Melanie Vianna Alencar

Improving the Source-to-Sea approach for marine litter in Brazil

São Paulo

2022

Melanie Vianna Alencar

Improving the Source-to-Sea approach for marine litter in Brazil

Thesis submitted to the Oceanographic Institute of the University of São Paulo in partial fulfillment of the requirements for the degree of Master in Science, program of Oceanography, Biological Oceanography area.

Advisor: Prof. Dr. Alexander Turra

São Paulo

2022

ALENCAR, Melanie V. **Improving the Source-to-Sea approach for marine litter in Brazil.** Thesis submitted to the Oceanographic Institute of the University of São Paulo in partial fulfillment of the requirements for the degree of Master in Science, program of Oceanography, Biological Oceanography area.

(Corrected version)

Evaluated on ___/___/___.

Prof(a). Dr(a). ____________________________ Institution _____________________________

Verdict ___________________________________ Signature ______________________________

Prof(a). Dr(a). ____________________________ Institution _____________________________

Verdict ___________________________________ Signature ______________________________

Prof(a). Dr(a). ____________________________ Institution _____________________________

Verdict ___________________________________ Signature ______________________________

ACKNOWLEDGEMENT

I thank the São Paulo Research Foundation (FAPESP) for financing this research through a master's scholarship, under Process no. 2019/14093-7. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

I thank the Oceanographic Institute of the University of São Paulo for the opportunity to develop my master's degree at such a renowned institution.

I thank my mother, Vera Vianna, for her love and encouragement.

Likewise, I thank my advisor, Alexander Turra, for his guidance and enthusiasm. I also thank him for giving me the opportunity to meet and work with such lovely people.

Furthermore, I thank all my colleagues and friends at the University of São Paulo. I especially thank Marília Nagata, Thais Rech, Carla Eliff and Gabriel Iturry for their valuable suggestions in my work, and also for their complicity and support. I also thank my colleague Jonathan Monteiro for his support and friendship during the period of my master's degree. Moreover, I thank Bianca Gabani, Vitória Scrich, Sylmara Gonçalves-Dias, Tiago Cetrulo, Letícia Rodrigues and Camila Sasahara for their valuable cooperation to make this work come true.

ABSTRACT

ALENCAR, Melanie V. **Improving the Source-to-Sea approach for marine litter in Brazil.** Master's thesis – Oceanographic Institute of the University of São Paulo, São Paulo, 2021.

Combating marine litter pollution is a major challenge nowadays, and it is also one of the targets proposed by the Sustainable Development Goal 14. It is estimated that 8 million tons of plastic waste enter the ocean each year. And Brazil is the 16th leading contributor to this kind of pollution. This study draws a panorama of marine litter in Brazil under the Source-to-Sea approach, in four steps: (I) assessing the current research network, existing knowledge, and coupling between science and policy-relevant concerns; (II) analyzing solutions proposed by the literature on macrolitter in Brazil and evaluating their alignment with upstream approaches; (III) understanding the potentialities and limitations of subnational estimates of litter leakage to the environment; and (IV) identifying hotspots of leak-prone plastic waste (LPW) generation and leakage to the ocean. To map studies and research groups, we performed a systematic mapping of scientific articles on macrolitter in Brazil. To analyze solutions proposed by the literature, we compared solutions to the Waste Hierarchy, Sustainable Supply Chain Management, and Source-to-Sea approaches. To systematize parameters for modeling litter leakage to the environment, we performed a mapping of specialized literature and study of parameters, followed by data prospection for Brazilian municipalities and evaluation of data usability. To map hotspots of LPW generation and leakage to the ocean, we correlated sociodemographic data with solid waste and water network information; using data for all 5570 Brazilian municipalities and prioritizing data sources with better usability. The present study found 189 articles on marine litter in Brazil, of which 59 were focused on macrolitter. Macrolitter studies were mostly episodic and fragmented, and they adopted a variety of sampling collection and processing strategies. Moreover, studies were not well linked to policy-relevant concerns and the research network was not well-integrated. While most articles proposed solutions for marine litter (71.2%), few studies urged changes in the production chain and patterns of waste generation (10.2%), which are essential under the source-to-sea approach. Based on various links of the production-consumption-discard-pollution chain, we systematized solutions and proposed a Marine Litter Hierarchy. Furthermore, we identified 51 parameters that can be used to estimate litter leakage to the environment, including socio-economic, environmental, and sanitation information that well represents subnational particularities. For Brazil, only 29.4% of these parameters were linked to data sources with great or good usability, a fact that exposes the difficulties of performing estimates without access to good quality data. We also estimated that Brazil has potential to generate 3.44 million tons of LPW a year. We indicated the hotspots of greater potential LPW generation and leakage to the ocean, at the level of municipalities and watersheds, highlighting the Guanabara Bay, Patos Lagoon and Amazon, São Francisco and Tocantins rivers as main hotspots of litter entry into the ocean. Produced information provides a baseline for future studies, supports prevention and mitigation measures, and subsidizes plans for monitoring marine litter and managing solid waste, thus supporting the attainment of local, national, and international agendas to prevent and mitigate marine litter.

Keywords: Coastal management. Environmental contamination. Marine pollution. Solid waste. Social networks.

RESUMO

ALENCAR, Melanie V. **Improving the Source-to-Sea approach for marine litter in Brazil.** Dissertação (Mestrado) – Instituto Oceanográfico, Universidade de São Paulo, São Paulo, 2021.

O combate ao lixo no mar é um dos grandes desafios da atualidade e uma das metas propostas pelo Objetivo 14 do Desenvolvimento Sustentável. Estima-se que 8 milhões de toneladas de plásticos sejam introduzidas nos oceanos ao ano. E o Brasil é o 16º país que mais contribui com esse lançamento. Este estudo traça um panorama do lixo marinho no Brasil sob a abordagem *Source-to-Sea*, em quatro etapas: (I) avaliação da rede de pesquisa, do conhecimento existente e do acoplamento entre a ciência e preocupações políticas; (II) análise das soluções propostas pela literatura do macrolixo no mar, no Brazil, e avaliação do alinhamento dessas soluções com abordagens *upstream*; (III) compreensão das potencialidades e limitações de estimativas subnacionais de vazamento de lixo para o ambiente; e (IV) identificação dos pontos críticos com maior risco de geração e entrada de lixo plástico propenso ao escape (LPPE) para o oceano. Os estudos e grupos de pesquisa foram identificados por meio de um mapeamento sistemático de artigos científicos. Soluções para o lixo marinho propostas pelos artigos foram analisadas e comparadas com as abordagens *Source-to-Sea*, Hierarquia dos Resíduos e Gestão de Sustentabilidade na Cadeia de Suprimentos. Para sistematizar parâmetros do escape de lixo para o ambiente, a nível municipal, foi feita consulta à literatura especializada e análise dos parâmetros, seguida de prospecção de dados disponíveis para os municípios brasileiros e avaliação da usabilidade dos dados. A estimativa dos pontos críticos de geração de LPPE e entrada no oceano foi feita através da correlação de informações sociodemográficas com dados sobre resíduos sólidos e rede hídrica, usando dados para todos os 5570 municípios brasileiros e priorizando fontes de dados com melhor usabilidade. O presente estudo identificou 189 artigos sobre o lixo marinho no Brasil, dos quais 59 focaram em macrolixo e foram majoritariamente episódios e fragmentados, além de adotarem uma variedade de estratégias de coleta e processamento de amostras. Além disso, os estudos produzidos no Brasil não estavam alinhados a preocupações políticas, e a rede de pesquisa não esteve bem integrada. Enquanto a maioria dos artigos propôs soluções para o lixo presente no meio ambiente (71,2%), poucos estudos preconizam mudanças na cadeia de produção e nos padrões de geração de resíduos (10,2%), que são essenciais. Baseado nos diversos elos da cadeia deprodução-consumo-descarte-poluição, foi proposta uma Hierarquia do Lixo Marinho, com soluções sistematizadas. Além disso, identificamos 51 parâmetros que podem ser usados nas estimativas do escape de lixo para o ambiente, incluindo informações socioeconômicas, ambientais e de saneamento, que representam bem as particularidades subnacionais. No Brasil, apenas 29,4% desses parâmetros foram associados a fontes de dados com usabilidade ótima ou boa, fato que explicita as dificuldades em realizar estimativas sem acesso a dados de boa qualidade. O estudo também indicou que o Brasil gera um total de 3,44 milhões de toneladas (MT) de LPPE por ano. Os hotspots de maior geração de LPPE e potencial vazamento para o oceano também foram indicados, dos quais se destacam a Baía de Guanabara, a Lagoa dos Patos, e os rios Amazonas, São Francisco e Tocantins. As informações produzidas fornecem uma linha de base para futuros estudos, orientam medidas de prevenção e mitigação, e subsidiam planos de gestão de resíduos sólidos ou monitoramento do lixo no mar. Assim, este estudo apoia agendas locais, nacionais e internacionais para prevenir e mitigar o lixo no mar.

Palavras-chave: Gerenciamento costeiro. Contaminação ambiental. Poluição do mar. Resíduos sólidos. Redes sociais.

FIGURE INDEX

TABLE INDEX

SUMMARY

1. GENERAL INTRODUCTION

Marine pollution consists of the release of substances and energy into coastal and marine environments that cause harmful effects to biodiversity, human health, or anthropic activities supported by the oceans (Marine Strategy Framework Directive, 2008). Marine pollution is one of the drivers of changes in nature with the greatest global impact, encompassing political, socioeconomic, and environmental inter-complexities (Díaz et al., 2019; UNEP, 2016). Hence, one target of the Sustainable Development Goal 14.1 (SDG), proposed by the United Nations, is to “prevent and significantly reduce marine pollution of all kinds, particularly from land-based activities, including marine debris”. In addition, one of the expected results of the United Nations Decade of Ocean Science for the Sustainable Development, a clean ocean, was strongly motivated by the challenge to face marine litter.

Marine debris, commonly denominated marine litter, consists of anthropogenic solid waste discarded, disposed of, or abandoned in the marine and coastal environments (UNEP, 2016). Marine litter is mostly composed of plastic, which is widely used nowadays due to its low-cost and high durability and versatility (Andrady & Neal, 2009; Galgani et al., 2015). Plastic litter has been reported in all portions of the ocean, from the poles to the equator, and from the surface to the seabed (Wowk, 2013; Galgani et al., 2015). These residues have numerous ecological impacts (on individuals, populations, and habitats) (Gregory, 2009; Teuten et al., 2009). Furthermore, the presence of litter in marine environments also impacts economic sectors (tourism, navigation, fisheries, and aquaculture), as well as social sectors (human health and wellbeing, food security, cultural disruption, loss of income, and intrinsic value) (Gregory, 2009; UNEP, 2016; GESAMP et al., 2020).

Marine litter enters the ocean via ocean-based and land-based sources. While ocean-based sources are mainly represented by vessels and offshore plants, land-based sources are mostly related to the disposal of solid waste on beaches, soils, and rivers (Wowk, 2013; Galgani et al., 2015), besides poor waste management and low recyclability of materials. Because the terrestrial compartment is drained by rivers, litter produced on land easily flows to the oceanic compartment through urban drainage systems, effluent outflows, and inland waterways (Wowk, 2013; Jambeck et al., 2015). Thus, applying actions upstream supports contamination mitigation on the coasts and oceans (Siwi, 2018). Upstream actions include not only applying measures at the river courses, but also in all links of the production-consumption chain. However, fragmentation of studies and actions in river basins and coastal areas can be a challenge for the integrated managing of these compartments

(Siwi, 2018). Thus, establishing common objectives and applying integrated actions lead to holistically solving environmental issues such as marine pollution (Granit et al., 2017).

To combat marine litter efficiently, analysis, planning, and decision-making should be conducted under the Source-to-Sea approach (UNEP, 2017). This approach covers the sources, pathways, and sinks of solid waste in aquatic environments, as well as the dynamics of social, ecological, and economic systems (Granit et al., 2017). The Source-to-Sea approach not only covers the identification of land- or ocean-based sources of marine litter, but also the proper understanding of the problem, its intrinsic socio-economic causes, and proper solutions. In addition to promoting integrated coastal management, the Source-to-Sea approach is also aligned with the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA), proposed by the United Nations Environmental Programme (UNEP), which Brazil is a member of (Siwi, 2018). The Source-to-Sea approach also encompasses the Axis 3 of the National Plan to Combat Marine Litter (PNCLM), which proposes marine litter diagnostic research on the Brazilian coast (MMA, 2019).

The Brazilian coastline extends for about 8.000 km, and comprises a large interface of litter leakage to the ocean. Brazil comprises the ninth-largest economy and the sixth-biggest population in the world (The World Bank, 2020a, 2020b). The country is located in the Global South and highlights the reality of most developing economies: medium-high income and purchasing power, social inequality and inefficient waste management (Jambeck et al., 2015; The World Bank, 2019). As a consequence, Brazil is ranked as a leading contributor of plastic leakage to the ocean (Jambeck et al., 2015; Meijer et al., 2021). Aiming to fight this problem, Brazil has established a specific agenda to monitor and combat marine litter, and also contributes to multiple international forums and initiatives (PEMALM, 2021, MMA, 2019, Turra et al., 2020).

The present study aims to improve the Source-to-Sea approach for marine litter in Brazil, in four steps: (I) assessing scientific potentialities and limitations regarding the current research network, existing knowledge (e.g. methods, type and amount of litter, and temporal and spatial coverage) and coupling between science and policy-relevant concerns; (II) analyzing marine litter solutions proposed by the literature reporting marine macrolitter in Brazil and evaluating their alignment with the following upstream approaches: Waste Management Hierarchy, Sustainable Supply Chain Management, and Source-to-Sea; (III) understanding the potentialities and limitations of subnational estimates of litter leakage to the environment, and (IV) identifying hotspots of leak-prone plastic waste generation and leakage to the ocean. Each step comprises a goal of this thesis, and it is developed and presented in a chapter, totaling four chapters sequentially presented.

2. CHAPTER 1: Marine litter baseline information in Brazil is still behind to report on the Sustainable Development Goal 14

2.1. INTRODUCTION

Marine litter is a major pollution concern with multiple environmental, economic and social implications (UNEP, 2012, 2016; Øhlenschlæger et al., 2013; Galgani et al., 2019; MMA, 2019). Litter enters coastal and marine regions via land-based and ocean-based sources, and is mostly composed of plastics (Galgani et al., 2015; UNEP, 2016; GESAMP, 2019). After being introduced into the ocean, plastics can be fragmented into smaller pieces due to photo-oxidative, thermal, chemical, and biological degradation, originating microplastics (< 5 mm) (Arthur et al., 2009; Ivar do Sul et al., 2014; Barboza & Gimenez, 2015; Castro et al., 2018). Plastics have great persistence and spreading amplitude in the ocean (Andrady, 2015). This material can currently be found in different environmental compartments, such as water (surface and column) and sediment (coastline and seabed), and also in association with the biota (Hanke et al., 2013; Galgani et al., 2015; GESAMP, 2019).

The presence of anthropogenic litter in the environment represents numerous issues, including impacts on animal welfare (e.g. ingestion, asphyxiation, and entanglement) (Gregory, 2009, Kühn et al., 2015; Agamuthu et al., 2019) and biodiversity (e.g. dispersion of invasive exotic species and biomagnification of contaminants on food webs) (Kiessling et al., 2015; Rochman, 2015; Galgani 2019). It also affects food security (ingestion of microplastics and contaminants) and human health (exposure to toxic chemicals, diseases, and lesions caused by sharp objects) (Ivar do Sul, 2007; Rochman, 2015; GESAMP, 2019; Agamuthu et al., 2019). Besides ecological and social issues, economic sectors are also affected by litter pollution, which can also impact navigation (equipment damage, maritime safety), tourism (aesthetic losses), fishing, and aquaculture (Newman et al., 2015; UNEP, 2016; Galgani et al., 2019; Maximenko et al., 2019).

Preventing and mitigating marine litter are on the spot of the international agenda (Turra et al., 2020; Karasik et al., 2020). An important initiative is the Global Partnership on Marine Litter (GPML), which aims to connect stakeholders and globalize information on marine litter. This partnership is led by the United Nations Environment Programme (UNEP) as part of the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA). UNEP has custodianship and responsibility for global monitoring of some indicators of the United Nations 2030 Agenda for the Sustainable Development (UNEP, 2021), including the Sustainable Development Goal 14.1 (SDG), which targets to “prevent and significantly reduce marine pollution of all kinds, particularly from land-based activities, including marine debris”. This issue is well aligned to one of the expected results of the United Nations Decade on Ocean Science for the Sustainable Development (2021-2030), a clean ocean (IOC/UNESCO, 2020a).

However, evaluating SDG 14.1 is challenging. According to UNEP (2021), the proposed national indicators for SDG 14.1 are: beach litter count per km^2 of coastline (surveys and citizen science data); floating plastic debris density (visual observation, manta trawls); water column plastic density (demersal trawls), and seafloor litter density (benthic trawls, divers, video/camera tows, submersibles, remotely operated vehicles). These indicators are based on feasibility and relevance and refer to macrolitter (UNEP, 2021). Even though these SDG indicators have established methods and available standards (see GESAMP, 2019), data is not regularly produced by countries yet (UNEP, 2021). Since national and sub-national data are supposed to strengthen information provided by global leakage models and satellite images (see Maximenko et al., 2019, UNEP, 2021), lack of regular data production by the countries is a significant issue (UNEP, 2021). Moreover, irregular data production can also impact design and evaluation of local public policies and mitigation measures (Smith & Markic, 2013, UNEP, 2021). Furthermore, regular data production, and especially long-term monitoring, is important to identify temporal changes, smooth policy decision-making, and feed the global monitoring system (GESAMP, 2019; MMA, 2019; Hanke et al., 2013), such as the Global Partnership on Marine Litter (GPML) Digital Platform (https://www.gpmarinelitter.org; UNEP, 2021) and the Integrated Marine Debris Observing System (IMDOS; Maximenko et al., 2019). Hence, lack of regular and widespread long-term data production on marine litter is a concern that needs to be addressed, in order to properly report on SDG 14.1.

SDG 14.1 reporting can be compromised or enhanced by the local “scientific capital”. The scientific capital of a country refers to its monitoring and assessment capacity, which affects not only SDG 14 reporting, but also data production and sharing and the design and evaluation of policies and mitigation measures (UNEP, 2021; Ryan et al., 2009; GESAMP, 2019; Galgani et al., 2015). Local litter monitoring and assessment schemes can be compromised by numerous challenges, such as data fragmentation, resources limitation, and low capacity for monitoring programmes (UNEP, 2021). Furthermore, monitoring is also impacted by lack of harmonization in sampling and processing methods, which can compromise data comparisons (Smith & Markic, 2013; Hanke et al., 2013; Galgani et al., 2019; GESAMP, 2019). In summary, the capacity to inform SDG 14.1 relies on local existing knowledge of the problem, ability and capacity to produce appropriate and comparable information, the possibility of data sharing, and potentiality for using information to guide policy. Improvements in many of these aspects can be stimulated by integrating science and decision-making, which depends, at least in part, on the local scientific capital. Understanding the scientific capital and its capacity to inform SDG 14.1 relies on accessing the research network in place, existing knowledge (e.g. methods, type and amount of litter, temporal and spatial coverage), and coupling between science and policy-driven questions, or policy-relevant concerns. Such information, especially in countries that are important international players in the agenda of marine litter, may shed light into pathways to understand and combat marine litter worldwide.

Brazil comprises one out of the top 10 largest economies and populations in the world (The World Bank, 2020a, 2020b). Brazil is a developing country, broadly characterized by fast economic growth, medium-high income, high social inequality, and inefficient sanitation and waste management system (The World Bank, 2019; IBGE, 2010, 2017; Alfaia et al., 2017; SNIS, 2019). Brazil shares these characteristics with many other least-developing and developing countries of the Global South (*sensu* Brandt, 1980). Regarding solid waste generation, Brazil (1.04 kg/person/day) is above the world average (0.96 kg/person/day) (World Bank, 2012). As a consequence, Brazil is estimated as the main source of land-based marine litter to the South Atlantic (Jambeck et al., 2015). On the other hand, Brazil is historically avant-garde in environmental issues. The country stands out in ocean science production (IOC/UNESCO, 2020b) and it is active in multiple international forums and initiatives, such as the United Nations Environment Assembly (UNEA) and the Decade of Ocean Science for Sustainable Development. Moreover, Brazil also has a distinguished agenda to combat marine litter at a national and sub-national level, synthesized by the National Plan to Combat Marine Litter (PNCLM) (MMA, 2019), and the São Paulo Strategic Plan for Monitoring and Assessment of Marine Litter (PEMALM, 2021). Besides its socioeconomic, environmental and scientific importance on a regional and global scale, the potential of Brazil to generate information on marine litter and feed the global monitoring system and the indicators of SDG 14.1 still need to be assessed.

Previous reviews on marine litter in Brazil covered research aspects and results of published studies (Ivar do Sul & Costa, 2007; Castro et al., 2018; Videla & Araújo, 2021). Ivar do Sul & Costa (2007) carried out a literature review on marine litter in Latin America and the Caribbean, systematizing existing information on environmental conditions and research lines. Castro et al. (2018) performed a review of studies on the presence of microplastic in the environment, in Brazil, identifying study compartments and characteristics of publications. Similarly, Videla & Araújo (2021) developed a review focused on macrolitter studies, to understand what information is available for different compartments. However, the growing visibility and urgency of this issue, at the national and global levels, demand an investigation to assess if scientific capital and existing knowledge are appropriate to face the challenges of addressing marine litter and guiding technical-scientific-policy development.

Considering the importance of Brazil in the international and regional panorama and the importance of accessing the existing scientific knowledge on marine litter, we conducted a broad assessment of the literature reporting marine litter in Brazil. We used this as a proxy to assess if the scientific capital and existing knowledge are appropriate to feed the indicator system of the Sustainable Development Goal 14.1, and also, as evidence of the scientific challenges that need to be overcome to face marine litter at the national and sub-national levels.

Thus, the present study aims to do a strategic and systematic assessment of marine litter scientific potentialities and limitations regarding the (1) current research network, (2) the existing knowledge (e.g. methods, type and amount of litter, and temporal and spatial coverage), and (3) coupling between science and policy-relevant concerns (connection made by researchers among their studies or marine litter issues and policy concerns). We hypothesized that research groups are not integrated with each other, studies are episodic and fragmented, methods are widely different, and studies are not well-coupled with policy concerns, features that may prevent Brazil from supporting SDG 14.1 indicators.

We circumscribed our analysis on studies of macrolitter. Macrolitter is defined by GESAMP (2019) as items larger than 2.5 cm, however, the minimum size of collected materials varies according to studies. Macrolitter monitoring is being recommended as a strategic starting point of national monitoring schemes since it is relatively faster, simpler and cheaper to survey and analyze, with well-established protocols (GESAMP, 2019; UNEP, 2021), especially on sandy beaches, in comparison to microlitter. Consequently, it is reasonable to expect that data on macrolitter in environmental compartments (shoreline, water surface and column, and seafloor) would have a broader geographical and temporal coverage in the scientific literature in comparison to microlitter, especially in countries with resources limitations. For this reason, macrolitter would have a greater potential to inform SDG 14.1. Moreover, there are significant differences in the methods employed, compartments analyzed (environment vs. biota), and the way the results are presented in relation to smaller items, which could divert readers from the main objective of the present paper. Finally, there are several policy concerns associated with larger plastic items (UNEP, 2021; GESAMP, 2019), which would allow a broader analysis of the adherence of marine litter indicators to policy-relevant issues.

2.2. MATERIAL AND METHODS

2.2.1. Systematic mapping of the literature reporting marine litter in Brazil

A systematic literature mapping (James et al. 2016) was conducted in order to gather scientific articles reporting marine litter in Brazil. The research was performed on Scopus and Web of Science platforms, using the following research strategy: ("marine litter" OR "marine debris" OR "plastic litter" OR "plastic debris" OR "plastic pollution" OR "lixo marinho" OR "lixo plástico" OR "poluição plástica") AND (Brasil OR Brazil). This search was performed on articles title, abstract, and keywords. The list of articles by researchers of Portuguese-speaking countries available in the Global Garbage database (http://www.globalgarbage.org) was also examined; only studies focusing on the Brazilian coast were selected. References cited in previous reviews on microplastics (Castro et al., 2018), fishing gear (Link et al., 2019) and marine litter (Ivar do Sul et al., 2007) in Brazil were also verified.

Articles published up to late 2019 were pre-selected. All peer-reviewed articles on marine litter in Brazil were considered, with the exception of papers presenting only general information on litter pollution (no data) or beach clean-ups. One paper could not be accessed, despite meeting the selection criteria and being cited in the relevant literature (Azevedo & Schiller, 1991 apud Ivar do Sul & Costa, 2007). All titles and abstracts were read in order to select only articles on marine litter in Brazil. References of each of these articles were used to identify other articles of interest using the snowball approach (Wohlin, 2014). The papers were then classified in the following categories: (a) macrolitter in the environment, (b) microlitter in the environment, (c) association of litter with biota, (d) experiments on interaction with biota, (e) litter interaction with contaminants, (f) beach users perception and other socioeconomic focuses, (g) reviews, and (h) other. These categories allowed the drawing of the research panorama in Brazil regarding the most and less studied topics, and the identification of studies focused on macrolitter in the environment, which were further analyzed.

2.2.2. Research network on marine macrolitter in Brazil

The 59 articles on marine macrolitter in the environment in Brazil were used to gather bibliometric data, which was used to systematize the current research network and analyze its integration. Bibliometric data were extracted in Research Information Systems (RIS) format, using the Mendeley software. RIS files were then imported to the VOSViewer software, in order to create maps and analyze the research network. In the maps created with VOSViewer, items (researchers) are represented by circles. The size of the circle and its label vary according to the item's weight (importance in the network). A link between a pair of items (co-authorship) is represented by a line. The thickness of this line varies according to the number of co-authorships between two authors. The total link strength increases according to the number of co-authorships between one author and multiple other authors, representing the integration of the network. Furthermore, items were grouped into clusters, according to the number of links and link strength among them; where clusters are represented by different colors (van Eck & Waltman, 2017).

In order to better understand the interactions within the macrolitter research network, we also analyzed the institutional network of articles. First, we registered institutions involved in each publication, then we analyzed the network collaboration. We evaluated national and international collaborations, and classified the research groups as independent (developed by a single group in a Brazilian university) or collaborative (involving integration among research groups, even in the same university) (Castro et al., 2018; Barboza & Gimenez, 2015). Collaborative research was further classified regarding the type of collaboration: (a) with other Brazilian universities, (b) with national government departments, (c) with international government departments, (d) with non-governmental organizations, (e) with foreign universities, (f) collaboration between departments from the same university, and (g) collaboration between laboratories from the same department.

Considering that the research network associated with scientific papers on macrolitter in the environment might be not enough to contribute to the challenge to feed the SDG 14.1 indicator system (given the low integration among research groups and with societal stakeholders; see results below), we widened the scope of network analysis to the set of scientific papers on marine litter in Brazil (n=189) and to the researchers that declare marine litter as their research subject in the Brazilian official curricula system (Lattes curriculum; https://lattes.cnpq.br/). Although there is some overlap in these databases, we hypothesized the "scientific capital" and the potential of science to contribute to local marine litter monitoring and assessment processes, driven by local governments, NGOs, or even researchers, could be widened when considering additional sources of information other than the researchers that have already published on macrolitter in the environment. The assumption behind this approach is that these "additional" researchers would be used to the issue of marine litter and would be able to contribute in different ways to the setting and evaluation of local generation of SDG indicators.

In this way, we first analyzed the research network, using the same strategy already done for studies published with macrolitter in the environment, but considering all the 189 scientific papers published on marine litter in Brazil. Then we compared the parameters of the network analysis (number of links and total link strength) to illustrate how the macrolitter network may benefit from the "marine litter" network in the context of the SDG indicator system.

We then mapped the scientists that work or have worked with marine litter in Brazil, based on the Lattes platform. Information available on this platform refers to data provided by the authors themselves. The search was conducted in May 2019, using the following keywords (in Portuguese and English): "lixo marinho", "marine litter", "marine debris", "pellets plásticos", "plastic pellets", "resíduos sólidos antropogênicos", "lixo plástico", "plastic litter", "plastic debris", "poluição plástica", and "plastic pollution". Only PhD researchers who currently work or have worked with marine litter in the country were identified, as well as their institutions and geographic location (states and regions).

This search focused on scientists who fit one or more of the following criteria: (I) mentioned at least one of the keywords in their research topics, expertise areas or in the summary of their curricula; (II) published at least one article as either first or last author; (III) coordinate or has coordinated at least one project on marine litter; or (IV) has several supervisions, participation in projects, publications as co-authors and/or congress presentations in the field. Exclusion criteria were related to researchers who: (I) only participated in academic committees; (II) did not fulfill any other inclusion criteria and had only one publication as co-author; and (III) only developed research with urban solid waste.

The following scientists' information was collected: name, expertise area, current institution, projects developed, and type of project (scientific research or public outreach).

Based on Menk (2018) and also on the codification of information recorded in the curricula, marine litter expertise was categorized as: (I) occurrence, abundance and/or distribution of marine litter; (II) monitoring; (III) interaction with biota; (IV) microplastics in biological and environmental samples; (V) interaction with contaminants; (VI) health, social, economic and environmental impacts; (VII) people's perception on marine litter; (VIII) environmental education; (IX) citizen science; (X) marine litter didactic-scientific collection; (XI) beach cleaning efficiency; (XII) public policies; (XIII) solid waste management and reversed logistics; and (XIV) alternatives to plastics. Then, we evaluated scientists' potential to participate in monitoring and assessment programs and contribute to feed the SDG 14.1 indicator system, considering expertise areas I, II and IV.

2.2.3. Existing knowledge on marine macrolitter in Brazil

Articles previously gathered by the systematic mapping were also used for an exhaustive analysis. We completely read and analyzed articles on macrolitter in the environment, and organized them according to their chronological order. We also extracted information on (1) spatio-environmental representation (sampling locations, spatial scale, compartments, environments, and spatial scale), (2) methods (type of litter, litter size range, type of study, sampling protocols, study duration, quantity of items analyzed, litter classification protocols and reporting unit), and (3) main results (e.g. abundance, plastic percentage, and potential sources).

2.2.3.1. Spatio-environmental representation of the studies on marine macrolitter in Brazil

For each article concerning macrolitter, we recorded sampling location (beach, municipality, state, and Brazilian region) and spatial scale (e.g. single beach, beaches within a municipality, beaches within a state, beaches spanning different coastal states). Moreover, we registered the compartment (shoreline, seafloor, water surface, water column; sensu GESAMP, 2019) and, within coastline, the environment (habitat) where sampling was carried out (e.g. beach, river, estuary, coral reef, seabed). We represented this information on a map produced on Qgis.

2.2.3.2. Methods used in the study of marine macrolitter in Brazil

We examined the sampling, processing and reporting strategies used by the studies to assess how variable are the methods to analyze marine macrolitter in the environment.

Decisions on these issues directly reflect the aim of the study and may influence the way the information gathered may be further used to support decision-making.

The following sampling methodological features were registered: type of litter (e.g. all kinds of litter, plastics, fishing debris), litter size range, and type of study (visual analysis or litter collection) (Galgani, 2015; Galgani et al., 2015b; Hidalgo-Ruz, 2012; Li, 2016). Moreover, we also registered the sampling unit (i.e. size and format of transects), area (backshore, foreshore, nearshore, dune/vegetation, strandline, estuary sectors etc.), study duration (time frame from the first to the last data collection), and number of items analyzed.

Sample processing methods (litter classification) were also recorded, as well as their adherence to pre-established protocols. Litter classification methods by the studies were also compared to GESAMP (2019) guidelines, since it comprises an internationally agreed standard for monitoring marine litter, and because this guideline is consistent with SDG 14 national indicators (UNEP, 2021). Thus, we compared studies processing protocols to the following categories proposed by GESAMP (2019) for physical characterization of marine litter: type of material (e.g. plastic, glass, metal), type of items (e.g. bottle, film, rope, net, bag), litter usage/source, flexibility, size, color, and weight. Furthermore, we checked if studies made chemical and biological characterization, as proposed by GESAMP (2019), and registered studies focus (indicate quantity and/or quality of litter in the environment, accounting litter input by beach users, or indicating the efficiency of beach cleaning services). Even more, we registered the units of measurement used for reporting data.

2.2.3.3. Results of the studies on marine macrolitter in Brazil

The main results of the studies on marine macrolitter in Brazil were recorded, including: litter abundance, plastic percentage (including cigarette butts, foam, styrofoam, and nylon; when data was available), and litter sources (e.g. beach users, river runoff, fisheries, navigation) (Derraik, 2002; Galgani, 2015; Hidalgo-Ruz 2012; Ivar do Sul 2007; Castro 2018; Li, 2016). In order to facilitate comparisons, we standardized data to items per linear, square, or cubic meter. All values that were standardized from raw data provided by the articles are accompanied by an asterisk (*) along the text and tables of this article. We did not consider data that were presented by studies only in graph format, without clear numerical data. Data expressed in total number of items without informing sampling area dimensions were also disconsidered.

2.2.4. Adherence of the literature reporting marine litter in Brazil to the policy agenda

We also evaluated the adherence of studies to policy-relevant concerns (*sensu* GESAMP, 2019; distribution and abundance; source identification; impacts on: tourism, seafood safety, human health and injuries, navigation hazards, animal welfare, biodiversity, and fisheries). Links to concerns were captured by the mention of these concerns along the papers, which usually happens when describing paper goals, explaining the importance of the study, exploring the potential of the paper, describing the impacts of marine litter, or proposing solutions for marine litter. Thus, we were able to identify if researchers have been relating their works and the potential impacts of marine litter to policy-relevant concerns.

2.3. RESULTS AND DISCUSSION

2.3.1. Systematic mapping of the literature reporting marine litter in Brazil

The searches resulted in 189 studies on marine litter in Brazil. The first paper was published in the early 1970s and focused on the presence of plastic pellets on the country's southernmost beaches (Gomes, 1973; Ryan, 2015). In the 1970s, international literature was emerging, right after recognizing plastic occurrence in the environment (Thompson et al., 2004). However, in Brazil, subsequent papers on marine litter were only published more than twenty years later, regarding litter ingestion by marine animals (Secchi & Zarzur, 1999; Bugoni et al., 2001). Since 2000's, the number of articles bloomed, and different categories showed up (Table 1). However, to date, studies on marine litter in Brazil focused mainly on litter association with biota (n=78; e.g. ingestion and entanglement) and on the presence of macro (n=59) and microlitter (n=27) in the environment.

Table 1. Number (N) of scientific papers on marine litter in Brazil published up to 2019 (189), separated into categories. Four articles were included in two different categories.

Categories	N
Association of litter with biota	78
Macrolitter in the environment	59
Microlitter in the environment	27
Beach users perception and other socioeconomic focuses	8
Experiments on interaction with biota	7
Interaction with contaminants	7
Reviews	3
Other survey axes	4

The category comprising other survey axes included an inquiry on the ideal transect width for monitoring source-related categories of plastics on beaches (Araújo et al., 2006), an evaluation of the effectiveness of beach ashtrays in preventing marine contamination (Widmer & Reis, 2010), an experiment on plastic debris retention and exportation by a mangrove (Ivar do Sul, 2014), and a fishing net float design for reducing its loss (Chaves & Silveira, 2016). Some papers encompassed two categories (Lima et al., 2015, 2016; Sampaio et al., 2015; Marin et al., 2019) and were counted twice. The three existing reviews that were published were considered a segregated category, even though they targeted microplastics (Castro et al., 2018), fishing gear (Link et al., 2019) and marine litter in general (Ivar do Sul et al., 2007).

Regarding macrolitter in the environment, the first short and medium-term monitoring studies were published in the early 2000s (Figueiredo Jr. et al., 2001; Araújo & Costa, 2004a; 2004b; Wetzel, 2004; Santos et al., 2004). Since then, numerous articles on the presence of macrolitter in the environment have been shared. These studies were mainly published over the past decade (2010-2019; 72.9%), with a peak in 2011, accompanying the boost also observed in international literature (Ryan, 2015). The cumulative number of macrolitter studies was greater than for microlitter studies, considering the same period (Fig. 1).

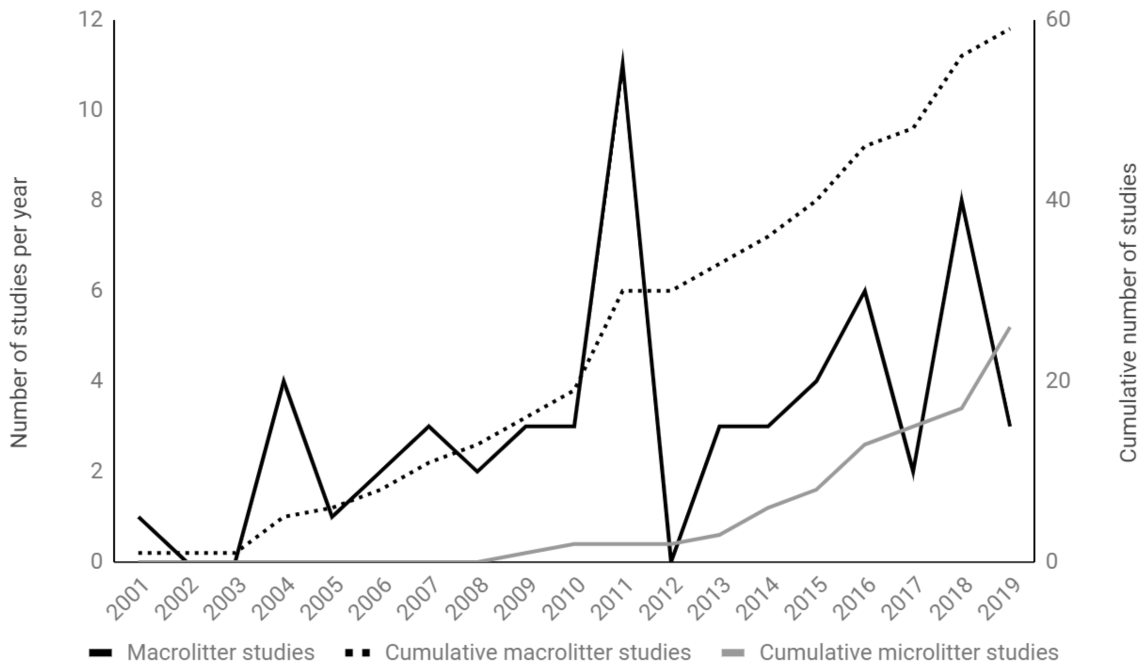


Fig. 1. Chronology of scientific publications on marine macrolitter in environmental compartments (shoreline, water surface or column, and shallow seafloor) in Brazil (from 2001 to 2019). Left axis: number of studies on macrocrolitter published in the respective year. Right axis: number of cumulative studies on macrolliter in Brazil.

2.3.2. Research network on marine macrolitter in Brazil

From the analysis of the research network on macrolitter in the environment, 153 researchers were identified as authors and co-authors of 59 articles. Researchers were part of 28 clusters, totaling 1381 links, with total link strength of 1615 (Fig. 2A). Only 22 researchers were involved in more than one publication, and 15 researchers were involved in three or more publications. The largest set of connected researchers was 36 (23.5%), through 6 clusters, forming 89 links with a total link strength of 112 (Fig. 2B). The main researchers identified were computed according to the number of publications (number of papers > 5), number of links, and total link strength: Mônica Costa (13 papers; 13 links; total link strength: 26), Maria Cristina Araújo (11 papers; 7 links; total link strength: 11), Jacqueline-Silva Cavalcanti (6 papers, 8 links; total link strength: 15), and Gilberto Fillmann (5 papers, 11 links; link strength: 13). The link was strongest among: Costa and Araújo (9), Costa and Silva-Cavalcanti (5), and Araújo and Silva-Cavalcanti (4).

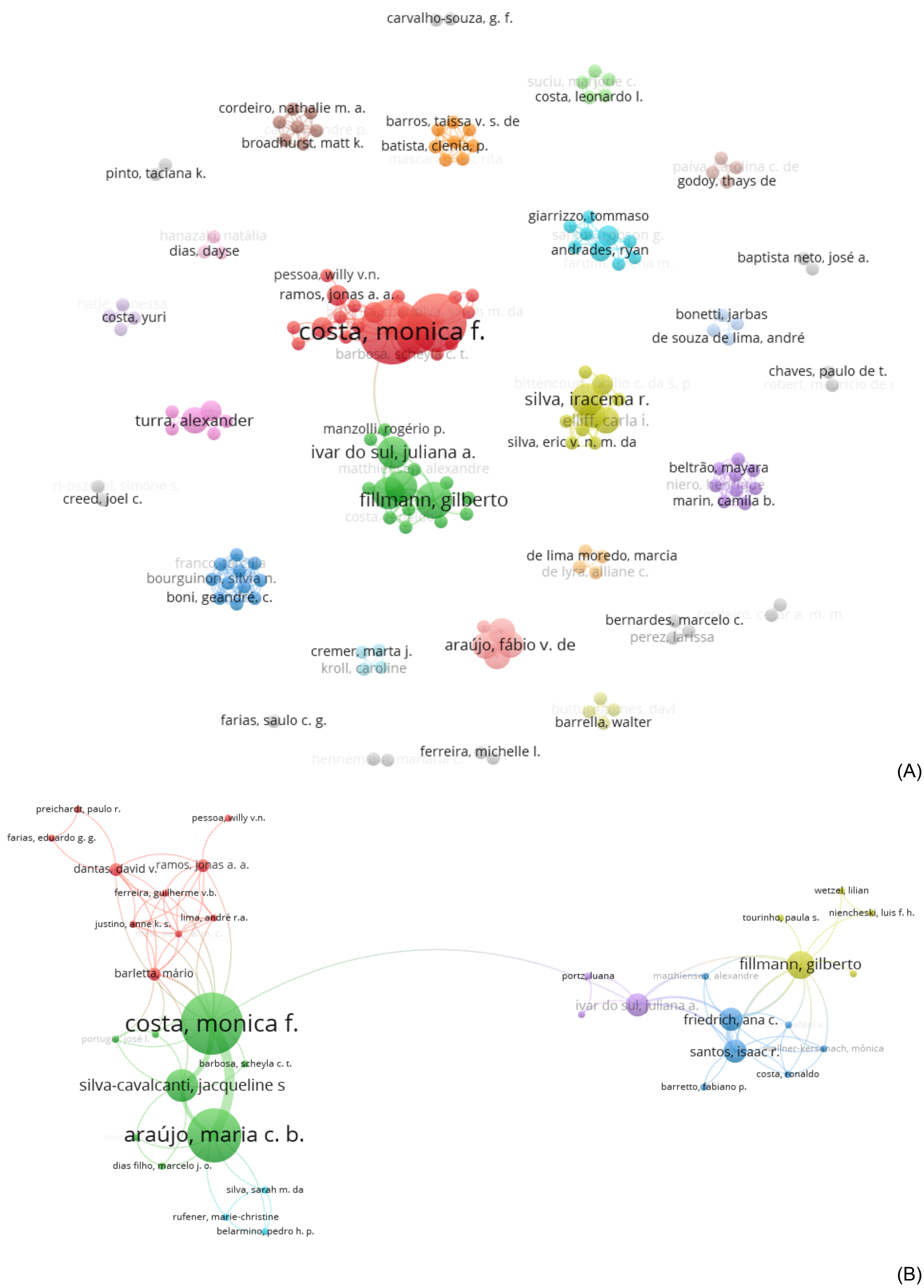


Fig. 2. (A) Research network on macrolitter in the environment in Brazil based on 59 articles (153 authors, 28 clusters, 1381 links; total link strength: 1615). The biggest clusters consisted of 21 (red) and 15 authors (green). (B) Zoom in the connected research network (36 authors, 6 clusters, 89 links, total link strength: 112). Label/circle

size is relative to the number of documents, the line width is relative to link strength among authors, and colors represent the different clusters.

The analysis of institutional collaborative networks showed that most studies were developed by independent groups (n=25), or involved collaboration between two or more Brazilian universities (n=14) (Fig. 3). Collaboration with foreign universities was incipient (n=5). We detected only a few collaborations among laboratories and departments from the same university, but such initiatives (including the collaboration between two or more Brazilian universities) may represent an initial effort in producing multi and interdisciplinary studies. On the other hand, the very low integration with government (national or foreign) and NGOs, although a common situation within the scientific literature, may represent the absence of dialogue between science and society/decision-makers. Such a dialogue is relevant in the context of the national indicators of marine litter of the SDG 14.1, since local governments and NGOs (and even the private sector) are important partners in the generation of information to support policymaking (see PEMALM, 2021). Lack of integration among research groups turns research networks powerless, since partnerships are essential to promote integrated science and knowledge sharing and construction (Castro et al., 2018; MMA, 2019), a core issue to feed the SDG 14.1 indicator system.

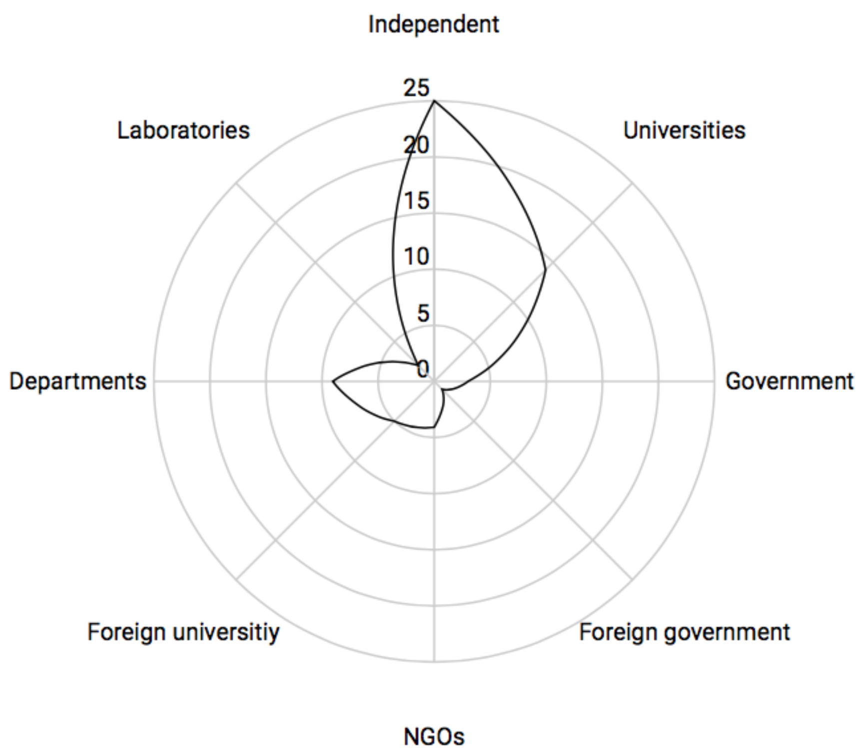


Fig. 3. Number of papers in collaboration among institutions in the published research on macrolitter in the environment in Brazil. Studies were classified as independent (a single group in a Brazilian university) or collaborative, when involving collaboration with: (a) other Brazilian universities (Universities), (b) a national government department (Government), (c) an international government department (Foreign government), (d) non-governmental organizations (NGOs), (e) a foreign university (Foreign university); and collaboration between: (f) departments from the same university (Departments) and (g) laboratories from the same department (Laboratories).

The results above revealed that the research groups working with marine macrolitter in the environment in Brazil are relatively limited in number and are not well integrated with each other. Even though a considerable number of researchers were identified as authors and co-authors of the papers, these scientists are placed in segregated clusters. A high fragmentation rate was observed on the macrolitter network, with few leading researchers responsible for most publications and a low number of links and total link strength. Moreover, fragmentation was also observed when analyzing collaboration among institutions. Monitoring and assessing marine litter in a continental-size country would be facilitated and improved by promoting collaboration among researchers and institutions.

In order to assess the growth potential of this network, we complemented our analysis by evaluating the research network of all 189 marine litter articles identified. Although still fragmented, this network had more players and higher integration (higher number of links and values of total link strength) than in the macrolitter network. We identified a higher number of researchers as authors or co-authors (n=481) and clusters (62) (Fig. 4A), which returned a higher number of links (n=1381) and a higher total link strength (1615). 94 researchers were involved in more than one publication, and 55 researchers published three or more papers. Integration was detected only among 162 researchers (33.7%), who were connected through 11 clusters, forming 589 links with a total link strength of 681 (Fig. 4B). The main researchers identified were: Mônica Costa (31 papers, 24 links; total link strength: 75), Alexander Turra (17 papers, 47 links; total link strength: 75), Maria Cristina Araújo (16 papers, 14 links; total link strength: 35), Juliana Ivar do Sul (14 papers, 24 links; total link strength: 41), Mário Barletta (15 papers, 17 links; total link strength: 47) and Jacqueline Silva-Cavalcanti (10 papers, 14 links; total link strength: 30). Strongest links were identified between Costa and Araújo (12), Costa and Barletta (12), Costa and Ivar do sul (9), Costa and Silva-Cavalcanti (7), and Turra and Fabiana Moreira (6).

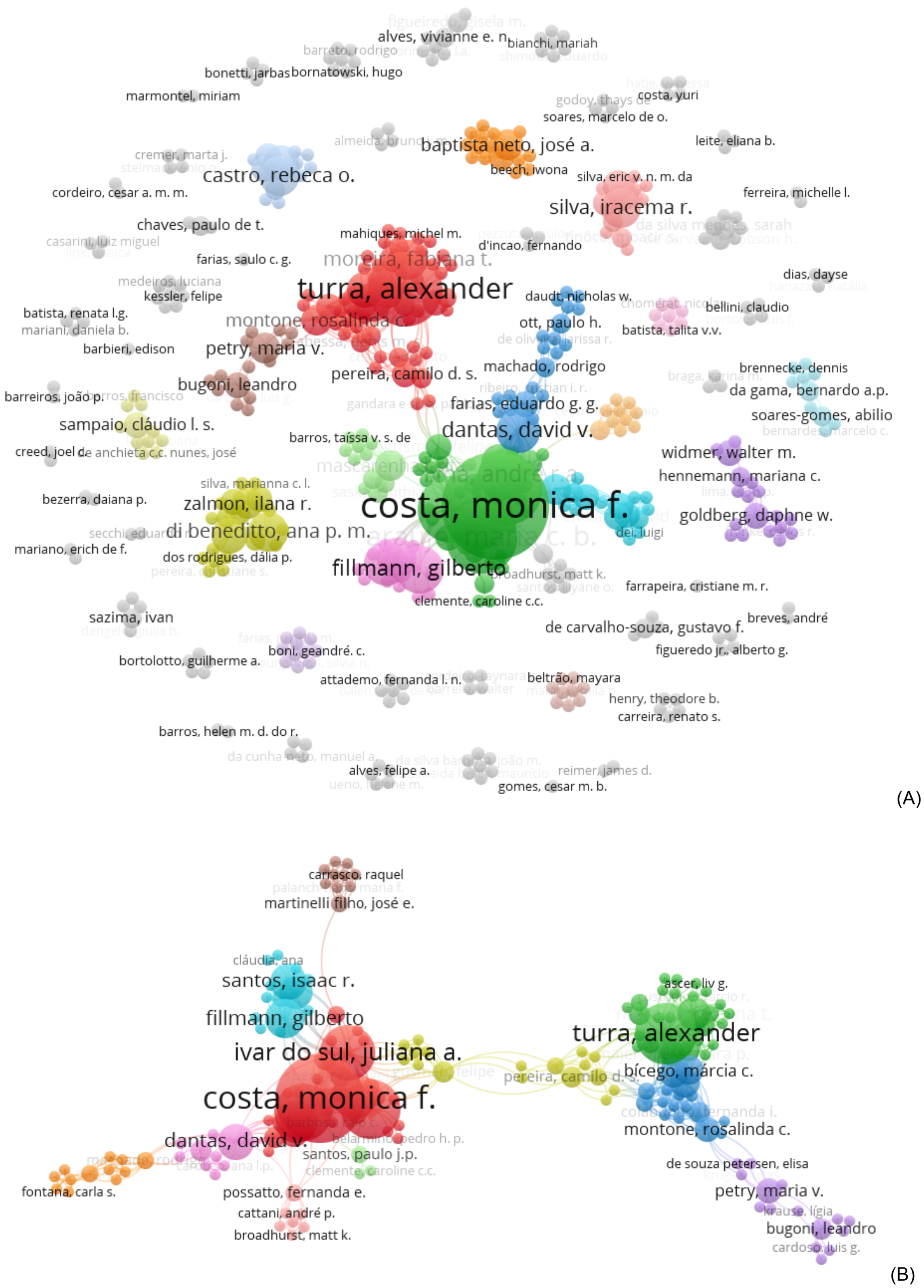


Fig. 4. (A) Research network on marine litter in Brazil based on 189 articles (481 authors, 62 clusters, 1381 links; total link strength: 1615). The biggest clusters consisted of 31 (red) and 27 authors (green). (B) Zoom in the connected research network (162 authors, 11 clusters, 589 links; total link strength: 681). Label/circle size is

relative to the number of documents, the line width is relative to link strength among authors, and colors represent the different clusters.

The complementary analysis to improve the Brazilian potential to inform SDG 14.1 national indicators based on the Lattes platform resulted in 271 Brazilian and 17 foreigners who have PhD and work or have worked with marine litter in Brazil. However, only 126 Brazilians and seven foreigners were selected according to the inclusion criteria. This total of 133 PhD researchers revealed highly qualified personnel in a large diversity of expertise areas, especially in the north and northeastern Brazilian regions (Supplementary Material A). Among the expertise areas, 66.2% (n=88) of the researchers were classified as working on occurrence, abundance and/or distribution of marine litter, monitoring and/or microplastics in biological and environmental samples, which are all directly correlated to the implementation of monitoring and assessment programs on marine litter.

This search strategy largely expanded the possibility to identify potential researchers and institutions to contribute to monitoring and assessment of marine litter in Brazil. The database we produced (Supplementary Material A) can be used to easily identify people and research centers in the whole country, promoting the identification of potential partnerships among scientists and collaboration with decision-makers. This effort led to the creation in 2021 of a network of scientists to promote integration among research groups, towards harmonizing methodologies, integrating efforts, promoting training and scientific events, etc. In addition to promoting the integration of scientists and research strategies, the network also intends to form a recognized body of experts for the articulation of scientists in governmental spheres. This network is being built collaboratively and horizontally, and intends to be continually adapted and expanded by articulating with other international networks. As the marine litter items get together in patches in oceanic gyres and due to different oceanographic processes, we considered the Brazilian scientific community could also get together driven by the circumstances and demands of the marine litter issue. Thus, we named the network as the Brazilian Marine Litter Science Patch.

2.3.3. Existing knowledge on marine macrolitter in Brazil

2.3.3.1. Spatio-environmental representation of the studies on marine macrolitter in Brazil

Scientific research on macrolitter in Brazil was conducted in twelve Brazilian states, mainly in Pernambuco (PE, n=14), Rio de Janeiro (RJ, n=9), Bahia (BA, n=8), Santa Catarina (SC, n=8) and São Paulo (SP, n=5). Only two studies covered spots located in more than one state (Paraná (PR) and Santa Catarina (SC), Chaves & Robert, 2009; Alagoas (AL) and Sergipe (SE), Sampaio & Pinto, 2015). The Northeast (n=27), Southeast (n=17) and Southern (n=15) regions of Brazil were covered by the scientific literature (Fig. 5). No studies investigated the Northern region, despite its wide coast and array of ecosystems. In general, researched areas comprised only one beach (n=23) (local scale), but studies investigated up to 25 beaches (regional scale) (Marin et al., 2019). The most studied sites were: Boa Viagem Beach (n=4), Tamandaré Beach (n=4) and Cassino Beach (n=3), Goiana Estuary (n=3), Paranaguá Estuary (n=2) and Guanabara Bay (n=2).

Regarding study compartments, the vast majority of the studies surveyed litter deposited on the substrate, while only a few investigated the water surface or column (n=4) (Sampaio & Pinto, 2015; Fernandino et al., 2016; Lima et al., 2016; Ramos & Pessoa, 2019). Our review of the literature did not return studies on marine litter in the seafloor in deeper areas (>15 m). Regarding environments, studies were concentrated in the shoreline with domination of sandy beaches (n=45) over estuaries (n=7), mangroves (n=4), and shallow seafloor composed of rocky and coral reefs and soft bottoms (up to 15 meters; n=4) (see Supplementary Material B). Some studies investigated more than one kind of environment, such as beach and rocky reef (Oigman-Pszczol & Creed, 2007), beach and estuary (Krelling et al., 2017; Krelling & Turra, 2019), and rocky shore and sea bottom (Machado & Fillmann, 2010).

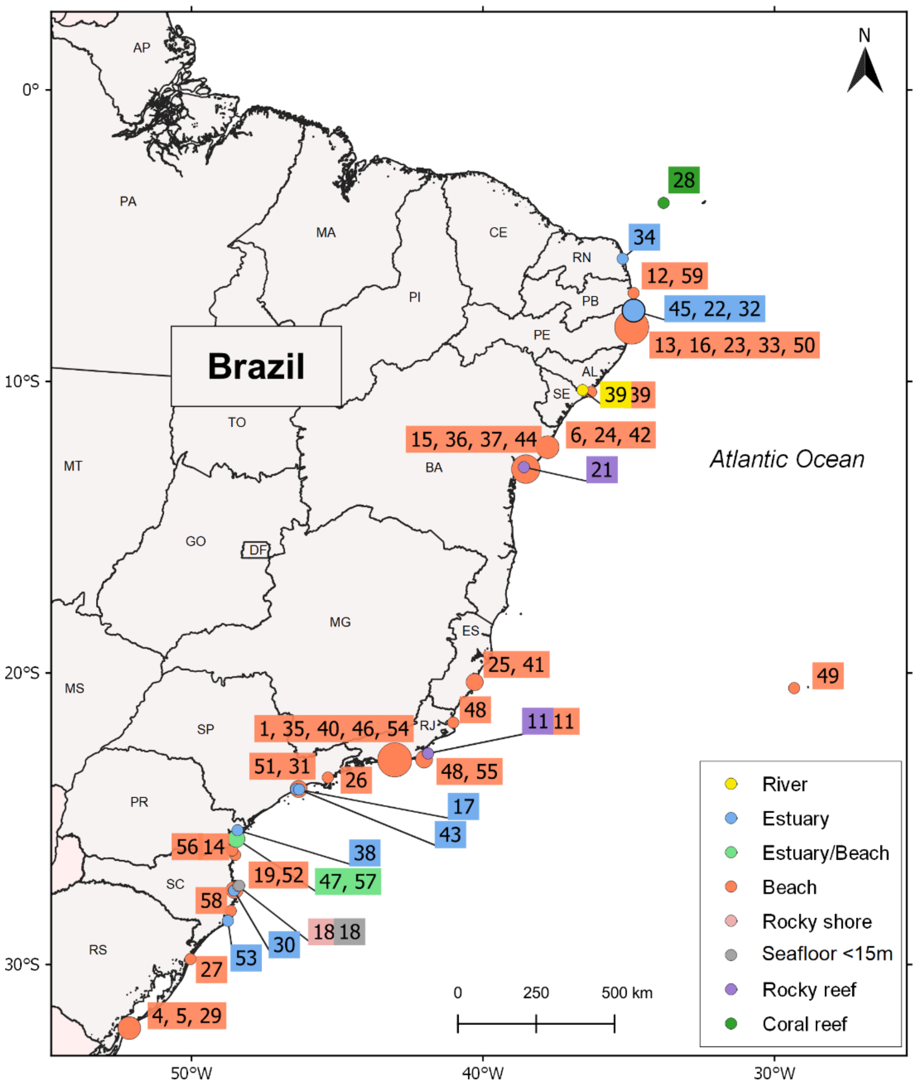


Fig. 5. Study location of articles on marine macrolitter in Brazil. Colors represent different environments where sampling was performed; numbers correspond to articles identification, which was established based on their chronological order. Complete data on methods, density and composition of marine litter for each location can be found in Supplementary Material B.

