodologies. However, there is a noticeable gap in efforts to organize and manage this data effectively, particularly in integrating diverse data sources and understanding their interconnectivity (HAARR; FALK-ANDERSSON; FABRES, 2022; PARTESCANO, 2021). Initiatives like Destination Earth (DestinE) (TONA et al., 2024), which aims to develop a digital twin of Earth's system, and repositories such as PANGAEA (DIEPENBROEK, 2002), exemplify ongoing efforts to standardize data practices and promote data interoperability. Effective management of these datasets is crucial to derive insights and support decision-making. While harmonizing data collection and recording methods for marine litter has been addressed in some initiatives (HARTMANN, 2019), significant challenges remain in integrating these datasets with other variables to create a more comprehensive understanding of the marine litter problem.

Our case study on Itamaracá Island, Brazil, exemplifies the practical benefits of using relational databases to integrate multiple data streams, including marine litter data, beach usage, and meteo-oceanographic factors. Using BeachLog (de Ramos and Costa, 2023) and CoastSnap (HARLEY; KINSELA, 2022) data at Forte Beach, we demonstrated the versatility of relational databases in managing and querying these diverse datasets, this can be understood as a new approach of using data available in generalist repositories such as Figshare.

Relational databases also enable the integration of data from citizen science initiatives and platforms such as CoastSnap (HARLEY; KINSELA, 2022), which provides photographic and georeferenced data that can enhance litter datasets. Linking litter data with meteo-oceanographic conditions enables a comprehensive understanding of the factors influencing litter accumulation and distribution, offering new insights into marine litter dynamics. This integrated approach fosters more effective management strategies, particularly in response to environmental changes like storms or increased human activity.

In summary, relational databases offer a powerful framework for organizing and analyzing complex marine litter datasets. By integrating data from diverse sources, these databases enhance research capabilities, providing a more complete understanding of marine litter and supporting informed decision-making for environmental management.

CODE AVAILABILITY

Custom code used in developing and maintaining the database is accessible at the following repository: <https://github.com/ramos-bruna/MarineLitter_database>. This includes SQL scripts, data processing scripts in Python, and documentation for the data dictionary.

ACKNOWLEDGEMENTS

BR received a Ph.D. Scholarship (Finance Code 001) from Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES).

AUTHORS CONTRIBUTIONS

B.R. designed, wrote, and tested the relational database workflow and code and wrote the draft manuscript. M.F. provided feedback on the datasets, and workflow, and provided overall supervision of the project. All authors have given approval to the final version of the manuscript.

COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

REFERENCES

Are presented at the end of the thesis

SUPPLEMENTARY MATERIAL - QUERIES EXAMPLE

```sql
--- Which beach had the fishing items such as lures, traps, pots and fishing nets observed during surveys?
--- PL17 = Fishing gear (lures, traps & pots)
--- PL20 = Fishing net
--- items per square meter
WITH FishingItems AS (
    SELECT
        L.beach_id,
        COALESCE(SUM(L.PL17), 0) + COALESCE(SUM(L.PL20), 0) AS total_fishing_items,
        COALESCE(SUM(L.area_m2), 0) AS total_area_m2
    FROM
        LitterData L
    GROUP BY
        L.beach_id
),
BeachInfo AS (
    SELECT
        B.beach_id,
        B.name AS beach_name,
        FI.total_fishing_items,
        FI.total_area_m2,
        CASE WHEN FI.total_area_m2 > 0 THEN FI.total_fishing_items / FI.total_area_m2 ELSE 0 END AS items_per_sqm
    FROM
        Beach B
    JOIN
        FishingItems FI ON B.beach_id = FI.beach_id
)
SELECT
    beach_name,
    total_fishing_items,
    total_area_m2,
    items_per_sqm
FROM
    BeachInfo
ORDER BY
    items_per_sqm DESC
LIMIT 3;
```

Figura 5 – Query performed in PostgreSQL.

Beach Name	**Total Fishing Items**	**Total Area (m^2)**	**Items per m^2**
Jaguaribe	76	14975	0.005075125
Forte Orange	47	12175	0.00386037
Sossego	60	16525	0.003630862

Tabela 1 – Fishing Items and Area Data, the output from the query

4 RETENTION OF FLOATING RIVERINE MACRO-PLASTICS IN BALTIC ESTUARIES AND COASTAL ZONES – A MODEL STUDY

Bruna de Ramos * [1,2], Gabriela Escobar Sánchez [1,3], Xaver Lange [1], Ulf Gräwe [1], Gerald Schernewski [1,3]

[1] Leibniz Institute for Baltic Sea Research Warnemünde (IOW) – D-18119 Rostock, Germany

[2] Departamento de Oceanografia, Universidade Federal de Pernambuco - UFPE, Recife, Pernambuco 50740-550, Brazil

[3] Klaipeda University, Lituanie (KU) – Herkaus Manto str. 84, 92294 Klaipeda, Lithuania

* Correspondent author: bruna.ramos@io-warnemuende.de

4.1 ABSTRACT

The dynamics of marine litter, particularly floating plastic, in aquatic environments, are increasingly being studied to understand their ecological and social impacts, accumulation points, and management strategies. This paper focuses on the retention and transport of floating macrolitter in two contrasting estuarine environments in the Baltic Sea: the Warnow Estuary and Greifswald Bay. While many studies have concentrated on beach litter or litter already present in the marine environment, estuaries play an important role as a link between riverine sources and the marine environment. This study employs hydrodynamic models with different resolutions (20m and 200m) to explore litter dynamics and retention rates under varying standalone wind conditions. The small size of the Baltic Sea basin and the availability of a validated high-resolution hydrodynamic model (GETM - General Estuarine Transport Model) make it an ideal setting for this research. The findings indicate that the Warnow estuary, located in northeastern Germany and characterized by its narrow channel, has an average litter retention rate of 90% under steady wind conditions over 4 days. In contrast, Greifswald Bay, a shallow, wide, and more open estuary, presented a retention rate of 15% under the same conditions and time frame. However, the particles in Greifswald Bay remain within the estuarine system, with a retention rate of about 80% after approximately 50 days. These results highlight the potential for litter retention in estuaries with different morphologies and urban influences. The study provides insights that can inform more effective management and mitigation strategies for marine litter pollution, such as accumulation points and retention

times, based on estuary morphology and releasing points of the particles. Also, it can contribute to improving large-scale models of marine litter dynamics.

Keywords: Marine litter, River, Hydrodynamic models, Lagrangian particle tracking, Litter retention

4.2 INTRODUCTION

Plastic litter in marine environments creates a complex challenge for ecosystems and human activities (ABALANSA et al., 2020; RANGEL-BUITRAGO; NEAL; GALGANI, 2023). Monitoring and developing mitigation strategies are key aspects of dealing with marine litter (HASELER et al., 2020), also modeling techniques could help to understand marine litter dynamics and accumulation sports (PäRN; MOY; STIPS, 2023).

In the literature it is possible to find the information that approximately 80% of marine litter in the ocean originates from land-based sources/activities and could be transported via rivers, and estuaries (WANG et al., 2024), this could be better explored taking into account the retention in estuarine systems. Marine litter in coastal environments can also be deposited locally, often due to tourism or other locally performed activities (LóPEZ-ARQUILLO et al., 2023). Understanding the mechanisms of plastic litter retention and transport in estuarine systems is important for developing targeted mitigation strategies and enhancing local, regional, and global marine litter models, especially regarding plastic input budged from rivers to the sea (SCHMIDT; KRAUTH; WAGNER, 2017).

There is a gap in marine litter research regarding the role of rivers and estuaries. Rivers and estuaries can act as reservoirs for litter (EMMERIK et al., 2022), holding back up to 98% of the waste introduced into these water bodies. Yet, they can also work as emission points (LEBRETON et al., 2017), releasing plastic into marine environments. However, the transport dynamics and retention rates within estuaries remain poorly understood.

In the literature, there are attempts to clarify riverine and estuarine plastic movements and retention. One example was the study of a flood-driven plastic spill in the Vesdre River, in Belgium, which found that rivers could retain large portions of plastic near their emission points, while a smaller fraction continues downstream under certain environmental conditions (HAUK et al., 2024).

Another example is the study of three German tributary rivers, which assessed riverine litter in different river compartments. This research highlighted differences between field-based litter outflow rates and model-based estimations, highlighting the need to validate models with field observations or improve the model approaches. These findings show the complexity of riverine plastic retention and movement and highlight the need for more refined approaches in estuarine systems (SCHöNEICH-ARGENT; DAU; FREUND, 2020).

Regarding the use of modeling tools, there is a wide range of research on the open ocean (BRABO et al., 2024; CHASSIGNET; XU; ZAVALA-ROMERO, 2021; POTEMRA, 2012), taking advantage of global models such as the one provided by the HYbrid Coordinate Ocean Model (HYCOM), which has a spatial resolution of 1/12° (8 km at the equator, 6 km at mid-latitudes). However, this spatial resolution is not suitable for application in a wide range of estuarine regions.

In seas such as the Mediterranean, Black Sea, and Baltic Sea are studies dealing with marine litter budget/input to the basin, its transport, and dynamics (CASTRO-ROSERO et al., 2023; GONZáLEZ-FERNáNDEZ et al., 2021; KAANDORP; DIJKSTRA; SEBILLE, 2020; SCHERNEWSKI et al., 2021). Still, there is a gap in understanding the retention of litter inside estuarine systems.

The dynamics of floating litter transport and retention in riverine and coastal systems reveal complex interactions shaped by environmental and anthropogenic factors. Rivers serve as major conduits of marine plastic pollution, with systems like the Vistula and Oder Rivers significantly contributing to the Baltic Sea's litter loads (PäRN; MOY; STIPS, 2023). However, the river's contribution to the input budget might be overestimated since the retention is in general not taken into account (GONZáLEZ-FERNáNDEZ et al., 2021).

Understanding plastic movements in rivers and estuaries poses significant challenges due to the complexity of coastal regions and the often low resolution of hydrodynamic models (Ward et al., 2023). The Baltic Sea offers a unique opportunity to address these challenges, serving as an open laboratory for studying plastic dynamics. The small, semi-enclosed sea area already has well-developed hydrodynamic models (e.g.: GETM) and this is an opportunity to deepen the knowledge about litter movement. The region near the city of Rostock also hosts the Digital Ocean Lab (DOL), representing the region's potential to foster a dynamic environment for the development and testing of marine technology. This infrastructure aims to promote close collaboration between interdisciplinary research and industry and highlight the potentialities of the region in developing detailed studies of coastal systems.

Additionally, the inner Baltic Sea lacks significant tidal influence (LANGE; KLINGBEIL; BURCHARD, 2020), simplifying the analysis of plastic transport by reducing the variability associated with tidal currents. The availability of in situ data and a record of previous studies (PIEHL et al., 2021; SCHERNEWSKI et al., 2021) enhance its suitability, allowing the use of previous models and a deeper understanding of the mechanisms responsible for plastic dynamics, especially regarding retention or input to the sea in coastal environments. The dynamic of floating plastics in the Baltic is a topic of interest since about 70% of the litter found on the Baltic beaches is plastic (HELCOM, 2018).

This paper aims to analyze marine litter retention patterns within the Warnow Estuary and in Greifswald Bay under different wind conditions. Specifically, it aims to: (1) determine the retention of marine litter across different wind scenarios; (2) assess the impact of spatial resolution on particle tracking models, focusing on retention; (3) evaluate the effects of extreme weather events on litter transport and retention, understanding how these events alter typical litter movement and deposition patterns.

4.3 METHODOLOGY

4.3.1 Study Area

The Baltic Sea's shallow basins have a mean depth between 13 and 24 m. The only connection to the Atlantic Ocean is via the North Sea through a narrow strait, allowing small and periodic exchanges of water masses (Ruvalcaba Baroni et al., 2024). This prevents the exchange of large amounts of marine litter, limiting the sources and deposition spots to the Baltic Sea region, this makes the region an interesting open lab also for marine litter studies.

Two estuarine systems in the Baltic Sea with different morphologies and urbanization levels were chosen as case studies: The Warnow Estuary (54.0833°N, 12.1333°E) (Figure 6) and Greifswald Bay (Figure 7) (54.15°N, 13.60°E). The Warnow Estuary, located in Mecklenburg-Western Pomerania, Germany in Rostock, is a highly modified ecosystem, influenced by urbanization, and industrial activities (SCHERNEWSKI et al., 2019). It is 13 km long and covers 12 km^2, with a water volume of 49.6 million m^3. The water exchange time of about 30 days. The estuary receives an influx of 1,180 km^3/year from the Baltic Sea and 440 km^3/year of freshwater. This water exchange is mainly driven by wind and salinity changes in the adjacent coastal waters, tides do not play an important role in the region (LANGE; KLINGBEIL; BURCHARD, 2020).

Urban, industrial, and nautical activities are relevant in the city of Rostock, consequently, it has altered the estuary's shoreline, with 74% of its coast being artificial. Harbors and shipping lanes occupy 37% of the water surface, which could facilitate the input of marine litter. The uses and activities in the estuary are complemented by recreational boating, which accounts for 6% of all moorings along Germany's Baltic Sea coast. Approximately 26% of the estuary remains in a more natural condition, with reed belts and low herbaceous vegetation, which might play a role in marine litter retention.

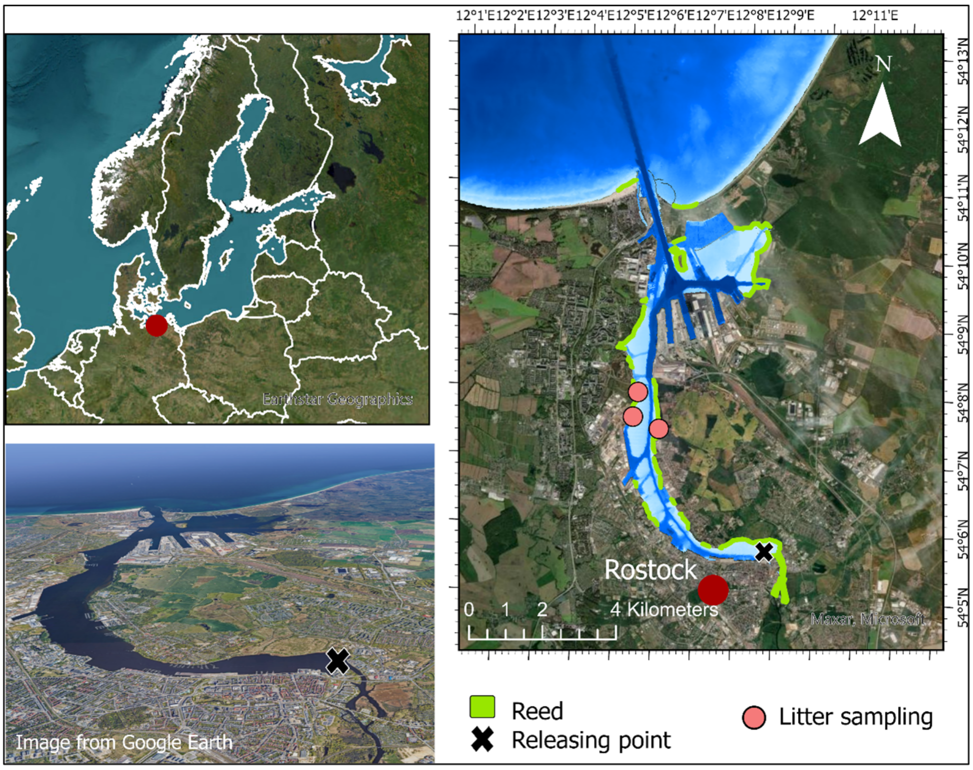

Figura 6 – Warnow estuary, Reed limits, Riverine litter collection points, and releasing point of the virtual particles.

The Greifswald Bay, located in northeastern Germany, is a semi-enclosed, eutrophic lagoon that is 514 km^2, characterized by its shallow depth with an average of 5.8 m and a maximum of 13.5 m. The most important river flowing into Greifswald Bay is the Ryck River, located on the southern shore of the bay. In the borders, there is the island of Rügen to the north and the German mainland to the south, with limited connections to the Baltic Sea through the narrow Strelasund channel to the west and a shallow opening to the east (Figure 7). This semi-enclosed structure limits water exchange, with an estimated rate of eight to twelve exchanges per year, influenced mainly by wind-driven dynamics, as tidal influence is minimal. These hydrodynamic conditions make Greifswald Bay an important site for studying litter retention and transport within semi-enclosed coastal systems. The Bay has also been a focus of studies and monitoring programs since 1975, especially related to water quality checks performed by the state agency

LUNG MV2 (State Office for Environment, Nature Conservation, and Geology), additionally, some marine litter monitoring on beaches are performed, but for rivers it is not done.

The bay also has significant ecological value, particularly as a spawning area for Western Baltic spring-spawning herring, which supports regional fisheries and biodiversity (Moll et al., 2018). The bay's shallow, brackish waters are sensitive to anthropogenic pressures, including nutrient loading and pollution, contributing to its eutrophic state. Approximately 67% of the bay's shoreline is natural, the composition is mostly wetland, reed belts, and low herbaceous vegetation. The artificial portion is about 33%, consisting of ports, marinas, and agricultural land. This balance between natural and modified areas and the bay's hydrodynamic and ecological characteristics provides an interesting study case for litter retention and dispersion.

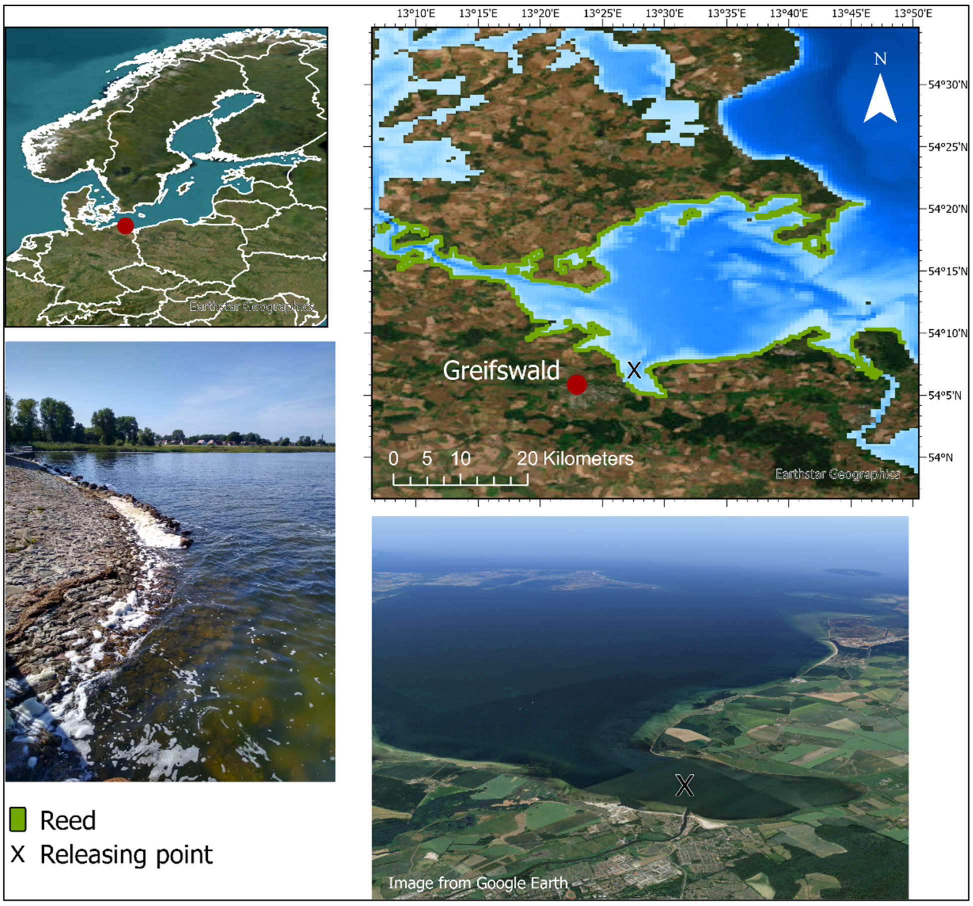

Figura 7 – Greifswald Bay, Reed limits, and releasing point of the virtual particles.

4.3.2 Riverine Litter Data

Litter items trapped in the reeds in the Warnow estuary were collected between October and November 2024 in opportunistic samplings in 3 areas (Figure 1; Newland et al., unpublished data). The litter was sorted, and classified using the J-CODE list (CENTRE; LITTER, 2023) and photographed. The quantities were used to estimate the amount of plastic trapped in the reed belts for the Warnow estuary. To do so, we extrapolated the number and weight of items per square meter found in the sampling to the reed belt area in the estuary, which was calculated with the Clip tool in ArcGIS 3.0 Pro.

4.3.3 Model Setup

Model simulations were carried out for the two areas, Greifswald Bay and the Warnow estuary in 200 m horizontal resolutions, and in 20 m horizontal resolution for the Warnow. The very high spatial model resolution, implemented in a previous study for Warnow (LANGE; KLINGBEIL; BURCHARD, 2020; SCHERNEWSKI et al., 2024), reflects the harbor infrastructure and bathymetry in detail and provides the precondition for sufficiently realistic model simulations

The 2D hydrodynamic model was calculated in hindcast simulations for 2018; the results were used for an offline Lagrangian particle-tracking approach. For the hydrodynamic model, the General Estuarine Transport Model (GETM) with the General Ocean Turbulence Model (GOTM) (UMLAUF; BURCHARD, 2005) was used as the turbulence closure model. And as particle tracking the Ocean Parcels framework (DELANDMETER; SEBILLE, 2019; LANGE; SEBILLE, 2017) was applied. Diffusion was considered using the Milstein scheme (first order). Particles were programmed to beach in coastal sections characterized by reeds and beaches. The model approach did not consider the remobilization of litter that was previously beached or the sinking processes.

4.3.4 Wind conditions - for Particle Tracking

A cluster analysis was conducted using 2018 hourly wind data from the Norwegian Meteorological System (https://thredds.met.no/thredds/metno.html) to identify dominant wind patterns in the West Baltic region. Data were processed with the Dask package. Wind speed and direction features were standardized, and K-Means clustering was applied, forming five clusters that represent distinct wind profiles. Each cluster categorizes common combinations of wind direction and velocity for the region. A representative date when the wind condition lasts for at least 4 days was chosen for each of the five wind conditions in the cluster to perform the particle tracking. A strong wind condition was selected taking into account the maximum velocity that lasts for a minimum of 4 days.

4.3.5 Model Scenario Simulations

A series of model scenario simulations were conducted to assess the impact of varying environmental conditions on marine litter transport, encompassing both standalone and extreme conditions. The scenarios were designed based on the study area's five most common wind directions (see Wind conditions – for particle tracking). An extreme event scenario was also included to simulate storm conditions, characterized by increased u and v velocities in the hydrodynamic model to replicate intensified currents and turbulence. The simulations considered a baseline scenario of simplified floating plastic emissions originating at the beginning of the estuary in the Warnow (54.096o N, 12.159o E) and the exit of the Ryck River (54.106o N, 13.454o E) for Greifswald Bay. To evaluate the influence of model resolution, both coarse (200 m) and fine (20 m) grid resolutions were applied for the most common wind condition in the region for the Warnow estuary.

The simulations ran for 4 days. The released virtual particles were considered passive floating plastic transported passively within the upper 50 cm surface water layer. Wind-driven transport of particles floating above the water surface and sinking plastic polymers or sinking processes were not considered.

An additional year's run was conducted for both estuarine systems. 100 particles were released every 12 hours, and seasonal retention and the average time for the particles to reach the Baltic were calculated.

A Generalized Linear Model Regression (GLM) was applied using the scenario simulation data. The percentage of particles retained was used as a dependent variable. The explanatory variables were the ratio between the reed belt area and estuary area (in square Kilometers), wind direction, and wind velocity at the beginning of the simulation period.

4.4 RESULTS

4.4.1 Riverine Litter Data

Estimating litter in the reed belts for the Warnow Estuary was 0.051 items.m-2, accounting for 25 kg (3.18 g.m2). The total reed belt area was calculated as 2.75 km2, and the extrapolation to the items retained in the estuary was 140220 items and 68,734,910 kg, which is a rough estimation but could give an idea about the proportions or the scale of the amount of litter trapped in the estuary. The type of litter found trapped in the estuary also varied (Figure 7) and represented the multiple uses of the water body. However, proportionally litter types related to food and packaging and fragments accounted for about 80% of the total. The top 5 items were Plastic crisps packets/sweets wrappers (J30; 18.00%); Fragments of foamed polystyrene (2.5 cm 50 cm) (J82; 12.75%), Plastic sheets, industrial packaging, sheeting (J67; 10.00%), Fragments of non-foamed plastic (2.5 cm 50 cm) (J79; 7.75%), and Glass bottles (J200; 6.75%).

The items collected in the Warnow reed belts (Figure 8) presented signs of long exposure in the river or entrapment within the reeds. More than 80% of the items showed evidence of biological interactions, including biofilms and algae encrustations. Additionally, many items had signs of fragmentation, and fragments were present in the top 5 items.

