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# Marine litter on Atlantic Ocean sandy beaches: Current state of knowledge by scientometric analysis and proposal for discussion of amelioration by coastal management

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## ABSTRACT

This study aimed to conduct a comprehensive review of marine litter of Atlantic sandy beaches. We performed a bibliometric analysis from 1970 to 2023 to identify patterns, flaws, and knowledge gaps. A total of 185 studies were found but only 126 were included in the analysis according to exclusion criteria adopted. The earliest studies on Atlantic beaches were registered in the 1980s, being Marine Pollution Bulletin the major journal. Among the countries bordering the Atlantic Ocean, the highest number of studies were carried out in Brazil, Portugal, Mexico, and Spain. A significant finding that emerged from our study was the lack of standardized methodology adopted for studying anthropogenic litter on sandy beaches. This lack of standardization makes it difficult to compare results across different years and areas, highlighting the need for the development of new techniques and means to standardize future studies. Our study also discussed strategies for minimizing the presence of litter on beaches via coastal management and climate changes. It emphasized the importance of review studies in identifying gaps and guiding integrated and shared actions across the Atlantic region. Overall, this comprehensive review provides valuable insights into the status of anthropogenic litter in beaches of the Atlantic and highlights the need for standardization and collaborative efforts to address this persistent problem. By integrating scientific research with effective coastal management strategies, we can strive towards reducing anthropogenic litter and preserving the health and beauty of the Atlantic sandy beaches and worldwide.

**Keywords:** Beach litter monitoring, Coastal zone, Environmental management, Plastic pollution

## INTRODUCTION

Sandy beaches are one of the most common types of coastal environments worldwide and are characterized by the presence of sandy grains (Defeo and McLachlan, 2005). The formation of sandy beaches is influenced by several factors such as waves, tides, and sediment sources, among others (Park et al., 2021). Sandy beaches provide important ecological functions and are habitats for numerous species of organisms. They play a significant role in coastal protection, acting as natural barriers against coastal erosion

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and land flooding by storm tide events (Defeo and McLachlan, 2005). Additionally, sandy beaches are important recreational and tourism destinations, attracting millions of visitors (Defeo and McLachlan, 2005; Barboza et al., 2016).

Human population growth, the real estate market, urban and industrial pollution, and marine litter are some of the factors that threaten the integrity of sandy beaches around the world. To preserve sandy beaches, it is crucial to implement sustainable coastal management practices, promote environmental conservation, and educate the public about the importance of preserving these valuable ecosystems (Andrades et al., 2020; Fanini et al., 2020).

Regarding litter, approximately 2.5 billion tons are generated annually across the planet (Williams and Rangel-Buitrago, 2019), and a large part of them have sandy beaches as its final destination (Rangel-Buitrago et al., 2020). The presence of marine litter on both beaches, sands, and seawater is considered one of the indicators of the Anthropocene in the stratigraphic register (Zalasiewicz et al., 2016; Rangel-Buitrago et al., 2019).

Beaches can receive litter from different sources and transport agents like rivers, sewages, winds, and improper disposal, and also from economic activities such as fishing, the oil industry, and aquaculture (Munari et al., 2015; Araújo et al., 2018; Rangel-Buitrago et al., 2020; Póvoa et al., 2022a). The local dynamics play important roles in the permanency of litter on the beaches such as the transport via tides and winds (Ryan et al., 2009; Prevenious et al., 2018). Beaches that are more influenced by currents and winds have a greater potential for the accumulation of marine litter, such as exposed beaches when compared to sheltered ones, influenced mainly by the action of cold fronts, currents, storms, waves, and winds and energy dynamics (Park et al., 2021; Póvoa et al., 2022a).

Marine litter is defined as all synthetic or processed material, discarded or abandoned on beaches that can be classified based on their type: plastic, anthropogenic wood, glass, and fabrics, among others (Cheshire et al., 2009). Approximately 8 million tons of litter reach the ocean basins and are subsequently deposited on sandy beaches (Williams and Rangel-Buitrago, 2019). Plastic is one of the most common types of anthropogenic litter, being a long-living and hardly decomposing material. It can persist in the environment for decades or even centuries, causing long-term harm to sandy beaches (Andrades et al., 2018; GESAMP, 2020). Plastic bags and food packaging, indeed among the most common items found on sandy beaches, constitute approximately 80% of the litter (Topçu et al., 2013; Thiel et al., 2013). The plastic on sandy beaches is fragmented by wind, solar radiation, and microbial action, and can be found in different shapes and sizes, including microplastics (Andrady, 2015; Waring et al, 2018; Castro et al., 2020).

The impacts of marine anthropogenic litter on human health, social, economic, and environmental aspects are relevant issues. They range from physical injuries to the transmission of diseases, and from decreased tourism to increased costs for beach cleaning and restoration efforts. It is essential to reduce and properly manage litter to mitigate these consequences and protect both human and environmental health (Erkes-Medrano et al., 2015; Rangel-Buitrago et al., 2020; GESAMP, 2020).

Climate change and marine litter are intricately linked, particularly evident along coastlines where their impacts converge. Rising temperatures and extreme weather events driven by climate change intensify storminess and runoff, consequently increasing the influx of litter into marine environments. Moreover, marine litter, predominantly plastics, exacerbates the vulnerability of coastal ecosystems to climate change by undermining their resilience (Lincoln et al., 2022).