2.3.3.2. Methods used in the study of marine macrolitter in Brazil

Studies presented different sampling, processing and reporting strategies (Supplementary Material B), which involved several aspects related to the scope of the studies and, indeed, their potential to support policies.

2.3.3.2.1. Sampling methods

Regarding sampling strategies, the variation in the types of litter investigated is an important source of noise in the attempts to analyze the existing information on marine litter. Most studies investigated all kinds of marine litter they found (81.4%). Two studies also included tarballs (Ivar do Sul et al., 2011; Krelling & Turra, 2019) and 30.5% clearly included organic matter. Even though marine litter consists of man-made or processed materials (UNEP, 2016), organic matter such as coconut shells and leftover food were occasionally included in investigations. The inclusion of different types of litter, but especially organic matter, may artificially reduce the representativeness of targeted items, such as plastics, besides compromising the comparability of results among studies. On the other hand, most articles focused on a qualitative analysis of plastics items (comparison of number of items irrespective of the total abundance recorded), and only 8.5% had plastics as the only studied object. Other than that, some studies also focused on fishing debris (Chaves & Robert, 2009), international litter (Santos et al., 2005), flag items (Silva et al., 2008) and freshly inputted litter (Krelling et al., 2017), which is extremely important to understand different aspects of marine litter, such as types of items and abundance. According to GESAMP (2019), studies focused on specific items are also very useful to address the effectiveness of policies. However, such an approach may be useless in the context of the national indicators of SDG 14.1.

Definition of the litter size to be recorded is an important aspect to be taken into account when setting monitoring and assessment programs of marine litter, since it is directly related to the sampling, processing and reporting methods and to the policies under concern (see GESAMP, 2019). Besides this relevance, almost half of the studies (47.5%; n=28) did not specify the size of investigated litter. Among those studies that specified the minimum size limit of the sampled items, there was a large variation, from 1 mm to 5 cm (Supplementary material C). One study mentioned it investigated "all sizes of litter" (> 0 cm). Some studies not only investigated macrolitter, but also the microlitter present in the environment (Costa et al., 2011; Lima et al., 2015; Lima et al., 2016; Marin et al., 2019). The inclusion of smaller items within samples of macrolitter is a relevant source of bias in the estimates of marine litter. Since the smaller the size of items, the larger their abundance (see Erikssen et al., 2014), smaller items may lead to an overestimate of the abundance of items. To overcome this situation, GESAMP (2019) recommended harmonizing the size of items sampled or, when sampling different sizes, report the abundance separately for each of the size classes agreed on this report (e.g. microplastics - <5 mm; mesoplastics - >5 mm < 2.5

cm; macroplastics - >2.5 cm). The national indicators of SDG 14.1 consider macrolitter as the targeted lower size limit of items, which, beyond harmonization of methods, is associated with higher feasibility (e.g. costs and time) to sample and process macrolitter samples in comparison to smaller size classes, especially for countries with lower scientific and institutional capital.

This rationale on minimum item size or item size range also relates to the sampling protocols and how to deal with the litter analyzed. Studies were mainly turned to debris collection for subsequent analysis in the laboratory (n=43). Other studies were based on direct visual analysis in the field (n=9) or a mix of both visual analysis and sample collection (n=7). Although faster, visual analysis tends to underestimate the smaller items in a given area (Smith & Turrell, 2021), being a relevant source of bias in marine litter estimates. Indeed, some specific hypotheses on marine litter behavior in the environment may demand litter is not collected. However, the removal of litter from the environment to analyze the samples and then dispose of it in an appropriate way can be considered a good practice since the scientific investigation also helps to remove litter from the environment. If a visual analysis is not mandatory by the study goal or hypothesis, removal of sampled litter items from the environment is recommended.

Moreover, 13.6% of studies did not present relevant protocol details regarding the sampling design. Considering studies that presented such information, there was a high variation in the size and format of sampling units (e.g. transect with established area, linear transect along the beach width, the entire beach), which are detailed on Supplementary Material C. Moreover, sampling area was not specified in 6.78% of papers. Specified surveyed area included: backshore (n=34), foreshore (n=32), nearshore (n=8), dune/vegetation (n=2), strandline (n=7), estuary sectors (n=4) and mangrove fringes (n=3). Many studies surveyed more than one area (Supplementary Material B). Additional sources of bias in data interpretation can be caused by studies whose sampling focused only on the strandline (portion where litter is highly concentrated) or that present litter abundance in different beach zones together. These limitations are closely related to lack of harmonization of strategies, despite difficulties in properly describing methods, which compromise further use of the information, in particular, to feed SDG 14.1 national indicators. In this study, concepts of nearshore, foreshore and backshore were also considered for estuarine beaches.

Studies also had different duration from the first to last sampling campaign (Fig. 6A), ranging from one or two days (Krelling et al., 2017; Araújo & Costa, 2004a) up to ten years

(Baptista Neto & Fonseca, 2011). Studies with two years (Santos et al., 2005), three years (Silva-Cavalcanti et al., 2013) and four years of duration were also identified (Santos et al., 2005; Tourinho & Fillmann, 2011). However, most studies were short-term, with 74.6% with less than one year. Lack of temporal series of data prevents the identification of trends in the abundance of litter through time and adds an additional layer of limitations to the already existing ones (e.g. lack of harmonization of methods) to allow the use of the available information in Brazil in decision making.

As an example of a potential misinterpretation of the results from the literature, there is a great difference between the number of analyzed items per study (Fig. 6B), ranging from 275 (Ferreira & Lopes, 2013) to 165,882 items (Silva-Cavalcanti et al., 2013). Such variation can not be attributed solely to the differences in amount of items in different locations, but to the sampling effort (e.g. spatial and temporal replication) of the studies, including the size of the area and of the items sampled. Many studies did not specify study duration (8.5%) and total amount of collected items (30.5%), or other sampling details (see above), which prevents comparison among studies.

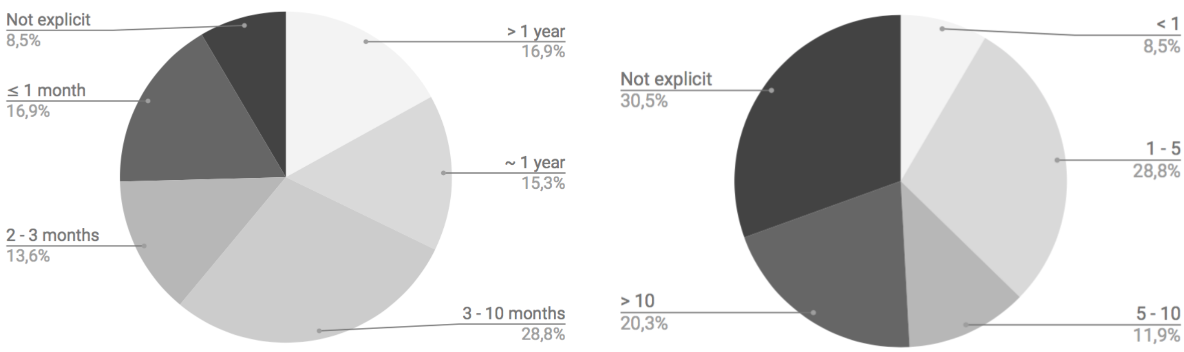


Fig. 6. (A) Studies duration, ranging from one day up to ten years. (B) Total of items collected per study (expressed in thousand items).

2.3.3.2.2. Processing methods

For sample processing, only ten studies followed IOC/FAO/UNEP protocols to classify the type of material, either from 1989 (Wetzel et al., 2004; Santos et al., 2004; Ivar do Sul et al., 2011; Portz et al., 2011; de Santana Neto et al., 2016) or from 2009 guidelines (Fernandino et al., 2015; Fernandino et al., 2016; Silva et al., 2016; Krelling et al., 2017; Krelling & Turra, 2019), with or without adjustments; and one study adopted the Ocean Conservancy protocol (Suciu et al., 2017). Other 49 studies created their own classification strategies of types of materials. The number of categories for types of materials ranged from one material category (plastic) to ten categories (rubber, foam, styrofoam, metal, nylon, paper, plastic, fabric, Tetra Pak packaging, and glass) (de Santana Neto et al., 2016). Some papers defined even more categories, however, they mixed the concept of material classification with item description (type of items) (e.g. bottle, film, rope, net, bag) or use. Possible material use and source were also presented by papers, with a thin line between these concepts and a wide variety of classification methods. The fact that a minority of studies followed pre-established protocols indicates that few of them have potential to aggregate discussions on national indicators.

Regarding the identification of litter sources, only 83.17% of studies indicated sources of marine litter based on data investigation. Some studies (10.17%) did not identify or suggest any source of marine litter, while 6.66% of them only speculated on possible sources. Difficulty to identify items source was a problem highlighted by many studies (Krelling et al., 2017; Krelling & Turra, 2019; Portz et al., 2011; Santos et al., 2005, 2009; Ivar do Sul et al., 2011; Santana Neto et al., 2016; Marin et al., 2019). This is a consequence of the variety of possible sources of marine litter. Our analysis revealed that 47.5% of studies presented limitations regarding litter categorization, which were related to indicating litter sources without identifying each item source, to classifying plastic items in different material categories (e.g. nylon, foam, styrofoam, polystyrene, cigarette butts, fishing materials), and also to merging material classification with items description and usage (e.g. plastics, fishing materials, personal hygiene, soccer balls). Because the terms type of material and type of items were often mixed by the analyzed articles, they were carefully treated by the present study. Moreover, information on litter use and source were combined in the present analysis, due to the thin line between these concepts and their non-consensus in the scientific community.

Regarding studies' cohesion with GESAMP (2019) recommendations, most studies employed litter classifications according to type of material (89.8%), type of item (39.0%), use/source (52.5%) and weight (49.2%), while few studies approached flexibility (27.1%), size (23.7%), color (6.8%), and chemical (5.1%) and biological characterization (6.8%) (Table 3). Only a few articles expanded categorization as suggested by GESAMP (2019). While almost all articles focused on litter physical characterization (type of material, type of item, use/source, and other physical characteristics) (n=58), few studies provided chemical characterization (e.g. identification of the polymer; Costa et al., 2011; Andrades et al., 2018) and biological characterization (e.g. identification of organisms associated with litter; Widmer et al., 2010; Mascarenhas et al., 2008; Costa et al., 2011; Tourinho & Fillmann, 2011). This is explained by the fact that most analyzed studies focused on indicating quantity and/or quality (types) of litter in the environment (n=56), accounting litter input by beach users (n=3) and/or indicating efficiency of beach cleaning services (n=1). As in Brazil, the international literature also commonly targets quantity, composition, and use/sources of marine litter (Galgani et al., 2015).

2.3.3.2.3. Reporting methods

Reporting results are also subjected to a high variation of units of measurement (Table 2). These units included the number of items (96.6%) and weight (g or kg; 13.6%), either considering or not the dimension of the surveyed area. The most common units were: total number of items (28.8%), items.m^{-2} (20.3%) and items.m^{-1} (16.9%). Some studies presented data in two or more units of measurements. Nevertheless, many studies expressed number of items present in a specific area, such as: 1000 m^{-2} (Carvalho-Souza & Tinôco, 2011; Machado & Fillmann, 2010) or 2000 m^{-2} (Araújo & Costa, 2004b); or in relation to a specific time range, like items.m^{-1}.day^{-1} (Santos et al., 2004). We verified that 27.1% of the studies reported data as quantities per linear distance (m^{-1}, km^{-1}, ha^{-1}), which is dependent on the non-steady beach width (Galgani et al., 2015) and thus, comprises a limitation to data comparisons. Furthermore, reporting data in terms of weight.$area^{-1}$ may demand some special attention, since while lightweight fragments tend to be abundant, heavy and big items are not so common and, when they are present, they can affect total sample weight (Smith & Turrell, 2021).

We estimated that only 50.8% of studies could possibly have their data transposed to number of items per square kilometers (item.km^{-2}). This is the format of data reporting proposed for SDG 14.1 national indicators related to beach litter count per km^2 of coastline. Thus, half of the studies on marine macrolitter in Brazil could have their data transposed to databases compatible with SDG 14.1 indicators. However, only four of these studies (Fernandino et al., 2015; Fernandino et al., 2016; Silva et al., 2016; Krelling et al., 2017) followed UNEP protocols and, therefore, could properly inform SDG 14.1.

Table 2. Units of measurement used by studies on macrolitter in the environment (Brazil). Items.Xm^{-y} refers to surveyed areas with specific dimensions (X).

Unit		Number of studies
total number of items	number of items	17
items/area or volume	items.m^{-1}	10
	items.Xm^{-1}	1
	items.m^{-2}	12
	items.Xm^{-2}	11
	items.km^{-1}	2
	items.km^{-2}	1
	items.ha^{-1}	1
	items.Xm^{-3}	1
items/area/day	items.m^{-1}.day^{-1}	1
	items.m^{-2}.day^{-1}	1
	items.person^{-1}.day^{-1}	1
weight/area	g.m^{-1}	1
	g.m^{-2}	1
	kg.m^{-2}	1
	kg.Xm^{-2}	1
	g.km^{-2}	1
total weight	total weight (g)	1
	total weight (kg)	2

2.3.3.3. Results of the studies on marine macrolitter in Brazil

We made an effort to get comparable results from the literature to understand the variation in litter mean density and plastic percentage along the Brazilian coast. There was a large variation according to the environment (Supplementary Material C) but the small number of locations sampled in estuaries, mangroves and shallow subtidal habitats (e.g. rocky and coral reefs) prevented any attempt to identify patterns of litter abundance. However, in general, the existing information indicates that along estuaries, abundance varied from 0 items.m^{-1}* (Possatto et al., 2015) to 59 items.m^{-3} (Costa et al., 2011), and plastic represented up to 100% of items (Costa et al., 2011). In mangroves, litter average density ranged between 0.51 and 8.69 items.m^{-2}. In mangroves, rocky bottom and rocky shore, the plastic proportion reached more than 90% (Belarmino et al., 2014; Machado & Fillmann, 2010), while in rocky reef it ranged between 33.4% and 64% (Carvalho-Souza & Tinôco, 2011; Oigman-Pszczol & Creed, 2007).

We concentrated this effort on beaches, where data is more available. National analysis revealed that litter density ranged from 0 items.m^{-1} (de Santana Neto et al., 2016) to 15.59 plastics.m^{-2} (Marin et al., 2019). The plastic rate varied from 22% (Fernandino et al., 2015) to 100%* (Silva et al., 2016), but represented more than 80% of litter in half of the studies. As in Brazil, marine litter density around the world is also in the 1 item.m^{-2} range, varying between 0.016 and 15.3 items.m^{-2}, and being mostly composed of plastics (Galgani et al., 2015).

The most common source registered by studies were: beach users (n=35), river runoff (n=20), fisheries (n=18), vessels (n=8), urban centres (n=4), illegal dumping by local residents (n=4) and urban drainage system (n=3) (Supplementary Material B).

2.3.4. Adherence to the policy agenda

Regarding adherence to policy-relevant concerns, most studies were essentially focused on investigating litter abundance and distribution (79.7%), and identifying litter sources (67.8%) (see Table 3). These aspects comprise two out of three main issues regarding marine litter that must be addressed (Ryan et al., 2009). The third aspect comprises the environmental and socio-economic impacts. Even though the papers analyzed were not focused on addressing the impacts of marine litter on tourism, seafood safety, human health and injuries, navigation hazards, animal welfare, biodiversity, and fisheries, many of them considered those implications when contextualizing the studies in the introductions and/or discussions (Table 3). The evidence on policy concerns in the papers expresses recognition of marine litter impacts on society, economy, and environment and the willingness to connect science with decision-making. However, even though papers cite some policy concerns, there are still many gaps that need to be overcome. Although there are several policy concerns associated with macrolitter (see UNEP, 2021; GESAMP, 2019), our results showed that there is an inclination for relating studies and the marine litter issue to some concerns. Most cited impact-based concerns were: animal welfare (62.7%), tourism (54.2%), human health and injuries (47.5%) and biodiversity (47.5%), while few studies cited navigation (15.3%), fisheries (3.4%), and seafood safety (1.7%). Additionally, it is clear that the studies are not being driven by policy concerns but focused on specific scientific questions, a panorama that may limit the use of information to feed SDG 14.1 national indicators.

Table 3. Litter classification and policy concerns of studies on marine macrolitter in Brazil. Criteria for litter classification and policy concerns were based on GESAMP (2019). Litter classification was gathered mostly from studies methods and results, while policy concerns were gathered mostly from studies introductions and discussions. To fulfill the use/source classification, only information resulting from items analysis was used; thus, we excluded speculations of litter sources. For the category of weight, we considered both information on total sample weight or weight of each item.

	Litter classification									Policy concerns								
Reference	type of material	type of item (description)	use/source	size	flexibility	color	biological characterization	chemical characterization	weight	distribution and abundance	source identification	tourism	seafood safety	human health and injuries	navigation hazards	animal welfare	biodiversity	fisheries
Figueiredo Jr. et al. (2001)	x									x	x							
Araújo & Costa (2004a)	x									x		x						
Araújo & Costa (2004b)	x	x								x	x	x						
Wetzel et al. (2004)	x		x						x	x	x							
Santos et al. (2005)	x									x	x							
Araújo & Costa (2006a)	x		x							x	x	x						
Araújo & Costa (2006b)	x		x							x	x	x		x	x		x	
Araújo & Costa (2007a)										x		x						
Araújo & Costa (2007b)			x							x	x	x		x		x		
Oigman-Pszczol & Creed (2007)	x									x		x		x			x	
Mascarenhas et al. (2008)	x	x	x		x		x			x	x					x	x	
Silva et al. (2008)	x	x								x	x							
Chaves & Robert (2009)		x	x															
Santos et al. (2009)	x		x		x					x	x	x				x	x	
Silva-Cavalcanti et al. (2009)	x		x							x	x	x		x				
Cordeiro & Costa (2010)	x	x							x	x		x				x		
Machado & Fillmann (2010)	x	x								x	x	x		x	x	x		x
Widmer et al. 2010)	x						x		x	x		x		x	x	x		
Baptista Neto & Fonseca (2011)	x	x								x	x	x				x	x	x
Carvalho-Souza & Tinôco (2011)	x									x						x		
Costa et al. (2011)	x		x	x	x		x	x	x	x	x					x		
Filho et al. (2011)	x		x							x	x					x		
Ivar do Sul et al. (2011)	x	x	x	x	x					x	x	x		x		x		
Neves et al. (2011)	x		x						x	x	x	x		x		x		
Oliveira et al. (2011)	x									x	x	x				x		x
Portz et al. (2011)	x	x	x							x	x	x		x		x		x
Soares et al. (2011)	x		x								x					x		
Tourinho & Fillmann (2011)	x		x				x			x	x	x				x	x	
Vieira et al. (2011)	x									x	x			x		x	x	
Ferreira & Lopes (2013)	x								x	x	x							
Ivar do Sul & Costa (2013)	x	x	x	x						x	x	x		x	x	x	x	
Silva-Cavalcanti et al. (2013)	x	x	x															


Belarmino et al. (2014)
Farias (2014)
Leite et al. (2014)
Fernandino et al. (2015)
Possatto et al. (2015)
Sampaio & Pinto (2015)
da Silva et al. (2015)
Andrades et al. (2016)
de Santana Neto et al. (2016)
Fernandino et al. (2016)
Fernandino et al. (2016)
Lima et al. (2016)
da Silva et al. (2016)
Krelling et al. (2017)
Suciu et al. (2017)
Andrades et al. (2018)
Araújo et al. (2018)
Cordeiro et al. (2018)
Corraini et al. (2018)
Farias et al. (2018)
Perez et al. (2018)
da Silva et al. (2018)
Stelmack et al. (2018)
Krelling & Turra (2019)
Marin et al. (2019)
Ramos & Pessoa (2019)

2.3.5. Overcoming difficulties and focusing on opportunities

The hypothesis that research groups are not integrated with each other was confirmed (section 2.3.2). Monitoring and assessing marine litter in a continental-size country would be facilitated and enhanced d by improving the collaboration among researchers and institutions. A strongly connected research network would promote data quality and accessibility more effectively with less effort and costs (Hanke et al., 2013). Partnership articulation would expand marine litter assessment at a national level, promoting knowledge construction and sharing for effectively implementing prevention and mitigation actions (MMA, 2019), including the support to the SDG 14.1 indicator system. Thus, robust integration would contribute to local, regional, national and international agendas, including the National Plan to Combat Marine Litter (PNCLM, 2021). Besides integration within information producers, we also emphasize the need of bringing different stakeholders together, including NGOs, government and the private sector (e.g. developing plans for monitoring and assessing marine litter - such as PEMALM).

The hypothesis that studies are episodic and fragmented was also confirmed (sections 2.3.3). The discontinuity of studies was emphasized by their non-constancy, short temporal scale and small spatial scale. Comparisons among studies can be burdened by this deficiency in frequency (Smith & Markic, 2013). This fragmentation is not common only in national studies, but also in the international literature (Ryan et al., 2009; Galgani et al., 2015). Among other resemblances, both national and international literature focus on local or regional spatial scale, cover a significant timescale range (from days up to years) and concentrate sampling effort in a few areas (backshore and foreshore zones) (Ryan et al., 2009; Galgani et al., 2015). To overcome these issues, it is essential to perform regular long-term surveys in order to generate reliable data on long-term patterns and cycles of litter accumulation (Ryan et al., 2009; Galgani et al., 2015).

Furthermore, studies must promote a transboundary approach, overcoming territorial borders (Krelling et al., 2017). Studies and results did not cover the entire Brazilian coast, thus, available information does not allow a representative view of national or sub-national panorama to dimensionalize hotspots of litter pollution and prioritize critical regions. Developing a monitoring program on a large spatial scale (as performed by Andrades et al., 2020, but on a long-term basis) would provide a good overview of marine litter in Brazil. Episodicity and fragmentation observed indicate that there is a lack of coordination at the national level. The National Plan to Combat Marine Litter (PNCLM), established in 2019 has not been implemented yet. To overcome the federal government's hiatus on that implementation, there are regional initiatives such as the São Paulo Strategic Plan for

Monitoring and Assessment of Marine Litter (PEMALM), which has been developing work at the state level, structuring regional partnerships and aiming to bring improvements for coming years.

Furthermore, the limitation of the studies to a few types of environments and compartments might not allow a representative estimate of national and sub-national panorama on marine macrolitter in Brazil. This prevents the country to be better represented in international platforms (e.g. Litterbase, https://litterbase.awi.de/litter; GPML Digital Platform, https://datahub.gpmarinelitter.org/) and also compromises the use of data to support national and sub-national policies, as the dimensionalization of hotspots of litter pollution and the prioritization of critical sites for interventions. Expanding studies to other environments (coral reefs, seafloor, rivers, estuaries, mangroves) and compartments (water surface and column), and increasing studies spatial scale, at least for sandy beaches, would allow a more comprehensive characterization of marine litter along the Brazilian coast. This is an important task that needs to be carried out within the National Plan to Combat Marine Litter, whose strategy for monitoring and assessment of marine litter should consider the rationale behind the selection of sampling sites. As GESAMP (2019) pointed out, a representative sample of a given locality (from the municipality to the country level) should consider a random approach to prevent biased data sampled in areas of higher concentration of litter, for example. This can only be achieved considering a national coordination of a monitoring and assessment program. However, there are several other triggers to set monitoring schemes as the assessment of the effectiveness of a given policy to face marine litter in a given locality (e.g. improvement of waste management services) or to combat specific types of items (e.g. straws or plastic bags). As mentioned above, as long as the information produced on marine litter is not clearly linked to specific policy concerns, countries will experience limitations and difficulties in interpreting marine litter data from the literature, and the national indicators of the SDG 14.1 will hardly be meaningful. Such constraints also apply to the need to harmonize sampling and processing methods (see GESAMP, 2019), which will be explored next.

The hypothesis that methods used by studies on macrolitter in Brazil are widely different was also confirmed (section 2.3.3). A wide variety of data collection, processing and reporting strategies was recognized. Besides differing among beaches, marine litter composition also fluctuates according to sampling strategy. For instance, data on litter abundance in strandlines must be used carefully, to not overestimate abundance in other beach zones when extrapolating. Another factor to be taken into consideration, when comparing different papers, is that some papers include data of organic debris and classify some sorts of plastics (e.g. foam, styrofoam, nylon, cigarette butts) in categories different from plastics. This variety of methods is important for some study goals, but reflects on the total plastic percentage. Thus, setting common goals and harmonizing strategies is important for producing comparable information. Furthermore, we also noted that study processing protocols were widely different. Even if studies use different (or more detailed) categories to classify the types of material or items, there is a need to report the information in a way the data can be rearranged to inform the categories agreed upon internationally (UNEP, 2009, GESAMP, 2019). In addition, there is no consensus on source terminology in the scientific community. While many authors classify litter in land-based and marine-based sources, other authors relate sources to specific human activities (Santos et al., 2009). Harmonizing these classifications, or allowing the link among them, would facilitate comparisons between studies. Developing a consistent national monitoring program would feed the global system for monitoring and evaluating marine litter. Because of its large territory, population, Gross Domestic Product (GDP), and solid waste generation, Brazil has a great potential to generate information on marine litter. However, the difficulties related to study fragmentation and lack of harmonization make this contribution difficult. It is necessary to orientate science towards producing information that can contribute to the global system for monitoring marine litter and be applied to management. Such a comprehensive characterization of marine litter would involve long-term large-scale monitoring, with harmonized research strategies.

Differences in sampling protocols, type of data recorded, and data reporting are also common in the international literature (Ryan et al., 2009; Galgani et al., 2015). Despite the existence of multiple official protocols to investigate and express data on marine litter, most studies followed their own approach. Study environments may be unique and require methodology adaptations from the official protocols, considering local and regional contexts (UNEP, 2021). Besides that, different goals may lead to different sampling approaches. However, employing distinct methods and expressing data in different units of measurement turns comparisons among studies complicated (Ryan et al., 2009; GESAMP, 2019; Smith & Turrell, 2021). Comparisons are also obstructed by lack of relevant information on strategies used, such as sampling area dimensions (Smith & Markic, 2013). Non-harmonization and lack of relevant information impede generalizing local observations into a global picture (Maximenko et al., 2019). Moreover, lack of harmonization makes it harder to provide solid knowledge to guide decision-making and regulations, and also, to monitor changes after implementations (Maximenko et al., 2019). Thus, harmonizing and informing protocols are crucial to achieving reliable monitoring and assessment programme, and must be promoted prior to the proposal and implementation of mitigation measures (Galgani et al., 2019; Galgani et al., 2015; Ryan et al., 2009; Carvalho-Souza & Tinôco, 2011).

Harmonizing data expression in terms of Items.m^{-2} facilitates comparisons between studies (Galgani et al., 2015). However, UNEP (2021) recommends the national indicator of marine litter in the coastline (e.g. beaches) to be expressed in Items.km^{-2}, unit that is being already used in some international databases (e.g. Litterbase, https://litterbase.awi.de/litter; GPML Digital Platform, https://datahub.gpmarinelitter.org/). In our survey, only one study reported litter abundance as Items.km^{-2} (Table 2), and only half of studies could have their data transposed to Items.km^{-2}. We recommend that studies prepare sample designs that allow data representation in units that can be transposed to other units, including Items.km^{-2}.

The hypothesis that studies are not well-coupled with policy concerns was also confirmed (section 2.3.4). Articulating knowledge building with policy-relevant concerns might guide us to building knowledge that can guide decision-making and feed national and global agendas. Recognizing the complexity of marine litter impacts and the potential of research on decision-makers' hands are foremost to tackle marine litter. Thus, we shall promote better coupling of scientific studies with policy-relevant concerns, informing decision-makers and other stakeholders, about litter impacts and the potential of our assessments.

This study presents Brazil's context on marine litter science production, and the challenges to monitoring litter and reporting SDG 14.1. Brazil faces the same problems as other countries that are just starting to address SDG targets and indicators at the country level, such as data fragmentation, resource limitation, and low capacity for monitoring programmes (UNEP, 2021). Even though issues exist, the country presents scientific strengths that lead to opportunities, such as the mastery of sampling and processing methods, and the existence of multiple research groups willing to improve marine litter science (GESAMP, 2020). Besides indicating the panorama of marine litter science in Brazil, this study also synthesized the existing data, which can be used for facilitating future studies, comparing environmental conditions, and analyzing the effectiveness of mitigation actions in order to promote adaptive management.

As in Brazil, for decades international research has been addressing marine litter abundance, composition, and distribution (Maximenko et al., 2019). However, knowledge gaps still exist and the scarcity of monitoring programs needs to be addressed (Maximenko et al., 2019; PEMALM, 2021). Marine litter science in Brazil has weaknesses in common with international research: information is fragmented, data quality is sometimes questionable, and sampling methods and reports are not harmonized (GESAMP et al., 2020). The difficulty of monitoring macrolitter is an international issue. It is related to the variety of litter characteristics (sizes, shapes, buoyancy, and composition), sources, pathways, movement to other compartments, decay processes, and seasonal variations in abundance and distribution (GESAMP, 2019; Maximenko et al., 2019; GESAMP, 2020). Moreover, defining harmonized methodologies that properly represent reality is also a challenge (GESAMP, 2019). As a consequence of so many difficulties, data produced up to now in Brazil is not enough for subsidizing SDG 14.1, which is targeted for 2025, unlike most SDGs, set for 2030. This is related to the fact that research has been turned to expose pollution conditions, and not necessarily to subsidize public politics. Overcoming the lack of science integration with policy concerns is a challenge faced worldwide, and addressing it is important to guide regulations and monitor differences after their implementation (Maximenko et al., 2019; GESAMP et al., 2020; UNEP, 2021). Thus, we highlight the importance of science at providing solid knowledge that can support decision-making and be applied to management.

Even though previous studies present limitations, there are multiple opportunities for data use. Existing data on marine litter in Brazil, synthesized by this study, can be incorporated into the Global Partnership on Marine Litter (GPML) Digital Platform, and contribute to building or calibrating baselines for marine litter monitoring parameters, which can be used for tracking progress against SDG Indicator 14.1.1b. (UNEP, 2021). Synthesized data also has potential to help understand marine litter dynamics and to monitor spatial-temporal litter distribution. Moreover, it can support innovative multidisciplinary research, choice of proper monitoring instruments at a given location, design mitigation measures and analyze their effectiveness (Maximenko et al., 2019). In situ data can also be used for calibrating and validating remote sensing information; and to feed the integrated marine debris observing system (IMDOS; Maximenko et al., 2019) which intends to use previous data on litter concentration, composition, origin, and pathways, to provide monitoring and to inform stakeholders. Thus, the synthesized information indicates new opportunities for better understanding marine pollution (UNEP, 2021).

Knowing marine litter science limitations, it is possible to change the way scientific information is produced and reframe existing data. The Decade of Ocean Science for Sustainable Development is a great opportunity to make meaningful changes. Marine litter assessment and monitoring must take into account the policy concern being addressed, and must communicate with policymakers (GESAMP et al., 2019, 2020). It is also important to simplify and harmonize methods, promote collaborations among researchers and with stakeholders, and innovate capacity building (GESAMP et al., 2020). In short, science must provide comprehensive, accurate, and harmonized information in order to inform stakeholders and to support decision-making (Maximenko et al., 2019).

2.4. CONCLUSIONS

Studies and results did not have a wide spatio-environmental distribution, thus, available information does not allow a representative view of national or sub-national panorama to dimensionalize hotspots of litter pollution and to prioritize areas. Informing SDG 14.1 requires a well-integrated research community, harmonized and robust knowledge, and defined strategies that dialogue with policy concerns. However, we analyzed the capacity for generating information and concluded that the existing literature on marine macrolitter in Brazil lacks capacity in this context. The macrolitter research network was not well integrated. Moreover, studies were episodic and fragmented, sampling and processing methods were widely different, and there was no harmonization of reporting units. Moreover, studies do not allow the identification and dimensionalization of hotspots of litter pollution, nor the trends in marine litter pollution over time. Besides that, studies lacked coordination with national and global policies. We concluded that scientific production in Brazil so far is not enough to inform SDG indicator 14.1. Even though Brazil is far from informing SDG 14.1, the national scientific capital has great potential to face this challenge, since we master methods, have highly qualified personnel, and researchers are willing to connect science with policy-relevant concerns, as shown in the studies.

It is important to highlight that reporting the SDG is just part of implementing it. Based on science-based information, governments, private sector and other social actors might support the creation of an innovation ecosystem in order to effectively implement prevention and mitigation actions and supply the demands of the SDG. Developing an innovative ecosystem surpasses the role of science and involves multiple social sectors, requiring national coordination and training. Considering the role of science of producing and reporting data, it is important to promote frequent long-term studies at a national level, to develop a unified database to gather results, and to confront episodicity and fragmentation of studies. Meanwhile, harmonizing protocols is paramount to avoid divergences and facilitate comparisons among studies. Supporting scientific collaborations is also important to articulate harmonized but innovative diagnoses. Furthermore, aligning studies with policy-relevant concerns is essential to properly inform stakeholders and impact decision-making. However, besides providing information to management, we also highlight the importance of keep developing science aimed at answering scientific questions that emerge.

Our systematic mapping and critical analysis in the context of SDG 14.1 provides a broad synthesis of methods and main results of studies on macrolitter in Brazil, facilitating the integration of new and existing information, and supporting information-gathering strategies and monitoring/assessment programs. This study can feed the Global Partnership on Marine Litter (GPML) Digital Platform and potential plans for monitoring and assessing marine litter, such as PEMALM. It also subsidizes actions of the Axis 3 of the National Plan to Combat Marine Litter (PNCLM), aimed at gathering data for establishing a database containing litter types, sources, and quantities of marine litter and for monitoring intervention measures. Moreover, this study carried out a research network analysis and provides a full database of researchers that work or have worked with marine litter in Brazil. This information can subsidize the Tutorial Education Program (PET - Programa de Educação Tutorial), and promote collaborations and guide scientists, decision-makers and stakeholders. Furthermore, this study indicates the connections authors have made among their studies and policy concerns, and demonstrates that there is a need to improve communication with decision-makers. In short, this study indicates directions marine litter science shall follow in order to subsidize Sustainable Development Goal 14.1: harmonizing protocols and reports, integrating researchers, and aligning study goals with policy-relevant concerns. For future studies, we recommend focusing on improving litter source identification, describing litter hotspots on the coast, and investigating social, economic and environmental costs of plastic pollution. Moreover, we recommend investing in citizen science for data production. Regarding reducing marine litter entry in the ocean, the most advisable step is to prevent solid waste from being generated, by articulating multiple social actors and embracing all links of the production-consumption chain.

2.5. REFERENCES

Agamuthu, P., Mehran, S. B., Norkhairah, A., & Norkhairiyah, A. (2019). Marine debris: A review of impacts and global initiatives. Waste Management & Research, 37(10), 987-1002.

Alfaia, R. G. D. S. M., Costa, A. M., & Campos, J. C. (2017). Municipal solid waste in Brazil: A review. Waste Management & Research, 35(12), 1195-1209.

Andrades, R., Martins, A. S., Fardim, L. M., Ferreira, J. S., & Santos, R. G. (2016). Origin of marine debris is related to disposable packs of ultra-processed food. Marine Pollution Bulletin, 109(1), 192–195. http://doi.org/10.1016/j.marpolbul.2016.05.083

Andrades, R., Santos, R. G., Joyeux, J. C., Chelazzi, D., Cincinelli, A., & Giarrizzo, T. (2018). Marine debris in Trindade Island, a remote island of the South Atlantic. Marine Pollution Bulletin, 137(October), 180–184. http://doi.org/10.1016/j.marpolbul.2018.10.003

Andrades, R., Pegado, T., Godoy, B. S., Reis-Filho, J. A., Nunes, J. L., Grillo, A. C., ... & Giarrizzo, T. (2020). Anthropogenic litter on Brazilian beaches: Baseline, trends and recommendations for future approaches. Marine pollution bulletin, 151, 110842.

Andrady, A. L. (2015). Persistence of plastic litter in the oceans. In Marine anthropogenic litter (pp. 57-72). Springer, Cham.

Araújo, M. C. B., & Costa, M. F. (2004a). Quantitative and qualitative analysis of the solid waste left by visitors on Tamandaré Bay, Pernambuco state, Brazil. Gerenciamento Costeiro Integrado, 58–61.

Araújo, M. C. B., & Costa, M. F. (2004b). Quali-Quantitative Analysis of the Solid Wastes at Tamandare Bay, Pernambuco, Brazil. Tropical Oceanography, 32(2), 159–170.

Araújo, M. C. B., & Costa, M. F. (2006a). Municipal Services on Tourist Beaches: Costs and Benefits of Solid Waste Collection. Journal of Coastal Research, 225(225), 1070–1075. http://doi.org/10.2112/03-0069.1

Araújo, M. C. B., & Costa, M. F. (2006b). The significance of solid wastes with land-based sources for a tourist beach: Pernambuco , Brazil. Pan-American Journal of Aquatic Sciences, 1(1), 28–34.

Araújo, M. C. B., & Costa, M. F. (2007a). Visual diagnosis of solid waste contamination of a tourist beach: Pernambuco, Brazil. Waste Management, 27(6), 833–839. http://doi.org/10.1016/j.wasman.2006.04.018

Araújo, M. C. B., & Costa, M. F. (2007b). An analysis of the riverine contribution to the solid wastes contamination of an isolated beach at the Brazilian Northeast. Management of Environmental Quality: An International Journal, 18(1), 6–12. http://doi.org/10.1108/14777830710717677

Araújo, M. C. B., Silva-Cavalcanti, J. S., & Costa, M. F. (2018). Anthropogenic Litter on Beaches With Different Levels of Development and Use: A Snapshot of a Coast in Pernambuco (Brazil). Frontiers in Marine Science, 5(July), 1–10. http://doi.org/10.3389/fmars.2018.00233

Arthur, C.A., Baker, J., Bamford, H., 2009. Proceedings of the International Research Workshop on the Occurrence, Effects, and Fate of Microplastic Marine Debris,September 9–11. NOAA Technical Memorandum NOS-OR&R-30, 2009, Washington.

Azevedo, T. D., & Schiller, A. (1991). Notes on the diet and the ingestion of plastic material by the Magellanic penguin Spheniscus magellanicus on Santa Catarina Island and mainland (Brazil). Unit. Doc. Zoologie. Seru. Ethol. Psichol. Anim. Universidade Liege, Bélgica. Rapport, 457, 1-8.

Baptista Neto, J. A., & Fonseca, E. M. da. (2011). Seasonal, spatial and compositional variation of beach debris along of the eastern margin of Guanabara Bay (Rio de Janeiro) in the period of 1999-2008. Journal of Integrated Coastal Zone Management, 11(1), 31–39.

Barboza, L. G. A., & Gimenez, B. C. G. (2015). Microplastics in the marine environment: Current trends and future perspectives. Marine Pollution Bulletin, 97 (1-2), 5–12. http://doi.org/10.1016/j.marpolbul.2015.06.008

Belarmino, P. H. P., Silva, S. M. da, Rufener, M.-C., & Araújo, M. C. B. (2014). Solid waste in mangrove in the Potengi River (Natal, RN, Brazil): relation to the location and uses. Journal of Integrated Coastal Zone Management, 14(3), 447–457. http://doi.org/10.5894/rgci451

Brandt, W. (1980). North-South: A Programme for Survival: Report of the Independent Commission on International Development Issues (London: Pan, 1980).

Bugoni, L., Krause, L., & Petry, M. V. (2001). Marine debris and human impacts on sea turtles in southern Brazil. Marine pollution bulletin, 42(12), 1330-1334.

Carvalho-Souza, G. F., & Tinôco, M. S. (2011). Evaluation of Marine Debris in Rock Reefs in the Todos os Santos Bay, Bahia, Brazil. Journal of Integrated Coastal Zone Management, 11(2), 135–143. Retrieved from http://www.aprh.pt/rgci/pdf/rgci-231_Carvalho-Souza.pdf

Castro, R. O., Silva, M. L. da, & Araújo, F. V. de. (2018). Review on microplastic studies in Brazilian aquatic ecosystems. Ocean and Coastal Management, 165 (October), 385–400. http://doi.org/10.1016/j.ocecoaman.2018.09.013

Chaves, P. de T., & Robert, M. de C. (2009). Loss and abandon of fishing gears in southern brazil and risks of occurrence of ghost-fishing. Boletim Do Istituto de Pesca, 35(3), 513–519.

Cordeiro, C. A. M. M., & Costa, T. M. (2010). Evaluation of solid residues removed from a mangrove swamp in the São Vicente Estuary, SP, Brazil. Marine Pollution Bulletin, 60(10), 1762–1767. http://doi.org/10.1016/j.marpolbul.2010.06.010

Cordeiro, T. C., Barrella, W., Butturi-Gomes, D., & Petrere Júnior, M. (2018). A modeling approach for reposition dynamics of litter composition in coastal areas of the city of Santos, Sao Paulo, Brazil. Marine Pollution Bulletin, 128(January), 333–339. http://doi.org/10.1016/j.marpolbul.2018.01.054

Corraini, N. R., de Souza de Lima, A., Bonetti, J., & Rangel-Buitrago, N. (2018). Troubles in the paradise: Litter and its scenic impact on the North Santa Catarina island beaches, Brazil. Marine Pollution Bulletin, 131(April), 572–579. http://doi.org/10.1016/j.marpolbul.2018.04.061

Costa, M. F., Silva-Cavalcanti, J. S., Barbosa, C. C., Portugal, J. L., & Barletta, M. (2011). Plastics buried in the inter-tidal plain of a tropical estuarine ecosystem. Journal of Coastal Research, 165(Special Issue 64), 339–343. http://doi.org/10.2112/SI65-206.1

Derraik, J. G. (2002). The pollution of the marine environment by plastic debris: a review. Marine pollution bulletin, 44(9), 842-852.

da Silva, M. L., Araújo, F. V. de, Castro, R. O., & Sales, A. S. (2015). Spatial-temporal analysis of marine debris on beaches of Niterói, RJ, Brazil: Itaipu and Itacoatiara. Marine Pollution Bulletin, 92(1-2), 233–236. http://doi.org/10.1016/j.marpolbul.2014.12.036

da Silva, M. L., Castro, R. O., Sales, A. S., & Araújo, F. V. de. (2018). Marine debris on beaches of Arraial do Cabo, RJ, Brazil: An important coastal tourist destination. Marine Pollution Bulletin, 130(December 2017), 153–158. http://doi.org/10.1016/j.marpolbul.2018.03.026

da Silva, M. L., Sales, A. S., Martins, S., Castro, R. O., & Araújo, F. V. de. (2016). The influence of the intensity of use, rainfall and location in the amount of marine debris in four beaches in Niteroi, Brazil: Sossego, Camboinhas, Charitas and Flechas. Marine Pollution Bulletin, 113(1-2), 36–39. http://doi.org/10.1016/j.marpolbul.2016.10.061

da Silva Videla, E., & de Araujo, F. V. (2021). Marine debris on the Brazilian coast: Which advances in the last decade? A literature review. Ocean & Coastal Management, 199, 105400.

de Santana Neto, S. P., Silva, I. R., & Bittencourt, A. C. D. S. P. (2016). Distribuição do lixo marinho e sua interação com a dinâmica de ondas e deriva litorânea no litoral norte do estado da bahia, brasil. Geociencias, 35(2), 231–246.

Dias Filho, M. J. O., Araújo, M. C. B., Silva-Cavalcanti, J. S., & Silva, A. C. M. (2011). Contamination of Boa Viagem Beach (Pernambuco State , Brazil) by marine litter: relationship with its usage. Labomar, 44(1), 33–39.

Eriksen, M., L. C. M. Lebreton, H. S. Carson, M. Thiel, C. J. Moore, J. C. Borerro, F. Galgani, P. G. Ryan and J. Reisser (2014). Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. Plos One, 9(12): e111913.

Farias, S. C. G. (2014). Accumulation of waste disposal in coastal environments: the ocean beach Piratininga-Niterói-RJ. Geo UERJ, 2(25), 276–296.

Farias, E. G. G., Preichardt, P. R., & Dantas, D. V. (2018). Influence of fishing activity over the marine debris composition close to coastal jetty. Environmental Science and Pollution Research, 25, 16246–16253.

Fernandino, G., Elliff, C. I., & Silva, I. R. (2015). Degree of pollution by benthic litter in beaches in Salvador, Bahia, Brazil. Sciencia Plena, 11(3), 9. Retrieved from file:///C:/Users/Yara Sanchez/Downloads/Fernandino et al_2015_Degree of pollution by benthic litter SSA.pdf

Fernandino, G., Elliff, C. I., Frutuoso, G. A., Silva, E. V. N. M. da, Gama, G. S., Sousa, J. H. de O., & Silva, I. R. (2016a). Considerations on the effects of tidal regimes in the movement of floating litter in an estuarine environment: Case study of the estuarine system of Santos-São Vicente, Brazil. Marine Pollution Bulletin, 110(1), 591–595. http://doi.org/10.1016/j.marpolbul.2016.05.080

Fernandino, G., Elliff, C. I., Silva, I. R., Brito, T. de S., & Bittencourt, A. C. da S. P. (2016b). Plastic fragments as a major component of marine litter: a case study in Salvador, Bahia, Brazil. Journal of Integrated Coastal Zone Management, 16(3), 281–287. http://doi.org/10.5894/rgci649

Ferreira, M. L., & Lopes, A. (2013). Análise Quali-Quantitativa Do Lixo Na Praia Da Santa Cruz Dos Navegantes-Guarujá-Sp-Brasil. Revista Ceciliana Jun, 5(1), 30–35.

Figueredo Jr., A. G., de Lyra, A. C., de Lima Moredo, M., & Santos, R. H. (2001). Lixo Flututante na Baía de Guanabara, Rio de Janeiro, Brasil. Gerenciamento Costeiro Integrado, 5.

Galgani, F. (2015). Marine litter, future prospects for research. Frontiers in Marine Science, 2, 87.

Galgani, F., Hanke, G., & Maes, T. (2015). Global distribution, composition and abundance of marine litter. In: Marine anthropogenic litter (pp. 29-56). Springer, Cham.

Galgani, L.; Beiras, R.; Galgani, F.; Panti, C.; & Borja, A. (2019). Editorial: impacts of marine litter. Frontiers in Marine Science, 6: 208. doi: 10.3389/fmars.2019.00208.

GESAMP (2019). Guidelines for the Monitoring and Assessment of Plastic Litter in the Ocean. Journal Series GESAMP Reports and Studies, 99 (123p.). Available at: http://www.gesamp.org/publications/guidelines-for-the-monitoring-and-assessment-of-plastic-litter-in-the-ocean

GESAMP (2020). Proceedings of the GESAMP International Workshop on assessing the risks associated with plastics and microplastics in the marine environment (Kershaw, P.J., Carney Almroth, B., Villarrubia-Gómez, P., Koelmans, A.A., and Gouin, T., eds.). (IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/ UNEP/UNDP/ISA Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). Reports to GESAMP No. 103, 68 pp.

Gregory, M. R. (2009). Environmental implications of plastic debris in marine settings—entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Philosophical Transactions of the Royal Society B: Biological Sciences, 364(1526), 2013-2025.

Gomes, C.M.B (1973). Lançamento de partículas de polietileno à costa do R.G.S. Véritas, Porto Alegre, v. 18, n. 70, p. 174-206, 1973.

Hidalgo-Ruz, V., Gutow, L., Thompson, R. C., & Thiel, M. (2012). Microplastics in the marine environment: a review of the methods used for identification and quantification. Environmental science & technology, 46(6), 3060-3075.

Hanke, G., Galgani, F., Werner, S., Oosterbaan, L., Nilsson, P., Fleet, D., ... & Palatinus, A. (2013). Guidance on monitoring of marine litter in European seas. A guidance document within the Common Implementation Strategy for the Marine Strategy Framework Directive, JRC MSDF Technical Subgroup on Marine Litter. EUR, 26113, 128.

IBGE (2010). Censo Demográgico. Instituto Brasileiro de Geografia e Estatística. Available at: https://www.ibge.gov.br/estatisticas/downloads-estatisticas.html

IOC/UNESCO (2020a). The Science we Need for the Ocean We Want: The United Nations Decade of Ocean Science for Sustainable Development (2021-2030). Paris, 20 pp. (English). IOC Brochure 2020-4 (IOC/BRO/2020/4)

IOC/UNESCO (2020b). Global Ocean Science Report 2020–Charting Capacity for Ocean Sustainability, Executive Summary. K. Isensee (ed.), Paris, UNESCO Publishing (IOC Policy Series, 2020-1).

Ivar do Sul, J. A., & Costa, M. F. (2007). Marine debris review for Latin America and the Wider Caribbean Region: From the 1970s until now, and where do we go from here? Marine Pollution Bulletin, 54(8), 1087–1104. http://doi.org/10.1016/j.marpolbul.2007.05.004

Ivar do Sul, J. A., Santos, I. R., Friedrich, A. C., Matthiensen, A., & Fillmann, G. (2011). Plastic Pollution at a Sea Turtle Conservation Area in NE Brazil: Contrasting Developed and Undeveloped Beaches. Estuaries and Coasts, 34(4), 814–823. http://doi.org/10.1007/s12237-011-9392-8

Ivar do Sul, J. A., & Costa, M. F. (2013). Plastic pollution risks in an estuarine conservation unit. Journal of Coastal Research, 65(January 2013), 48–53. http://doi.org/10.2112/si65-009.1

Ivar do Sul, J.A.I; & Costa, M.F. (2014). The present and future of microplastic pollution in the marine environment. Environmental pollution, 185: 352-364.

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., ... & Law, K. L. (2015). Plastic waste inputs from land into the ocean. Science, 347(6223), 768-771.

James, K. L., Randall, N. P., & Haddaway, N. R. (2016). A methodology for systematic mapping in environmental sciences. Environmental evidence, 5(1), 1-13.

Karasik, R., Vegh, T., Diana, Z., Bering, J., Caldas, J., Pickle, A., et al. (2020). 20 Years of Government Responses to the Global Plastic Pollution Problem: The Plastics Policy Inventory. NI X. Durham, NC: Duke University.

Kiessling, T., Gutow, L., & Thiel, M. (2015). Marine litter as habitat and dispersal vector. In Marine anthropogenic litter (pp. 141-181). Springer, Cham.

Krelling, A. P., Souza, M. M., Williams, A. T., & Turra, A. (2017). Transboundary movement of marine litter in an estuarine gradient: Evaluating sources and sinks using hydrodynamic modelling and ground truthing estimates. Marine Pollution Bulletin, 119(1), 48–63. http://doi.org/10.1016/j.marpolbul.2017.03.034

Krelling, A. P., & Turra, A. (2019). Influence of oceanographic and meteorological events on the quantity and quality of marine debris along an estuarine gradient. Marine Pollution Bulletin, 139(July 2018), 282–298. http://doi.org/10.1016/j.marpolbul.2018.12.049

Kühn, S., Rebolledo, E. L. B., & van Franeker, J. A. (2015). Deleterious effects of litter on marine life. In Marine anthropogenic litter (pp. 75-116). Springer, Cham.

Leite, A. S., Santos, L. L., Costa, Y., & Hatje, V. (2014). Influence of proximity to an urban center in the pattern of contamination by marine debris. Marine Pollution Bulletin, 81(1), 242–247. http://doi.org/10.1016/j.marpolbul.2014.01.032

Lima, A. R. A., Barletta, M., Costa, M. F., Ramos, J. A. A., Dantas, D. V., Melo, P. A. M. C., … Ferreira, G. V. B. (2016). Changes in the composition of ichthyoplankton assemblage and plastic debris in mangrove creeks relative to moon phases. Journal of Fish Biology, 89(1), 619–640.

Link, J., Segal, B., & Casarini, L. M. (2019). Abandoned, lost or otherwise discarded fishing gear in Brazil: A review. Perspectives in ecology and conservation, 17(1), 1-8.

LoBiondo-Wood, G. Part III Processes and Evidence Related to Quantitative Research: Understanding Research Findings p 305-316. In: LoBiondo-Wood, G., & Haber, J. (2017). Nursing research-E-book: methods and critical appraisal for evidence-based practice. Elsevier Health Sciences.

Machado, A. A., & Fillmann, G. (2010). Study of the contamination of litter in island Arvoredo, marine biological reserve of the Arvoredo - SC, Brasil. Journal of Integrated Coastal Zone Management, 10(3), 381–393.

Marin, C. B., Niero, H., Zinnke, I., Pellizzetti, M. A., Santos, P. H., Rudolf, A. C., … Polette, M. (2019). Marine debris and pollution indexes on the beaches of Santa Catarina State, Brazil. Regional Studies in Marine Science, 31, 100771. http://doi.org/10.1016/j.rsma.2019.100771

Mascarenhas, R., Batista, Clenia, P., Moura, I. F., Caldas, A. R., Neto, J. M. da C., Vasconcelos, M. Q., … Barros, T. V. S. de. (2008). Marine debris at a sea turtles nesting area at Paraiba State, Brazilian Northeast. Revista de Gestão Costeira Integrada, 8(2), 221–231. http://doi.org/10.5894/rgci138

Maximenko N, Corradi P, Law KL, Van Sebille E, Garaba SP, Lampitt RS, Galgani F, Martinez-Vicente V, Goddijn-Murphy L, Veiga JM, Thompson RC, Maes C, Moller D, Löscher CR, Addamo AM, Lamson MR, Centurioni LR, Posth NR, Lumpkin R, Vinci M, Martins AM, Pieper CD, Isobe A, Hanke G, Edwards M, Chubarenko IP, Rodriguez E, Aliani S, Arias M, Asner GP, Brosich A, Carlton JT, Chao Y, Cook A-M, Cundy AB, Galloway TS, Giorgetti A, Goni GJ, Guichoux Y, Haram LE, Hardesty BD, Holdsworth N, Lebreton L, Leslie HA, Macadam-Somer I, Mace T, Manuel M, Marsh R, Martinez E, Mayor DJ, Le Moigne M, Molina Jack ME, Mowlem MC, Obbard RW, Pabortsava K, Robberson B, Rotaru A-E, Ruiz GM, Spedicato MT, Thiel M, Turra A and Wilcox C (2019) Toward the Integrated Marine Debris Observing System. Front. Mar. Sci. 6:447. doi: 10.3389/fmars.2019.00447

Menk (2018). Breve panorama de ações de combate ao lixo no mar - Brasil e Santos (SP). Combate às fontes de poluição marinha por resíduos sólidos. Available at: http://lixoforadagua.com.br/wp-content/uploads/PORT-Relatorio1A-Panorama%20Brasil_051218.pdf

MMA (2019). Plano Nacional de Combate ao Lixo no Mar. Available at: https://www.mma.gov.br/agenda-ambiental-urbana/lixo-no-mar.html

Neves, R. C., Santos, L. A. S., Oliveira, K. S. S., Nogueira, I. C. M., Loureiro, D. V., Franco, T., … Quaresma, V. da S. (2011). Qualitative Analysis of the Distribution of Litter in the Barrinha Beach (Vila Velha - ES). Journal of Integrated Coastal Zone Management, 11(1), 57–64. http://doi.org/10.5894/rgci193

Newman, S., Watkins, E., Farmer, A., ten Brink, P. J., and Schweitzer, P. (2015). “The economics of marine litter,” in Marine Anthropogenic Litter, eds. M. Bergmann, L. Gutow, and M. Klages (Cham: Springer Open; Elsevier), 367–394. doi: 10.1007/978-3-319-16510-3_14

Øhlenschlæger, J.P.; Newman, S.; & Farmer, A. (2013). Reducing ship generated marine litter—Recommendations to improve the EU port reception facilities directive. Institute for European Environmental Policy (IEEP), London, 31p.

Oigman-Pszczol, S. S., & Creed, J. C. (2007). Quantification and Classification of Marine Litter on Beaches along Armação dos Búzios, Rio de Janeiro, Brazil. Journal of Coastal Research, 232(March), 421–428. http://doi.org/10.2112/1551-5036(2007)23(421:qacoml)2.0.co;2

Oliveira, A. de L., Tessler, M. G., & Turra, A. (2011). Longshore distribution of litter in sandy beaches – Case study in Massaguaçu Beach, Caraguatatuba, SP. Journal of Integrated Coastal Zone Management, 11(1), 75–84.

PEMALM (2021). São Paulo Strategic Plan for Monitoring and Assessment of Marine Litter. Org: Turra, A.; Neves, A.M.; Panarelli, A.M.; Elliff, C.I.; Romanelli, M.F.; Mansor, M.T.; Andrade, M.M.; Grilli, N.M.; Cardoso, O.A.; Zanetti, R.; Scrich, V.M. First edition. São Paulo: PEMALM, 72 p

Perez, L., Soares-Gomes, A., & Bernardes, M. C. (2018). A case study on the influence of beach kiosks on marine litter accumulating in Camboinhas beach, Southeast Brazil. Journal of Coastal Conservation, 22(6), 1085–1092. http://doi.org/10.1007/s11852-018-0615-z

PERS (2020). São Paulo State Plan for Solid Waste. Available at: https://smastr16.blob.core.windows.net/home/2020/12/plano-resi%CC%81duos-solidos-2020_final.pdf

Portz, L., Manzolli, R. P., & Ivar do Sul, J. A. (2011). Marine debris on Rio Grande do Sul north coast, Brazil: Spatial and temporal patterns. Journal of Integrated Coastal Zone Management, 11(1), 41–48. http://doi.org/10.5894/rgci187

Possatto, F. E., Spach, H. L., Cattani, A. P., Lamour, M. R., Santos, L. O., Cordeiro, N. M. A., & Broadhurst, M. K. (2015). Marine debris in a World Heritage Listed Brazilian estuary. Marine Pollution Bulletin, 91(2), 548–553. http://doi.org/10.1016/j.marpolbul.2014.09.032

Ramos, J. A. A., & Pessoa, W. V. N. (2019). Fishing marine debris in a northeast Brazilian beach: Composition, abundance and tidal changes. Marine Pollution Bulletin, 142(April), 428–432. http://doi.org/10.1016/j.marpolbul.2019.04.002

Rochman, C. M. (2015). The complex mixture, fate and toxicity of chemicals associated with plastic debris in the marine environment. In Marine anthropogenic litter (pp. 117-140). Springer, Cham.