4.4.2 Wind conditions – for particle tracking

Five standalone wind conditions and one extreme wind condition were established for the region. For each wind condition, the date and time that represents this condition to start the simulation (Table 2; Figure 7).

Condition	Date	Time	Wind Speed (m/s)	Wind Direction
1	22-Jun-18	3:00:00 AM	6.56	W
2	22-May-18	3:00:00 AM	4.10	E
3	24-Oct-18	7:00:00 AM	2.72	NW
4	14-Feb-18	1:00:00 AM	4.00	SW
5	4-Mar-18	12:00:00 PM	8.99	SE
Extreme Wind	02-Oct-18	19:00:00 PM	23.08	W

Tabela 2 – Wind Speed and Direction Data

4.4.3 Retention rates

The annual simulation for the Warnow estuary in 2018 showed that during the summer months (January to March), particles tended to remain closer to their source. However, there

Figura 8 – Plastic items found in the reed from the Warnow estuary. Photos from Aubrey Newland 2024.

were no significant seasonal differences in retention rates, which remained above 90% throughout the year. Retention rates averaged 95.0% ± 3.4%, while the percentage of free particles averaged 5.0% ± 3.4%. Specifically, retention rates were 91.0% (9.0% free) in January–March, 93.3% (6.7% free) in April–June, 97.4% (2.6% free) in July–September, and 98.2% (1.8% free) in October–December. The water renovation time in the estuary is approximately

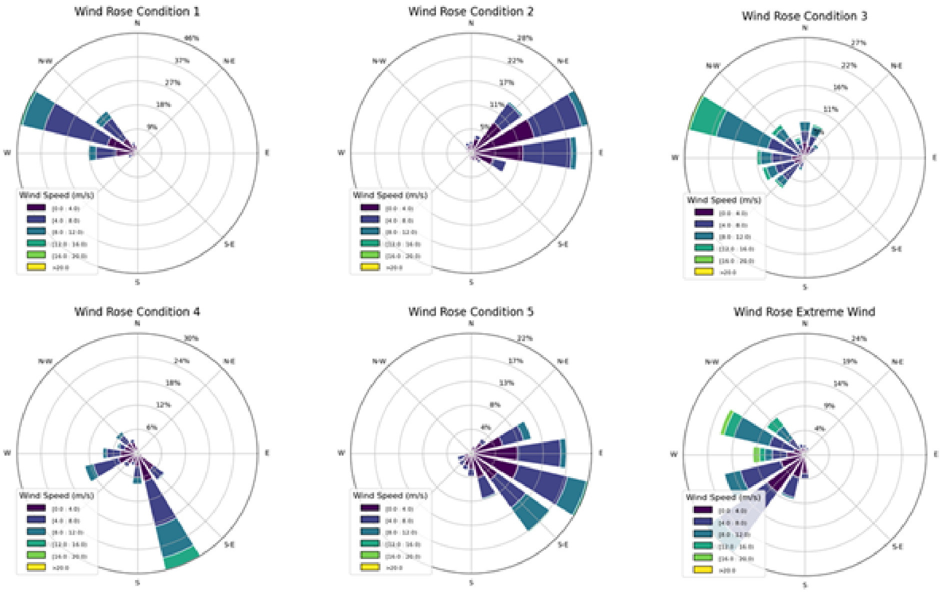

Figura 9 – Wind roses for the wind conditions.

30 days, although the particles took about 16 days to reach the Baltic Sea.

Two horizontal spatial resolutions were tested for particle tracking in the Warnow Estuary: 200 m and 20 m. The performance of the 200 m resolution was inadequate because the grid size was larger than the width of the estuary in most areas of the lower estuary, which caused the model to crack in the first time-steps. Results obtained using the 220 m grid with release points at the estuary center, where the estuary is wider, are presented in Appendix A.

In contrast, the performance of the 20 m resolution was good for all tested conditions, including the Extreme Wind scenario. Simulations with the 20 m resolution took approximately 25 minutes each to finish. On average, 90.38% $\pm$ 13.08% of particles were retained within the estuary after four days, mostly in the reed beds, except in Condition 3, where some of the particles became trapped in artificial structures, they were not accounted as retained but it was possible to visually check the final positions and previous timestamps, assuming that the particles were in a concrete channel for more than 12 hours.

Retention rates across conditions (Figure 10) varied slightly: Condition 1 retained 97.4% of particles, with 2.8% remaining in the water but not exiting to the Baltic Sea; Condition 2 retained 96.2% in the reeds, with 3.8% staying in the estuarine surface water; and Condition 3 had 61.3% retained in reeds, with around 38.7% trapped in artificial structures, specifically a concrete branch in the estuary. Condition 4 showed a retention rate of 93.3%, with 6.7% of particles remaining in the estuary, while Condition 5 retained 96.4%, with 3.6% of particles staying in the water. Finally, the Extreme Wind Scenario resulted in 97.7% of particles retained, with 2.3% remaining in the estuarine water. The effect of wind velocity and direction played a role in the accumulation spot of floating litter, although the retention rates were similar regardless of the condition. Also, four days of steady wind in all scenarios were insufficient to transport particles from the estuary to the Baltic Sea.

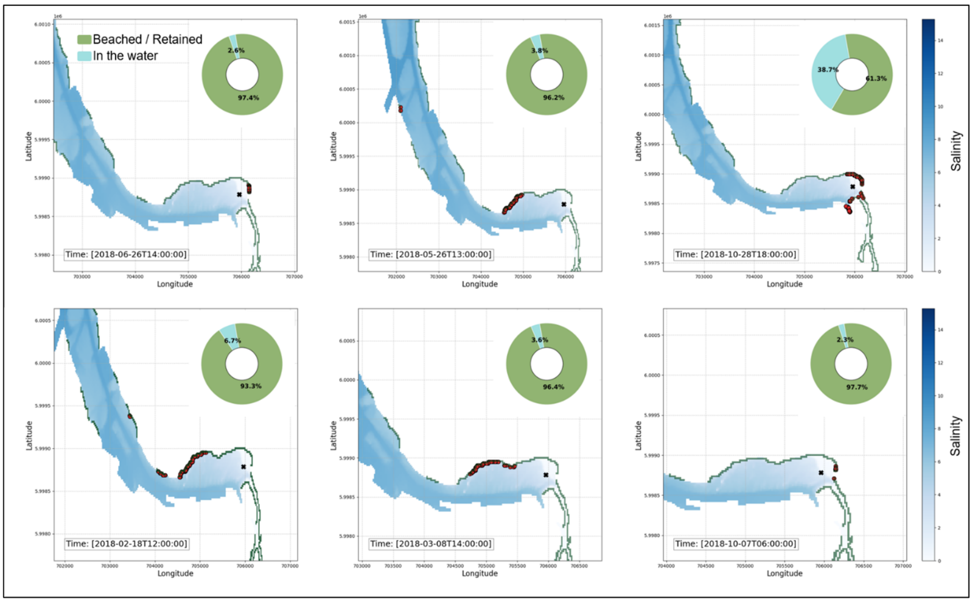

Figura 10 – Retention rates and particles release (X) and final locations (red dots), in the Warnow Estuary.

During the annual simulation in Greifswald Bay, it was observed that particles took approximately 92 days to reach the Baltic Sea through the eastern exit. The narrow channel in the west acted as a conduit for floating material, but the time for litter to reach the sea via this route was around 173 days. Of the released particles, 10% were directed toward the open eastern exit, 24% moved through the western channel, and 66% remained near the Ryck River release point. The retention rate showed no significant seasonal variation, with a mean value of 83.45% ± 8.80% across all seasons. However, in the winter months (January to March) the retention was lower (70.6%) (Figure 11).

For the simulations using the wind conditions (standalone and extreme wind) conducted in Greifswald Bay, we used only the 200-meter horizontal resolution model. Under a 4-day steady wind condition, an average of 15.00% ± 10.84% of particles was retained within the reed zones. Meanwhile, an average of 85.00% ± 10.84% of the particles remained within the bay, mostly concentrated in the southern region. It is important to note that none of the particles were transported into the Baltic Sea.

Conditions 1 and 3 showed similar retention rates (14.1% and 14.4%, respectively), but the dispersion patterns differed. In Condition 1, particles moved horizontally, being in the same latitude, while in Condition 3, their movement followed a south-to-north direction. This south-to-north movement was also observed in Condition 2 but with a lower retention rate of 2.5%. Condition 4 had the highest retention rate (36.5%) and was the scenario where particles traveled the farthest, reaching a distance of 6.52 kilometers. In Condition 5, 5.9% of particles were retained in the reed beds near the release point. Under the Extreme Wind conditions, 16.6% of particles were trapped near the Ryck River and traveled northward along a channel in the bay.

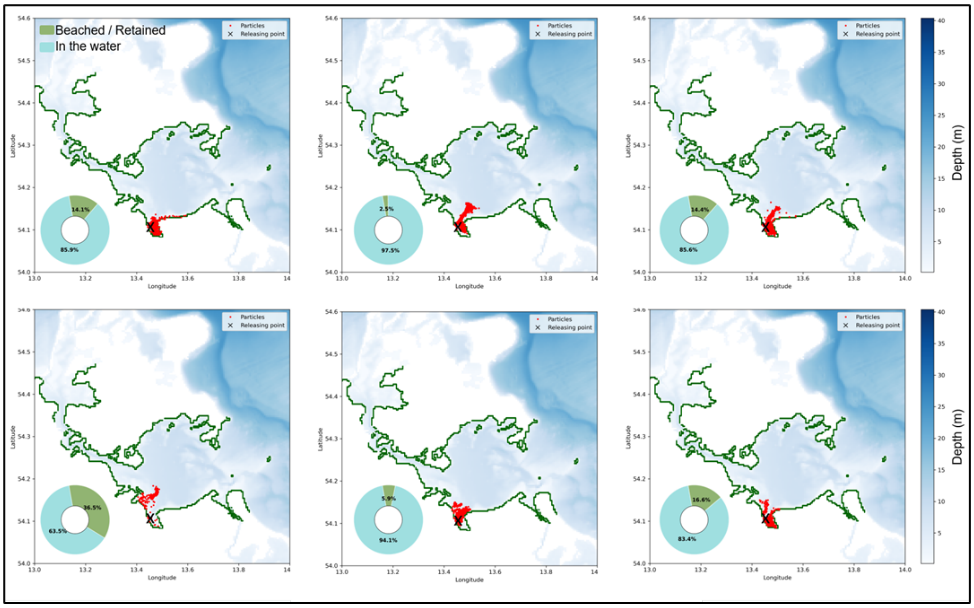

Figura 11 – Retention rates and particles release (X) and final locations (red dots), in the Greifswald Bay.

With the Linear Regression Model, we obtained the following equation:

$$\text{Retention Rate} = 538.45 \times \text{Ratio (Reed area / Estuary area)} - 33.46 \tag{4.1}$$

with an R-squared value of 0.91. This indicates that 91% of the variation in Retention Rate could be explained by the ratio variable, which may represent the estuary morphology. It is important to highlight the complexity of riverine dynamics, and the possible interaction of these variables does not allow a straightforward relationship. Tests conducted in the Oder Lagoon in the Baltic Sea and Babitonga Bay in southern Brazil revealed negative retention values. These results highlight the case-specific nature of the factors influencing trapping rates.

4.5 DISCUSSION

Modeling approaches for marine litter frequently use Lagrangian particle tracking combined with hydrodynamic ocean models to explore the pathways of marine litter. In the Baltic Sea, various studies have used different models to understand marine litter dynamics, although there is a lack of studies considering detailed litter dynamics in estuarine systems. For instance, one study used the HIROMB-BOOS Model (HBM), a model focused on sea-ice interactions, to track litter originating from rivers and coastal areas (CHRISTENSEN et al., 2023), but not taking into account the internal estuarine budget. Another study applied the General Estuarine Transport Model (GETM) to investigate particle pathways under three litter source scenarios: a uniform distribution, land-based sources, and sources from Gdańsk Bay in Poland (PäRN; MOY; STIPS, 2023).

Microplastic loads from rivers were modeled using the HBM model, while urban pathways of microplastics were simulated with GETM (MURAWSKI; SHE; FRISHFELDS, 2022). Additionally, GETM was also used to implement an Eulerian particle tracking approach with a uniform initial particle concentration (OSINSKI et al., 2020). These examples point out the gap in understanding estuarine systems regarding their role in marine litter dynamics, retention, and input to the open ocean.

The average marine litter retention in the Warnow Estuary was estimated to be around 90% in four days of standalone wind conditions. This high retention rate highlights the estuary's role as an important reservoir of plastic waste (EMMERIK et al., 2022). Previous research in the Warnow highlighted its retention capacity, showing that a low amount of macro-litter (0.4% in 2010) was transported to the Baltic Sea when particles were released further within the estuary during a sailing event (SCHERNEWSKI et al., 2024). This study also observed particle accumulation in artificial structures within the estuarine environment, the same observed for wind condition 3 in the present study.

Assuming full reflection of litter from fixed/artificial structures is not realistic, as floating litter can become trapped in various physical structures within coastal and estuarine environments. For instance, harbor piers, marina infrastructure, and spaces between moored boats often act as barriers that capture floating litter. These structures create local retention zones where plastics accumulate. Incorporating these dynamics into models would be an interesting improvement and may help to identify hotspots for targeted cleanup and mitigation efforts.

No significant seasonal or monthly differences in particle retention were detected for both cases of studies. The consistency of particle loads across months and seasons highlights wind patterns' dominant role in influencing the region's litter dynamics. This finding suggests that the Warnow Estuary functions as a stable system regarding particle distribution and retention. Previous studies have also emphasized the importance of wind in driving surface water dynamics and influencing the distribution of floating debris (GARELLO et al., 2021).

Autumn (September to November) marks the transition to colder weather in the Northern Hemisphere, often influenced by low-pressure systems that bring increased storm activity, particularly in October and November for the Baltic region (DąBROWSKA; TORBICKI, 2024). These storms result from pronounced temperature contrasts between land and sea, driving stronger wind systems. Despite the increased wind velocities during storms leading to more widespread particle dispersion within Greifswald Bay, strong wind events had a limited impact on litter transport and retention patterns. Wind direction remained the dominant factor influencing retention outcomes and /or the arrival of particles to the open sea. It is important to highlight that the tide influence in the Baltic can be neglected (LANGE; KLINGBEIL; BURCHARD, 2020).

Even with no statistical significance, the results indicate a slightly higher accumulation of litter in the estuarine vegetation during colder periods, likely driven by environmental conditions such as wind intensity and direction. Summer and spring winds may differ in intensity and direction compared to autumn and winter, influencing how litter is trapped in vegetation. Combined with greater waste generation in warmer months, this could increase litter accumulation, highlighting the need to consider local realities and seasonal interactions between environmental and human factors.

On a global scale, the retention of floating plastic in coastal vegetation and estuarine systems has been documented (EMMERIK et al., 2022). Estuarine dynamics and morphology play a crucial role in limiting plastic emissions into the ocean, as most plastic waste (approximately 98.5%) remains entrapped within terrestrial environments (MEIJER et al., 2021). This retention leads to the accumulation of plastics, contributing to the accumulated pollution of inland aquatic ecosystems (MEIJER et al., 2021). In tropical areas also mangroves' dense root systems serve as barriers that intercept and retain plastics (Ivar do Sul et al., 2014). Depending on the latitude, vegetation type, estuary morphology, and environmental factors such as wind and tide, estuarine systems' retention rates could vary. This is why the regression model applied to the retention rates in the Warnow and Greifswald systems does not perform well in other environments.

The effect of estuary morphology and model horizontal resolution on floating plastic retention was observed in the varying retention rates between the Warnow Estuary and Greifswald Bay. Fine-resolution models, with spatial resolutions of less than 100 meters, provide more detailed insights into localized accumulation zones compared to coarser models (WARD et al., 2023). These models are essential for understanding the dynamics of coastal dispersal, as they can capture the fine-scale variations that influence plastic retention. However, high-resolution models are still largely unavailable in many coastal regions, especially in the Global South, where higher rates of waste mismanagement could increase plastic pollution challenges (STOETT et al., 2024).

The dynamics of floating litter transport and retention in riverine and coastal systems reveal complex interactions shaped by environmental and anthropogenic factors. Estuarine systems like the Vistula and Oder Rivers could contribute to the Baltic Sea's litter loads, due to its size and morphology (GONZáLEZ-FERNáNDEZ et al., 2021). However, the river's contribution to the input budget might be overestimated since the studies suggest that much of the plastic from these sources is dispersed across the Baltic Sea due to cyclonic currents, with accumulation in areas such as the Gulf of Finland and the Northern Baltic Proper (PäRN; MOY; STIPS, 2023). However, retention is not considered. This highlights the role of rivers as both potential sources and potential reservoirs of marine litter, as retention and remobilization depend on hydrodynamic and morphological conditions (EMMERIK et al., 2022). Comparing these insights to the high retention in 4-day timeframe rates observed in the Warnow Estuary highlights the importance of local modeling approaches to represent plastic dynamics better and inform targeted mitigation strategies in the accumulation points. The sampling points and litter collection do not match with potential hotspots of litter accumulation, even though the amount of litter accumulated in the Warnow is approximately 1,000 times lower than what was estimated in previous studies (GONZáLEZ-FERNáNDEZ et al., 2021).

One indication that river litter and its retention potential are relevant topics comes from programs like Ocean Cleanup, which recognizes rivers as a significant source of plastic pollution. Indeed, rivers play a crucial role in transporting plastic to the oceans, although not all rivers contribute equally, and the amount of litter in rivers may be underestimated. The retention rates observed in this study align with those predicted by the model developed by the Ocean Cleanup Project. For example, in the Warnow Estuary, initial measurements at the river mouth showed 2,300 kg of plastic. Our extrapolation suggests that up to 68734910 kg of plastic could be retained in the reeds, which is about 30 times higher than the amount of floating plastic on the water's surface. However, at the estuarine outlet, only 400 kg of plastic remains, resulting in a retention rate of 82.61%, which closely matches the retention rate observed in this study.

In contrast, Greifswald Bay, where 1100 kg of plastic enters via the Ryck River, shows significantly lower retention, with only 800 kg remaining in the canal, yielding a retention rate of 27.27%, our study found a lower retention rate (about 15%), but considering the whole Bay. These differences in retention rates point out the influence of estuarine morphology, hydrodynamics, and other environmental factors on the dynamics of floating plastic retention across various systems. The Warnow Estuary is smaller and narrower than the Greifswald Bay system, presenting a quicker accumulation of particles in the coastal areas. Additionally, while the Warnow has a proportionally more artificial coastline, the region where particles were released is characterized by a more natural coastline, facilitating better trapping of plastics. In contrast, Greifswald Bay is wider, and the particles take more than four days to reach the coast and be trapped. This difference highlights the importance of considering both the spatial and temporal components of plastic retention when calculating plastic emissions from land to sea. The temporal aspect of retention plays a significant role in understanding the transport and fate of plastics, influencing how they are managed in coastal environments. In this context, it would be important that coastal managers consider estuaries as marine litter hotspots. Long-term monitoring could help to understand accumulation points for intercepting litter before it reaches the ocean. Since 2019 the NGO The Ocean Cleanup installed 16 interceptors in 8 countries in an attempt to tackle plastic pollution from its source (https://theoceancleanup.com/rivers/).

While vegetation plays a role in trapping floating litter (EMMERIK et al., 2022), other factors, such as estuarine morphology, and variability in plastic input characteristics, may play a stronger influence on retention. For instance, studies on the Baltic Sea have highlighted the importance of estuarine shape and the presence of artificial structures in determining retention hotspots (Schernewski et al., 2021). The simulations demonstrated that wind direction often plays a more significant role in plastic transport and retention than wind velocity. Similar findings have been reported in studies using Lagrangian particle models, where the direction of wind-driven currents orientated the accumulation patterns of floating debris (PäRN; MOY; STIPS, 2023).

A study conducted a detailed analysis of the river belts and showed that riverside litter accumulates close to highly populated areas even after floods. Population density showed the highest explanatory power for litter accumulation. Geomorphological factors also played a key role in the accumulation dynamics (PACE et al., 2024).

Riverine macroplastics present a threat to the environment and society, yet a harmonized monitoring method for litter in riverbanks has not yet been implemented (GONZáLEZ-FERNáNDEZ; HANKE, 2017), beach litter monitoring has already shown promising results for mitigation and a better understanding of the problem. In this context, modeling tools could help to identify monitoring spots and be a complementary approach.

4.6 CONCLUSION

Understanding the dynamics of estuarine systems is essential for managing plastic emissions from land to sea. Mitigation strategies should focus on retention hotspots, particularly in areas where localized accumulation occurs. Integrating high-resolution modeling into management practices can further improve the effectiveness of these strategies and help address the growing challenge of plastic pollution in coastal and estuarine environments. However, the solution might depend on human creativity and local knowledge and expertise, from communities, previous management experiences, and collaboration with academia.

APENDIX A - MODEL RUN IN THE WARNOW WITH 200M RESOLUTION

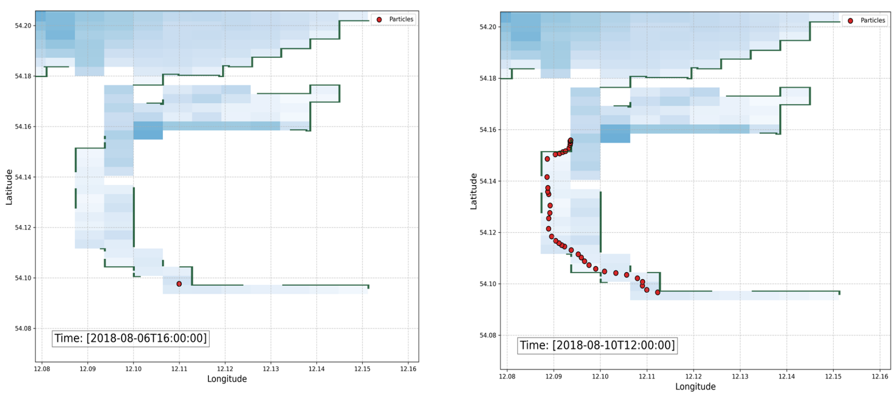

Figura 12 – Model run in 200m horizontal resolution for the Warnow estuary. The particle releasing point was changed due to the lack of a model cell at the beginning of the estuarine system

AUTHORS CONTRIBUTION

Conceptualization, G.S., G.E.S, and B.R.; methodology, G.S., B.R., and G.E.S.; model simulations, X.L., U.G., B.R.; writing, B.R; visualization, B.R.; review and corrections, all authors; supervision, G.S.; project administration and funding acquisition, G.S. All authors have read and agreed to the published version of the manuscript.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this paper, the author(s) used ChatGPT -4omini in order to improve English written in terms of clarity and grammar. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

FUNDING

BR received a Ph.D. Scholarship (Finance Code 001) from Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES). This work was financially supported by the German Federal Ministry of Education and 820 Research, projects “Coastal Futures II” (grant number 03F0980B) and “Prime Prevention” (grant 821number 03F0911B). DAM Prime prevention.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

ACKNOWLEDGMENT

We thank Aubrey Newland for providing data about marine litter items trapped in the reed on the Warnow.

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Are presented at the end of the thesis

5 CONSIDERAÇÕES FINAIS

A presente tese de doutorado abordou algumas lacunas relacionadas ao estudo do lixo no mar. Foram enfocados temas como disponibilização de dados seguindo o princípio FAIR (RAMOS; LIMA; COSTA, 2022; TANHUA, 2019), áreas sub amostradas do ambiente praial como a praia submersa (0.5 até 3m) (RAMOS; COSTA; LIMA, 2024) e uso de ferramentas tecnológicas para avançar na compreensão dessa problemática (MAXIMENKO et al., 2019). A partir de uma abordagem inovadora, que combinou coleta de dados in situ, desenvolvimento de banco de dados e utilização de modelo de rastreamento de partículas, esta pesquisa contribuiu para o campo de estudos de lixo no mar, tanto no Brasil quanto em outros contextos, como o do Mar Báltico. Apesar de serem estudos de caso, as ferramentas e abordagens para estudo de lixo no mar desenvolvidas nessa tese podem ser extrapoladas para diversos contextos sociais e ambientais.

Os produtos científicos apresentados destacam a importância da disponibilização e da integração de dados robustos e acessíveis para o estudo e gestão do lixo no mar. No Brasil, a escassez de dados que sigam o princípio FAIR limita a capacidade de gestores e cientistas em desenvolverem soluções eficazes (RAMOS; LIMA; COSTA, 2022), busca recente (novembro de 2024) aponta que existem apenas 2 dataset registrados no Google Dataset Search com a temática lixo no mar no Brasil, ao expandir abusca para microplásticos 4 novos dataset foram encontrados, todos publicados após 2023. Este tese aponta a necessidade urgente de melhorar a infraestrutura de dados e de promover a interoperabilidade entre plataformas que possam conectar informações ambientais, oceanográficas e socioeconômicas, com ênfase para o sul global.