Studies on Atlantic Ocean beaches report the presence of marine litter in terms of abundance and geographic distribution, litter accumulation, and correlation between precipitation and abundance; however, to the best of our knowledge, there is no comprehensive review focusing on their entire coastline (Videla and Araújo, 2021; Lima et al., 2022; Anastacio et al., 2023). To fill this gap, we compiled data from studies conducted with marine anthropogenic litter on Atlantic beaches since the 1970s. In this context, one of the techniques used by review studies is the bibliometric network analysis, which is considered a useful tool to assess trends and patterns in the scientific literature, aiming to identify trends and gaps in several relevant topics (Sorensen and Jovanović, 2021).

Bibliometric network analysis is a quantitative method that involves analyzing the relationships between scientific publications in terms of their citations and co-citations. This technique allows researchers to map the knowledge domain of a specific topic by identifying key papers, influential authors, and research clusters (Serenko et al., 2010; Sorensen and Jovanović, 2021). In the context of review studies, bibliometric network analysis can provide valuable insights into the current state of a research field. This information can aid researchers understand the evolution of the topic over time and identify gaps or areas that have received less attention (Serenko et al., 2010). Additionally, bibliometric network analysis can reveal patterns and trends in the literature, allowing them to gain a comprehensive overview of the existing literature, identify key papers and authors, and uncover trends and gaps in the research field (Serenko et al., 2010; Sorensen and Jovanović, 2021). Therefore, bibliometric network analysis is considered a useful tool to assess trends and patterns in the scientific literature to identify trends and gaps in various relevant topics (Sorensen and Jovanović, 2021).

In this sense, this study conducted a survey of the current state of knowledge of studies on Atlantic sandy beach marine litter using scientometrics to identify possible gaps, as well as to propose solutions for reducing litter presence on beaches via coastal management strategies.

# METHODS

## Processing of the bibliographic review

The bibliographic searching was conducted in the Scopus and Pubmed databases, covering 53 years, from 1970 to 2022. The studies were selected in the 1970s, as it was when the first were published, aiming to observe the evolution of these in relation to the theme over time. Studies on marine litter have contributed to understanding its complexity and developing solutions to combat it since the 1970s, particularly due to the rise of plastics as a serious issue, prompting research into mitigation strategies. The search was performed using the following keywords in combination: “TITLE-ABS-KEY ( ( ( sandy beach* ) AND ( “anthropogenic litter” OR “marine litter” OR “marine debris” OR “beach litter” OR “litter” OR “plastic” ) AND ( “Atlantic” ) ) )”. We used the bibliometrix package in the R interface to analyze the gathered literature (Linnenluecke et al., 2020). The bibliometrix package is an open-source tool developed in R that facilitates bibliometric analysis of scientific data, offering a wide range of resources to examine scientific output and provide insights into trends and relationships across various research fields (Linnenluecke et al., 2020). This package provides tools for bibliometric analysis, allowing for the evaluation and visualization of scientific publications (Linnenluecke, et al., 2020).

Out of a total of 185 studies retrieved, 126 articles (52 and 77 retrieved from Scopus and Pubmed, respectively) were included in the analysis. The other 59 studies were excluded in this review because they corresponded a conference abstracts, theses and dissertations, monographs. This study considered surveys conducted only on sandy beaches. Studies carried out in the pelagic or other ecosystems were also discarded.

This study aimed to address several research questions related to marine litter on Atlantic Ocean beaches. Questions include the period during which studies have been conducted, the main journals that have published such studies, the leading researchers in this field of knowledge, the most studied regions along the Atlantic coast, the types of marine anthropogenic litter commonly found on these beaches, and if there is a standardized methodology adopted in such studies. Moreover, the study draws inspiration from a previous review study conducted by Póvoa et al. (2021) on the topic of *rafting* in marine litter worldwide. In addition to exploring these research questions, this study also delves into the impacts of litter on beaches in the context of coastal management and climate change.

Based on the findings from the scientometric analysis, a solution or recommendations for coastal management was proposed, aiming to identify activities and measures that can effectively minimize the presence of marine litter on Atlantic

Ocean beaches. This may include strategies such as public awareness campaigns, improved waste management systems, beach clean-up initiatives, and regulations to prevent littering. The proposed solution was based on scientific evidence and best practices identified via scientometric analysis. It aimed to contribute to the sustainable management of coastal areas and the reduction of anthropogenic litter, ultimately leading to cleaner and healthier Atlantic beaches.

### Processing of metrics used

Lotka's Law, proposed by Alfred Lotka in 1926, was used in this study to analyze the scientific production of authors. It aims to determine how each author contributes to the advancement of research. The law states that the proportion of authors with a certain number of articles, "x," is a fraction of those who have written only one article, and this fraction follows a power-law distribution of (1/x^a), in which "a" is a constant usually equal to 2. This law aids measure the impact of citations and identify prolific authors in a specific field (Lotka, 1926).

We also used the h-index proposed by Hirsch (2005). Its purpose is to measure the impact of the main journals in the study area. The number of publications, "h," that have received at least "h" citations, determines the h-index. For example, if a journal has five publications and each received at least five citations, its h-index would be five (Hirsch, 2005).

The above-mentioned metrics aid quantifying the scientific impact and contribution of authors and journals, respectively, in the study area. Lotka's Law provides insights into the productivity and impact of individual authors, whereas the h-index focuses on the impact of journals based on their citation counts.