Ryan, P. G., Moore, C. J., van Franeker, J. A., & Moloney, C. L. (2009). Monitoring the abundance of plastic debris in the marine environment. Philosophical Transactions of the Royal Society B: Biological Sciences, 364(1526), 1999-2012.

Ryan, P. G. (2015). A brief history of marine litter research. In Marine anthropogenic litter (pp. 1-25). Springer, Cham.

Sampaio, R. F., & Mancini, M. C. (2007). Systematic review studies: a guide for careful synthesis of the scientific evidence. Brazilian Journal of Physical Therapy, 11(1), 83-89.

Sampaio, C. L. S., & Pinto, T. K. (2015). Pollution by solid waste in low San Francisco, northeastern Brazil. Revista de Desenvolvimento Econômico, 1(39), 431. http://doi.org/10.21452/rde.v17nesp.4015

Santos, I. R., Friedrich, A. C., Fillmann, G., Wallner-Kersanach, M., Schiller, R. V., & Costa, R. (2004). Litter Production By Beach-Users At Cassino Beach (RS, Brazil). International Journal, 12–14.

Santos, I. R., Friedrich, A. C., & Barretto, F. P. (2005). Overseas garbage pollution on beaches of northeast Brazil. Marine Pollution Bulletin, 50(7), 778–782. http://doi.org/10.1016/j.marpolbul.2005.03.002

Santos, I. R., Friedrich, A. C., & Ivar do Sul, J. A. (2009). Marine debris contamination along undeveloped tropical beaches from northeast Brazil. Environmental Monitoring and Assessment, 148(1-4), 455–462. http://doi.org/10.1007/s10661-008-0175-z

Secchi, E. R., & Zarzur, S. (1999). Plastic debris ingested by a Blainville’s beaked whale, Mesoplodon densirostris, washed ashore in Brazil.

Silva-Cavalcanti, J. S., Araújo, M. C. B., & Costa, M. F. (2009). Plastic litter on an urban beach - A case study in Brazil. Waste Management and Research, 27(1), 93–97. http://doi.org/10.1177/0734242X08088705

Silva-Cavalcanti, J. S., Araújo, M. C. B., & Costa, M. F. (2013). Medium-term patterns and trends of solid waste contamination on the beach of Boa Viagem, Northeast Brazil. Quaternary and Environmental Geosciences, 4(1-2), 17–24. http://doi.org/10.5380/abequa.v4i1-2.25691

Silva-Cavalcanti, J. S., Barbosa, S. C. T., & Costa, M. F. (2008). Flag Items as a Tool for Monitoring Solid Wastes from Users on Urban Beaches. Journal of Coastal Research, 244(244), 890–898. http://doi.org/10.2112/06-0695.1

Smith, S. D., & Markic, A. (2013). Estimates of marine debris accumulation on beaches are strongly affected by the temporal scale of sampling. PLoS One, 8(12).

Smith, L., & Turrell, W. R. (2021). Monitoring Plastic Beach Litter by Number or by Weight: The Implications of Fragmentation. Frontiers in Marine Science, 1359.

SNIS (2019). Diagnóstico do manejo de Resíduos Sólidos Urbanos - 2019, Sistema Nacional de Informações sobre Saneamento, Ministério do Desenvolvimento Regional. Available at: www.snis.gov.br/diagnostico-anual-residuos-solidos/diagnostico-do-manejo-de-residuos-solidos-urbanos-2019

Soares, M. D. O., Paiva, C. C. De, Godoy, T. De, & Silva, M. D. B. (2011). Rocas Atoll (Equatorial South Atlantic): A case of Marine Debris in Remote Areas. Journal of Integrated Coastal Zone Management, 11(1), 149–152.

Stelmack, Ê. O., Vieira, C. V., Cremer, M. J., & Kroll, C. (2018). Marine debris in coastal environments: the case of praia grande in São Francisco do Sul island/SC, Brazil. GeoSul, 33(66), 11–28.

Suciu, M. C., Tavares, D. C., Costa, L. L., Silva, M. C. L., & Zalmon, I. R. (2017). Evaluation of environmental quality of sandy beaches in southeastern Brazil. Marine Pollution Bulletin, 119(2), 133–142. http://doi.org/10.1016/j.marpolbul.2017.04.045

The World Bank (2019). World Development Indicators. Gini index. Available at: https://data.worldbank.org/indicator/SI.POV.GINI

The World Bank (2020a). World Development Indicators. GDP ranking. Available at: https://datacatalog.worldbank.org/dataset/gdp-ranking-ppp-based

The World Bank (2020b). World Development Indicators. Population ranking. Available at: https://datacatalog.worldbank.org/dataset/population-ranking

Thompson, R. C., Olsen, Y., Mitchell, R. P., Davis, A., Rowland, S. J., John, A. W., ... & Russell, A. E. (2004). Lost at sea: where is all the plastic?. Science, 304(5672), 838-838.

Tourinho, P. S., & Fillmann, G. (2011). Temporal trend of litter contamination at Cassino beach, Southern Brazil. Journal of Integrated Coastal Zone Management, 11(1), 97–102. http://doi.org/10.5894/rgci201

Turra, A., Santana, M. F. M., Oliveira, A. L., Barbosa, L., Camargo, R. M., Moreira, F., & Denadai, M. R. (2020). Lixo nos mares: do entendimento à solução. São Paulo: Instituto Oceanográfico da Universidade de São Paulo. 124p.

UNEP (2012). Manila Declaration on Furthering the Implementation of the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities. UNEP/GPA/IGR.3/5, 4p. Available at: http://wedocs.unep.org/bitstream/handle/20.500.11822/13212/manila%20declaration.pdf?sequence=1&isAllowed=y

UNEP (2016). Marine Plastic Debris and Microplastics: Global Lessons and Research to Inspire Action and Guide Policy Change. United Nations Environmental Program, Nairobi, 252p. Available at: http://hdl.handle.net/20.500.11822/7720

UNEP (2021). Understanding the State of the Ocean: A Global Manual on Measuring SDG 14.1.1, SDG 14.2.1 and SDG 14.5.1. Nairobi.

van Eck, N. J., & Waltman, L. (2013). VOSviewer manual. Leiden: Universiteit Leiden, 1(1), 1-53.

Vieira, B. P., Dias, D., & Hanazaki, N. (2011). Homogeneity of Solid Waste Stranding in a Santa Catarina Island's Mangrove, Brazil. Journal of Integrated Coastal Zone Management, 11(1), 21–30. http://doi.org/10.5894/rgci188

Wetzel, L., Fillmann, G., & Niencheski, L. F. H. (2004). Litter contamination processes and management perspectives on the southern Brazilian coast. International Journal of Environment and Pollution, 21(2), 153. http://doi.org/10.1504/ijep.2004.004182

Widmer, W. M., & Hennemann, M. C. (2010). Marine Debris in the Island of Santa Catarina, South Brazil: Spatial Patterns, Composition, and Biological Aspects. Journal of Coastal Research, 26(6), 993–1000. http://doi.org/10.2112/JCOASTRES-D-09-00072.1

3. CHAPTER 2: Marine Litter Hierarchy as a strategy to balance the skewness of marine litter literature to downstream solutions

3.1. INTRODUCTION

Modern society is marked by a consumerist lifestyle and material waste. The constant increase in plastic production, consumption and discard is fueled by consumerism and accelerated by planned obsolescence of products (Bauman, 2008; Vergara & Tchobanoglous, 2012; Gonçalves-Dias, 2015a). As a result of this system, the global generation of solid urban waste is currently estimated at 2.01 billion tons per year; of which more than 33% do not receive adequate destination (The World Bank, 2018). The production and management of this waste have several impacts on public health and environmental quality, including climate change intensification (Espinoza et al., 2010; Vergara & Tchobanoglous, 2012) and pollution of the ocean by litter (UNEP, 2021a).

In urban centers, inappropriately managed solid waste is often carried to the ocean through winds, rivers, sewers, rainwater, and urban drainage systems (UNEP, 2009; Wowk, 2013; Jambeck et al., 2015; Galgani et al., 2015). When solid waste reaches coastal and marine environments, whether on purpose or accidentally, it is denominated marine litter (UNEP, 2009; GESAMP, 2019). Marine litter is mainly represented by plastics, as a result of the widespread use, associated with mismanagement, of this material by modern society due to its physical-chemical qualities (Andrady & Neal, 2009; Andrady, 2011; Derraik, 2002). Currently, it is estimated that 8 million tons of plastics enter the ocean each year (Jambeck et al., 2015).

Marine litter has gained progressive visibility due to the increasing recognition of its ecological, economic and social impacts (UNEP, 2016). The consequences of marine litter include damage to human health, food security, biodiversity, tourism, navigation, fishing and aquaculture (Gregory, 2009; GESAMP, 2019). Thereby, finding solutions for marine litter is a major current challenge, and is also the target of the Sustainable Development Goal 14.1 (SDG), which sets to: “prevent and significantly reduce marine pollution of all kinds, particularly from land-based activities, including marine debris and nutrient pollution”.

Litter pollution is a multi-complex and cross-cutting issue (UNEP, 2020). Marine litter is not only related to poor coastal and waste management, but also to product design, supply chain operations, and current patterns of consumption and waste generation (Gonçalves-Dias et al., 2012; UNEP, 2021a, UNEP, 2021d). To overcome this complex problem, the United Nations Environment Assembly (UNEA) emphasizes the need for soothing solutions in the whole plastic chain, and transitioning the current business model towards a circular economy (UNEP, 2019a; UNEP, 2021d). Thus, fighting marine litter requires actions in several links of the production-consumption chain, mainly actions focused on the prevention of waste generation at source (i.e., upstream solutions; Lau et al., 2020; Bellou et al., 2021; UNEP 2021b; Lohr et al., 2017; Williams & Rangel-Buitrago, 2019). The prevention of solid waste refers to measures taken before materials become waste, and aims at restraining material entry into the waste flow and avoiding adverse impacts on human health and the environment (Gonçalves-Dias & Bortoleto, 2014; Directive 2008/98/EC). Prevention might rely on productive processes or consumption (Gonçalves-Dias et al., 2015), encompassing promotion of awareness, change in attitudes and behaviors, or imposition of regulations (Gonçalves-Dias & Bortoleto, 2014). Besides prevention, the circular economy also contemplates sustainable design, waste reuse and recovery (Kirchherr et al., 2017, UNEP, 2021d).

Aspects of the circular economy, and other marine litter solutions, are addressed by the Waste Management Hierarchy framework (Waste Framework Directive 2008/98/EC), which defines strategies to reduce and manage solid waste, in order of preference. Other solutions are also contemplated in the Sustainable Supply Chain Management, which integrates operational strategies on the supply chain with social, economic, and environmental dimensions of sustainability (Seuring et al., 2008; Koberg & Longoni, 2019; CSCMP, 2013; Gonçalves-Dias et al., 2012). Sustainable Supply Chain Management considers suppliers, producers, consumers and reverse logistics, considering shared responsibility for solid waste and leading to a closed-loop supply chain (Gonçalves-Dias et al., 2012; Touboulic & Walker, 2015). Another relevant framework to address marine litter solutions is the Source-to-Sea approach, which considers different marine litter sources and their pathways through aquatic systems (UNEP, 2017). This approach also recognizes social and economic issues implicated within the topic of marine litter (Granit et al., 2017).

Actions to prevent and mitigate marine litter can be subsidized by the marine litter literature. More than that, the participation of marine litter scientists in decision-making processes is highly desired to secure the use of the best available knowledge. However, although it is extremely important to implement integrated solutions, covering not only downstream but also upstream actions, the marine litter scientific capital available in some locations (e.g., countries, states) may limit the array of solutions to be considered. Even though the scientific literature on marine litter often seeks to propose solutions to the problem, the integration of these actions to upstream solutions has never been accessed before. In order to provide an analysis of potential solutions proposed by the marine litter literature (and scientists) and to test the hypothesis that such a scientific capital would encompass a limited repertoire of potential solutions skewed to downstream actions, we selected Brazil as a case study. Brazil is a middle-income country with great socioeconomic inequality and multiple gaps in solid waste management, coastal management, and public policies (The World Bank, 2019, 2020; Chaves et al., 2014; Nicolodi et al., 2021; OECD, 2021), potentially representing the reality of other countries of the Global South (*sensu* Brandt, 1980). Even more, as a consequence of poor waste management and high consumption patterns, Brazil is a leading contributor of plastic pollution to the world's ocean, as are many other Global South countries (Jambeck et al., 2015; Lebreton & Andrady, 2019; Meijer et al., 2021). To fight this reality, Brazil has a distinguished agenda to combat litter pollution, including the National Plan to Combat Marine Litter (PNCLM) (MMA, 2019) and the São Paulo Strategic Plan for Monitoring and Assessment of Marine Litter (PEMALM, 2021).

Following the growing attention that marine litter has been receiving globally, the number of studies in the country has also been increasing (more information in Chapter 1). Aligned to the proposed national indicators for SDG 14.1 (UNEP, 2021b), we circumscribed our analysis on studies of macrolitter in the environment. Macrolitter is commonly defined as items larger than 2.5 cm (GESAMP, 2019), however, the minimum size collected varies according to studies. Macrolitter has established investigation protocols and is faster, simpler and cheaper to survey and analyze (GESAMP, 2019; UNEP, 2021b). Thus, it is reasonable to expect that studies on macrolitter in environmental compartments (shoreline, sea surface and column, and seafloor) would have a broader geographical and temporal coverage in the scientific literature in comparison to microlitter, especially in countries with resources limitations. In this way, studies on macrolitter may be a good proxy to assess the potential solutions presented in the marine litter literature.

Our analysis comes from the necessity to verify the potentialities and limitations of scientific literature at informing upstream solutions to fight marine litter; and, therefore, if these papers comprise a broad and comprehensive source to inform decision-makers about litter problematics and solutions. Thus, the present study aimed to: (a) analyze the literature reporting marine macrolitter in Brazil and evaluate its proposed solutions to prevent and mitigate litter pollution; and (b) analyze the alignment of proposed solutions with the following upstream approaches: Waste Management Hierarchy, Sustainable Supply Chain Management, and Source-to-Sea. Based on the results of our analyzes and also in the concepts of the Waste Management Hierarchy, Sustainable Supply Chain Management and Source-to-Sea approaches, we systematized, in the discussion section, a Marine Litter Hierarchy, which presents integrated strategies to prevent and mitigate marine litter. Considering that marine litter solutions can cover various levels of economic, social and political complexities, and that downstream solutions comprise simpler and short-term actions, we hypothesized that studies propose different marine litter solutions, but solutions extracted from papers refer mainly to downstream actions. It is important to note that the present study has an inherent vice of contemplating studies that did not aim to propose solutions for marine litter, but that potentially propose solutions in their discussion, not always as a consequence of information produced by the study. In doing this, we considered that this literature and the scientists behind it would represent the scientific capital that normally may engage and influence participatory processes to face marine litter and that the repertoire of solutions cited in the papers would comprise the potentialities (or limitations) to face marine litter in a holistic way.

3.2. MATERIAL AND METHODS

Marine litter solutions were accessed through a broad systematic mapping (James et al. 2016) of the literature reporting marine macrolitter in Brazil. The main question was: of the literature reporting marine macrolitter in Brazil, what are the cited/proposed solutions to prevent and mitigate litter pollution? The search was carried out in the Scopus and Web of Science databases, up to late 2019, following the subsequent research strategy: ["marine litter" OR "marine debris" OR "plastic litter" OR "plastic debris" OR "plastic pollution" OR "lixo marinho" OR "lixo plástico" OR "poluição plástica"] AND [Brasil OR Brazil]. This search was performed on articles title, abstract and keywords. References cited in previous reviews on fishing gear (Link et al., 2019) and marine litter (Ivar do Sul et al., 2007) in Brazil were also verified.

Articles published up to late 2019 were pre-selected. Article titles and abstracts were read to select only studies addressing macrolitter in different environmental compartments (shoreline, seafloor, sea surface, and water column; sensu GESAMP, 2019). Studies focusing on microplastics, litter interaction with biota, and beach users' perception were excluded. We also consulted the list of articles available on the Global Garbage database (http://www.globalgarbage.org). Only studies focusing on the Brazilian coast were selected. All peer-reviewed articles found on marine macrolitter in Brazil were considered, except for papers presenting only general information on litter pollution (no data) or beach clean-ups. One paper that met all selection criteria could not be accessed (Azevedo & Schiller, 1991 apud Ivar do Sul & Costa, 2007) and was thus excluded from the analysis. We also applied the snowball technique (Wohlin, 2014), using the reference lists of the primary articles to identify other studies of interest. The same critical reading and search for solutions were done in the secondary articles.

After reading the selected articles, we first observed if the authors suggested solutions to prevent and mitigate marine litter, based or not on the studies' results. The mention of these solutions was generally presented in the discussion or conclusion sections. Secondly, we extracted each solution that was suggested. Thirdly, we analyzed if these solutions were related only to marine litter, if they involved solid waste management actions, or if they dealt with both themes together. We also verified if the articles proposed solutions related to products and supply processes. Fourthly, we evaluated the insertion of solutions into the context of Waste Management Hierarchy, suggested by the European Commission (Waste Framework Directive 2008/98/EC), and in the context of Sustainable Supply Chain Management (Gonçalves-Dias et al., 2012) (Table 4). It is important to note that actions mentioned by an article could fit more than one approach, so our fractional results surpass 100%. Solutions that did not fit into these two approaches were also checked, and comprised actions that either contemplated punctual (non-integrated) actions or very wide changes in society (e.g. income and basic education). In addition, we verified the conformity of suggested solutions with the main aspects of the Source-to-Sea approach (Granit et al., 2017). The list of aspects related to the Source-to-Sea approach was formulated based on topics mentioned by the analyzed articles and the framework itself (Granit et al., 2017). Even though the aspects of the Source-to-Sea approach were interconnected, we divided them into categories, maintaining the particularities of proposed solutions.

3.3. RESULTS

We identified 59 articles reporting the presence of macrolitter in Brazilian coastal environments (beach and bottom sediments, and surface and water column (Table 5). The studies were published between 2001 and 2019. Among the studies analyzed, 49 suggested solutions to deal with marine litter (83.1%). Studies focused on actions directed to litter in the environment (e.g. clean-ups, beach cleaning services) (39.0%), solid waste management (e.g. waste discard, collection and disposal) (8.5%), or both (35.6%) (Fig. 7). In addition, some articles also proposed upstream changes in products and supply processes (10.2%) (e.g. reverse logistics, change in consumption patterns, environmentally friendly materials). Proposed solutions tended to focus on the spectrum of downstream solutions, however, isolated mentions in the papers indicated solutions that encompass the entire spectrum of upstream and downstream solutions (Table 5).

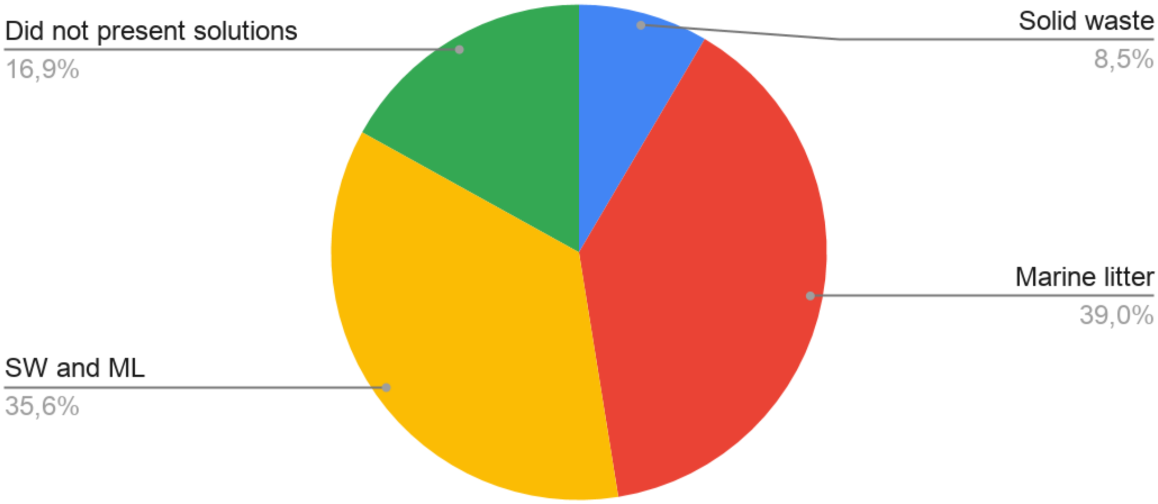


Fig. 7. Targets of the solutions to prevent and mitigate marine litter proposed by the surveyed literature of macrolitter in the environment in Brazil: marine litter (ML), solid waste (SW), or both (SW and ML).

Only 33.9% of articles indicated actions related to the Waste Management Hierarchy framework, while 71.2% presented solutions related to Sustainable Supply Chain Management. In addition, 42.4% of studies proposed solutions related to the Source-to-Sea approach, by considering marine litter sources and different aspects of integrated management.

Regarding the match of solutions within the Waste Management Hierarchy, studies mostly mentioned downstream actions, related to proper disposal (23.7%), recycling (11.9%), and products reuse (5.1%) (Table 4). Only 10.2% of studies mentioned upstream prevention actions, with focus on changes in consumption patterns (Ramos & Pessoa, 2019; Widmer et al., 2010; Andrades et al., 2016) and waste generation rates (Ivar do Sul et al., 2011, Corraini et al., 2018, Araújo & Costa, 2006a).

Table 4. Approaches and focal aspects of marine litter solutions proposed in the Brazilian literature surveyed. The classification of aspects is based on the Waste Management Hierarchy (Waste Framework Directive 2008/98/EC), Sustainable Supply Chain Management (adapted from Gonçalves-Dias et al., 2012) and Source-to-Sea approaches (adapted from Granit et al., 2017). The table also presents the main focal aspects of other main approaches, which either contemplated punctual actions or very wide changes in society. A single article could have more than one focal aspect mentioned regarding proposed solutions. Actions mentioned by an article could fit more than one approach, thus, the sum of the values is not 100%.

Approaches and their focal aspects	Definitions and specific actions	% of articles
Waste Management Hierarchy	**Priority of actions for waste prevention and management**	**33.9%**
Prevention of solid waste generation	Measures taken before a material becomes waste, like decreasing amounts of waste that are generated	10.2%
Reuse	Use again products or components for the same purpose for which they were conceived	5.1%
Recycling	Material recovery with waste reprocessing for the original or other purposes	11.9%
Other recovery methods	Processing of waste for useful purposes such as energy	0
Final disposal	Any operation which is not recovery	23.7%
Sustainable Supply Chain Management	**Strategic approach to reach socio-economic and environmental sustainability in the supply chain**	**71.2%**
Green products	Design for the environment (design durable items that generate less waste and can be reused, recovered)	6.8%
	Life cycle analysis (quantifying environmental impacts of products or processes along with their lifespan)	0
Green purchasing	Sustainable supplier selection, development, and evaluation (Within industry and market)	0
Green manufacturing and remanufacturing	Reuse products or components	5.1%
	Recycling materials	11.9%
	Other: production planning and control, inventory management, and recovery, repair, reconditioning	0
Distribution	Logistics strategies to minimize environmental harm	0
Reverse logistics	Collect, selection and pre-processing materials for proper disposal or return to production processes	3.4%
Waste management	Purchases reduction (consumer education)	8.5%
	Pollution prevention - environmental education	54.2%
	Pollution prevention - contamination control	10.2%
	Discard of products and packages	32.2%
	Solid waste collection	15.3%
New market development	Development of market to absorb remanufactured products and incorporate recyclables in industry	0
Source-to-Sea	**Integrated approach that contemplates sources, pathways, and sinks of solid waste, considering social, ecological, and economic dynamics**	**42.4%**
Integrated governance and management arrangements in the	Integrated coastal management	10.2%
	Integrated watershed management	10.2%

continuum from source to sea, through cooperation and strategic overview	Environmental management integrated with social and economic aspects	3.4%
	Integration between different social actors	6.8%
	Integration at an international level (agreements, plans, actions)	6.8%
	Basic sanitation	8.5%
	Identification of marine litter sources	6.8%
	Control of marine litter sources	6.8%
	Transboundary approach	1.7%

Regarding the Sustainable Supply Chain Management, most studies mentioned downstream actions focused on discard (32.2%) and pollution prevention (54.2% through environmental education and 10.2% through contamination control) (Table 5). Some examples of contamination control were: installing garbage bins (Fernandino et al., 2015); controlling contamination through environmental agencies (Andrades et al., 2016), or coordinating actions between government, society and the private sector (Farias, 2014); fighting sources (Fernandino et al., 2016b); considering waste management and proximity of protected areas to litter sources into Coastal Management Programs (Vieira et al., 2011); and reducing the input of marine-based litter (litter reception facilities in ports, inspection and fees for vessels that do not follow regulations, financial compensation for degradation) (Santos et al., 2005a).

Other aspects of the Sustainable Supply Chain Management were also addressed in the studies, such as remanufacturing (13.6%; recycling and/or reuse) and collection (15.3%; improvement of waste collection system). Few studies mentioned upstream changes in the production chain, such as reverse logistics (3.4% of total articles) (Stelmack et al., 2018; Widmer et al., 2010) and manufacturing of green products (6.8%; design for the environment). Some examples of green manufacture were: developing materials that are biodegradable (Mascarenhas et al., 2008) and environment-friendly (Possatto et al., 2015), designing products with reduced decomposition time (Chaves & Robert, 2009, Tourinho & Fillmann 2011); and making technological and operational adaptations to reduce material losses during fishing (Chaves & Robert, 2009).

Regarding the Source-to-Sea approach, the most mentioned actions were related to integrated management of municipalities or environments connected by watersheds (10.2%) or along the coast (10.2%). However, studies also made suggestions on the spectrum of basic sanitation (8.5%) and litter sources identification (6.8%) and control (6.8%). Besides that, integration of several different social actors (6.8%) and integration at an international level (agreement, plans, actions) (6.8%) also consisted in relevant aspects. Few studies approached the integration of environmental management with social and economic aspects (3.4%) (Araújo & Costa, 2006b; Silva-Cavalcanti et al., 2008). Only one article used the term “transboundary approach” when referring to marine litter solutions (1.7%) (Krelling & Turra, 2019).

Studies that made suggestions beyond the spectrum of the Waste Management Hierarchy and Sustainable Supply Chain Management, but concentrated on actions such as the removal of litter from the environment, which is also foreseen by the Honolulu Strategy (NOAA & UNEP, 2011). However, studies also addressed punctual issues such as incentive policies (Blue flags) (Widmer et al., 2010), infrastructure (dumps placement) and inspection; in addition to actions such as recovering affected habitats (Andrades et al., 2016), reducing use of single-use plastics in kiosks (Mascarenhas et al., 2008), making kiosks responsible for cleaning adjacent areas (Suciu et al., 2017), and improving port infrastructure to receive litter (Santos et al., 2005a). Besides that, other broader issues were suggested, such as: urban planning (Leite et al., 2014; Possatto et al., 2015), education and income improvement (Araújo & Costa, 2006b), working conditions of litter collectors (Ferreira & Lopes, 2013), and employment formalization of litter collectors (Silva-Cavalcanti et al., 2008).

Table 5. Aspects of marine litter solutions proposed by studies on marine macrolitter in Brazil, including: (a) solutions presence or absence, as well as their focal aspects (products/supply processes, solid waste, or marine litter); (b) adherence of solutions to aspects covered by the Waste Management Hierarchy, Sustainable Supply Chain Management, or both; (c) solutions related to the Source-to-Sea approach; and (d) solutions beyond the spectrum of these frameworks and other details. Considering the upstream-downstream spectrum, solutions highlighed by * comprise most upstream solutions that can be taken before materials become waste. Solutions highlighted by ** can comprise upstream solutions and also some downstream actions.

	Solutions				**WH**		**WH & SSCM**		**Sustainable supply chain management**						**Source-to-Sea approach**		
Reference	Solutions are cited	Products/processes*	Solid Waste	Marine Litter	Reuse*	Recycling	Prevention*	Final disposal	Sustainable design*	Purchase reduction*	Reverse logistics*	Discard	Collection	Pollution prevention	Source-to-Sea**	**Source-to-Sea aspect**	**Details and other solutions**
Figueiredo Jr. et al. (2001)																	
Araújo & Costa (2004a)	X			X										X			
Araújo & Costa (2004b)	X		X	X		X		X				X	X	X	X	integrated watershed management (solid waste collection, disposal and treatment)	
Wetzel et al. (2004)	X			X										X	X	integrated coastal management; integration between social actors; integration at international level and source identification	
Santos et al. (2004)	X			X										X			
Santos et al. (2005)	X		X	X								X		X	X	international management actions; integration between social actors	waste reception in ports, inspection and enforcement of fines
Araújo & Costa (2006a)	X		X	X			X	X				X	X	X	X	integrated coastal management	
Araújo & Costa (2006b)	X		X	X				X				X	X	X	X	integrated watershed management; integration between social, economic and environmental aspects	investments in education and income
Araújo & Costa (2007a)	X			X				X				X		X			
Araújo & Costa (2007b)	X		X					X				X	X		X	source identification	
Oigman-Pszczol & Creed (2007)	X		X	X													
Mascarenhas et al. (2008)	X	X	X	X		X		X	X			X	X	X	X	integrated actions between the municipalities of the same watershed	bins installation on the beaches; inspection and legislation on the fishing industry; encouraging the use of biodegradable materials; reducing plastic disposables use in bars and restaurants by the sea
Silva et al. (2008)	X		X	X										X	X	integration between social, economic and environmental aspects	employment formalization
Chaves & Robert (2009)	X	X		X					X								technological and operational adaptations to prevent fishing gear loss
Santos et al. (2009)	X			X										X	X	integrated watershed management	

Silva-Cavalcanti et al. (2009)		beach cleaning
Cordeiro & Costa (2010)	sanitation; source control	waste discharge monitoring
Machado & Fillmann (2010)		
Widmer et al. (2010)	integrated watershed management (manholes, catchment basins, waterways and beaches cleaning)	designating packaging and plastics industry responsibility; blue flags
Baptista Neto & Fonseca (2011)		
Carvalho-Souza & Tinôco (2011)	integrated coastal management	organizing commercial practices; conditions of use; educational-social practices
Costa et al. (2011)		
Dias Filho et al. (2011)		
Ivar do Sul et al. (2011)	international integration (agreements)	
Neves et al. (2011)	integration between municipalities belonging to the watershed	
Oliveira et al. (2011)		beach cleaning
Portz et al. (2011)		
Soares et al. (2011)		
Tourinho & Fillmann (2011)		designation of responsible parties
Vieira et al. (2011)	integrated coastal management considering litter sources	
Ferreira & Lopes (2013)		incentives for waste pickers (improving working conditions)
Ivar do Sul & Costa (2013)		
Silva-Cavalcanti et al. (2013)		beach cleaning; installation of bins
Belarmino et al. (2014)		beach cleaning; installation of bins
Farias (2014)	integration between social actors (government, society and the private sector)	
Leite et al. (2014)	source control	urban planning; beach cleaning
Fernandino et al. (2015)	integrated coastal management, source control	
Possatto et al. (2015)	integration between local government and civil society	urban planning
Sampaio & Pinto (2015)		
da Silva et al. (2015)		installation of bins on the beaches
Andrades et al. (2016)	international integration (global agreements)	recovering areas affected by marine litter
de Santana Neto et al. (2016)		
Fernandino et al. (2016a)	sanitation	

Fernandino et al. (2016b)	source control: sanitation and sewage treatment	
Lima et al. (2016)		
Sampaio & Pinto (2015)		
Krelling et al. (2017)		
Suciu et al. (2017)		beach cleaning; installing bins; educational signs; laws to make kiosks responsible for cleaning adjacent areas; laws and fines
Andrades et al. (2018)		
Araújo et al. (2018)		bins on the beaches; distribution of waste collection containers
Cordeiro et al. (2018)		
Corraini et al. (2018)	sanitation; source control	beach cleaning
Farias et al. (2018)		
Perez et al. (2018)		
da Silva et al. (2018)	source identification	replacing the disposables use; anti-smoking campaigns; distribution of ashtrays to beach users
Stelmack et al. (2018)		marine litter inspection and monitoring
Krelling & Turra (2019)	transboundary approach; source control	
Marin et al. (2019)		laws and programs to ensure environmental quality
Ramos & Pessoa (2019)		

3.4. DISCUSSION

Our analysis revealed that studies presented a wide spectrum of solutions, mainly focused on downstream actions. Downstream actions comprised measures to only mitigate marine pollution, such as environmental education for pollution prevention and proper solid waste discard and disposal. Most of the proposed solutions referred to downstream actions and were not greatly related to changes in the current patterns of production, consumption and waste generation (i.e. upstream solutions). The adherence of solutions to the Waste Management Hierarchy and Sustainable Supply Chain Management was observed through proposals focused on final waste processes (discard, recycling, and disposal). The adherence to the Source-to-Sea approach occurred mainly through proposals related to the integrated management of municipalities and watersheds. These results support our hypothesis that the literature reporting marine macrolitter in Brazil harbors a repertoire of different marine litter solutions, but solutions refer mostly to downstream actions. Thus, we observed that solutions were mostly directed to the scale of the phenomenon the studies were investigating - the presence of litter in the coastal and marine environments is a downstream consequence of solid waste generation, which may bias the contribution of science in participatory processes. To attenuate such a bias, other knowledge areas, such as sustainability, management, business and product engineering, should be enrolled in participatory processes.

Although most analyzed articles presented marine litter solutions, it is important to emphasize that all the analyzed studies intended to assess litter presence in the coastal environment. Thus, solutions emerged as complements or conclusions, being associated with information obtained from external sources. It was not expected that studies based on field collections and litter quantification/qualification would necessarily present solutions for marine litter, or would present solutions related to a broader view than the study object. However, we observed that most articles presented solutions. Most studies proposed solutions only related to marine litter, such as environmental education for pollution prevention, beach cleaning, and integrated management between coastal municipalities and/or municipalities inserted in the same watershed. Some articles also proposed solutions related to solid waste, such as waste discard, collection, recycling, and final disposal. Few articles brought solutions related to the products and supply processes. Pre-consumption actions are considered essential to ensure recycling, waste generation reduction, and final disposal optimization (Hyman et al., 2015). Although the studies were not made to propose solutions, they reveal the perspective of scientists about marine litter solutions, which is partial and does not allow a comprehensive systemic perspective of the problem.

The proposed solutions in the literature were mainly focused on removing litter from coasts and ocean, and on intercepting litter input into these environments. The most common strategies were water/beach cleaning (15.3%) and environmental education for pollution prevention (52.2%). Beach cleanings are sporadic, palliative and insufficient in the absence of permanent policies, as they do not prevent recontamination (Caldas, 2007; Dantas et al., 2011; Portz et al., 2011; Fernandino et al., 2015; Santos et al., 2009). However, beach cleaning can also be used as a tool for awareness-raising and education, gaining greater transformative potential in society (Thompson & Maximenko, 2016; Santos et al., 2005b). Environmental education is essential to engage citizens in fighting marine litter. However, action plans involving only environmental education, and litter disposal plus removal from beaches are not enough to solve this problem in the long term (Tourinho & Fillmann, 2011; NOAA & UNEP, 2011; UNEP, 2021d). Environmental education must be accompanied by other changes in the production-consumption chain (Thompson & Maximenko, 2016).

The adherence among the proposed solutions to the Waste Management Hierarchy framework was unbalanced and mostly directed to downstream solutions. Steps related to final waste processes, such as recycling and waste disposal were frequently mentioned. However, waste generation prevention and reuse of materials and products was addressed by very few articles. Although recycling is essential because it represents one of the possible restarts of the product life cycle (Thompson & Maximenko, 2016), waste generation prevention is still considered the initial and preferred step of the Waste Management Hierarchy (Vergara & Tchobanoglous, 2012). Following generation prevention, reuse is a primary alternative to generated waste, because it reduces material entry into the waste stream (Gonçalves-Dias et al., 2015b; Waste Framework Directive 2008/98/EC). Furthermore, no article mentioned (energy) recovery, a stage of the Waste Management Hierarchy that represents the last alternative to non-reused and non-recycled waste (Thompson & Maximenko, 2016; Waste Framework Directive 2008/98/EC, Hyman et al., 2015). The recovery stage is only recommended when economically and environmentally viable (Espinoza et al., 2010), which may not be the case in Brazil, where recovery technologies are still expensive (da Silva et al., 2020).

The adherence of proposed solutions within the Sustainable Supply Chain Management scheme was also unbalanced. Articles focused on waste final stages, such as pollution prevention through environmental education, waste discard and remanufacturing (recycling/reuse). Some aspects of green operations, such as green purchase and distribution, were not considered by the articles. Other aspects, such as reduction of purchases, reverse logistics and green design were hardly mentioned. Green purchase and reduction of purchases are essential to prevent and reduce waste generation. Whereas reverse logistics is important considering product reuse, recycling or proper final destination, after the product is collected and returned to the producer. Thus, reverse logistics is directly related to the implementation of shared responsibility for products life cycle (Federal Law No. 12.305, 2010). Another important factor is green design, which promotes technologies focused on durable, repairable, reusable, and recyclable products (Waste Framework Directive 2008/98/EC; Vergara & George Tchobanoglous, 2012; Gonçalves-Dias et al., 2015b). In addition, green design enables resource recovery; from this perspective, waste is considered a source to be recovered and used (Hyman et al., 2015). Little mention of changes in the supply chain may reveal an inertia of scientific literature from appropriating knowledge from other areas, even though these areas complement marine litter science.

Even though the Source-to-Sea concept was recently introduced in the literature, its aspects have been regularly mentioned by the literature reporting marine macrolitter in Brazil. The Source-to-Sea approach is already widely discussed as an innovative and important approach for water system management and governance (SIWI, 2021). The Source-to-Sea approach is being promoted and potentialized by the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA/UNEP) (UNEP, 2021c). The adherence of the proposals to the Source-to-Sea approach occurred due to multiple studies considering integrated management (mainly of neighboring municipalities and aquatic systems) as an important marine litter solution. Integrated management consists of action planning based on regional and global contexts and complexities (Granit et al., 2017), and can effectively control pollution sources. Since marine litter can have multiple land-based and ocean-based sources, proposing actions to control litter sources is essential to fight pollution (UNEP, 2020). Thus, the adherence of solutions within the Source-to-Sea approach indicates a transboundary view of marine litter. The transboundary view surpasses geopolitical limits and promotes ecosystem-based cooperation among neighboring municipalities, states, or nations (Sandwith et al., 2001; Krelling et al., 2017). The Source-to-Sea approach is essential to planning preventive actions that consider the sources, pathways, and destinations of litter in aquatic environments (UNEP, 2017; Granit et al., 2017).

The studies’ adherence to each framework can be explained by the background of authors who publish on marine litter, as well as the studies’ focuses. Most authors are biology and marine science professionals, and most studies published in the selected literature are turned to environmental pollution and conservation. Moreover, since marine litter studies are historically developed by environmental sciences (Gregory, 2009; Ryan, 2015), there may be a trend to compartmentalize marine litter into this research field. These facts explain the strongest adhesion of litter solutions to the Source-to-Sea approach. Likewise, they also clarify the little adherence to the Waste Management Hierarchy and SSCM frameworks. Most authors who make publications on marine litter are neither waste managers nor environmental/sanitary engineers and do not have, necessarily, a strong background in waste management. However, they will certainly be those who will have great interest and participation in processes of discussion of actions to combat marine litter (e.g. PEMALM, 2021). The perception scientists are sharing in discussion arenas might be similar to the perception they couple their papers with. Thus, we extracted from studies a repertoire of possible solutions that could be shared in discussion arenas, even though this repertoire sampling has a vice due to the scope of studies. Our analyses revealed partiality in the scientific capital perspective, towards downstream solutions for marine litter, which needs to be ruptured. Although some papers mentioned some upstream solutions, during a scientist's participation in a discussion arena, the broad spectrum of solutions may not necessarily be evident in the participants' repertoire, which can lead to a trend towards more downstream-oriented solutions. To properly foster solutions-building processes, we might focus on strengthening participatory processes and promoting integration among professionals of different expertise areas.

The alignment of scientists' perspectives to integrated marine litter solutions is especially important when considering local-level impact. When studies are read or scientific capital participates in discussions at the local level, they do not necessarily expose a mature, strategic and systemic framework to combat marine litter. Thus, it is necessary to align perspectives to upstream integrated solutions. This is especially important when developing and implementing local innovation ecosystems to solve the problem in a municipality. Although at the national and international level, dialogues tend to be more comprehensive and interdisciplinary, the international literature and UNEP's training (The United Nations Environment Programme) may not be able to bring elements to guide actions in the most appropriate way. However, the progressive recognition of marine litter socioeconomic causes and consequences guides science, governance and management towards integrated solutions.

Little integration of studies to Waste Management Hierarchy and the SSCM frameworks may indicate the need for more interdisciplinary approaches to marine litter, as well as the involvement of a wide range of professionals with different views on participatory processes. Hence, we encourage environmental scientists to broaden marine litter solutions towards an upstream perspective. Moreover, we recommend that waste managers include marine litter in their topic of study, since aquatic systems comprise possible destinations of leak-prone plastic waste. Improving interdisciplinarity of marine litter solutions supports the subsidy of efficient plans for combating this complex problem. For improving interdisciplinarity, it is extremely important to build a solid network and integrate professionals with different expertise in discussion arenas.

3.4.1. Systematizing marine litter solutions

The analyzed articles presented several marine litter solutions. Based on the solutions proposed by the studies, as well as the Waste Management Hierarchy, Sustainable Supply Chain Management and Source-to-Sea approaches, the present study proposes a Marine Litter Hierarchy (Fig. 8). The Marine Litter Hierarchy systematizes the steps to prevent and mitigate marine litter, considering actions in various links of the production-consumption-discard-pollution chain. The steps are presented in order of environmental preference (based on the Waste Management Hierarchy), where upstream actions are prioritized and waste generation prevention is the primary step (base of the pyramid). Prevention is possible mainly through education, public policies, and green design (Hyman et al., 2015; Gonçalves-Dias et al., 2015b; Waste Framework Directive 2008/98/EC; UNEP, 2021d).

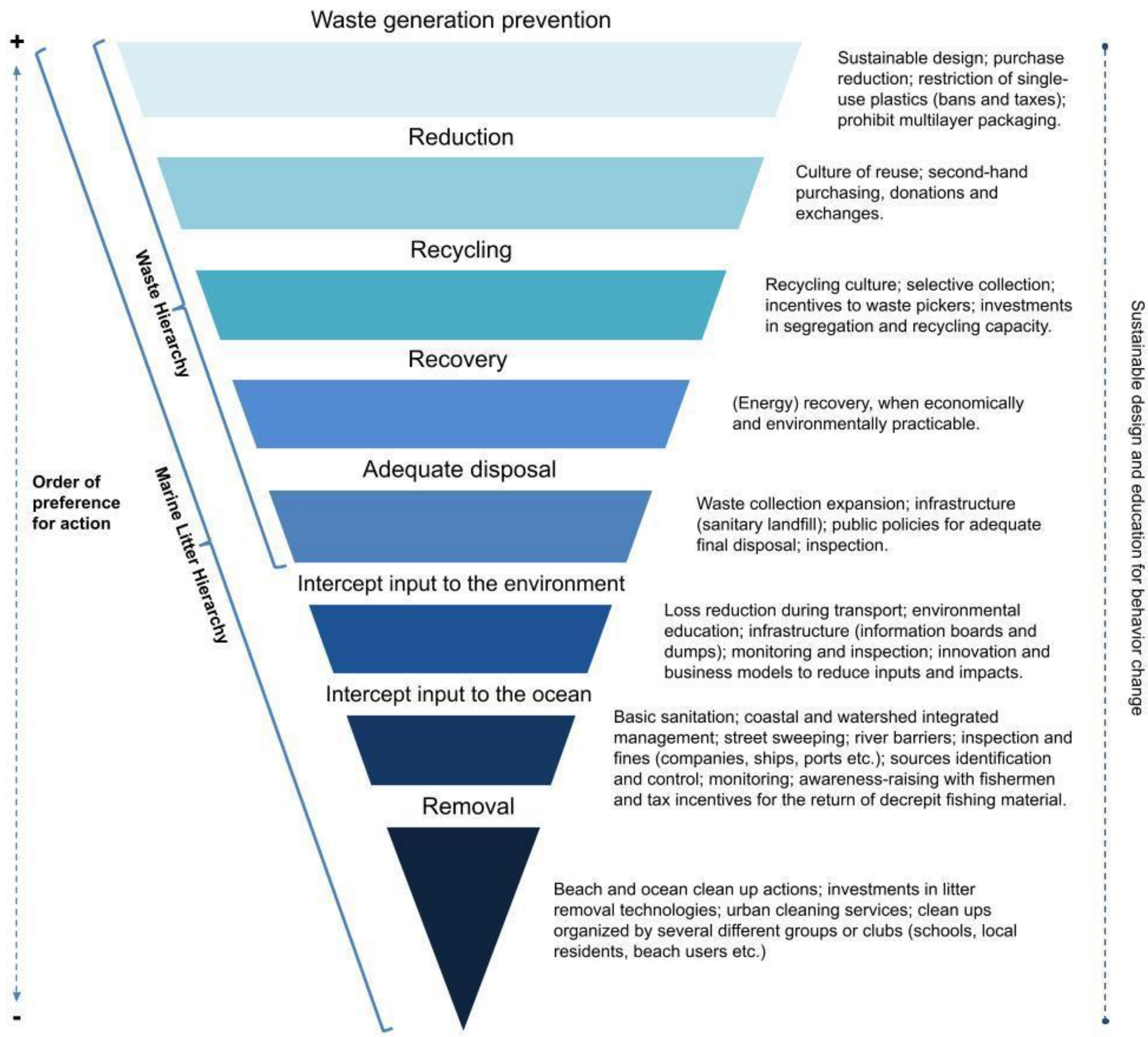


Fig. 8. Marine Litter Hierarchy: strategies to prevent and mitigate marine litter, in order of preference and including examples of actions. Adapted from the Waste Management Hierarchy (Waste Framework Directive 2008/98/EC). This framework includes some strategies of Sustainable Supply Chain Management (Gonçalves-Dias et al., 2012) and examples of solutions proposed in the marine macrolitter literature in Brazil. Sustainable design and education for behavior change allow and facilitate all stages of this hierarchy.

Marine Litter Hierarchy is an innovative systematization. Even though a Waste Management Hierarchy already exists, this is not introduced in the context of marine litter. Usually, frameworks and public policies on solid waste do not cover specific themes of marine litter. For example, the Brazilian National Solid Waste Policy (PNRS) and the National Basic Sanitation Policy (PNSB) do not have specific focuses on marine litter, even though available instruments are partially adequate to combat marine litter (Oliveira & Turra, 2015). Compared to Waste Management Hierarchy, Marine Litter Hierarchy is innovative by adding downstream elements to the pyramid. However, compared to solutions that have been proposed by the literature reporting marine macrolitter in Brazil, Marine Litter Hierarchy adds upstream measures to the existing solutions' framework. The proposed pyramid couples downstream actions with upstream solutions in a systematized way, having the potential to contribute to national and international frameworks such as the Honolulu Strategy for prevention and management of marine debris (NOAA & UNEP, 2011).

The Waste Management Hierarchy and the Marine Litter Hierarchy illustrate the progression of material through successive stages of waste management. They represent the final stages of a product's life cycle, which begin with designing and proceed to bill, distribution, use and, lastly, the final stages of waste management (Hyman et al., 2015). In the Marine Litter Hierarchy, there are additional steps to intercept litter input to the environment and, specifically, to the ocean; in addition to litter removal from coastal and marine environments. Each stage of this pyramid offers intervention opportunities: rethinking the product’s need, designing to minimize waste and extend the product’s use, recovering incorporated resources (Hyman et al., 2015), optimizing appropriate final disposal, developing strategies to prevent litter entry in the environment, and investing in efficient removal strategies. This framework is aligned with the Sustainable Development Goal 12.5, which aims to “substantially reduce waste generation through prevention, reduction, recycling, and reuse”.

Improvements in education quality and access have the potential to impact all stages of the Marine Litter Hierarchy, by expanding socio-environmental justice and causing behavior changes in purchasing, reusing, recycling, and discarding (Hyman et al., 2015; Thompson & Maximenko, 2016). Another factor that can reflect in all pyramid stages is the design of products. Sustainable design not only prevents solid waste generation, but it also facilitates actions at each of the next steps in this hierarchy (e.g. product use extension, component repair, and resource recovery) (Hyman et al., 2015; Waste Framework Directive 2008/98/EC). Thus, the sustainable design also has the potential to improve end-of-life product management, as it allows the conclusion of the production-consumption cycle in a closed circuit (Vergara & Tchobanoglous, 2012), contributing to a circular economy (UNEP, 2021d). Monitoring is another significant factor in the Marine Litter Hierarchy, especially in the final steps. Monitoring environmental quality and the effectiveness of prevention and mitigation measures is important to promote adaptations that may be necessary (GESAMP, 2019; Thompson & Maximenko, 2016).

Besides environmental management, preventing and mitigating litter in coastal and marine environments requires coordination throughout the entire supply chain. This includes measures focused on: product design, raw material obtainment, production, distribution, consumption, and adequate final disposal (Gonçalves-Dias et al., 2015b). In this process, collaboration among several social actors and economic sectors is needed (government, industries, companies, population, NGOs, waste pickers' cooperatives etc.). Strong coordination of stakeholders across the plastics value chain is essential (UNEP, 2020), since plastics are the most common type of marine litter. Transitioning the current business model towards sustainable economic models, such as the circular economy, can better guide society towards sustainable production and consumption (UNEP, 2021e). Circular economy promotes sustainable design, materials reuse, and waste recovery (UNEP, 2021d, 2021e). Even more, circular economy implies cultural, technological and strategic changes in society, and relies on changes in behavior and supply processes (Kirchherr et al., 2017).

As illustrated by the Marine Litter Hierarchy, a set of technological, strategic, structural and cultural changes are necessary together to address marine litter (Vergara & Tchobanoglous, 2012; Gonçalves-Dias, 2015a; Thompson & Maximenko, 2016; Waste Framework Directive 2008/98/EC, Hyman et al., 2015). Solutions must also cover policy, management, financing, research, awareness-raising, and behavior change (UNEP, 2019b; UNEP, 2020). It is also extremely important to invest in knowledge, capacity building, innovation and business models to reduce litter inputs and impacts; in addition to technology to remove marine litter (UNEP, 2020).

3.5. CONCLUSIONS

The scientific literature on marine macrolitter in Brazil proposed several solutions to prevent and mitigate marine litter. These solutions were occasionally linked to the Source-to-Sea approach, mainly by proposing integrated management and sources identification and control. Many studies also adhered to the Waste Management Hierarchy and the Sustainable Supply Chain Management, mainly by addressing final waste processes, such as discard and disposal (downstream actions). A minority of studies mentioned changes in the production chain and current consumption patterns, not encompassing the shared responsibility for solid waste and upstream solutions that fulfill the circular economy. These changes are essential to prevent litter pollution and other environmental problems. Based on the solutions proposed by the analyzed articles and considering the Waste Management Hierarchy, Sustainable Supply Chain Management and Source-to-Sea approaches, the present study proposes the Marine Litter Hierarchy, a systematization of marine litter solutions. This framework considers actions in various links of the production-consumption-discard-pollution chain, which can be applied through the collaboration of multiple stakeholders. The Marine Litter Hierarchy integrates the Sustainable Development Goals 14.1 (reduce land-based marine pollution), 12.5 (reduce waste generation) and 4 (education), tying up waste generation reduction to marine pollution prevention and including education as an important transversal approach to solve the problem. This framework provides an upstream view of the marine litter issue, establishing a baseline for science, governance and management. In order to promote the upstream solutions for marine litter, we emphasize the importance of integrating professionals with different expertise and promoting interdisciplinary approaches.

We checked the potential of articles on marine macrolitter in Brazil to inform integrated solutions for marine litter. If a decision-maker read these articles seeking not only knowledge of the problem, but solutions, they would not be well-informed, since papers mostly focus on downstream actions (e.g. better managing solid waste and removing litter from the environment). Although studies indicate pathways to combat marine litter, they often do not include integrated approaches. We analyzed the wealth of solutions presented by these papers. We conclude that the potential of solutions extracted from literature reporting marine macrolitter in Brazil is directed towards downstream actions. The solutions presented in the papers might reflect the perception of the authors about possible pathways to tackle marine litter. This perception might be the same one these scientists are sharing in discussion arenas. Thus, it is important to guarantee that environmental scientists have a broad view of litter solutions, which can be improved through integration with professionals from other expertise areas. Aligning downstream and upstream actions is important not only at the national but also at the global level. Thus, it is essential to promote a global agreement to promote integrated solutions.

3.6. REFERENCES

Andrades, R., Martins, A. S., Fardim, L. M., Ferreira, J. S., & Santos, R. G. (2016). Origin of marine debris is related to disposable packs of ultra-processed food. Marine Pollution Bulletin, 109(1), 192–195. http://doi.org/10.1016/j.marpolbul.2016.05.083

Andrades, R., Santos, R. G., Joyeux, J. C., Chelazzi, D., Cincinelli, A., & Giarrizzo, T. (2018). Marine debris in Trindade Island, a remote island of the South Atlantic. Marine Pollution Bulletin, 137(October), 180–184. http://doi.org/10.1016/j.marpolbul.2018.10.003

Andrady, A. L., & Neal, M. A. (2009). Applications and societal benefits of plastics. Philosophical Transactions of the Royal Society B: Biological Sciences, 364(1526), 1977-1984.

Andrady, A. L. (2011). Microplastics in the marine environment. Marine pollution bulletin, 62(8), 1596-1605.

Araújo, M. C. B., & Costa, M. F. (2004a). Quantitative and qualitative analysis of the solid waste left by visitors on Tamandaré Bay, Pernambuco state, Brazil. Gerenciamento Costeiro Integrado, 58–61.

Araújo, M. C. B., & Costa, M. F. (2004b). Quali-Quantitative Analysis of the Solid Wastes at Tamandare Bay, Pernambuco, Brazil. Tropical Oceanography, 32(2), 159–170.

Araújo, M. C. B., & Costa, M. F. (2006a). Municipal Services on Tourist Beaches: Costs and Benefits of Solid Waste Collection. Journal of Coastal Research, 225(225), 1070–1075. http://doi.org/10.2112/03-0069.1

Araújo, M. C. B., & Costa, M. F. (2006b). The significance of solid wastes with land-based sources for a tourist beach: Pernambuco , Brazil. Pan-American Journal of Aquatic Sciences, 1(1), 28–34.

Araújo, M. C. B., & Costa, M. F. (2007a). Visual diagnosis of solid waste contamination of a tourist beach: Pernambuco, Brazil. Waste Management, 27(6), 833–839. http://doi.org/10.1016/j.wasman.2006.04.018

Araújo, M. C. B., & Costa, M. F. (2007b). An analysis of the riverine contribution to the solid wastes contamination of an isolated beach at the Brazilian Northeast. Management of Environmental Quality: An International Journal, 18(1), 6–12. http://doi.org/10.1108/14777830710717677

Araújo, M. C. B., Silva-Cavalcanti, J. S., & Costa, M. F. (2018). Anthropogenic Litter on Beaches With Different Levels of Development and Use: A Snapshot of a Coast in Pernambuco (Brazil). Frontiers in Marine Science, 5(July), 1–10. http://doi.org/10.3389/fmars.2018.00233

Azevedo, T. D., & Schiller, A. (1991). Notes on the diet and the ingestion of plastic material by the Magellanic penguin Spheniscus magellanicus on Santa Catarina Island and mainland (Brazil). Unit. Doc. Zoologie. Seru. Ethol. Psichol. Anim. Universidade Liege, Bélgica. Rapport, 457, 1-8. apud do Sul, J. A. I., & Costa, M. F. (2007). Marine debris review for Latin America and the wider Caribbean region: from the 1970s until now, and where do we go from here?. Marine Pollution Bulletin, 54(8), 1087-1104.

Baptista Neto, J. A., & Fonseca, E. M. da. (2011). Seasonal, spatial and compositional variation of beach debris along of the eastern margin of Guanabara Bay (Rio de Janeiro) in the period of 1999-2008. Journal of Integrated Coastal Zone Management, 11(1), 31–39.

Bauman, Z. (2008). Consumismo versus Consumo. In: Bauman, Z. Vida para o consumo: a transformação das pessoas em mercadoria. Rio de Janeiro: Zahar, p.37-69 [cap.1].

Belarmino, P. H. P., Silva, S. M. da, Rufener, M.-C., & Araújo, M. C. B. (2014). Solid waste in mangrove in the Potengi River (Natal, RN, Brazil): relation to the location and uses. Journal of Integrated Coastal Zone Management, 14(3), 447–457. http://doi.org/10.5894/rgci451

Bellou, N., Gambardella, C., Karantzalos, K., Monteiro, J. G., Canning-Clode, J., Kemna, S., ... & Lemmen, C. (2021). Global assessment of innovative solutions to tackle marine litter. Nature Sustainability, 4(6), 516-524.

Brandt, W. (1980). A Programme for Survival. The Report of the Independent Commission on International Development Issues. The journal of Human Resources, 81(5), 52-120.

Caldas, A. H. M. (2007). Análise da disposição de resíduos sólidos e da percepção dos usuários em áreas costeiras-um potencial de degradação ambiental. CEP, 40, 630.

Carvalho-Souza, G. F., & Tinôco, M. S. (2011). Evaluation of Marine Debris in Rock Reefs in the Todos os Santos Bay, Bahia, Brazil. Journal of Integrated Coastal Zone Management, 11(2), 135–143. Retrieved from http://www.aprh.pt/rgci/pdf/rgci-231_Carvalho-Souza.pdf

Chaves, L.D., dos Santos Jr, J. L., & Rocha, S. M. S. (2014). The challenges for solid waste management in accordance with Agenda 21: a Brazilian case review. Waste Management & Research, 32(9_suppl), 19-31.

Chaves, P. de T., & Robert, M. de C. (2009). Loss and abandon of fishing gears in southern brazil and risks of occurrence of ghost-fishing. Boletim Do Istituto de Pesca, 35(3), 513–519.