A criação de um banco de dados relacional, apresenta uma alternativa prática para superar parte dessas lacunas. Já que pode ser aplicado localmente e utilizar dados de bases de dados globais, integrando diversos tipos de dados e proporcionando uma ferramenta para a gestão e análise de dados. Além disso, a tese traz à tona a relevância de áreas subexploradas, como a região submersa em praias, para um entendimento mais completo da dinâmica do lixo no ambiente praial (RAMOS; COSTA; LIMA, 2024). A comparação entre áreas de banho submersas e praias emersas revelou variações na composição e nas possíveis origens do lixo, destacando a importância de se considerar todas as facetas do ambiente costeiro. Além disso, o estudo chama atenção para a presença de marcas locais na composição do lixo submerso, corroborando com outros estudos da região (SILVA; ARAúJO; CAVALCANTI, 2023).

No contexto da gestão costeira, o lixo no mar tem papel chave. Seja atuando como "espécie bandeira" e/ou fomentando discussões mais aprofundadas sobre o ambiente marinho costeiro. Este trabalho oferece uma ferramenta inovadora e interativa de descrição de praias chamada BeachLog, que visa retratar (or tirar uma fotografia) da praia em seu estado atual, sem juízo de valor ou julgamento de qualidade. O BeachLog permite que os usuários registrem detalhadamente informações sobre as praias, incluindo a presença de lixo no mar, e oferece uma maneira fácil e sistemática de coletar e analisar dados para apoiar projetos de gestão costeira, monitoramento de longo prazo e estabelecimento de linhas de base para descrição de praias. Além disso, o BeachLog pode ser usado como uma ferramenta didática para aproximar as ciências ambientais da tecnologia, fornecendo uma interface amigável baseada em planilhas e painéis interativos (RAMOS; COSTA, 2023).

Por fim, o uso de modelos hidrodinâmicos e técnicas de rastreamento de partículas apresentou novas perspectivas sobre a dispersão e retenção de macroplásticos em regiões estuarinas, oferecendo insights que podem ser aplicados tanto no contexto brasileiro quanto em outras regiões costeiras. Embora o estudo focado no Mar Báltico não seja diretamente aplicável ao Brasil, ele demonstra a importância e aplicabilidade dessas abordagens tecnológicas e abre caminho para futuras investigações sobre como os estuários brasileiros podem contribuir para a retenção ou dispersão do lixo no mar. A infraestrutura computacional brasileira e a falta de modelos hidrodinâmicos de alta resolução para a costa brasileira ainda é um desafio nesse campo de estudo.

Ao longo desta tese, ficou claro que, para enfrentar o desafio do lixo no mar, é crucial integrar múltiplas disciplinas, dados de diferentes naturezas e inovar nas ferramentas utilizadas. A combinação de dados ambientais, ferramentas tecnológicas e abordagens computacionais oferece uma alternativa para a criação de soluções mais eficazes e sustentáveis.

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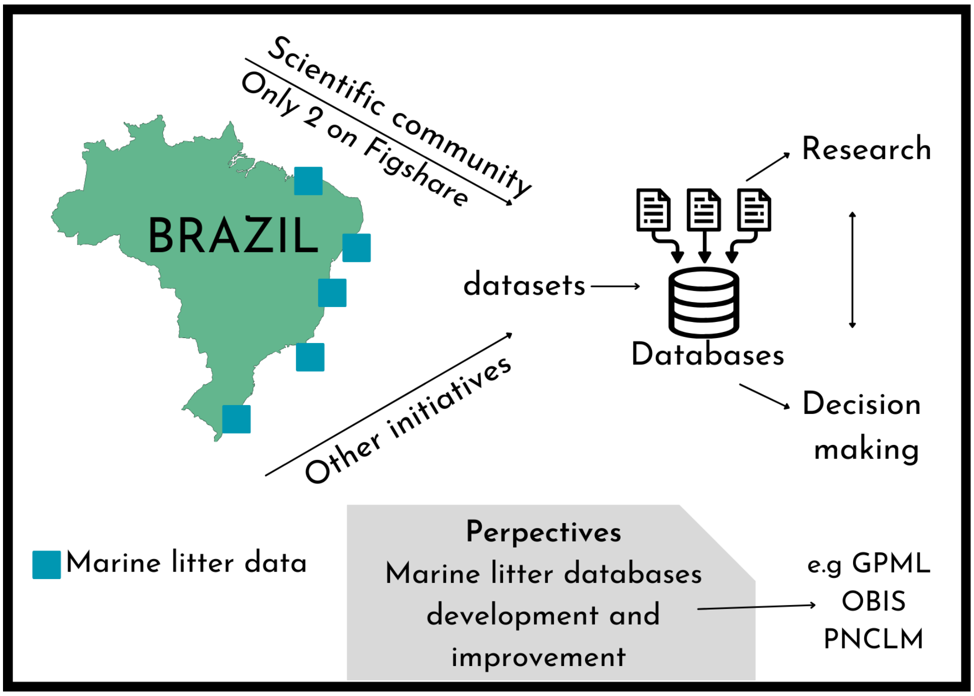
APÊNDICE A – WHERE ARE BRAZIL'S MARINE LITTER SCIENTIFIC DATA?

Artigo publicado em 04 de agosto de 2022 na revista Frontiers in Sustainability.

ISSN eletrônico: 2673-4524, Front. Sustain. 2022. 3:947343.
doi: 10.3389/frsus.2022.947343.



frontiers | Frontiers in Sustainability

TYPE Review
PUBLISHED 04 August 2022
DOI 10.3389/frsus.2022.947343

Check for updates

OPEN ACCESS

EDITED BY
Tomaso Fortibuoni,
Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA), Italy

REVIEWED BY
Anna Maria Addamo,
Joint Research Centre (JRC), Italy
Matteo Vinci,
Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Italy

*CORRESPONDENCE
Bruna de Ramos
ramos.de.bruna@gmail.com

SPECIALTY SECTION
This article was submitted to Waste Management, a section of the journal Frontiers in Sustainability

RECEIVED 18 May 2022
ACCEPTED 24 June 2022
PUBLISHED 04 August 2022

CITATION
Ramos Bd, Lima TMd and Costa MFd (2022) Where are Brazil's marine litter scientific data? *Front. Sustain.* 3:947343.
doi: 10.3389/frsus.2022.947343

Where are Brazil's marine litter scientific data?

Bruna de Ramos[1]*, Tábata Martins de Lima[2] and Monica Ferreira da Costa[1]

[1]Departamento de Oceanografia, Universidade Federal de Pernambuco, Recife, Brazil, [2]Programa de Pós-graduação em Oceanografia, Universidade Federal de Santa Catarina, Florianópolis, Brazil

The environmental sciences work with datasets every day. Recently, data sharing has become a more familiar activity for academic researchers. Records of marine litter are scarce and generally difficult to find worldwide, especially in databases. This work reviews and analyzes data repositories to identify the existence of datasets related to marine litter in Brazil. Only one global repository specializing in marine litter was found, and it is in the early stages of operation. Only two datasets about marine litter in Brazil were found in the generalist repository Figshare that do not follow all the FAIR principles (Findable, Accessible, Interoperable, and Reusable) for data sharing. A few initiatives are being developed aiming to collect and share marine litter data, but only one of them (Our Blue Hands) is already in place and uses a standardized, replicable method, and aims to share the data by design. Our work identified interoperability as the main point to be tackled within our context. In the UN Decade of Ocean Science for Sustainable Development (2021–2030), it is essential that repositories are created, improved, and encouraged to address the specific needs of marine litter data-sharing and researchers' behavioral shift to start sharing the data already collected. Data sharing not only allows for the integrated vision of the academic community but can also contribute to public policies, helping decision-makers and encouraging a more sustainable science regarding financial and natural resource use.

KEYWORDS

FAIR principles in open education, interoperability among databases, dataset, repositories in science and technology, sustainability, predictable ocean, GPML, cooperation (with civil society organizations)

Introduction

The environmental sciences work with data every day. Recently, data sharing has become a more familiar activity for academic researchers (Goben and Sandusky, 2020). Available data can support new research and can be used by decision-makers. Technological advances, including the internet and easy access to information, help advance science. Despite the technology available, more data are produced every year that needs to be organized and accessible. Data accessibility brings advantages to science and society and links different study areas (Barreto et al., 2019). It would be possible to carry out many studies with already existing data. An example is that in the

COVID-19 pandemic scenario, some reviews and reanalysis used previously available data. This shows that the available data is important to guide our next works more consciously (Saadat et al., 2020). During COVID-19, the universities were closed in Brazil and most parts of the world to contain the spread of the virus. Due to the global lockdown, researchers had no access to their laboratories, and fieldwork was canceled. Since scientists are "rated" by their number of publications, they had to find some way to keep publishing during this time. Some options were review articles and analysis using data that were previously collected and/or available in repositories.

However, it is not only in a pandemic scenario that data should be shared; if not shared, data remain unused. Hence, sustainable initiatives for resources and/or biological samples are used for data collection and processing, which can be optimized by sharing and reusing the data.

Marine litter is an important theme worldwide, presented in the Sustainable Development Goals (SDGs) target 14.1, "By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution" (United Nations, 2022). Among a wide range of pollutants, marine litter and nutrients were prioritized. Also, marine litter is listed as an Essential Ocean Variable (EOV) by the Global Ocean Observing System (GOOS), highlighting the relevance of marine litter impacts on marine conservation and the importance to collect and provide such data. In the scenario of the UN Decade of Ocean Science for Sustainable Development (2021–2030), marine litter datasets following FAIR principles can help to achieve a clean and predictable ocean.

Depending on research areas, data sharing can be in its early stages or better developed. In some study areas, it is possible to choose a suitable repository, organize the data, prepare the metadata, accessory documents, copyright, consent, and permissions, and deposit the dataset (EDCTP, 2022) more easily than in other fields. Data regarding marine litter could help better understand the current scenario and support decision-making. In this work, we bring a review of previously used and potential scientific marine litter data and databases focusing on Brazil.

Brazil is the fifth largest country in the world in terms of land area (8,547,403 km^2) (IBGE, 2021). The Brazilian economy has components based on coastal and marine activities, for example, oil and gas exploitation, harbor and industrial activities, fishing, leisure, and tourism. Also, almost 30% of the population lives in the coastal zone (IBGE, 2011). Besides being a large and developing country with diverse and complex environmental and socio-economic issues, Brazil is the fourth largest plastic waste producer in the world (Zamora et al., 2020). This can cause a loss of 5.7 billion Real (Brazilian currency) a year for not dealing with this problem (Zamora et al., 2020), and also increase marine litter pollution. In this context, the number of papers about marine litter in Brazil is increasing (Castro et al., 2018; da Silva Videla and de Araujo, 2021). However, there are few datasets available related to these publications for further development of possible solutions to marine litter problem based on data.

This work aims to review and analyze data repositories to identify the existence of datasets related to marine litter in Brazil, bringing a global point of view of marine litter data sharing. In addition, we aim to highlight the importance of FAIR principles and data sharing as key points for improving and encouraging sustainable science of natural resource use and conservation.

Data, databases, and related repositories

It is common sense that data is the primary building block for both information and knowledge (Zins, 2007b). Data, information, and knowledge are the major components of information science (Zins, 2007a). Although there are some divergences in the definitions of what really involves this area (e.g., the subtypes of knowledge), for the purpose of this work, we are going to consider data, information, and knowledge as parts of sequential order. Therefore, data will be the precursor of information, which will serve as the base for knowledge. Data for this work is any set of records from observation or measurement arranged comprehensively.

The use of data is important for different areas, including environmental sciences. The use of natural resources and the ecological footprint for data collection in the environmental sciences can be optimized if more studies are carried out with the same dataset. Oceanographic cruises that collect a large amount of data also have polluting potential, for example, due to the use of fossil fuel. Using data already collected can better justify the polluting activity and allow more people to use, discuss and compare data. In addition, data availability can support better understanding or even the integration of ideas, allowing the detection of temporal and spatial patterns, such as physical oceanography data that can indicate patterns of accumulation and disposal of marine litter (Van Sebille et al., 2020). Thus, places to store and share data are becoming more common in the scientific community. Data storage requires infrastructure and energy. To make this more sustainable, it is recommended to optimize existing data repositories and resources to improve interoperability and reusability (Tanhua et al., 2019).

In agreement with this, some government and funding agencies require that researchers make their data available to receive financial support (Michener, 2015; Brainard, 2021), which plays an important role in the open science and open data movement. In 2022, the Brazilian government launched the National Consortium for Open Science (ConCIenciA in Portuguese), an initiative that aims to encourage open data repositories for research data in the national territory and support their governance with international acceptance and visibility. An action of ConCIencia was the launching of

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LattesData platform (https://lattesdata.cnpq.br/) from Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), a funding agency from Brazilian government. The repository was created to reunite, storage and share scientific data from funded CNPq researchers, in the future it can be open for every researcher. It highlights the role of universities in facilitating pathways to address environmental problems (Gardner et al., 2021) by providing FAIR (Findable, Accessible, Interoperable, and Reusable) data.

There are several repositories where scientists from different areas are able to share their data. Data repositories can be generalists or specialists. Generalists do not require specific formatting and/or topic of research, while specialists accept only data referring to a research area and/or certain formatting for the database (De Pooter et al., 2017). Most of the time, scientists do not know where to publish, which leads to unavailable and scattered data (Park and Wolfram, 2017). Nevertheless, the importance of sharing has been overcoming the difficulties, allowing the sharing culture to grow despite the adversities (Pendleton et al., 2019).

The open scientific data approach is proposed to help increase the speed of science, allow the comparison and cross information, increase the reproducibility of scientific work as well as mitigate data manipulation (Hampton et al., 2013; Pendleton et al., 2019). In addition, it is a strategy to optimize resources and produce a more sustainable scientific outcome, including transparency of public funds used in data acquisition.

The goal of Open Science is to make scientific research and its dissemination accessible to all levels of society. Also encompassed in the concept of Open Science are open access, open educational resources, open-source software, and citizen science, all of which are grounded in equity, diversity, and inclusion (European Commission, 2019).

In addition to online repositories, many countries have a Spatial Data Infrastructure (SDI) that includes technology, policy, standards, and human resources and encompasses activities, such as data acquisition, processing, distribution, use, maintenance, and preservation. In other words, an SDI goes far beyond an online repository. Some examples are the British Oceanographic Data Center (BODC), the Centro Argentino de Datos Oceanográficos, the Australian Ocean Data Network (AODN), the North American National Centers for Environmental Information (NCEI), and the Infrastructure for Spatial Information in Europe (INSPIRE). However, the SDI might not have data on marine litter; an exception is EMODnet, which is an EU SDI including marine litter data.

In Brazil, the National Spatial Data Infrastructure (NSDI) was launched in 2010, aiming at the integration between systems of different institutions. Its purpose is to catalog, integrate, and harmonize existing geospatial data in Brazilian government institutions. It has good documentation and defined standards for data and metadata (Gandra et al., 2018). However, in general and globally, there is still a lack of national and international collaboration for SDIs (Gandra et al., 2018); in addition, it is necessary to increase the scope to cover timely themes such as marine litter. An example is the vanguard work that is done in EMODnet, an SDI that covers most of the Essential Ocean Variables (EOVs) and keeps updated on new themes such as marine litter.

Sharing is not a problem

Despite the importance of sharing data, this is still a trend for most researchers all over the world that used to keep their data under personal control and now are dealing with the data sharing process (Reichman et al., 2011). Therefore, the first big challenge is the cultural change shift (Pendleton et al., 2019). Some of the factors that do not collaborate to this change are time and effort to find suitable repositories to upload the data, write appropriate metadata, and format the data in templates that do not always fit the type of data sampled (Park and Wolfram, 2017). Since it is still a new field, there is not much information on what to do in terms of standardized procedures and guidelines for the authors. In this regard, an example is a step-by-step guide developed by Soranno (2019) to facilitate this decision process. There are other examples such as the EMODnet ingestion portal (EMODnet, 2022a) and the EDCTP Knowledge Hub (EDCTP, 2022) guidelines.

Another factor contributing to the resistance to sharing data is data authorship/ownership (Costello, 2009; Reichman et al., 2011), which concerns about data misinterpretation and misuse (Campbell et al., 2002; Borgman, 2012). Both of these are related since many times authors start viewing this data as a product that was created by them and not only as a result/output of their work (Broom et al., 2009). There are laws about intellectual property and initiatives as the Creative Commons license, which guarantee the authors the credit for the data. However, the problem seems to be more related to the work put into collecting the data and the need to overprotect it rather than the actual ownership (Broom et al., 2009; Perrier et al., 2020). On the other hand, researchers understand that collected and processed data should be accessible to contribute to science and assure transparency, especially in the case of government funding bodies (Broom et al., 2009).

Despite some governmental and funding agencies moving toward implementing data sharing, there is still lack of specific incentives for researchers to share the data (Costello, 2009; Reichman et al., 2011), such as clear rules, training, and planned financial support. Additionally, there is resistance from some spheres of the scientific community to make data available in an organized and open manner (Perrier et al., 2020). So, there is an urgent need to change this culture and work together in a less-competitive way making cooperation the mainstream science model (Figure 1).

In an attempt to mitigate some of the problems related to data sharing, various societal sectors worldwide—academia,

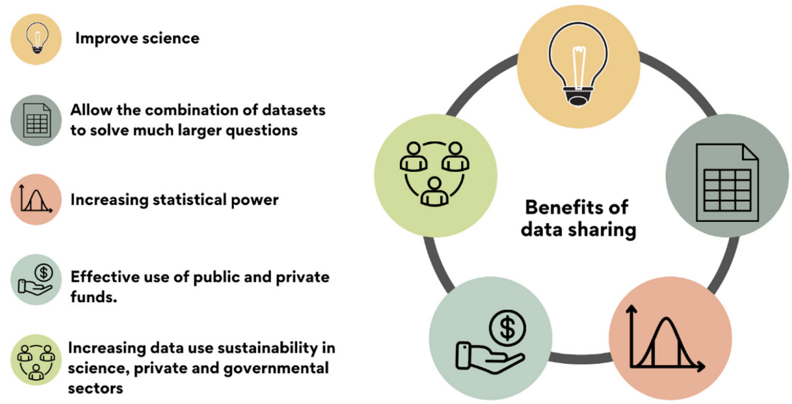

FIGURE 1
Benefits of data sharing under FAIR principle, based on Perrier et al. (2020).

industry, funding agencies, and publishers—have agreed to use the FAIR principle (Findable, Accessible, Interoperable, and Reusable). In this context, data must be Findable, having a unique identifier for the data file and the data content. Accessibility: the sampling/data collection protocol and datasets are open and free. Interoperable: data representation is done with language that follows the FAIR principle, and different repositories can access and provide datasets. Reusable: the data are made available with detailed metadata that allows more than one use/study (Wilkinson et al., 2016; Tanhua et al., 2019).

The FAIR principle allows data to be easily used by other researchers, decision-makers, and machines (Wilkinson et al., 2016). The FAIR principle help to mitigate the problems raised related to data integrity, quality, and adequate amount of details that allow the reuse of the data (Perrier et al., 2020). Quality check and control performed by humans and/or machines is an important practice to keep repositories reliable.

The publication of articles with supplementary material containing the data used does not characterize a data repository since it does not meet the FAIR principles, has no specific identifier for the dataset (e.g., DOI) (not Findable), and rarely presents metadata or standardization (not Accessible and Reusable). Also, journal publishers do not have a repository structure to store and make available datasets submitted as Supplementary material. There are papers being published with Supplementary material that could also be datasets to be placed in repositories.

Metadata are data that provides basic information about the main dataset, such as the time zone of collection, details about equipment, method used, etc. Some publishers and journals encourage data sharing in repositories, such as Data in Brief and Mendeley Data, that have started the process of publishing data papers and/or dataset. In this case, the data present a detailed metadata in agreement with the FAIR principle. However, the publication process is costly.

Methodology

This review analyzed open data repositories to identify the presence of datasets related to marine litter in Brazil. Google's Dataset search (https://datasetsearch.research.google.com/) was used on the first search to find datasets and their host repositories. Google's Dataset is a platform that compiles all datasets available online being a powerful tool for global searches. The main goal is to organize the information that exists in the world and make it accessible and useful.

In Google's Dataset website, a search was performed using the terms: "marine litter," "marine debris," "lixo marinho," "lixo no mar," "Brasil," "Brazil," "plástico," "plastic," "microplástico," "microplastic." The searches were conducted until April 2022, with no restrictions on the start date. The datasets found in the searches were assessed and checked for the rules of FAIR principles (Wilkinson et al., 2016; Tanhua et al., 2019).

Although, Google's Dataset search is not considered a repository since it is a search tool that redirects users to the repositories. It was not possible to find data papers through Google's Dataset search, indicating that this type of publication is in an intermediate area between data publication and a scientific article. Second, an active search was conducted to

TABLE 1 A summary of data repositories and potential of data related to marine litter in Brazil.

Coverage	Type	Repository	Marine litter data for Brazil	Notes
National	Specialist	BNDO	None	Distribution of data through an e-mail request. Difficult to search for available data. Incomplete metadata. Brazilian Navy is responsible for keeping the repository.
	Specialist	GOOS	None	Each project associated has its own website and criteria for uploading and downloading the data. Difficult to search for available data.
International	Specialist	OBIS	None	Depends on the cooperation of institutions to feed the database. Specialist repository. Darwin Core format
	Generalist	Figshare	2	No data audit/curation Incomplete metadata Provide metrics (view, downloads and citations)
	Generalist	PANGAEA	None	With data audit/curation
	Generalist	KNB	None	With data audit/curation
	Specialist	GPML	None	Gathers data from partners

identify other repositories. In each repository, there was a search using the same keywords used in Google's Dataset. Active searches have a controlled level of uncertainty. However, by overlapping different search methods, it is possible to keep it to an acceptable minimum.

Regional repositories, e.g., focused on the EU Member States, Artic region, Indonesia, or other region outside the analyzed area, were not considered in the analysis because they were not related to the main goal of the study. However, Brazilian and global repositories that did not present marine litter's data in Brazil accounted for a better understanding of the possibilities of future data hubs focusing on marine litter in the region.

Results and discussion

Marine Litter is a pressing environmental problem in the 21st century; many scientific papers are published in Brazil annually involving macro and/or microlitter, especially in coastal zones (Castro et al., 2018; da Silva Videla and de Araujo, 2021). The complex nature of litter data and the lack of standardization regarding the use of the already existing guidelines (e.g., GESAMP, UNEP, and NOAA) for collection and nomenclatures are often detrimental in the process of making litter databases available, as well as entailing management and conservation challenges (Hartmann et al., 2019). Marine litter encompasses a wide range of materials from various sources, including Abandoned Lost or otherwise Discarded Fishing Gear (ALDFG), sanitary materials, and construction waste; there are a lot of litter typologies, glass objects, anthropic wood, plastic fragments, microplastics. Different types of litter have different measurable parameters, e.g., size, weight, color, malleability, material, brand, possible source, among others.

Marine litter data

Seven data repositories related to environmental science with the potential to present a Brazilian marine litter dataset were identified (Table 1). Two repositories had national coverage: Banco Nacional de Dados Oceanográficos in Portuguese (BNDO) and the Brazilian node of Global Ocean Observing System (GOOS). Five repositories had international coverage: Ocean Biogeographic Information System (OBIS), which is integrated with the Brazilian Biodiversity Information System (SiBBr), Figshare, Pangaea, KNB, and Global Partnership for Marine Litter (GPML).

One specialist repository for marine litter was found: the Global Partnership on Marine Litter (GPML) Data Hub. However, in 2022, the platform is in its early stages of operation and there are no clear guidelines on how the data curation and/or auditing process will work. GPML works as a hub that puts together data from different data partners, such as Florida State University, University of Leeds, Alliance to End Plastic Waste, GRID Arendal, and EMODNet Chemistry. The platform also proposes to be a place to deposit best practices and experiences to tackle marine litter worldwide. There is no dataset from Brazil available in GPML yet.

Regarding national repositories, one possible database for marine litter data could be the National Oceanographic Database (BNDO) (https://www.marinha.mil.br/chm/dados-do-bndo/acesso-dados-e-produtos), which is managed by the Brazilian Navy. The aim of the institution is to promote and coordinate the participation of Brazil in the activities of the Intergovernmental Oceanographic Commission of UNESCO (IOC - UNESCO) related to Ocean Services and Ocean Mapping. However, the data are focused on physical and geological oceanography, and for some access data, it is necessary to contact by e-mail to request access, which in many cases can delay the research and/or decision-making process. Also, besides its difficult user interface and incomplete metadata, it does not meet the accessibility and reusability of the FAIR principles and has no data on marine litter listed in its available variables.

The Global Ocean Observing System (GOOS) is led by the Intergovernmental Oceanographic Commission (IOC) of UNESCO and co-sponsored by the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP), and the International Science Council (ISC). The Brazilian node (https://www.marinha.mil.br/secirm/psrm/goos) is led by the Brazilian Navy and is focused on physical oceanographic measurements from 10 projects, such as Prediction and Research Moored Array in the Tropical Atlantic (PIRATA). A weak point is that each project associated with the Brazilian GOOS node has its own website and criteria for uploading and downloading the data, making it difficult to search for available data, especially regarding format files and time series. It also does not present marine litter data listed in its available variables.