## RESULTS AND DISCUSSION

The 126 studies analyzed included four review articles (Ivar do Sul and Costa, 2007; Monteiro et al., 2018; Andrades et al., 2020; Videla and Araújo, 2021). Among these four reviews, one is on the presence of marine litter in the Caribbean and Latin America (Ivar do Sul and Costa, 2007). Monteiro et al. (2018) evaluated the presence of plastic on Atlantic Ocean beaches, whereas Andrades et al. (2020) and Videla and Araújo (2021) evaluated published studies and made recommendations regarding litter pollution in the coastal area of Brazil. These four reviews contribute to the understanding of marine litter pollution in coastal areas, providing insights into the sources, distribution, and impact of marine litter, particularly plastic, in the Caribbean, Latin America, and Brazil.

The main keywords reported in the literature were environmental monitoring, bathing beaches, plastic, waste products/analysis, and Atlantic Ocean (Figure 1). In this study, although Atlantic was the focal keyword, we found studies from the Baltic Sea. This suggests that the literature on marine litter could include studies from various geographical regions, including closed or semi-closed seas near the Atlantic Ocean.


**Figure 1.** Map of the keywords retrieved from the bibliometric analysis.

The query << “beach debris” >> points out that scientific interest in this topic is relatively recent. This study considered several studies, especially in the past, which may not have clearly used “beach litter” and/or “marine litter,” as also demonstrated by Cesarano et al. (2021) in a review of the presence of marine litter on beaches around the world.

The results below are organized into different sections that cover the timeline of the research on Atlantic beaches. This includes the temporal period, main journals, main researchers, countries, main types of litter studies, main methodologies, and a discussion focused on coastal management in the scenario of climate change as suggestions for improvement in coastal management.

## Temporal period of studies with marine litter on beaches.

The first studies dated back to the 1980s, the first being in 1982 and the last in 2022. The increase in production and consumption of different types of artificial materials since the 1970s has generated enormous amounts of litter used by human populations, mainly plastic. From 2010, there has been a notable increase in the number of articles published on the subject (Figure 2).

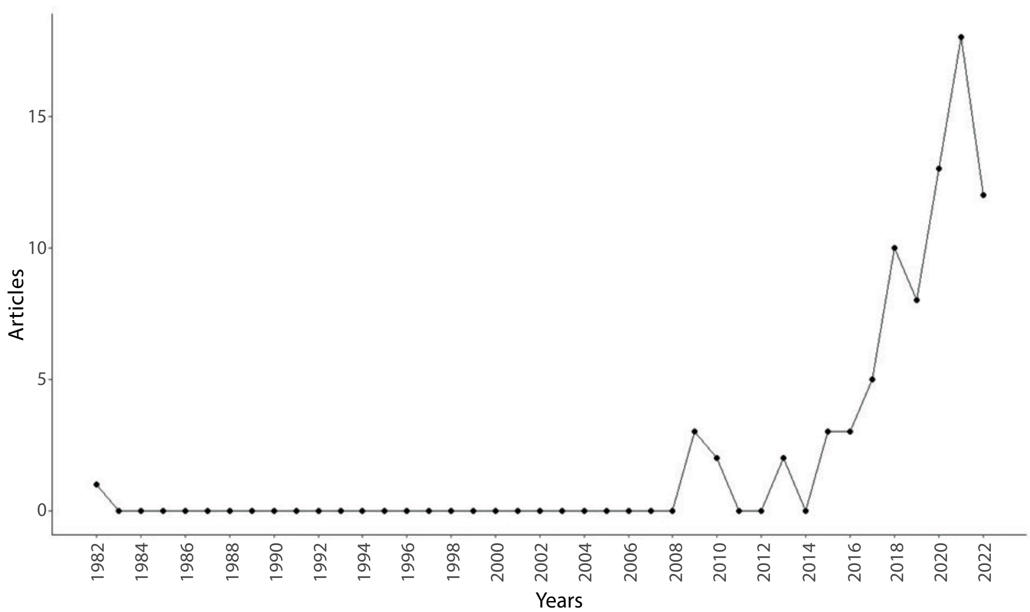


**Figure 2.** Bibliographic production on marine litter sand beaches by year.

According to Ivar do Sul and Costa (2007), beaches are one of the places that present the largest number of studies with marine litter since it is an ecosystem that is part of everyday life. Educational campaigns and cleaning activities are commonly carried out on beaches. Moreover, the simplicity of sampling design for several studies, as well as the greater accessibility, makes beaches suitable places for marine litter surveys.

A remarkable increase in marine litter studies on beaches was observed from 2010 to 2023, representing 90.4% of the total. There is a clear increase in studies since 2010 that continue to advance until present times, as pollution by marine litter affects beaches all over the world (Videla and Araújo, 2021; Póvoa et al., 2021; Cesarano et al., 2021). The increase in the number of studies that continues in this decade (2021 – 2030) might also be result of an entire decade focused on efforts to raise awareness of the population regarding the ocean (Gacutan et al., 2022). Overall, the increase in studies from 2010 to 2030 reflects a growing recognition of the detrimental impacts of marine litter on coastal ecosystems and a concerted effort to better understand and address this issue. It highlights the global commitment to protect the ocean and the urgent need to mitigate litter pollution to ensure the health and sustainability of coastal environments (Gacutan et al., 2022).

Recent studies still demonstrate the greater presence of marine litter, but this depends on the location and its characteristics, as well as seasonality. In some countries, depending on the topography, rocky shores show the highest debris density, followed by sandy beaches (Iñiguez et al., 2016).