Cordeiro, C. A. M. M., & Costa, T. M. (2010). Evaluation of solid residues removed from a mangrove swamp in the São Vicente Estuary, SP, Brazil. Marine Pollution Bulletin, 60(10), 1762–1767. http://doi.org/10.1016/j.marpolbul.2010.06.010

Cordeiro, T. C., Barrella, W., Butturi-Gomes, D., & Petrere Júnior, M. (2018). A modeling approach for reposition dynamics of litter composition in coastal areas of the city of Santos, Sao Paulo, Brazil. Marine Pollution Bulletin, 128(January), 333–339. http://doi.org/10.1016/j.marpolbul.2018.01.054

Corraini, N. R., de Souza de Lima, A., Bonetti, J., & Rangel-Buitrago, N. (2018). Troubles in the paradise: Litter and its scenic impact on the North Santa Catarina island beaches, Brazil. Marine Pollution Bulletin, 131(April), 572–579. http://doi.org/10.1016/j.marpolbul.2018.04.061

Costa, M. F., Silva-Cavalcanti, J. S., Barbosa, C. C., Portugal, J. L., & Barletta, M. (2011). Plastics buried in the inter-tidal plain of a tropical estuarine ecosystem. Journal of Coastal Research, 165(Special Issue 64), 339–343. http://doi.org/10.2112/SI65-206.1

CSCMP (2013). Supply Chain Management Definitions and Glossary. Available at: https://cscmp.org/CSCMP/Educate/SCM_Definitions_and_Glossary_of_Terms.aspx

Dantas, V. C., Silva, J. C., Morais, E. C., Bezerra, K. B., Chaves, M. F., & Riul, P. (2011) Influência da desembocadura do rio paraíba na densidade de resíduos sólidos em praias de Lucena, Paraíba, Brasil. Resíduos, 513(763.32), 1-488.

da Silva, M. L., Araújo, F. V. de, Castro, R. O., & Sales, A. S. (2015). Spatial-temporal analysis of marine debris on beaches of Niterói, RJ, Brazil: Itaipu and Itacoatiara. Marine Pollution Bulletin, 92(1-2), 233–236. http://doi.org/10.1016/j.marpolbul.2014.12.036

da Silva, M. L., Sales, A. S., Martins, S., Castro, R. O., & Araújo, F. V. de. (2016). The influence of the intensity of use, rainfall and location in the amount of marine debris in four beaches in Niteroi, Brazil: Sossego, Camboinhas, Charitas and Flechas. Marine Pollution Bulletin, 113(1-2), 36–39. http://doi.org/10.1016/j.marpolbul.2016.10.061

da Silva, M. L., Castro, R. O., Sales, A. S., & Araújo, F. V. de. (2018). Marine debris on beaches of Arraial do Cabo, RJ, Brazil: An important coastal tourist destination. Marine Pollution Bulletin, 130(December 2017), 153–158. http://doi.org/10.1016/j.marpolbul.2018.03.026

da Silva, L. J.V.B, dos Santos, I. F. S., Mensah, J. H. R., Gonçalves, A. T. T., & Barros, R. M. (2020). Incineration of municipal solid waste in Brazil: An analysis of the economically viable energy potential. Renewable Energy, 149, 1386-1394.

de Santana Neto, S. P., Silva, I. R., & Bittencourt, A. C. D. S. P. (2016). Distribuição do lixo marinho e sua interação com a dinâmica de ondas e deriva litorânea no litoral norte do estado da bahia, brasil. Geociencias, 35(2), 231–246.

Derraik, J. G. (2002). The pollution of the marine environment by plastic debris: a review. Marine pollution bulletin, 44(9), 842-852.

Dias Filho, M. J. O., Araújo, M. C. B., Silva-Cavalcanti, J. S., & Silva, A. C. M. (2011). Contamination of Boa Viagem Beach (Pernambuco State , Brazil) by marine litter: relationship with its usage. Labomar, 44(1), 33–39.

Espinoza, P. T., Arce, E. M., Daza, D., Faure, M. S., & Terraza, H. (2010). Avaliação Regional da Gestão de Resíduos Sólidos Urbanos na América Latina e Caribe 2010. México: BID, OPAS e AIDIS.

Farias, S. C. G. (2014). Accumulation of waste disposal in coastal environments: the ocean beach Piratininga-Niterói-RJ. Geo UERJ, 2(25), 276–296.

Farias, E. G. G., Preichardt, P. R., & Dantas, D. V. (2018). Influence of fishing activity over the marine debris composition close to coastal jetty. Environmental Science and Pollution Research, 25, 16246–16253.

Federal Law No. 12.305 (2010). Institui a Política Nacional de Resíduos Sólidos; altera a Lei no 9.605, de 12 de fevereiro de 1998; e dá outras providências. Presidência da República: Cassa Civil

Fernandino, G., Elliff, C. I., & Silva, I. R. (2015). Degree of pollution by benthic litter in beaches in Salvador, Bahia, Brazil. Sciencia Plena, 11(3), 9. Retrieved from file:///C:/Users/Yara Sanchez/Downloads/Fernandino et al_2015_Degree of pollution by benthic litter SSA.pdf

Fernandino, G., Elliff, C. I., Frutuoso, G. A., Silva, E. V. N. M. da, Gama, G. S., Sousa, J. H. de O., & Silva, I. R. (2016a). Considerations on the effects of tidal regimes in the movement of floating litter in an estuarine environment: Case study of the estuarine system of Santos-São Vicente, Brazil. Marine Pollution Bulletin, 110(1), 591–595. http://doi.org/10.1016/j.marpolbul.2016.05.080

Fernandino, G., Elliff, C. I., Silva, I. R., Brito, T. de S., & Bittencourt, A. C. da S. P. (2016b). Plastic fragments as a major component of marine litter: a case study in Salvador, Bahia, Brazil. Journal of Integrated Coastal Zone Management, 16(3), 281–287. http://doi.org/10.5894/rgci649

Ferreira, M. L., & Lopes, A. (2013). Análise Quali-Quantitativa Do Lixo Na Praia Da Santa Cruz Dos Navegantes-Guarujá-Sp-Brasil. Revista Ceciliana Jun, 5(1), 30–35.

Figueiredo Jr., A. G., de Lyra, A. C., de Lima Moredo, M., & Santos, R. H. (2001). Lixo Flutuante na Baía de Guanabara, Rio de Janeiro, Brasil. Gerenciamento Costeiro Integrado, 5.

Galgani, F., Hanke, G., & Maes, T. (2015). Global distribution, composition and abundance of marine litter. In Marine anthropogenic litter (pp. 29-56). Springer, Cham.

GESAMP (2019). Guidelines for the monitoring and assessment of plastic litter in the ocean. GESAMP Reports & Studies no. 99. Available at: http://www.gesamp.org/publications/guidelines-for-the-monitoring-and-assessment-of-plastic-litter-in-the-ocean.

Global Garbage (2019). Global Science. Acesso em: Novembro de 2019. Disponiível em: http://www.globalgarbage.org/blog/index.php/global-science/

Gonçalves-Dias, S. L. F. G., Labegalini, L., & Csillag, J. M. (2012). Sustentabilidade e cadeia de suprimentos: uma perspectiva comparada de publicações nacionais e internacionais. Production, 22(3), 517-533.

Gonçalves-Dias, S. L. F., & Bortoleto, A. P. (2014). A Prevenção de Resíduos Sólidos e o Desafio da Sustentabilidade. Design, Resíduo e Dignidade. São Paulo: Olhares, 91-114.

Gonçalves-Dias, S.L.F. (2015). Consumo & resíduos: duas faces da mesma moeda. GV Executivo. FGV-EAESP, São Paulo, v. 14, p. 38-41.

Gonçalves-Dias, S. L. F., Ghani, Y. A., & Cipriano, T. A. R. P. (2015). Discussões em torno da prevenção e da Política Nacional de Resíduos Sólidos. Ciência e Sustentabilidade, 1(1), 34-49.

Granit, J., Liss Lymer, B., Olsen, S., Tengberg, A., Nõmmann, S., & Clausen, T. J. 2017. A conceptual framework for governing and managing key flows in a source-to-sea continuum. Water Policy, 19 (4): 673-691.

Gregory, M. R. (2009). Environmental implications of plastic debris in marine settings — entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Philosophical Transactions of the Royal Society B: Biological Sciences, 364(1526), 2013-2025.

Hyman, M., Turner, B., Carpintero, A. (2015). Guidelines for National Waste Management Strategies: Moving from Challenges to Opportunities. United Nations Environment Programme, 108p.

Ivar do Sul, J. A., & Costa, M. F. (2007). Marine debris review for Latin America and the wider Caribbean region: from the 1970s until now, and where do we go from here?. Marine Pollution Bulletin, 54(8), 1087-1104

Ivar do Sul, J. A., & Costa, M. F. (2013). Plastic pollution risks in an estuarine conservation unit. Journal of Coastal Research, 65(January 2013), 48–53. http://doi.org/10.2112/si65-009.1

Ivar do Sul, J. A., Santos, I. R., Friedrich, A. C., Matthiensen, A., & Fillmann, G. (2011). Plastic Pollution at a Sea Turtle Conservation Area in NE Brazil: Contrasting Developed and Undeveloped Beaches. Estuaries and Coasts, 34(4), 814–823. http://doi.org/10.1007/s12237-011-9392-8

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., ... & Law, K. L. 2015. Plastic waste inputs from land into the ocean. Science, 347(6223), 768-771.

James, K. L., Randall, N. P., & Haddaway, N. R. (2016). A methodology for systematic mapping in environmental sciences. Environmental evidence, 5(1), 1-13.

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. Resources, conservation and recycling, 127, 221-232.

Koberg, E., & Longoni, A. (2019). A systematic review of sustainable supply chain management in global supply chains. Journal of cleaner production, 207, 1084-1098.

Krelling, A. P., Souza, M. M., Williams, A. T., & Turra, A. (2017). Transboundary movement of marine litter in an estuarine gradient: Evaluating sources and sinks using hydrodynamic modelling and ground truthing estimates. Marine Pollution Bulletin, 119(1), 48–63. http://doi.org/10.1016/j.marpolbul.2017.03.034

Krelling, A. P., & Turra, A. (2019). Influence of oceanographic and meteorological events on the quantity and quality of marine debris along an estuarine gradient. Marine Pollution Bulletin, 139(July 2018), 282–298. http://doi.org/10.1016/j.marpolbul.2018.12.049

Lau, W. W., Shiran, Y., Bailey, R. M., Cook, E., Stuchtey, M. R., Koskella, J., ... & Palardy, J. E. (2020). Evaluating scenarios toward zero plastic pollution. Science, 369(6510), 1455-1461.

Lebreton, L., & Andrady, A. (2019). Future scenarios of global plastic waste generation and disposal. Palgrave Communications, 5(1), 1-11.

Leite, A. S., Santos, L. L., Costa, Y., & Hatje, V. (2014). Influence of proximity to an urban center in the pattern of contamination by marine debris. Marine Pollution Bulletin, 81(1), 242–247. http://doi.org/10.1016/j.marpolbul.2014.01.032

Link, J., Segal, B., & Casarini, L. M. (2019). Abandoned, lost or otherwise discarded fishing gear in Brazil: A review. Perspectives in ecology and conservation, 17(1), 1-8.

Lima, A. R. A., Barletta, M., Costa, M. F., Ramos, J. A. A., Dantas, D. V., Melo, P. A. M. C., … Ferreira, G. V. B. (2016). Changes in the composition of ichthyoplankton assemblage and plastic debris in mangrove creeks relative to moon phases. Journal of Fish Biology, 89(1), 619–640.

Löhr, A., Savelli, H., Beunen, R., Kalz, M., Ragas, A., & Van Belleghem, F. (2017). Solutions for global marine litter pollution. Current opinion in environmental sustainability, 28, 90-99.

Machado, A. A., & Fillmann, G. (2010). Study of the contamination of litter in island Arvoredo, marine biological reserve of the Arvoredo - SC, Brasil. Journal of Integrated Coastal Zone Management, 10(3), 381–393.

Marin, C. B., Niero, H., Zinnke, I., Pellizzetti, M. A., Santos, P. H., Rudolf, A. C., … Polette, M. (2019). Marine debris and pollution indexes on the beaches of Santa Catarina State, Brazil. Regional Studies in Marine Science, 31, 100771. http://doi.org/10.1016/j.rsma.2019.100771

Mascarenhas, R., Batista, Clenia, P., Moura, I. F., Caldas, A. R., Neto, J. M. da C., Vasconcelos, M. Q., … Barros, T. V. S. de. (2008). Marine debris at a sea turtles nesting area at Paraiba State, Brazilian Northeast. Revista de Gestão Costeira Integrada, 8(2), 221–231. http://doi.org/10.5894/rgci138

Meijer, L. J., van Emmerik, T., van der Ent, R., Schmidt, C., & Lebreton, L. (2021). More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean. Science Advances, 7(18), eaaz5803.

MMA (2019). Plano Nacional de Combate ao Lixo no Mar. Available at: https://www.mma.gov.br/agenda-ambiental-urbana/lixo-no-mar.html

Neves, R. C., Santos, L. A. S., Oliveira, K. S. S., Nogueira, I. C. M., Loureiro, D. V., Franco, T., … Quaresma, V. da S. (2011). Qualitative Analysis of the Distribution of Litter in the Barrinha Beach (Vila Velha - ES). Journal of Integrated Coastal Zone Management, 11(1), 57–64. http://doi.org/10.5894/rgci193

Nicolodi, J. L., Asmus, M. L., Polette, M., Turra, A., Seifert Jr, C. A., Stori, F. T., ... & Gonçalves, R. K. (2021). Critical gaps in the implementation of Coastal Ecological and Economic Zoning persist after 30 years of the Brazilian coastal management policy. Marine Policy, 128, 104470.

NOAA, UNEP, 2011. The Honolulu Strategy: A Global Framework for Prevention and Management of Marine Debris.. Available at: https://repository.library.noaa.gov/view/noaa/10789

OECD (2021). Evaluating Brazil's progress in implementing Environmental Performance Review recommendations and promoting its alignment with OECD core acquis on the environment. e

Organisation for Economic Co-operation and Development. Available at: https://www.oecd.org/environment/country-reviews/Brazils-progress-in-implementing-Environmental-Performance-Review-recommendations-and-alignment-with-OECD-environment-acquis.pdf

Oigman-Pszczol, S. S., & Creed, J. C. (2007). Quantification and Classification of Marine Litter on Beaches along Armação dos Búzios, Rio de Janeiro, Brazil. Journal of Coastal Research, 232(March), 421–428. http://doi.org/10.2112/1551-5036(2007)23[421:qacoml]2.0.co;2

Okoli, C., & Schabram, K. (2010). A guide to conducting a systematic literature review of information systems research.

Oliveira, A. de L., Tessler, M. G., & Turra, A. (2011). Longshore distribution of litter in sandy beaches – Case study in Massaguaçu Beach, Caraguatatuba, SP. Journal of Integrated Coastal Zone Management, 11(1), 75–84.

Oliveira, A. L. ; Turra, A. (2015). Solid waste management in coastal cities: where are the gaps? Case study of the North Coast of São Paulo, Brazil. Revista da Gestão Costeira Integrada, v. 1, p. 1-13, 2015.

PEMALM (2021). São Paulo Strategic Plan for Monitoring and Assessment of Marine Litter. Org: Turra, A.; Neves, A.M.; Panarelli, A.M.; Elliff, C.I.; Romanelli, M.F.; Mansor, M.T.; Andrade, M.M.; Grilli, N.M.; Cardoso, O.A.; Zanetti, R.; Scrich, V.M. First edition. São Paulo: PEMALM, 72 p

Perez, L., Soares-Gomes, A., & Bernardes, M. C. (2018). A case study on the influence of beach kiosks on marine litter accumulating in Camboinhas beach, Southeast Brazil. Journal of Coastal Conservation, 22(6), 1085–1092. http://doi.org/10.1007/s11852-018-0615-z

PERS (2020). São Paulo State Plan for Solid Waste. Available at: https://smastr16.blob.core.windows.net/home/2020/12/plano-resi%CC%81duos-solidos-2020_final.pdf

Portz, L., Manzolli, R. P., & Ivar do Sul, J. A. (2011). Marine debris on Rio Grande do Sul north coast, Brazil: Spatial and temporal patterns. Journal of Integrated Coastal Zone Management, 11(1), 41–48. http://doi.org/10.5894/rgci187

Possatto, F. E., Spach, H. L., Cattani, A. P., Lamour, M. R., Santos, L. O., Cordeiro, N. M. A., & Broadhurst, M. K. (2015). Marine debris in a World Heritage Listed Brazilian estuary. Marine Pollution Bulletin, 91(2), 548–553. http://doi.org/10.1016/j.marpolbul.2014.09.032

Ramos, J. A. A., & Pessoa, W. V. N. (2019). Fishing marine debris in a northeast Brazilian beach: Composition, abundance and tidal changes. Marine Pollution Bulletin, 142(April), 428–432. http://doi.org/10.1016/j.marpolbul.2019.04.002

Ryan, P. G. (2015). A brief history of marine litter research. In Marine anthropogenic litter (pp. 1-25). Springer, Cham.

Sampaio, C. L. S., & Pinto, T. K. (2015). Pollution by solid waste in low San Francisco, northeastern Brazil. Revista de Desenvolvimento Econômico, 1(39), 431. http://doi.org/10.21452/rde.v17nesp.4015

Sandwith et al. (2001). Sandwith, T., Shine, C., Hamilton, L., & Sheppard, D. (2001). Protected areas for peace and co-operation. Best practice protected area guidelines series, (7).

Santos, I. R., Friedrich, A. C., Fillmann, G., Wallner-Kersanach, M., Schiller, R. V., & Costa, R. (2004). Litter Production By Beach-Users At Cassino Beach (RS, Brazil). International Journal, 12–14.

Santos, I. R., Friedrich, A. C., & Barretto, F. P. (2005a). Overseas garbage pollution on beaches of northeast Brazil. Marine Pollution Bulletin, 50(7), 778–782. http://doi.org/10.1016/j.marpolbul.2005.03.002

Santos, I. R., Friedrich, A. C., Wallner-Kersanach, M., & Fillmann, G. (2005b). Influence of socio-economic characteristics of beach users on litter generation. Ocean & Coastal Management, 48(9-10), 742-752.

Santos, I. R., Friedrich, A. C., & Ivar do Sul, J. A. (2009). Marine debris contamination along undeveloped tropical beaches from northeast Brazil. Environmental Monitoring and Assessment, 148(1-4), 455–462. http://doi.org/10.1007/s10661-008-0175-z

Seuring, S., Sarkis, J., Müller, M., & Rao, P. (2008). Sustainability and supply chain management–an introduction to the special issue. Journal of cleaner production, 16(15), 1545-1551.

Silva-Cavalcanti, J. S., Barbosa, S. C. T., & Costa, M. F. (2008). Flag Items as a Tool for Monitoring Solid Wastes from Users on Urban Beaches. Journal of Coastal Research, 244(244), 890–898. http://doi.org/10.2112/06-0695.1

Silva-Cavalcanti, J. S., Araújo, M. C. B., & Costa, M. F. (2009). Plastic litter on an urban beach - A case study in Brazil. Waste Management and Research, 27(1), 93–97. http://doi.org/10.1177/0734242X08088705

Silva-Cavalcanti, J. S., Araújo, M. C. B., & Costa, M. F. (2013). Medium-term patterns and trends of solid waste contamination on the beach of Boa Viagem, Northeast Brazil. Quaternary and Environmental Geosciences, 4(1-2), 17–24. http://doi.org/10.5380/abequa.v4i1-2.25691

Soares, M. D. O., Paiva, C. C. De, Godoy, T. De, & Silva, M. D. B. (2011). Rocas Atoll (Equatorial South Atlantic): A case of Marine Debris in Remote Areas. Journal of Integrated Coastal Zone Management, 11(1), 149–152.

Stelmack, Ê. O., Vieira, C. V., Cremer, M. J., & Kroll, C. (2018). Marine debris in coastal environments: the case of praia grande in São Francisco do Sul island/SC, Brazil. GeoSul, 33(66), 11–28.

SIWI (2021). Source-to-Sea: About S2S Platform. Stockholm International Water Institute. Available at: https://www.siwi.org/source-to-sea/

Suciu, M. C., Tavares, D. C., Costa, L. L., Silva, M. C. L., & Zalmon, I. R. (2017). Evaluation of environmental quality of sandy beaches in southeastern Brazil. Marine Pollution Bulletin, 119(2), 133–142. http://doi.org/10.1016/j.marpolbul.2017.04.045

The World Bank (2018). What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. Available at: https://openknowledge.worldbank.org/handle/10986/30317.

The World Bank (2019). World Development Indicators. Gini index. Available at: https://data.worldbank.org/indicator/SI.POV.GINI

The World Bank (2020). The world by income. Available at: https://datatopics.worldbank.org/world-development-indicators/the-world-by-income-and-region.html

Thompson, R. C. & Maximenko, N. 2016. Plastic pollution of the marine environment. In: Williamson, P., Smythe-Wright, D., and Burkill, P. Future of the Ocean and its Seas: a non-governmental scientific perspective on seven marine research issues of G7 interest. ICSU-IAPSO-IUGG-SCOR, Paris.

Touboulic, A., & Walker, H. (2015). Theories in sustainable supply chain management: a structured literature review. International Journal of Physical Distribution & Logistics Management.

Tourinho, P. S., & Fillmann, G. (2011). Temporal trend of litter contamination at Cassino beach, Southern Brazil. Journal of Integrated Coastal Zone Management, 11(1), 97–102. http://doi.org/10.5894/rgci201

UNEP (2009). Marine Litter: A Global Challenge. Nairobi: UNEP. 232 pp. https://wedocs.unep.org/bitstream/handle/20.500.11822/10744/MarineLitterAglobalChallenge.pdf?sequence=1&isAllowed=y

UNEP (2016). Marine plastic debris and microplastics–Global lessons and research to inspire action and guide policy change. Available at: http://wedocs.unep.org/handle/20.500.11822/7720

UNEP (2017). RESOLUTION UNEP/EA.3/L.20: Draft resolution on marine litter and microplastics. UN Environment Assembly. Available at: https://papersmart.unon.org/resolution/uploads/k1709154.docx

UNEP (2019a). Proceedings of the United Nations Environment Assembly at its fourth session. Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/28467/English.pdf?sequence=2&isAllowed=y

UNEP (2019b) Addressing marine plastics: A systemic approach directive: Recommendations for action. Available at: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:312:0003:0030:EN:PDF

UNEP (2020). National guidance for plastic pollution hotspotting and shaping action - Introduction report. Boucher J.,; M. Zgola, et al. United Nations Environment Programme. Nairobi, Kenya.

UNEP (2021a). Drowning in Plastics: Marine litter and plastic waste vital graphics. Available at: https://gridarendal-website-live.s3.amazonaws.com/production/documents/:s_document/867/original/DrowningInPlastics_final.pdf?1634815429

UNEP (2021b). From Pollution to Solution: a global assessment of marine litter and plastic pollution. Available at: https://www.unep.org/resources/pollution-solution-global-assessment-marine-litter-and-plastic-pollution

UNEP (2021c). Addressing Land-Based Pollution. Available at: https://www.unep.org/explore-topics/oceans-seas/what-we-do/addressing-land-based-pollution

UNEP (2021d). Making Peace With Nature. United Nations Environment Assembly (UNEA-5).
Available at: https://www.unep.org/resources/making-peace-nature maki

UNEP (2021e). Agenda Item 2: inputs of the United Nations Environment Assembly to the High Level Political Forum on Sustainable Development. Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/35338/2nd%20rev%20draft%20UNEA%20inputs%20to%20HLPF%2012%20March.pdf?sequence=1&isAllowed=y

Vergara, S. E., & Tchobanoglous, G. (2012). Municipal solid waste and the environment: a global perspective. Annual Review of Environment and Resources, 37, 277-309.

Vieira, B. P., Dias, D., & Hanazaki, N. (2011). Homogeneity of Solid Waste Stranding in a Santa Catarina Island's Mangrove, Brazil. Journal of Integrated Coastal Zone Management, 11(1), 21–30. http://doi.org/10.5894/rgci188

Waste Framework Directive 2008/98/EC (2008). Waste framework directive of the European Parliament and of the Council of 19 November 2008. Available at:https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32008L0098.

Wetzel, L., Fillmann, G., & Niencheski, L. F. H. (2004). Litter contamination processes and management perspectives on the southern Brazilian coast. International Journal of Environment and Pollution, 21(2), 153. http://doi.org/10.1504/ijep.2004.004182

Widmer, W. M., & Hennemann, M. C. (2010). Marine Debris in the Island of Santa Catarina, South Brazil: Spatial Patterns, Composition, and Biological Aspects. Journal of Coastal Research, 26(6), 993–1000. http://doi.org/10.2112/JCOASTRES-D-09-00072.1

Williams, A. T., & Rangel-Buitrago, N. (2019). Marine litter: solutions for a major environmental problem. Journal of coastal research, 35(3), 648-663.

Wohlin, C. (2014, May). Guidelines for snowballing in systematic literature studies and a replication in software engineering. In Proceedings of the 18th international conference on evaluation and assessment in software engineering (pp. 1-10).

World Bank. (2018). What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. Available at: https://openknowledge.worldbank.org/handle/10986/30317.

4. CHAPTER 3: How far are we from robust estimates of litter leakage to the environment?

4.1. INTRODUCTION

Solid waste, or litter, can be found in a wide range of environments as a consequence of a complex series of phenomena across the production-consumption-discard chain. Leak-prone plastic waste comprises materials that are disposed of in dumps and open landfills, and litter that is not even collected. In low-income regions of the Global South (*sensu* Brandt, 1980), uncollected litter is often disposed of directly into watercourses, green areas, vacant lots, drainage networks and other improper deposition sites, exposing soils and rivers to pollution (Ferronato & Torretta, 2019; Vergara & Tchobanoglous, 2012). Fighting litter pollution is an important goal of the international agenda, including the Sustainable Development Goals (SDG), which contemplate waste generation reduction (12.5), responsible waste management (12.4), wastewater treatment (6.3) and marine pollution prevention (14.1).

Since terrestrial and oceanic compartments are both linked through watersheds and coastlines (Wowk, 2013), litter from land-based sources may reach the ocean (Jambeck et al., 2015; GESAMP, 2019). Litter pollution can impact both terrestrial and marine environments on different scales (Vergara & Tchobanoglous, 2012). Besides affecting water quality, human health, biodiversity and animal welfare, marine litter can impact ecosystem services (Vergara & Tchobanoglous, 2012; Galgani et al., 2019, GESAMP, 2019). Thus, combating litter pollution is essential to guarantee environmental conservation and sustainability.

Diagnosing litter leakage to the environment is fundamental to establishing prevention and mitigation measures to solve the problem. Litter leakage to the environment has been estimated worldwide by previous studies, as part of their estimate of litter reaching the ocean (Jambeck et al., 2015; Lebreton et al., 2017; Schmidt et al. 2017a, 2017b; Lebreton & Andrady, 2019; Meijer et al., 2021). However, studies have provided estimates at a country-level, using limited parameters, and also some outdated and inconsistent data - e.g., past estimates have used waste management information for Brazil that is over two decades old (The World Bank, 2012; PAHO, 2005). Moreover, by considering collected waste and generated waste as correlated entities, studies potentially underestimated waste generation in countries like Brazil, where collection reaches only 70.3% of households (IBGE, 2010a). While global studies have placed an important spotlight on the issue of litter leakage to the environment and, subsequently, to the ocean, in order to subsidize local actions to combat environmental litter pollution, it is essential to improve models and the granularity of their spatial scales.

Environmental litter pollution encompasses a series of political, socioeconomic, and environmental issues (UNEP, 2016; Chassignet et al., 2021). The inter-complexity of litter is linked to production, operations of the supply chain, patterns of consumption, waste generation, and quality of waste treatment, recovery and final disposal (Gonçalves-Dias et al., 2012; Vergara & Tchobanoglous, 2012). All these factors define the propensity for plastic waste leakage. Both waste generation and management have an intrinsic relationship with the socio-economic situation of populations (Santos et al., 2005; Bandara et al., 2007; Khan et al., 2016; Trang et al., 2016; The World Bank, 2018). Therefore, diagnosing litter leakage requires accessing socio-economic information, as much as monitoring environmental data and analyzing plastic flow along the value chain. This is especially important when drawing panoramas of countries that comprise the Global South, mostly characterized by low and middle-income economies with a great degree of socio-economic inequality, like Brazil.

Thus, this study aimed to understand the potentialities and limitations of subnational estimates of litter leakage to the environment, and to identify the most relevant parameters for modeling litter leakage to the environment used in the incipient literature, considering the reality of plastic flows through production, consumption and disposal phases, and recognizing the influence of socio-economic conditions on litter generation and management. This study also aimed to evaluate the availability and usability of existing data, to provide a robust municipality-based subnational estimate of litter leakage to the environment, using the 5570 municipalities of Brazil as a case study. Finally, we conclude by extrapolating this panorama to the Global South, discussing the way to overcome existing information gaps on the subnational scale.

4.2. MATERIAL AND METHODS

4.2.1. Identification of relevant parameters for estimating litter leakage to the environment

A specialized literature mapping was carried out to assess the most used parameters to estimate litter leakage to the environment, and potentially, to the ocean. In recent years, there have been important contributions to the field of plastic pollution and marine litter regarding estimates of litter leakage to the ocean. A survey was carried out searching for scientific materials which address the use of parameters to estimate litter leakage to the environment, on either global or subnational levels. We sought to compile the main publications of this sort to compare and understand the choices made in each case, seeking to build a replicable framework. The survey comprehended different types of scientific publications, such as articles, handbooks and public policies. Only studies and materials focusing on estimates of plastic leakage to the ocean were selected. We analyzed each publication regarding its goal, spatial scale and parameters that were either used or suggested to estimate litter leakage to the environment.

After listing all parameters surveyed, an expert opinion discussion took place to fill in potential gaps. Experts in the subjects of sustainability, environmental management, oceanography, solid waste, marine litter and geographic information system participated in numerous meetings, and discussed each parameter with potential to fill existing gaps. Gaps were mostly related to the need of using more parameters to represent the complex reality of least-developing and developing countries (i.e., the Global South), regarding socioeconomic inequality and its influence on waste generation, management, and potential leakage. For that, we used the reality of Brazil as a case study. Experts discussed the most relevant parameters considering the reality of plastic flows through production, consumption and disposal, and recognizing the influence of socio-economic conditions on litter generation and management. Thus, further parameters considered relevant for improving subnational estimates of litter leakage were proposed.

4.2.2. Data availability and usability for estimating litter leakage to the environment

The parameters found through the literature mapping and expert consultation were grouped into eight categories: territory, population density, socio-economic status of the population, solid waste generation and composition, solid waste collection, selective collection and recycling, final destination of solid waste, and hydrology (Fig. 9). We analyzed each category and their respective parameters regarding the existing limitations and relevance for estimating litter leakage, considering the reality of plastic flows through production, consumption and disposal, and also the importance of assessing socio-economic conditions on litter generation. We did not deeply study hydrological parameters, since this study focused on litter leakage to the environment. We did not include the analysis of litter decay in rivers and ocean. However, we considered the study of these parameters in order to synthesize all parameters used and proposed by previous works.

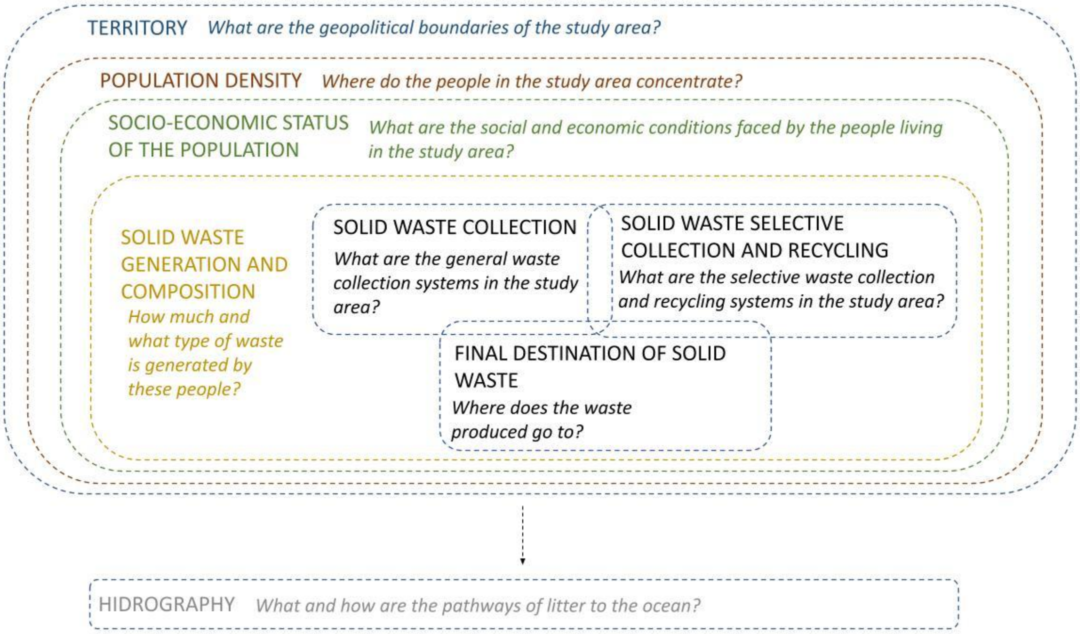


Fig. 9. Categories of parameters to estimate litter leakage to the environment and their respective definitions.

We then prospected data available for each category and parameter for each of the 5570 Brazilian municipalities. We consulted several national and international databases, including demographic censuses, surveys by government agencies and reports from plastic industry associations.

We systematized data according to their adherence to the eight categories of parameters. Many parameters were linked to multiple data sources, while other parameters had no data sources. Moreover, we classified data sources in a gradient of five levels of usability (very good/good/average/bad/very bad), which are related to existing information gaps (Table 6). Data source usability was defined by its reliability and temporal and spatial granularity. Reliability expresses both method and range of data collection. Granularity is defined here as the level of detail in which data is presented. The year attributed to each data source refers to the year in which the most recent data was obtained or estimated. The ideal scenario consisted of recently sampled data (last 4 years; highest level of reliability and temporal granularity) available for all or most Brazilian municipalities or other units (highest level of spatial granularity). The worst scenario consisted of parameters with no data available. The different levels of usability consider that recent data with relevant geographical detailing brings a more trustworthy representation of the current scenario, as data collected. On the other hand, old data with low geographical granularity may not well represent the current situation, and self-declared data may be a source of bias.

Table 6. Criteria used to assess data usability of the parameters defined to estimate litter leakage to the environment. Each of the three criteria (reliability, temporal granularity, and geographical granularity) has different levels of usability, from very bad to very good. Description of each criterion and definition of each level is presented, where definitions are different for hydrological and other environmental/spatial data, in comparison with other parameters.

<table>
<tr><th>Criteria</th><th>Level</th><th>Definition</th><th>Definition (for Hydrology and other environmental/ spatial data)</th></tr>
<tr><td rowspan="4">R= Reliability

Level in which data can be trusted, regarding the robustness in which data was collected</td><td>1</td><td colspan="2">R1= sampled data (universe or sample)</td></tr>
<tr><td>2</td><td colspan="2">R2= estimated or extrapolated data</td></tr>
<tr><td>3</td><td colspan="2">R3= data self-declared by the public sector</td></tr>
<tr><td>4</td><td colspan="2">R4= data self-declared by the private sector</td></tr>
<tr><td rowspan="5">T= Temporal granularity

When data was collected or estimated, as to understand how updated information is</td><td>1</td><td colspan="2">T1= last four years (2018-2021)</td></tr>
<tr><td>2</td><td colspan="2">T2= five to ten years ago (2011-2017)</td></tr>
<tr><td>3</td><td colspan="2">T3= ten to fifteen years ago (2006-2010)</td></tr>
<tr><td>4</td><td colspan="2">T4= fifteen to twenty years ago (2001-2005)</td></tr>
<tr><td>5</td><td colspan="2">T5= more than twenty years</td></tr>
<tr><td rowspan="5">G= Geographical granularity

Spatial scale in which data is available, once data might exist for some states, regions and municipalities, but not others</td><td>1</td><td>G1= all/most municipalities</td><td>G1= all units</td></tr>
<tr><td>2</td><td>G2= few municipalities (incomplete data)</td><td>G2= most units</td></tr>
<tr><td>3</td><td>G3= microregions</td><td>G3= few units</td></tr>
<tr><td>4</td><td>G4= states or stratum (e.g. urban areas, rural areas)</td><td rowspan="2">where units = number of dams or dumps, or territory cover (for precipitation, wind, slope, rivers, watersheds and land use)</td></tr>
<tr><td>5</td><td>G5= country</td></tr>
<tr><td rowspan="5">U= Data usability

The sum of the ranking for the 3 criteria listed above, as to understand the overall data usability of each parameter</td><td>1</td><td>U1= very good: G1, T1 and R1;</td><td>U1= very good: G1, T1/T2 and C1/C2</td></tr>
<tr><td>2</td><td>U2= good: G1, T2 and R2/R3;</td><td>U2= good: E1, T2/T3 and C1/C2; or E1, T3 e C1</td></tr>
<tr><td>3</td><td>U3= average: G2/G3 and/or T2/T3/T4/T5; many data also have R2/R3;</td><td>U3= average: G1, T5 and C1; G2, T4 and C1; or G3, T1 and C2</td></tr>
<tr><td>4</td><td>U4= bad: G4/G5; many data also have granularity R2/R3/R4 and/or T3/T4/T5;</td><td>U4= bad: G2, T2 and C3; or G3, T1 and C3;</td></tr>
<tr><td>5</td><td colspan="2">U5= very bad: data not available for the whole country, at any spatial scale.</td></tr>
</table>

4.3. RESULTS

4.3.1. Identification of relevant parameters for estimating litter leakage to the environment

From several results of literature prospected, we identified the publications by Jambeck et al. (2015), Hardesty et al. (2016), Lebreton et al. (2017), Schmidt et al. (2017, 2018), Lebreton & Andrady (2019), Liro et al. (2020), UNEP (2020), Meijer et al. (2021), and PEMALM (2021) considering their adherence to the theme. These publications comprise global and national estimates, as well as a concept paper for estimating litter leakage into the environment, a public policy for monitoring and assessing marine litter, and a guide for hotspotting plastic pollution along the value chain.

These studies made progressive advances and proposed parameters associated with litter leakage to the environment (Supplementary Material D). Jambeck et al. (2015) created a model to estimate litter leakage from coastal regions (up to 50 km from the coast) to the ocean; considering the annual mass of waste generated per capita, the percentage of plastic waste in the litter, the percentage of plastic waste that is mismanaged and, therefore, the potential of litter to enter the ocean. Subsequent global studies considered plastic leakage from rivers to the ocean (Lebreton et al., 2017, Schmidt et al., 2017; Lebreton & Andrady, 2019; Meijer et al., 2021), using parameters similar to Jambeck et al. (2015), and adding environmental parameters to their models. All global studies used national-based information on waste generation, and uniformly distributed data according to the gridded population. They all considered mismanaged litter as the sum of inadequately managed waste (deposited in dumps and open landfills) plus 2% littering. Other works provided national estimates or suggested approaches for estimating litter leakage. Hardesty et al. (2016) developed a model to estimate litter leakage in Australia, using Australian socio-economic indexes to address particularities of different locations. Liro et al. (2020) indicated a method to model litter leakage into the environment, in a concept paper. UNEP (2020) guided plastic pollution hotspotting along the entire plastic value chain at the national and sub-national levels. The São Paulo Strategic Plan for Monitoring and Assessment of Marine Litter (PEMALM, 2021) recommended parameters for monitoring marine litter in the most populous Brazilian state, including potential parameters of litter generation.

We identified multiple parameters used by models of litter leakage to the environment, as well as parameters suggested by guidelines of plastic hotspotting and plans to monitor marine litter. The parameters used by the analyzed studies were systematized into eight categories, introduced below, accompanied by the additional parameters that resulted from the case study analysis (Table 7).

Table 7. Parameters for improving estimates of litter leakage to the ocean, at the municipal level. The list of parameters was based on previous studies on litter leakage to the environment, and also on concept works, plans and guides. Some parameters are also being proposed by the present study (*), after experts' analysis on how to improve subnational estimates in Brazil. Parameters are categorized into eight categories, whose definitions and importance are detailed below.

Category	Rationale for inclusion	Parameters
Territory	The geopolitical boundaries of a territory are commonly used to define management units. These can be entire countries, states within a country, municipalities, districts etc.	- Coastal countries (Jambeck et al., 2015) - Countries (Schmidt et al., 2017; Lebreton et al., 2017; Lebreton & Andrady, 2019; Meijer et al., 2021) - Census district (Australia) (Hardesty et al., 2016) - Municipalities and states*
Population density	The number of people consuming in a given place is a driver of litter production (PEMALM, 2021). Population dynamics is an important aspect to consider, such as the spatial distribution characteristics of the population (e.g. urban vs. rural), how population fluctuations can cause problems to infrastructure during holidays periods in touristic destinations (CETESB, 2019), and how this relates to future scenarios of global plastic waste generation and disposal (Lebreton & Andrady 2019)	- Population density (Jambeck et al., 2015; Lebreton et al., 2017; Schmidt et al., 2017; Lebreton & Andrady, 2019; Liro et al., 2020; PEMALM, 2021) - Gridded population (Jambeck et al., 2015, Lebreton et al., 2017; Schmidt et al., 201; Lebreton & Andrady, 2019) - Historical population estimates (1992-2014) (Hardesty et al., 2016) - Long-term population projection (2015 to 2060) (Lebreton & Andrady, 2019) - Urban population* - Rural population* - Floating population*
Socio-economic status of the population	There is empirical evidence of a non-linear, exponential relationship between per capita income and marine litter (Alisha et. al, 2020), therefore	- Economic status (based on GNI - Gross National Income) (Jambeck et al., 2015; Schmidt et al., 2017) - GDP (gross domestic product) distribution and projections for 2015 to 2021 (Lebreton & Andrady, 2019)

	showing differences in the generation of plastic solid waste in different socioeconomic classes (Khan et al, 2016; Alisha et al, 2020; Campos, 2012; Trang et al, 2016). Therefore, it is important to consider aspects such as income inequality, purchasing power, and development indexes.	- Long-term economic growth projections for 2022 to 2060 (Lebreton & Andrady, 2019) - Index of Relative Socio-economic Advantage and Disadvantage (Hardesty et al., 2016) - Index of Economic Resources (income) (Hardesty et al., 2016) - Index of Education, Employment and Occupation (Hardesty et al., 2016) - Income concentration (Gini Index) (PEMALM, 2021) - Population well-being - income, education, longevity - Human Development Index (HDI) (PEMALM, 2021) - Number of households or area occupied in/by informal settlements (PEMALM, 2021) - Ecological awareness of the population (Liro et al., 2020) - Consumption pattern - per capita family expenditure* - Per capita income*
Solid waste generation and compositio n	The amount of solid waste generated by a population is intrinsically linked to aspects related to the population's consumption. In turn, consumption is correlated to supply. As plastics represent the majority of solid waste composition found in the environment and ocean, it is crucial to understand aspects relating to the import and export of this material, production of plastic items, lifetime of plastic products, and other industry dynamics.	- Mass of waste generated (Jambeck et al., 2015; Schmidt et al., 2017; Lebreton et al., 2017 Lebreton & Andrady, 2019; UNEP, 2020; Meijer et al., 2021) - Percentage of plastic in the waste generated (Jambeck et al., 2015; Schmidt et al., 2017; Lebreton et al. 2017; Lebreton & Andrady 2019; UNEP, 2020; Meijer et al., 2021) - Plastic consumption (total) (UNEP, 2020) - Plastic consumption (per capita) (UNEP, 2020) - Import of plastic inputs (UNEP, 2020) - Export of plastic inputs (UNEP, 2020) - Lifetime of plastic products (short vs. long-lived) (%) (UNEP, 2020) - National production of plastic resins (ton.) (UNEP, 2020) - Initial and ending stock (UNEP, 2020) - Annual growth rate of plastic supply and use (UNEP, 2020) - Sector distribution and value-added (UNEP, 2020) - Plastic classification (basic vs converted) (UNEP, 2020) - Plastic classification (direct vs embodied) (UNEP, 2020) - Plastic sources (UNEP, 2020)

		- Plastic applications (UNEP, 2020) - Apparent consumption of plastics in the country (ton.)* - Apparent consumption of plastics by municipality (ton/year) based on*: •Distribution of the national apparent consumption •Production, import and export of plastics •Lifetime of plastics products (short vs long-lived) - Spatial variations of plastic fraction in solid waste, according to different socio-economic conditions* - Information on the plastic industry: list of products made of plastic materials manufactured in the country; number of active employees in the plastic products retail sector*
Solid waste collection	Waste collection services are not always homogeneous across a given territory. Thus, it is important to analyze the amount of litter collected by formal collection, which can then be adequately disposed of.	- Waste collection (UNEP, 2020) - Number of households served by door-to-door collection (PEMALM, 2021) - Amount of waste removed by sweeping and street cleaning (PEMALM, 2021) - Amount of domestic and public waste collected (total or per capita)*
Solid waste selective collection and recycling	As with the general solid waste collection, selective collection and recycling can vary greatly. The amount of litter collected by formal and, importantly, informal selective collection represents the amount of solid waste recovered and that can be reintroduced in the material cycle through recycling.	- Number of households served by selective collection (PEMALM, 2021) - Mass or volume of waste destined for recycling (PEMALM, 2021; UNEP, 2020) - Mass of solid waste recovered by reverse logistic (PEMALM, 2021) - Mass of post-consumer plastic resins recycled in the country* - Mass of plastics recovered by formal selective collection* - Mass of plastics recovered by informal selective collection* - Number of informal waste pickers* - Mass of plastic waste produced in the municipality that is recycled (based on the distribution of the total amount of plastics recycled in the country per municipality - subtracting amount collected by formal selective collection - by the number of collectors in each municipality)*

Final destination of solid waste	The final destination of solid waste can be either adequate or inadequate. Identifying where litter is being directed to once at the end of its lifecycle is crucial to understanding leakage points.	- Quality of waste (PEMALM, 2021) - Quality of landfills (PEMALM, 2021) - Quality of composting management (PEMALM, 2021) - Location of dumps and open landfills* - Amount of waste sent to appropriate final destination units*
Hydrology and other environmental/spatial data		- Watersheds (Lebreton et al., 2017; Lebreton & Andrady, 2019) - River catchment and runoff (Schmidt et al., 2017; Lebreton et al., 2017; Meijer et al., 2021; Liro et al., 2020) - Distance to river mouth (Meijer et al., 2021) - Flow accumulation (Hardesty et al., 2016; Lebreton et al., 2017) - Seasonality of hydrological information (Lebreton et al., 2017) - Precipitation; rainfall season (Lebreton at el., 2017; Meijer et al., 2021) - Wind (Meijer et al., 2021; Hardesty et al., 2016) - Artificial barriers (Lebreton et al., 2017); dam reservoirs (Liro et al., 2020) - Quality of sewage collection and treatment; amount of solid waste retained in the grating and sieving of the Sewage Treatment Stations (ETEs) and Preconditioning Stations (EPCs) (PEMALM, 2021) - Amount of solid waste in stormwater / urban drainage systems / in natura sewage (PEMALM, 2021) - Other anthropogenic factors: location of dumping sites on river floodplains; road density and proximity of roads to rivers (Liro et al., 2020) - Topography (Lebreton et al., 2017; Liro et al., 2020; Meijer et al., 2021; Hardesty et al., 2016) - Land use (Liro et al., 2020; Meijer et al., 2021; Hardesty et al., 2016) - Urbanization (Liro et al., 2020) - Potential number of people accessing sites - distance to the nearest road and proximity to railways stations (Hardesty et al, 2016) - Distance to the rivers (Meijer et al., 2021)

4.3.1.1. Territory

Territory dimensions and limits (including municipalities, states, countries, or other territorial units) are the basis for understanding the issue at hand. This information allows spatially locating data on population density, socioeconomic status, solid waste management, and visualizing locations with highest risk of litter leakage in the environment. And because rivers systematically flow into the ocean, with the exception of endorheic rivers, it is also important to know coastal territories, since they consist of locations where litter may also escape directly to the ocean. Actions to prevent and mitigate marine litter can be applied in all municipalities with leakage risk. These actions are especially essential in municipalities located in coastal regions, where litter accumulated by rivers flows into the ocean (Jambeck et al., 2015; GESAMP, 2019; UNEP, 2020; PEMALM, 2021).

4.3.1.2. Population density

Population size and density in a territory can inform the relative amount of solid waste produced and discarded in that location. Population size is considered one driving force of waste generation, as it predicts the number of people consuming (PEMALM, 2021). Thus, population density stipulates the number of people consuming per territorial area, and it allows inferences on local capacity, and possible overloads of municipal waste management capacity. Although previous studies have only used the parameter of population density, recent analyses have shown that population density alone is not the best predictor of plastic leakage to the environment. Population density must be combined with other factors such as land use, infrastructure, socio-economic data and spatial parameters as well (Schuyler et al., 2021). It is also important to consider population fluctuations where there are significant temporary population changes. Significant seasonal population fluctuations can be related to high rates of waste generation, and overload of collection systems (Teixeira et al., 2017; Bernal, 2021; Guarda, 2012; Campanário, 2007). Due to the fact that, for many sites, waste collection data is available only for the urban population, it is often necessary to differentiate urban and rural populations. Moreover, litter composition of urban populations might be different from rural ones, as urban families tend to generate higher amounts of waste per capita (Hardesty, 2021; Miezah et al., 2015).

4.3.1.3. Socio-economic status of the population

Recent studies have shown that rates of inadequate litter management vary not only with population density, but also according to the socio-economic status of the population (Borrelle et al., 2020; Lau et al., 2020). The socio-economic status of populations in developing countries comprises a complex matrix of social inequality (ECLAC, 2016). Thus, several socio-economic parameters are required for holistic analyses. Previous studies considered the socio-economic parameters of Gross Domestic Product (GDP) to represent purchasing power, relating higher per capita use and generation of plastics to higher GDP and local population (Lebreton & Andrady 2019, Hoornweg et al., 2013, UNEP, 2017). They also indicated that GDP is negatively related to the proportion of inadequately managed waste. These relationships can vary between rural and urban areas (Lebreton and Andrady, 2019). However, GDP is a sensitive parameter when used individually, since it only considers economic size to define responsibilities for polluting activities (Montibeller-Filho, 2010) and sustainability. Besides GDP, it is also important to consider other socio-economic information to represent purchasing power, since GDP does not indicate income and consumption. There is empirical evidence of an exponential non-linear relationship between per capita income and litter pollution (Alisha et al, 2020); which points to differences in plastic waste generation in different socio-economic classes (Khan et al, 2016, Alisha et al, 2020, Campos, 2012, Trang et al, 2016). Moreover, the Marginal Propensity to Consume also indicates that income increases in lower-income groups result in increases in consumption, which are proportionally greater than in higher-income groups (Campos, 2012).

Another important socio-economic parameter is the consumption pattern. If necessary, it is possible to use data on consumption, expenditure, income structures and household patrimony variation. Inequality in income distribution is also important, and it is represented here by the Gini Index. This index can be used to estimate different amounts of waste generated through income inequality within the municipality. Another socio-economic parameter is the Human Development Index (HDI), which measures three basic dimensions of human development: income, education and health. However, it is linked to GDP, whose limitations were previously exposed. HDI can be used considering that education determines environmentally conscious behaviors, including environmental littering (Alisha et al, 2020). Moreover, according to Trang (2017), families more concerned with the environment generate less waste. The socio-economic parameter that reveals the estimated population living in irregular settlements is extremely important. In irregular settlements, which are often characterized by high household density and precarious housing and socio-economic conditions (IBGE, 2020a), and where public basic sanitation services are either non-existent or precarious, contributing to the undue accumulation of solid waste. It is empirically and scientifically known that a large amount of solid waste is mismanaged in informal settlements (Furigo et.al., 2014), and that these areas are common in many municipalities in developing and least-developing countries in the Global South, such as Brazil. For example, in 2010, Brazil had 41.4% of urban population living in precarious settlements, informal settlements or inadequate housing (IBGE, 2010a).

4.3.1.4. Solid waste generation and composition

To understand potential risk of litter leakage, it is necessary to know the dimension of waste generation. Because plastic is the most prevalent material among marine litter, it is essential to know its production, import, and export rates (Morales-Caselles et al, 2021). Information about plastic introduction into the waste chain can be understood by industrial production and consumption. In addition to the amount of plastic produced, imported and exported, it is also important to consider the lifetime of plastic items produced. While some items are discarded soon after use (disposables and packaging for food and beverages, and hygiene and cleaning products), others have a medium-term (textiles and clothing, trade items) or even long-term lifespan (cars and auto parts, machinery and equipment, materials for civil construction) (ABIPLAST, 2020). Information on solid waste composition (or gravimetric composition) is also required in order to assess the percentage of plastic present.

4.3.1.5. Solid waste collection

It is also important to understand the patterns of solid waste collection in different geographic regions, especially when studying developing countries. In Brazil, the existence of selective collection varies from 10% to 55% among the municipalities (SNIS, 2017), which indicates failures, or even non-existence of collection services, which include collection of domestic waste and public waste, as well as waste from industries, construction, health services etc. Ultimately, the lack of collection can influence litter leakage into the environment.

4.3.1.6. Solid waste selective collection and recycling

It is important to consider selective collection and waste recycling separately from regular collection, since these aspects have very different meanings. A first basic aspect refers to the portion of the population that is served by selective collection services, which operate independently of regular collection services in most Brazilian municipalities. It is also necessary to consider the mass of waste collected by selective collection. In Brazil, as well as in many other developing countries, a considerable portion of recyclable waste is collected by independent waste collectors, which comprise fundamental elements of the recycling chain (The World Bank, 2018). However, most collectors do not work under an organization, but autonomously (The World Bank, 2018), which makes it difficult to collect information about this informal activity. Despite limitations, knowing the number of collectors in a municipality allows estimating the amount of litter collected for recycling. Finally, we understand that the mass of waste collected selectively does not necessarily equal the mass of materials that are actually recycled. Since there are important technological and operational limitations, there are also obstacles to effectively recycling some materials. Therefore, post-consumer plastic resin recycling data are essential to analyze the effectiveness of selective collection and its consequent effect on preventing litter leakage to the environment.

4.3.1.7. Final destination of solid waste

For monitoring and evaluating environmental litter, it is necessary to estimate the potential stock of waste that can escape the conventional management system. This is commonly referred to in the literature as mismanaged waste, which is defined as materials that are improperly disposed of, including disposal in open dumps and uncontrolled landfills, where litter is not fully contained (Jambeck et al, 2015), and are exposed to environmental factors (e.g., wind, drainage; Lebreton and Andrady, 2019). Thus, it is essential to understand the quality of the final waste disposal carried out by a given municipality (PEMALM, 2021). These final destinations include open dumps (active and inactive ones), and landfills with and without cover. In Brazil, 40.9% of collected waste is been dumped in inappropriate locations (ABRELPE, 2017). It is interesting to consider not only the total mass of solid waste collected and properly or improperly disposed of, but also waste destination per inhabitant or household. In this context, sanitary landfills and controlled landfills with waste cover, can be considered adequate forms of waste disposal regarding the risk of leakage of litter to the environment. While open dumps and landfills without waste cover can be considered inappropriate destinations (Jambeck et al., 2015).

4.3.1.8. Hydrology and other environmental/spatial data

The solid waste generated in the municipalities can be mobilized to the environment as consequence of different factors. These factors include local environmental variables, such as rain and wind (Schirinzi et al., 2020; Meijer et al., 2021; Hardesty et al., 2016), topographic slope (Liro et al., 2020; Meijer et al., 2021), land use (Liro et al., 2020; Meijer et al., 2021; Hardesty et al., 2016) and distance from the source of waste to water bodies (Meijer et al., 2021; Liro et al., 2020). In addition, waste can be mobilized by anthropogenic factors such as human transport (Hardesty et al., 2016). Transport by human action is aggravated by the presence of subnormal agglomerations, precarious socioeconomic conditions, the inefficiency of waste collection and basic sanitation, the existence of open dumps and landfills, etc. Thus, it is interesting to consider various sociodemographic and environmental data to estimate litter leakage to the environment.

From the moment that solid waste is introduced into rivers, its transport to the ocean depends on the river pathways to the ocean and on the characteristics of the rivers, including dimensions, flow direction, discharge (m3/s), accumulated discharge, distance to ocean etc (Liro et al., 2020; Schmidt et al., 2017; Lebreton et al., 2017; Meijer et al., 2021). Rivers and their tributaries form hydrographic basins, divided into different degrees of sub-basins. Thus, it is important to know the water network, river characteristics and watersheds. Moreover, since the amount of litter transported by rivers can be suppressed by the existence of artificial barriers, such as dams and reservoirs (Lebreton et al., 2017; Liro et al., 2020), it is also important to consider their locations.

4.3.2. Data availability and usability for estimating litter leakage to the environment

Among the 51 parameters identified, 7.8% were not linked to any data source. Only 29.4% of the parameters were related to at least one source with very good or good usability, and most (45.1%) had average usability at the very best (Table 8). In our study case, geographical granularity was the most critical factor that compromises the usability of data sources. Considering the eight categories of indicators, data related to solid waste generation and composition comprised the worst scenarios, with 83.3% of indicators only related to sources with bad or very bad usability.

Table 8. Parameters for modeling litter leakage to the environment and possible data sources of these parameters for Brazil, at the country level. Each data source was evaluated according to its usability, depending on reliability of data source, temporal correlation, and geographical correlation. The best possible panorama consists of recent data available for all Brazilian municipalities at the national level, from reliable sources.