Regarding international coverage repositories, the Ocean Biogeographic Information System (OBIS) is a specialist repository focusing on marine biodiversity. The repository compiles data from various national nodes. One of these nodes and also Brazil's first initiative for sharing environmental data is the Brazilian Biodiversity Information System (SiBBr—Sistema de Informação Sobre a Biodiversidade Brasileira in Portuguese), an online platform that integrates data on biodiversity and ecosystems from various sources in Brazil and abroad. The platform is easy to use and has a user-friendly interface. Strengths include data curation and the use of the Darwin Core (DwC) format to write and publish data. It is one of the platforms with better adherence to the FAIR principle. Additionally, OBIS has packages in R that make it easy to import data for exploratory and statistical analysis; the data is accessible and interoperable. The dependence on partner institutions to feed the platform can be a weakness. However, the scientific community is very active and presents acceptance of the idea of data sharing, and the platform is kept updated. It has no data for marine litter, not even related to interactions with the fauna globally. It happens because OBIS accepts data in Darwin Core (DwC) format, which is not applicable to marine litter data.

Figshare is a generalist repository (https://figshare.com/). The biggest weakness is the lack of auditing and curation of the published datasets, which makes searching difficult. It also allows datasets in several data formats; hence, it does not meet the FAIR principle. However, Figshare was the only database that had Brazilian marine litter data. Only two datasets were found in Brazil, one regarding microplastic (Zanetti and Leonel, 2019) and one on macro litter (Ramos et al., 2020). Both datasets have complete metadata, data identification keys, and meet the FAIR principles. Also, both datasets are relatively recent, highlighting that Brazil is only starting the process of sharing marine litter data. In Brazil, there is one case of marine litter dataset publication in a repository (Ramos et al., 2020) and its related article (de Ramos et al., 2021). For the other dataset (Zanetti and Leonel, 2019) located during our search, there is no published paper associated yet. It shows that data publication can happen in different phases of paper publication (pre, during, or post); licenses and temporary data embargoes help scientists decide when they will make data available. However, the growing number of publications on the topic (Castro et al., 2018; da Silva Videla and de Araujo, 2021) suggests that Brazilian researchers have a fair amount of data kept under personal control while it could be published, giving a better picture of the marine litter situation and even helping decision-makers address this problem. PANGAEA is an open access data hosting system aiming to archive, publish, and distribute georeferenced data from environmental surveys; it is a generalist repository. The data goes through an auditing process, which ensures integrity and authenticity, as well as high usability. Also, PANGAEA is hosted by the Alfred Wegener Institute, Helmholtz Center for Polar and Marine Research (AWI) and the Center for Marine Environmental Sciences, University of Bremen (MARUM). The repository does not present marine litter datasets for Brazil despite presenting these data for other locations, thus emerging as a viable option regarding marine litter data sharing for Brazilian researchers. In addition, the repository meets all FAIR principle.

Knowledge Network for Biocomplexity (KNB) is an international repository aiming to facilitate ecological and environmental research. It is similar to PANGAEA; it also has data auditing and curation and adheres to the FAIR principle. The platform is focused on data management, and the metadata pass through a quality check, following the guidelines proposed by Borer et al. (2009). It has no datasets of marine litter for Brazil, but it does have marine litter data for other places. Again, being a possible option for datasets on the topic.

The BNDO and SiBBr (OBIS) databases are examples that Brazil has specific databases. In the case of BNDO, it still could improve some features, but it shows potential to share data in other areas (e.g., physical and geological oceanography). On the matter of marine litter, there is no specialist database in the world or in Brazil to host a marine litter dataset.

Direct observations, remote sensing, and numerical modeling can be integrated to compose a specialized marine litter repository and a global Integrated Marine Debris Observing System (IMDOS), as proposed by Maximenko et al. (2019). Data regarding marine litter can have different sources and formats; it will be important

10.3389/frsus.2022.947343

TABLE 2 FAIR principle according to repositories with marine litter data fitness for the Brazilian context.

	Figshare	PANGAEA	KNB
Findable	Datasets are not easy to find. It is necessary to know dataset details or its DOI.	The interface is user-friendly, and it is easy subset regions, time ranges, or themes to find datasets. It is possible to search using DOI.	
Accessible	Metadata is not mandatory. Metadata is not always explaining all the necessary things to understand the dataset. There is no curation process	All data and metadata are quality checked. There is a tutorial in how to prepare data and metadata. Experienced data curators are available to help with each dataset submission.	There are guidelines for submissions. It uses MetaDig program to evaluate metadata quality (https://github.com/NCEAS/metadig-engine).
Interoperable	Datasets from different sources or publishers.	Data processed for machine readability. Some web portals connected (e.g., OBIS, Google Dataset Search)	Some connected portals [The State of Alaska's Salmon and People (SASAP)].
Reusable	Since metadata sometimes is poor, it can impair data reusability. It is free without a review process.	Data is verified to be readable for machines, which allows efficient and reliable data re-usage. Quality data and metadata allows people to reuse the data. Python (pangaeapy) and R (pangaear) packages It is free.	Quality data and metadata allows people to reuse the data. R package (rdataone) There are available tools to help manage data such as Metacat (https://knb.ecoinformatics.org/knb/docs/). It is free.

and facilitate the researcher or decision-maker usage if they can see, subset, and download the data in a unique portal that is integrated with other data repositories enhancing the interoperability.

However, GPML is being developed and will soon make great progress for the scientific community. A database specific for this topic have to take into consideration all the characteristics and peculiarities of litter data, highlighting the quality of the data and increasing the chance of reuse, facilitating a sustainable scientific approach to minimize financial resources use and allow best management decisions. Despite not having a local database focused on marine litter, Brazilian researchers need to start sharing data on the topic in favor of the benefits this can cause. In this case, generalist databases can be the temporary solution, at least while the GPML is not fully operational to deposit data directly.

Three generalist repositories (Figshare, PANGAEA, and KNB) present the potential to receive marine litter data. Only Figshare presents it for Brazil, although it is important to pay attention to the FAIR principle on these repositories (Table 2). The FAIR principle was analyzed following Tanhua et al. (2019) approach.

Analyzing the FAIR principle regarding the generalist repositories Figshare, PANGAEA, and KNB, it is possible to observe that Figshare is the repository that worst fits in FAIR principle, especially related to data and metadata quality checks. The two datasets found for marine litter in Brazil are placed on Figshare. Despite having some weaknesses related to the FAIR principles, from a scientific point of view, this characteristic can allow that not well-standardized data to be published.

An important initiative from PAGAEA and KNB is using open-source programming languages (Python and R) to spread data usability, which can save resources from research institutions and environmental agencies and expand the analysis. In addition, connections between different data portals optimize resources since the maintenance costs can be distributed. Interoperability and reusability are factors related to sustainability since it is possible to optimize resources (natural and/or financial) and analyze data with greater consistency, allowing more developed environmental monitoring that results in practical actions in society. Marine litter data in emerging economies should be a key topic to be addressed by repositories due to its importance in local, regional, and international spheres. GPML is a starting repository that should be integrated into other repositories, such as Figshare, PANGAEA, and KNB, to optimize computational efforts and encourage interoperability.

The increasing number of research papers on marine litter topic suggests that the data is being collected. The reason why it is not being shared remains unclear but can possibly rely on the same fears/problems most of the researchers that do not publish data, have. However, the benefits of sharing should overcome insecurities and fears.

Marine litter data sharing around the world

A successful legislative framework involving the standardization of marine litter data and the construction of data baselines was the European initiative within the Marine Strategy Framework Directive (MSFD) that created the first world's beach litter database. This consultation included 22 European countries, and 3,063 surveys were conducted on 389 beaches between 2012 and 2016. In addition, data from non-European countries that have coastlines facing Europe were also included (European Commission, 2013; Addamo et al., 2018).

The biggest challenges encountered by Addamo et al. (2018) in building the European baseline were related to the compilation of data with different formats, quality, and protocols used for litter sampling. Europe is the most advanced territory regarding marine litter sharing data; there are more than 15,000 dataset results for marine litter search on data.europa website (search done on December 2021).

The European Environment Agency has developed a Marine LitterWatch mobile app to collect information on marine litter. It is a citizen science initiative that aims to help fill data gaps in beach litter monitoring. All data is available on an online platform, and it is possible to visualize and download all data easily. Despite being an European platform, there is a record of Copacabana beach in Brazil. It is possible to observe that it was a top-down initiative but included citizen science approach. Different stakeholders should work together to achieve the best data sharing and availability.

Also, in Europe, European Marine Observation and Data Network (EMODnet) in the chemistry hub developed the first pan European Marine Litter Database (MLDB). It expresses a collective effort involving specially the EU-Technical Group on Marine Litter and EMODnet Chemistry structure; they developed guidelines focused on harmonizing marine litter data, vocabulary, and quality controls (EMODnet, 2022b,c). Hanke et al. (2019) devolved an analysis of a pan-European 2012–2016 beach litter dataset, including data availability, spatial and temporal data coverage, data treatment, and results (Hanke at al., 2019). This report is important to understand gaps and priorities. In the near future, with repositories about marine litter worldwide, it will be possible to have a global picture following Hanke et al. (2019) data treatment and analysis.

EMODnet marine litter data hub contains data on beach and sea floor litter from a variety of sources, including existing International and Regional Sea Conventions, and data submitted by the EU Member States, EMODnet partners, and external research or monitoring projects. Most datasets have come from existing monitoring projects that have published their data in project-specific databases (e.g., OSPAR, ICES DATRAS, even in the PAGAEA repository). These databases may hold more and differently formatted information, so direct comparison with these sources is not always possible, although it is possible to download harmonized datasets where data are formatted following Guidelines regarding vocabulary and values accepted in EMODnet marine litter data hub (EMODnet, 2022b,c). Also, the interoperability between repositories appears to be working well and FAIR principles were considered and are being applied to marine litter in Europe in the context of EMODnet chemistry, improving released data sets quality (Partescano et al., 2021).

A global initiative is the G20 Implementation Framework for Actions on Marine Plastic Litter (MOEJ, 2019). It aims to put in place the Action Plan on Marine Litter, based on each country's national policies, approaches, and circumstances. Brazil presented advances related to the National Plan to Combat Marine Litter (MMA, 2019). For efficient information sharing and updating, as well as for outreach to wider international communities, a network was created; the idea was the same as that proposed by IMDOS stakeholders (Maximenko et al., 2019).

Data usability

The importance of shared data spreads to different areas of society through academic, educational, and management purposes. Data from satellites, autonomous underwater vehicles, and other platforms are coming together and producing emerging data streams from social media, smartphones, and low-cost distributed sensors to create a "data tsunami" (Jucan and Jucan, 2014). More data have been collected about the oceans in 2018 alone than in the entire 20th century. Citizen science is becoming a major player in this change and how we make data available. It is necessary that data from automatic systems and citizen science pass through a quality check process that verify its usability, metadata quality, and reliability. There are some frameworks being developed to access the quality control of oceanographic data; an example is an open-source package on Python called CoTeDe, which aims to provide an adaptive and automatic quality check that combines different quality control standards according to the equipment (CBT, Argo, and CTD) and the researchers' own needs (Castelao, 2020). In addition, data quality check procedures on ocean wave data, which include automatic and manual check procedures, are well described by Doong et al. (2007).

Regarding citizen science data, there are also some ways of accessing data quality. Successful projects have characteristics such as volunteer training and testing, expert validation, replication across volunteers, and statistical modeling of systematic error (Kosmala et al., 2016). Wiggins et al. (2011) created a framework of mechanisms (e.g., rating participant performance, expert review, paper data sheets submitted in addition to online entry, and data mining). These mechanisms can be used in citizen science projects before, during, and/or after their execution for ensuring data quality. They mapped two sources of errors (protocols and participants).

Data and metadata quality, data curation, and check are important to obtain meaningful information, and for the accomplishment of the FAIR principle, otherwise there is the risk to extrapolate data and information not well linked to the real situation, especially when it was measured by automatic systems and citizen science without a data quality check process.

However, ocean data management has not kept pace with the growth of data production, which limits the ability to use both new and old data in marine science (Serrat, 2008; Pendleton et al., 2020). A substantial time and geographical data series may help to identify and understand anomalies and their frequency, strength, and duration. In a climate-changing scenario, it can be helpful to develop management strategies in cases of oil spills, floods, coastal erosion, among others. It is important to inform and engage stakeholders about the importance of ocean observing systems to society, decision-making, academia, and secure financial support to improve data infrastructure (Sales et al., 2020; Teixeira, 2022).

Marine litter is a theme to explore the potentialities of the free and open-source software (FOSS); R and Python are programming languages that have packages available to PANGAEA, KNB, and OBIS. A study in Brazil developed an open-source geospatial framework for beach litter monitoring using R and QGIS (Schattschneider et al., 2020); initiatives in this context can grow, improve, and/or can be easily used if there are marine litter data available to perform tests, thus improving sampling methods or base some management decisions. The available marine litter data in repositories can enhance the usability of open-source tools and framework analysis, such as proposed by Schattschneider et al. (2020).

There are some initiatives about marine litter in Brazil with potential regarding data sharing. An example is the Blue Flag program, which suggests a marine litter monitoring program on accredited beaches. With the monitoring program, beaches with Blue Flag in Brazil should have data in their annual reports, but it is not publicly available. Tombo beach in São Paulo, Brazil has Blue Flag certification for 12 years in a row in 2022, which means that probably there are many of marine litter data about this beach, although it is not yet possible to find/access it.

The challenges of working with data on marine litter are great; however, ocean management is often hampered by a lack of available and clear data on human activity and how it affects the ocean. To solve this type of problem, a "National Plan to combat marine litter" (PNCLM) (Plano Nacional de Combate ao Lixo no Mar in Portuguese) was launched in 2019 (MMA, 2019). The PNCLM encourages the development of a virtual platform to organize and share National marine litter data aiming for continuous improvement of prevention actions of pollution and environmental recovery (MMA, 2019). A virtual dashboard (https://app.powerbi.com/view?r=eyJrIjoiNDY2OTU3NmMtOGVmZS00NDEwLTlhNzItYjI2Y2FjNTYxOWE5IiwidCI6IjM5NTdhMzY3LTZkMzgtNGMxZi1hNGJhLTMzZThmM2M1NTBlNyJ9) with clean-up actions data is already being developed and is available online. However, there are some concerns about the type of data. Most of the information on the dashboard is from NGOs and may lack data curation, metadata, common vocabulary, and unit measure. Another problem is that sometimes litter was not classified, and when they are, the categories used can be overlapping. For example, two categories are "Plastic" and "Fishing materials"; however, most of the fishing materials are made of some sort of plastic. Data sharing should follow guidelines (e.g., UNEP, GESAMP, and EMODnet vocabulary) with adequate vocabulary and hierarchy for layers of terms. In addition, the data cannot be downloaded to perform other analyses. Although it is an interesting initiative to begin data sharing, it still needs improvement. Initiatives regarding the scientific community can also be developed to fulfill the actions established by the PNCLM. In addition, a sub-national scale (Federation states) is developing and launching its own plans to combat marine litter; this can spread and scatter actions and data regarding marine litter in Brazil.

In this context, it is important to have data curation and well-detailed metadata. To agree with the FAIR principle. In the future, it could be possible to integrate different platforms with different kinds of data that can improve environmental analysis. For example, marine litter data can be influenced by meteo-oceanographic factors, such as wind, tide, currents, among others, and an integrated platform with data can allow a much deeper understanding. This integration is one of the aims of the Spatial Data Infrastructure (SDI). Marine litter data available following the FAIR principle can also contribute to model inland waste management initiatives, mainly those ones that use a mathematical model to optimize management actions (Barma et al., 2022).

Another initiative in Brazil involving citizen science is "Our Blue Hands" (https://www.ourbluehands.com.br/), which was implemented for the first time in Brazil on Itamambuca beach and now is spreading to more cities in Brazil through volunteers and a citizen-science approach. The focus of this initiative is microplastic pollution with the aim of data sharing in a developing partnership with the OBIS repository. The strengths of this initiative is that the methodology applied is standardized, following the Monitoring Strategy for microplastic in the European Union in the context of the Marine Strategy Framework Directive (Hanke, 2013). This allows data comparison worldwide, especially in Europe. Also, Our Blue Hands aims to share the data following FAIR principles by design.

The data-sharing culture is only in its infancy. There are other initiatives focused on other environmental areas in Brazil aiming for data sharing and its public availability (Table 3), but they lack some aspects of the FAIR principle, mainly the interoperability and accessibility. In some cases, there is a bureaucratic process to access data, or it is possible to only see processed data in a dashboard (e.g., PNCLM and NOAA), nearer to NGO's (e.g., Ocean Conservancy) model to make information available.

Since data are the building blocks for information and knowledge, the scientific community is responsible for the collection and quality of this data. It is important to highlight

TABLE 3 Some initiatives to share environmental/marine data in Brazil.

Name	Summary	Year	Website
National Bank of Biological Samples of Albatrosses and Petrels—BAAP	It maintains biological samples of albatrosses and petrels from bycatch in commercial fisheries. A collaborative network.	2013	https://baap.org.br/
Open Access Atlantic and Eastern Pacific Reef Fish Database	A dataset of 2,200 species of reef fish from the Atlantic Ocean and the east side of the Pacific. Easy download in.csv format.	2021	https://zenodo.org/record/4455016#.YnOnrdrMLIW
Oceanographic buoy data from PELD ILOC (Long-Term Monitoring of the Brazilian Oceanic Islands)	The buoys provide near real-time surface (1 m) and bottom (23 m) water temperature data, wind direction and intensity and wave height at 6-h intervals. Download is only possible for temperature data.	2022	https://aqualink.org/sites/1186

that some initiatives are starting in Brazil, bringing scientists together to discuss the marine litter issue. Brazilian Marine Litter Science Patch is an initiative that is being created in a collaborative and transversal way to integrate research projects and researchers on this topic. Another is "Polimera: a scientific network about marine litter" (https://polimera.org/). This initiative was created by universities in south Brazil. Despite being in their initial stages, they can bring a new paradigm to marine litter studies. Collaborative work among researchers is extremely important for the growth of the scientific community and enables standardized data, quality work, integrated views, findings, and the training of more researchers on the topic.

Future perspectives

Despite the various possible uses, the importance of sharing data and the great number of publications about marine litter in Brazil, there are still very little data published in databases. Some initiatives have already started, but there is still a long path ahead. More funding for environmental science, associated with incentives from funding agencies, should encourage scientists to share their data.

Brazil has numerous institutions and researchers that collect, analyze, and publish data on marine litter derived from specific projects in the form of scientific papers, thesis, dissertations, and reports. However, there are only a few frameworks to facilitate and encourage the availability and harmonization of these data. Ways need to be found to collect ocean data with quality and share following the FAIR principle; if data will be shared, resources can be optimized, and possible environmental impacts can be minimized since it will not be necessary to replicate sampling processes. Also, studies and decision-making will be based on more extended time series, improving science quality, which can support better management decisions in the context of SDG (Sustainable Development Goals) and beyond. The benefits are not only related to marine litter but also the information is the base of successful management actions regarding society and the environment.

In the management sphere, there are still gaps related to curbing marine litter. It is difficult to establish management strategies to combat marine litter if there is no accessible and standardized data baseline. It is urgent to seize the scenario of the UN Decade of Ocean Science for Sustainable Development (2021–2030) to build new relationships and alliances with stakeholders inside and outside academia. Especially regarding the objective of a predictable ocean in the Ocean Decade where society has the capacity to understand current and future ocean conditions. All societal sectors should enter the era of innovation, data sharing, and scientific co-creation. In this context, initiatives such as Our Blue Hands and clean-up actions may bring society closer to academia. Public spheres should encourage and support this initiative so it can be improved.

Soon, repositories such as GPML (entering in operational phase) and OBIS (through a partnership with Our Blue Hands) are some options to share marine litter data. Since OBIS follows the FAIR principle, it gives more credibility to datasets published in their repository. However, at present, the only option for marine litter datasets is generalist repositories, such as Figshare, PANGAEA, and KNB; since GPML is not fully operational, OBIS only accepts datasets on Ocean Biodiversity and uses Darwin Core (DwC) format. Partnership with new platforms, such as Global Ghost Gear Initiative (GGGI) data portal (https://globalghostgearportal.net/login.php), should be encouraged to gather together efforts and computational infrastructure.

The FAIR principles remain unknown and need promotion and compliance in the scientific community. In this context, sharing data should be encouraged, and not participating will lead to isolation in or outside academia. Scientists should also be encouraged to use available data worldwide in their field to give these data new analysis interpretations, and even more integrative uses, thus highlighting the international cooperation approach. Organization for sampling and protocols are well developed in marine sciences and even in marine litter sampling (Cheshire et al., 2009; GESAMP, 2019). So, it is necessary to use this expertise to incorporate data management and publication in the sampling protocols process.

Finally, FAIR data sharing can also be a question of environmental justice. Developed territories with resources to maintain data centers and their infrastructure should be made available worldwide to encourage data sharing and its use by worldwide researchers. Also, different places may benefit from shared data interpretation when considering similar environmental settings to elaborate their own management strategies, thus saving resources and speeding up ocean conservation and restoration actions.

Author contributions

BR contributed to the conception and design of the review and wrote the first draft of the manuscript. TL and MC contributed with new insights and wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

Funding

BR received a Ph.D. Scholarship from Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES).

Acknowledgments

We acknowledge Dr. Marianna Lanari and Dr. Valéria Lemos for first insights about data sharing and FAIR principles. In addition, we acknowledge Dr. Juliana Leonel for reading first draft.

Conflict of interest

MC is a Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) fellow.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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APÊNDICE B – BEACHLOG: A MULTIPLE USES AND INTERACTIVE BEACH PICTURE

Artigo publicado em 16 de junho de 2023 na resvista Marine Pollution Bulletin.
Online ISSN: 1879-3363, Volume 193, August 2023, 115156.
doi: 10.1016/j.marpolbul.2023.115156.

Marine Pollution Bulletin 193 (2023) 115156

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

BeachLog: A multiple uses and interactive beach picture

Bruna de Ramos [*], Monica Ferreira da Costa

Departamento de Oceanografia, Universidade Federal de Pernambuco - UFPE, Recife, Pernambuco 50740-550, Brazil

A R T I C L E I N F O

Keywords:
Beach management
Tool
Coastal zone
Scenario
Dashboard

A B S T R A C T

There are some tools in place that classifies and/or rank beaches according to a series of parameters. It is possible to identify a gap in the development of tools that map and describe beaches without putting the results into a classification status of good or bad. Since beaches are important from different points of views such as ecology, tourism, economy, pollution or invasive species studies and management, fisheries, estate development, protected areas, among others it is relevant to describe and understand parameters in detail. This work offers a multi-purpose and interactive beach descriptor called BeachLog. It can be used by beachgoers to keep their own records in the same way a diver uses a Diver's LogBook, managers can use the tool to support coastal management projects, long-term monitoring, and beach description baseline. Also, BeachLog can be a didactic tool to aiming to bring environmental sciences closer to technology through the use of spreadsheets and dashboards. BeachLog is based on the more frequent parameters in the literature, selected, organized, accounted for, and altered/added according to expert opinion. We created a list of 28 parameters, all of which were described in details of what is expected to be observed by the user. They were divided into 5 groups (Environmental characteristics, Services & Infrastructure, Information & Security, Planning & Management, and Descriptive). Here, we describe 14 Brazilian beaches using the BeachLog by inputting the results as parameters presence or absence (0/1) and descriptives in a table that can be transformed into an interactive dashboard for better/easier visualization. Planning & Management was absent on all 14 beaches studied, pointing out the relevance and gaps in this group. In the other groups it was possible to observe variation in the parameter occurrence, indicating that each beach is different and it is important to observe parameters individually. Beach Litter and Invasive Species parameters from the Environmental characteristics group were present in all beaches. *BeachLog* showed as an easy way to describe a beach and can be a tool to support diagnosis and understanding of the beach's status.

1. Introduction

Beaches offer a diverse array of ecosystem services across various domains, including climate regulation, cultural and scientific values, as well as provisioning food and coastal protection, some examples are sediment storage and transport, shoreline erosion protection, water filtration, and nutrient cycling (Blythe et al., 2020). Also, some beaches can provide essential socio-economic services for the local community, especially related to fishing, leisure, and tourism activities (Amaral et al., 2016).

For various reasons, beaches evoke environmental, social, economic, and scientific interests. Many socioeconomic and cultural activities depend on and influence beaches and coastal zones (Clark, 1997). These regions are exposed to a wide range of activities, such as harbors, industries, fisheries, housing, protected areas, and tourism (Lu et al., 2018). In addition, environmental conditions such as climate change and rising global temperatures are altering environmental patterns such as hydrodynamics and sea level, affecting coastlines (Toimil et al., 2020), and influencing policies (Lima et al., 2022).

Each beach has its own environmental, economic, and social characteristics. It is almost impossible to find two or more beaches that are the same, even the same beach can go through changes during the days, months, and years. These differences among beaches and the variability in parameters should be considered for an effective management, scientific interests and to identify the beach potentialities.