## Main journals

The main journals were found linked to the areas of "Environmental Structure Science disciplines," "Earth and Planetary Sciences," and "Agrarian and Biological Sciences," the same areas found by Cesarano et al. (2021). The Marine Pollution Bulletin published 49 studies (59.8%), followed by Science of the Total Environment, with 9 studies (11%), 7 studies in Marine Environmental Research and 6 in Environmental Pollution (8.5% and 7.3% respectively), while remainder journals published less than 6 articles.

The study of Videla and Araújo (2021) observed the number of studies in the Brazilian Atlantic from 2010 to 2020. They found that the Marine Pollution Bulletin and the Journal of Integrated Coastal Zone Management published most studies, corroborating the present study. It should be noted that the Journal of Integrated Coastal Zone Management was not cited in the bibliometric analysis but when searched separately, it was found to be one of the journals with the highest number of studies. However, there was a notable difference in the number of studies published in the Marine Pollution Bulletin compared to the other journals. This suggests that the Marine Pollution Bulletin is the leading journal specialized on the subject, as it presented a higher number of studies conducted both in Brazil and in the entire Atlantic Ocean context. This discrepancy in the number of studies among journals implies that researchers and scholars in the field of marine pollution and coastal zone management prefer to publish their findings in the Marine Pollution Bulletin. This could be due to the journal's reputation, impact factor, or specialization in the subject matter. The journal is specialized in documenting marine pollution and introducing new ways of measuring and analyzing different types of pollution. Moreover, this journal conducted a special issue on litter pollution on beaches and in the marine environment around the world that could improve the number of publications. This journal mainly reflects the importance attributed by European and Asian countries to the collection of litter on their beaches, especially in the Atlantic and North Pacific, the world region of greatest production and disposal of waste (Cesarano et al., 2021). The journal predominantly features research conducted by experts in the fields of oceanography, geomorphology, and marine biology. These professionals contribute their expertise to understanding the ecological implications of marine pollution and proposing strategies for its mitigation (Pauna et al., 2019; Sorensen and Jovanović, 2021).

## Main researchers

The more prolific authors are Andriolo (7 studies) and Golçalves (7 studies), followed by Bessa (5 studies), Garcia-Vazquez (5 studies), and Sobral (5 studies). Of these, E. Garcia-Vazquez is the one that have been publishing for a longer period, with the first study published in 2018, but all continue to study the subject until the present moment. Regarding Lotka's Law, behavior similar to the law was found at the end of the scientific production of waste on beaches, with two authors producing seven studies (proportion of 0.008) and 134 authors producing only one (proportion of 0.556). This proportion of 0.556 is different from the normal behavior of the law, and this result is probably because the subject is not published by other than specialists in the subject. In the image below, the dotted line represents the theoretical behavior of Lotka's Law, whereas the complete line represents the analyzed works (Figure 4).

The author F. Raynon-Viña presents an h-index of 5, whereas U. Andriolo, E. Garcia-Vazquez, G. Gonçalves, and P.G. Ryan have an h-index of 4. Considering the low values in relation to the h-index and the low total of local citations (17 is the maximum number of local citations), it is possible to conclude that this is an area of study that is not yet cited among itself or that it is still very incipient.

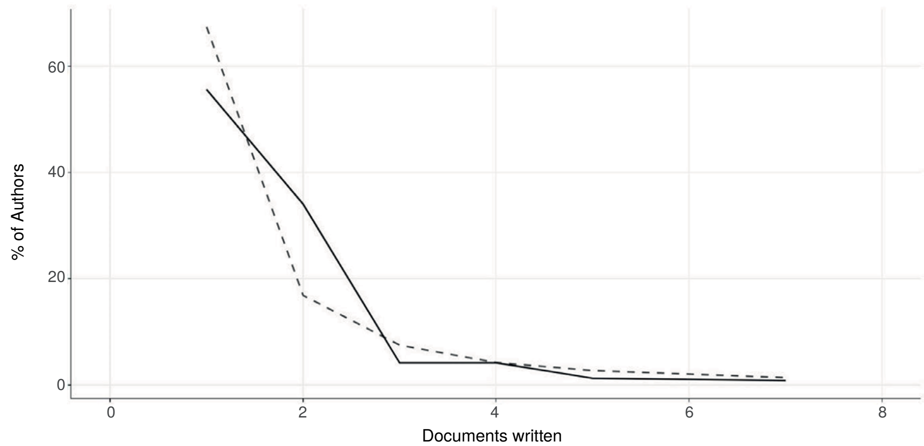


**Figure 3.** Influence of frequency of distribution of scientific production. The dotted line represents the theoretical behavior of Lotka's Law, while the full line represents the analyzed works.

The use of metrics such as Lotka's Law and the h-index has the advantage of valuing influential studies, rather than those who publish a lot but their works are soon forgotten and those who publish few highly cited articles (Kelly and Jennions, 2006). The number of citations of a study is used as a proxy for its importance, being considered as a measure of the impact on science (Bornmann and Marx, 2014). The citation is used as a way of evaluating the areas that need development (Bornmann and Marx, 2014).

About the method used for finding papers, we noticed that not all the articles were indexed by Scopus, thus they had to be added manually, meaning that the use of a single database is not enough to contemplate all articles on the subject. Burnham (2006) compared two databases, Scopus and Web of Science (WOS), and concluded that they complement each other; He also suggested that, although WOS presented a greater range of years (since 1945 versus 1960), the use of one or other is interchangeable—some queries had more results on WOS, whereas others on Scopus.