Category	Parameter	Details and data sources	Year	R	T	G	U
Territory	Brazilian territory	Brazilian Institute of Geography and Statistics (IBGE, 2020b)	2020	1	1	1	Very good
	Coastal municipalities	Ministry of the Environment (MMA, 2021)	2021	1	1	1	Very good
Population density	Total population by municipality	Brazilian Institute of Geography and Statistics (IBGE, 2010a) - Atlas Brasil	2010	1	3	1	Average
		Continuous National Household Sample Survey (PNAD) - Atlas Brasil	2017	1	2	4	Bad

		Brazilian Institute of Geography and Statistics (IBGE, 2021)	2021	2	1	1	Good
	Floating population	Total floating population - Data not available*	-				Very bad
		Floating population: domestic tourism - Ministry of Tourism/FIPE (2012)	2012	2	2	2	Average
		International tourism - Ministry of Tourism/FIPE (2017)	2017	2	2	2	Average
	Urban population	National Sanitation Information System (SNIS, 2019)	2019	2	1	2	Average
		Brazilian Institute of Geography and Statistics (IBGE, 2010a)	2010	1	3	1	Average
	Projected population for 2030 and 2060	Brazilian Institute of Geography and Statistics (IBGE, 2018a)	2018	2	1	4	Bad
	Gridded population density	Socio-economic Data and Applications Center (Sedac) / (CIESIN) (2018)	2010	1	3	1	Average
		Socio-economic Data and Applications Center (Sedac)/ (CIESIN) (2018)	2020	2	1	1	Good
Socio-economic status of the population	Per capita Gross Domestic Product (GDP)	IBGE/DATASUS, 2010	2010	1	3	1	Average
		Annual Social Information Report (RAIS) - Atlas Brasil	2016	1	2	1	Good
		Brazilian Institute of Geography and Statistics (IBGE, 2018b)	2018	2	1	1	Good
	Economic Dynamism	Institute for Applied Economic Research (IPEA, 2018)	2010	1	3	3	Average
	Average income	Brazilian Institute of Geography and Statistics (IBGE, 2010a) - Atlas Brasil	2010	1	3	1	Average
		Continuous National Household Sample Survey (PNAD) - Atlas Brasil	2017	1	2	4	Bad
	Education - level of instruction	Brazilian Institute of Geography and Statistics (IBGE, 2010a)	2010	1	3	1	Average

	Inequality of income distribution (Gini Index)	Brazilian Institute of Geography and Statistics (IBGE, 2010a) - Atlas Brasil	2010	1	3	1	Average
		Continuous National Household Sample Survey (PNAD) - Atlas Brasil	2017	1	2	4	Bad
	Population wellbeing (Human Development Index - HDI)	Brazilian Institute of Geography and Statistics (IBGE, 2010a) - Atlas Brasil	2010	1	3	1	Average
		Continuous National Household Sample Survey (PNAD) - Atlas Brasil	2017	1	2	4	Bad
	Consumption pattern	Per capita family expenditure by stratum (e.g. urban, rural) - Brazilian Institute of Geography and Statistics (IBGE, 2018c) - Consumer Expenditure Survey (POF)	2018	1	1	4	Bad
	Population living in informal settlements	Brazilian Institute of Geography and Statistics (IBGE, 2010b)	2010	1	3	4	Bad
		Brazilian Institute of Geography and Statistics (IBGE, 2020a)	2019	2	1	1	Good
		Brazilian Institute of Geography and Statistics (IBGE, 2010a)	2010	1	3	2	Average
	Percentage of the extremely poor population	Brazilian Institute of Geography and Statistics (IBGE, 2010a) - Atlas Brasil	2010	1	3	1	Average
		Continuous National Household Sample Survey (PNAD) - Atlas Brasil	2017	1	2	4	Bad
Solid waste generation and composition	Plastic production	Soft plastics vs. hard plastics- ABIPLAST (2020)	2019	4	1	5	Bad
		Soft plastics vs. hard plastic - ABIPET (2019)	2019	4	1	5	Bad
		Production of thermoplastic and thermosetting resins - Brazilian Institute of Geography and Statistics (IBGE, 2019) - Annual Industrial Survey (PIA-Product)	2019	4	1	5	Bad
	Import and export of plastic inputs	Ministry of Industry, Foreign Trade and Services (MDCI, 2019) - Comex Stat	2019	4	1	5	Bad
	Plastic consumption	Data not available*	-				Very bad

	Plastic waste generation	Inter-American Development Bank (IDB, 2020)	2020	2	1	5	Bad
	Solid waste generation	Brazilian Association of Public Cleaning and Special Waste Companies (ABRELPE, 2020)	2019	4	1	4	Bad
	Solid waste composition - percentage of plastic	Brazilian Association of Public Cleaning and Special Waste Companies (ABRELPE, 2020)	2019	4	1	5	Bad
		United Nations Statistics Division (UNSD) (2020)	2015	3	2	5	Bad
		National Sanitation Information System (SNIS, 2019)	2019	3	1	2	Average
Solid waste collection	Population served by solid waste collection	Brazilian Institute of Geography and Statistics (IBGE, 2010a) - Atlas Brasil	2010	1	3	1	Average
		National Sanitation Information System (SNIS, 2019)	2019	3	1	2	Average
		Brazilian Association of Public Cleaning and Special Waste Companies (ABRELPE, 2020)	2019	4	1	4	Bad
	Mass of uncollected solid waste	Brazilian Association of Public Cleaning and Special Waste Companies(ABRELPE, 2020)	2019	4	1	4	Bad
	Mass of collected solid waste	National Sanitation Information System (SNIS, 2019)	2019	3	1	2	Average
		Brazilian Association of Public Cleaning and Special Waste Companies (ABRELPE, 2020)	2019	4	1	4	Bad
	Urban cleaning sustainability index	Union of Urban Cleaning Companies (SELUR, 2020) based on data provided by 2018 SNIS	2018	3	1	2	Average
	Municipalities with sweeping services	National Sanitation Information System (SNIS, 2019)	2019	3	1	2	Average
	Mass of solid waste collected from sweeping	Public waste - National Sanitation Information System (SNIS, 2019)	2019	3	1	2	Average
Solid waste selective collection and recycling	Population served by formal selective collection	National Sanitation Information System (SNIS, 2019)	2019	3	1	2	Average
		Brazilian Institute of Geography and Statistics (IBGE, 2000b)	2000	1	5	4	Bad
	Mass of waste collected by formal selective collection	National Sanitation Information System (SNIS, 2019)	2019	3	1	2	Average

	Existence of independent waste pickers	National Sanitation Information System (SNIS, 2019)	2019	3	1	2	Average
		CadÚnico (2018)	2018	2	1	1	Good
	Mass of waste collected by independent waste pickers	Literature - multiple sources	-				Very bad
	Existence of waste classifiers	Brazilian Institute of Geography and Statistics (IBGE, 2010a)	2010	1	3	1	Average
	Recovery rate of recyclable items	National Sanitation Information System (SNIS, 2019)	2019	3	1	2	Average
	Plastic recycling index	ABIPLAST (2020)	2019	4	1	5	Bad
		ABIPET (2019)	2019	4	1	5	Bad
		ABIPLAST (2019)	2019	4	1	5	Bad
	Mass of solid waste recovered by reverse logistic	Data not available*	-				Very bad
Final destination of solid waste	Solid waste destination per habitant or household	IBGE/DATASUS (2019)	2010	1	3	1	Average
	Final disposal of collected solid waste	Brazilian Association of Public Cleaning and Special Waste Companies (ABRELPE, 2020)	2019	4	1	4	Bad
	Mass of waste properly disposed (landfills with waste coverage)	National Sanitation Information System (SNIS, 2019)	2019	3	1	2	Average
	Existence of open dumps	National Sanitation Information System (SNIS, 2019)	2019	3	1	2	Average
	Mass of waste improperly disposed (open dumps and landfills without waste coverage)	National Sanitation Information System (SNIS, 2019)	2019	3	1	2	Average
	Location of open dumps (coordinates)	Data not available*	-				Very bad
Hydrology and other environmental/spatial data	Hydrographic regions, watersheds and sub-watersheds	Agência Nacional das Águas (ANA, n.d.)	2017	2	2	1	Good
		HydroSHEDS (Lehner & Grill, 2013)	2006	2	3	1	Good
	Water network	Agência Nacional das Águas (ANA, n.d.)	2013	1	2	1	Good
		Diva-gis and SIGEO	-	1		1	Very good
	Rivers' characteristics (discharge, Strahler order, flow order etc.)	HydroSHEDS (Lehner & Grill, 2013)	2006	2	3	1	Good
		University Corporation for Atmospheric Research (UCAR)	2001	2	4	1	Average

		GRUN: An observations-based global gridded runoff (Ghiggi et al., 2019)	2014	2	2	1	Good
		Monthly average runoff - Lebreton et al. (2017a, 2017b)	2016	2	3	1	Good
	Dams and reservoirs	Agência Nacional das Águas (ANA, 2021)	2015	3	2	2	Bad
		Aquastat (FAO, 2015)(data from ANA)	2015	3	2	2	Bad
		Global Reservoir and Dam database (GRanD) (Lehner et al., 2011)	2011	1	2	1	Good
	Services of sewage and water drainage	National Sanitation Information System (SNIS, 2019)	2019	3	1	2	Average
	Topographic slope	HydroSHEDS (Lehner & Grill, 2013)	2006	1	3	1	Good
		The Global Land Data Assimilation System - GLDAS (Rodell et al., 2004)	2021	1	1	1	Very good
		Shuttle Radar Topography Mission (SRTM)	-	1		1	Very good
	Land use and land cover	GLC2000 (Bartholome & Belward, 2005)	2000	1	5	1	Average
		MODIS (Friedl & Sulla-Menashe, 2019)	2019	1	1	1	Very good
		Global human modification of terrestrial systems - GHMTS (Kennedy et al., 2020)	2016	1	2	1	Good
	Wind	Worldclim 2 (Fick & Hijmans, 2017)	2018	2	1	1	Very good
	Precipitation	Worldclim 2 (Fick & Hijmans, 2017)	2018	2	1	1	Very good

4.4. DISCUSSION

Previous studies on litter leakage to the ocean represent great advances in identifying leakage hotspots to the environment and marine litter sources. Most studies explored data at the country level, providing a worldwide panorama of litter leakage across the planet. However, improvements are still possible, and they are necessary for guiding local actions to combat marine litter. Therefore, it is necessary to refine models at the spatial scale, making extensive use of data available at the subnational level. The only subnational information used by previous studies was the spatial distribution of population density (Lebreton et al., 2017; Jambeck et al., 2015; Schmidt et al., 2017; Lebreton & Andrady, 2019), and the Gross Domestic Product (GDP) (Lebreton & Andrady, 2019). Only Hardesty et al. (2016) analyzed particularities of different regions within a country (Australia), using specific socio-economic indexes provided by local entities. The reduced use of subnational data can suppress the contribution of subnational variations on litter generation, management, and leakage. Thus, using subnational data is extremely important to improve spatial scale of estimates and also to guide local actions.

Improvements are also possible when using additional parameters than previous studies. In general, international studies presented models based on population density, economic classification of the country (high, medium-high, low-middle, and low income), municipal solid waste disposal, and waste composition (percentage of plastics). The same plastic fraction was considered for a whole territory of a country (The World Bank, 2012). However, waste generation (amount and plastic fraction) and management can vary widely in national territory, according to different socio-economic conditions of the population (Spinola et al., 2019). The only socio-economic factors considered by studies were GDP per capita and economic classification based on Gross National Income (GNI), which is also based on GDP (Jambeck et al., 2015; Schmidt et al., 2017; Lebreton & Andrady; 2019). Nonetheless, socioeconomic conditions have an intrinsic relationship with waste generation and management (Santos et al., 2005; Bandara et al., 2007; Khan et al., 2016; Trang et al., 2016; The World Bank, 2018). The amount of waste and percentage of plastics generated by a given population is directly connected to their purchasing power. On the other hand, the quality of waste management is inversely proportional to the population's socio-economic condition and well-being. Thus, socio-economic information should be widely used by studies aimed at estimating litter leakage to the environment.

Most previous studies considered mismanaged litter as the sum of inadequately managed waste (deposited in dumps and open landfills) plus 2% littering. The rate of littering was based on data available for the United States, and it is equivalent to 2% of the total national waste generation. However, the reality of the United States does not reflect the reality of the Global South. In developing countries, deficiencies are often observed in municipal waste management (Jin et al., 2006). These deficiencies are associated with institutional factors, including storage and unloading, collection, transport and disposal, and lack of adequate legislation, environmental education and professional training (Abarca-Guerrero et al., 2012; Seng et al., 2010; Chung and Lo, 2008). Thus, littering estimates for Global South countries have room for significant improvement. Moreover, previous international estimates considered waste collection data as equal to waste generation for Brazil (The World Bank, 2012, PAHO, 2005, IBGE, 2000a), a striking limitation considering that in this country, waste collection reaches only 70.3% of households (IBGE, 2010a). The same disparity is likely to be true for other countries, due to the high amount of information processed by the World Bank and used by previous studies. Thus, it is necessary to improve littering estimates for other countries, especially for countries located in the Global South, characterized by high rates of mismanaged waste and absence of policies to solve solid waste issues (The World Bank, 2012; 2018). To improve these estimates, it is necessary to widen the use of socio-economic parameters, mainly for countries with abundant socioeconomic inequality.

Besides systematizing parameters that were used or suggested by previous works, we have also recommended parameters that have potential to improve existing models. A country with access to data referent to these parameters might be able to provide a robust estimate of litter leakage to the environment. The list of parameters was based on the understanding that litter pollution is a complex problem, whose solutions must involve systemic thinking across the entire plastic value chain (UNEP, 2020). Therefore, it is important to diagnose and monitor the entire life cycle of plastic, and to understand plastic design, production, distribution, consumption and disposal, until its eventual entry into the environment (Abalansa et al., 2020; Van Berkel & Fadeeva, 2020). It is, therefore, necessary to integrate a series of social, economic and environmental parameters to obtain a representative panorama of the issue.

Models can also be improved by adopting holistic approaches with potential to improve the understanding of litter sources. A mass balance assessment through a Material Flow Analysis, the DPSIR (Driver-Pressure-State-Impact-Response) model, and the Source-to-Sea approach can be adopted in order to contemplate the sources, paths and destinations of environmental litter. Material Flow Analysis considers the flow and stock of materials in a complex system in a given space and time (Cencic & Rechberger, 2008; Allesch & Brunner, 2016). This approach involves the entire life cycle of products, connecting source to sink (Brunner & Rechberger, 2016). This method supports decision-making and the application of environmental management strategies and waste management (Allesch & Brunner, 2016; Brunner & Rechberger, 2016). The DPSIR model (Abalansa et al., 2020; Van Berkel & Fadeeva, 2020) is generally used to deal with problems systematically, focusing on causal relationships (Gari et al., 2015). Finally, the Source-to-Sea approach contemplates the dynamics between terrestrial and oceanic compartments, and the dynamics of social, ecological and economic systems (Granit et al., 2017). By integrating the management of coastal areas and watersheds, this approach advocates that actions applied upstream support contamination mitigation on coasts and in the ocean (SIWI, 2018). These approaches provide a holistic view of environmental litter pollution, and provide a strategic foundation to define effective parameters to diagnose litter leakage to the environment.

Most parameters analyzed in the present study showed data with average usability at the very best. Very few parameters were linked to data sources of good or very good usability. Moreover, some parameters did not present any data source at the national level. Low usability of data on plastic production, solid waste management and sociodemographic aspects is a problem in Brazil. Results express problems of data existence, availability and quality in Brazil and may indicate a panorama of the Global South: studies addressing waste management in developing countries have shown that available information in the public domain is scarce (Chung & Lo, 2008) and that, when available, data tends to be incomplete or dispersed. Moreover, difficulties in accessing data and challenges of low-quality data from summary papers have also been reported (Troschinetz & Mihelcic, 2009). Therefore, understanding urban waste management in this condition is complex (Seng et al., 2010), and represents a challenge in the Global South.

The limitations identified regarding modeling litter leakage to the environment were related to spatial granulometry, temporal granulometry and data reliability. While spatial granularity gaps pinpoint the insufficiency of current sampling amplitudes, temporal gaps expose suppression in censuses and surveys. In other words, spatial granularity gaps were related to data available only for some municipalities or at the state level, while temporal gaps were associated with a lack of frequent and updated samplings. For example, the last demographic Brazilian census was performed in 2010 (IBGE, 2010a) and the census scheduled to take place in 2021 was postponed due to budgetary constraints. Developing countries, such as Brazil, usually present a context of constant social, economic and, to a lesser extent, territorial changes. Thus, performing frequent good quality samplings are necessary in order to provide access to proper data. The temporal gap also leads to a reduction in data reliability, as the scarcity of recently sampled data makes it necessary to project or estimate data, based on the last census, for example. Data reliability is also influenced by the fact that some databases rely on self-declared information. Some examples are the National Sanitation Information System (SNIS), the Brazilian Plastic Industry Association (ABIPLAST) and the Brazilian Association of Special Waste and Public Cleaning Companies (ABRELPE). Estimates and self-declarations generate a degree of uncertainty, directly associated with data usability.

There are multiple information gaps regarding production, consumption and waste disposal on a municipal scale in Brazil. Even though limitations exist, using national databases increases reliability of data on waste generation and management, and, therefore, they have the potential to improve models of litter leakage to the ocean. However, it is important to point out that, in order to improve models, it is important to have access to recently sampled data from reliable sources, available at the municipal level and for all municipalities of a country. However, many reports show results at a country or state level, even when declaring that their information results from municipal data. Data availability at the municipal level is, therefore, important for scientific and management purposes. Furthermore, because it is difficult to deal with fragmented data to link various socio-economic data from different years, it is also important to unify databases and broaden data availability.

Even with information gaps, it is still possible to refine models and overcome limitations, by developing models that fill existing information gaps. As an example, it is possible to improve waste generation parameters through the estimation of the Apparent Consumption of Plastics by municipality. The use of proxies is also possible in some cases, even though proxies may not always be pragmatic. As an example, floating population data is not available in Brazil in national databases, but it is possible to use tourism data to estimate population fluctuations. Even though tourism data does not include all forms of population fluctuations (e.g. fluctuations generated by work and study shifts in other municipalities), it can be the best proxy available in this case. In Brazilian studies at state or municipal levels, it is possible to use other proxies for floating population: data on household occupation (Guarda, 2012), lodging beds (Godinho, 2008; Guarda, 2012), solid waste production and electrical connections (Campanário, 2007), and water use (Zuanazzi and Bartels, 2016; Bernal, 2021).

4.5. CONCLUSIONS

This study has organized information on parameters for modeling litter leakage to the environment. We gathered what has been done across the globe regarding estimates of litter leakage, systematized parameters used by previous studies, and proposed additional parameters that may bring greater robustness to existing models. Key points of the proposed improvements comprise parameters of socio-economic condition of the population and of waste generation and management. These parameters have great potential to upgrade the quality and granularity of estimates, contributing to Sustainable Development Goals (SDG) 6, 12 and 14. Moreover, the Group of the Twenty major economies (G20), has established an Action Plan on Marine Litter, committing to preventing and reducing marine litter and its impacts (OECD, 2019). Another important initiative is the Global Partnership on Marine Litter

(GPML), which aims to connect stakeholders and globalize information on marine litter. This partnership is led by the United Nations Environment Programme (UNEP) as part of the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA).

This study has also revealed the difficulties and limitations of estimating litter leakage to the environment without access to high-quality data. However, it has shown that it is possible to improve modelings at the spatial scale, in order to subsidize decision-making at a local level. Thus, this study generated information with potential to improve existing modelings of litter leakage to the environment, and to speed future studies at regional and local scales, complying with international agendas to combat litter pollution. Local-scale modeling can support decision-making at a local level.

Improving estimates of litter leakage to the environment relies on data availability and consistency. Thus, we strongly recommend that government agencies perform periodic data sampling and invest in data availability in national systems. Harmonization of data produced in different time-spaces is also important, since handling fragmented data and linking different socio-economic data from different years can stun the robustness of multivariable modelings. Urban cleaning companies and agencies of solid waste management and water treatment, should also invest in the unification and availability of data for all municipalities. Data transparency in the plastic industry is also important for understanding the problem and improving litter leakage modelings. To improve estimate models, we recommend the wide use of parameters that represent socio-economic conditions and litter generation and management, as well as feed models at the municipalities level, at least, improving their spatial granularity. Furthermore, we also stand by the adoption of the Material Flow Analysis, Source-to-Sea approach, and DPSIR (Driver-Pressure-State-Impact-Response) model to improve estimates on litter leakage to the environment.

4.6. REFERENCES

Abalansa, S., El Mahrad, B., Vondolia, G. K., Icely, J., & Newton, A. (2020). The marine plastic litter issue: a social-economic analysis. Sustainability, 12(20), 8677.
ABARCA-GUERRERO, L; MAAS, G.; HOGLAND, W. (2012). Solid waste management challenges for cities in developing countries. Waste Management (New York, N.Y.). 33. 10.1016/j.wasman.2012.09.008.
ABIPLAST (2019). PICPlast - Estudo aponta crescimento no índice de plástico reciclado pós-consumo - panorama de 2019. Plano de Incentivo à Cadeia do Plástico. Available at: http://www.picplast.com.br/estudoreciclagem
ABIPLAST (2020). Perfil 2020: A indústria de Transformação e Reciclagem De Plástico no Brasil. Associação Brasileira da Indústria do Plástico. Available at: http://www.abiplast.org.br/publicacoes/
ABIPET (2019). Associação Brasileira da Indústria do PET. Available at: https://www.abipet.org.br/
Allesch, A., & Brunner, P. H. (2017). Material flow analysis as a tool to improve waste management systems: the case of Austria. Environmental science & technology, 51(1), 540-551.
ABIPLAST. Associação brasileira da indústria do plástico. (2020). Perfil 2020: a indústria de Transformação e Reciclagem de Plástico no Brasil. Disponível em: http://www.abiplast.org.br/publicacoes/perfil-2020/. Acesso em: 30 set. 2021.
ABRELPE (2017). Panorama dos Resíduos Sólidos no Brasil 2017. Available at: https://abrelpe.org.br/pdfs/panorama/panorama_abrelpe_2017.pdf
ABRELPE. 2020. Panorama dos resíduos sólidos no Brasil 2020. Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais Available at: https://abrelpe.org.br/panorama/

Alisha, F., Davlasheridze, M., & Mykoniatis, N. (2020). Socioeconomic drivers of marine debris in North America. Marine Environmental Research, 160, 105042.
AtlasBR. Atlas do Desenvolvimento Humano no Brasil. Available at: http://www.atlasbrasil.org.br/consulta/planilha
ANA (2021). Fiscalização de Barragens. Agência Nacional de Águas. Available at: https://dados.gov.br/dataset/fiscalizacao-de-barragens
ANA (n.d.). Agência Nacional de Águas. Available at: https://dadosabertos.ana.gov.br/search?groupIds=084346aa5c18467782432f48bb687f83
Bandara, N. J., Hettiaratchi, J. P. A., Wirasinghe, S. C., & Pilapiiya, S. (2007). Relation of waste generation and composition to socio-economic factors: a case study. Environmental monitoring and assessment, 135(1), 31-39.
Bernal, N. (2021). Avaliação dos impactos do aumento da população flutuante no município de Bertioga no período da pandemia de COVID-19. / Nury Bernal; Orientador Ronaldo José Torres; Santos.
Borrelle, S. B., Ringma, J., Law, K. L., Monnahan, C. C., Lebreton, L., McGivern, A., ... & Rochman, C. M. (2020). Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. Science, 369(6510), 1515-1518.
Brandt, W. (1980). North-South: A Programme for Survival: Report of the Independent Commission on International Development Issues (London: Pan, 1980).
Brunner, P. H., & Rechberger, H. (2016). Handbook of material flow analysis: For environmental, resource, and waste engineers. CRC press.
CadÚnico (2018). Microdados amostrais do Cadastro Único, Ministério da Cidadania. Available at: https://dados.gov.br/dataset/microdados-amostrais-do-cadastro-unico
Campanário, P. (2007) Florianópolis: Dinâmica Demográfica e Projeção da População por Sexo,Grupos Etários, Distritos e Bairros (1950-2050). Florianópolis. IPUF.
Campos, H. K. T. (2012). Evolution of income and per capita generation of solid wastes in Brazil. Engenharia Sanitaria e Ambiental, 17(2), 171-180.
Chassignet, E. P., Xu, X., & Zavala-Romero, O. (2021). Tracking marine litter with a global ocean model: Where does it go? Where does it come from?. Frontiers in Marine Science, 8, 414.
Chung, S. S., & Lo, C. W. (2008). Local waste management constraints and waste administrators in China. Waste Management, 28(2), 272-281.
Cencic, O., & Rechberger, H. (2008). Material flow analysis with software STAN. In EnviroInfo (pp. 440-447).
CIESIN (2018). Gridded Population of the World, Version 4 (GPWv4): Population Density, Revision 11. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). Center for International Earth Science Information Network - CIESIN - Columbia University. Available at: https://sedac.ciesin.columbia.edu/data/set/gpw-v4-population-density-rev11/data-download and https://developers.google.com/earth-engine/datasets/catalog/CIESIN_GPWv411_GPW_UNWPP-Adjusted_Population_Density
DATASUS (2010). Ministério da Saúde. Instituto Brasileiro de Geografia e Estatística (IBGE). Available at: https://datasus.saude.gov.br/informacoes-de-saude-tabnet/

Diva-gis. n.d.. Download data by country. Brazil: Inland water, by Digital Chart of the World. https://www.diva-gis.org/gdata

ECLAC. (2016). The social inequality matrix in Latin America. First meeting of the Presiding Officers of the Regional Conference on Social Development in Latin America and the Caribbean. United Nations, Economic Commission for Latin America and the Caribbean

Ferronato, N., & Torretta, V. (2019). Waste mismanagement in developing countries: A review of global issues. International journal of environmental research and public health, 16(6), 1060.

Furigo, R.F.R.; Ferrara, L. N.; Samora, P. R. ; Moretti, R. S. Universalização do Saneamento: Possibilidades para superar o déficit dos assentamentos precários urbanos. In: III Seminário Nacional sobre Urbanização de Favelas - URB Favelas, 2018, Salvador, BA. Anais do III UrbFavelas. Salvador,BA: UCSal - Universidade Católica de Salvador, 2018. p. 1-20.

Galgani, L.; Beiras, R.; Galgani, F.; Panti, C.; & Borja, A. (2019). Editorial: impacts of marine litter. Frontiers in Marine Science, 6: 208. doi: 10.3389/fmars.2019.00208.

Gari, A. Newton, J.D. Icely (2015). A review of the application and evolution of the DPSIR framework with an emphasis on coastal social-ecological systems Ocean Coast. Manag., 103

GESAMP (2019). Guidelines for the Monitoring and Assessment of Plastic Litter in the Ocean. Journal Series GESAMP Reports and Studies, 99 (123p.). Available at: http://www.gesamp.org/publications/guidelines-for-the-monitoring-and-assessment-of-plastic-litter-in-the-ocean

Granit, J., Liss Lymer, B., Olsen, S., Tengberg, A., Nõmmann, S., & Clausen, T. J. (2017). A conceptual framework for governing and managing key flows in a source-to-sea continuum. Water Policy, 19(4), 673-691.

Guarda, A. (2012). Gestão Urbana: Projeção da População Flutuante. COBRAC 2012 · Congresso Brasileiro de Cadastro Técnico Multifinalitário. UFSC Florianópolis.

Godinho, R.E.(2008) Nova Metodologia de Projeção da População Flutuante. São Paulo. ABEP.2008.

Gonçalves-Dias, S. L. F. G., Labegalini, L., & Csillag, J. M. (2012). Sustentabilidade e cadeia de suprimentos: uma perspectiva comparada de publicações nacionais e internacionais. Production, 22(3), 517-533.

Hoornweg, D., Bhada-Tata, P., & Kennedy, C. (2013). Environment: Waste production must peak this century. Nature News, 502(7473), 615.

Hardesty, B. D., Schuyler, Q., Lawson, T. J., Opie, K., & Wilcox, C. (2016). Understanding debris sources and transport from the coastal margin to the ocean. Final Report to the National Packaging Covenant Industry Association.

IDB (2020). Plastic Waste Management and Leakage in Latin America and the Caribbean. Inter-American Bank (IDB). Available at: https://publications.iadb.org/en/plastic-waste-management-and-leakage-latin-america-and-caribbean

Jin J, Wang Z and Ran S (2006) Solid waste management in Macao: practices and challenges. Waste Management 26: 1045–1051.

IBGE (2000a). Pesquisa Nacional de Saneamento Básico: Tabela 2332 - Quantidade diária de lixo coletado, por unidade de destinação final do lixo coletado. Available at: https://sidra.ibge.gov.br/Tabela/2332

IBGE (2000b). Indicadores de Desenvolvimento Sustentável: Tabela 1203 - Serviço de coleta seletiva de lixo por número de municípios e residências atendidos e quantidade de lixo coletado (série encerrada). Available at: https://sidra.ibge.gov.br/tabela/1203

IBGE (2010a). Censo Demográfico. Instituto Brasileiro de Geografia e Estatística (IBGE). Available at: https://www.ibge.gov.br/estatisticas/sociais/saude/9662-censo-demografico-2010.html?=&t=downloads

IBGE (2010b). Aglomerados Subnormais. Instituto Brasileiro de Geografia e Estatística (IBGE). Available at: https://www.ibge.gov.br/geociencias/organizacao-do-territorio/tipologias-do-territorio/15788-aglomerados-subnormais.html?edicao=15949&t=downloads

IBGE (2018a). Projeções da População. Instituto Brasileiro de Geografia e Estatística (IBGE). Available at: https://www.ibge.gov.br/estatisticas/sociais/populacao/9109-projecao-da-populacao.html?=&t=downloads

IBGE (2018b). Produto Interno Bruto dos Municípios. Instituto Brasileiro de Geografia e Estatística (IBGE). Available at: https://www.ibge.gov.br/estatisticas/economicas/contas-nacionais/9088-produto-interno-bruto-dos-municipios.html?=&t=downloads

IBGE (2018c). Pesquisa de Orçamentos Familiares (POF). Instituto Brasileiro de Geografia e Estatística (IBGE). Available at: https://www.ibge.gov.br/estatisticas/sociais/saude/24786-pesquisa-de-orcamentos-familiares-2.html?=&t=downloads

IBGE (2019). PIA - pesquisa industrial anual. Instituto Brasileiro de Geografia e Estatística (IBGE). Available at: https://questionarios.ibge.gov.br/downloads-questionarios/pia-pesquisa-industrial-anual-empresa-e-pia-pesquisa-industrial-anual-produto

IBGE (2020a). Aglomerados subnormais 2019: classificação preliminar e informações de saúde para o enfrentamento à COVID-19: notas técnicas. PIA - pesquisa industrial anual. Instituto Brasileiro de Geografia e Estatística (IBGE). Available at: https://biblioteca.ibge.gov.br/index.php/biblioteca-catalogo?view=detalhes&id=2101717

IBGE (2020b). Malhas Territoriais. Instituto Brasileiro de Geografia e Estatística (IBGE). Available at: https://www.ibge.gov.br/geociencias/organizacao-do-territorio/malhas-territoriais/15774-malhas.html?=&t=downloads

IBGE (2021). Estimativas da População. Instituto Brasileiro de Geografia e Estatística (IBGE). Available at: https://www.ibge.gov.br/estatisticas/sociais/populacao/9103-estimativas-de-populacao.html?=&t=downloads

IPEA (2018). TD 2414 - Proposta de Atualização das Tipologias da PNDR: nota metodológica e mapas de referência. Instituto de Pesquisa Econômica Aplicada (IPEA). Available at: https://www.ipea.gov.br/portal/index.php?option=com_content&view=article&id=34214

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., ... & Law, K. L. (2015). Plastic waste inputs from land into the ocean. Science, 347(6223), 768-771.

Khan, D., Kumar, A., & Samadder, S. R. (2016). Impact of socioeconomic status on municipal solid waste generation rate. Waste Management, 49, 15-25.

Lau, W. W., Shiran, Y., Bailey, R. M., Cook, E., Stuchtey, M. R., Koskella, J., ... & Palardy, J. E. (2020). Evaluating scenarios toward zero plastic pollution. Science, 369(6510), 1455-1461.

Lebreton, L. C., Van Der Zwet, J., Damsteeg, J. W., Slat, B., Andrady, A., & Reisser, J. (2017). River plastic emissions to the world's oceans. Nature communications, 8, 15611.

Lebreton, L., & Andrady, A. (2019). Future scenarios of global plastic waste generation and disposal. Palgrave Communications, 5(1), 1-11.

Lehner, B., Grill G. (2013): Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. Hydrological Processes, 27(15): 2171–2186.

Liro, M., Emmerik, T. V., Wyżga, B., Liro, J., & Mikuś, P. (2020). Macroplastic storage and remobilization in rivers. Water, 12(7), 2055.

MDCI (2019). Ministério da Indústria, Comércio Exterior e Serviços. Comex Stat. Available at: http://comexstat.mdic.gov.br/pt/home.

Meijer, L. J., van Emmerik, T., van der Ent, R., Schmidt, C., & Lebreton, L. (2021). More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean. Science Advances, 7(18), eaaz5803.

Miezah, K. Obiri-Danso, Z. Kádár, B. Fei-Baffoe, M.Y. Mensah. (2015). Municipal solid waste characterization and quantification as a measure towards effective waste management in Ghana. Waste Management, 46, pp. 15-27.

Ministério do Turismo (2019). Dados e fatos: Demanda turística. Available at: http://www.dadosefatos.turismo.gov.br/2016-02-04-11-54-03.html

MMA (2021). PORTARIA MMA Nº 34, DE 2 DE FEVEREIRO DE 2021. Ministério do Meio Ambiente. Available at: https://www.in.gov.br/web/dou/-/portaria-mma-n-34-de-2-de-fevereiro-de-2021-302053267

Montibeller-Filho, G. (2010). Indicadores e Equidade social: propriedades dos indicadores de sustentabilidade e ausência do princípio de Justiça Social em estudos sobre mudança climática E C02.R. Inter. Interdisc. INTERthesis, Florianópolis, v.7, n.1, p. 199-221

Morales-Caselles, C., Viejo, J., Martí, E., González-Fernández, D., Pragnell-Raasch, H., González-Gordillo, J. I., ... & Cózar, A. (2021). An inshore–offshore sorting system revealed from global classification of ocean litter. Nature Sustainability, 4(6), 484-493.

OECD (Organisation for Economic Co-operation and Development) (2019). Improving Resource Efficency to Combat Marine Plastic Litter. Issue Brief. G20 Ministerial Meeting on Energy Transitions and Global Environment for Sustainable Growth. Available at: https://www.oecd.org/g20/summits/osaka/OECD-G20-Paper-Resource-Efficiency-and-Marine-Plastics.pdf

PAHO (2005). Report on the Regional Evaluation of Municipal Solid Waste Management Services in Latin America and the Caribbean. Area of Sustainable Development and Environmental Health, Pan American Health Organization - PAHO.

PEMALM (2021). Plano Estratégico de Monitoramento e Avaliação do Lixo no Mar do Estado de São Paulo. Org: Turra, A.; Neves, A. M.; Panarelli, A. M.; Elliff, C. I.; Romanelli, M. F.; Mansor, M. T., Andrade, M. M.; Grilli, N. M.; Cardoso, O. A.; Zanetti, R.; Scrich, V. M.. Primeira edição. São Paulo: PEMALM, 72 p.

Santos, I. R., Friedrich, A. C., Wallner-Kersanach, M., & Fillmann, G. (2005). Influence of socio-economic characteristics of beach users on litter generation. Ocean & Coastal Management, 48(9-10), 742-752.

Schmidt, C., Krauth, T., & Wagner, S. (2017). Export of plastic debris by rivers into the sea. Environmental science & technology, 51(21), 12246-12253.

Schmidt, C., Krauth, T., & Wagner, S. (2018). Correction to export of plastic debris by rivers into the sea. Environmental science & technology, 52(2), 927-927.

Schuyler, Q., Wilcox, C., Lawson, T. J., Ranatunga, R. R. M. K. P., Hu, C. S., & Hardesty, B. D. (2021). Human population density is a poor predictor of debris in the environment. Frontiers in Environmental Science, 9, 133.

Seng, B., Kaneko, H., Hirayama, K., & Katayama-Hirayama, K. (2011). Municipal solid waste management in Phnom Penh, capital city of Cambodia. Waste management & research, 29(5), 491-500.

SIGEO. n.d.. Shapes disponibilizados pelo Comitê da BH do Rio São Francisco (CBHSF). Available at: https://sosgisbr.com/2011/07/11/shapes-disponibilizados-pelo-comite-da-bh-do-rio-sao-francisco/

Siwi (2018). High-level panel on source-to-sea management: Towards joint action by the freshwater and ocean communities. 8th World Water Forum, Brasilia, Brazil, March 2018. S2S Platform. Disponível em: http://xpdv319.m.attendify.com/ app/sessions/9TltNOSFav ZirdteO3/details.

SNIS (2017). Diagnóstico do manejo de Resíduos Sólidos Urbanos - 2017. Available at: www.snis.gov.br/diagnostico-anual-residuos-solidos/diagnostico-rs-2017

SNIS (2019). Diagnóstico do manejo de Resíduos Sólidos Urbanos - 2019. Available at: http://www.snis.gov.br/diagnosticos

SNIS (2019). Diagnóstico do manejo de Resíduos Sólidos Urbanos - 2019, Sistema Nacional de Informações sobre Saneamento, Ministério do Desenvolvimento Regional. Available at: www.snis.gov.br/diagnostico-anual-residuos-solidos/diagnostico-do-manejo-de-residuos-solidos-urbanos-2019

SELUR (2020). Índice de Sustentabilidade da Limpeza Urbana - ISLU - edição 2020. Sindicato das Empresas de Limpeza Urbana no Estado de São Paulo - SELUR. Available at: https://selur.org.br/estudos/

UCAR (n.d.) Data for Climate & Weather Research. Research Data Archive. University Corporation for Atmospheric Research (UCAR). Available at: https://rda.ucar.edu/

UNSD (2020). Composition of municipal waste. Environment Statistics. United Nations Statistics Division (UNSD) Environmental parameters. Available at: https://unstats.un.org/unsd/envstats/qparameters.cshtml

Teixeira, P. T. R., Souza, J. A. R., Moreira, D. A., Viana, A. M. S., & Soares, J. M. C. (2017). INFLUÊNCIA DA População flutuante no planejamento do sistema de limpeza urbana. Revista Engenharia Na Agricultura - Reveng, 24(6), 457-462. https://doi.org/10.13083/reveng.v24i6.672

Trang, P. T. T., Dong, H. Q., Toan, D. Q., Hanh, N. T. X., & Thu, N. T. (2017). The effects of socio-economic factors on household solid waste generation and composition: a case study in Thu Dau Mot, Vietnam. Energy Procedia, 107, 253-258.

Troschinetz, A. M., & Mihelcic, J. R. (2009). Sustainable recycling of municipal solid waste in developing countries. Waste management, 29(2), 915-923.

UNEP (2016). Marine Plastic Debris and Microplastics: Global Lessons and Research to Inspire Action and Guide Policy Change. United Nations Environmental Program, Nairobi, 252p.

UNEP (2020). National guidance for plastic pollution hotspotting and shaping action - Introduction report. Boucher J.; M. Zgola, et al. United Nations Environment Programme. Nairobi, Kenya.

van Berkel, R., Fadeeva, Z. (2020). Role of industries in resource efficiency and circular economy. In: Sadhan (Ed.), Waste Management as Economic Industry towards Circular Economy, by S.K. Springer, Singapore.

Vergara, S. E., & Tchobanoglous, G. (2012). Municipal solid waste and the environment: a global perspective. Annual Review of Environment and Resources, 37, 277-309.

World Bank (2012). What a Waste: A Global Review of Solid Waste Management. Urban Development & Local Government Unit., World Bank, 98.

World Bank (2018). What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. World Bank, 272.

Wowk, K. M. (2013). Paths to Sustainable Ocean Resources. Managing Ocean Environments in a Changing Climate: Sustainability and Economic Perspectives, 301.

Zuanazzi, P.T. (2016). Estimativas para a população flutuante do litoral norte do Rio Grande do Sul. Porto Alegre: FEE, 28p.

5. CHAPTER 4: Improving estimates of litter leakage to the ocean at the subnational level: a case study in Brazil

5.1. INTRODUCTION

Marine litter pollution is a leading driver of change in nature, with numerous social, economic and environmental implications (Díaz et al., 2019; UNEP, 2016; GESAMP, 2019; Galgani, 2019). Marine litter is mostly composed of plastic, which is widely used nowadays due to its low-cost and high durability and versatility (Andrady & Neal, 2009; Galgani et al., 2015). Eight out of the 242 million tons (mt) of annual production of plastic litter reach the ocean (The World Bank, 2018; Jambeck et al., 2015). These residues have numerous ecological and socio-economic impacts, affecting: biodiversity, animal welfare, tourism, navigation, fisheries, aquaculture, human health, food security, loss of income and intrinsic value (Gregory, 2009; UNEP, 2016; GESAMP, 2019, 2020). Thus, preventing and reducing marine litter pollution is a crucial target of the Sustainable Development Goal 14.1 (SDG), proposed by the United Nations (UN).

Litter reaches the ocean via ocean-based and, mainly, land-based sources, which correspond to about 80% of litter input to coastal and marine environments (Galgani et al., 2015; Andrady, 2011). This rate is mostly associated with poor municipal solid waste (MSW) management and direct disposal on beaches, soils and rivers (Galgani et al., 2015), besides low recyclability of materials and slow development of the recycling market. MSW can be transported to the ocean through urban drainage systems, effluent outflows and inland waterways (Wowk, 2013; Jambeck et al., 2015). Hence, rivers consist of permanent litter sources to the ocean (Araújo & Costa, 2007; Lebreton & Andrady, 2019; Schmidt et al., 2017). Plastic leakage from world watersheds was estimated at up to 2.75 mt per year (Schmidt et al., 2017; Meijer et al., 2021). Thus, watersheds connect the ocean to the terrestrial compartment, from where a significant amount of litter flows (Schmidt et al., 2017).

The dynamics between terrestrial and oceanic compartments are contemplated by the Source-to-Sea approach (Siwi, 2018). This integrated concept considers the sources, paths and destinations of MSW in aquatic environments, as well as the dynamics of social, ecological and economic systems (Granit et al., 2017). By integrating the management of coastal areas and river basins, this approach advocates that actions applied upstream support contamination mitigation on the coast and in the ocean (Siwi, 2018). Thus, the Source-to-Sea approach is aligned with the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA/UNEP).

Identifying litter source locations is crucial for delineating and adopting appropriate prevention and mitigation measures (Araújo & Costa, 2007). Plastic litter input into the ocean has already been estimated on a global scale, considering coastal areas (Jambeck et al., 2015) and river basins (Lebreton et al., 2017, 2019; Schmidt et al., 2017, 2018; Meijer et al., 2021). However, to date, besides Hardesty et al. (2016), no study focused on mapping marine litter source locations has considered particularities of different subnational geographic regions, such as the variety of socio-economic conditions and litter generation and management. Considering geographic specificities may lead to improved and more reliable modeling of marine litter source locations.

Previous studies on MSW entry into the ocean used data on population density, per capita income, amount of poorly managed plastics, and river runoff (Jambeck et a., 2015; Lebreton et al., 2017; Schmidt et al., 2017, 2018). However, designing mitigation actions also requires a more in-depth analysis of social and economic dynamics (Granit et al., 2017), mostly because the MSW generation depends on the population's standard of living and lifestyle (education, income, environmental concern etc.) (Santos et al., 2005; Bandara et al., 2007; Khan et al., 2016; Trang et al., 2016). Generally, locations with lower average income and educational levels present less MSW generation and deficient MSW management (The World Bank, 2018). In this sense, the socio-economic specificities of different locations may also contribute to more reliable estimates of litter entry into the ocean.

Brazil comprises the ninth-largest economy and the sixth-biggest population in the world (The World Bank, 2020a, 2020b). The country highlights the reality of most developing economies: fast economic growth, medium-high income, and inefficient waste management (Jambeck et al., 2015). As a consequence, Brazil was ranked among the top 16 leading contributor countries to plastic leakage into the ocean (Jambeck et al., 2015; Lebreton & Andrady, 2019; Meijer et al., 2021). Moreover, two hydrographic basins that drain the Brazilian territory (Paraná and Amazon) were indicated as major contributors of MSW to the ocean (Lebreton & Andrady, 2019). This input can also result from other characteristics of least-developed and developing economies: income inequality and abundance of informal settlements with poor sanitation conditions (Cordeiro & Costa, 2010; Fries et al., 2019). Thus, Brazil is an important case among the biggest contributors to marine litter pollution. Moreover, Brazil has a specific agenda to identify litter sources, as defined by its National Plan to Combat Marine Litter (PNCLM) (MMA, 2019). The country is also a signatory of the GPA/UNEP (Siwi, 2018).

Considering the importance of refining models to identify litter source locations, and also considering the importance of Brazil among the biggest contributors to marine litter pollution, this study aimed to draw a panorama of marine litter in Brazil under the Source-to-Sea approach, by pinpointing hotspots of leak-prone waste generation and leakage to the ocean, using plastics as a proxy. Our hypothesis was that throughout the Brazilian territory there are locations with greater potential to generate and input litter into aquatic systems.

5.2. MATERIAL AND METHODS

We estimated hotspots of plastic litter generation and leakage based on Jambeck et al. (2015), Lebreton et al. (2017) and Meijer et al. (2021), who estimated plastic leakage from coastal areas and rivers to the ocean. These studies generated data at a country level, by crossing data on population density, per capita income, and solid waste destination. We built on these methods and applied them to the municipal level, which has never been done before, considering the Brazilian territory. We took into account the organization of river basins and the reality of litter generation and management systems in Brazil. Subnational peculiarities of Brazil were pondered by the inclusion of information on plastic production, socio-economic condition and solid waste management, which were considered for the first time in this kind of modeling. This information expresses structural characteristics of the productive system and the propensity of litter leakage in each of the 5,570 Brazilian municipalities. Demographic, socio-economic, solid waste and environmental data for Brazilian municipalities were mostly obtained from national official public agencies' online platforms. However, we consulted several other national and international databases, including demographic censuses, surveys by government agencies, and reports from plastic industry associations and agencies of urban cleaning companies and solid waste management (Table 9). The use of national databases allowed us to improve estimates of litter generation and leakage. We processed data using R and QGIS software.

An important methodological difference in our study, compared to previous estimates of litter leakage to the ocean, was the choice of not using the term "mismanaged plastic waste" (MPW). Most previous studies defined MPW as litter deposited in dumps and open landfills, plus a fixed littering rate (2% of total waste generation) (Jambeck et al., 2015; Lebreton et al., 2017; Schmidt et al., 2017; Lebreton & Andrady, 2019; Meijer et al., 2021). However, the term "mismanaged waste" is polysemic and can also be understood in a wider perspective, as waste can be mismanaged at multiple stages of the waste chain, not only deposition and final disposal. Thus, we proposed a method for modeling litter leakage considering a more comprehensive approach to "mismanaged waste", indicating waste management optimization in all stages of the hierarchical chain. Hence, in this study, we use the term “leak-prone plastic waste” (LPW) for the estimated post-consumer plastic waste that has inadequate final disposal, including uncollected waste and also part of litter sent to destination units unable to retain waste.

5.2.1. Plastic waste generation and potential stock of leak-prone plastic waste

We identified hotspots of plastic waste generation and propensity of leakage to the environment, considering “hotspots” as geographical locations with critical conditions. To estimate the location and dimension of hotspots, we correlated multiple parameters of population density, socio-economic drivers, and municipal solid waste management (see Chapter 3). These parameters were identified through specialized literature and experts’ orientation and were based on holistic approaches such as the Source-to-Sea approach and the DPSIR (Driver- Pressure- State- Impact- Response) framework (Gari et al., 2015; Miranda et al., 2020; Granit et al., 2017). Parameters were chosen based on their importance for the study, considering how well they represent territories' socio-environmental particularities, and also based on data availability and usability (see Chapter 3). When a parameter was present in different data sources, the source with the best usability and applicability to the model was selected. The following parameters were selected for this analysis (Table 9):

Table 9. Parameters used for estimating plastic waste generation and stock of leak-prone plastic waste. Each parameter is followed by data year and source. Some parameters did not have any data available and, therefore, were estimated based on other parameters.

Category	**Parameter for estimating stock of leak-prone plastic waste and probability of litter mobilization and transport to the ocean**
Territory	- National territory (country, states, municipalities) 2019 - Brazilian Institute of Geography and Statistics (IBGE, 2020b) - Coastal municipalities 2021 - Ministério do Meio Ambiente (MMA, 2021)

Population density	- Total population per municipality - Estimated total population 2021 - Brazilian Institute of Geography and Statistics (IBGE, 2021) - Urban population (%) 2010 - Brazilian Institute of Geography and Statistics (IBGE, 2010) x Pop 2021 (IBGE, 2021) - Rural population (estimated based on the subtraction total-urban) - Floating population (occupancy rate of accommodation beds, unoccupied households for occasional use) 2019 - Ministry of Tourism (2019); 2010 - Brazilian Institute of Geography and Statistics (IBGE, 2010); 2018-2021 - Brazilian Association of the Hotel Industry - ABIH) - Demographic density (Pop 2021 / municipality area - IBGE) - Geographically distributed (gridded) population density 2020 - Socio-economic Data and Applications Center (Sedac - CIESIN, 2018) - Number of households in the municipality 2010 - Brazilian Institute of Geography and Statistics (IBGE, 2010)
Socio-economic status of the population	- Inequality in income distribution - Gini Index 2010 - Brazilian Institute of Geography and Statistics (IBGE, 2010) - Consumption pattern - per capita family expenditure 2018 - Consumer Expenditure Survey - POF - Brazilian Institute of Geography and Statistics (IBGE, 2018a) - Per capita income 2010 - Brazilian Institute of Geography and Statistics (IBGE, 2010) - Educational level of the population 2010 - Brazilian Institute of Geography and Statistics (IBGE, 2010) - Location of subnormal agglomerates and number of households 2019 - Brazilian Institute of Geography and Statistics (IBGE, 2020a)
Solid waste generation and composition	- Apparent consumption of plastics by municipality (tons.year^{-1}) (estimated based on the production, import, and export of plastic) - National production of thermoplastic and thermoset resins (tons.year^{-1}) 2015-2019, Annual Industrial Survey PIA - Brazilian Institute of Geography and Statistics (IBGE, 2019) - Import and export of plastic commodities 2015-2019 - Comex Stat (MDIC, 2019) - List of products made of plastic materials manufactured in Brazil (CNAE 22) 2019 - PRODLIST - Industry - Annual Industrial Survey PIA - Brazilian Institute of Geography and Statistics (IBGE, 2019) - Lifetime of plastic products (short vs. long life)(%) 2018 - ABIPLAST (2020) - Number of active employees in the plastic products retail sector considering the retail activities that consume more plastic materials

	(CNAE 2.0: 47.7, 47.5, 47.4, 47.2) 2018 - 2019, RAIS - Ministry of Labour (2021); 2019 - ABIPLAST (2020) - Solid waste composition (% of plastics) (Literature, described in the text)
Solid waste collection	- Mass of household and public waste collected (2015-2019, National Sanitation Information System (SNIS, 2019) - Mass of household and public waste collected per capita per day (estimated based on collected mass and Pop 2021)
Solid waste selective collection and recycling	- Existence of selective collection in the municipality 2019 - National Sanitation Information System (SNIS, 2019) - Mass of plastics recovered through formal selective collection 2015-2019 - National Sanitation Information System (SNIS, 2019) - Mass of post-consumer plastic resins recycled in Brazil 2019 - ABIPLAST, 2020) - Number of people employed as waste collectors 2014-2018 - CadÚnico (2018); 2010 - IBGE(2010) - Mass of recycled garbage via informal collection (estimated based on distribution of the quantity of plastic recycled in Brazil - excluding formal selective collection - according to the number of collectors in each municipality)
Final destination of solid waste	- Plastic waste mass disposed in Final Destination Units able to retain waste (dumps and controlled landfills with waste cover, sanitary landfills, recycling area of civil construction waste, landfills for civil construction waste, incineration treatment unit, burning in oven and specific ditch for health services waste) (2016-2019 - National Sanitation Information System (SNIS, 2019) - Plastic waste mass disposed in Final Destination Units unable to retain waste) (open dumps and landfills without waste coverage) (2016-2019 - National Sanitation Information System (SNIS, 2019) *waste = domestic, public, civil construction, and health services waste
Hydrology and other environmental factors	- Precipitation 2018 - Worldclim 2 (Fick & Hijmans, 2017) - Wind 2018 - Worldclim 2 (Fick & Hijmans, 2017) - Topographic slope 2004 - The Global Land Data Assimilation System - GLDAS (Rodell et al., 2004) - Degradation x urbanization rate (land use) 2016 - Global human modification of terrestrial systems - GHMTS (Kennedy et al., 2020) - Water network 2008 - HydroSHEDS (Lehner & Grill, 2013)

	- River discharge (Flow river order) 2010-2019 - GRUN - (Ghiggi et al., 2021) - Strahler river order (deviations to the ocean) 2008 - HydroSHEDS - (Lehner & Grill, 2013) - Distance to the ocean 2008 - HydroSHEDS - (Lehner & Grill, 2013) - Dams and reservoirs 2011 - Global Reservoir and Dam database - GRanD - (Lehner et al., 2011) - Watersheds - Pfafstetter level 12 2008 - HydroSHEDS - (Lehner & Grill, 2013)

After we selected relevant parameters (see Chapter 3), the part of our team specialized in solid waste developed a formula to calculate the mass balance among plastic entry to the consumption system and exit to the discard system, through a Material Flow or Mass Balance Analysis (Cecnic & Rechberger, 2008). A Material Flow Analysis contemplates the flow and stock of materials in a complex system across a given space and time (Cencic & Rechberger, 2008; Allesch & Brunner, 2016). This analysis ponders the principle of mass conservation and considers the entire lifecycle of the products, connecting source to sink (Brunner & Rechberger, 2016). Thus, we looked at production, consumption and disposal chain processes to the potential stock of leak-prone plastic waste (LPW) in the 5,570 existing Brazilian municipalities, using the following formula:

$$LPW = mAPC - (R + D1 + (D2 \; x \; 0.75)) \qquad (1)$$

where:

LPW= potential stock of leak-prone plastic waste

$mAPC$= municipal Apparent Plastic Consumption (per year)

R = amount of plastic sent to recycling in the municipality (per year)

$D1$ = amount of plastic sent to destination units **able** to retain litter (dumps and controlled landfills with waste cover, sanitary landfills, recycling area of civil construction waste, landfills for civil construction waste, incineration treatment unit, burning in oven and specific ditch for health services waste), according to the municipality where waste was generated.

$D2$ = amount of plastic sent to destination units **unable** to retain litter (dumps and controlled landfills without waste coverage), considering waste import and export between municipalities. For $D2$, we considered that 25% of plastic waste is prone to leaking into the environment (The World Bank, 2012; UNEP, 2018; Jambeck et al., 2018; Jambeck et al. al., 2015; Lebreton and Andrady, 2019; Meijer et al., 2021).

The municipal Apparent Plastic Consumption ($mAPC$) was derived from the distribution of national APC among the Brazilian municipalities. The APC corresponds to “domestic industrial production increased by imports and reduced by exports” and is being used as a proxy for the demand for consumer goods (Carvalho & Ribeiro, 2015). Thus, we first calculated national APC, considering the national production, import and export (PIA-IBGE, 2019; MDIC, 2019), and differentiating plastics with different lifetimes (< 1 year; 1 - 5 years; > 5 years) (IBGE, 2019; MDIC, 2019). Then, we proportionally distributed the national APC to all 5,570 Brazilian municipalities, considering municipal data on per capita expenditure in different stratum (capitals, metropolitan regions, remaining urban areas in the state, and remaining rural areas) corrected for the inflationary effect on income and purchases of goods and services (POF - IBGE, 2018a). Moreover, we also elaborated a distribution factor of plastic input for each municipality, considering total population (IBGE, 2021), seasonal variations of floating population (CBHLN, 2017; Semarh, 2016; MMA, 2021; IBGE, 2010; Ministry of Tourism, 2019), percentage of urban population (IBGE, 2010), per capita income (IBGE, 2010), degree of inequality of income distribution (Gini index) (IBGE, 2010), plastic consumption pattern (based on per capita expenditure per stratum) (POF - IBGE, 2018a), amount of domestic and public waste collected (SNIS, 2015-2019), and number of active employees in the retail sector (RAIS, 2018 - 2019) (Ministry of Labour, 2021).

The amount of plastic sent to recycling (R) in each municipality was used as a proxy for approaching the mass of plastic recycled. In order to estimate that, we approached the annual production of recycled plastic resin at the national level (838,000 tons) (ABIPLAST, 2019). The national amount was distributed among the Brazilian municipalities, considering the origin of recycled plastic waste (geographic region) (ABIPLAST, 2019). Since in Brazil recycled waste is collected via formal and informal selective collection, we distributed the national mass considering both forms of collection. We first distributed the national amount among municipalities considering formal collection. The remaining national amount was then distributed according to an estimated informal collection. Data on formal selective collection was obtained from the National Sanitation Information System (SNIS, 2015-2019), at the municipality level; and outliers were excluded through the Z-SCORE test (-2+2)). Data on informal selective collection was obtained by subtracting formal collection from the total amount of plastic recycled in the country. The resulting value was distributed to the municipalities, proportionally to the number of families of waste pickers (CadÚnico, 2014-2018) and the estimated per capita plastic entry in each municipality. In the absence of data from formal selective collection in the SNIS, the amount was estimated through logistic regression (using continuous predictors - normalized per capita income; % of garbage collection; number of people who have completed at least high school (IBGE, 2010) - and categorical predictors - waste classifiers (IBGE, 2010); number of families of recyclable material collectors (CadÚnico, 2014 - 2018)).

To estimate the amount of plastic sent to final destination units able to retain litter and avoid leakage to the environment ($D1$), we considered the amounts of waste destined to dumps and controlled landfills with waste cover, and also amounts sent to sanitary landfills, recycling area of civil construction waste, landfills for civil construction waste, incineration treatment units, burn oven and ditch for health services waste (SNIS, 2016-2019). In this phase, we considered the amount of waste that each municipality sent to these units, independently of the location of units. Then, we considered the plastic percentage among total waste, based on the literature for each kind of waste, where plastic percentage in civil construction waste is 2.29% (Llatas, 2011; Miranda et al., 2009; Mancini et al., 2007; Marques Neto, 2003), for health services waste is 14.39% (Silva et al., 2015; Schneider et al., 2000; Aduan, 2009; Moreira, 2012), and for domestic and public waste is 13.23% - 14.75% (Abreu and Vilar, 2017; Lino and Ismail, 2011; Da Silva et al., 2020; Alfaia et al., 2017; Gutierrez-Gomes et al., 2021; Silva et al., 2021; Nordi et al., 2017; Drudi et al., 2019; Spinola et al., 2019).

For the amount of plastic sent to final destination units unable to retain litter and avoid leakage to the environment ($D2$), we considered the total amounts of waste destined to open dumps and controlled landfills without waste cover (SNIS, 2016-2019). When necessary, data were corrected according to the average per capita collection of domestic and public waste (SNIS, 2015-2019). For municipalities without data on final disposal, we attributed the national average amount of plastic waste. For both $D1$and $D2$, we considered the same percentage of plastic waste. In this phase, we considered the import and export of waste between municipalities, contemplating the fact that some municipalities send waste to dumps and landfills located in other municipalities. This recognition is important since units unable to retain litter have significant risk of litter leakage to the environment. For $D2$, we considered that 25% of plastic waste is prone to leaking into the environment, since uncovered waste is subject to wind, rain, human action, and other factors that lead to litter mobilization (The World Bank, 2012; Ryberg et al., 2018; Jambeck et al., 2015; Lebreton and Andrady, 2019; Meijer et al., 2021).

Considering $mAPC$, R, $D1$, and $D2$, we generated 5 values of potential stock of total LPW and 5 values of potential stock of per capita LPW to each of the 5,570 Brazilian municipalities. These values consisted of the upper limit, upper limit mean, mean value, lower limit mean, and lower limit. Our final results express the mean value among the 5 values, within a 99% confidence interval.

5.2.2. Risk of plastic litter leakage to the ocean

After calculating potential leak-prone plastic waste (LPW) in each of the 5,570 Brazilian municipalities, we estimated the risk of litter leakage to the ocean. The risk estimate was based on geographic information system tools and depended on several parameters. Parameters used to calculate the mobilization and transport of LPW were selected based on their importance for the study and also data availability and usability (see Chapter 3). Thus, 10 parameters were selected and used in our analyses (Table 9). To map hotspots of LPW leakage to the aquatic systems, we correlated data on LPW, gridded population (CIESIN, 2018), environmental factors, and water network. We prioritized data sources with better usability and processed data using QGIS software.