Describing a beach can be important from various perspectives such as beach use associated to the tourism/leisure activities, decision making, and science. For the beach user, to describe a beach can bring an overview of what the beach could offer. Related to tourism and leisure activities Williams and Micallef (2009) point out five critical criteria reflecting beach quality (safety, water quality, litter, facilities, and scenery), taking into account the different beach types, describing a

* Corresponding author.
E-mail address: ramos.de.bruna@gmail.com (B. Ramos).

https://doi.org/10.1016/j.marpolbul.2023.115156
Received 12 April 2023; Received in revised form 4 June 2023; Accepted 6 June 2023
Available online 16 June 2023
0025-326X/

beach can be an accessible way to pass on these information to the beach user. Also, beach users can keep a record related to their preferences associated to the beach characteristics in criteria such as safety, water quality, litter presence and/or management, facilities, scenery, among others. A beach description made by the beach user itself, some tourism or governmental agency, can benefit a user by providing information on amenities, water quality, weather conditions, hazards, nearby attractions, and more to help them plan their visit and make informed decisions. Without relying in a score or math calculus associated to an index, which can facilitate the understanding of each parameter individually.

For the decision making or managers perspective describing a beach could point out the beach potentialities, and strengths. A well-described beach can be an effective baseline and/or long term monitoring tool, understand beach characteristics, uses, activities and its variations could help management strategies, stablishing priorities. This can involve tracking changes in beach uses and activities, water quality, or the presence of invasive species, and developing management strategies to address any issues that arise. Even Protected Areas creation/managing, or some dune recovery program could benefit from a well described beach since the surroundings and the beach can influence in the preservation sphere… For example, they may use information about the types of vegetation or wildlife present on the beach to determine where to locate access points or where to restrict certain activities. Overall, describing a beach from a manager's perspective can be important for promoting tourism or other activities related to the beach potentialities and local level reality, informing planning and development decisions, and monitoring and evaluating the beach's condition over time.

Regarding scientific interests, describing a beach can give insights into how beach processes work and how they change over time. The description of individual parameters can give much more information than features masked in an index. This can be useful for understanding issues such as erosion, changes in beach activities, invasive species, water quality, protected areas, and the impacts of climate change. By describing the beach and monitoring changes over time, scientists can identify human activities impacts and suggest innovative strategies for mitigate, recover, or maintain environmental and social beach functions. By monitoring changes over time, scientists can gain insights into larger environmental trends. Also, there are beaches that need a descriptive baseline to start to build the knowledge and understand its ecosystem, beach description can help in this task. Even though describing and understanding beach parameters separately is important/relevant for different perspectives, the current scientific literature is focused on beach classifications and awards. Some tools are already in place and classify beaches according to a series of parameters (Botero et al., 2013). There is still a gap in the development of tools that describe beaches regardless of their uses or activities, or an attempt to describe the beach in terms of the natural ecosystem and its anthropogenic features. The aim of this work is to create a flexible tool for beach description that can be used in any beach. The main difference between this new tool that we propose to current tools is that this tool is not seeking to classify, rank or compare beaches.

The beach description without classification or comparisons can help to improve, not only, the touristic product but the whole beach understanding focused in other activities such as surf, protected areas, housing, among others. By doing a beach description is possible evaluate individual parameters, instead of some holistic comparison where the parameter is inputted in some index with mathematical calculus and/or with numerical weights. Also, long term monitoring can be beneficial to managers, and scientist to identify beach changing, taking local specificity into account.

Describing a beach can also provide information about the beach's status. It can be used to support coastal management projects worldwide, such as Marine Spatial Planning (MSP), to perform analyses such as DPSIR (Drivers, Pressures, State changes, Impacts, and Responses) (Elliott, 2002), DAPSI(*W*)R(M) (Drivers of basic human needs require Activities which lead to Pressures. The Pressures are the mechanisms of State change on the natural system, which then leads to Impacts – on human Welfare. Those then require Responses as Measures) (Elliott et al., 2017), and SWOT (Strengths, Weaknesses, Opportunities, and Threats). Also, data about beach description in a presence and absence matrix that describe a beach can be a useful input in machine learning algorithms such as 'association rules' that indicate co-occurrence of variables in a matrix (Grus, 2015), being an important descriptive insight that can support sampling efforts or help to prioritize and/or put together variables that can be an important baseline for support beach management.

Among parameters that are present in most of the beach quality assessments is the beach litter. The presence of beach litter is always associated with downgrading beach classification. On the other hand, the presence of waste management strategies on the beach is evaluated as a positive indicator of beach management and quality. Although, Beach Litter is not an easy parameter to be monitored and compared thought time and/or space (Hartmann et al., 2019). In scientific literature regarding beach management and beach quality indexes Beach Litter can appear as litter on the beach and/or as waste management strategies on the beach. The nomenclature of beach litter types and the measurement units had no consensus in the beach management literature. Beach litter can be a key parameter in beach description and works as a flag specie for other environmental problems. In this context, standardized methodologies for beach litter collection and nomenclature should be used in beach classification or description schemes.

There are different quality indexes schemes for beach evaluation that can help beach management involving lot of parameters besides beach litter. In general, the aim of beach management supported by the classification schemes is to maintain/improve environmental quality and stimulate the potential of the beaches. Depending on the activities, specific legislations applied according to the local, regional, and national contexts. For leisure and tourism, in general, the local level is responsible for managing the facilities and supplying the leisure/touristic support equipment (Diederichsen et al., 2013; Scherer et al., 2020). The approach chosen to manage a beach will affect the recreational function of the beaches (Cabezas-Rabadán et al., 2019; Lukoseviciute and Panagopoulos, 2021). Also, management strategies can impact the beach environment. An example is wrack management that can remove organic matter from the ecosystem (Zielinski et al., 2019; Mainardis et al., 2021; Robbe et al., 2021). In synthesis, beaches will not need managing if no humans were wanting to use them (Williams and Micallef, 2009). On the other hand, management actions and beach use can improve or endanger beach environmental, economic, and/or social quality.

Some directives to provide the best beach management tools are in the scientific and technical literature and the laws and are important to beach management success. Many methodologies are used to base management, classify a beach, or give them some score, often based on touristic/leisure interests. In this work we seek to break the beach classification paradigm and propose an innovative tool to describe a beach that can be useful for beach users, managers, and the scientific community. Currently, there is a lack of tools that provide a comprehensive description of beaches that encompasses both their natural ecosystem and human-made features, regardless of their intended uses or activities. This study aims to fill this gap by developing a versatile tool for describing any beach. We developed a multi-purpose and interactive beach descriptor. Unlike existing tools, our approach does not seek to classify or compare beaches. Instead, it provides a flexible framework for beach description that can be adapted to various contexts.

2. Methods

We have developed a tool named BeachLog, which is based on a spreadsheet and the output is an interactive dashboard. The name BeachLog is a reference to a diver's logbook, which is used to record,

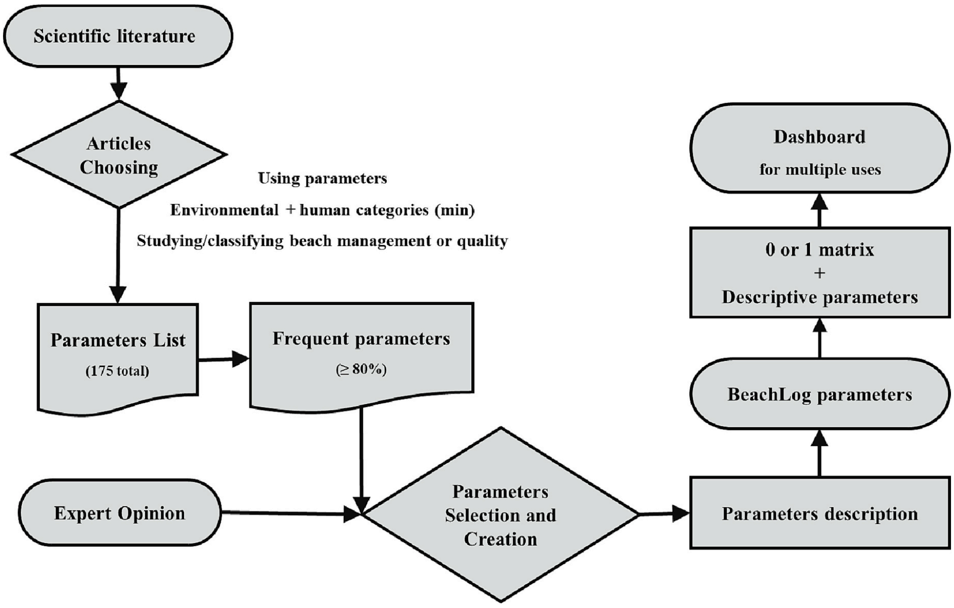

Fig. 1. Flowchart of BeachLog parameters construction.

annotate, and store memories and historical data. Similar to a diver's logbook, BeachLog is unique to each beach and enables the addition of new information as needed. Another similarity is that both, diver's logbook and BeachLog. do not aim to classify or establish some quality comparison between dive spots or beaches, respectively. BeachLog main purpose is to describe a beach. The parameters that compose the BeachLog were chosen based on 11 articles from the scientific literature (Cendrero and Fischer, 1997; Leatherman, 1997; Ergin et al., 2004; Araújo and Costa, 2008; Cervantes and Espejel, 2008; Ariza et al., 2010; Botero et al., 2015; Lucrezi et al., 2016; Peña-Alonso et al., 2018a, 2017; Marchese et al., 2021) and experts opinion (Krueger et al., 2012). The articles were selected based on some criteria: the articles used parameters, in at least environmental and human categories to suggest an index aiming evaluate, classify or rank beach management or quality (Fig. 1).

During our literature search, we were unable to find any articles that systematically organized parameters for describing a beach taking into account various aspects. As a result, we relied on articles that classified beaches, even though our focus was specifically on identifying and utilizing parameters to describe beaches irrespective of their characteristics. A list of all parameters from each article was made (total of 175 parameters) from where a new list with the most common parameters

Table 1
Summary the frequent parameters (≥80 %) in analyzed beach classification literature and how it appears on *BeachLog*.

Presence (≥80 %)	Example	Present	Absent	How it appears on BeachLog
Access (focused mainly on disabled people)	Access for disabled people, Beach access difficulty, Parking for disabled users, access type	1, 2, 3, 4, 6, 8, 9, 10, 11	5, 7	Access
Utilities, services, infrastructure, amenities, facilities	Bars, restaurants, hammocks, umbrellas	1, 2, 3, 4, 5, 6, 8, 9, 10, 11	7	Recreation Services, Toilets/Showers, Food services
Beach Sediment's characteristics	Sediment composition, color.	1, 2, 3, 4, 5, 6, 8, 9, 10,11	7	Beach Sediment's characteristics (descriptive parameter)
Width	Beach width at low tide, width	1, 2, 3, 4, 5, 6, 8, 9, 10	7, 11	Indirectly considered in Erosion marks Indirectly related to the activities performed on the sand strip.
Beach litter	Thrash, litter, solid waste	1, 2, 3, 4, 5, 7, 8, 9, 10,11	6	Beach litter

1 Cendrero and Fischer, 1997
2 Leatherman, 1997.
3 Ergin et al., 2004.
4 Araújo and Costa, 2008.
5 Cervantes and Espejel, 2008.
6 Ariza et al., 2010.
7 Botero et al., 2015.
8 Lucrezi et al., 2016.
9 Peña-Alonso et al., 2017.
10 Peña-Alonso et al., 2018a, 2018b.
11 Marchese et al., 2021.

(≥80 %) was then extracted (Table 1). These parameters were included in BeachLog's parameters list (Fig. 1).

The BeachLog, was based in the more common parameters in the literature (Table 1), selected, organized, and altered accordingly to expert opinion, a technique supported by the current literature (Krueger et al., 2012). The parameters included in BeachLog, which were not commonly found in the literature's most frequent parameters (as shown in Table 1), were carefully selected based on the author's expertise, personal beach observations, informal discussions with beach users, management experts, and non-governmental organizations (NGOs).

Before implementing BeachLog, the authors conducted on-site visits to the selected beaches. During these visits, they wrote detailed beach descriptions and took photographs. Following this preliminary and exploratory fieldwork, the authors organized the parameters that aligned with a comprehensive beach description.

We considered 28 parameters that describe a beach (Table 2). The parameters were chosen and organized into 5 groups: Descriptive, Environmental characteristics, Services & Infrastructure, Information & Security, Planning & Management. The groups division was based on Marchese et al. (2021).

The descriptive parameters (usual beach activities, activities around the beach, and legal arrangement), Fauna & Flora (Native) and beach sediment characteristics, both from environmental characteristics were expressed as topics. The Scientific Literature parameter was presented as a spreadsheet, which included examples of papers for each beach, whenever available. This spreadsheet is linked to the dashboard for easy access and reference.

To gauge the usability of the chosen parameters, 14 beaches with different characteristics were used. The information necessary for the BeachLog's construction was collected from primary data (direct observation) and secondary data (newspaper and technical documentary research, and scientific literature review). The direct observation methodology consisted of an observation of a chosen beach (by the same person walking all the beach area) considering all parameters. The observations occurred in two different months of the year (e.g.: March-southern autumn and September-southern spring), aiming to detect possible changes in beach characteristics due to interannual variation in beaches activities or some other factor.

To utilize BeachLog, the user (whether a beachgoer, a manager, or a scientist) should dedicate at least an hour to observing the beach, walking along the sandy shoreline, and gathering information from local newspapers and scientific literature pertaining to the beach. Parameters that can benefit from a literature search (newspaper or scientific) are indicated with (*) in Table 2. During the beach and literature search, the user will note whether each parameter is present or absent based on the parameter description provided in Table 2. Additionally, the user will record the descriptive parameters. Subsequently, this data can be entered into a spreadsheet and used to construct a personalized dashboard for visualizing the parameters. All parameters were organized in a database using MS Excel in which the line is the beach/georeferenced location, and the columns are the parameters. The parameters were described in a 0/1 (absence/presence) matrix or descriptive information for the descriptive parameters. If it was not possible to find data or information regarding a parameter it can be inputted the −1 value in the MS Excel, representing data absence. An example of −1 applicability was the water quality parameter. An interactive dashboard with each beach results was developed using MS Power BI software.

2.1. BeachLog test

BeachLog tool was applied in 14 Brazilian beaches (Fig. 2), between 2019 and 2022. All beaches were visited at least twice in months that are not in the same season (e.g.: January and July). These could help to identify temporal variations in the parameters in the same beach.

The beaches choice occurred based on travel opportunity or places that authors lived in. The beaches presented different characteristics, uses, and activities. Accordingly, Projeto Orla (SPU, 2022), it is possible to identify sheltered beaches (Matadeiro, Bombas, Meia Praia, Iracema, Meireles, Náutico), exposed beachfront (Cassino, Campeche, Forte, Pilar, Boa Viagem), and semi sheltered beachfront (Tabatinga, Arapuca, and Sossego). Also, it is possible to identify beaches in three categories from Williams and Micallef (2009) beach description types, there are Village beaches (Cassino, Matadeiro, Campeche, Forte, Pilar, Tabatinga), Rural beaches (Sossego, Arapuca), and Urban beaches (Boa Viagem, Bombas, Meia Praia, Iracema, Meireles, Náutico). Finally, there are beaches that are used mainly by tourist or for leisure purposes all the year (Forte, Pilar, Tabatinga, Boa Viagem, Iracema, Meireles, and Nautico), beaches with a marked touristic summer season (Cassino, Campeche, Matadeiro, Bombas, Meia Praia), and beaches that receive few visitors all the year (Sossego, Arapuca). The differences between beaches are an important factor to test the BeachLog since it show the tool versatility. These characteristics are represented by the Usual beach activities and Activities around the beach descriptive parameters that were displayed separately on the dashboard (Fig. 3B).

3. Results and discussion

An interactive dashboard was developed for parameters visualization (Fig. 3) (it is possible to access the dashboard in the link: l1nq.com/beachlog-eng). Despite being a flexible tool where the more suitable parameters might be chosen to better represent the beach characteristic and realities, all 28 parameters were used on the 14 beaches to validate the tool.

3.1. Descriptive

The Descriptive group is composed by 4 parameters (Scientific literature, usual beach activities, activities around the beach, and legal arrangement). Scientific literature is a BeachLog original contribution, this parameter usually appears as a support to describe or classify a beach, but in BeachLog Literature also can be used to map beach scientific interests, that means that the absence of scientific articles in a beach can represent the lack of scientific interest in that place or related to some research topic. Scientific literature r was present in 12 beaches and absent in 2. An important qualitative observation is that issues related to parameters that are absent in the BeachLog results such as Marine Protected Areas, Zoning, Carrying Capacity, and Monitoring are also more difficult to find in the literature. Also, that the scientific literature on beach litter is expanding in Brazil (Videla and de Araujo, 2021). Papers addressing this topic were founded for over 50 % of the beaches in this study.

Descriptive parameters woks as supportive information to understand each beach local reality. Usual beach activities, Activities around the beach, Legal Arrangements searching, and description helps to understand seasonal patterns in beach activities especially related to the leisure/touristic activities and infrastructure that support the activity on the beach.

Leisure and tourist sector appears as an important stakeholder in the BeachLog. The touristic activity appears in all beaches, in different intensities and periods. Tourism and the travel industry can be extremely profitable activities (UNWTO, 2020; Duro et al., 2021; Gabriel, 2021; UNCTAD, 2021). Considered a sociocultural phenomenon of industrial and urbanized capitalist society, tourism has stimulated interest and taken advantage of conservation regions, causing environmental and management problems (Kent et al., 2002; Alvarez-Sousa, 2018), which is possible to observe in BeachLog. Examples of touristic/leisure influences on the beach management can be observed on Forte beach where vendors create a place with tables and hammocks to visitors, BeachLog detected food service on the beach. Another example was on Meireles beach where BeachLog identified improvements on the coastal infrastructure with toilets construction and local market organization.

Table 2
BeachLog parameters description. Parameters/information in bold and underlined were originated from frequent parameters list. (*) represent that it is recommended search in scientific literature or newspapers about the topic. Gray parameters are considered original in beach description.

	PARAMETER	DESCRIPTION
Descriptive	Scientific Literature	Scientific literature, peer-reviewed article (minimum 3 scientific articles) about any of the *BeachLog* parameters, economic and/or social themes on the beach. It can be from any area of knowledge
	Usual beach activities	Descriptive. It can be seasonal or annual tourism, fishing, nautical activities, religious, sports, cultural activities, ...
	Activities around the beach	Descriptive (Consider a field of view) Residential, port, non-urbanized environment, hotel chain, shopping center, hospital, school, fishing colony, industrial, institutional projects. Occupation: Urban, semi urban or rural. It is possible to use other classifications such as Williams & Micallef, 2009
	Legal Arrangement	Descriptive. Some examples are: • Coastal management projects. • Blue Flag certification. • Oil disaster contingence plan. Marine Spatial Planning (MSP) initiatives
Environmental characteristics	Erosion marks*	Marks of possible coastal erosion such as plastic sandbags, containment structures, exposed roots from dune vegetation or other vegetation (even exotic) in the beach strip Constructions related debris can also be an erosion indicative. **Very narrow or non-existent sand strip (especially on the high tide).**
	Beach sediment chracteristics*	Briefly describe the beach sediment, color, grain

		size if it is possible.
	Wrack*	Evidence of macrophytes, seagrass, branches, leaves, vegetation in general. Wrack on the strand line.
	Odors	Unpleasant odors on the beach such as sewage, decomposing organic material.
	Noise	Noises from human activities such as loud music, children playing, loud laughter. Also consider noises originated by boats and water sports.
	Geological features	Presence of remarkable geological features on the beach or visible surroundings, examples: cliffs, rivers, islands, reefs, mountains, rocky shore.
	Water Quality*	Beach suitable for bathing in the month being analyzed (or at least 80% of the analyzed period if more than one measure is available).
	Beach litter	Categories for grading a beach (EA/NALG, 2000). A or B class = 0; C or D class = 1. Another methodology can be used. Blue Flag GESAMP, UNEP, NOAA. Data can be expressed in items / m^2
	Fauna & Flora (Native)	Descriptive. Animals such as crabs, fish, turtles, birds (owls, migratory). Presence of vegetation, coconut trees, other trees
	Exotic and/or invasive Species*	Presence of exotic and/or invasive species (plant and/or animal; marine and/or terrestrial) on the beach. Including zoonoses vectors (pigeon, rat). More information: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/exotic-species https://www.sciencedirect.com/topics/earth-and-planetary-sciences/invasive-species
Services & Infrastructure	**Recreational Services**	Availability of services such as sports on the sand, boardwalk or water, walks, public or rental beach umbrellas.
	Access	Easy access (car and pedestrian) for different audiences including people with disabilities, the elderly, children, pregnant women, obese people,

		etc.
	Toilets / showers	Public or private toilets/showers. Clean, with running water and toilet paper. Showers in a good state for use, clean and with clean water.
	Food Services	Food services such as bars and restaurants, street vendors properly identified and trained (it is important to pay attention on how food is being handling and other microbiological aspects).
	Public or private cleaning services	Cleaning of the sand and/or water strip, presence of trash cans that are not overflowing, adequate, not cracked. Cleaning performed by local employees / stall holders / kiosks. Sweeping and collection. Manual or mechanical cleaning.
	Historical and/or Cultural assets*	Presence of historical or cultural building, well preserved, with planned/organized visitation or for research purposes. Cultural activity carried out on the beach such as traditional fishing, periodic events.
Information & Security	Policing*	Presence of police station or police agents on the beach or visible in the surroundings.
	Users Security*	Programs to prevent natural risks and risks to beach users. Warnings / availability of information about possible dangers on the beach. Shark, jellyfish, sea warning flags, rip current, landslides. Presence of updated beach warning flags Available on site and/or website.
	Lifeguards	Presence of lifeguards (military or civilian) on the beach, well-maintained and equipped stations.
	Environmental Information	Clear and highly visible warnings about local biodiversity, presence of Conservation Units. Suggestions for conscious behavior on the beach. Available on site and/or website.
Planning & Management	Marine Protected Area (MPA)	Beach in marine or terrestrial Protected Area. Active management board and existence of a management plan.
	Zoning	Presence of zoning of activities that are developed on the beach (boardwalk, sand and water). Zoning needs to be visible, informed, complied with, and supervised.
	Carring capacity*	Calculation of social carrying capacity estimated and updated (maximum 10 years). Information available to the user. Capacity control monitoring and control.
	Monitoring Programmes	Monitoring (over 2 years of data) on the beach. Examples: beach litter, microplastic, erosion, number of users, beach profile, wave period, biological diversity, charismatic macrofauna, exotic species... Raw or processed data need to be accessible and widely disseminated. Ex: CoastSnap, Our Blue Hands

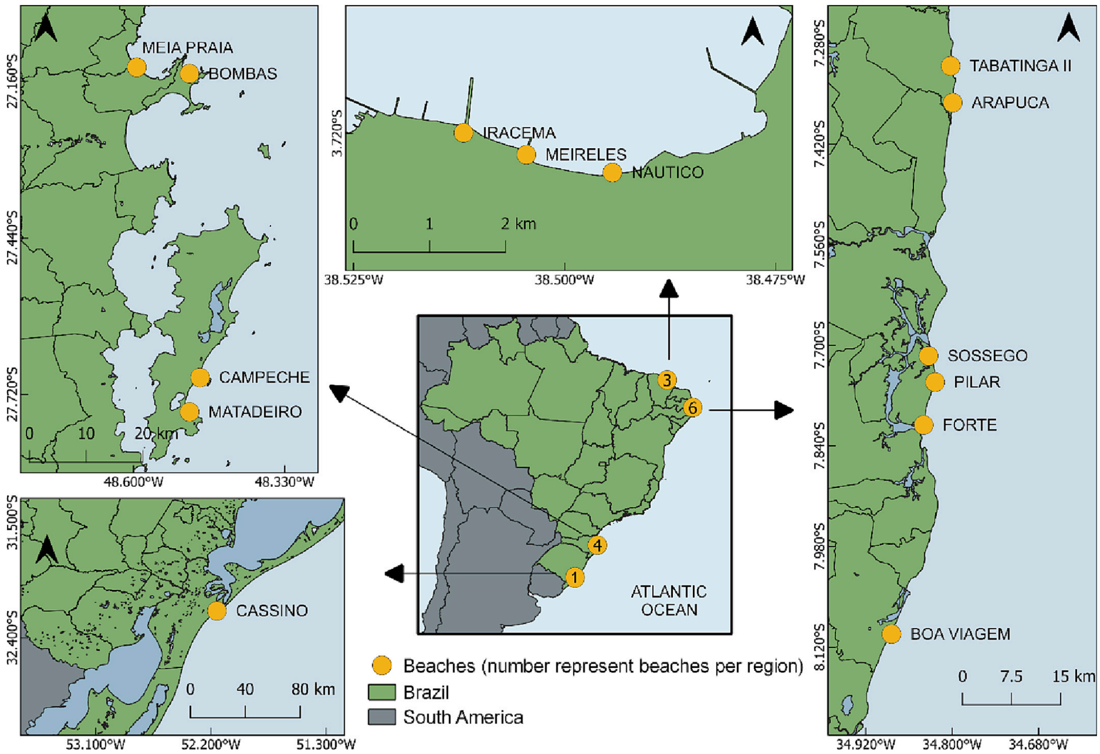

Fig. 2. Map of the 14 beaches to which BeachLog was applied. At the center the map of Brazil indicating inside the yellow dot how many beaches in each region were visited to apply the BeachLog. The surrounding maps indicates with yellow dots the beaches in each region. (Own authorship). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Literature can help to detect how BeachLog parameters can related each other and understand chronical and extreme environmental need in the local reality. An example of the utility of literature search that help to understand some parameter (e.g.: Monitoring Programmes) was the tar balls presence in Northeast Brazil in 2019. Tar balls, allegedly from oil spill, appeared in >100 municipalities in 11 states in the Northeast and Southeast of Brazil, the topic was a trend on social media and generated public engagement (Almeida et al., 2022). In August 2022, new tar balls arrived on the northeast coast. Environmental agencies intend to intensify monitoring in the region,[1] identifying the most affected points and the origin of the fragments.