## Countries

Brazil, Portugal, Norway, and Argentina are the countries with the highest number of studies on marine litter on Atlantic sandy beaches. The country with the highest number of corresponding authors is Brazil, with 46 publications representing 56.1% of the studies, followed by Portugal with 31 studies (37.8%), and Norway with 12 studies (14.6%) (Figure 5). Interestingly, only four studies were found in the Atlantic of the United States (US) but there are more studies on marine litter conducted in the Pacific Coast of the US (Figure 4).

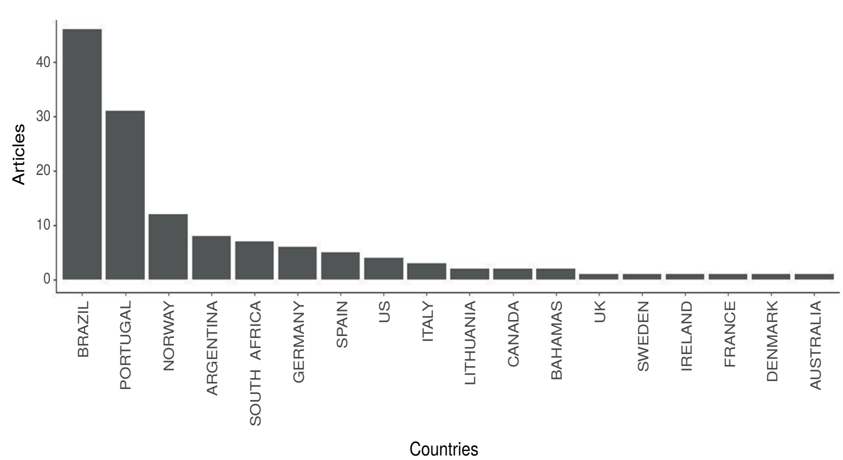


**Figure 4.** Main countries publishing on beach marine litter in the Atlantic Ocean.

The University of Oviedo, in Spain, showed the highest productivity, with 22 studies with authors from Oviedo, followed by the Federal University of Paraná with 16 studies. Publications by the University of Oviedo began in 2018, with 7 publications, indicating the possible emergence of a study group on the subject in that year. The US authors were pioneers on the subject in the Atlantic, publishing the first study in 1982, although it remained until 2010 without publishing additional papers. According to Cesarano et al., (2021), in relation to worldwide distribution, Spain and Brazil are the countries with most studies on marine litter; however, the US and Spain studies carried out in the Pacific and the Mediterranean were not considered, as they are countries also bathed by these basins in addition to the Atlantic.

The discrepancy in the number of studies found in the present study compared to Cesarano et al. (2021) is due to several factors. This study focuses on macrolitter on sandy beaches (plastics, anthropogenic wood, glass, fabrics, among others), excluding studies on microplastics, stomach content analysis, and natural woody debris.

Cesarano et al. (2021) found 443 studies on the topic in Atlantic beaches of the US. In the Scopus database, we found 336 studies, of which 107 were corresponded a conference abstracts, theses and dissertations, monographs. These studies were reviewed one by one to determine if they fit the theme and in which coast they were conducted. Conference abstracts, theses and dissertations, monograph was excluded from this study since it is not peer reviewed and is not always as reliable as journal-published articles, although some authors advocate for its analysis (Conn et al., 2003). However is also more difficult to retrieve (Mahood et al., 2013), so it was excluded to ensure that the documents included in this work were peer reviewed, ensuring that most studies had a certain degree of quality and research standardization.

Moreover, it was found that a scientific database provides the number of studies by country used in the article. This information was obtained before detailed inspection to exclude articles outside the theme, as indicated in the article. Of the 336 articles, 262 (77.98%) were outside the theme, 33 (9.82%) were conducted in beaches on the West Coast of the US, 21 (6.25%) were about microplastics (from both the West and East Coasts), 11 (3.27%) were on the theme but along the East Coast, and 8 (2.38%) were already in our results.

Interestingly, some articles on the theme classified by Scopus as from the US were not actually conducted in the US (Santos et al., 2009, Pieper et al., 2019; Rangel-Buitrago et al., 2019;). This happens because Scopus assigns the country based on the authors' addresses, meaning that if an article has at least one author from the US, it is credited as American scientific production. However, we ensured that the studies included in the analysis were conducted in our study area by reviewing them one by one.

The discrepancies in the number of studies indicated by Cesarano et al. (2021) can also be attributed to the use of different keywords in the query. For example, Cesarano et al. (2021) used "waste" as a synonym for litter. Our query found 229 articles on Scopus, in which 24 were classified as American production but only four were actually from the Atlantic coast of the US (16.67%). Cesarano et al. (2020) found 447 productions out of a total of 1,765, with 73 fitting the topic (16.33%). In other words, although the efficiency of both queries is the same, our set of results is easier to analyze. If we excluded "Atlantic" from the query, we would have fewer articles (1,340) to refine but probably the same results. Moreover, most off-topic results in Cesarano et al. (2020) were influenced by the keyword "waste" (Walsh & Waliczek, 2020; Resendiz et al., 2019; Adell et al., 2016), which refers to litter but also other types of pollutants in the literature.

The high number of studies conducted in Spain and Brazil is probably related to the great population density of these countries, although Brazil's population (216.4 million citizens) is about fourfold that of Spain (48.8 million citizens). This result could reflect a high number of studies such as prestigious academic institutions, diverse ecosystems, and interest by researchers from all over the world, in addition to being countries frequented by tourists (Videla and Araújo, 2021; Herrera et al., 2023). As popular tourist destinations, these countries attract a significant number of visitors, especially during the summer season when beach activities are prevalent. This influx of tourists, coupled with intense port activity, has contributed to the deposition of waste in their coastal areas (Videla and Araújo, 2021; Herrera et al., 2023).