Our estimate of risk of plastic litter leakage to the ocean was based on the principle of risk, defined by the Society for Risk Analysis as the potential for the occurrence of undesired negative outcomes (SRA, 2018; Sanchez, 2013), which can represent the effect of uncertainty (ISO 31000; SRA, 2018). Formally, risk can also be defined by the product of the probability of occurrence of a given event by the magnitude of its consequences ($R = C\ x\ P$) (Sanchez, 2013). In this case,

R = risk (of leak-prone plastic waste becoming marine litter)

C = consequences (impacts of leak-prone plastic waste)

P = probability (of litter mobilization and transport to the ocean)

Thus, we defined the risk of plastic litter leakage to the ocean as $Risk = LPW\ x\ P.$ It is important to notice that, in our model, the results of $Risk$ are obtained on a relative scale, meaning that the resulting values of $Risk$ can be compared between those calculated in the same analysis, but not with others obtained in separate analyses. The relative scale, which goes from the lowest value obtained to the highest obtained, was categorized for better visualization in the maps.

The concept of risk was applied to the present study in accordance with the definition of probability proposed by Meijer et al. (2021), who estimated the probability of litter leakage to the ocean based on the intersection of probabilities of different events: litter mobilization, transport to rivers and transport to the ocean. Thus, we defined the probability of litter leakage to the ocean as $P = P1\ x\ P2,$ where:

P = probability of LPW mobilization and transport to the ocean

$P1$ = probability of primary mobilization of LPW, linked to mobilization and transport of solid waste to aquatic environments (reaching mainly rivers, but also the ocean in the case of coastal locations)

$P2$ = probability of secondary mobilization of LPW, linked to litter transport to the ocean, via rivers

LPW generated in the municipalities can be mobilized to the environment and transported to rivers due to different factors. Mobilization can be particularly significant in open dumps and landfills (Barnes et al., 2009). Local variations of environmental factors, such as rain and wind, can provoke different litter mobilization rates (Beck et al., 2019; Schirinzi et al., 2020; Meijer et al., 2021; Hardesty et al., 2016). Other factors that vary greatly across the territories and can influence litter mobilization are topographic slope (Liro et al., 2020; Meijer et al., 2021) and distance to water bodies (Meijer et al., 2021). Besides that, litter mobilization to the environment can be highly influenced by anthropogenic factors such as land use (urbanization, cultivated areas and other human modifications of terrestrial systems) (Liro et al., 2020; Meijer et al., 2021; Hardesty; et al., 2016) and human-induced transport (Hardesty et al., 2016). Human-induced litter transport and disposal is aggravated by the presence of subnormal agglomerates, which comprise irregular land occupation for housing purposes in urban areas, and are generally characterized by precarious socioeconomic conditions and lack of waste collection and basic sanitation (IBGE, 2020a). Thus, we considered that $P1$ depends on precipitation, wind, slope, distance to the nearest river, urbanization rate, and existence of subnormal agglomerates. Annual average wind and total precipitation were calculated based on historical raster data for each month (1970-2000; 30 sec; Fick & Hijmans, 2017). The distance to the nearest river was calculated as a straight line (euclidean distance) considering rivers with long-term discharge > 0.1 m^3/s (Meijer et al., 2021). Data on location of subnormal agglomerates and number of households were considered according to the number of households in subnormal agglomerates in each watershed (level 12 Pfafstetter). All other $P1$ data sources are listed on Table 9.

After litter is introduced into rivers, its transport to the ocean depends mostly on riverine transportation. The amount of litter that can be transported via rivers to the ocean can be determined by river characteristics (dimension, discharge, flow direction), design of the water network (river pathways, connections with other rivers, deviations) and distance to the ocean (Liro et al., 2020; Schmidt et al., 2017; Lebreton et al., 2017; Meijer et al., 2021; Liro et al., 2020). Furthermore, the amount transported by rivers can be repressed by the existence of artificial barriers such as dams and reservoirs, which may act as particles sinkers or retainers (Lebreton et al., 2017; Liro et al., 2020; Zhang et al., 2015; Weideman et al., 2019; González et al., 2016). Dams are structures built to confine water for different purposes (e.g. water supply, flood control, and electricity generation). Dams built only to hold water back can totally block the passage of fishes and flow of sediment (NWcouncil, nd; FAO, 2001; Poff & Hart, 2002). On the other hand, hydroelectric dams without meshes and floating barriers can allow the passage of fish through their turbines and spillways, with significant mortality being reported (Hassan, 2020; Swiss Committee on Dams, 2017; FAO, 2001). Considering the diverse complexity of dam systems, plastics transported by dam-affected rivers can have different fates, including sinking in reservoirs, being retained, getting shattered by turbines and going through dam structures etc. Thus, we considered that $P2$ depends on river discharge, river Strahler order (represents cross-section, friction, and river deviations before reaching the ocean), distance to the ocean and existence of dams. To calculate the number of dams in each hydrographic basin and in its respective downstream basins, we developed and ran a code on IPython QGIS, considering all watersheds (Pfafstetter level 12) in South America, since the water network is transboundary. Average annual river discharge was calculated using monthly total discharge of the last 10 years with data available (2009-2019) (Ghiggi et al., 2021). All other $P2$ data sources are listed in Table 9.

The use of environmental and anthropogenic data for estimating litter leakage to the ocean is limited by the lack of empirical information about the level of influence of each factor on litter mobilization and transport, especially at the subnational level. To overcome this issue, we considered these factors in our probability model ($P1$ x $P2$). For pondering the weight of each parameter within our model, we adopted the Analytic Hierarchy Process (AHP), which is a theory of measurement through pairwise comparisons (Saaty, 1987; 1990; 2008; Vaidya & Kumar, 2006). During this analysis, a team of specialists compared two factors at a time, determining the importance of one factor over another (Saaty, 2008). This comparison could result in 1 (meaning that both factors have equal importance) or range between 2 (low-moderate importance) and 9 (extreme importance), (Saaty, 1987; 1990). After comparing a set of pairwise factors, AHP arranges all factors within the model in a hierarchic structure, and informs the priority scale of each factor (Vaidya & Kumar, 2006). Besides that, AHP also measures the consistency of a given model and among all factors, indicating necessary adaptations (Saaty, 1987; 2008). We used AHP for both $P1$ and $P2$, and obtained the weight of each normalized factor within our model, where the sum of weights equals 1. Thus, we obtained the following formulas:

$$P1 = (0.44\,x\,SA) + (0.252\,x\,vD) + (0.161\,x\,Pr) + (0.059\,x\,W) + (0.055\,x\,U) + (0.032\,x\,S) \quad (2)$$

where:

SA = presence of subnormal agglomerates

$vD = (D\ x\ (-\ 1))\ +\ 1$; where D= distance to the nearest river

Pr = precipitation

W = wind

U = urbanization rate

S = topographic slope

and

$$P2\ =\ (0.723\ x\ vDam)\ +\ (0.129\ x\ vDo)\ +\ (0.087\ x\ Di)\ +\ (0.061\ x\ vRO) \quad (3)$$

where:

$vDam\ =\ (Dam\ x\ (-\ 1))\ +\ 1$; where Dam = total number of dams located in that basin and in downstream basins

$vDo\ = (Do\ x\ (-\ 1))\ +\ 1$; where Do = distance to the ocean

$Di\ =$ river discharge

$vRO\ =\ (RO\ x\ (-\ 1))\ +\ 1$; where RO = river order (deviations to the ocean)

To run our models, we used normalized raster data (each variable $Pr,\ W,\ S,\ SA,\ U,\ vD,\ Di,\ vRO,\ vDo,\ vDam,$ is normalized to be in the range 0 to 1). The result of our model ($P1$ x $P2$) was the probability of litter leakage to the ocean for every pixel in the Brazilian territory. After obtaining P, we organized our results according to the municipalities, metropolitan regions, and also to watersheds that drain the Brazilian territory, which were previously grouped according to their sink basin (final watershed before flowing into the ocean). To organize approximately 136,000 basins (level 12 Pfafstetter) in South America, we developed and ran a code on IPython QGis. For each group of basins, we identified the total stock of LPW, probability P, and risk of plastic litter leakage to the ocean. To facilitate determining to which basin a LPW stock belongs, we first multiplied per capita LPW of each municipality for the spatially distributed gridded population (x 0.99, to standardize data to national estimates of population count). The LPW value aggregated to each pixel was then multiplied by the probability P in the respective area, resulting in a $Risk$ value for each pixel. Thus, the calculation of $Risk$ of plastic litter leakage from the hydrographic basins considered the pixels (i) geographically delimited by each basin, i.e.: $\Sigma_i\ EPRPE_i\ x\ P_i$. Finally, to compare the risk of plastic litter leakage in different estuaries, we regrouped sink basins that reach the same river/bay before flowing to the ocean.

5.3. RESULTS

5.3.1. Potential stock of leak-prone plastic waste

Through the Material Flow Analysis (1), we estimated an annual entry of 10.33 million tons (mt) of plastic in the Brazilian domestic market, of which 3.44 mt comprises the total potential stock of leak-prone plastic waste (LPW). While 8.9% of Brazilian municipalities had a potential stock above 1,000 tons.year^{-1}, 52.3% of municipalities overcame 100 tons.year^{-1}. High rates were observed in different regions of the country. The Brazilian municipalities with the greatest absolute potential stock of LPW were São Paulo (SP), Rio de Janeiro (RJ), Brasília (DF), Curitiba (PR) and Belo Horizonte (MG) (Fig. 10), with the municipality of São Paulo and Rio de Janeiro reaching more than 200,000 tons of LPW per year (Table 10). Many locations with high LPW rates comprise capitals and other big cities. Regarding relative values (per capita), the potential stock of LPW were higher in Arroio do Sal (RS), Xangri-lá (RS), Ubatuba (SP), Arambaré (RS), Ilha Comprida (SP) and Cidreira (RS) (Fig. 11), where LPW is higher than 100 kg.pp^{-1}.year^{-1} (Table 11). Many locations with a high per capita stock of LPW comprise coastal municipalities. The average potential stock of LPW was 16.15 kg.pp^{-1}.year^{-1}, with 6.8% of the municipalities presenting a value greater than 20 kg.pp^{-1}.year^{-1}. Only 0.006% of municipalities presented significant waste importation or exportation to landfills and dumps of other municipalities, and none of them had a high LPW rate. Thus, most municipalities presented the same values for LPW generation and availability to leak to the ocean.

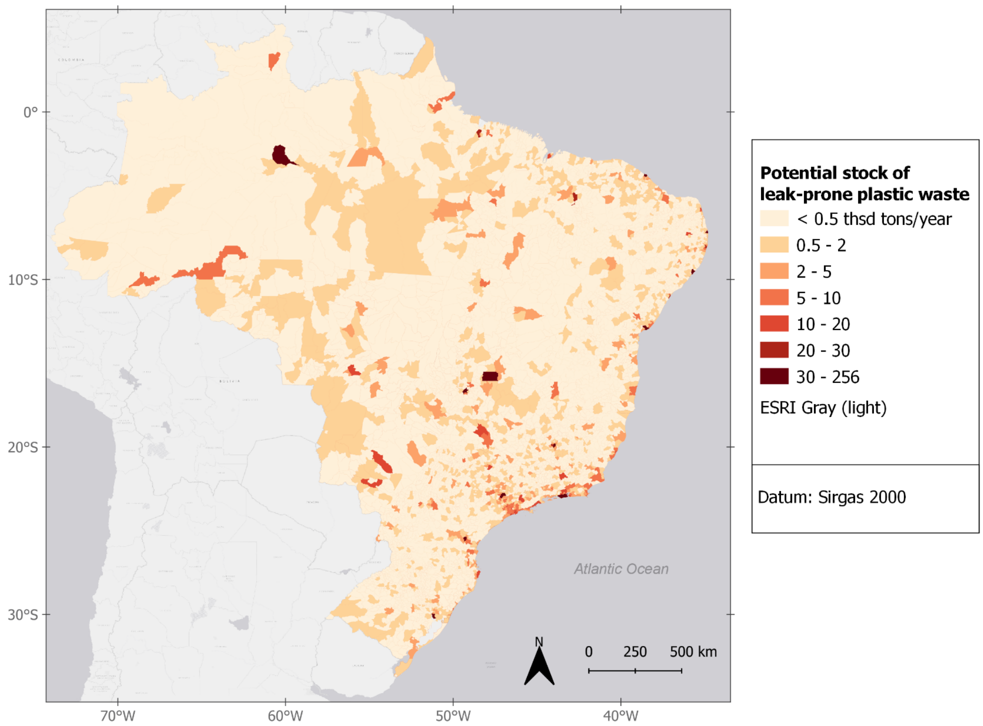


Fig. 10: Potential stock of leak-prone plastic waste (LPW), per municipality (thsd tons.year^{-1}). Results were obtained through a Material Flow Analysis.

Table 10. Top 20 Brazilian municipalities with the highest potential stock of leak-prone plastic waste (LPW), ordered according to total stock values (tons.year^{-1}). Results were obtained through a Material Flow Analysis.

Ranking	**Municipality**	**State**	**Potential stock of LPW (ton.year^{-1})**	**Per capita LPW (kg.pp^{-1}.year^{-1})**
1	São Paulo	SP	**256,196.98**	20.67
2	Rio de Janeiro	RJ	**203,112.15**	29.98
3	Brasília	DF	**66,155.74**	21.38
4	Curitiba	PR	**58,557.81**	29.82
5	Belo Horizonte	MG	**57,273.10**	22.63
6	Fortaleza	CE	**56,988.85**	21.08
7	Salvador	BA	**56,237.96**	19.39
8	Maceió	AL	**49,676.36**	48.16
9	Manaus	AM	**42,330.10**	18.76

10	Campinas	SP	**34,209.88**	27.97
11	Goiânia	GO	**31,894.49**	20.50
12	Porto Alegre	RS	**31,187.33**	20.90
13	João Pessoa	PB	**31,147.88**	37.72
14	Recife	PE	**29,647.91**	17.85
15	Contagem	MG	**28,447.36**	42.22
16	Belém	PA	**27,799.30**	18.45
17	Aracaju	SE	**21,705.61**	32.27
18	Teresina	PI	**20,274.99**	23.27
19	Natal	RN	**18,942.33**	21.12
20	Campo Grande	MS	**18,886.80**	20.62

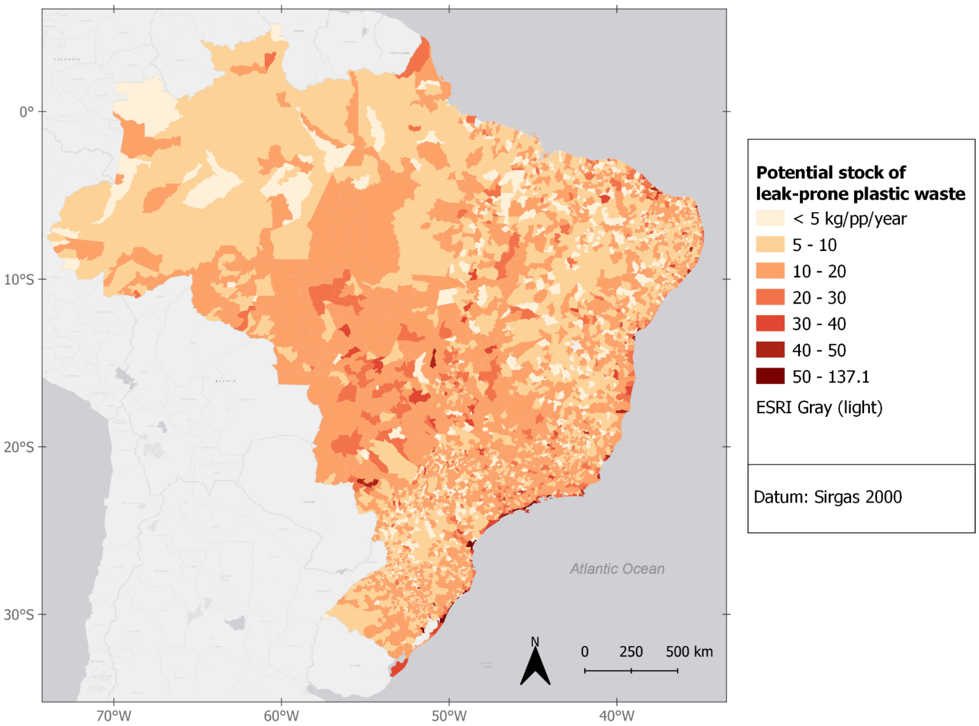


Fig. 11. Potential stock of leak-prone plastic waste (LPW), per capita, per municipality (kg.pp^{-1}.year^{-1}). Results were obtained through a Material Flow Analysis.

Table 11. Top 20 Brazilian municipalities with the highest potential stock of leak-prone plastic waste (LPW), ordered according to per capita values ($kg.pp^{1}.year^{-1}$). Results were obtained through a Material Flow Analysis.

Ranking	**Municipality**	**State**	**Per capita LPW ($kg.pp^{-1}.year^{-1}$)**	**Potential stock of LPW ($ton.year^{-1}$)**
1	Arroio do Sal	RS	**137.06**	1,436.78
2	Xangri-lá	RS	**109.74**	1,879.40
3	Ubatuba	SP	**109.00**	10,116.90
4	Arambaré	RS	**103.82**	367.95
5	Ilha Comprida	SP	**102.89**	1,188.56
6	Cidreira	RS	**100.66**	1,700.81
7	Capão da Canoa	RS	**96.61**	5,314.42
8	Pontal do Paraná	PR	**96.00**	2,738.82
9	Balneário Pinhal	RS	**88.28**	1,292.90
10	Imbé	RS	**87.66**	2,079.32
11	Bombinhas	SC	**84.72**	1,769.73
12	Fernando de Noronha	PE	**82.59**	259.33
13	Bertioga	SP	**81.07**	5,363.34
14	Palmares do Sul	RS	**80.20**	909.60
15	Jaguaruna	SC	**79.65**	1,636.60
16	Matinhos	PR	**79.06**	2,822.75
17	Balneário Arroio do Silva	SC	**76.72**	1,057.30
18	Mongaguá	SP	**72.76**	4,261.23
19	Tramandaí	RS	**72.50**	3,879.30
20	Barra de São Miguel	AL	**72.48**	611.30

5.3.2. Risk of plastic litter leakage to the ocean

The analysis of probability indicated that most Brazilian territory presents a low-middle probability of primary mobilization and transport of LPW ($P1$) (2), while few spots present high probability (Fig. 12). Regarding $P2$ (3), most of the territory presented a high-middle probability (Fig. 13); while the highest rates were observed by the coast, inland territory drained by dam-affected rivers presented lower $P2$. As a consequence, P along the Brazilian territory was low-middle, with few spots of high probability, especially on the coast (Fig. 5). The municipalities with higher average P in their territory were Guarujá (SP), Bayeux (PB), Recife (PE) and Olinda (PE) (Table 12). Considering $P1$, Rio Grande da Serra (SP), Guarujá (SP) and Bayeux (PB) were noteworthy (Supplementary Material E). Regarding $P2$, higher rates were observed in Oiapoque (AP), Santa Bárbara do Pará (PA) and Colares (PA) (Supplementary Material F). When obtaining $P2$, our analysis indicated that watersheds (Pfafstetter level 12) located in Brazil are affected by up to 16 dams, considering the total number of dams located in each watershed and its downstream basins (Supplementary Material G). Our analysis also indicated that 38.8% of the Brazilian territory is drained by dam-affected rivers.

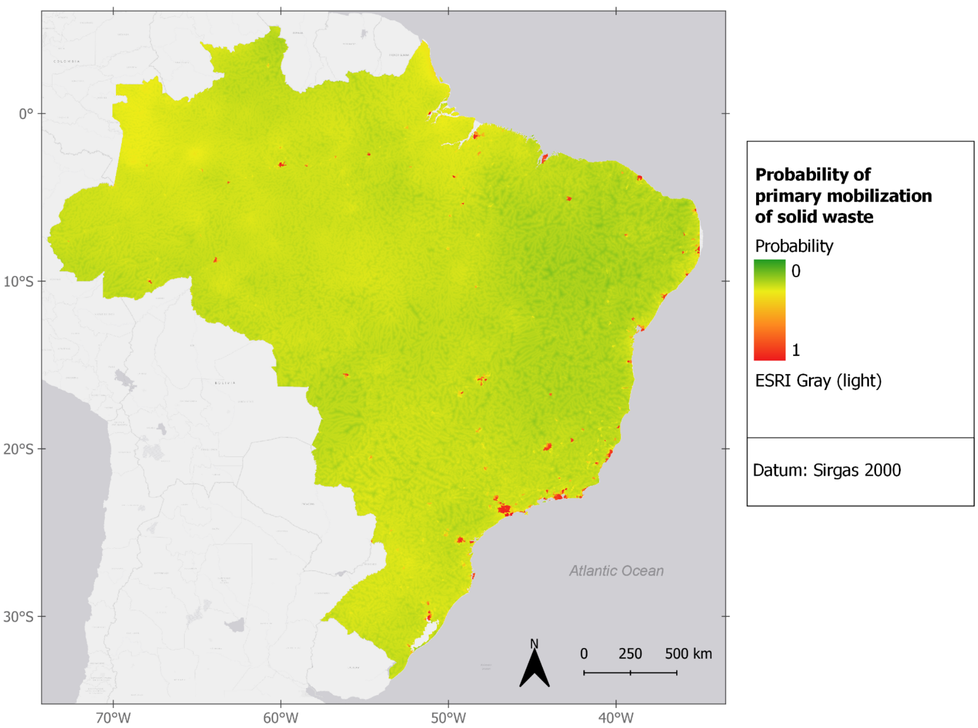


Fig. 12. Probability of primary mobilization of leak-prone plastic waste ($P1$), linked to mobilization and transport of solid waste to aquatic environments (reaching mainly rivers, but also the ocean in the case of coastal locations). The calculation of $P1$ considers local rates of precipitation, wind, topographic slope, degradation/urbanization rate, existence of subnormal agglomerates, and distance to rivers. On 0 to 1 scale, the resulting probability ranges between 0.134 and 0.839.

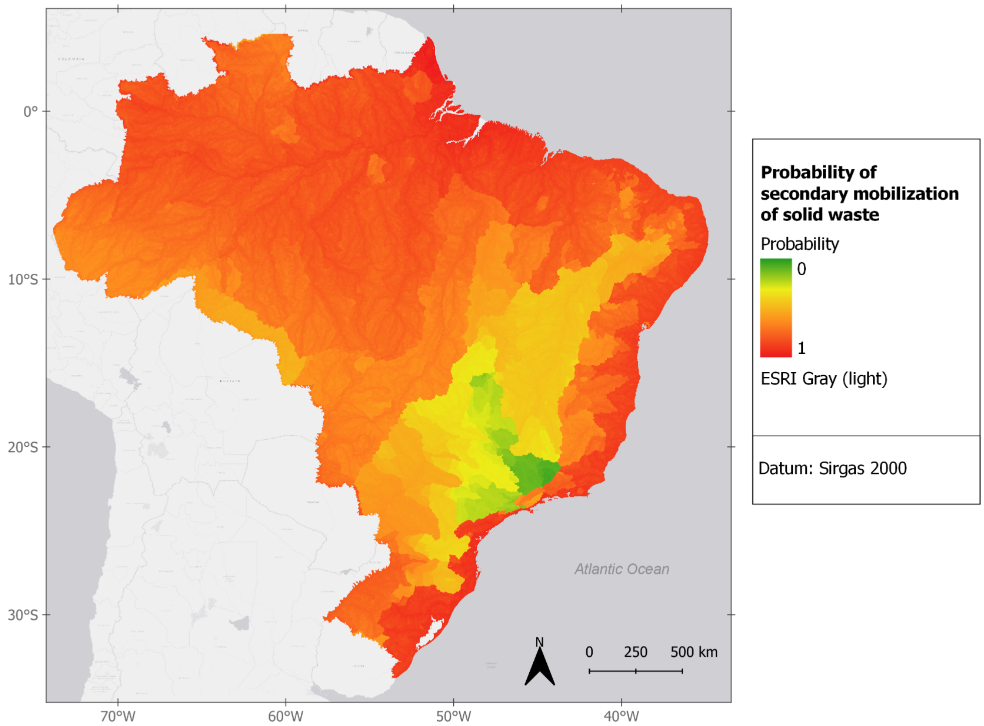


Fig. 13. Probability of secondary mobilization of leak-prone plastic waste ($P2$), linked to litter transport to the ocean, via rivers. The calculation of $P2$ considers river flow, Strahler order, distance to the ocean, and existence of dams. On a 0 to 1 scale, the resulting probability ranged between 0.081 and 0.978.

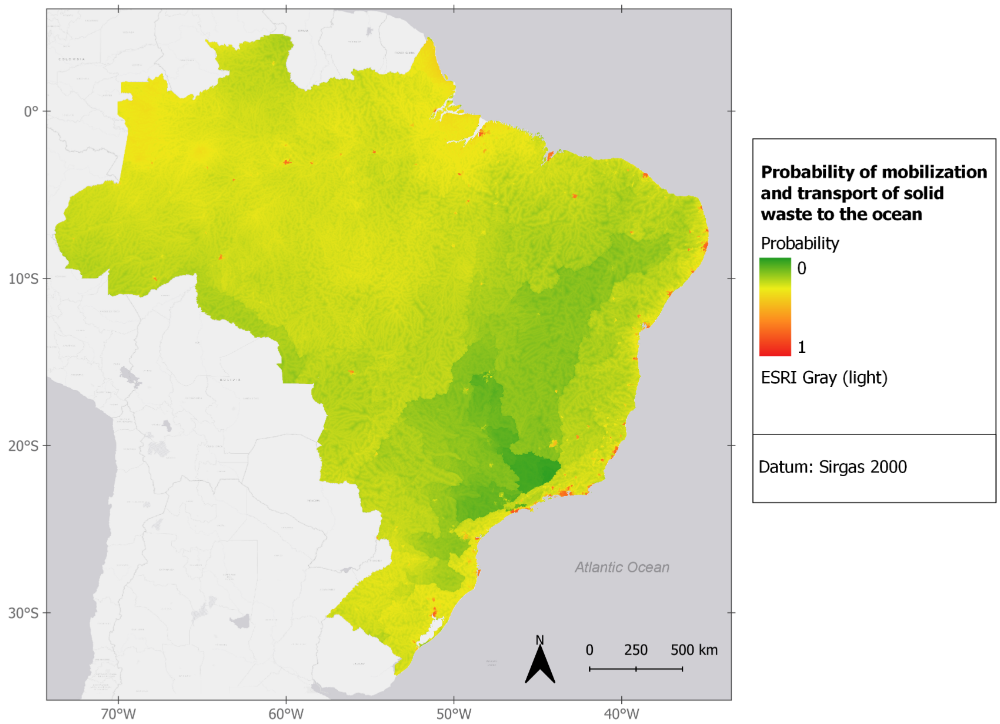


Fig. 14. Probability of mobilization and transport of leak-prone plastic waste to the ocean ($P = P1xP2$), considering local rates of precipitation, wind, topographic slope, degradation/urbanization rate, existence of subnormal agglomerates, distance to rivers, river discharge, Strahler order, distance to the ocean and existence of dams. On a 0 to 1 scale, the resulting probability ranged between 0.026 and 0.777.

Table 12. Top 20 Brazilian municipalities with the highest probability (P) of mobilization and transport of leak-prone plastic waste to the ocean. For each municipality, we calculated the average probability within its territory, considering the probability of primary mobilization $(P1)$ and secondary mobilization $(P2)$. For $P1,$ we considered local rates of precipitation, wind, topographic slope, degradation/urbanization rate, existence of subnormal agglomerates, and distance to rivers. For $P2,$ we considered river discharge, Strahler order, distance to the ocean, and existence of dams.

Ranking	Municipality	State	*P*	*P1*	*P2*
1	Guarujá	SP	**0.779**	0.825	0.944
2	Bayeux	PB	**0.758**	0.822	0.922
3	Recife	PE	**0.754**	0.813	0.927
4	Olinda	PE	**0.741**	0.799	0.927
5	Camaragibe	PE	**0.740**	0.799	0.926
6	São João de Meriti	RJ	**0.739**	0.801	0.923
7	Fortaleza	PE	**0.733**	0.802	0.914
8	Paulista	CE	**0.726**	0.784	0.926
9	Paço do Lumiar	MA	**0.724**	0.781	0.928
10	São Vicente	ES	**0.719**	0.770	0.934
11	Vitória	SP	**0.716**	0.771	0.929
12	Jaboatão dos Guararapes	PE	**0.715**	0.776	0.922
13	Nilópolis	PA	**0.714**	0.773	0.924
13	Ananindeua	RJ	**0.714**	0.749	0.952
15	Mesquita	RJ	**0.709**	0.766	0.925
16	Belford Roxo	RJ	**0.705**	0.761	0.926
17	Rio de Janeiro	SC	**0.695**	0.747	0.930
18	Cachoeirinha	RJ	**0.693**	0.741	0.934
19	Florianópolis	RS	**0.692**	0.570	0.941
20	São Leopoldo	RJ	**0.682**	0.735	0.929
20	São Luís	MA	**0.682**	0.730	0.928
20	Raposa	MA	**0.682**	0.723	0.928

When calculating the risk of plastic litter leakage from the Brazilian municipalities analyzed to the ocean, we observed that Rio de Janeiro (RJ), São Paulo (SP), Fortaleza (CE) and Salvador (BA) presented the highest total risk (Table 13), while most of the national territory had low risk (Fig. 15). Considering per capita risk, the municipalities of Arroio do Sal (RS), Ubatuba (SP), Bertioga (SP) and Xangri-lá (RS) stood out (Fig. 16; Table 14). The grouping of risk information for the Brazilian Metropolitan Regions highlighted the relevance of Baixada Santista both in terms of total and per capita risk (Supplementary Material H).

Our analysis also showed that rivers that drain the Brazilian territory flow to 1,018 sink basins (Pfafstetter level 12) (Supplementary Material I), located in Brazil and also in neighboring countries (Argentina, Uruguay, Venezuela, Guyana, French Guyana, and Suriname). Moreover, we also observed the concentration of LPW generation by the coast (Supplementary Material J). Considering smaller rivers that flow out in large estuaries and bays (including the Patos Lagoon, La Plata River Guanabara Bay), as well as other coastal areas, we identified the following hotspots where litter leaks to the ocean (Table 15). Due to the fact that information was generated at the basin level, the hotspots are associated to both coastal municipalities (small basins) and large rivers (macrobasins). By grouping hotspots that flow into the same estuaries or bays, we identified that the Guanabara Bay, Patos Lagoon and the La Plata, Amazon, São Francisco and Tocantins Rivers are the main hotspots for leakage of plastic waste produced in Brazil into the ocean (Table 16). Considering the organization of the water network and the distribution of LPW according to population, we identified that the Guanabara Bay, the Patos Lagoon, and the La Plata, Amazon, São Francisco and Tocantins rivers comprise the main leakage hotpots of plastic waste produced in Brazil to the ocean (Fig. 17).

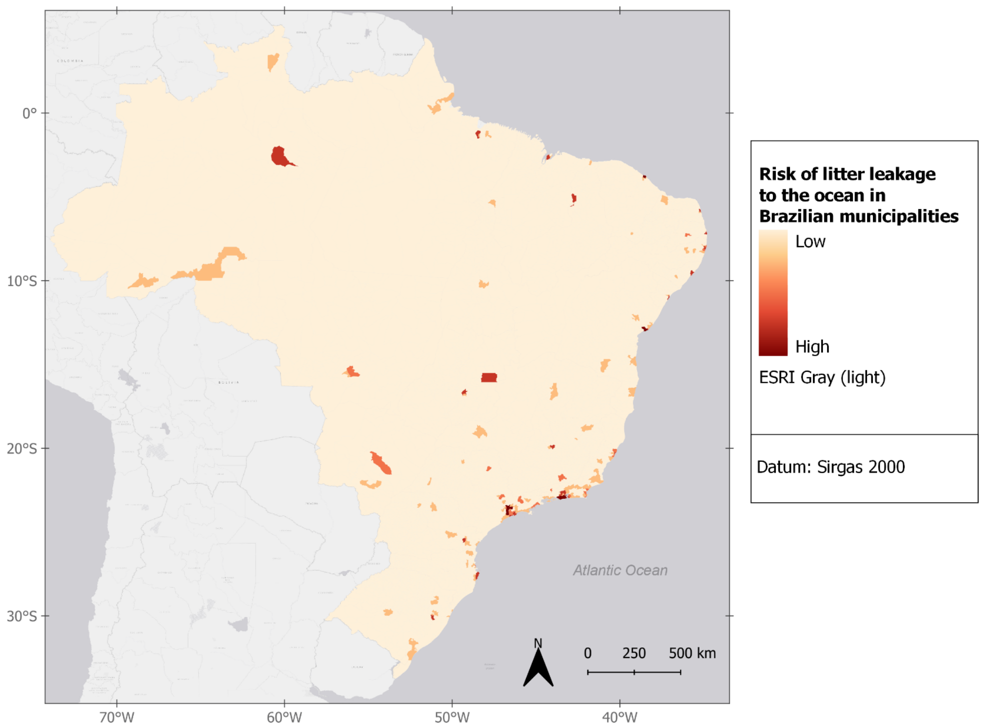


Fig. 15. Risk of plastic litter leakage to the ocean for all the 5,570 Brazilian municipalities, considering potential stock of leak-prone plastic waste (LPW) and probability of primary and secondary mobilization to the ocean.

Table 13. The main Brazilian municipalities with highest **risk** of plastic litter leakage into the ocean, considering the potential stock of leak-prone plastic waste (LPW) and the probability of litter mobilization and transport to the ocean. The value of Risk, obtained from the product of LPW and probability (P), is relative, for comparison purposes.

Ranking	Municipality	State	Risk	Per capita Risk
1	Rio de Janeiro	RJ	141,065.74	20.69
2	São Paulo	SP	64,890.56	5.17
3	Fortaleza	CE	41,767.03	15.39
4	Salvador	BA	37,295.44	12.80
5	Belo Horizonte	MG	26,426.40	10.41
6	Curitiba	PR	25,035.46	12.82
7	Maceió	AL	24,146.01	23.60
8	Recife	PE	22,345.15	13.39
9	Porto Alegre	RS	20,813.28	14.00
10	João Pessoa	PB	20,580.63	24.90

11	Belém	PA	17,044.63	11.26
12	Aracaju	SE	14,049.52	20.98
13	Manaus	AM	13,998.17	6.19
14	São Luís	MA	12,642.59	11.30
15	Natal	RN	12,523.37	13.94
16	Praia Grande	SP	11,620.86	34.76
17	Vitória	ES	10,645.80	28.96
18	Brasília	DF	10,569.58	3.42
19	Santos	SP	10,255.55	23.55
20	Niterói	RJ	10,226.85	19.77

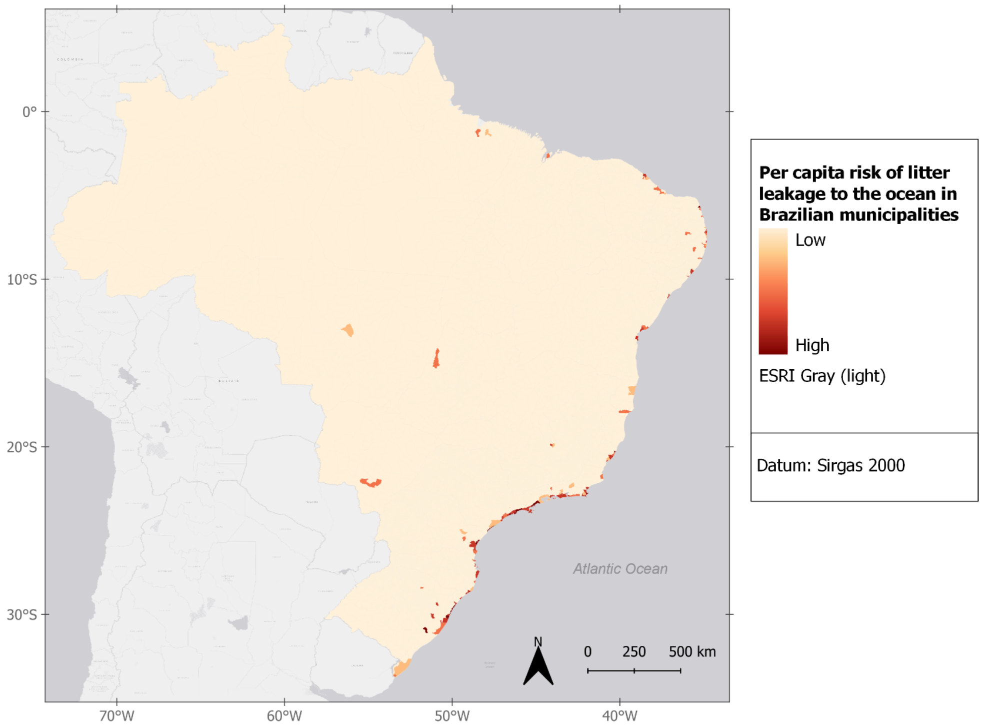


Fig. 16. Per capita risk of plastic litter leakage to the ocean for all the 5,570 Brazilian municipalities, considering potential stock of leak-prone plastic waste (LPW) and probability of primary and secondary mobilization to the ocean.

Table 14. The main Brazilian municipalities with highest **per capita risk** of plastic litter leakage into the ocean, considering the potential stock of leak-prone plastic waste (LPW) and the probability of litter mobilization and transport to the ocean. The value of Risk, obtained from the product of LPW and probability (P), is relative, for comparison purposes.

Ranking	Municipality	State	Per capita Risk	Risk
1	Arroio do Sal	RS	43.86	462.32
2	Ubatuba	SP	43.6	4,006.77
3	Bertioga	SP	40.54	2,672.38
4	Xangri-lá	RS	39.51	683.69
5	Armação dos Búzios	RJ	36.69	1,291.39
6	Capão da Canoa	RS	35.75	1,954.57
7	Pontal do Paraná	PR	35.52	1,017.07
8	Praia Grande	SP	34.76	11,620.86
9	Arambaré	RS	33.22	117.13
10	Imbé	RS	32.43	779.20
11	Cidreira	RS	32.21	542.67
12	Matinhos	PR	30.04	1,068.49
13	Ilha Comprida	SP	29.84	346.81
14	Balneário Pinhal	RS	29.13	428.79
15	Vitória	ES	28.96	10,645.80
16	Guarujá	SP	27.07	8,785.05
17	Extremoz	RN	27.07	801.81
18	Mongaguá	SP	26.19	1,552.91
19	Palmares do Sul	RS	25.66	290.12
20	Jaguaruna	SC	25.49	528.36

Table 15. Top 10 coastal hotspots with the highest risk of plastic litter leakage to the ocean, considering **non-grouped hotspots** when they flow to the same bay or estuary. The table also presents the amount of leak-prone plastic waste (LPW) generated within the watershed that is available to enter the ocean (tons.year^{-1}). Hotspots are associated with both coastal municipalities and rivers/estuaries, since this information results from processing data at the micro-watershed level (Pfafstetter level 12), grouped according to their final basin (before flowing into the ocean). The value of Risk, obtained from the product of LPW and probability (P), is relative, for comparison purposes.

Risk ranking	Main hotspots identified by this study	Risk	Amount of LPW available in the watershed
1	Paraná-Guazú river - mouth located in Argentina, via La Plata river)	270,884.43	1,139,112.38
2	São Francisco river - mouth located between the municipalities of Piaçabuçu (AL) and Brejo Grande (SE)	73,713.46	231,531.98
3	Amazon river - numerous micro and mesobasins are connected to this river, with mouths close to different municipalities. The Amazon River macrobasin meets the Brazilian coastal region (MMA, 2021) on the outskirts of the municipalities of Gurupá and Breves (PA)	68,484.69	147,957.87
4	Rio de Janeiro (RJ) - north, south and central areas of the city, which is partially located around the Guanabara Bay)	63,295.08	88,826.49
5	Paraíba do Sul river - mouth located between the municipalities of São João da Barra (RJ) and São Francisco de Itabapoana (RJ)	40,563.30	103,990.06
6	Pavuna river - mouth located between the municipalities of Duque de Caxias (RJ) and Rio de Janeiro (RJ), via Guanabara Bay	39,685.20	53,920.37
7	Salvador (BA)	32,965.90	51,952.50
8	Parnaíba river (RJ) - mouth between the municipalities of Ilha Grande (PI) and Araioses (MA)	26,686.81	63,206.42
9	Tocantins river - different micro and mesobasins are connected to this river. The Tocantins macrobasin has its mouth located in the surroundings of the municipality of Cametá (PA)	24,164.61	81,107.85
10	Fortaleza (CE)	23,041.18	32,698.30

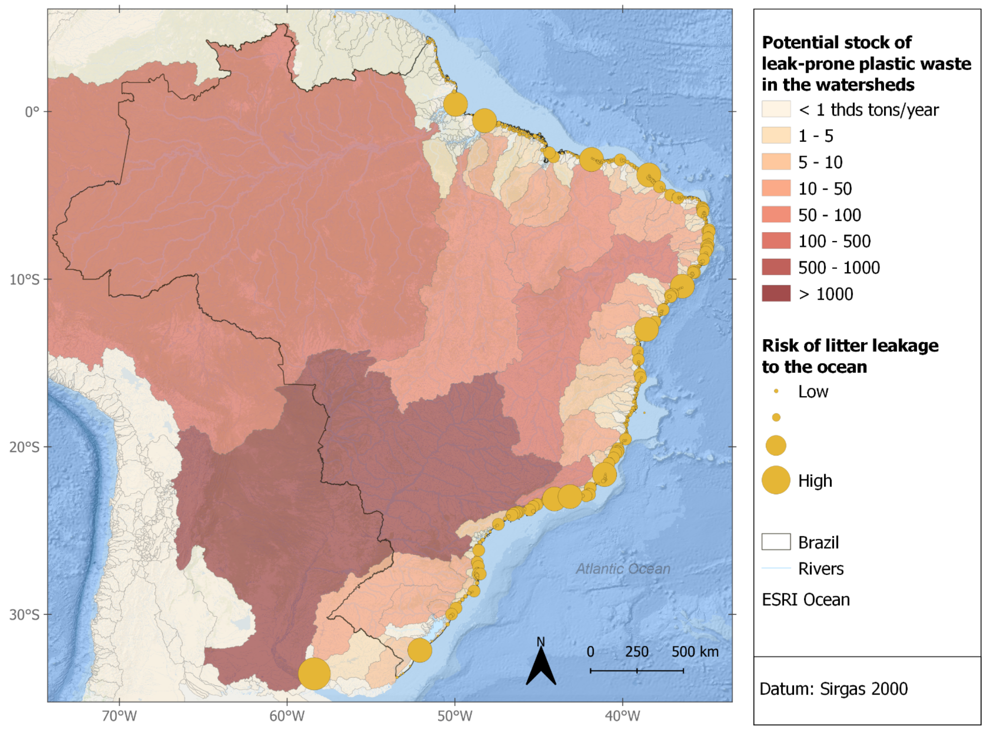


Fig. 17. Potential stock of leak-prone plastic waste per sink basin and risk of litter leakage to the ocean. Locations with higher risk comprise coastal hotspots of litter leakage. Rivers that flow out to the ocean through the same estuary or bay are grouped as the same hotspot.

Table 16. Top 10 coastal hotspots with the highest risk of plastic litter leakage to the ocean, considering **grouped hotspots** when they flow to the same bay or estuary. The table also presents the amount of leak-prone plastic waste (LPW) generated within the watershed that is available to enter the ocean ($tons.year^{-1}$). Hotspots are associated with both coastal municipalities and rivers/estuaries, since this information results from processing data at the micro-watershed level (Pfafstetter level 12), grouped according to their final basin (before flowing into the ocean). The value of Risk, obtained from the product of LPW and probability (P), is relative, for comparison purposes.

Risk ranking	Main hotspots identified by this study	Risk	Amount of LPW available in the watershed
1	Rio de la Plata - mouth between Argentina and Uruguay	283,248.64	1,180.360
2	Guanabara Bay and region - Rio de Janeiro	149,630.50	216.431
3	Amazon River - mouth between the states of Amapá and Pará	75,741.01	158.469
4	São Francisco River - mouth between the states of Alagoas and Sergipe	73,713.46	231.531
5	Tocantins River - mouth in the Pará state	59,036.54	139.734

6	Patos Lagoon - Rio Grande do Sul	57,307.29	114.547
7	Todos os Santos Bay and region - Bahia	42,557.37	79.038
8	Paraíba do Sul River- mounth in Rio de Janeiro	40,563.30	103.990
9	Sepetiba Bay - Rio de Janeiro	28,050.35	44.106
10	Parnaíba River - mouth between the states of Maranhão and Piauí	26,686.81	63.206

5.4. DISCUSSION

5.4.1. Potential stock of leak-prone plastic waste

The potential annual stock of leak-prone plastic waste (LPW) in Brazil was estimated at 3.44 million tons (mt), which is equivalent to 33.3% of the annual entry of plastic in the Brazilian domestic market (10.33 mt, considering plastic production, import, and export). Our estimated annual entry of plastic in the market is very close to what has been previously estimated (10.85 mt; Inter-American Development Bank; IDB, 2020), and ranges among estimates by the plastic industry (7.6 mt; ABIPLAST, 2020), scientific research (8.9 mt Lebreton & Andrady, 2019) and national urban cleaning association (13.3 mt; ABRELPE, 2020). Since one-third of the plastic that enters the market is available to leak to the environment, our results show that a significant portion of plastic waste is not receiving a proper final destination in Brazil. The percentage of plastics that become LPW (33.3%) in Brazil is very similar to what has been proposed for Brazil (25.2%) (IDB, 2020) and for Latin America & Caribbean (31%) (UNEP, 2018) previously. This reality is very different from developed regions such as Oceania, Japan, Western Europe, and North America, where mismanagement rate is zero. On the other hand, the Brazilian reality is similar or much better than the reality of other Global South regions, such as China (32%), Africa (93%), and India (90%) (UNEP, 2018). The national LPW resulting from our analysis is also similar to previous estimates, which ranged from 3.30 mt (for 2021) (Meijer et al., 2021) to 3.72 mt (for 2015) (Lebreton & Andrady, 2019). Considering this LPW rate, Brazil is considered the 4th leading nation to generate mismanaged plastic waste (Lebreton & Andrady, 2019).

In order to make comparisons with previous studies that estimated coastal “mismanaged waste”, which is generated within 50 km of the coastline, we selected our LPW results only in this region, estimating a generation of 1.62 mt in this area. Our estimate was higher than previously calculated by Jambeck et al. (2015) (0.47 mt) and IDB (2020)

(0.83 mt), probably due to the different definitions of mismanaged plastic waste and LPW, which are explored in section *4.1.1*.

The hypothesis that throughout the Brazilian territory there are locations with greater potential to generate and input litter into aquatic systems was confirmed. The Material Flow Analysis indicated that all Brazilian regions presented municipalities with low and high rates of LPW. São Paulo (SP), the municipality with the highest LPW generation (> 0.20 mt) was previously identified as the 4th global urban center with the highest generation of mismanaged plastic waste (0.48 mt) (Lebreton & Andrady, 2019). Moreover, we also identified other big cities with high rates of LPW, including Rio de Janeiro (RJ), with LPW generation very similar to São Paulo. Among the top 20 municipalities regarding LPW generation, nine comprise coastal municipalities, which is a concern. Municipalities with high level of LPW generation comprise hotspots of litter generation and improper management, where prevention and mitigation measures are more urgent. The identification of hotspots, resulting from the Material Flow Analysis, supports decision-making and the application of strategies for better management of the environment, waste, and available resources (Allesch & Brunner, 2016; Brunner & Rechberger, 2016).

The potential stock of LPW was estimated on an absolute basis and per capita basis. When the resident population of each municipality was taken into account, the panorama was very different. While, in the first case, hotspots comprise big cities, in the second case, many of the top 20 municipalities comprise small coastal cities with high floating population rates, especially during festivals and holidays season. Different results for absolute values and relative values are expected and widely reported by the literature. Relative values are important to reveal socioeconomic dynamics that are often hidden in absolute values (Carvalho & Pardini, 2020; Cestari et al., 2021; Silva et al., 2021; Silva et al., al., 2019), particularly for solid waste management in Brazil (Moore et al., 2019; Silva et al., 2021; Redivo, 2021). However, both absolute and relative values can be used to guide decision-making, and efficiently select proper prevention and mitigation measures that better fit each situation. Information on LPW can be used to guide actions turned to the plastic industry and solid waste management in municipalities, as well as investments in education, socioeconomic condition of the population, and infrastructure to receive non-resident population.

5.4.1.1. Challenges and advances in estimating leak-prone plastic waste at the subnational level

Estimating LPW generation and leakage to the environment is complex and demands the use of multiple parameters. However, available data may not be compatible with relevant parameters, which leads to numerous gaps. Thus, data availability and usability comprise the main limitation of estimating LPW. Data with low usability leads to increased uncertainties. As shown in the third chapter of this thesis, Brazil has low data quality on plastic production, solid waste management, and sociodemographic information (e.g. the last demographic census in Brazil was performed in 2010). Data gaps encompass government (Chung & Lo, 2008), plastic industry, and private agencies for urban cleaning, solid waste management and water treatment. Thus, for improving models, it is important to also improve data systems, regarding data acquisition and availability. Moreover, it is also essential to promote the unification of data produced in different temporal spaces, since dealing with fragmented data and linking different socioeconomic data from different years can atrophy the robustness of multivariate modeling.

During our analysis, one important gap was the non-existence of data for plastic production, consumption and disposal for Brazilian municipalities. Data availability at the municipal level would allow phasing out the distribution of national data among municipalities. In order to overcome limitations, this study performed a Material Flow Analysis adapted to existing data for Brazilian locations, estimating plastic waste generation in each municipality through plastic demand. The lack of data can sometimes be countered by the use of proxies. However, proxies may not completely represent the desired information, even though they comprise the best information available. For example, we represented floating population by using tourism information as a proxy, which does not represent all forms of population fluctuations (e.g. fluctuations by work and study displacements to other municipalities). Another relevant gap linked to low data usability is the existence of systems that rely on self-declared information (plastic industry, municipalities), which might lead to uncertainties and difficulties in proposing solutions. This may delineate a common challenge in the Global South.

Even though the present study has limitations, it represents a great advance towards improving LPW estimates at the subnational level. While global estimates are necessary to provide an overview, subnational estimates are necessary to efficiently subsidize actions. Moreover, while previous studies made great progress at establishing a baseline for litter leakage estimates, providing estimates at the national level, we improved estimates regarding its reliability, spatial and temporal granularity. Spatial granularity was upgraded by the use of data at the subnational level, while previous studies only provided estimates at the national level. Temporal granularity was improved by the use of the most recent data available for each parameter used in our analysis. Reliability was improved by the use of multiple national data sources that reflects the reality of socioeconomic inequality in the Global South and its influence on different waste generation and final disposal situations.

Besides considering socioeconomic information, we also considered spatial and environmental particularities of the Brazilian territory. The importance of considering spatio-environmental particularities relies on the worldwide diversity of territorial characteristics. A great portion of the Brazilian territory is drained by rivers that flow inland, including locations that are very close to the coast. Previous estimates of litter leakage from coastal areas to the ocean considered locations up to 50 km from the coast (Jambeck et al., 2015). However, in Brazil, this definition of the coastal area would include municipalities like São Paulo, whose rivers run inland and flow out in the La Plata River. La Plata comprises the continental-size Paraná basin, which drains five countries (Brazil, Argentina, Uruguay, Paraguay and Bolivia). This way, LPW generated in Brazil, in territories drained by the Paraná basin, can flow out into international waters, between Argentina and Uruguay.

Reliability was also improved by the calculation of plastic entry in the consumption system of each municipality, while previous global estimates used waste collection data from the year 2000 as waste generation information for Brazil (The World Bank, 2012, PAHO, 2005, IBGE, 2000a), a country where waste collection reaches only 70.27% households (IBGE, 2010a). Another important improvement was the substitution of the term “mismanaged plastic waste”, which previous studies use to refer to litter that, in middle-income countries, is deposited in dumps or littered. The littering rate was previously used as a fixed rate of 2% of the total waste generation, based on estimates in the United States (Jambeck et al., 2015), which is a developed country whose reality does not reflect the reality of the Global South. In this study, we used the term leak-prone plastic waste, which comprises all post-consumption plastic waste that did not take proper final destination (e.g. recycling, destination units with proper waste coverage), improving the previously littering estimate. Moreover, previous studies only considered landfills as an improper destination in low-income countries. However, Brazil, which is a high-middle income country, has unusual situations, such as “dumps” with waste cover, and “controlled landfills” without waste cover. This particularity expresses the complexity of countries that are not fully developed or that are least-developed. Thus, a subnational estimate in Brazil was important to represent the complexity of Global South countries, and help understanding the mass balance of plastic litter.

5.4.1.2. Future scenarios for leak-prone plastic waste generation

With the population growth predicted for the upcoming years (IBGE, 2010), the demand for plastics will inflate significantly (Plastics Europe, 2015). Thus, the amount of waste generated and introduced into the oceans tends to increase (Lebreton & Andrady, 2019; Alfaia et al., 2017; Geyer et al., 2017; Jambeck et al., 2015). Projections of plastic litter entry into the marine environment have already been developed on a global scale for up to 2025 (Jambeck et al., 2015) and 2050 (The World Bank, 2018) and, on a national scale, until 2060 (Lebreton & Andrady, 2019). To date, this estimate has not been made on a subnational scale. In order to provide this information on the subnational scale for Brazil, we projected our LPW data to up to 2060. First, we tested the LPW of each Brazilian state against state population and GDP, through an Ordinary Least Squares (OLS) regression model. National population size and GDP were previously related to LPW generation (Jambeck et al., 2015; Lebreton & Andrady, 2019; The World Bank, 2018). The test indicated that, at the state level, LPW generation is related to population (p-value < 0.05) and not related to GDP (p-value > 0.05). Testing again only LPW and population, we set up the following equation:

$$stock\ of\ LPW\ =\ e^{-4.245}\ x\ population^{1.006}$$

Using this equation, we projected LPW for the next 40 years, using data on population projections up to 2060 for each Brazilian state (IBGE, 2018b) (Supplementary Material K, L, M). According to IBGE, the Brazilian population, which currently comprises 213.32 million people, will reach 233.23 million by 2047, when it will start to decrease until 2060. Considering fixed rates of per capita LPW generation and no future changes in solid waste management systems, we estimated that, by 2047, LPW generation will reach 3.75 million tons.year^{-1}. Our model is conservative since it does not consider future socioeconomic changes. Thus, our results are also conservative when compared to Lebreton & Andrady (2019), who pointed out that by 2060 Brazil will reach 5.42 million tons of LPW.year^{-1}.

However, future scenarios of Brazil and other Global South countries might be uncertain, considering not only economic uncertainties but also possible increasing inequality in the next years associated with covid-19, political scenarios, economic recession, and the climate crisis. Even though projections estimated a strong GDP growth (OECD, 2018), Brazil has been falling in the ranking of the biggest economies in the world (The World Bank, 2020). Economic uncertainties might lead to socio-economic inequality and an increasing number of people living in subnormal agglomerates, with precarious sanitation conditions. Thus, future changes in socioeconomic condition and population size can lead to the expansion of existing hotspots of litter generation and leakage to the environment, as well as to the formation of new hotspots. However, we currently only have data forecasts for population growth and GDP, which were both tested by this study. Prevention and mitigation actions might be taken in order to change the current patterns of consumption and waste generation, including improving the social-economic condition of the population. Moreover, actions to improve waste management infrastructure (Lebreton et al., 2019; Jambeck et al., 2015) and offer basic services to all the population are essential to avoid the increase in waste production and leakage into the ocean in the next few years. In order to improve predictions of future scenarios, it is important to keep tracking the annual potential stock of leak-prone plastic waste.

5.4.2. Risk of plastic litter leakage to the ocean

The analysis of probability indicated few spots in the Brazilian territory with high $P1$, particularly influenced by the presence of subnormal agglomerates, generally characterized by insufficiency of basic services such as sanitation, including waste collection. Subnormal agglomerates do not count on door-to-door solid waste collection. They usually rely only on trash cans in the nearby streets (agglomerates often have only alleys), from where litter is collected unfrequently. As a consequence of lack of infrastructure, litter generated in subnormal agglomerates is often disposed of in soils and rivers (Scheler et al., 2018). This situation is aggravated by the occurrence of floods, since agglomerates are often located near streams (Castro et al., 2020). The existence of subnormal agglomerates is associated with social inequality, caused by income concentration and lack of adequate living conditions for a large part of the population. Thus, subnormal agglomerates are an extremely complex socioeconomic issue that shall be understood and resolved, by promoting social equality.

For $P2$, most of the territory presented high-middle probability. The highest probabilities were observed on the coast, while regions drained by dam-affected rivers presented lower $P2$. Previous estimates considered that dams retain all riverine plastic litter, indicating that they are responsible for retaining 65% of the global plastic input into the ocean. However, studies on the impacts of dams on fishes shows that depending on the purpose of dams, fishes might be able to go through the turbines and spillways (Hassan, 2020; Swiss Committee on Dams, 2017; FAO, 2001). The same way, litter might also be able to go through some kinds of dams, especially small items. However, the chances of litter retention and sinking in reservoirs associated with dams are still high (Gonzalez, 2016).

Given the hydroelectric-based energy matrix in Brazil, some rivers have numerous hydroelectric dams along with their courses. As a consequence, dam-affected rivers drain more than one-third of the national territory, and comprise conditions where litter can be retained and not leaked to the ocean. However, even though retained litter is not reaching the ocean, they are reaching rivers and possibly impacting the ecosystems. Thus, actions might be taken everywhere with significant probability of litter leakage to the environment.

Considering $P1$ and $P2$, a higher probability of litter leakage from land-based sources to the ocean (P) was also observed in coastal municipalities, in different Brazilian regions. Combining P and potential stock of leak-prone plastic waste (LPW), we identified the municipalities and metropolitan regions with highest risk of plastic litter leakage into the ocean. This synthesis may subsidize decision-making and facilitate the prioritization of actions in critical locations when resources are limited. It is important to note the different profiles of municipalities regarding total and per capita risk. While the ranking of municipalities with the highest total risk was mostly comprised of big cities with large population, the per capita risk was composed of coastal cities with high population fluctuations, including small cities with low resident population.

Our analysis of risk indicated that the Guanabara Bay, Patos Lagoon, and La Plata, Amazon, São Francisco and Tocantins rivers comprise the main leakage hotpots of plastic waste produced in Brazil to the ocean (Fig. 17). These results are slightly different from those found by Lebreton et al. (2017) and Meijer et al. (2021) (Table 17). Considering the rivers that drain the Brazilian territory, Lebreton et al. (2017) highlighted the Amazon and Paraná basins as main entry points of litter to the ocean. Even though the Amazon river presents great discharge (which is very important in the model developed by Lebreton et al., 2017) and does not have dams on its course, it has low population density in its catchment. The Paraná basin was underlined, although it presents numerous dams on its numerous tributaries, which flows out through the Plata river. It is important to know that, when considering the La Plata river, other studies are considering LPW generated in Brazil and other countries drained by La Plata tributary rivers. In the present study, we are considering only LPW generated in the Brazilian territory, whose value is extremely high within the limits of the Paraná-Guazu basin, which drains many municipalities with high LPW, such as São Paulo (SP).