Legal Arrangements are particularly important to improve management strategies focused on local realities, also is important to highlight that no beach present a beach award such as Blue Flag. Another important observation was related to the presence or absence of Projeto Orla methodology, the official beach management plan in Brazil. It was possible to identify that touristic places tend to have the local administration worried about beach activities that generates financing resources to the city, probably that is why these beaches and cities adopted the local administration beach management accordingly to Brazilian legislation launched in 2019 and executed the Projeto Orla methodology (Scherer et al., 2020). It is important to highlight that each country, region and/or local sphere have its own beach management system and rules. In the Legal Arrangements a local knowledge or local consultancy could be an important contribution to improve the parameter description.

If a beachgoer is using BeachLog, legal arrangement could be excluded or substituted with the presence or absence of beach certification awards. This is because beachgoers are generally less inclined to spend time researching legal aspects, while beach certification awards predominantly focus on assessing the quality of the beach for tourist activities.

3.2. Environmental characteristics

The Environmental characteristics group is composed by 10 parameters. Eight beaches were dealing with Erosion marks problems. Temporal feature (different months) had no interference in Erosion marks. It was observed beaches with hard coastal engineering interventions (Iracema, Meireles and Naútico), beaches in situation of loss of properties (Pilar), and alternative measures using trees (Forte) to try to avoid erosion. Also, there are beaches with dune field and/or coastal vegetation well preserved (Cassino, Arapucas).

Regarding Geological Features, it can be exposed to human influence or extreme events that could change the landscape and it could be explored in different intensities throughout the year in terms of touristic attractiveness. On the beaches of this study, it did not change during the months on the same beach probably due to the slow rate of changing of the geological process. Was possible to identify Geological Features in 9 beaches.

[1] https://www.folhape.com.br/noticias/governo-intensificara-monitoramento-do-litoral-de-pe-apos-aparecimento/238545/.

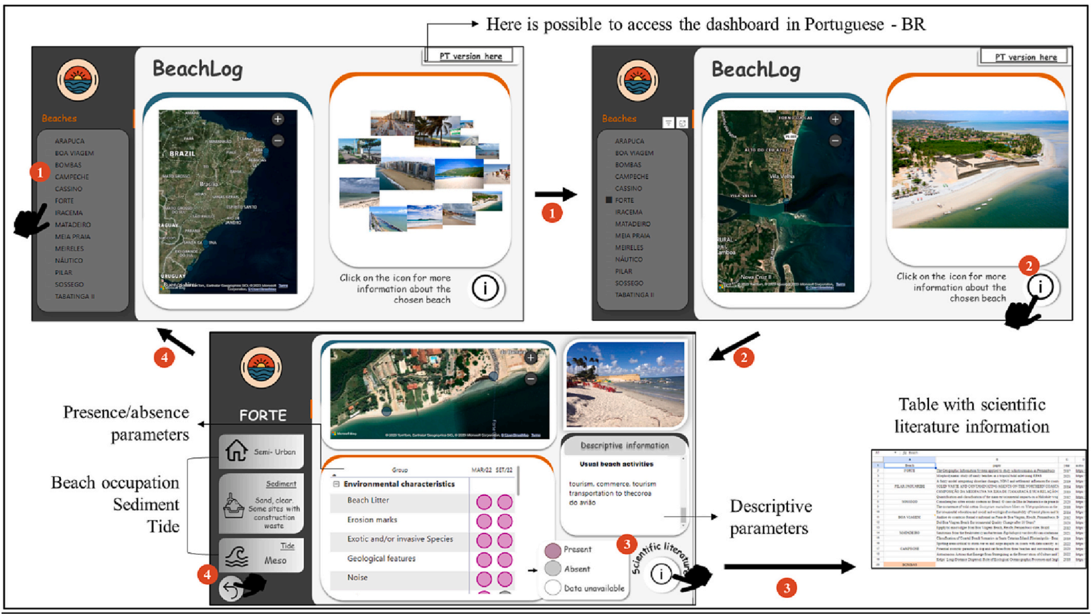

Fig. 3. Dashboard images developed on PowerBI (available on l1nq.com/beachlog-eng), representing how to access and where the information is placed. (1) The users select a beach that they want to see the parameters. (2) Click in the icon to go to the selected beach page. Here the user can observe a beach picture, a map, the descriptive and presence/absence parameters. (3) Click on the icon about scientific literature to access a spreadsheet with this information. (4) Click in the return icon to go to the main menu again and select another beach.

Parameter with no abrupt seasonal and interannual variation such as Erosion marks and Geological Features can be influenced and/or influence leisure/touristic activities. Erosion can lead to coastal engineering constructions to preserve the sand strip to leisure (Andrade et al., 2014), or lead to ecosystem services losses if not well managed (Paprotny et al., 2021). Geological Features can lead to possibilities of Geotourism (Gordon, 2018) and environmental sensibilization, with better management practices (Cristiano et al., 2020). In places like Coroa do Avião a sand bar in front of Praia do Forte; Campeche Island in front of Campeche Beach, rain forest area in Matadeiro Beach, beach rocks on the Pilar and Boa Viagem beaches, cliffs in Arapucas, pleistocene marine terrace in Tabatinga II, the Geological features can be part of a Geotourism route or at least considered in the local beach management plan.

Wrack was identified in 4 beaches in both months that the BeachLog was applied. In 8 beaches wrack was not present in both months, and in 2 beaches wrack was present in one month, being possible to detect interannual changes. In Forte beach, when there are wracks, it is mainly cleaned by local vendors. No other action or management strategy to deal with wracks was observed in situ or founded in the literature. Odors varied in 6 beaches and remain present (4) or absent (4) in 8 beaches. Odors are present mainly on beaches with streams (Iracema, Bombas, Campeche, Matadeiro, Pilar, and Sossego). It was not directly related with wracks. Also, Noise varies among the months on 6 beaches. A pattern observed is that Noise and Odors are related to the leisure/touristic activities.

Wracks can be a challenge for leisure and touristic activities (Zielinski et al., 2019), beaches such as Sossego and Arapucas have wracks, but they are little frequented by mass tourism. On the other hand, Forte beach presented wrack in one month, and it was possible to observe local vendor cleaning the beach, they also clean beach litter in this process. It makes explicit how BeachLog can describe the beach status.

Odors can influence and be influenced by leisure/touristic activity, increase in sewage or the runoff concentrated on the beach for example (Meia Praia, Bombas, and Iracema) or the presence of wracks and rainfall on the beach (Sossego and Pilar) can influence odors.

Water Quality with no information available, received −1 in the description. It changes among the months in 5 beaches, data was not available in situ or online for 2 beaches all the yearlong and for 3 beaches in one month that BeachLog was applied. Water quality data acquisition depends on the environmental regional agencies in Brazil and 10 beaches did not have visible information on the beach or the website about the parameter.

Exotic and/or invasive Species were reported for all the beaches with no seasonal variability indication. Some species such as pigeons and dogs are more common and present in most of the beaches (13). This parameter can be a potential chronic environmental problem requiring a management plan. That is why it was important describe native animal and plants that are present at the beach.

Following the same pattern observed for Exotic and/or invasive Species, Beach litter was present in all beaches. It can vary in terms of quantity and litter types, especially in the summer season as reported in Cassino (Ramos et al., 2021) and Meia Praia (Marin et al., 2019). However, this study, even using a more generalist method (EA/NALG, 2000), we identified Beach Litter in all beaches thought the year without a potential seasonal variation, indicating a chronicle environmental problem. The use of more refined method to measure Beach Litter are, in general, more detailed, and requires more human work.

It has been reported that beach litter can play a role as an indicator of beach scenic quality (Corraini et al., 2018), environmental quality (Rangel-Buitrago et al., 2019), and influence leisure and touristic activities (Krelling et al., 2017). Litter is a parameter that can play a significant role regardless the beach use or type. Even in artificial river beaches, more common in Europe, where water quality monitoring and lifeguards are not needed, litter is a parameter that is measured (Williams and Micallef, 2009).

Beach Litter is a relevant parameter in the BeachLog and in beach management literature. This parameter stands out as the sole parameter from the Environmental Characteristic group that appears frequently (≥80 %) in the parameters (Table 1). Additionally, Beach Litter can be linked to the other four groups in the BeachLog. Within the Services & Infrastructure group, parameters like Private/public Cleaning and Food Services are associated with cleaning practices and the generation of beach litter, respectively. In the Information & Safety group, certain beach litter items such as glass and construction-related debris pose risks to users.

3.3. Services & infrastructure

The Services & Infrastructure group is composed by 6 parameters. Recreation Services were present in both months in 6 beaches, absent also in 6 beaches and varied in 2. Variations can be explained by leisure or touristic activities intensities at the beaches. Access in general was not influenced by seasonal variations. It was present in 6 beaches and absent in 7. It only varies at Cassino beach due the summer season and construction of car routes on the beach. Although surroundings traffic and parking availability could change due increase of leisure and touristic activities.

Toilets/Shower was present in 1 beach (Meia Praia) and a new toiled was constructed in Meireles, the variation in this case was related to beach infrastructure improvements but is a long-term construction that will be available in the future. In 1 beach toilet change due to the seasonality and for 11 beaches it was absent. Food Services is directed related to beach activities, it was present in 8 beaches and absent in 2. Seasonality in Food Service was detected in 4 beaches.

Public/private cleaning is related to Beach Litter (Environmental Characteristics group), but it was not possible to see cleaning effects in Beach Litter results. Public/private cleaning is present in 7 beaches, absent in 3 and vary in 4.

An original parameter in the BeachLog was to identify Historical and Cultural assets on the beach, it is rarely considered in beach description or studies (Galamba, 2022). This parameter was present all the year most for fixed structures such as a fortress or sculptures (2 beaches) and with an interannual pattern related to traditional events, religious celebrations, and fisheries (4 beaches), Historical and Cultural assets was not present in 8 beaches.

3.4. Information & security

The Information & Security group is composed by 4 parameters. Police officers are present in 2 beaches, absent in 9 and varies in 3. Personal observation and literature searching showed that crimes and policing receive greater attention in the summer or holidays when the beach occupation due to leisure and tourism increases (Drawve et al., 2020).

Users security was absent for all beaches. There are initiatives partially working like shark attention signs in Boa Viagem and in the summer in Bombas and Cassino lifeguards put sea warning flags, but it is in the early stages. Lifeguard parameter varies in 5 beaches, it is present in 3 beaches all the year and absent in 6 beaches. Regarding Environmental Information, it was absent for all beaches in both months. Some beaches presented old signs with outdated information.

3.5. Planning & management

The Planning & Management group is composed by 4 parameters. All the parameters in this group (Marine Protected Area - MPA, Zoning, Carry Capacity, and Monitoring) were absent. Beaches located in Itamaracá Island (Forte, Pilar, and Sossego) are inside the Canal de Santa Cruz Protected Area, although the management was not detected in situ or thought literature or official websites search, a similar situation is present in Tabatinga and Arapuca beaches that are inside the Tambaba Protected Area, but it was not possible to find the management plan. That is why the feature was considered as absent.

Beach litter collection campaigns were conducted in Cassino, Campeche, and Forte; however, the collected data was not reported to a monitoring program. The Planning & Management group can be associated with beach litter through the implementation of a monitoring program (Oliveira and Turra, 2015; Schernewski et al., 2018) or through actions within a Protected Area or beach management plan. Beach litter monitoring could work as a successful case of study for other environmental parameters (Maximenko et al., 2019) Water Quality monitoring was not considered here since the Water Quality (Environmental characteristics group) already consider the presence of monitoring programmes to measure and make available water quality data. There was a Zoning attempted on Itamaracá Island (Pilar and Forte Beaches), but not fully implemented. In Campeche beach there is a delimited area for boats departure to the Campeche Island in the summer, but without a plan associated.

3.6. BeachLog original contributions

BeachLog presents three original contributions of parameters that can be used to describe a beach. Historical & Cultural assets, Scientific Literature and Legal Arrangement appear as important descriptors for cultural, economic, and social and political spheres in the local level. The presence, description, and search of these parameters in a beach can bring new points of view for the local reality and point out information that in general are not accessed.

It is rare but historical, artistic, archaeological assets appear in some scientific literature (Cendrero and Fischer, 1997; Peña-Alonso et al., 2018b). Although the use these assets to describe a beach and possible identify its talent is new. Permanent structures such as fortresses are common along the Brazilian coast, there are several beaches named as 'Fortress beach'. The book 'Brazilian Beach Systems' (Short and Klein, 2016) highlight the importance of historical and cultural asset in the Brazilian coast. 'Fortress' beaches are cited as study cases in four Brazilian states. The historical and cultural context in which the beaches are included received attention especially on Northeast beaches from Maranhão and Pernambuco states (Short and Klein, 2016). Although rarely this Historical and/or cultural assets receives attention in management plans, that is why the inclusion of this parameter in BeachLog is an important originality. This identify and point out the importance of structures like Fortress in Brazilian coast and shows that they are connect to Brazilian history and leisure/touristic activities. Also, it can become a touristic spot with social media appeal.

By contrast to the historical assets that appear in some beach management literature, cultural activities are almost absent. Cultural assets such as religious celebrations, traditional events, and cultural fisheries are important activities that most of the time are not explicit on beach description, but have cultural, economic, and social relevance. Especially if it is a multiple use area and the Legal Arrangement is not solid. Protected Areas and/or coastal management plans can include traditional communities and/or activities in its guidelines. Also, Zoning and Carrying Capacity could include usual cultural activities in its planning/implementation.

Some beaches with an active night life could include Light as a parameter and apply the BeachLog in day and night periods. It will allow comparisons between uses and priorities in the beach activities between day and night. Light pollution can be a serious issue for human health and the local biodiversity (Grubisic et al., 2019; Mu et al., 2021), also can be an original contribution regarding beach description. The possibility to apply the BeachLog during the night, regardless the beach tide range, uses or activities performed on the beach can be beneficial for beach description.

BeachLog is a versatile tool, another originality that can be beneficial to adjust the tool for different local realities (e.g.: including Light as a parameter). The parameters choices are not a trivial activity. It is recommended to follow the parameters list suggested in this article in the first BeachLog application and make adaptations accordingly the local reality. This process can be done consulting local managers, local entrepreneurs such as hotel and restaurant owners, people that live in the beach surroundings, scientists, NGOs, among others. Analytical approaches using machine learning models could help to identify priorities and co-occurrence in the parameters.

4. Future perspectives

BeachLog represents one of the early efforts to systematically organize parameters for describing a beach, presenting them in a visually appealing dashboard format. The tool can be used by beachgoers, managers, and scientists. BeachLog also holds potential as an educational tool, serving scholars and university students in their exploration of environmental topics and the development of technological skills.

In terms of management or science, the BeachLog tool can work as a baseline and as a monitoring tool. It is important to guide decision-makers about the starting point and possible changes on the beach without a comparison with other realities (Fig. 4). An important contribution of the BeachLog is to break the paradigm of beach classifications of what is ugly or beautiful, good, or bad. The concept of beautiful is influenced by cultural and socioeconomic backgrounds (Hull IV and Reveli, 1989; Gordon, 2018). The BeachLog also can help to establish priorities since some parameters change during the year due to the changes in beach use, environmental conditions, or cultural events.

4.1. BeachLog potential applications

BeachLog can serve as a valuable tool for beach users who want to keep a record of their preferred beaches. They can maintain a physical BeachLog with a map marking all the beaches they have visited. Also, beachgoers can use the BrachLog for better understand the beach they live. For managers and scientists, BeachLog can provide an easy way to describe beaches, establish baselines, and develop long-term monitoring programs. However, the difference between how managers and scientists use this information lies in their respective goals. Managers can use the information to identify beach talent, prioritize management actions, and monitor changes in the same beach over time. Scientists, on the other hand, can use it to identify research gaps and suggest measures to improve beach quality.

In all three cases, the parameters list in BeachLog is flexible and can be customized based on individual needs. However, this choice should be made with some criteria. For example, beach users may select parameters based on their interests and preferences, such as focusing on surf or trekking zones instead of recreational services. Managers, meanwhile, can analyze the utility and relevance of parameters based on technical capacity, critical thinking, data availability, and local reality. We suggest applying the 28-parameter list presented in this paper for at least two seasons in the same beach to identify what is relevant in the local context. Afterward, managers and technicians can proceed to make parameter alterations.

For scientists, parameter changes can be based on research questions and local realities. Additionally, machine learning techniques can help identify parameters that can be grouped, removed, or tested to determine if adding a parameter provides new information. Another potential use for BeachLog is in an educational context. Scholars and university students can benefit from using BeachLog as a tool for learning about environmental-related subjects and developing technological abilities such as working with spreadsheets and visualization tools like PowerBI.

The main advantages of the BeachLog are parameters description available to the user, flexibility, and that it is not related to an index or math calculus. These advantages allow people understand what each parameter means The BeachLog can have various uses, including as an auxiliary tool in coastal management plans such as the Projeto Orla methodology to develop the diagnosis phase, including citizen participation (Scherer et al., 2020).

Another advantage is the possibility to add or remove parameters without compromising the analysis since it is not inputted in an index or calculus. The BeachLog is flexible in the parameters and in the audience that uses. Each group can draw their conclusions according to their interest, this approach also is important in beach management participatory methodologies where different stakeholders build collaborative a beach management plan.

4.2. Insights about beach litter

Beach litter is a key parameter in beach classification schemes and in the BeachLog since it was present in all the beaches in the study. Although beach litter is an important parameter it is not standardized in the beach management support methodologies.

USER	RECOMENDED	NOT RECOMENDED
BEACHGOER	Record of the beaches they visit Understand the beach that lives	Select the beach that most fit in their needs Beach comparison
MANAGER & SCIENTIST	Describe beaches Establish baselines Long-term monitoring programs	Classify beaches Beach comparison
MANAGER	Tool in participatory methodologies	Achieve some beach award
SCIENTIST	Identify research gaps Suggest measures to improve beach quality.	Compare beach's quality

Fig. 4. Summary of BeachLog applicability focused on their main users, beachgoers, managers, and scientists.

Parameters such as solid waste (on water and sand), floating debris, and litter can be used (Table 3). Although the way how it recorded varies, some methodologies measure beach litter as beach proportion covered by litter, the number of items, or in categories (Table 3). The nomenclature of Beach Litter types and the measurement units had no consensus in the beach management literature (Table 3).

There are some guidelines about Marine Litter study and classification. The most used and well established were developed by the United Nation Environmental Programme - UNEP (Cheshire et al., 2009), by the Group of Experts on the Scientific Aspects of Marine Environmental Protection – GESAMP (GESAMP, 2019), and by the National Oceanic and Atmospheric Administration – NOAA (Burgess et al., 2021). Although these guidelines are not used to feed beach management methodologies (Table 3). And it was not possible to observe a temporal evolution in beach litter measurement in beach management literature.

Waste management on the beach is the other way that Beach Litter is considered in beach classification. It can appear as the following: number of garbage collectors on the beach, beach area affected by mechanized cleaning (%), litter bins, or recycling receptacles, among others (Table 3).

This study highlights the importance of Beach Litter as a parameter of beach classification, description, and its influence on beach quality assessment results, especially regarding touristic/leisure attractivities. For future studies and for future BeachLog application marine litter should be considered and measured in a quantitative way. Especially because there is a gap in how Beach Litter is measured to feed beach management strategies, how its presence influences economic activities in coastal zones, and where to find data about marine litter to feed beach classification methodologies through time, especially in emerging economies (Ramos et al., 2022).

4.3. Possible analytical uses to BeachLog records

One possibility of analyzing the BeachLog data are machine learning models, one goal can be modeling or predict the occurrence of some parameter. For the BeachLog, the target variable is a chosen parameter, and the other parameters, the beach geographical coordinates, and the month of data acquisition will be explanatory variables. With the machine learning models it will be possible to predict the probability of a parameter occur, given a random observation. The analysis inputs are the parameters (in a presence (1)/absence (0) matrix), beach location, and the temporal feature (*e.g.:* month). It will be also possible to analyze the importance of each parameter in the target parameter prediction. Possibilities of models to be tested include KNN (k-nearest neighbors), Random Forest and Ensemble methods. Analyzes can be performed using the sklearn library in Python (Grus, 2015).

Each beach also could be analyzed using association rules, the main goal will be to find associations between parameter sets (Grus, 2015). It is done using an algorithm that find rules for predicting the occurrence of some parameter based on the occurrence of other parameter items in the same beach. The advantage is that the input dataset in the analysis should be a presence/absence matrix, exactly what the BeachLog generates. It can be done using the mlxtend library, algorithm 'association_rules' in Python (Grus, 2015).

An example using association rules were performed using all the BeachLog beaches and presence/absence parameters. The analysis showed, for example, that all beaches that have Beach Litter also have Exotic and/or invasive Species. Also, beaches that have Scientific Literature have Beach Litter and Exotic and/or invasive Species. The analysis does not indicate causality, it indicates co-occurrence (Grus, 2015). It is possible to infer in those beaches that one parameter (e.g.: Beach Litter) and other parameter (e.g.: Exotic and/or invasive Species) occur at the same time. The probability of co-occurrence is 1 (100 %). The scientific literature parameter can co-occur with beach litter, and

Table 3
Timeline of beach litter related parameters in literature. Important methodological approaches regarding beach litter measurements are placed in the table.

Article	Parameter name	Recording
Cendrero and Fischer, 1997	Floating debris	n°/m^2; m^3/m; coast/year
Leatherman, 1997	Trash and litter (paper, plastic, nets, ropes, planks) Floatable in water (garbage, toilet paper) Glass and rubble	5 categories (common to rare or none)
Ergin et al., 2004	Litter	5 categories (Continuous, Full strand line, Single accumulation, Few scattered items, virtually absent)
Araújo and Costa, 2008	Floating debris Accumulation of marine debris on the beach (Items per linear meter on strand line) Litter bins or recycling receptacles[a]	3 categories (Frequently present, occasionally present, Absent) 3 categories (Heavily contaminated (>10), Present, with some accumulations (5 to 10), Absent or traces (0 to 4)) yes or no
Cervantes and Espejel, 2008	Trash Garbage collectors[a]	4 categories (Too much, Moderate, Few, None) 4 categories (None, 1–5, 6–10, >10)
UNEP 2009		
Ariza et al., 2010	Bins[a]	3 categories (Good, Regular, Bad)
Botero et al., 2015	Solid waste (sand)	Measured using a sampling technique adapted from Silva-Iñiguez and Fischer (2003)
GESAMP 2015		
Lucrezi et al., 2016	Beach inorganic trash Seawater inorganic trash	The data were separated into three classes of management attention
Peña-Alonso et al., 2017	Waste on the beach (%) Beach surface affected by mechanized cleaning (%)[a]	4 categories (0–5, 6–15, 16–25, 26–40, >40) 4 categories (0, 1–25, 26–50, 51–75, >75)
Peña-Alonso et al., 2018a, 2018b	Floating particles/debris in water Points of illegal dumping within 1 km Cleaning of the beach[a] Litter bins	Yes or no 3 categories (>2, 2–1, None) Yes or no 3 categories (At least every >100 m, Every 50–100 m, Every <50 m or less)
Marchese et al., 2021	Solid waste Recycling[a]	Not available
NOAA 2021		

[a] Waste management related.

the likelihood of it happening is 0.785 (78.5 %). In a small dataset it is possible to identify co-occurrence by a visual analysis, although in bigger datasets the algorithm can automatize and prevent human error in the analysis. It is important to highlight that the analysis shows a description of the dataset that is analyzed, the samplings number is not an indicative of analysis certainty. Also, the result cannot be interpreted as a global or general trend for beaches, it is related to the dataset that the analyses was performed on.

The co-occurrence of parameters on different beaches or over time if the BeachLog is applied periodically, can help by being an indication of prioritization for management. Also, the association rules algorithm can justify the importance or sampling effort of some parameter (e.g., Beach Litter) depending on the local reality.

5. Conclusions

BeachLog can be a tool to describe the beach local reality without judgment and understand the beach talent. These can lead to a well-planned management to sustain beaches as social-ecological systems, maintaining its ecosystem services. BeachLog records allows a wide range of analytical methods, mostly based on machine learning approach that can use a presence/absence matrix as input.