The situation regarding marine litter on Atlantic beaches in the US is concerning due to the lack of studies conducted on this issue. With a population of 331.9 million people, the high population density contributes to the improper disposal of waste by beachgoers and inadequate waste management practices. This problem is not unique to the US, as Brazil also faces similar challenges (personal observation). In Brazil, over 79 million tons of solid waste are produced annually, with 6.3 million tons not being properly collected (ABRELIPE, 2019). As a result, a significant portion of this litter ends up in the ocean, further exacerbating the problem (Videla and Araújo, 2021). This highlights the need for increased research and effective waste management strategies to protect the Atlantic beaches in both countries.

Portugal has implemented various technological solutions for marine litter monitoring on its beaches. For instance, studies conducted by Andriolo et al. (2021); Gonçalves et al. (2020a, 2020b) have highlighted the use of drones, remote sensing imaging equipment, and satellites to streamline the monitoring process. These technologies help minimize the sampling effort and enable monitoring of different beach areas. They also provide insights into the volume of the litter deposited and help researchers identify its presence on sandy beaches. This early detection allows relevant authorities to take timely actions for waste management (Gonçalves et al., 2020 a, b; Andriolo et al., 2021;). Portugal's significant tourist industry adds further complexity to the waste management challenges faced by these beaches. Portugal has leveraged technological advancements in waste monitoring to tackle the challenges associated with waste management on its beaches. By utilizing drones, remote sensing imaging equipment, and satellites, the country has been able to reduce sampling efforts and monitor various beach sites, as well as track the volume of litter deposited. These efforts are particularly important given the high number of tourists visiting popular coastal destinations in Portugal (Gonçalves et al., 2020a, 2020b, Andriolo et al., 2021;).

The lack of research on marine litter on the African Atlantic is concerning, as it hinders our understanding of the extent and impact of pollution in that continent (Tavares et al., 2020; Abelouah et al., 2021). The issue of marine litter on African beaches is particularly alarming, considering the significant pollution levels observed. The lack of large research centers and the less developed status of the countries in Africa contribute to the limited studies. Marine litter pollution is a pressing environmental problem globally, and Africa is no exception. The Atlantic coast of Africa faces numerous challenges, including the accumulation of plastic bottles, bags, and other debris on its beaches (Ryan, 2009; Ryan et al., 2021). This marine litter comes from various sources, including local communities, shipping and fishing industries, and even ocean currents that carry debris from distant locations (Tavares et al., 2020; Abelouah et al., 2021).

## Main types of marine litter

Several studies have reported the presence of marine litter on Atlantic beaches (Rangel-Buitrago et al., 2019 Andriolo et al., 2021; Póvoa et al., 2022a). The various types of litter deposited on sandy beaches can reach the marine environment through river currents, daily tidal fluctuations, accidental discharges into the open seas, or accidents involving drilling platforms, fishing, and maritime activities such as commercial, sports, and recreational navigation (Hidalgo-Ruz and Thiel, 2015; Munari et al., 2016; Hidalgo-Ruz et al., 2018).

The main type found on the Atlantic beaches is plastic (Table S1), as all studies reported that plastic is the main type of litter found (Rangel-Buitrago et al., 2018; Andriolo et al., 2021; Póvoa et al., 2021; Póvoa et al., 2022a). Brazil and the European Union, both located facing the Atlantic, are among the top 20 countries that mismanage different plastic litter, according to a study by Jambeck et al. (2015). The spread of plastic waste has been driven by the growth in the production and use of plastic, supported by linear economic models that have not prioritized integrated waste management (Geyer et al., 2017; Lebreton et al., 2019). Plastic is widely used in modern everyday life due to its durability, resistance, malleability, and low cost (Chesire et al., 2009; Gregory, 2009; Castro et al., 2020). However, this widespread use has led to plastic becoming the predominant type of litter found on beaches around the world. Over time, plastic litter can degrade and become microplastics, which are plastics smaller than 5 millimeters (Castro et al., 2020; da Silva et al., 2022). This type of plastic contaminant is persistent in the marine environment and readily bioavailable for a wider range of organisms along the food chain (De-la-Torre et al., 2023).

The main items collected during clean-up campaigns on Atlantic beaches include cigarette butts, plastic, glass, and paper, all of which reflect behavioral aspects of society (Póvoa et al., 2021). Cigarette filters are the second most common item found on sandy beaches around the world, including Atlantic beaches, which are most likely incorrectly disposed of by beachgoers (Araújo and Costa, 2019; Araújo et al., 2022). These butts are inaccessible to conventional cleaning services due to their small size, low weight, and color, which causes them to mix in the lower layers of beach sand and make it difficult to collect (Silva et al., 2018).

Other litter types such as wood, glass, and paper are also found on Atlantic beaches and are reported in several studies (Mantelatto et al., 2020; Póvoa et al., 2022a). The presence of these items is related to tidal deposition (Póvoa et al., 2022 a), as well as consumption by beachgoers (Póvoa et al., 2022 b). The consumption habits of individuals visiting the beach can lead to the generation of such litter. For example, people may bring drinks in glass bottles, food wrapped in paper, or wooden utensils for picnics or barbecues. The study by Perez et al. (2018), carried out on Camboinhas beach, in the municipality of Niterói, for example, found a greater quantity of napkins in kiosk areas. Improper disposal or accidental loss of these items can result in their presence on the beach (Dias Filho et al., 2011; Timbó et al., 2019; Póvoa et al., 2022b).