Table 17. Ranking of most polluting estuaries and coastal regions, according to the present study (non-grouped hotspots), Meijer et al. (2021) and Lebreton et al. (2017). The rivers' names are followed by the region or Brazilian state.

Ranking	This study	Meijer et al. (2021)	Lebreton et al. (2017)
1	Paraná-Guazú (La Plata river - Argentina)	Pavuna river (Guanabara Bay - RJ)	Amazon river (PA/AM)
2	São Francisco river (AL/SE)	Guajará Bay (Tocantins river - PA)	La Plata river (including the Paraná-Guazu basin)
3	Amazon river (PA)	Jacuí river (Patos Lagoon - RS)	Paraíba do Sul river (RJ)
4	Rio de Janeiro (Guanabara Bay - RJ)	Jacuí river 2 (Patos Lagoon - RS)	Guandu river (Sapetiba Bay - RJ)
5	Paraíba do Sul river (RJ)	Salvador (BA)	Jacuí river (Patos Lagoon - RS)
6	Pavuna river (Guanabara Bay - RJ)	Capim river (Tocantins river - PA)	Jacuí river 2 (Patos Lagoon - RS)
7	Parnaíba river (PI/MA)	Teijipió river (PE)	Parnaíba river (PI/MA)
8	Salvador (BA)	Fortaleza (CE)	Lagoa da Tijuca (RJ)
9	Tocantins river (PA)	Piripama river (PE)	Santos Estuary (SP)
10	Fortaleza (CE)	São Gonçalo (Guanabara Bay - RJ)	Itajaí-Açu river (SC)

Actions to prevent and mitigate marine litter might be applied everywhere, regarding decreasing the amount of waste generated and improving waste management. However, in situations where it is necessary to distribute limited resources, it is important to know where to prioritize actions, based on leakage risk. Prevention and mitigation actions focused on litter generation and management may be prioritized in municipalities with a high stock of LPW. On the other hand, mitigation measures to stop litter in the environment from reaching the ocean can be prioritized in locations with a bigger risk of plastic litter leakage into the ocean. These actions are especially essential in critical municipalities located in coastal regions, where plastic litter accumulated by rivers will flow into the ocean, besides direct litter discharge from coastal municipalities to the ocean. Actions to address hotspots of plastic litter can be considered in terms of interventions (actions) and instruments (regulatory, financial or informative measures to implement interventions), which might be defined and prioritized according to local, regional and national context (UNEP, 2020).

5.4.2.1. Challenges and advances in estimating the risk of plastic litter leakage to the ocean

We estimated comparative risk of plastic litter leakage to the ocean, considering land-based sources, which are considered the dominant input of plastics into the ocean

(GESAMP, 2019; Lebreton et al., 2017, Wowk et al., 2013). During our analysis, we included factors that influence LPW availability (subnormal agglomerates, level of degradation/urbanization), mobilization (wind, rain, river discharge) and retention (distances to the river, slope, distance to the ocean, dams, detours). We took parameters used by the most recent and most complete global estimate of litter leakage to the ocean (Meijer et al., 2021) and added information on subnormal agglomerates and dams. The presence of dams was only considered in the study by Lebreton et al. (2017), while the presence of subnormal agglomerates was never considered before, despite its importance on litter leakage to the environment. Thus, we provide data that improve knowledge on litter leakage hotspots in Brazil, contributing to SDG 14.1.1b (plastic debris density), which currently uses data from zero-order national estimates provided by Jambeck et al. (2015) (UNEP, 2020).

Estimating LPW mobilization to rivers and transport to the ocean is complex, since many different aspects affect litter mobilization and transport across river basins. Moreover, these aspects have great variety across different territories, including diversity of population size, socioeconomic condition (education, income level), environmental factors (river characteristics, presence of dams and quality of their management, distance to the ocean), waste generation and management (González et al., 2016; UNEP, 2020; Araújo & Costa, 2006). Thus, the hotspots are a combination of critical variables (UNEP, 2020), and all events occurring in the watershed have an impact on the amount and type of litter (González et al., 2016). However, there is no empirical information on the influence of each parameter on litter mobilization and transport. Thus, we developed a theoretical model based on existing knowledge, which has room for improvements.

Further steps for improving hotspotting at the subnational level include collecting litter in different river surfaces and environments and providing empirical data for validating models (Lebreton et al., 2017; Meijer et al., 2021). Furthermore, assessment and monitoring of litter in different compartments is important to validate information at the local level. hotspotting. Moreover, it is also essential to provide baseline information for calibrating the influence level of each parameter on litter mobilization, transport, and accumulation. Besides calibrating the model for each variable, it is also important to obtain data and consider other parameters, such as the distance of dumps to aquatic systems and empirical leakage rate from dumps to the environment. Up to now, this analysis is also limited by the non-availability of information on exact location of dumps and landfills in a national system. However, besides legal dumps, another concern is the existence of clandestine spots of solid waste accumulation. Furthermore, it is also critical to better understand the influence of each kind of dam on litter retention. Different artificial barriers have different effects on river flow and turbulence, and, therefore, on litter transport to the ocean. However, empirical information is non-existent. Opportunistic sampling can take place at dams that already have structures such as grids or weirs (González et al., 2016; van der Wal, 2015; Hassan, 2020).

5.5. CONCLUSIONS

We indicated the potential stock of leak prone-plastic for all 5,570 Brazilian municipalities, and also the hotspots where litter leaks to the ocean. We estimated that 3.44 million tons (mt) of plastic waste produced in Brazil are prone to leak to the environment, which is similar to previous estimates (3.30 mt - 3.72 mt; Meijer et al., 2021; Lebreton & Andrady, 2019). We applied innovative approaches and contemplated socioeconomic factors, plastic consumption and environmental particularities considered for the first time in this kind of estimate. Besides that, we improved previous estimates both in spatial and temporal granularity, increasing the degree of certainty of the estimate. However, current estimates can still be constantly improved, according to data availability by governments, industries, and agencies. Improvements can also be done by understanding the influence of different parameters on litter generation, mobilization, and transport. Moreover, there are still gaps regarding plastic litter stocks (mass balance), flows, and pathways in the environment. However, the present study represents great progress in understanding sources and pathways of land-based litter, providing a ranking of the most critical locations in Brazil and also generating a complete database that will be available online. The identification and dimensionalization of hotspots provide decision-makers baseline information, which can be used for defining proper interventions and instruments to address the problem. Moreover, hotspotting allows for prioritization of critical locations and monitoring of the progress of implemented actions. It is important to note that implementing actions and monitoring indicators should be done periodically. We might develop adequate governance for the construction of local and national plans to monitor marine litter. Since marine litter is a complex issue, we might integrate science, government, NGOs and private sectors to tackle it. Moreover, promoting integrated management of municipalities within a hydrographic basin is essential to set common objectives towards reducing litter pollution.

5.6. REFERENCES

ABIPLAST (2019). Plano de Incentivo à Cadeia do Plástico. Associação Brasileira da Indústria do Plástico. Available at: http://www.picplast.com.br/.

ABIPLAST (2020). Perfil 2020: A indústria de Transformação e Reciclagem de Plástico no Brasil. Associação Brasileira da Indústria do Plástico. Available at: http://www.abiplast.org.br/publicacoes/

ABRELPE (2020). Panorama dos resíduos sólidos no Brasil 2020. Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais Available at: https://abrelpe.org.br/panorama/

Abreu, A. E. S.; Vilar, O. M. (2017). Influence of composition and degradation on the shear strength of municipal solid waste. Waste Management, v. 68, p. 263-274.

Aduan, S. A. (2009). Caracterização Gravimétrica dos Resíduos do Grupo A de Hospitais de Vitória – ES. Dissertação (Mestrado em Engenharia Ambiental) - Universidade Federal do Espírito Santo. Espírito Santo..

Alfaia, R. G. S. M.; Costa, A. M.; Campos, J. C. (2017). Municipal solid waste in Brazil: A review. Waste Management & Research, v. 35, n. 12, p. 1195-1209.

Allesch, A., & Brunner, P. H. (2017). Material flow analysis as a tool to improve waste management systems: the case of Austria. Environmental science & technology, 51(1), 540-551.

Andrady, A. L., & Neal, M. A. (2009). Applications and societal benefits of plastics. Philosophical Transactions of the Royal Society B: Biological Sciences, 364(1526), 1977-1984.

Andrady, A. L. (2011). Microplastics in the marine environment. Marine pollution bulletin, 62(8), 1596-1605.

Araújo, M. C. B., & Costa, M. F. (2006). Municipal Services on Tourist Beaches: Costs and Benefits of Solid Waste Collection. Journal of Coastal Research, 225(225), 1070–1075. http://doi.org/10.2112/03-0069.1

Araújo, M.C.B., & Costa, M., (2007). An analysis of the riverine contribution to the solid wastes contamination of an isolated beach at the Brazilian Northeast. Management of Environmental Quality: An International Journal, 18: 6–12.

Bandara, N.J., Hettiaratchi, J.P.A., Wirasinghe, S.C., & Pilapiiya, S. (2007). Relation of waste generation and composition to socio-economic factors: a case study. Environmental monitoring and assessment, 135 (1-3): 31-39.

Beck, H. E., Wood, E.F., Pan, M., Fisher, C.K., Miralles, D. G., VanDijk, A. I. J. M., McVicar, T. R., Adler, R. F. . MSWep v2 Global 3-hourly 0.1° precipitation: Methodology and quantitative assessment. Bull. Am. Meteorol. Soc. 100, 473–500 (2019).

Brunner, P. H., & Rechberger, H. (2016). Handbook of material flow analysis: For environmental, resource, and waste engineers. CRC press.

CadÚnico (2018). Microdados amostrais do Cadastro Único, Ministério da Cidadania. Available at: https://dados.gov.br/dataset/microdados-amostrais-do-cadastro-unico

Carvalho, L. M.; & Ribeiro, F. J. F. P (2015). Indicadores de consumo aparente de bens industriais: metodologia e resultados. Brasília: IPEA, 2015. Available at: https://www.ipea.gov.br/portal/images/stories/PDFs/TDs/td_2101.pdf.

Carvalho, P. F. B., & Pardini, H. (2020). Análise da distribuição espacial da COVID-19 em Minas Gerais. Metodologias e Aprendizado, 3, 159-166.

Cencic, O., & Rechberger, H. (2008). Material flow analysis with software STAN. In EnviroInfo (pp. 440-447).

Cestari, V. R. F., Florêncio, R. S., Sousa, G. J. B., Garces, T. S., Maranhão, T. A., Castro, R. R., ... & Moreira, T. M. M. (2021). Vulnerabilidade social e incidência de COVID-19 em uma metrópole brasileira. Ciência & Saúde Coletiva, 26, 1023-1033.

CIESIN (2018). Gridded Population of the World, Version 4 (GPWv4): Population Density, Revision 11. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). Center for International Earth Science Information Network - CIESIN - Columbia University. Available at: https://sedac.ciesin.columbia.edu/data/set/gpw-v4-population-density-rev11/data-download and https://developers.google.com/earth-engine/datasets/catalog/CIESIN_GPWv411_GPW_UNWPP-Adjusted_Population_Density

Chung, S. S., & Lo, C. W. (2008). Local waste management constraints and waste administrators in China. Waste Management, 28(2), 272-281.

Comitê de Bacias Hidrográficas do Litoral Norte - CBHLN. Relatório de situação dos recursos hídricos do Litoral Norte. 2017. Available at: https://sigrh.sp.gov.br/public/uploads/documents//CBH-LN/12454/rs2017final.pdf

Cordeiro, C. A. M. M., & Costa, T. M. (2010). Evaluation of solid residues removed from a mangrove swamp in the São Vicente Estuary, SP, Brazil. Marine Pollution Bulletin, 60 (10), 1762–1767.

Da Silva, L. J. (2020). et al. Incineration of municipal solid waste in Brazil: An analysis of the economically viable energy potential. Renewable Energy, v. 149, p. 1386-1394.

Díaz, S.; Settele, J; & Brondízio, E (Eds). (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Available at: https://www.ipbes.net/sites/default/files/downloads/spm_unedited_advance_for_posting_htn.pdf.

Drudi, K. C. R. et al. (2019). Statistical model for heating value of municipal solid waste in Brazil based on gravimetric composition. Waste Management, v. 87, p. 782-790.

FAO (2011). Dams, fish and fisheries. Opportunities, challenges and conflict resolution. FAO fisheries technical report. Available at: http://www.friendsofmerrymeetingbay.org/Cybrary/pages/20010000_UN_FAO_Dams,%20fish%20and%20fisheries.pdf

Fick, S. E., & Hijmans, R. J. (2017). WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. International journal of climatology, 37(12), 4302-4315.

Fries, A. S., Coimbra, J. P., Nemazie, D. A., Summers, R. M., Azevedo, J. P. S., Filoso, S., ... & Dennison, W. C. (2019). Guanabara Bay ecosystem health report card: Science, management, and governance implications. Regional Studies in Marine Science, 25, 100474.

Galgani, F., Hanke, G., & Maes, T. (2015). Global distribution, composition and abundance of marine litter. In: Marine anthropogenic litter (pp. 29-56). Springer, Cham.

Galgani, L.; Beiras, R.; Galgani, F.; Panti, C.; & Borja, A. (2019). Editorial: impacts of marine litter. Frontiers in Marine Science, 6: 208.

Gari, A. Newton, J.D. Icely (2015). A review of the application and evolution of the DPSIR framework with an emphasis on coastal social-ecological systems Ocean Coast. Manag., 103

GESAMP (2019). Guidelines for the Monitoring and Assessment of Plastic Litter in the Ocean. Journal Series GESAMP Reports and Studies, 99 (123p.). Available at: http://www.gesamp.org/publications/guidelines-for-the-monitoring-and-assessment-of-plastic-litter-in-the-ocean

GESAMP (2020). Proceedings of the GESAMP International Workshop on assessing the risks associated with plastics and microplastics in the marine environment (Kershaw, P.J., Carney Almroth, B., Villarrubia-Gómez, P., Koelmans, A.A., and Gouin, T., eds.). (IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/ UNEP/UNDP/ISA Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). Reports to GESAMP No. 103, 68 pp.

Ghiggi, G., Humphrey, V., Seneviratne, S. I., & Gudmundsson, L. (2021). G-RUN ENSEMBLE: A multi-forcing observation-based global runoff reanalysis. Water Resources Research, 57(5), e2020WR028787. https://doi.org/10.1029/2020WR028787

González, D., Hanke, G., Tweehuysen, G., Bellert, B. ...(2016). GES, M. (2016). Riverine Litter Monitoring-Options and Recommendations. European Commission. Available at: https://mcc.jrc.ec.europa.eu/documents/201703034325.pdf

Granit, J., Liss Lymer, B., Olsen, S., Tengberg, A., Nõmmann, S., & Clausen, T. J. (2017). A conceptual framework for governing and managing key flows in a source-to-sea continuum. Water Policy, 19(4), 673-691.

Gregory, M. R. (2009). Environmental implications of plastic debris in marine settings—entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Philosophical Transactions of the Royal Society B: Biological Sciences, 364(1526), 2013-2025.

Gutierrez-Gomez, A. C. et al. (2021). Energy recovery potential from Brazilian municipal solid waste via combustion process based on its thermochemical characterization. Journal of Cleaner Production, v. 293, p. 126145.

Hardesty, B. D., Schuyler, Q., Lawson, T. J., Opie, K., & Wilcox, C. (2016). Understanding debris sources and transport from the coastal margin to the ocean. Final Report to the National Packaging Covenant Industry Association.

Hassan, A. (2020). Handling river floating debris for dam safety – the state of the practice. Master of Science, Stockholm, Sweden 2020. Availeble at:http://kth.diva-portal.org/smash/get/diva2:1523252/FULLTEXT01.pdf

IBGE (2010). Censo Demográfico. Instituto Brasileiro de Geografia e Estatística, 2010. https://www.ibge.gov.br/estatisticas/sociais/populacao/22827-censo-2020-censo4.html?=&t=o-que-e.

IBGE (2018a). POF-Pesquisa de Orçamentos Familiares. Instituto Brasileiro de Geografia e Estatística.https://www.ibge.gov.br/estatisticas/sociais/saude/24786-pesquisa-de-orcamentos-familiares-2.html?=&t=o-que-e.

IBGE (2018b). Projeções da População. Instituto Brasileiro de Geografia e Estatística. Available at: https://www.ibge.gov.br/estatisticas/sociais/populacao/9109-projecao-da-populacao.html

IBGE (2019). Pesquisa Industrial Anual (PIA)- Produto. Instituto Brasileiro de Geografia e Estatística, 2019. https://www.ibge.gov.br/estatisticas/economicas/industria/9044-pesquisa-industrial-anual-produto.html?=&t=o-que-e.

IBGE (2020a). Aglomerados subnormais 2019 : classificação preliminar e informações de saúde para o enfrentamento à COVID-19: notas técnicas. Available at: https://biblioteca.ibge.gov.br/index.php/biblioteca-catalogo?view=detalhes&id=210171

IBGE (2020b). Malhas Territoriais. Instituto Brasileiro de Geografia e Estatística (IBGE). Available at: https://www.ibge.gov.br/geociencias/organizacao-do-territorio/malhas-territoriais/15774-malhas.html?=&t=downloads

IBGE (2021). Estimativas 2021 - População estimada do país chega a 213,3 milhões de habitantes em 2021. Instituto Brasileiro de Geografia e Estatística. Available at:. https://agenciadenoticias.ibge.gov.br/agencia-noticias/2012-agencia-de-noticias/noticias/31458-populacao-estimada-do-pais-chega-a-213-3-milhoes-de-habitantes-em-2021

IDB (2020). Plastic Waste Management and Leakage in Latin America and the Caribbean. Inter-American Bank (IDB). Available at: https://publications.iadb.org/en/plastic-waste-management-and-leakage-latin-america-and-caribbean

ISO 31000 (N.D.). ISO 31000 RISK MANAGEMENT. Available at: https://www.iso.org/iso-31000-risk-management.html

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., ... & Law, K. L. (2015). Plastic waste inputs from land into the ocean. Science, 347(6223), 768-771.

Kennedy, C. M., J. R. Oakleaf, D. M. Theobald, S. Baruch-Mordo, and J. Kiesecker. 2020. Global Human Modification of Terrestrial Systems. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/edbc-3z60

Khan, D., Kumar, A., & Samadder, S. R. (2016). Impact of socio-economic status on municipal solid waste generation rate. Waste Management, 49, 15-25.

Lebreton, L. C., Van Der Zwet, J., Damsteeg, J. W., Slat, B., Andrady, A., & Reisser, J. (2017). River plastic emissions to the world’s oceans. Nature communications, 8, 15611..

Lebreton, L., & Andrady, A. (2019). Future scenarios of global plastic waste generation and disposal. Palgrave Communications, 5 (1), 1-11.

Lehner, B., C. Reidy Liermann, C. Revenga, C. Vörösmarty, B. Fekete, P. Crouzet, P. Döll, M. Endejan, K. Frenken, J. Magome, C. Nilsson, J.C. Robertson, R. Rodel, N. Sindorf, and D. Wisser (2011). High-Resolution Mapping of the World's Reservoirs and Dams for Sustainable River-Flow Management. Frontiers in Ecology and the Environment 9 (9): 494-502. https://doi.org/10.1890/100125.

Lehner, B., Grill G. (2013): Global river hydrography and network routing: baseline data and new approaches to study the world’s large river systems. Hydrological Processes, 27(15): 2171–2186.

Lino, F. A. M.; Ismail, K. A. R. (2011). Energy and environmental potential of solid waste in Brazil. Energy Policy, v. 39, n. 6, p. 3496-3502.

Liro, M., Emmerik, T. V., Wyżga, B., Liro, J., & Mikuś, P. (2020). Macroplastic storage and remobilization in rivers. Water, 12(7), 2055.

Llatas, C. (2011). A model for quantifying construction waste in projects according to the European waste list. Waste management, v. 31, n. 6, p. 1261-1276.

Mancini, S. D. et al. (2007). Caracterização dos resíduos da construção civil de Sorocaba-SP com ênfase em plásticos. In: Anais do 9º Congresso Brasileiro de Polímeros. Campina Grande: IPEN. p. 1-9.

Marques Neto, J. C. (2003). Diagnóstico para estudo de gestão dos resíduos de construção e demolição do município de São Carlos-SP. Dissertação (Mestrado em Hidráulica e Saneamento) - Escola de Engenharia de São Carlos, Universidade de São Paulo. São Carlos, 2003. DOI:10.11606/D.18.2016.tde-19082016-162322.

MDIC (2019). Ministério Do Desea Indústria, Comércio Exterior E Serviços. COMEX STAT. 2019. Available at: http://comexstat.mdic.gov.br/pt/home.

Meijer, L. J., van Emmerik, T., van der Ent, R., Schmidt, C., & Lebreton, L. (2021). More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean. Science Advances, 7(18), eaaz5803.

Ministry of Tourism (2019). Secretaria Nacional de Atração de Investimentos, Parcerias e Concessões. Estratégias Territoriais para o Desenvolvimento Turístico: Resultados. 2019. Disponível em: http://www.regionalizacao.turismo.gov.br/index.php?option=com_content&view=article&id=89&Itemid=272. Acesso em: 08 dez. 2021.

Ministry of Labour (2021). Programa de Disseminação das Estatísticas do Trabalho. Microdados RAIS e CAGED. 2021. Available at: http://pdet.mte.gov.br/microdados-rais-e-caged.

Miranda, L. F. R.; Angulo, S. C.; Careli, É. D. (2009). A reciclagem de resíduos de construção e demolição no Brasil: 1986-2008. Ambiente Construído, v. 9, n. 1, p. 57-71.

Miranda, M.N., Silva, A.M.T., Pereira, M.F.R. (2020). Microplastics in the environment: a DPSIR analysis with focus on the responses. Science of The Total Environment, 134968 doi:10.1016/j.scitotenv.2019.134968

MMA (2019). Plano Nacional de Combate ao Lixo no Mar. Available at: https://www.mma.gov.br/agenda-ambiental-urbana/lixo-no-mar.html

MMA (2021). PORTARIA MMA Nº 34, DE 2 DE FEVEREIRO DE 2021. Aprova a listagem atualizada dos municípios abrangidos pela faixa terrestre da zona costeira brasileira.

Moore, S. A., Roth, R. E., Rosenfeld, H., Nost, E., Vincent, K., Arefin, M. R., & Buckingham, T. M. (2019). Undisciplining environmental justice research with visual storytelling. Geoforum, 102, 267-277.

Moreira, I. G. (2012). Caracterização gravimétrica dos resíduos gerados em enfermaria do Hospital Santa Casa de Misericórdia de Vitória. Monografia (Bacharelado em Engenharia Ambiental) - Universidade Federal do Espírito Santo, Centro Tecnológico. Espírito Santo. Available at: https://ambiental.ufes.br/sites/ambiental.ufes.br/files/field/anexo/caracterizacao_gravimetrica_dos_residuos_gerados_em_enfermaria_do_hospital_santa_casa_de_misericordia_de_vitoria.pdf

Nordi, G. H. et al. (2017). Electricity production from municipal solid waste in Brazil. Waste Management & Research, v. 35, n. 7, p. 709-720.

NWcouncil, n.d. Dams: impacts on salmon and steelhead. Northwest Power and Conservation Council. Available at: https://www.nwcouncil.org/reports/columbia-river-history/damsimpacts

PAHO (2005). Report on the Regional Evaluation of Municipal Solid Waste Management Services in Latin America and the Caribbean. Area of Sustainable Development and Environmental Health, Pan American Health Organization - PAHO.

PEMALM (2021). São Paulo Strategic Plan for Monitoring and Assessment of Marine Litter. Org: Turra, A.; Neves, A.M.; Panarelli, A.M.; Elliff, C.I.; Romanelli, M.F.; Mansor, M.T.; Andrade, M.M.; Grilli, N.M.; Cardoso, O.A.; Zanetti, R.; Scrich, V.M. First edition. São Paulo: PEMALM, 72 p.

Poff, N. L., & Hart, D. D. (2002). How dams vary and why it matters for the emerging science of dam removal: an ecological classification of dams is needed to characterize how the tremendous variation in the size, operational mode, age, and number of dams in a river basin influences the potential for restoring regulated rivers via dam removal. BioScience, 52(8), 659-668.

Redivo, A. L. (2021). Spatial distribution of residential solid waste generation in Brazil: estimating residential solid waste generation and CO2eq emissions based on the nominal income, towards the achievement of the Sustainable Development Goals (Doctoral dissertation).

Rodell, M., Houser, P. R., Jambor, U. E. A., Gottschalck, J., Mitchell, K., Meng, C. J., ... & Toll, D. (2004). The global land data assimilation system. Bulletin of the American Meteorological Society, 85(3), 381-394.

Saaty, R. W. (1987). The analytic hierarchy process—what it is and how it is used. Mathematical modelling, 9(3-5), 161-176.

Saaty, T. L. (1990). How to make a decision: the analytic hierarchy process. European journal of operational research, 48(1), 9-26.

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. International journal of services sciences, 1(1), 83-98.

Sanchez, L.E (2013). Avaliação de impacto ambiental: conceitos e métodos, 2a Ed. Sao Paulo: oficina de textos, 2013. p 363.

Santos, I. R., Friedrich, A. C., Wallner-Kersanach, M., & Fillmann, G. (2005). Influence of socio-economic characteristics of beach users on litter generation. Ocean & Coastal Management, 48(9-10), 742-752.

Schirinzi, G. F., Köck-Schulmeyer, M., Cabrera, M., González-Fernández, D., Hanke, G., Farré, M., & Barceló, D. (2020). Riverine anthropogenic litter load to the Mediterranean Sea near the metropolitan area of Barcelona, Spain. Science of The Total Environment, 714, 136807.

Schmidt, C., Krauth, T., & Wagner, S. (2017). Export of plastic debris by rivers into the sea. Environmental science & technology, 51(21), 12246-12253.

Schmidt, C., Krauth, T., & Wagner, S. (2018). Correction to export of plastic debris by rivers into the sea. Environmental science & technology, 52(2), 927-927.

Schneider, V. E.; Caldart, V.; Gastadello, M. (2000). A caracterização de Resíduos de Serviços de Saúde como ferramenta para o monitoramento de sistemas de gestão destes resíduos em estabelecimentos hospitalares. In: Congresso Interamericano de Engenharia Sanitária e Ambiental, 27º

SEMARH (2016). Plano Estadual de Resíduos Sólidos do Rio Grande do Norte - PERS-RN. Produto 3: Estudo da Prospecção e Escolha do Cenário de Referência. Natal: Governo do Estado do Rio Grande do Norte; Brencorp. Secretaria de Estado de Meio Ambiente e Recursos Hídricos

Silva, M. S. et al. (2015). Avaliação gravimétrica dos resíduos de serviços de saúde no município de Rondonópolis, MT, Brasil. Revista Verde de Agroecologia e Desenvolvimento Sustentável, v. 10, n. 5, p. 29.

Silva, R. G. P., Lima, C. L., & Saito, C. H. (2019). Análise Per Capita dos Espaços Verdes Urbanos na Região Metropolitana de São Paulo-Brasil. Revista do Departamento de Geografia, 38, 31-41

Silva, C. O. et al. (2021). Discretização da estimativa de geração per capita e análise gravimétrica de resíduos sólidos urbanos. Revista em Agronegócio e Meio Ambiente, v. 14, n. 3, p. 1-19.

Siwi, 2018. High-level panel on source-to-sea management: Towards joint action by the freshwater and ocean communities. 8th World Water Forum, Brasilia, Brazil, March 2018. S2S Platform. Available at: http://xpdv319.m.attendify.com/ app/sessions/9TItNOSFavZirdteO3/details.

SNIS (2019). SISTEMA NACIONAL DE INFORMAÇÕES SOBRE SANEAMENTO. Diagnósticos SNIS 2019. Available at: http://www.snis.gov.br/diagnosticos.

Spinola, G. M. R. et al. (2019). Análise estatística da composição gravimétrica dos Resíduos Sólidos Urbanos com o Índice de Desenvolvimento Humano para os municípios do estado de São Paulo. Geoambiente On-line, n. 33.

SRA (2018). Society for risk analysis glossary. Society for Risk Analysis. Available at: https://www.sra.org/wp-content/uploads/2020/04/SRA-Glossary-FINAL.pdf

Swiss Committee on Dams (2017). Floating Debris at Reservoir dam spillways. Report of the Swiss Committee on Dams on the state of floating debris issues at dam spillways. Available at: http://www.swissdams.ch/fr/publications/publications-csb/2017_Floating%20debris.pdf

The World Bank. (2012). What a Waste: A Global Review of Solid Waste Management. Urban Development & Local Government Unit., World Bank, 98.

The World Bank. (2018). What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. World Bank, 272.

Trang, P. T. T., Dong, H. Q., Toan, D. Q., Hanh, N. T. X., & Thu, N. T. (2017). The effects of socio-economic factors on household solid waste generation and composition: a case study in Thu Dau Mot, Vietnam. Energy Procedia, 107, 253-258.

UNEP (2016). Marine Plastic Debris and Microplastics: Global Lessons and Research to Inspire Action and Guide Policy Change. United Nations Environmental Program, Nairobi, 252p.

UNEP (2018). Mapping of global plastics value chain and plastics losses to the environment: with a particular focus on marine environment. Available at: https://stg-wedocs.unep.org/handle/20.500.11822/26745

UNEP (2020). National guidance for plastic pollution hotspotting and shaping action - Introduction report. Boucher J.,; M. Zgola, et al. United Nations Environment Programme. Nairobi, Kenya

Vaidya, O. S., & Kumar, S. (2006). Analytic hierarchy process: An overview of applications. European Journal of operational research, 169(1), 1-29.

van der Wal, M., M. van der Meulen, G. Tweehuysen, M. Peterlin, A. Palatinus, M. Kovač Viršek, L. Coscia and A. Kržan (2015). SFRA0025: Identification and Assessment of Riverine Input of (Marine) Litter. http://ec.europa.eu/environment/marine/goodenvironmental-status/descriptor-10/pdf/iasFinal%20Report.pdf

Weideman, E. A., Perold, V., & Ryan, P. G. (2019). Little evidence that dams in the Orange–Vaal River system trap floating microplastics or microfibres. Marine Pollution Bulletin, 149, 110664.

Wowk, K. M. (2013). Paths to Sustainable Ocean Resources. Managing Ocean Environments in a Changing Climate: Sustainability and Economic Perspectives, 301.

Zhang, K., Gong, W., Lv, J., Xiong, X., & Wu, C. (2015). Accumulation of floating microplastics behind the Three Gorges Dam. Environmental Pollution, 204, 117–123. doi:10.1016/j.envpol.2015.04.023

6. FINAL CONSIDERATIONS

In this thesis, we explored, in four chapters, the different spectra of marine litter sources, considering different definitions of the term “sources”. In the first chapter, we investigated the development of marine litter science in Brazil and explored the sources of research limitations and potentials, considering the research network, the existing knowledge, and the studies’ coupling with policy-relevant concerns. In the second chapter, we analyzed whether the marine litter literature in Brazil links the litter problem to holistic solutions. Moreover, in this chapter, we also systematized solutions to combat marine litter, including not only mitigation measures, but also prevention solutions based on the intrinsic sources of this complex issue. In the third chapter, we presented a study of potential parameters to estimate litter leakage to the ocean, considering the socioeconomic sources of litter generation and leak propensity; and also explored the sources of previous estimates’ limitations and raw data weaknesses. In the fourth chapter, we presented an estimate of litter leakage from the Brazilian territory to the ocean, considering land-based sources of leak-prone plastic waste. Next, we present the conclusions of this multicomplex analysis of marine litter in Brazil.

In the first chapter, we showed that marine litter research in Brazil is recent and has been maturing over time. Hence, the national scientific capital and knowledge have limitations, strengths, and great potential to contribute to global science and policy. Our analysis indicated that previous studies on marine macrolitter were episodic, fragmented, and presented unharmonized research strategies. Even though there was a great effort to couple studies with policy-relevant concerns, studies still lacked coordination with national and global policies. Moreover, the research network was not well integrated. Thus, we concluded that Brazil is far from informing Sustainable Development Goal 14.1 (preventing and reducing marine pollution, including marine debris). Nonetheless, even though science in Brazil has been facing limitations and challenges, there are multiple opportunities on the horizon, regarding data use and improvements in the way scientific information has been produced. Existing information can be incorporated by gathering information platforms, and it can feed the global monitoring system of marine litter. Furthermore, we can make future changes by promoting national coordination, strengthening the research network, harmonizing research strategies, and aligning studies to policy-relevant concerns. Following these paths, we will be able to inform SDG 14.1. The Decade of Ocean Science for Sustainable Development is a great moment to make meaningful changes in this regard, since there are many emerging initiatives to reformulate and improve litter assessment, monitoring, prevention and mitigation.

In the second chapter, our analysis showed that studies on marine macrolitter in Brazil have been relating marine litter solutions to waste management and downstream actions. However, achieving SDG 14.1 demands integrated solutions to prevent and mitigate marine litter, including actions aligned to SDG 12.5 (reduction of waste generation), SDG 6.a (sanitation), and SDG 4 (quality education). Thus, we concluded that the solutions presented in the literature on macrolitter in Brazil are focused on end-of-pipe solutions and limited to informing decision-makers, and other readers, about integrated solutions for marine litter. For tackling marine litter, actions are required in all plastic life-cycle, and they shall focus on preventing plastic waste generation. Therefore, it is essential to promote changes in the production chain and current consumption patterns. Cultural and structural changes might be accompanied by logistical and technological changes, towards sustainability in the design, production, and distribution of materials. Besides pre-consumption actions, post-consumption measures are also necessary. After consumption, products reuse, recycling and return to the production chain (reverse logistics) are priorities before adequate final disposal of litter. While the current challenges of addressing these measures still exist, we also need to stop litter input in the terrestrial and oceanic environment. However, these actions do not comprise permanent solutions, since excessive amounts of litter are still being produced. Thus, we need to inform readers that efficient solutions must articulate production, consumption, waste management, and pollution prevention. Based on integrated solutions, we proposed a Marine Litter Hierarchy, which systematizes solutions for marine litter considering actions in the various links of the production-consumption-discard-pollution chain, and involves multiple social actors and economic sectors.

Preventing and mitigating marine plastic litter can be more efficient when prioritizing actions on hotspots of litter generation and leakage to the environment. In the third chapter, we systematized parameters for identifying litter hotspots at the subnational level, considering the complex reality of plastic flows through production, consumption and disposal, and also recognizing the influence of socio-economic conditions on litter generation and management. This systematization may guide future estimates worldwide. Estimates at subnational levels are extremely important since there are great variations of subnational characteristics in a territory and previous studies tend to focus on national estimates. Towards contemplating subnational particularities, it is essential to consider socioeconomic factors that influence litter generation and quality of waste management, as well as environmental factors that impact litter spread. Therefore, it is possible to use subnational particularities to reduce models' uncertainties and improve spatial granularity. However, improving models relies on data availability and consistency. We indicated a deficiency in data availability and usability in Brazil, which exposes the difficulties of estimating litter leakage from the Brazilian territory to the ocean. This panorama of non-access to good-quality data might represent the reality of the Global South, characterized by low- and middle-income countries. Compared to other countries in this part of the globe, Brazil has a good statistical capacity. Hence, accessing information in other Global South countries might be as bad as in Brazil, or even worse. The problem of lacking good-quality data can be overcome by the use of proxies. However, it is extremely important to improve data availability by governments, the plastic industry, urban cleaning companies, and agencies of solid waste management and water treatment. By having data available to estimate subnational litter leakage to the environment, we can subsidize decision-making at a local level and tackle marine litter more efficiently.

In order to subsidize decision-making at the subnational level, in the fourth chapter, we estimated litter leakage from the Brazilian territory to the ocean, prioritizing data with the best available usability. By informing hotspots of litter generation, leakage to the environment, and input to the ocean, we provided a baseline for prioritizing critical spots and efficiently allocating resources. Moreover, information can be used to guide the set of common objectives to reduce plastic leakage not only at the national level, but also at the state, municipal and watershed levels. We consider that actions to prevent waste generation might be applied everywhere, while actions to mitigate excessive litter generation can be prioritized in municipalities with considerable rates of waste generation and/or risk of leakage to the environment. Both prevention and mitigation actions are especially essential in coastal municipalities. While top-down actions might be applied in all municipalities, bottom-up actions (such as eco-barriers) can be prioritized in coastal municipalities, where litter leaks into the ocean. Short-term and long-term measures are necessary in order to combat marine litter. Considering that population and plastic demand will grow in the coming years, as predicted, waste generation will increase. Thus, if the quality of waste management does not improve in the future, the number of litter hotspots may increase, as well as the extent of existing hotspots. Thus, actions are necessary at reducing solid waste generation, improving the quality of waste management, and stopping litter from reaching the ocean.

In summary, this study has shown that, in order to inform SDG 14 and combat marine litter, we need to change the way we tackle this problem. Regarding the improvement of information production, we can focus on filling the gaps, align studies to policy-relevant concerns, and properly inform stakeholders (e.g. governments, private sector, and civil society). In order to efficiently fight marine litter, we need to promote integrated solutions and evolve different social actors (e.g. governments, industries, resellers, consumers, NGOs, waste pickers' cooperatives). Moreover, in order to properly address marine litter, we might transpose the link of litter pollution to structural, cultural, and socioeconomic causes of this problem. Aligned to considering the complexity of litter pollution causes, we can improve national and international litter leakage estimates by using a broad spectrum of socio-economic, environmental, and waste management information. By knowing the dimension of hotspots of plastic waste generation and leakage, as identified by this study, we can prevent and mitigate contamination on the coasts and oceans by applying not only downstream but also upstream actions that consider the complexity of marine litter sources and pathways across aquatic systems.

This thesis provides an overview of marine litter in Brazil. Thus, it has the potential to subsidize decision-making at a local level and contribute to national and international agendas to combat litter pollution. This study is aligned to the Decade of Ocean Science for Sustainable Development (2021–2030), proclaimed by the United Nations, and contemplates not only SDG 14 (life below water), but also SDG 6 (water and sanitation), SDG 4 (quality education), and SDG 12 (sustainable consumption and production). Besides having the potential to refine SDG 14.1 goals, this study can contribute to international initiatives such as the G20 Action Plan on Marine Litter (G20, 2017), the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA) (UNEP, 1995), the Global Partnership on Marine Litter (GPML) Digital Platform (UNEP, 2021), the Integrated Marine Debris Observing System (IMDOS) (Maximenko et al., 2019), among others (Turra et al., 2020). At the national level, this study can support targets of the National Plan to Combat Marine Litter (PNCLM) (MMA, 2019), and the Action Plan to Combat Marine Litter (MMA, 2021). Furthermore, it has the potential to contribute to the National Coastal Management Plan (PNGC) (Brazil, 1988) and the Federal Action Plan for the Coastal Zone (PAF-ZC) (MMA, 2017).

The current environmental pollution situation demands a metamorphosis of the current socio-economic model. Paramount changes include reorganizing production and consumption in a closed-loop, decreasing waste generation, properly managing waste, and reducing pollution. Plastic waste is a shared responsibility that requires action by all actors involved. Because marine litter is not just an environmental, but also a social issue, reducing poverty and promoting socio-economic equity is also part of its solution. Even though this study covered many gaps in marine litter science in Brazil, there are still gaps in understanding and addressing marine litter, at the subnational, national, and international scales. These research gaps might be related to improving monitoring, upgrading source identification, assessing risk, understanding litter pathways in the environment, and investigating the social, economic and environmental costs of plastic pollution. We recommend that future studies focus on filling these gaps, besides aligning objectives with policy-relevant concerns and informing decision-makers. By aligning our research to decision-making processes, we might be able to combat this growing environmental problem efficiently.

7. REFERENCES

Andrady, A.L., & Neal, M.A. (2009). Applications and societal benefits of plastics. *Philosophical Transactions of the Royal Societyof London B*, 364: 1977–1984.

Brazil (1988). Plano Nacional de Gerenciamento Costeiro: Lei Federal nº 7.661/1988, regulamentado pelo Decreto Federal nº 5.300/2004.

Díaz, S.; Settele, J; & Brondízio, E (Eds). (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES. Available at: https://www.ipbes.net/sites/default/files/downloads/spm_unedited_advance_for_posting_htn.pdf.

G20 (2017). G20 Action Plan on Marine Litter. 7 p. Available at: http://www.g20germany.de/Content/DE/_Anlagen/G7_G20/2017-g20-marine-litter-en_nn=2190012.htm

Galgani, F., Hanke, G., & Maes, T. (2015). Global distribution, composition and abundance of marine litter. In Bergmann, M., Gutow, L. & Klages, M. (Eds.). Marine anthropogenic litter. Berlin: Springer, 29–56.

GESAMP (2020). Proceedings of the GESAMP International Workshop on assessing the risks associated with plastics and microplastics in the marine environment (Kershaw, P.J., Carney Almroth, B., Villarrubia-Gómez, P., Koelmans, A.A., and Gouin, T., eds.). (IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/ UNEP/UNDP/ISA Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). Reports to GESAMP No. 103, 68 pp.

Granit, J., Liss Lymer, B., Olsen, S., Tengberg, A., Nõmmann, S., & Clausen, T. J. (2017). A conceptual framework for governing and managing key flows in a source-to-sea continuum. Water Policy, 19 (4): 673-691.

Gregory, M.R. 2009. Environmental implications of plastic debris in marine settings entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Philosophical Transactions of the Royal Society B, 364: 2013–2025.

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., & Law, K. L. (2015). Plastic waste inputs from land into the ocean. Science, 347 (6223): 768–771.

Marine Strategy Framework Directive (2008). Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy. Official Journal of the European Union, L 164 (19). Available at: http://data.europa.eu/eli/dir/2008/56/oj.

Maximenko N, Corradi P, Law KL, Van Sebille E, Garaba SP, Lampitt RS, Galgani F, Martinez-Vicente V, Goddijn-Murphy L, Veiga JM, Thompson RC, Maes C, Moller D, Löscher CR, Addamo AM, Lamson MR, Centurioni LR, Posth NR, Lumpkin R, Vinci M, Martins AM, Pieper CD, Isobe A, Hanke G, Edwards M, Chubarenko IP, Rodriguez E, Aliani S, Arias M, Asner GP, Brosich A, Carlton JT, Chao Y, Cook A-M, Cundy AB, Galloway TS, Giorgetti A, Goni GJ, Guichoux Y, Haram LE, Hardesty BD, Holdsworth N, Lebreton L, Leslie HA, Macadam-Somer I, Mace T, Manuel M, Marsh R, Martinez E, Mayor DJ, Le Moigne M, Molina Jack ME, Mowlem MC, Obbard RW, Pabortsava K, Robberson B, Rotaru A-E, Ruiz GM, Spedicato MT, Thiel M, Turra A and Wilcox C (2019). Toward the Integrated Marine Debris Observing System. Front. Mar. Sci. 6:447. doi: 10.3389/fmars.2019.00447

Meijer, L. J., van Emmerik, T., van der Ent, R., Schmidt, C., & Lebreton, L. (2021). More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean. Science Advances, 7(18), eaaz5803.

MMA (2017). Plano de Ação Federal para a Zona Costeira (PAF-ZC). Ministério do Meio Ambiente. Available at: https://antigo.mma.gov.br/informma/item/8962-plano-de-a%C3%A7%C3%A3o-federal-para-a-zona-costeira-paf_zc.html

MMA (2019). Plano Nacional de Combate ao Lixo no Mar. Agenda Nacional de Qualidade Ambiental Urbana: Fase 1. Brasília, MMA, 2019.

MMA (2021). Available at: Combate ao lixo no mar: Plano de Ação. Ministério do Meio Ambiente. Available at: https://www.gov.br/mma/pt-br/assuntos/agendaambientalurbana/combate-ao-lixo-no-mar/Plano-de-acao.pdf/@@download/file/Plano-de-A%C3%A7%C3%A3o.pdf

PEMALM (2021). São Paulo Strategic Plan for Monitoring and Assessment of Marine Litter. Org: Turra, A.; Neves, A.M.; Panarelli, A.M.; Elliff, C.I.; Romanelli, M.F.; Mansor, M.T.; Andrade, M.M.; Grilli, N.M.; Cardoso, O.A.; Zanetti, R.; Scrich, V.M. First edition. São Paulo: PEMALM, 72 p

Siwi, (2018). High-level panel on source-to-sea management: Towards joint action by the freshwater and ocean communities. 8th World Water Forum, Brasilia, Brazil, March 2018. S2S Platform. Available at: http://xpdv319.m.attendify.com/_app/sessions/9TItNOSFavZirdteO3/details

Teuten, E.L., Saquing, J.M., Knappe, D.R.U., Barlaz, M.A., Jonsson, S., & Björn, A. (2009). Transport and release of chemicals from plastics to the environment and to wildlife. Philosophical Transactions of the Royal Society B, 364 (1526): 2027–2045.

The World Bank (2019). World Development Indicators. Gini index. Available at: https://data.worldbank.org/indicator/SI.POV.GINI

The World Bank, (2020a). World Development Indicators. GDP ranking. Available at: https://datacatalog.worldbank.org/dataset/gdp-ranking-ppp-based

The World Bank, (2020b). World Development Indicators. Population ranking. Available at: https://datacatalog.worldbank.org/dataset/population-ranking

Turra, A., Santana, M. F. M., Oliveira, A. L., Barbosa, L., Camargo, R. M., Moreira, F., & Denadai, M. R. (2020). Lixo nos mares: do entendimento à solução. São Paulo: Instituto Oceanográfico da Universidade de São Paulo. 124p.

UNEP (1995). Washington Declaration on Protection of the Marine Environment from Land-Based Activities. Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/13421/WashingtonDeclaration.pdf?sequence=1&isAllowed=y

UNEP (2016). Marine plastic debris and microplastics – Global lessons and research to inspire action and guide policy change. United Nations Environment Programme. Nairobi, 179 p.

UNEP (2017). RESOLUTION UNEP/EA.3/L.20: Draft resolution on marine litter and microplastics. UN Environment Assembly. Available at: https://papersmart. unon.org/resolution/uploads/k1709154.docx

UNEP (2021). Concept Document GPML Digital Platform Draft external document for consultation. United Nations Environment Programme (UNEP) March 2021. Available at: https://wedocs.unep.org/handle/20.500.11822/34453

Wowk, K.M. (2013). Paths to Sustainable Ocean Resources. In: Diaz, R.J., Noone, K.J., & Sumaila, U.R. (Eds.). Managing Ocean Environments in a Changing Climate: Sustainability and Economic Perspectives. Amsterdam, 301–348.

8. SUPPLEMENTARY MATERIAL

8.1 Supplementary Material A - Researchers working with marine litter in Brazil

PhD researchers who work or have worked with marine litter in Brazil, institutions, States and geographic regions where they are currently assigned. All data correspond to self-declared information by researchers, updated up to May 2019. Based on Menk (2018) and also on information found in curricula, marine litter expertise areas were defined as: (I) occurrence, abundance and/or distribution of marine litter (macrolitter in the env); (II) monitoring; (III) interaction with biota; (IV) microplastics in biological and environmental samples (microplastics); (V) interaction with contaminants; (VI) health, social, economic and environmental impacts (impacts of marine litter); (VII) people's perception on marine litter (perception); (VIII) environmental education; (IX) citizen science; (X) marine litter didactic-scientific collection (educational collection); (XI) beach cleaning efficiency; (XII) public policies; (XIII) solid waste management and reverse logistics (solid waste management); and (XIV) alternatives to plastics.

Researcher	Institution	Affiliation	Expertise	Contact
NORTHERN BRAZIL				
Pará (PA)				
José Eduardo Martinelli Filho	Federal University of Pará	Instituto de Geociências	Microplastics	martinelli@ufpa.br
Marcelo Costa Andrade	Federal University of Pará	Núcleo de Ecologia Aquática e Pesca da Amazônia	Interaction with biota Microplastics	andrademarcosta@gmail.com
Sury de Moura Monteiro	Federal University of Pará	Faculdade de Oceanografia	Macrolitter in the env Environmental education Microplastics	sury@ufpa.br
Tommaso Giarrizzo	Federal University of Pará	Laboratório de Biologia Pesqueira e Manejo dos Recursos Aquáticos	Macrolitter in the env Microplastics Interaction with biota	tgiarrizzo@gmail.com
NORTHEAST BRAZIL				
Ceará (CE)				
Ana Carolina Oliveira de Meirelles	Association for Research and Preservation of Aquatic Ecosystems - Aquasis	Programa de Mamíferos Marinhos	Interaction with biota	caomeirelles@gmail
Edirsana Maria Ribeiro de Carvalho	University Centre UniFanor Wyden	Curso de Engenharia Ambiental e Sanitária	Macrolitter in the env Perception	edirsana.carvalho@unifanor.edu.br

Sandra Tédde Santaella	Federal University of Ceará	Instituto de Ciências do Mar	Macrolitter in the env Microplastics Solid waste management Alternatives to plastics	sandra@ufc.br
Tarin Cristino Frota Mont Alverne	Federal University of Ceará	Faculdade de Direito	Solid waste management. Public politics	tarincfmontalverne@gmail.com

Rio Grande do Norte (RN)

Guelson Batista da Silva	The Federal University of the Semi-Arid Region	Centro de Estudos em Pesca e Aquicultura Sustentável do Semiárido	Interaction with biota	guelson@ufersa.edu.br
Maria Christina Barbosa de Araújo	Federal University of Rio Grande do Norte	Departamento de Oceanografia e Limnologia	Macrolitter in the env Perception	mcbaraujo@yahoo.com.br
Marisa Ribeiro Moura	Federal Institute of Rio Grande do Norte	Geografia	Perception	marisageog@yahoo.com.br

Paraíba (PB)

Alexandre Ramlo Torre Palma	Federal University of Paraíba	Departamento de Sistemática e Ecologia	Microplastics	alexandre@ccen.ufpb.br
Ana Lúcia Vendel	Federal University of Paraíba	Laboratório de Ictiologia	Interaction with biota	analuciavendel@gmail.com
Jonas de Assis Almeida Ramos	Federal Institute of Paraíba	Cursos de Recursos Pesqueiros	Macrolitter in the env	jonas.ramos@ifpb.edu.br
Rita de Cassia Siriano Mascarenhas	Federal University of Paraíba Guajiru Association (NGO)	Programa de Pós-Graduação em Zoologia	Monitoring Interaction with biota	rita.mascarenhas@gmail.com

Pernambuco (PE)

Ana Carolina Matos da Silva	Colégio Elo	-	Macrolitter in the env Solid waste management Public politics Perception	carolinamsdias@gmail.com
André Ricardo de Araújo Lima	Federal University of Pernambuco	Departamento de Oceanografia	Interaction with biota Microplastics	andre.ralima@ufpe.br
Jacqueline Santos Silva Cavalcanti	Federal Rural University of Pernambuco	Departamento de Biologia	Macrolitter in the env Monitoring Perception Microplastics	jacque_ss@hotmail.com
Mara Fisner Cesar	Escritor Osman da Costa Lins College	Cursos de Especialização	Microplastics Contaminants	marafisner@gmail.com
Mario Barletta	Federal Rural University of Pernambuco	Departamento de Oceanografia	Macrolitter in the env Interaction with biota Microplastics	mario.barletta@ufpe.br

Monica Ferreira da Costa	Federal University of Pernambuco	Departamento de Oceanografia	Macrolitter in the env Interaction with biota Monitoring Microplastics Educational collection	monica.costa@ufpe.br

Alagoas (AL)

Cláudio Luis Santos Sampaio	Federal University of Alagoas	Instituto de Ciências Biológicas e da Saúde	Macrolitter in the env Interaction with biota	claudio.sampaio@penedo.ufal.br
Robson Guimarães dos Santos	Federal University of Alagoas	Instituto de Ciências Biológicas e da Saúde	Macrolitter in the env Interaction with biota	robsongsantos@gmail.com

Bahia

Alexandra Marselha Siqueira Pitolli	State University of Santa Cruz	Departamento de Ciências Biológicas	Environmental education	amspitolli@gmail.com
Ana Cecília Rizzatti de Albergaria Barbosa	Federal University of Bahia	Departamento de Oceanografia do Instituto de Geociência	Macrolitter in the env Interaction with biota Macrolitter in the env Contaminants	cecilia.albergaria@ufba.br
Carlos Roberto Franke	Federal University of Bahia	Escola de Medicina Veterinária e Zootecnia	Interaction with biota	franke@ufba.br
Iracema Reimão Silva	Federal University of Bahia	Instituto de Geociências	Macrolitter in the env	iracemars@yahoo.com.br
Jose Rodrigues de Souza Filho	Federal Institute of Bahia	Mestrado Profissional em Educação Profissional e Tecnológica em Rede Nacional	Monitoring Macrolitter in the env Educational collection	jose.rodrigues@ifbaiano.edu.br
Leopoldo Melo Barreto	Federal University of Recôncavo da Bahia	Centro de Ciências Agrárias, Ambientais e Biológicas	Environmental education Perception	leopoldo.barreto@ufrb.edu.br
Leonardo Evangelista Moraes	Federal University of Southern Bahia	Instituto Sosígenes Costa de Humanidades, Artes e Ciências	Macrolitter in the env	leomoraes@ufsb.edu.br
Moacir Santos Tinôco	Catholic University of Salvador	Centro de Ecologia e Conservação Animal	Environmental education Macrolitter in the env Perception Environmental impacts	moacirtinoco@gmail.com
Plínio Martins Falcão	Federal Institute of Bahia	Departamento de Geografia	Macrolitter in the env Microplastics Environmental impacts	plinio@ifba.edu.br
Vanessa Hatje	Federal University of Bahia	Departamento de Química Analítica	Macrolitter in the env	vhatje@ufba.br

SOUTHEAST BRAZIL

Espírito Santo (ES)

Agnaldo Silva Martins	Federal University of Espírito Santo	Departamento de Oceanografia e Ecologia	Interaction with biota	agnaldo.martins@ufes.br
Ryan Carlos de Andrades	Federal University of Espírito Santo	Departamento de Oceanografia e Ecologia	Macrolitter in the env Interaction with biota	ryanandrades@gmail.com
Valeria da Silva Quaresma	Federal University of Espírito Santo	Departamento de Oceanografia e Ecologia	Macrolitter in the env	valeria@dern.ufes.br

Minas Gerais (MG)

Bernadete Maria de Sousa	Federal University of Juíz de Fora	Departamento de Zoologia	Interaction with biota	bernadete.sousa@ufjf.edu.br
Jeamylle Nilin Goncalves	Federal University of Uberlândia	Instituto de Biologia	Macrolitter in the env Solid waste management	jeamylle@gmail.com
Kátia Gomes Facure Giaretta	Federal University of Uberlândia	Faculdade de Ciências Integradas do Pontal	Interaction with biota	katiafacure@ufu.br

Rio de Janeiro (RJ)

Abilio Soares Gomes	Fluminense Federal University	Departamento de Biologia Marinha	Microplastics Beach cleaning efficiency	abiliosg@id.uff.br
Alexandre de Gusmão Pedrini	State University of Rio de Janeiro	Instituto de Biologia	Macrolitter in the env Environmental education	pedrini@uerj.br
Ana Helena Varella Bevilacqua	Foundation Institute for Fishing of the State of Rio de Janeiro	-	Socioenvironmental impacts	anahelena.bevilacqua@gmail.com
Ana Paula Madeira Di Beneditto	State University of Northern Rio de Janeiro	Laboratório de Ciências Ambientais	Interaction with biota	anapaula@uenf.br
André Luiz Carvalho da Silva	State University of Rio de Janeiro	Departamento de Geografia	Microplastics Abundance and	andrelcsilvageouerj@gmail.com
Barbara Franz	Fluminense Federal University	Instituto de Geociências	Solid waste management Macrolitter in the env Environmental impacts	barbara_franz@id.uff.br
Bernardo Antonio Perez da Gama	Fluminense Federal University	Departamento de Biologia Marinha	Microplastics Interaction with biota	bapgama@gmail.com
Cesar Augusto Marcelino Mendes Cordeiro	Fluminense Federal University	Instituto de Biologia	Macrolitter in the env	cammcordeiro@id.uff.br
Elen Beatriz Acordi Vasques Pacheco	Federal University of Rio de Janeiro	-	Solid waste management	elen@ima.ufrj.br
Eulógio Carlos Queiroz de Carvalho	State University of Northern Rio de Janeiro	Centro de Ciências e Tecnologias Agropecuárias	Interaction with biota	eulogio@uenf.br

Fabio Vieira de Araujo	State University of Rio de Janeiro	Faculdade de Formação de Professores (FFP) e Programa de Pós Graduação em Biologia Marinha e Ambientes Costeiros	Environmental education Macrolitter in the env Interaction with biota	fvaraujo@uol.com.br
Gisele Lôbo Hajdu	State University of Rio de Janeiro	Instituto de Biologia Roberto Alcantara Gomes	Environmental education	glhajdu@uerj.br
Gisela Mandali de Figueiredo	Federal University of Rio de Janeiro	Departamento de Biologia Marinha	Microplastics	gmandali@biologia.ufrj.br
Hassan Jerdy Leandro	State University of Northern Rio de Janeiro	-	Interaction with biota	hjerdy@hotmail.com
Ilana Rosental Zalmon	State University of Northern Rio de Janeiro	Laboratório de Ciências Ambientais	Microplastics	ilana@uenf.br
Joel Christopher Creed	State University of Rio de Janeiro	Departamento de Ecologia	Macrolitter in the env	jcreed@uerj.br
Jose Antonio Baptista Neto	Fluminense Federal University	Instituto de Geociências	Interaction with biota Macrolitter in the env Microplastics	jabneto@id.uff.br
Luis Felipe Skinner	State University of Rio de Janeiro	Departamento de Ciências	Interaction with biota	lskinner@uerj.br
Marcelo Borges Rocha	Federal Center for Technological Education Celso Suckow da Fonseca	-	Solid waste management Environmental education Perception	rochamarcelo3676@gmail.com
Melanie Lopes da Silva	Fluminense Federal University	Faculdade de Formação de Professores	Macrolitter in the env	melaniels_1@hotmail.com
Rachel Ann Hauser-Davis	Oswaldo Cruz Foundation	Laboratório de Avaliação e Promoção da Saúde Ambiental	Contaminants Interaction with biota	rachel.hauser.davis@gmail.com
Renato da Silva Carreira	Pontifical Catholic University of Rio de Janeiro	Departamento de Química	Microplastics	carreira@puc-rio.br
Salvatore Siciliano	Instituto Oswaldo Cruz/Fiocruz	Laboratório de Enterobactérias	Interaction with biota	gemmlagos@gmail.com
Simone Siag Oigman Pszczol	ONG BrBio	-	Macrolitter in the env	simone@rjpug.com.br