The parameters flexibility (delete, add, change) is a strong point and can reflect the local reality, save time and money for sampling not relevant parameters. Also, it does not compromise the description analysis since it is not based on an index or math calculus. The interactive dashboard is a visualization tool that can compile the information in a more palatable way than an Excel spreadsheet. This also can be modified and adapted accordingly the objective and parameters selection, being a multiuse interactive beach picture.

BeachLog can help to understand the changes the beach went through until reaching their status and/or can help estimate future scenarios and tendencies. Data Collection and establishment of baseline criteria followed by long term monitoring are essential concepts of beach management. BeachLog can be a supportive tool in different contexts, beach types and methodologies being a new tool that break the paradigm of beach classifications.

CRediT authorship contribution statement

Bruna de Ramos: Conceptualization, Investigation, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Monica Ferreira da Costa:** Conceptualization, Validation, Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Bruna de Ramos reports financial support was provided by Coordination of Higher Education Personnel Improvement.

Data availability

Data will be made available on request.

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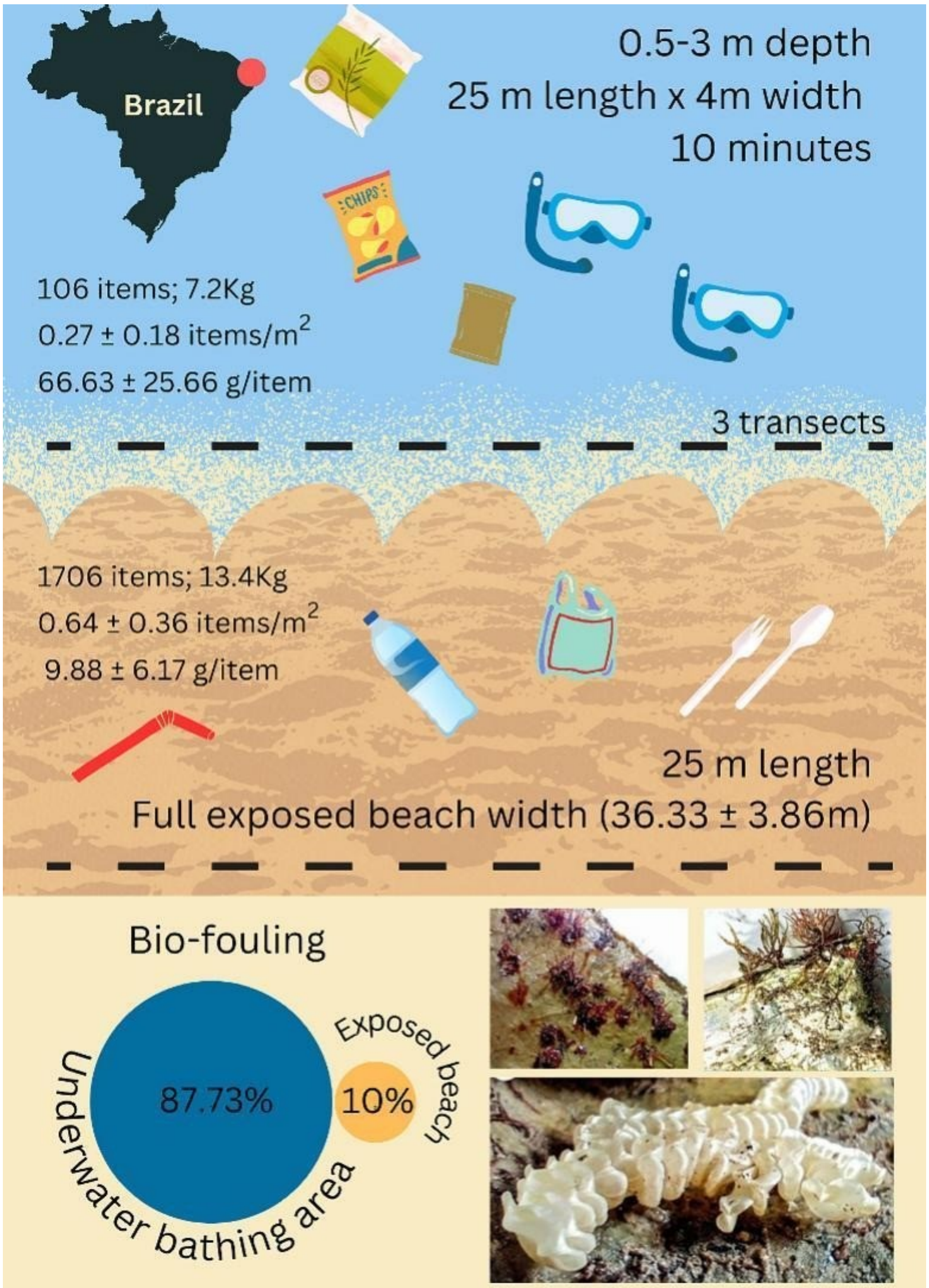
APÊNDICE C – WHAT LIES UNDERNEATH: COMPARISON AMONG BEACH LITTER IN THE UNDERWATER BATHING AREA AND EXPOSED BEACH

Artigo publicado em 09 de julho de 2024 na revista Science of The Total Environment.
Online ISSN: 1879-1026, Volume 947, October 2024, 174661.
doi: 10.1016/j.scitotenv.2024.174661.



Science of the Total Environment 947 (2024) 174661

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

What lies underneath: Comparison among beach litter in the underwater bathing area and exposed beach

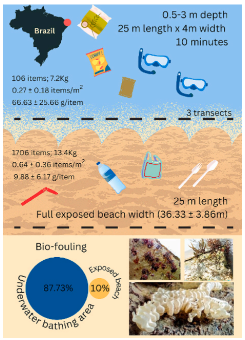
Bruna de Ramos [a], Monica F. Costa [a], Tábata Martins de Lima [b,*]

[a] Departamento de Oceanografia, Universidade Federal de Pernambuco - UFPE, Recife, Pernambuco 50740-550, Brazil
[b] Departamento de Biociências, Universidade do Estado de Minas Gerais – UEMG, Unidade Passos, Minas Gerais, Brazil

HIGHLIGHTS

- Methods and beach regions were compared to enhance litter assessment completeness.
- Exposed beaches and bathing areas contain different proportions of litter sources.
- Brand audit showed local/national companies as major contributors to beach litter.
- Biofouling more visible in underwater area than in the exposed beach litter.

GRAPHICAL ABSTRACT



ARTICLE INFO

Editor: Thomas Kevin V

Original content: Marine litter data in Itamaracá Island, Brazil. 2022. (Original data)

Keywords:
Monitoring
Marine litter
Marine litter sources
Plastic waste
Brand audit
Fouling

ABSTRACT

The standard techniques for monitoring beach litter focus on the litter that is accumulated on beaches. Therefore, the underwater bathing area is usually overlooked. Our study aims to start the discussion about the litter in the bathing area, an important connection between the exposed beach and the ocean. We aimed to compare sampling methodologies between the underwater bathing area and the exposed beach. We highlighted litter's similarities and differences regarding the amount, material, possible sources, and interaction with the biota. We also performed a brand audit on the underwater bathing area litter. In the underwater region, 106 items were collected while 1706 items were collected from the exposed beach region. Plastic was the dominant type of material in both sites, exposed beach (89.92 %) and bathing area (83.96 %). The litter's possible source was different. In the underwater bathing area was more related to food packages (couscous, rice). On the other hand, litter on the exposed beach was associated with beach use (single-use plastic such as plastic cups). The brand audit identified 21 companies, whereby most brands were Brazilian and food-related. Regarding interactions with the biota, the litter in the bathing area had more bio-fouling (87.73 %) than the litter collected on the exposed beach (10.00 %). Information about bathing area litter can be useful to draw different management

* Corresponding author.
E-mail address: tabatalimafac@gmail.com (T.M. Lima).

https://doi.org/10.1016/j.scitotenv.2024.174661
Received 29 March 2024; Received in revised form 5 July 2024; Accepted 7 July 2024
Available online 9 July 2024
0048-9697/

strategies. Due to the differences in litter types and behavior between the two sites, the same mitigation strategies might not be equally efficient.

1. Introduction

Marine litter is a worldwide problem that has been increasing for the last decades (Löhr et al., 2017). Several studies address the problem of stranded litter, characterizing the types, materials, and possible sources (Burgess et al., 2021; Velez et al., 2019). Due to its easy access and low-cost methodology for sampling, beaches are places of interest for studies and actions. However, little is known about the litter in the underwater bathing area. Bathing areas are often overlooked in beach evaluations, which include marine litter sampling and monitoring, despite the crucial role of this region in enhancing the visitor experience (Williams and Micallef, 2009). Litter that lies underwater (laying on the seafloor or floating) in the underwater bathing area (0 to 3 m) is often ignored in sampling efforts, whether for research (Cesarano et al., 2023) or in volunteering beach cleanup actions (Buijs et al., 2023). The scientific research regarding marine litter in the bathing area is still scarce, especially compared with the stranded litter. This can indicate a gap in beach litter sampling, research, and an emerging concern. Also it is known that the low number of sampling efforts in underwater regions is related to logistic issues (*e.g.*, Haarr et al., 2022). The comparison between stranded litter and litter in the underwater bathing area in the same location is limited, studies focused only on stranded litter (Cesarano et al., 2023) or underwater (Buijs et al., 2023; Vlachogianni and Kalampokis, 2013). Yet sampling in both sites simultaneously can offer valuable insights into the dynamics of the region and inform marine litter management strategies.

Another example is World Cleanup Day (https://www.worldcleanupday.org/) which happens on the last Saturday of September yearly, and rarely considers the underwater bathing area. This gap in the assessment of beach litter can result in the omission of valuable insights for managers and scientists. The lack of standardized methodology for shallow areas such as the underwater bathing area that can be applied together with the exposed beach is part of the challenge.

Comparatively, while there is some research concerning marine litter on the seafloor, it is usually regarding greater depths rather than the connection areas such as the bathing area or an intertidal region (Haarr et al., 2022). Regions characterized by shallower depths, such as underwater bathing areas and coral reefs, continue to suffer from a scarcity of comprehensive information and studies (Canals et al., 2021). Since underwater bathing areas and exposed beach regions have different characteristics, litter in these regions faces different environmental factors and/or intensities, for example, sunlight radiation may affect more stranded litter than underwater, although biofouling is more expected in underwater (in the seafloor or floating) litter, as observed in some Abandoned, Lost, or Discarded Fishing Gear (ALDFG) (Enrichetti et al., 2021). These can favor differences in litter characteristics such as possible sources, residence time, age estimation, biofouling rates, and degradation level.

Beach litter in contact with water may leach harmful chemicals (*e.g.* batteries, additives), impacting local water quality and the health of aquatic organisms (Rios Mendoza et al., 2018). Toxic substances released into the water can easily spread and accumulate in sediments, potentially affecting the entire aquatic ecosystem (Carbery et al., 2018). Showing the differences between stranded litter on the exposed beach and litter in the underwater bathing area may help the understanding of diversity in marine litter pollution. The interaction with the biota is another aspect that may change depending on where the litter is deposited, on the sediment, in the water column, or stranded. For instance, plastics and other waterlogged materials may settle on the ocean floor, potentially altering sediment composition and affecting benthic communities. The impacts of marine litter on marine biodiversity are vast (Angiolillo and Fortibuoni, 2020), even being extended to Marine Protected Areas (MPAs) (Perna et al., 2024). These impacts encompass various interactions, including entanglement, ghost fishing, seafloor coverage, behavioral changes (Freitas et al., 2022), litter serving as substratum, and incorporation (Angiolillo and Fortibuoni, 2020). In the case of ghost fishing and/or ALDFG, it can also threaten human security in bathing areas, this can be exemplified by the presence of a fishing hook or other sharp piercing material.

Collecting litter data on the underwater bathing area contributes to a more complete understanding of marine pollution and aids in the development of data-driven, well-informed, and targeted litter management strategies. This comprehensive approach helps protect marine ecosystems, aquatic life, and coastal communities from the adverse effects of litter pollution. The sampling of the underwater bathing area and the exposed beach can help identify sources of pollution, as well as the pathways through which litter reaches the underwater environment.

Our research focused on Forte Orange Beach, located on Itamaracá Island in northeast Brazil, chosen due to its tropical climate and consistent influx of beachgoers year-round. Within this context, our study aimed to investigate whether submerged litter can be assessed similarly to beach litter; and, comprehensively characterize the collected material. We hypothesized that similar litter types would be found in both environment due to the close connection, with a lower amount of litter expected in the underwater bathing area compared to the exposed beach. We seek to highlight the similarities and differences between litter in the underwater bathing area and the exposed beach, in Forte Orange Beach. It is a step towards a more comprehensive beach litter assessment and management.

2. Methodology

2.1. Sampling methodology

The sampling took place on December 22nd 2022 during low tide at Forte Orange Beach (7°48′38″S; 34°50′17″W) (Fig. 1). This is an enclosed beach in Northeast Brazil with tourist activities, especially for Sun and Beach tourism, throughout the year. It is important to note that the beach sediment dynamic is under a river influence and a sand bank (Coroa do Avião). Also, the area is used for aquatic sports and fishing activities.

We explored some methods (Sciutteri et al., 2024; UNEP and IMO, 2005; Vlachogianni and Kalampokis, 2013) for shallow underwater litter sampling to guide our approach. However, we did not find any recommendation specifically tailored to sampling the underwater bathing area. Scuba diving is not applicable in this shallow area. Additionally, we did not find consistent comparisons between the exposed beach and the underwater bathing area being sampled in the same effort. The litter was collected from two sites: the ‘exposed beach’ was categorized as the intertidal area, with fine sand grains and low interference of the water at low tide, where the litter was stranded, and the ‘underwater bathing area’ sampling referred to the first meters of the bathing area, with a depth ranging from 0.5 to 3 m, where all litter floating or in the seafloor was collected (Fig. 1). The sediment in the underwater bathing area was similar to that of the exposed beach, although some rocks and concrete from the remains of coastal protection structures were present.

The litter collection at the exposed beach was done according to the United Nations Environmental Programme (UNEP) guidelines (Cheshire et al., 2009). We sampled three transects of 25 m in width parallel to the sea, and the collection took place along the length of the beach (36.33 ± 3.86 m, the beach length was measured for each transect). Two people walked through the transects collecting every litter that was visible on the sand surface inside the sampling area.

To test the methodology for the underwater bathing area, a trial sampling was performed in a region close to the sampling area. Two researchers with diving/snorkeling experience did the sampling. It was observed that 10 min was enough to do a sweep in the environment taking into consideration the depth (0.5–3 m) and width (25 m) required to be comparable to stranded litter collection. The underwater bathing area length was estimated at 4 m. The data from the trial was also analyzed.

For underwater bathing area litter, active sampling was performed by two researchers equipped with snorkeling gear (snorkel, mask, and fins) and collecting bags. The collection occurred in the 3 zones of the bathing area, parallel with each transect placed on the exposed beach. The underwater survey took place in a time frame of 10 min per transect, during this time the researchers collected all the visible litter, floating or lying down in the sediment. Some of the items were partially covered by the sediment. If the items were strongly attached to the sediment and/or more than ~60 % buried, it was not collected.

All the collected litter was classified according to UNEP guidelines regarding its material and type (Cheshire et al., 2009), and possible sources accordingly (Araújo et al., 2006). The litter was also sorted regarding interactions with the biota or biofouling. Additionally, all the litter was photographed and the total weight per transect (for both areas) was recorded using a handheld scale. The data analysis was done with Jamovi (version 2.5) to perform a normality test (Shapiro-Wilk) and One-Way ANOVA (Welch's test) to compare abundances and weight per item between sampling sites. We used Python (3.12.2), packages Pandas and SciPy (chi2_contingency module) for the chi-square test to compare the frequency of occurrence of litter types between underwater bathing area and exposed beach. A brand audit analysis was performed (Stanton et al., 2022) for the underwater litter. The brand identification was done by searching for logos, labels, and product names in the collected material.

3. Results

3.1. Litter's materials and types

A total of 106 items, accounting for 7200 g, were collected from the underwater bathing area, comprising trial sampling ($n = 18$, 325 g) and three transects ($n = 53$, 3735 g; $n = 17$, 1090 g; and n = 18, 1750 g) (Fig. 3). In contrast, 1706 items, totaling 13,365 g, were collected from the exposed beach region, resulting in 1812 items and 20,565 g in total. The abundance for the exposed beach was 0.64 ± 0.36 items·m^{-2}, with an average weight per item of 9.88 ± 6.17 g·item^{-1}. In the underwater bathing area, the abundance was 0.27 ± 0.18 items·m^{-2}, and the average weight per item was 66.63 ± 25.66 g·item^{-1} (Fig. 2). The Normality Test (Shapiro-Wilk > 0.05) indicated normality for the data. Subsequently, a one-way ANOVA (Welch's test) was applied, revealing no significant difference in the number of items per square meter between the sites ($p = 0.207$), but a significant difference in grams per item

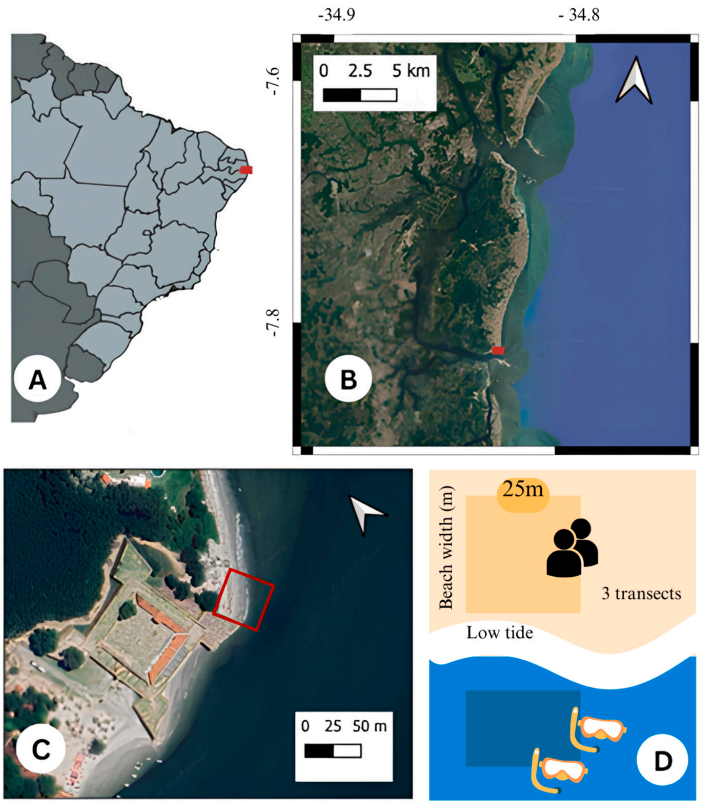


Fig. 1. Schematic indicating the sampling site and methodology. The sampling took place in Pernambuco state, northeast Brazil (A), on Itamaracá Island (B). At Forte Orange Beach (C). The sampling took place at two regions: 'exposed beach' and 'underwater bathing area' area during low tide (D).

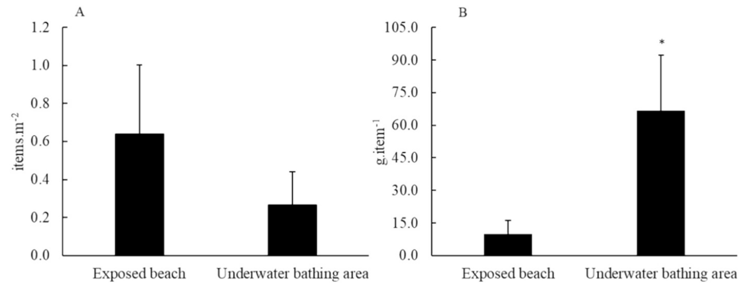


Fig. 2. Mean values and standard deviation of litter in the exposed beach and underwater bathing area. (A) abundance in number of items·m^{-2} and (B) weight per item in grams·item^{-1}. The * represents statistical differences ($p < 0.05$).

($p = 0.018$) (Fig. 2).

Plastic was the predominant material at both sampling sites. Plastic represented 83.96 % of the collected underwater bathing area litter and 89.92 % in the exposed beach (Table 1, represented by the UNEP code PL). Foam plastic represented 42.85 % of the plastic in the exposed beach (Table 1, represented by the UNEP code FP), while in the underwater bathing area, the Styrofoam or foam plastic was not found/collected. Regarding other materials (Table 1, note the UNEP code), glass & ceramic represented 13.21 % in the underwater bathing area and 3.58 % in the exposed beach. Metal represented 2.83 % and 1.41 % in the bathing area and exposed beach respectively.

The underwater bathing area presented four categories of materials (Plastic, Glass & Ceramic, Metal and Other). On the other hand, in the exposed beach, it was possible to find all material types from the UNEP classification, including wood (1.00 %), rubber (0.64 %), paper & cardboard (0.41 %), and cloth (0.23 %). Another category that included material without possible identification represented 2.81 % of the exposed beach items. Regarding litter types, the exposed beach presented more litter types than the underwater bathing area, following the same pattern as the results on material composition (Table 1). For the bathing area, were observed 10 litter types (Table 1). The top five items corresponded to 93.40 % of the total sampled.

A total of 39 litter types were registered for the exposed beach. The top five items in the exposed beach were foamed cups & food packs (FP02), food containers (PL06), cigarette buts (PL11), fragments (PL24), and single-use cutlery (PL04) which represent 77.61 % of the total collected. The foam plastic is originated from foamed cups & food packs (FP02), foam (insulation & packaging) (FP04), and foam buoys (FP03). When combining foam plastics with cigarette butts (PL11), these account for over 50 % of the litter collected on the exposed beach. Interestingly, both litter types were not found in the underwater bathing area. The exposed beach samples did not present wire mesh & barbed wire (ME09), or medicine glass container (GC08). In the bathing area, these categories are responsible for 1.89 % and 0.94 % of the material respectively. When summing the common items in the underwater bathing area and exposed beach, it becomes evident that the areas differ, as the common items represent 36 % ($n = 667$) of the total collected ($n = 1812$).

Some items appeared <0.5 % in the exposed beach composition being considered not frequent items. They were Ice-cream sticks (WD03), processed timber (WD04), Paper (including newspapers & magazines) (PC01), rubber bands (RB06), tableware (ME01), burned litter (OT05.1), fishing net (PL20), cloth fragments (CL06), glass bottles and jars (GC02), pen (PL24.6), balloons (RB01), foam buoys (FP03), tar balls (OT05.3), flip flops (RB02), carpet (CL05), erosion control bags (OT05.2), syringes (PL12), condoms (RB07), and matches (WD05).

The chi-square test revealed significant differences ($p = 0.03$) in the distribution of litter types between the sampling sites. These differences were observed for rare items found exclusively on the exposed beach. Fiberglass fragments (PL22), ropes (PL19), and toys and party poppers (PL08) exhibited frequencies of 1.52 %, 0.59 %, and 0.58 %, respectively (Table 1). Additionally, items with even lower frequencies (<0.5 %), such as fishing gear (PL17), rubber bands (RB06), tableware (ME01), and paper (PC01), displayed distinct distributions between the underwater bathing area and the exposed beach. These findings underscore the differences between the sites and emphasize the diversification of marine litter, particularly on the exposed beach.

Table 1
Litter types composition in the underwater bathing area and exposed beach. Items with <0.5 % in the exposed beach were not presented. The UNEP code represents the material following these codes: PL (Plastic), GC (Glass & Ceramic), ME (Metal), FP (Foam Plastic), OT (Other).

UNEP code	Description	Underwater bathing area		Exposed beach	
		n° items	%	n° items	%
PL06	Food containers (including domestic food packages)	58	54.72	242	14.18
GC01	Construction material (brick, cement, pipes)	11	10.38	49	2.87
PL04	Knives, forks, spoons, straws, stirrers, (cutlery)	11	10.38	89	5.22
PL24	Other (fragments)	10	9.43	164	9.61
PL07	Plastic bags	9	8.49	14	0.82
ME09	Wire, wire mesh & barbed wire	2	1.89	–	–
GC02	Bottles & jars	1	0.94	3	0.18
ME07	Fishing related (sinkers, lures, traps, pots)	1	0.94	5	0.29
OT02	Sanitary (nappies, cotton buds, tampon applicators, toothbrushes)	1	0.94	41	2.40
PL02	Bottles <2 L	1	0.94	19	1.11
GC08	Other (medicine glass bottle)	1	0.94	–	–
FP02	Cups & food packs	–	–	654	38.34
PL11	Cigarettes, butts & filters	–	–	175	10.26
FP04	Foam (insulation & packaging)	–	–	75	4.40
PL22	Fiberglass fragments	–	–	26	1.52
PL24.7	Other (construction)	–	–	17	1.00
PL01	Bottle caps & lids	–	–	16	0.94
ME02	Bottle caps, lids & pull tabs	–	–	10	0.59
ME08	Fragments	–	–	10	0.59
PL19	Rope	–	–	10	0.59
GC07	Glass or ceramic fragments	–	–	9	0.53
PL03	Bottles, drums, jerrycans & buckets > 2 L	–	–	9	0.53
PL08	Toys & party poppers	–	–	9	0.53

3.2. Possible sources of litter

Regarding the possible source of the beach litter, in the underwater bathing area, 45.28 % was related to domestic food packaging and 31.13 % was beach user related (Fig. 4). Most of the domestic food packaging categories include packages from beans, rice, pasta, and flour, among others, which can be related to houses near the beach and/or restaurants that support tourist activity on the beach. In the exposed beach, beach user related possible sources were dominant (68.46 %) with items such as single-use plastic (*e.g.* plastic cups), and toys, among others. The General home possible source refers to debris from construction such as bricks and pipes, it represented 16.04 % in the underwater bathing area and 10.55 % in the exposed beach. The unknown category is mostly related to plastic fragments comprising 3.77 % of underwater bathing area litter and 11.49 % in the exposed beach. Sewage & personal hygiene items appeared in similar proportions in both sampling sites. International items appeared once in each area, although it represented 0.94 % in the bathing area and 0.06 % in the exposed beach. Finally, hazardous items such as syringes appeared only on the exposed beach.