## Methodologies used with marine litter on Atlantic beaches and proposals reported in the literature for standardization

The topic will be organized into three subtopics, which are data collection methodologies and the need for standardization, the diversity of types of marine litter and their influences, and the incorporation of new technologies and investment challenges.

### Data collection methodologies and the need for standardization

The studies were carried out with various methodologies. A total of 56 studies focused on monitoring marine litter (53.3%), 22 studies used a quali-quantitative analysis (21.0%), 14 focused on the environmental perception (13.3%), eight aimed at studying *rafting* on marine litter (7.6%), and four encompassed tourism (3.8%) (Figure 5).

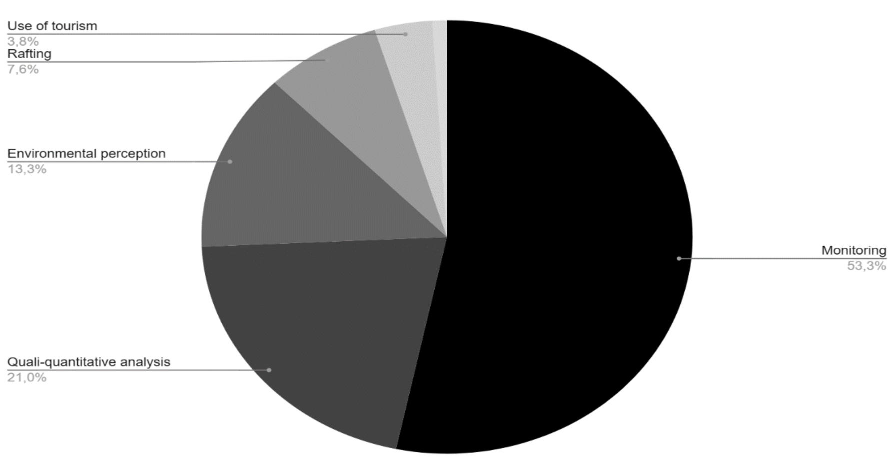


**Figure 5.** Main subjects studied marine litter on Atlantic beaches.

Upon reviewing the selected studies, the lack of standardization for data collection became evident for data collection across studies. Most marine litter is collected along the entire length of the beach or just in specific areas, but it is separated, while some weigh and others do not (Rech et al., 2018). Most studies are carried out with manual collection coupled with random selection on beach sands, and few of them present delimitation of areas or transects, without considering the type of tide and sampling time, limiting themselves only to actions and occasional cleaning. Beach cleaning events are not effective strategies as they do not involve transect sampling (Weslawski and Kotwicki, 2018; Póvoa et al., 2021). Due to these factors, we suggest that future studies standardize methodologies regarding data collection time, sampling hours, post-storm and surf-cleaning actions, and manual data collection. However, Fleet et al. (2021) recommend that marine litter categorization should be photographed and digitally documented using a code provided by the authors.

Future studies should consider the standardization of different methodological approaches, such as collections along sandy beaches at the highest daily tide line for the concentration of marine litter by replicas and triplicates, primarily considering the ends of the beaches since these are the places that most receive litter by tidal action (Póvoa et al., 2021, 2022a). However, the middle of the beach receives litter from the tides, as well as from the regulars themselves (Póvoa et al., 2022b). Moreover, digital approaches are needed to facilitate data collection in the local (De-la-Torre et al., 2023). The COVID-19 pandemic has introduced new types of marine litter, such as personal protective equipment (PPE), including gloves and facemasks, to beaches (Costa et al., 2023). These items need to be properly identified and included in a standardized glossary to ensure consistent reporting and classification (Fleet et al., 2021; De-la-Torre et al., 2023).

## Methodological variation regarding types of marine litter

Studies examining marine litter on beaches employ various classifications, often dependent on the diversity of types encountered. This variability can be attributed to differences in sampling design, contamination sources, and sampling efforts (Rees and Pond, 1995; Velander and Mocogni, 1999). The lack of consistency in methodologies poses a challenge when attempting direct comparisons between studies conducted in the Atlantic and those in other oceans globally.

Notably, researchers like Ivar do Sul and Costa (2007), as well as Videla and Araújo (2021), have contributed to the body of knowledge in this field. However, the divergent objectives and methods employed in these studies further contribute to the absence of standardized methodologies. This lack of uniformity underscores the importance of establishing consistent approaches for better comparability and a more comprehensive understanding of marine litter across diverse regions (Table S1).

## Incorporation of new technologies and investment challenges

Recent research has revealed the adoption of advanced technologies like drones and remote sensing images for monitoring marine litter on sandy beaches. This insight is drawn from a study conducted on beaches in Portugal (Gonçaves et al., 2020a; Gonçalves et al., 2020b; Andriolo et al., 2021). Drones are predominantly employed in beach areas, focusing on plastic waste, whereas remote sensing captures images targeting the presence of accumulated waste in specific beach locations (Salgado-Hermanz et al., 2021).

However, it is worth noting that less developed countries, including Brazil, Uruguay, Argentina, the Caribbean, and African nations, face obstacles due to limited financial resources, technology, and a shortage of specialized personnel. This situation emphasizes the need for increased efforts from both local governments and research agencies, as observed personally. Addressing these challenges is crucial to ensure that these technological solutions can be effectively implemented more widely, thereby enhancing beach monitoring and cleanup initiatives globally (personal observation).