São Paulo (SP)

Alessandra Pereira Majer	Estácio University	-	Macrolitter in the env Interaction with biota Monitoring Solid waste management Contaminants	lhemajer@gmail.com

Alexander Turra	University of São Paulo	Instituto Oceanográfico	Macrolitter in the env Monitoring Interaction with biota Microplastics Contaminants Citizen science	turra@usp.br
Andre Felipe Simoes	University of São Paulo	Escola de Artes, Ciências e Humanidades	Microplastics Solid waste management	afsimoes@usp.br
Augusto Cesar	Federal University of São Paulo	Instituto do Mar	Microplastics Interaction with biota Macrolitter in the env Contaminants	acesar@unifesp.br
Camilo Dias Seabra Pereira	Federal University of São Paulo	Departamento de Ciências do Mar	Environmental impacts Interaction with biota Microplastics	camilo.seabra@unifesp.br
Carla Isobel Elliff	University of São Paulo	Instituto Oceanográfico	Macrolitter in the env Perception	carlaelliff@gmail.com
Cassiana Carolina Montagner Raimundo	University of Campinas	Instituto de Química	Microplastics Contaminants Environmental impacts	ccmonta@unicamp.br
Carlos Eduardo Malavasi Bruno	Fisheries Institute of Santos	-	Interaction with biota Microplastics	sharkeduardo@gmail.com
Carolina Pacheco Bertozzi	São Paulo State University	Instituto de Biociências	Interaction with biota	carolina.bertozzi@unesp.br
Celia Regina de Gouveia Souza	Secretaria do Meio Ambiente-SP	Instituto Geológico	Microplastics	celiagouveia@gmail.com
Denis Moledo de Souza Abessa	São Paulo State University	-	Microplastics Contaminants Solid waste management	abessa@unesp.br
Danilo Balthazar Silva	Paulista University	Curso de Ciências Biológicas	Microplastics	danilobalthazar@gmail.com
Ednilson Viana	University of São Paulo	Escola de Artes, Ciências e Humanidades	Macrolitter in the env Solid waste management Environmental education	ednilson.viana@gmail.com
Fabiana Tavares Moreira	University of São Paulo	Instituto Oceanográfico	Contaminants	fabianamoreira@hotmail.com
Fernanda Imperatrice Colabuono	University of São Paulo	Instituto Oceanográfico	Contaminants Macrolitter in the env Interaction with biota	ferimp@hotmail.com
Homero Fonseca Filho	University of São Paulo	Escola de Artes, Ciências e Humanidades.	Microplastics	homeroff@usp.br
Ítalo Braga de Castro	Federal University of São Paulo	Instituto de Ciências do Mar	Macrolitter in the env Environmental impacts	ibcastro@unifesp.br
Ivan Sazima	São Paulo State University	Instituto de Biologia	Interaction with biota	isazima@unicamp.br
Luiz Felipe Mendes Gusmão	Federal University of São Paulo	Instituto do Mar	Microplastics Interaction with biota	gusmao@unifesp.br
Luiz Miguel Casarini	Institute of Fisheries	Núcleo de Pesquisa e Desenvolvimento	Solid waste management Public politics	lumicas@pesca.sp.gov.br

Márcia Caruso Bícego	University of São Paulo	Instituto Oceanográfico	Contaminants Interaction with biota	marcia@io.usp.br
Márcio Reis Custódio	University of São Paulo	Instituto de Biociências	Interaction with biota Microplastics	mcust@usp.br
Marília Cunha Lignon	São Paulo State University	Curso de Engenharia de Pesca	Macrolitter in the env Interaction with biota	cunha.lignon@unesp.br
Natalia Pirani Ghilardi-Lopes	Federal University of ABC	Centro de Ciências Naturais e Humanas	Environmental education Citizen Science	natalia.lopes@ufabc.edu.br
Paola Lupianhes Dall'Occo	Mackenzie Presbyterian University	Centro de Ciências Biológicas e da Saúde	Macrolitter in the env Solid waste management	paola.occo@mackenzie.br
Rafael Andre Lourenço	University of São Paulo	Instituto Oceanográfico	Contaminants	rafaell@usp.br
Rosalinda Carmela Montone	University of São Paulo	Instituto Oceanográfico	Microplastics Macrolitter in the env	rmontone@usp.br
Satie Taniguchi	University of São Paulo	Instituto Oceanográfico	Contaminants	satie@usp.br
Sylmara Lopes Francelino Gonçalves Dias	University of São Paulo	Escola de Artes, Ciências e Humanidades	Solid waste management Environmental education Socioenvironmental impacts	sgdias@usp.br
Walter Barrella	University of Santa Cecília Paulista University	Programa Pós Graduação Ecologia Ciências Biológicas	Macrolitter in the env	walterbarrella@gmail.com

SOUTHERN BRAZIL				
Paraná (PR)				
Allan Paul Krelling	Federal Institute of Paraná	Curso Técnico Integrado em Meio Ambiente	Solid waste management Macrolitter in the env Socioeconomic impacts Perception Public politics	allan.krelling@ifpr.edu.br
Angela Maria Palacio Cortés	Federal University of Paraná	Laboratório de Morfologia e Fisiologia de Culicidae e Chironomidae	Contaminants	a_mariap@yahoo.com
Fernanda Eria Possatto	Federal University of Paraná	Projeto de Monitoramento de Praias da Bacia de Santos (PMP-BS)	Macrolitter in the env Interaction with biota	fernandapossatto@yahoo.com.br
Gislaine de Fatima Filla	Federal Institute of Paraná	-	Interaction with biota	gislaine.filla@ifpr.edu.br
Marta Luciane Fischer	Pontifical Catholic University of Paraná	Centro de Ciências Biológicas e da Saúde	Perception	marta.fischer@pucpr.br
Leticia Knechtel Procopiak	Federal University of Technology – Paraná	-	Solid waste management Macrolitter in the env Environmental education	leprocopiak@utfpr.edu.br

Santa Catarina (SC)

Alessandra Larissa D Oliveira Fonseca	Federal University of Santa Catarina	Departamento de Geociências	Macrolitter in the env Environmental education	alessandra.larissa@ufsc.br
Alexandre Matthiensen	Embrapa	-	Macrolitter in the env Environmental impacts	alexandre.matthiensen@embrapa.br
Arnaldo D Amaral Pereira Granja Russo	Santa Catarina State University	Cursos de Engenharia da Pesca e Biologia Marinha	Macrolitter in the env	arnaldorusso@gmail.com
David Valença Dantas	Santa Catarina State University	Centro de Educação Superior da Região Sul	Interaction with biota Microplastics	david.dantas@udesc.br
Eduardo Guilherme Gentil de Farias	Santa Catarina State University	Programa de Pós-Graduação em Planejamento Territorial e Desenvolvimento Socioambiental	Interaction with biota	eduardo.gentil@udesc.br
Mariana Coutinho Hennemann	Municipal Environment Foundation of Florianópolis	-	Macrolitter in the env	mari.henn@gmail.com
Walter Martin Widmer	Federal Institute of Santa Catarina	-	Solid waste management Macrolitter in the env Interaction with biota Educational collection	walter.widmer@ifsc.edu.br

Rio Grande do Sul (RS)

Andreia Neves Fernandes	Federal University of Rio Grande do Sul	Instituto de Química	Microplastics Health impacts	andreia.fernandes@ufrgs.br
Ana Luzia de Figueiredo Lacerda	Federal University of Rio Grande	Instituto de Oceanografia	Macrolitter in the env Interaction with biota Microplastics	analuzialacerda@gmail.com
Daphne Wrobel Goldberg	Federal University of Rio Grande	Programa de Monitoramento da Biodiversidade Aquática	Interaction with biota	daphwrobel@gmail.com.
Erli Schneider Costa	State University of Rio Grande do Sul	Mestrado Profissional Ambiente e Sustentabilidade	Environmental education	erli-costa@uergs.edu.b
Eduardo Resende Secchi	Federal University of Rio Grande	Instituto de Oceanografia	Interaction with biota	edu.secchi@furg.br
Eduardo Saldanha Vogelmann	Federal University of Rio Grande	Instituto de Ciências Biológicas	Macrolitter in the env	eduardovogelmann@furg.br
Fábio Lameiro Rodrigues	Federal University of Rio Grande do Sul	Departamento Interdisciplinar	Macrolitter in the env Interaction with biota Microplastics	oclameiro@gmail.com
Felipe Kessler	Federal University of Rio Grande	Escola de Química e Alimentos	Interaction with biota Microplastics	felipekessler@furg.br

Gerson Fernandino de Andrade Neto	Federal University of Rio Grande do Sul	Instituto de Geociências	Macrolitter in the env Perception	gerson.fernandino@yahoo.com.br
Gilberto Fillmann		Instituto de Oceanografia	Macrolitter in the env Interaction with biota Microplastics Contaminants Environmental Impacts	docfill@furg.br
Grasiela Lopes Leães Pinho	Federal University of Rio Grande	Instituto de Oceanografia	Macrolitter in the env Interaction with biota Microplastics Contaminants Environmental Impacts Educational collection	grasielapinho@hotmail.com
Gustavo Martinez Souza	Federal University of Rio Grande	Instituto de Matemática, Estatística e Física	Interaction with biota	gustavomarsouza@gmail.com
Juliana Assunção Ivar do Sul	Federal University of Rio Grande	Instituto de Oceanografia	Macrolitter in the env Interaction with biota Monitoring Microplastics Educational collection	julianasul@gmail.com
Leandro Bugoni	Federal University of Rio Grande	Instituto de Ciências Biológicas	Interaction with biota	lbugoni@yahoo.com.br
Maíra Carneiro Proietti	Federal University of Rio Grande	Instituto de Oceanografia	Interaction with biota Macrolitter in the env Microplastics	mairaproietti@gmail.com
Maria Virginia Petry	University of Vale do Rio dos Sinos	Laboratório de Ornitologia e Animais Marinhos	Interaction with biota	vpetry@unisinos.br
Mônica Wallner-Kersanach	Federal University of Rio Grande	Instituto de Oceanografia	Macrolitter in the env Environmental impacts Interaction with biota	monicawallner@furg.br
Uwe Horst Schulz	University of Vale do Rio dos Sinos	Laboratório de Ecologia de Peixes	Microplastics	uwe@unisinos.br

OTHER REGIONS

Other regions and unknown location

Daniel Gorman	Comm.. Sci. and Ind. Res. Org. (CSIRO, Australia)	-	Contaminants	dgorman@usp.br
Daphiny Cristina Vicente Pottmaier	veleiro ECO	ECO sailboat	-	daphiny@gmail.com
Davi Castro Tavares	-	-	Interaction with biota	davi.tavares@ leibniz-zmt.de
Helen Maria Duarte do Rêgo Barros	-	-	Interaction with biota	helenrbarros@yahoo.com.br

Isaac Rodrigues dos Santos	-	-	Macrolitter in the env Perception	santos@ocean.fsu.edu
Jociery Einhardt Vergara Parente	-	-	Interaction with biota	jociery.parente@gmail.com
Luana Carla Portz	Universidad de la Costa (Colombia)	-	Macrolitter in the env	luanaportz@gmail.com
Matthew Kenyon Broadhurst	-	-	Macrolitter in the env	matt.broadhurst@dpi.nsw.gov.au
Natália Carla Fernandes de Medeiros Dantas	-	-	Macrolitter in the env Microplastics	nataliacarladantas@hotmail.com

8.2. Supplementary Material B - Data available for marine macrolitter in Brazil

Marine litter data available in Brazil, including mean litter density (standardized to m^{-1}, m^{-2} or m^{-3}) and kind of litter analyzed, plastic percentage (including cigarette butts, foam, styrofoam and nylon, when data was available), sources of marine macrolitter in the environment. Methods used by studies on marine litter in Brazil, including sampling area, sampling design and original unit of measurement. Some studies are present in more than one table due to sample collection in two different environments (Oigman-Pszcol & Creed, 2007; Sampaio & Pinto, 2015). Krelling et al. (2017) and Krelling & Turra (2019) have sampled beaches along an estuary gradient, so results are shown in the Estuaries table. Concepts of nearshore, foreshore and backshore were also considered for estuarine beaches.

nearshore= underwater region where sediment is affected by waves, limited by the mean low-water line and region with minor sediment transport by waves
foreshore= periodically wet and dry region, which extends from the mean low-water line to the upper limit of waves at normal high tide
backshore= usually dry region, lying between the upper limit of waves at normal high tide and the maximum upper limit during storms
dune/vegetation= dunes are subaerial sediment accumulations scarce in the backshore and abundant afterward. Dunes can be more or less vegetated.
strandline= line of organic and anthropogenic debris along the beach left when the tide goes out
estuary sectors = different regions of an estuary, described below
mangrove= forest ecosystem lying in estuaries along with tropical and some subtropical regions, subjected to tidal cycles

article identification number, correspondent to article number in Figure 6
† study also considered organic matter, which can influence the total plastic percentage
* value calculated (standardized) from data provided by the articles, when possible
** possible source only suggested by the articles (articles did not analyze each item's source)
weight = percentage calculated based on total sampling weight instead of total number of items.
⬦= visual analysis; ◈= visual analysis and litter collection; components without a symbol on the Sampling design field were performed through litter collection.

BEACHES

Location	Mean litter density/kind	Plastic %	Litter sources	Sampling area	Sampling design	Unit of measurement	Reference	#
Guanabara Bay, Rio de Janeiro	-	-†	Rivers and urban drainage system	Strandline	⬦ 2m transects	x	Figueiredo Jr. et al. (2001)	1

Praia do Forte, Pernambuco	0.17 items.m^{-2}.day^{-1}*	87.6%*†	Beach users	Not explicit	two samples on a 70x28m transect	items.person-.day^{-1}	Araújo & Costa (2004a)	2
Tamandaré Beach, Pernambuco	0.30 items.m^{-2}*	89.4%†	Rivers, beach users and vessels	Backshore and foreshore	10m transects x beach width (~50 m)	items.2000m^{-2}	Araújo & Costa (2004b)	3
Cassino Beach, Rio Grande do Sul	7.6 items.m^{-1} (well visited by beach users)	53.7%†	Beach users, rivers and vessels	Backshore and foreshore	5m wide transects x beach width	items.m^{-1}; mass (g).m^{-1}	Wetzel et al. (2004)	4
	4.7 items.m^{-1} (beach users)	52.6%†						
	14.9 items.m^{-1} (few beach users)	51.3%†						
	2.3 items.m^{-1} (virtually no beach users)	66.7%†						
Cassino Beach, Rio Grande do Sul	3.09 items.m^{-1}.summer day^{-1}	64%*†	Beach users	Foreshore and part of the backshore	◇ Two areas from the waterline to the artificial sand wall (~50 m)	items.m^{-1}.day	Santos et al. (2004)	5
Costa dos Coqueiros, Bahia	0.01 international litter.m^{-1}*	70.2%*	Vessels	Not explicit	Collection of all overseas litter found on the beach	items.km^{-1}	Santos et al. (2005)	6
Tamandaré Beach, Pernambuco	before beach cleaning service: 0.93 plastics.m^{-2}; after: 0.17 plastics.m^{-2} *	-	Beach users and rivers	Backshore and foreshore	50m wide transects x beach width (~50m)	plastic items.2500m^{-2}	Araújo & Costa (2006a)	7
Tamandaré Beach, Pernambuco	plastics	-	Beach users, rivers, fisheries and vessels	Backshore and foreshore	50m wide transects x beach width (~ 50m)	plastic items.2500m^{-2}	Araújo & Costa (2006b)	8
Tamandaré Beach, Pernambuco	-	-	-	Backshore and foreshore	◇ 9km of beach categorized according to contamination level	x	Araújo & Costa (2007a)	9
Várzea do Una Beach, Pernambuco	14.74 plastics.m^{-2}*	-	Rivers	Backshore and foreshore	50m wide transect x beach width (~50m)	total number of items; items.m^{-2}	Araújo & Costa (2007b)	10
Tartaruga L, Armação dos Búzios, Rio de Janeiro	0.14 items.m^{-2}*	80.8%*†	Beach users	Backshore	◇ 4m transects above the high tide line, parallel to the coast	items.100m^{-2}	Oigman-Pszczol & Creed (2007)	11

Tartaruga R, Armação dos Búzios, Rio de Janeiro	0.34 $items.m^{-2}$*							
Canto, Rio de Janeiro	0.21 $items.m^{-2}$*							
Ilha do Caboclo, Rio de Janeiro	0.12 $items.m^{-2}$*							
Ossos L, Rio de Janeiro	0.61 $items.m^{-2}$*							
Ossos R, Rio de Janeiro	0.14 $items.m^{-2}$*							
Azeda, Rio de Janeiro	0.23 $items.m^{-2}$*							
Azedinha, Rio de Janeiro	0.18 $items.m^{-2}$*							
João Fernandes, Rio de Janeiro	0.89 $items.m^{-2}$*							
João Fernandinho, Rio de Janeiro	0.17 $items.m^{-2}$*							
Bessa and Intermares, Paraíba	0.56 $items.m^{-2}$*							
Boa Viagem Beach, Pernambuco	flag items	40.19%*†	Beach users	Backshore and foreshore	10m wide transects	total number of items	Silva et al. (2008)	13
Guaratuba (PR); Barra do Saí, Itapema do Norte, Figueira, Ervino and Balneário Barra do Sul (SC)	fishing litter	-	Fisheries	Backshore	◇ 35 km campaigns across the supralittoral	x	Chaves & Robert (2009)	14
Costa do Dendê, Bahia	9.1 $items.m^{-1}$	90%*†	Rivers, beach users and fisheries	Backshore and foreshore	10m wide transects x beach width	$items.m^{-1}$	Santos et al. (2009)	15
Boa Viagem Beach, Pernambuco	0.67 $items.m^{-1}$* on the strandline	> 60.31%†	Beach users and rivers	Strandline	◇ 1mx8km transect on the fresher strandline	total number of items	Silva-Cavalcanti et al. (2009)	16

beaches in Florianópolis, Santa Catarina	1.02 items.m^{-2}*	~ 90%†	Beach users, vessels and fisheries	Backshore	50x2m transects	items.100m^{-2}	Widmer et al. (2010)	19
Guanabara Bay, Rio de Janeiro	-	70.6%	Beach users and rivers	Strandline	◇10x1m transects	total number of items	Baptista Neto & Fonseca (2011)	20
Boa Viagem Beach, Pernambuco	3.7 items.m^{-2}.day^{-1}	37.84%*†	Beach users	Backshore and foreshore (partially)	10x15m transects	items.m^{-2}.day^{-1}	Dias Filho et al. (2011)	23
Costa dos Coqueiros, Bahia	8.4 items.m^{-1} (undeveloped beaches); 30.5 items.m^{-1} (developed beaches)	52 – 94%†	Beach users (developed beaches); rivers and fisheries (undeveloped beaches); marine-based sources.	Backshore and part of the foreshore	◈ 10m x 100-200m transects; 10-100m wide transects to assess tourism influence	items.m^{-1}	Ivar do Sul et al. (2011)	24
Barrinha Beach, Espírito Santo	-	46% - weight†	Rivers	Backshore and foreshore	10m wide transects x beach width (~20m)	x	Neves et al. (2011)	25
Massaguaçu Beach, São Paulo	0.06 items.m^{-2} (backshore) and 6.70 items.m^{-1} (beach face)*	> 80%†	Urban drainage system and local shops	Backshore and foreshore	30m transects on beach face; 10x1m perpendicular to the waterline	items.m^{-2}; items.m^{-1}	Oliveira et al. (2011)	26
Xangri-Lá, Rio Grande do Sul	-	81%†	Beach users	Coast and backshore	10m wide transects	items.m^{-1}	Portz et al. (2011)	27
Cassino Beach, Rio Grande do Sul	7.3 items.m^{-1}	71.2%†	Beach users, rivers and fisheries	Backshore and foreshore	5m and 10m wide transects	items.m^{-1}	Tourinho & Fillmann. 2011	29
Santa Cruz dos Navegantes Beach, São Paulo	-	> 39%	Beach users, shipyards and illegal dumping by local residents**	Backshore and foreshore*	798 m^2 and 144 m^2 transects	total number of items	Ferreira & Lopes (2013)	31
Boa Viagem Beach, Pernambuco	1.15 items.m^{-2}*	74.3%†	Beach users, rivers and fisheries	Strandline	◈ 8km x 1m transects	total number of items.$year^{-1}$.8km2 ; items.km^{-1}; items/m^{-1}	Silva-Cavalcanti et al. (2013)	33
Piratininga, Rio de Janeiro	-	-	-	Not explicit	Not explicit	total of items	Farias (2014)	35
Porto da Barra, Bahia	0.65 items.m^{-1}	57.91%†	Beach users	Foreshore	10m wide transects perpendicular to the coast	total number of items; items.m^{-2},	Leite et al. (2014)	36

Ondina, Bahia	1.98 items.m^{-1}	95.42%†				weight.m^{-2}; richness (number of debris categories)		
Jardim de Alá, Bahia	1.48 items.m^{-1}	87.20%†						
Praia dos Artistas, Bahia	1.26 items.m^{-1}	87.55%†						
Jaguaripe, Bahia	0.36 items.m^{-1}	67.22%†						
Aleluia, Bahia	0.26 items.m^{-1}	88.46%†						
Genipabu, Bahia	0.71 items.m^{-1}	97.53%†						
Itacimirim, Bahia	0.27 items.m^{-1}	56.22%†						
Praia do Forte, Bahia	0.59 items.m^{-1}	94.72%†						
Porto da Barra, Bahia	1.27 items.m^{-2}	21.99%†	Local sources	Nearshore: 2-10m depth	2x100m diving transects perpendicular to the coastline	items.m^{-2}	Fernandino et al. (2015)	37
Hospital Espanhol, Bahia	0.39 items.m^{-2}	51.69%†						
Farol da Barra, Bahia	0.25 items.m^{-2}	68.18%†						
Pontal do Peba, Alagoas	33.1 g.m^{-2}*	60%	Beach users and fisheries**	Not explicit	◈ 30x2m transects parallel to the beach; free photographing dives	mass (kg).1800m^{-2}	Sampaio & Pinto (2015)	39
Itaipu, Rio de Janeiro	-	69.03%*	Beach users and fisheries	Backshore and foreshore	30min 20m wide transects x beach width	total number of items	Silva et al. (2015)	40
Itacoatiara, Rio de Janeiro	-	73.7%*						
Curva da Jurema, Espírito Santo	0.58 items.m^{-2}	73.2%	Rivers and beach users	Backshore and foreshore	⬦ 1.7 to 12.6m length transects	items.m^{-2}	Andrades et al. (2016)	41
Porto da Lama and Enseada das Garças, Espírito Santo	0.18 items.m^{-2}	83.2%			⬦ 5.3 to 41.1m length transects			
Regência, Espírito Santo	0.24 items.m^{-2}	85.9%			⬦ 7.4 to 48.8m length transects			
Subaúma, Baixio and Barra do Itariri, Bahia	0-4 items.m^{-1}	82%	Marine-based sources	Backshore and foreshore	10m transects every 1 km	items.m^{-1}	de Santana Neto et al. (2016)	42

Salvador, Bahia	0.19 items.m^{-2} - 31.50 items.m^{-2}	86.35%*	Beach users	Backshore	⋄ 30min ~50 m register of litter floating within	total number of items	Fernandino et al. (2016)	43
Sossego, Rio de Janeiro	0.58 items.m^{-2}* or 7.75 g.m^{-2}*	94%*	Beach users and rivers	Backshore and foreshore	20min 20x30m transects	number items; mass (kg)	Silva et al. (2016)	46
Camboinhas, Rio de Janeiro	0.21 items.m^{-2}* or 2.33 g.m^{-2}*	100%*						
Flechas, Rio de Janeiro	0.18 items.m^{-2}* or 1.21 g.m^{-2}*	96%*						
Charitas, Rio de Janeiro	0.19 items.m^{-2}* or 0.98 g.m^{-2}*	93%*						
Praia Grande, Arraial do Cabo, Rio de Janeiro	6.25 items.m^{-2}* (urbanized sector); 0.6 items.m^{-2}* (non-urbanized)	84%	Beach users	Backshore and foreshore	Transects perpendicular to the coastline	items.m^{-2}	Suciu et al. (2017)	48
Grussaí Beach, São João da Barra, Rio de Janeiro	2.65 items.m^{-2}* (urbanized sector); 0.9 items.m^{-2} (non-urbanized sector)							
Trindade Island, Espírito Santo	0.5 items.m^{-2}	> 77.39%	-	Backshore and foreshore	◈ 30x2 m transects	items.m^{-2}	Andrades et al. (2018)	49
Forte Orange, Maracaípe, and Carneiros, Pernambuco	2.3 items.m^{-2}	57.3%†	Beach users, fisheries, land-based and mixed	Strandline	◈ 100x1m transects	items.m^{-2}	Araújo et al. (2018)	50
Porto de Galinhas, Maria Farinha, and Campas, Pernambuco	5.7 items.m^{-2}							
Bairro Novo, Boa Viagem, and Piedade, Pernambuco	6.3 items.m^{-2}							
Boqueirão and Embaré, São Paulo	-	76.8%	Beach users**	Foreshore*	2×2m quadrats	total number of items; total mass (kg)	Cordeiro et al. (2018)	51

Daniela, Santa Catarina	0.19 items.m^{-2} / 1.27 g.m^{-2}	~ 97%	Beach users, rivers and fisheries	Backshore and foreshore	100m long transect x beach width	items.m^{-2}; g.m^{-2}	Corraini et al. (2018)	52
Forte, Santa Catarina	0.09 items.m^{-2} / 1.52 g.m^{-2}							
Jurerê, Santa Catarina	0.10 items.m^{-2} / 2.10 g.m^{-2}							
Canasvieiras, Santa Catarina	0.42 items.m^{-2} / 1.99 g.m^{-2}							
Ponta das Canas, Santa Catarina	0.20 items.m^{-2} / 2.01 g.m^{-2}							
Lagoinha do Norte, Santa Catarina	0.25 items.m^{-2} / 4.08 g.m^{-2}							
Brava, Santa Catarina	0.53 items.m^{-2} / 2.86 g.m^{-2}							
Ingleses, Santa Catarina	0.55 items.m^{-2} / 1.64 g.m^{-2}							
Camboinhas Beach, Rio de Janeiro	-	66.54%* (kiosks area). 84.35%* (no kiosks area)	-	Coast, backshore and foreshore	Three 30m x 2m transects	total mass (g)	Perez et al. (2018)	54
Prainha beach, Rio de Janeiro	1.65 items.m^{-2}*	76.5% - 88.1%*	Beach users	Backshore and foreshore	20m transect x beach width	items.m^{-2}	Silva et al. (2018)	55
Pontal beach, Rio de Janeiro	0.68 items.m^{-2}*							
Praia Grande, Arraial do Cabo, Rio de Janeiro	0.41 items.m^{-2}*							
Praia Grande, São Francisco do Sul Island, Santa Catarina	-	79.19% - weight	-	Backshore and foreshore	100m transects x beach width	total mass (kg)	Stelmack et al. (2018)	56
Praia Vermelha, Santa Catarina	3.59 plastics.m^{-2}	69%	-	Strandline	50mx2m transect	total number of items; plastic.m^{-2}	Marin et al. (2019)	58
Gravatá Norte, Santa Catarina	15.59 plastics.m^{-2}							

Guarda do Embaú, Santa Catarina	1.23 plastics.m^{-2}							
Ibiraquera, Santa Catarina	0.28 plastics.m^{-2}							
Estaleiro, Santa Catarina	0.07 plastics.m^{-2}							
Miramar beach, Paraíba	0.97 items.m^{-2}*; 17.78 g.m^{-2}*	88.37%*	Beach users, fisheries, local shops and houses**	Nearshore: surf zone (water)	5min hauls using a seine net parallel to the shore	items.km^{-2}; mass (g).km^{-2}	Ramos & Pessoa (2019)	59

ESTUARIES

Location	Mean litter density	Plastic %	Litter sources	Sampling area	Sampling design	Unit of measurement	Reference	#
Goiana Estuary, Pernambuco	59 plastics.m^{-3}	100%*	Rivers, illegal dumping by local residents and fisheries (mussel pickers)	Estuary: near the mangrove, and on the top and the fringe of the tidal plain	20cm diameter x 20 cm height cylindrical cores	items.m^{-3}	Costa et al. (2011)	22
Goiana Estuary, Pernambuco	0.1 items.m^{-2}*	> 95%	Fisheries, beach users and rivers	Backshore and foreshore	20m wide transects x beach width	items.100m^{-2}	Ivar do Sul & Costa (2013)	32
Paranaguá Estuarine Complex, Paraná	0 - 0.002 items.m^{-1}*	92.4%	Urbanized areas nearby	Estuary: outer, middle and inner sectors; up to 3 m depth	5min straight line tows, using trawls	items.ha^{-1}	Possatto et al. (2015)	38
Santos-São Vicente estuarine system, São Paulo	-	89.64%	Illegal dumping by local residents	Estuary (water surface)	10m transects x beach width	total number of items	Fernandino et al. (2016)	44
Paranaguá Estuarine Complex, Paraná	1.23 freshly inputted litter.m^{-2}*	89.61%	Rivers	Backshore and foreshore	5x50m transects	total number of items.250m^{-2}	Krelling et al. (2017)	47
Laguna Estuarine Complex (LES), Santa Catarina	0.02 items.m^{-2}*	> 3.17%*†	Fisheries	River: 1-6m depth	1min freediving covering 4 sectors of 26,400 m2	total number of items.26,400m^{-2}	Farias et al. (2018)	53

Paranaguá and Pontal do Paraná, Paraná	freshly inputted litter	74.8%	Beach users, rivers, fisheries and vessels	Foreshore	5m wide transects along the estuarine gradient	total number of items	Krelling & Turra (2019)	57

MANGROVES

Location	Mean litter density	Plastic %	Litter sources	Sampling area	Sampling design	Unit of measurement	Reference	#
Santos-São Vicente Estuary Complex, São Paulo	1.33 items.m^{-2} or 129.66 g.m^{-2}	> 62.81%	Illegal dumping by local residents	Mangrove's edge, at the river side	10x10 m transects; litter on the surface of the ground were recorded	items.m^{-2}; mass (g).m^{-2}	Cordeiro & Costa (2010)	17
Pontal do Jurerê, Santa Catarina	1.48 item.m^{-2}*	-	Beach users and urban drainage system	Mangrove forest and bordering that	15min 50m2 transects in the mangrove margin and forest	items.100m^{-2}	Vieira et al. (2011)	30
Potengi River, Rio Grande do Norte	0.51 items.m^{-2} - 8.69 items.m^{-2}	> 90%*†	Beach users	Mangrove zones; parallel to the river or the beach	◈ 50m2 transects	items.m^{-2}	Belarmino et al. (2014)	34
Goiana Estuary, Pernambuco	1.4 plastics.m^{-3}	-	Fisheries	Estuary: lower sectors (water)	Creek mouths were blocked with a mesh	items.100m^{-3}	Lima et al. (2016)	45

OTHER ENVIRONMENTS

Location	Mean litter density	Plastic %	Litter sources	Environment and Sampling area	Sampling design	Unit of measurement	Reference	#
Armação dos Búzios, Rio de Janeiro	0.03 items.m^{-2}*	64%†	Beach users	Rock reef - Nearshore: up to 4m depth	◇ 5 minutes snorkeling campaigns (~115m2)	items.100m^{-2}	Oigman-Pszczol & Creed (2007)	11
Arvoredo Island, Santa Catarina	0.01 items.m^{-2}*	> 90%	Vessels and urbanized areas nearby	Sea bottom - Nearshore: 3-15m depth	Scuba dives covering 763,5m²	items.1000m^{-2}	Machado & Fillmann (2010)	18
	3.33 items.m^{-1}			Rocky shore - Backshore and foreshore	10m transects from the waterline to the vegetation	items.100m^{-1}; items.m^{-1}		
Todos os Santos Bay, Bahia	0.13 items.m^{-2}*	33.40%*	Intentional disposal, fishing	Rocky reef - Nearshore: 0.5-10 m depth	◈ 30x4m transects for quali-quantitative	total number of items;	Carvalho-Souza & Tinôco (2011)	21

			waste and accidental loss		censuses; 30min visual censuses	$items.1000m^{-2}$		
Atol das rocas, Rio Grande do Norte	-	-	Vessels and urban areas nearby	Coral reef - Backshore, foreshore and nearshore*	Sampling on reef plateau and sandy islands; freediving	x	Soares et al. (2011)	28

8.3. Supplementary Material C - Minimum litter size by macrolitter studies in Brazil

Minimum litter size considered by studies on macrolitter in the environment (Brazil). Only 31 studies provided information on minimum item size considered during sample collection. Besides investigating macrolitter, some studies also investigated meso and microlitter.

Minimum size	**# of studies**
> 1mm	1
> 5 mm	7
> 0 cm (all sizes)	1
> 1 cm	6
> 2 cm	7
> 2.5 cm	2
> 3 cm	1
> 5 cm	1
Visible to the naked eye	5

8.4. Supplementary Material D - Summary of the specialized literature

Summary of goals and parameters used or suggested in the specialized literature relevant for assessing the risk of litter leakage to the environment, eventually contributing to marine pollution.

STUDY	GOAL	USED/SUGGESTED PARAMETERS
Jambeck et al. (2015)	To present a framework to calculate the amount of mismanaged plastic waste generated annually by populations living within 50 km of a coast worldwide that can potentially enter the ocean as marine debris.	- Mass of waste generated (kg/person/day); percentage of plastic; mismanaged waste (%, MMT/year) - Coastal population density (inhabitant/km² living within 50km of the coast) - Country economic status (based on GNI - gross national income)
Lebreton et al. (2017)	To provide a global estimate of river plastic inputs into the world's oceans, considering both the seasonality and spatial variability of local sources.	- Mismanaged plastic waste production/inhabitant (kg/inhab/day) - Population density (inhabitant/km²) - Hydrological information (watersheds, river catchments, and average runoff) considering seasonality, topographic elevation, rainfall seasons and location of dams
Lebreton & Andrady (2019)	Examining the possibility of improving the granularity of data at the national level on plastic waste generation, using reasonable assumptions based on population density and affluence.	- Per capita municipal solid waste generation (kg/ppy), mismanaged fraction (%) and plastic fraction (%) - Population density (inhabitant/km²) - Long-term population projection (2015 to 2060) - Watersheds (number, size and limits) - GDP (Gross Domestic Product) distribution; sub-national GDP - GDP projections for 2015 to 2021 - Long-term economic growth projections for 2022 to 2060
Schmidt et al. (2017)	To compile available data of plastic debris in rivers, to identify patterns of plastic concentrations and loads and to provide an estimate of the amount of plastic exported from river catchments into the sea.	- Solid waste generation rate (kg/capita/day) and the fraction of plastic (%) - Mismanaged waste (kg/person/day) - Population density (inhabitant/km²) - Catchment boundaries of river catchments - Socio-economic classification of the countries (based on GNI - Gross National Income)
Liro et al. (2020)	To develop a framework to support future studies on macroplastic storage and remobilization in river systems, describing processes of macroplastic input, transport, storage, remobilization and output.	- Urbanization - Waste management - Population density - Ecological awareness of the population - Road density - Land use - Dam reservoirs - Proximity of roads (???) - Location of dumping sites on river floodplains - Natural factors (runoff, drainage area, land cover, hydrometeorological regime, topography, flow regime etc.)
Meijer et al. (2021)	To present a revised estimate of global riverine macroplastic emissions into the ocean using the most recent field observations on macroplastics and a newly developed model to more accurately	- Per capita mismanaged plastic waste (kg/year) and plastic fraction (%) - Transport to rivers: land use, slope, distance to rivers - Mobilization: precipitation, wind - Transport to the ocean: stream order, river discharge,

	represent driving mechanisms of plastic transport.	distance to river mouth
UNEP (2020)	To allow users of the Guide at national, sub-national or local levels to prioritize actions by identifying hotspots of plastic leakage and its impacts along the entire plastic value chain.	- Plastic production (total, per capita) - Plastic imports of all kinds - Plastic consumption (total, per capita) - Waste generation (total, per capita) - Import and export dependency - Initial and ending stock - Annual growth rate of plastic supply and use - Sector distribution and value-added - Plastic classification: short-lived vs long-lived; basic vs converted; direct vs embodied - Plastic sources and applications - Waste collection and mismanaged rates - Plastic waste recycling
Hardesty et al. (2016)	To better understand the pathways of land-based litter into the marine environment.	- Potential number of people accessing sites - distance to the nearest road and proximity to railways stations - Land cover and land use (vector dataset) - Population density/historical population estimates (1992-2014) - Index of Relative Socio-economic Advantage and Disadvantage - Index of Economic Resources (income) - Index of Education, Employment and Occupation - Wind - Topographic slope - Flow accumulation
PEMALM (2021)	To suggest a set of parameters for the monitoring and assessment of marine litter in the state of São Paulo, Brazil. (indicators of generation of litter)	- Total population - Population well being - income, education, longevity - Human Development Index (HDI) - Income concentration (Gini Index) - Number of households or area occupied in/by informal settlements - Number of households served by door-to-door collection of litter - Number of households served by selective collection of litter - Mass or volume of waste destined for recycling - Mass of solid waste recovered by reverse logistic - Quality of waste, landfills and composting management - Quality of sewage collection and treatment - Amount of solid waste in stormwater / urban drainage systems / in natura sewage - Amount of solid waste retained in the grating and sieving of the Sewage Treatment Stations (ETEs) and Preconditioning Stations (EPCs) - Amount of waste removed by sweeping and street cleaning

8.5. Supplementary Material E - Ranking of Brazilian municipalities with highest probability of primary mobilization of solid waste

Brazilian municipalities with highest probability $P1$ of litter mobilization and transport to rivers, considering average local rates of precipitation, wind, topographic slope, degradation/urbanization rate, existence of subnormal agglomerates and distance to rivers.

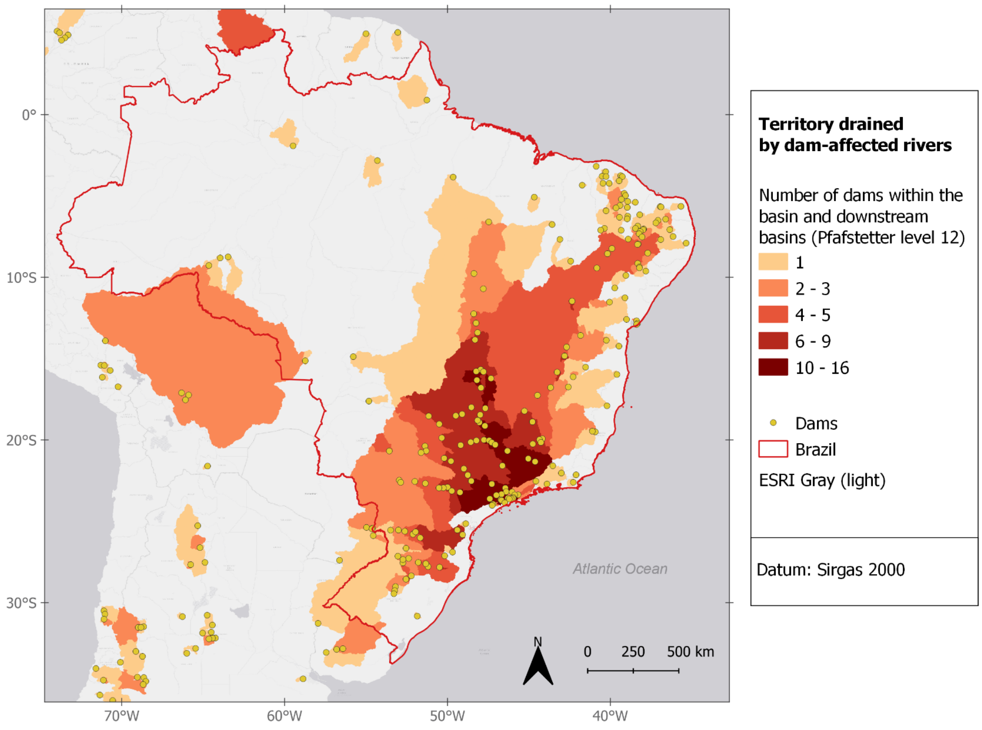
Ranking	**Municipality**	**State**	***P1***
1	Rio Grande da Serra	SP	0.843
2	Guarujá	SP	0.825
3	Bayeux	PB	0.822
4	Recife	PE	0.813
5	Poá	SP	0.811
6	São Caetano do Sul	SP	0.810
7	Diadema	SP	0.809
8	Carapicuíba	SP	0.805
9	Ferraz de Vasconcelos	SP	0.805
10	Mauá	SP	0.804
11	Osasco	SP	0.802
11	Fortaleza	CE	0.802
11	Embu das Artes	SP	0.802
14	São João de Meriti	RJ	0.801
15	Olinda	PE	0.799
15	Camaragibe	PE	0.799
17	Taboão da Serra	SP	0.798
18	Jandira	SP	0.788
19	Paulista	PE	0.784
20	Paço do Lumiar	MA	0.781

8.6. Supplementary Material F - Ranking of Brazilian municipalities with highest probability of secondary mobilization of solid waste

Brazilian municipalities with highest probability $P2$, considering average local rates of river discharge, Strahler order, distance to the ocean and existence of dams.

Ranking	Municipality	State	***P2***
1	Oiapoque	AP	0.954
2	Santa Bárbara do Pará	PA	0.953
2	Colares	PA	0.953
2	Santo Antônio do Tauá	PA	0.953
5	Ananindeua	PA	0.952
5	Belém	PA	0.952
5	Vigia	PA	0.952
5	Marituba	PA	0.952
5	São Caetano de Odivelas	PA	0.952
5	São João da Ponta	PA	0.952
11	Barcarena	PA	0.951
11	Curuçá	PA	0.951
11	Benevides	PA	0.951
14	Magalhães Barata	PA	0.950
14	Maracanã	PA	0.950
16	Terra Alta	PA	0.949
16	Matinhos	PR	0.949
16	Salinópolis	PA	0.949
16	Pontal do Paraná	PR	0.949
16	Marapanim	PA	0.949
16	Paranaguá	PR	0.949
16	Amapá	AP	0.949
16	Quatipuru	PA	0.949
16	Chaves	PA	0.949

8.7. Supplementary Material G - Territory drained by dam-affected rivers



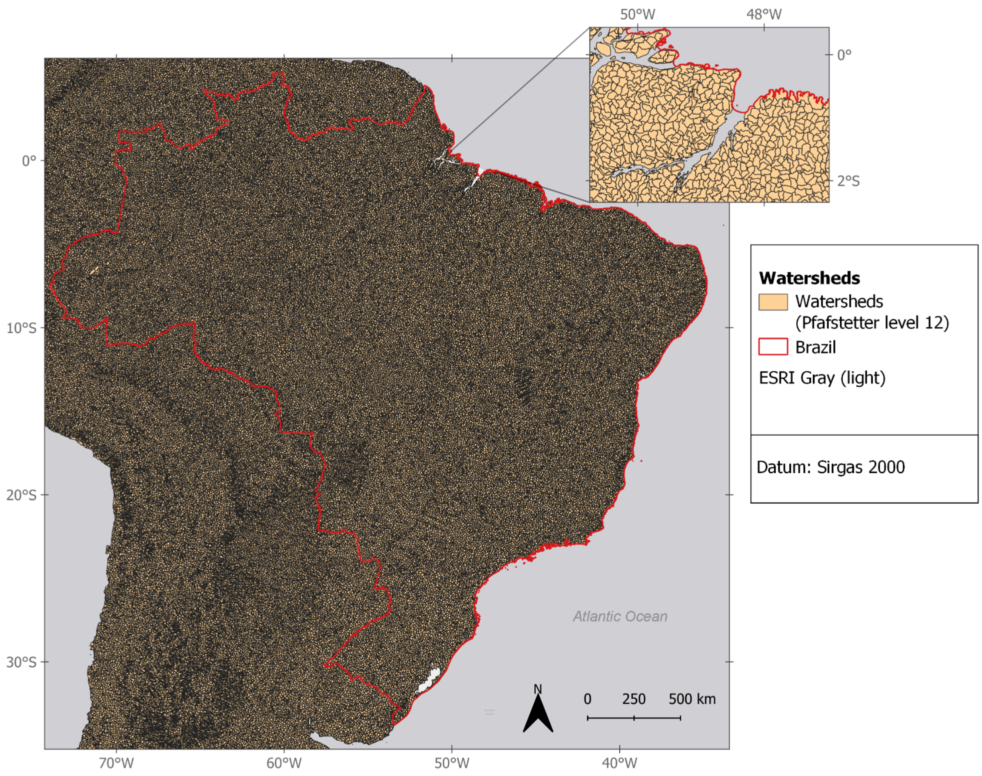
8.8. Supplementary Material H - Risk of litter leakage in Brazilian metropolitan regions

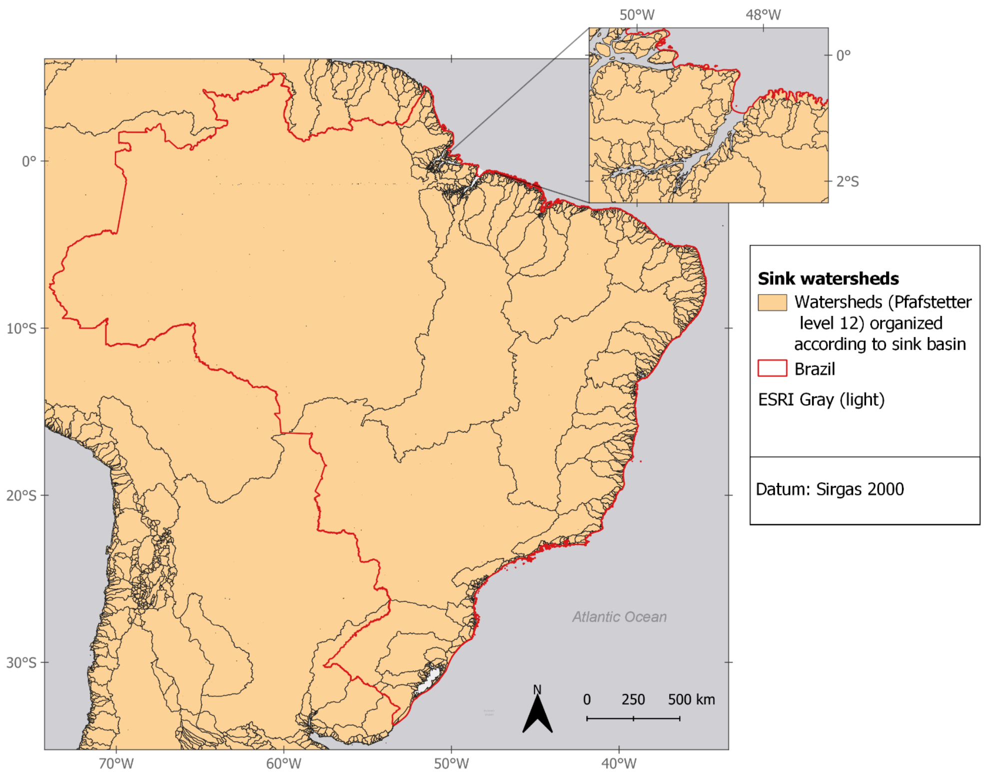
Relative risk of plastic litter leakage to the ocean in the 24 Brazilian metropolitan regions, considering the potential stock of leak-prone plastic waste (LPW) and the probability of litter mobilization (P). RM= Metropolitan Region; RIDE= Integrated Development Region.

Ranking	Metropolitan Region	State	Risk	Per capita Risk
1	RM Rio de Janeiro	RJ	191,222.56	7.86
2	RM São Paulo	SP	94,812.27	3.32
3	RM Salvador	BA	47,957.91	9.78
4	RM Fortaleza	CE	47,870.58	6.87
5	RM Baixada Santista	SP	46,437.85	24.67
6	RM Belo Horizonte	MG	44,365.54	3.76
7	RM Recife	PE	42,908.27	8.68
8	RM Porto Alegre	RS	34,897.89	4.66
9	RM Curitiba	PR	34,474.92	4.26
10	RM Grande Vitória	ES	26,214.78	12.31
11	RM Maceió	AL	26,013.41	8.75
12	RM Belém	PA	23,019.13	7.02
13	RM Vale do Paraíba e Litoral Norte	SP	17,235.85	5.55
14	RM Natal	RN	16,867.69	7.01
15	RM Grande São Luís	MA	15,376.08	7.37
16	RM Manaus	AM	15,281.84	3.29
17	RM Florianópolis	SC	13,949.36	7.06
18	RM Distrito Federal e Entorno	DF	13,456.52	2.13
19	RM Campinas	SP	12,586.30	2.59
20	RM Goiânia	GO	10,639.72	2.39
21	RIDE Grande Teresina	MA	9,522.87	2.94
22	RM Vale do Rio Cuiabá	MS	7,028.18	4.71
23	RM Sorocaba	SP	2,694.91	1.55
24	RIDE Petrolina Juazeiro	PE	1,235.29	1.99

8.9. Supplementary Material I - Watersheds grouped according to sink basins in common

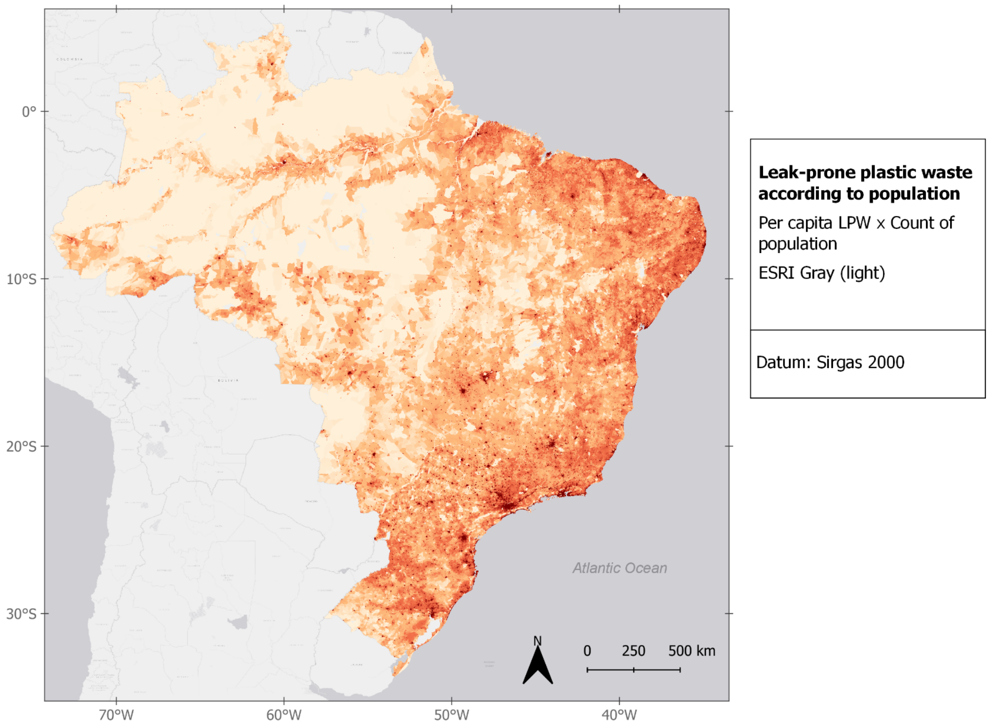
Original watersheds (Pfafstetter level 12) and grouped watersheds (according to sink basins in common)





8.10. Supplementary material J - Spatial distribution of LPW according to population

Potential stock of leak-prone plastic (LPW) waste distributed according to gridded population



8.11. Supplementary material K - Statistical test: Population x GDP x LPW

Population x GDP x LPW:

OLS Regression Results

		R-squared:	0.969
Model:	OLS	Adj. R-squared:	0.967
Method:	Least Squares	F-statistic:	381.2
		Prob (F-statistic):	6.54e-19
		Log-Likelihood:	8.2117
No. Observations:	27	AIC:	-10.42
Df Residuals:	24	BIC:	-6.536
Df Model:	2		
Covariance Type:	nonrobust		

	coef	std err	t	P>|t|	[0.025	0.975]
Intercept	-4.3117	0.567	-7.608	0.000	-5.481	-3.142
np.log(data["pop"])	0.9875	0.041	23.865	0.000	0.902	1.073
np.log(data["GDP"])	0.0321	0.034	0.940	0.357	-0.038	0.103

Omnibus:	0.622	Durbin-Watson:	2.340
Prob(Omnibus):	0.733	Jarque-Bera (JB):	0.407
Skew:	0.290	Prob(JB):	0.816
Kurtosis:	2.842	Cond. No.	295.

Population x LPW:

OLS Regression Results

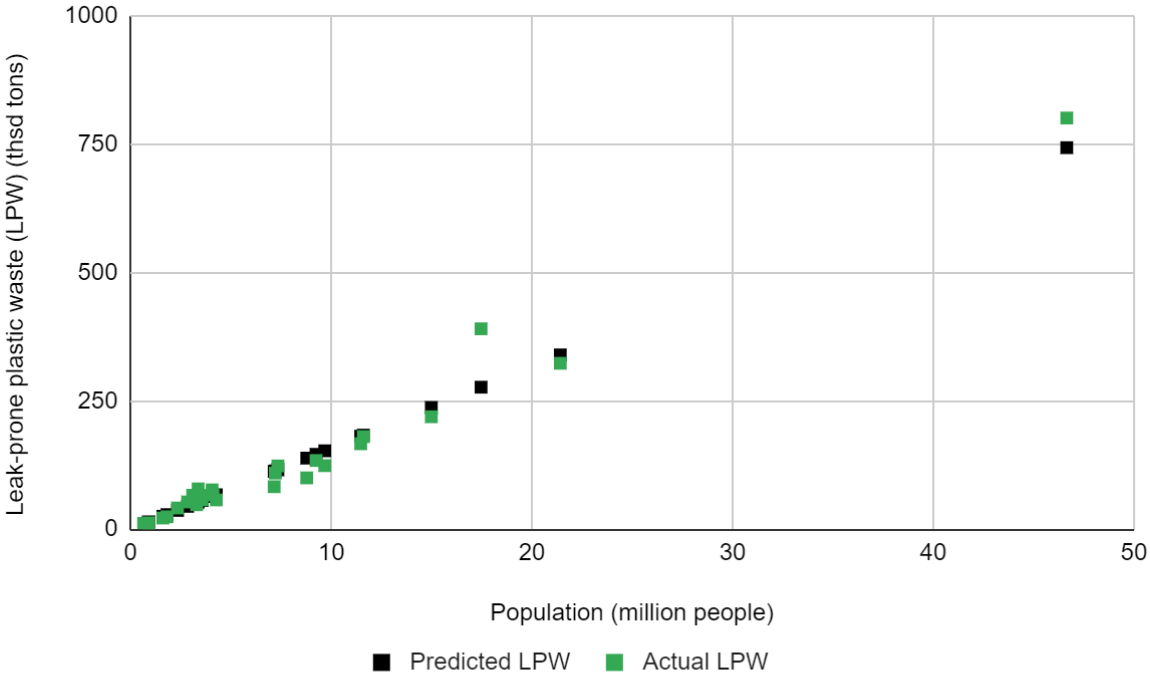
Dep. Variable:	np.log(data["col3"])	R-squared:	0.968
Model:	OLS	Adj. R-squared:	0.967
Method:	Least Squares	F-statistic:	765.0
		Prob (F-statistic):	2.88e-20
		Log-Likelihood:	7.7236
No. Observations:	27	AIC:	-11.45
Df Residuals:	25	BIC:	-8.856
Df Model:	1		
Covariance Type:	nonrobust		

	coef	std err	t	P>|t|	[0.025	0.975]
Intercept	-4.2454	0.561	-7.567	0.000	-5.401	-3.090
np.log(data["pop"])	1.0059	0.036	27.658	0.000	0.931	1.081

Omnibus:	0.979	Durbin-Watson:	2.411
Prob(Omnibus):	0.613	Jarque-Bera (JB):	0.885
Skew:	0.401	Prob(JB):	0.642
Kurtosis:	2.621	Cond. No.	239.

8.12. Supplementary material L - Statistical test: LPW x population

Potential stock of leak-prone plastic waste (LPW) against population. Actual values vs model prediction



8.13. Supplementary material M - Future panorama of leak-prone plastic waste

Potential stock of leak-prone plastic waste (LPW), considering actual rates (2021) and future projections, in thousand tons (tt) a year. Population in million people (mp).

State	2021 Pop. (mp)	2021 LPW (tt)	2025 LPW	2030 LPW	2040 LPW	2050 LPW	2060 LPW
Acre	0.91	12.20	14.87	15.74	17.19	18.15	18.59
Alagoas	3.36	78.52	53.59	54.38	54.84	53.58	50.68
Amazonas	4.27	57.01	70.88	75.27	82.78	88.30	91.54
Amapá	0.88	11.74	14.62	15.74	17.75	19.35	20.47
Bahia	14.99	219.14	240.16	242.50	241.77	233.68	218.76
Ceará	9.24	133.89	148.95	151.95	154.64	153.13	147.51
Distrito Federal	3.09	66.16	50.81	53.38	57.25	59.29	59.50
Espírito Santo	4.11	67.10	67.17	70.03	74.35	76.82	77.49
Goiás	7.21	109.38	119.15	125.19	134.82	141.52	145.04
Maranhão	7.15	82.78	115.03	117.46	120.18	119.69	115.97
Minas Gerais	21.41	323.28	346.41	352.57	356.61	350.43	335.65
Mato Grosso	2.84	53.08	46.26	48.20	51.26	53.22	53.99
Mato Grosso	3.57	65.87	58.43	61.14	65.47	68.37	69.67
Pará	8.78	99.98	143.72	149.55	158.28	162.80	163.02
Paraíba	4.06	76.62	64.96	66.10	67.05	66.21	63.58
Pernambuco	9.68	123.82	156.18	159.69	163.54	162.67	157.05
Piauí	3.29	47.65	51.98	52.23	51.63	49.56	46.21
Paraná	11.60	180.44	188.01	192.78	198.33	198.95	195.15
Rio de Janeiro	17.46	390.48	282.15	287.21	291.48	288.61	279.64
Rio Grande do Norte	3.56	57.09	57.46	59.09	61.11	61.38	59.91
Rondônia	1.82	24.14	29.48	30.65	32.31	33.14	33.17
Roraima	0.65	11.06	10.98	11.79	13.22	14.43	15.33
Rio Grande do Sul	11.47	166.50	183.58	185.48	185.36	180.74	172.93
Santa Catarina	7.34	123.22	120.79	126.31	134.66	139.93	142.27
Sergipe	2.34	41.26	37.76	38.99	40.63	41.20	40.70
São Paulo	46.65	801.25	764.61	786.24	813.47	819.78	806.80
Tocantins	1.61	21.71	26.13	27.27	29.01	30.03	30.27
Total (Brazil)	213.32	3,445.38	3,523.42	3,617.93	3,732.07	3,748.48	3,673.25