3.3. Brand audit

The brand audit was done for the sampled items in the bathing area. It identified 23 brands belonging to 21 companies in 28 items (Table 2). The brand audit represented 25.47 % of the items collected. In the remaining litter, we could not identify brands because the litter was degraded or covered by biofouling, not presenting clear information to the brand audition.

One international item was identified as a Chinese washing powder (Fig. 5). The location was based on the three first numbers in the barcode (691) that are associated with the Chinese industry. The product translation is: "Diaopai laundry detergent super-enzyme 1.28 kg (barcode 6910019009885)".

An interesting item was an ignition piece from a Japanese company (Niterra, model NGK - BKR6E-D). The curious was that this piece was attached with fishing lines and a hook (visible in Fig. 3A, lower left). It means that it was not being used for its original purpose but as a weight for fishing.

Most of the items were from Brazilian companies (60.00 %) and food-related (82.14 %). *M. Dias Branco* was the Brazilian company with more items identified (four items from three different brands), all of them related to food packages (Table 2). The international company *Unilever* accounted for three items from two different brands, one related to food packaging and the other one related to washing powder (Table 2).

Table 2
Brand audit summary. Brands are in italic in the description. The two companies with more items are shown in bold.

Origin	Company	Description	Items
National (17 items)	Adram	*Nutrivita* (couscous)	1
	Alvolar lácteos	*Betània* (yogurt)	1
	Camil	*POP* (rice)	1
	Elegê	*Elegê* (rice)	1
	Grupo Coringa	Couscous	1
	Hiperbom	Supermarket plastic bag	1
	Itambé	*Itambé* (yogurt)	1
	M. Dias Branco (4 items)	*Treloso* (cookie)	2
		Vitarella (pasta)	1
		Bonsabor (pasta)	1
	Milet	Ice cream	2
	Pepsico	*Elma chips* (cebolitos chips)	1
	Rei de Ouro Alimentos	Couscous	2
	Turquesa	Cassava flour	1
Regional (5 items)	Bolo de Rolo & CIA	traditional local cake	1
	Flokão	Couscous	1
	Grãos do Agreste	Beans	1
	Karintó	Chips	1
	Natural da vaca	Yogurt	1
Global (5 items)	Heineken	Beer bottle	1
	Niterra	NGK - BKR6E-D, Japanese ignition, found in fishing gear	1
	Unilever (3 items)	*ALA* washing powder	2
		ARISCO (tomato sauce)	1
International (1 item)	Diaopai	Chinese washing powder	1

3.4. Interaction with the biota

It was considered interaction with the biota if the item preset biofouling or some mobile animal attached to the surface. In the bathing area, 87.73 % of the litter showed some form of interaction, while on the exposed beach, it was observed in 10.00 % of the items. We were able to identify several interactions among the collected litter and the biota, including algae, bryozoan, mollusks, polychaeta, and crustaceans (Fig. 6). Additionally, an interesting observation was made in the international washing powder package (Fig. 5), it presented some marks on the borders that can be bites from some animals.

4. Discussion

The total amount of litter collected on the exposed beach was higher than in the underwater bathing area, but it did not present a significant difference in abundance (items·m^2). In terms of weight per item, the underwater litter was heavier than the exposed beach litter. This could be associated with more sand and water in these items, but also with the weight of associated biota.

It is important to recognize that despite differences in sampling strategies and environment, the methods employed are comparable, utilizing similar approaches and grouping of litter based on (Cheshire et al., 2009) and (Araújo et al., 2006). It is recommended to utilize these methods in tandem, as this approach strengthens the understanding of beach litter. The standardization of a sampling protocol for beach litter in the underwater bathing area would be a great contribution to the scientific community. Including our study in a broader discussion about plastic monitoring in the marine environment, it can be understood as basic research (Aliani et al., 2023), since we still testing comparisons between underwater bathing area and exposed beach. The different shapes, densities, and sizes mean that marine litter occupies different compartments within the environment, and can be found floating, in suspension, or in the sediment (buried or deposited). Our approach was innovative sampling two different environment in the same sampling effort and comparing them. Additionally, it can be used in citizen sciences initiates, and it is low cost when we compare it with scuba diving or drone (aerial and underwater) assessments (Escobar-Sánchez et al., 2022).

It is important to note that the knowledge about the sampling site regarding tidal regime, coastal currents, including riptide, and visibility are determining factors in the sampling success. A zigzag movement within the sampling area helps to be more effective in covering the region. Determining a depth that is accessible through diving is also an essential factor, at a depth of 1 to 3 m the researchers were able to have good visibility and access to the seafloor. However, this depth may vary depending on the location, especially regarding the visibility factor. Our approach can also be complemented with drone assessments for example (Escobar-Sánchez et al., 2022).

The results presented in this study have the potential to be extrapolated to a broader scope. Marine litter on Itamaracá Island was collected from three beaches (de Ramos et al., 2023), with sampling conducted in March (0.11 ± 0.09 items·m^2), June (0.20 ± 0.15 items·m^2), September (0.27 ± 0.19 items·m^2), and December (0.31 ± 0.32 items·m^2) 2022, following the methodology outlined in this paper for the exposed beach. Analysis of the data using PERMANOVA revealed no significant difference ($p > 0.05$) in the amount of litter collected across the four seasons of the year across three beaches on Itamaracá Island in 2022. This finding suggests a stability in the amount of litter present on these beaches over time. Such consistency could offer valuable insights for the planning and implementation of marine litter management

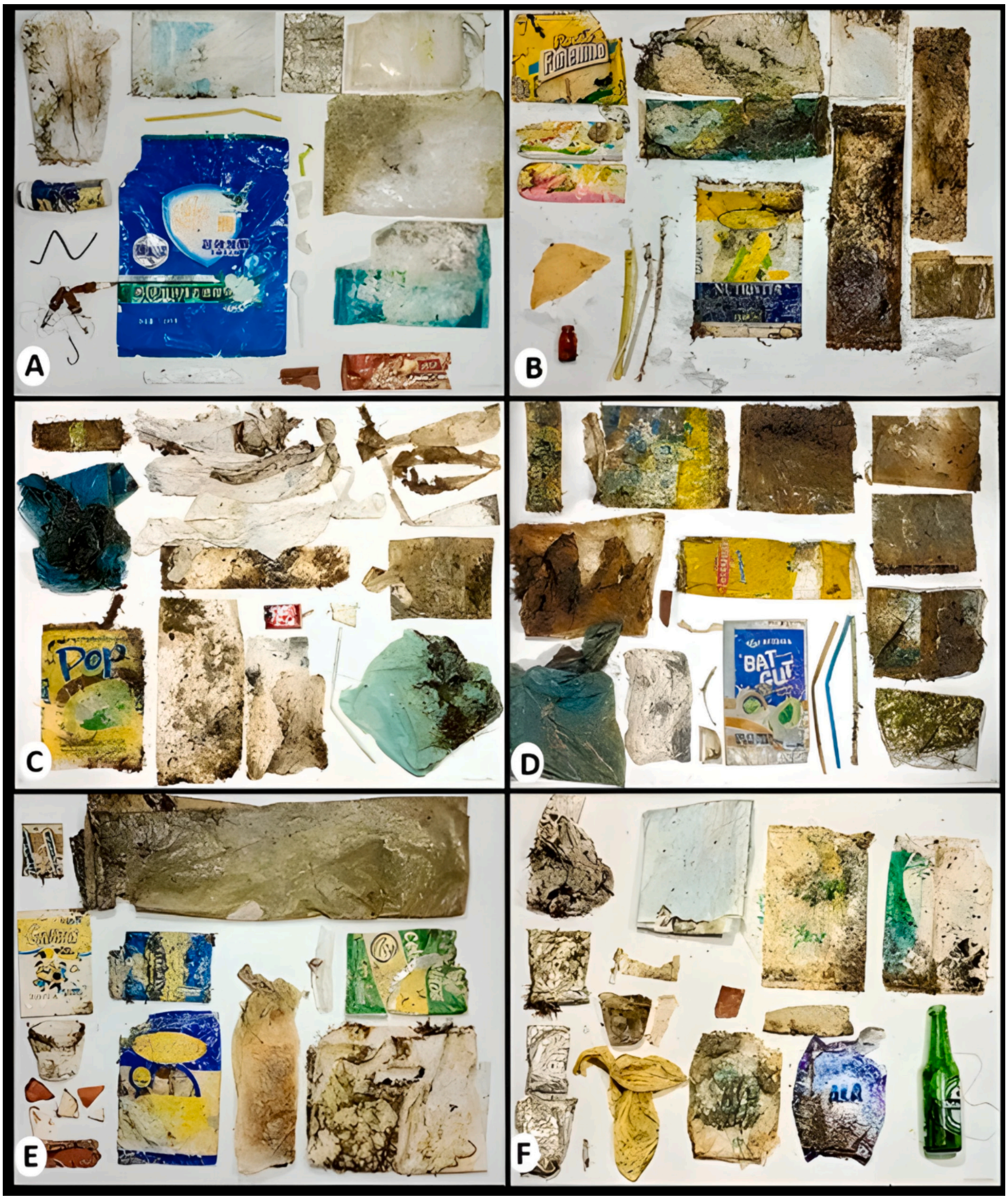


Fig. 3. Items collected in the bathing area (floating or on the seafloor). (A) trial sampling, (B, C, D) first transect; (E) second transect; (F) third transect.

strategies. Moreover, it emphasizes the importance of extending studies and monitoring efforts to include the underwater bathing area.

Considering the ocean compartments, the underwater bathing area is part of the beach system (Fanini et al., 2021), which means that it will be a step forward in managing strategies including the bathing area in monitoring and/or mitigation campaigns. The social-economical information such as beach infrastructure and activities performed on the beach are relevant factors. However, for this study this information did

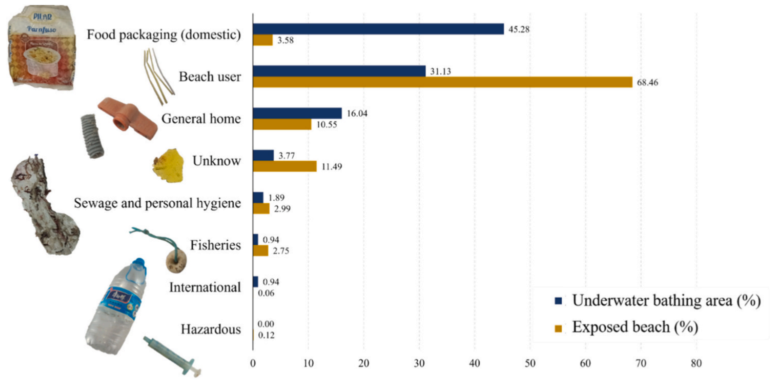


Fig. 4. Percentages of possible sources in the underwater bathing area (blue) and exposed beach (yellow). The images are from the collected litter (in the exposed beach) to represent each category.

Fig. 5. Chinese washing powder collected in the bathing area. (A) Package front part and (B) back, where it is possible to see the barcode.

not interfere with how the method was applied. In Itamaracá Island the tool *BeachLog*, which aims to describe the beach, was applied and it is available (de Ramos and Costa, 2023).

Qualitative comparisons between the litter in the exposed beach and underwater bathing area can raise insights about a more complete view of beach litter pollution. Plastic was the dominant material in both sampling sites which is a common finding in the literature regarding marine litter composition on beaches (Grundlehner et al., 2023), seafloor (Garofalo et al., 2020), lakes (Nava et al., 2023), and ingestion by animals (Neto et al., 2020). Plastic pollution was already characterized for being a multifaceted, cross-sectoral, and ongoing environmental problem related to a series of human activities and needs such as food security, goods' movements, services, and shelter (Abalansa et al., 2020).

Among the plastic variety, in the underwater bathing area foam plastic was not reported. The general low density of this material can contribute to their buoyancy, facilitating the transport by wind and waves (Ryan, 2015), making it easier to be found in wrack lines or stranded on the exposed beach. In the underwater bathing area foam plastic may not be visible, but that does not mean they are absent in the underwater environment.

Looking at the item types, the differences between sites are more explicit, it was possible to observe qualitatively and apply the chi-square test that highlighted the differences between sites in terms of litter composition. The presence of more litter types in the exposed beach can give clues about the higher variety of sources in this region, especially related to beach use and local deposition. For example, cigarette butts are present on the exposed beach but not in the underwater bathing

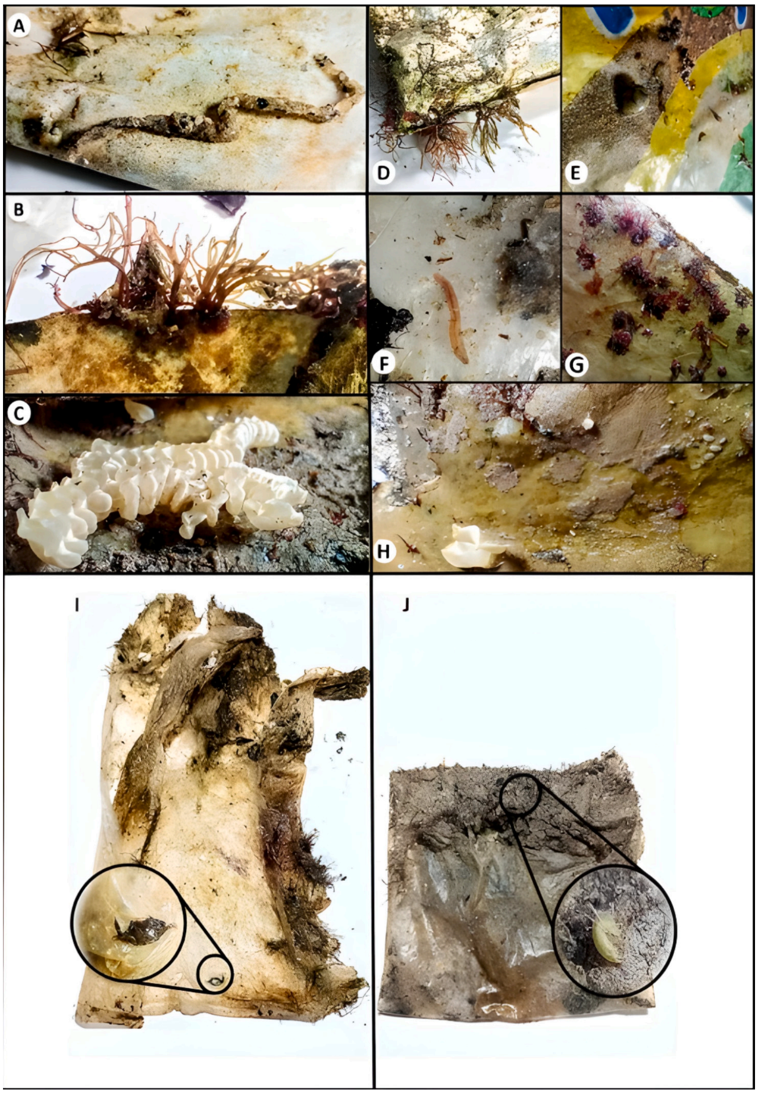


Fig. 6. Items collected with biota interaction. (A) tetra pack with algae fouling, (B) rice food Package with gastropod, (C) transparent plastic bag with polychaeta, (D) and (E) plastic packages with biofouling (bryozoa), (F) polychaeta tubes, (G) algae fouling, and (H) gastropod eggs. Zoom in animals trapped in plastic packages. (I) crustacean (Portunidae) trapped in a plastic bag, (J) amphipod over a packaging.

area, this item can be acknowledged as a chronic issue on the beaches of Recife (Silva et al., 2023a), potentially extending to Itamaracá island. The same applies to bottle caps & lids, only found on the exposed beach and also reported for the region as a problem (Silva et al., 2023b). Differences between litter composition in the land and seafloor were already reported (Roman et al., 2020). The findings are comparable with our study since Roman et al. (2020) found items of beach use (*e.g.* bottle caps) just on land.

Two items' categories presented in the bathing area were not present in the exposed beach (wire mesh & barbed wire (ME09), and medicine glass container (GC08)), although it was not detectable in the chi-square test. The items present only in the underwater bathing area are rare (<2 %), which can be a reason for not finding them on the exposed beach. This could be the reason that these items differences were not detected by statistical analysis. Also, the high density of metal and glass items could allow them to deposit in the seafloor in the bathing area, not being easily remobilized.

When analyzing the possible sources of marine litter in both sites, it mainly included food packaging and items related to beach use. However, the higher presence of beach user items such as single-use plastic items, on the exposed beach can be attributed to tourist activity. The presence of food packaging such as rice, beans, pasta, and couscous in the underwater bathing area can be related to river input and the local population habits. Food packaging presence has been extensively reported in the marine environment. They had been reported for mangroves (Duarte et al., 2023), sandy beaches (de Ramos et al., 2021), coral reefs, and seagrass (Fong et al., 2023). In the mangrove, it has been reported as the main component of plastic items (Rambojun et al., 2024). Also, being stated that the food packaging's most probable source is from land-based human activities rather than sea-based. For the seafloor, food packages were already reported as the second most abundant plastic type in the Brazilian continental slope (Masumoto et al., 2023). Masumoto et al. (2023) found food packages produced over 26 years ago and from Brazilian brands.

Rivers can act as reservoirs and/or conduits, transporting or trapping a variety of debris and/or litter (Schmidt et al., 2017; van Emmerik et al., 2022), which encompasses items like food packaging. This can happen especially in regions where the urban areas are near a river and beach. Storms or strong winds also can influence the arrival of debris in the marine environment (van Emmerik et al., 2022). The bathing area collected litter can highlight some sources of marine litter in a region/beach that is overlooked by the traditional beach sampling efforts.

In this regard, brand audit can serve as an important tool in identifying sources in a more precise way, allowing the assessment of the most common brands of marine litter in a region. Additionally, the litter types and brands found in the coastal and marine areas are often indicative of the preferences and habits of the local population. For instance, if the nearby community has a higher consumption of certain types of packaged foods, then the marine litter will reflect those preferences, likely including a significant amount of food packaging related to those dietary choices and local culture (Silva et al., 2023b). The brand audit identified items showcasing the culinary tradition of consuming corn-based couscous in Northeast Brazil, which might be related to the identification of national brands. Also, rice, beans, and local cake packages are associated with local habits.

Looking at the item's origin it was possible to identify local, regional, national, and international companies, which can raise discussions about shared responsibility regarding beach litter (Stanton et al., 2022). The majority of the brands were Brazilian (60 %), but the global company *Unilever* appears in second place, alerting us to the globalization of marine litter issue in the commerce and distribution spheres.

This issue also was explicit in items such as a Japanese brand ignition part found in fishing gear (NGK - BKR6E-D) that highlights the international scope of marine debris, the variety of uses of an item, and the complexity of its management. Especially related to regional habits.

This brand audit reinforces the extended producer responsibility principle, which places the responsibility on manufacturers to oversee the entire lifecycle of their products, including their proper disposal. This is clear on local, regional, and national scales, but regarding global companies and international litter, there are still regulation gaps. Although some NGOs are starting the discussion. The Surfers Against Sewage (SAS) in their annual brand audit for 2023 identified the *Dirty Dozen* brands in the marine litter (https://brandaudit.sas.org.uk/#dirty-dozen), in our study we identified two of them (PEPSICO and Heineken).

The main aspects that prevented the brand audit were the level of item degradation and interaction with the biota, such as biofouling. Interaction among marine litter and biota has already been reported in several studies (Battaglia et al., 2019; Freitas et al., 2022; Mancini et al., 2021). It is important to understand the various types of interactions with the different species of fauna and flora, mostly to know where to focus the research efforts and management strategies (Costa et al., 2022).

The type of interaction depends on the type of litter, type of sediment, and biota characteristics (Kim et al., 2023). The use of the litter as shelter or substrate, for example, can be related to different groups. Field experiments have found an increased number of species, including fishes, crustaceans, sea-urchins, and octopuses, on a site with litter presence (16 items100m^{-2}) compared with a site without litter. The authors discussed the possible reason for a higher number of species in a site with litter could be that the animals were searching for refuge (use of litter cavities or digging sediment under the litter), reproduction sites, and/or hard substrates to the fixation in case of sessile organisms (Katsanevakis et al., 2007). However, the litter represents a threat to marine animals, impacting on marine biodiversity. A study conducted throughout an internet search was able to identify 127 cases of interaction among litter and marine animals, over the period of 15 years on the Italian coast. A total of 16 species among turtles, cetaceans, seabirds, elasmobranchs, teleost, and invertebrates were reported to have interacted with litter. Being entanglement and ingestion the most common interactions (Bottari et al., 2024). Another study showed the interactions of 18 species with marine litter on the Morocco coast. Turtles and cetaceans were the most affected species and fishing related litter was the responsible for entanglement of several species (Mghili et al., 2023).

Despite most of the studies about litter interaction with the biota being regarding vertebrates, there are also several possible interactions with invertebrates. Bottari et al. (2024) studied plastic colonization in brackish water and found that invertebrates were often found associated with plastic. Most of the plastic collected (76.8 %) had invertebrates associated. Being the most common groups Arthropoda, Annelida, and Mollusca. One of the associations that Bottari et al. (2024) found among litter and the faunae was mollusk's egg mass. In our study, we also found mollusk's egg mass on the litter collected in the underwater bathing area. This data can indicate that some species can be using litter for reproductive ends, potentially facilitating dispersion.

In our study, many of the items (83.96 % in the bathing area) were covered in various types of algae, often clinging tightly to plastic objects. Previous studies have already reported biota interaction with marine litter collected in depths ranging from 50 to 120 m, being the most abundant bryozoans and polychaeta (Mancini et al., 2021). Both bryozoa and polychaeta were also found in our sampling along with mollusks, and crustaceans. The high rate of biofouling in the underwater bathing area litter compared to the exposed beach can be important for studying litter's time of permanence in the environment (Enrichetti et al., 2021).

Regarding time of permanence another contamination problem must be taken into consideration, the release of additives and plastic-associated chemicals. These substances can cause several problems for marine biota such as bioaccumulation that can lead to biomagnification and subsequent acute or chronic toxicity (Andrady and Rajapakse, 2019; Hong et al., 2014).

Additionally, biofouling and animals trapped in the litter can serve as data input to models of wildlife transport, alien species dispersion (Rech et al., 2018), and plastisphere studies. Biota interaction with marine litter also raises concerns about the impacts of cleaning and removing litter from the environment that can remove important taxa (Zielinski et al., 2019).

The biofouling data is important not only to better understand the types and levels of interactions among the biota and the litter but also to base management strategies. For example, the management strategy to reduce entanglement is different from those to deal with plasticizers. Our study has shown that the underwater method of collection used is an efficient method to acquire information about biota and litter association.

5. Conclusions

This study introduces a novel perspective on beach litter, emphasizing the significance of understanding the differences between the underwater bathing area and the exposed beach for comprehensive litter assessment and management. Neglecting litter in the underwater bathing area may result in underestimations and overlook crucial insights into its distribution, composition, biota interactions, and behavior at this critical land-to-sea interface. The heightened biota interaction rate in the underwater bathing area litter underscores its scientific importance and warrants different management strategies. Given the additional challenges of sampling underwater environment, such as visibility and training requirements, we propose the integration and a more complete beach litter sampling. Integrating tourism, food packaging, and general household litter sources into a cohesive strategy inclusive of the bathing area enhances management comprehensiveness and beachgoer safety, as certain items can pose hazards. Responsibility for marine litter falls not only on local and national brands but also on international and global companies, necessitating their involvement in improving disposal habits and combating marine litter across the entire product lifecycle.

CRediT authorship contribution statement

Bruna de Ramos: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Monica F. Costa:** Writing – review & editing. **Tábata Martins de Lima:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used ChatGPT 3.5 in order to improve English written in terms of clarity and grammar. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

I have shared the link to my data

Marine litter data in Itamaracá Island, Brazil. 2022. (Original data) (Figshare)

Acknowledgment

BR received a Ph.D. Scholarship (Finance Code 001) from Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES). We would like to express our sincere gratitude to the reviewers for their insightful comments and valuable suggestions to improve our manuscript.

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