## Discussion of marine litter in relation to coastal management with a focus on climate change

The lack of waste management on Atlantic beaches is a significant problem that requires the involvement of various stakeholders (Ivar do Sul and Costa, 2007). These stakeholders include legislators, scientists, and representatives of large companies from different sectors, as well as industries, organized civil society, members of conservation units, fishermen, and aquaculturists. It is important to establish partnerships among these actors across the Atlantic, including countries in South, Central, and North America, Europe, and Africa, in order to effectively manage coastal waste (like paper).

Coastal management planning should involve quantifying periods with higher waste abundance, as well as identifying the main sources of pollution and activities that contribute to the increase of litter deposition. By understanding these factors, appropriate strategies can be developed to mitigate and eliminate waste deposition and pollution in the medium- and long-term (da Silva et al., 2018; Mghili et al., 2023). It is crucial to prioritize environmental education and increase awareness among the population regarding the protection of coastal and marine environments. This can help foster a sense of responsibility and encourage individuals to take action to reduce litter generation and promote sustainable practices (da Silva et al., 2018; Timbó et al., 2019).

Other practical and community measure are the activities of cleaning beaches that are performed periodically, this action promotes the instant reduction of marine litter and allows employees to exercise their environmental protection and sustainability ideas (Póvoa et al. 2022 b). Moreover, climate change should also be observed in this process together with coastal erosion and the increase in sea level (Lincoln et al, 2022; Andriolo and Gonçalves, 2022).

Climate change is an elementary factor in the distribution, source, and degradation of marine litter, also contributing to the spread of several exotic species that can become invasive when they invade ecosystems (Lincoln et al, 2022). This process of climate change influences the intensity and frequency of rainfall (Masson-Delmotte et al., 2018), which, consequently, increases the entry of litter into waterways due to the lack of adequate drainage of urban surfaces, which results in an increase of fragments (Hitchcock, 2020).

The rise in sea level, with the aforementioned events, causes erosion and retreat of the global coastline. Coastal erosion can exhume buried waste and make it available in the coastal environment (Andriolo and Gonçalves, 2022). In addition to these factors, the vegetation associated with these environments captures and holds marine litter that is discarded irregularly and can return to the aquatic environment (Andriolo and Gonçalves, 2022). Climate change can influence the litter decomposition process due to high temperatures, exposure to sunlight, and abrasion, which alters the persistence of this material in the environment (Deng et al., 2021). Further, degradation releases pollutants that affect organisms associated with these systems, which causes different environmental and economic impacts, especially in vulnerable communities that depend on the coastal environment as a source of livelihood (Tudor and Williams, 2021).

These risks must be considered to guide, coordinate, and monitor anthropogenic litter management, planning, and actions, as effectively addressing the combined impacts of litter and climate change requires a comprehensive approach. Therefore, correlating global issues such as climate change and marine litter is essential to mitigate damage to marine biodiversity and society (Lincoln et al., 2022). The response to this problem must be global, urgent, and coordinated (Farrelly et al., 2020).

Legislation and policies related to marine anthropogenic litter present in coastal environments are linked to the generation and dissemination of these materials, neglecting efforts to mitigate these wastes in coastal environments (UNEP, 2016). Therefore, currently, actions aimed at the production and disposal of products are even more relevant to prevent inappropriate disposal (UNEP, 2016). Inaction in resolving marine anthropogenic litter in coastal environments has environmental and socioeconomic costs (Brouwer et al., 2017). In this context, decreasing production and increasing plastic removal has been suggested as the main way to dispose of plastic litter (Hohn et al., 2020). Even so, global strategies and actions are needed to be put into practice by policymakers and stakeholders on this issue (Burt et al., 2020; Canning-Clode et al., 2020). However, tackling the problem of marine anthropogenic litter requires global cooperation and coordinated efforts. Policymakers and stakeholders must come together and implement strategies and actions on a global scale. Collaborative initiatives can help in sharing knowledge, best practices, and resources to address the issue effectively (UNEP, 2016; Hohn et al., 2020; Burt et al., 2020; Canning-Clode et al., 2020).

## CONCLUSION

The countries bathed by the South Atlantic, especially those in Africa, demand a greater need for public policy management applied to the management of coastal environments. The application of effective methodologies for comparing different coastal areas can provide valuable insights into the best practices for managing these environments. By examining successful case studies and comparing them with current practices, policymakers can identify areas for improvement and implement strategies that are more effective. The better utilization of present technologies can greatly enhance the management of coastal environments. Utilizing advanced monitoring systems, satellite imagery, and data analysis tools can provide real-time information on coastal health and aid in identifying potential threats or areas of concern.

Creating environmental perception via engagement with multiple actors in society is also essential. Coastal management should involve the participation and input of various stakeholders, including local communities, industries, and governmental organizations. Engaging these stakeholders in the decision-making process and raising awareness about the importance of coastal conservation can lead to a more holistic and sustainable approach to management.

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A.A.P.: Conceptualization, Investigation, Formal analysis, Funding acquisition, Methodology, Visualization, Writing- Original Draft; Writing – Review & Editing.

L.R.S.: Investigation, Formal analysis, Methodology, Writing – Original Draft; Writing – Review & Editing.

I.R.H.: Investigation, Methodology; Writing – Original Draft; Writing – Review & Editing.

G.E.D.L.T.: Writing – Review & Editing.

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