Regional Studies in Marine Science 63 (2023) 102991

Contents lists available at ScienceDirect

Regional Studies in Marine Science

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

Monitoring marine litter on Funchal beaches (Madeira Island): Insights for litter management

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ARTICLE INFO

Article history:
Received 9 February 2023
Received in revised form 1 April 2023
Accepted 30 April 2023
Available online 8 May 2023

Keywords:
Marine litter pollution
Monitoring
Beaches cleanups
Land-based sources
Marine litter management
Oceanic island

ABSTRACT

Marine litter is a complex and multi-dimensional problem, with beach litter surveys being an important cost-effective tool for monitoring and assessing marine litter pollution. In Madeira Island (Portugal, NE Atlantic), a region awarded several times as 'Europe's Leading Island Destination' and with a particular orography, there is a scarce understanding of the situation of marine debris. A two-year monitoring (July 2020 to April 2022) of macro-litter was conducted on two beaches in Funchal, the largest city and capital of the island. The abundance, composition, sources, and pathways of the stranded marine litter were assessed following OSPAR guidelines. During the two years, a total of 14,265 items were recorded. The mean litter density was found to be 0.29 items/m^2 and the beaches' clean index ranged between 'very clean' and 'dirty'. Cigarette butts (30.9%) and plastic objects (30.7%) were the most frequent marine litter items, followed by paper/cardboard (9.2%) and metal items (8.3%). The composition of the litter showed that most of the monitored marine debris has a land-based source, with a strong contribution from smoking-related activities and littering in streams. By characterizing the waste and identifying its source, it was possible to propose integrated management actions at a local level. Outreach and raising awareness campaigns, together with actions to limit single-use plastic items and stimulate a circular economy, could contribute to limit marine litter on the studied island but also in other regions with similar profiles.

1. Introduction

Marine litter refers to all processed and/or synthetic solid materials in the coast and marine environment that have been deliberately discarded, indirectly transported, or unintentionally lost (United Nations Environment Programme (UNEP), 2009). According to its size, marine litter can be either classified as macro-, meso- or micro-litter. Macro-litter items are the ones easily observed by the naked eye (items larger than 25 mm), whereas micro-litter has a size of less than 5 mm (Chassignet et al., 2021). These items originate from different economic sectors or human activities (defined as *sources*) and enter the marine environment through physical and/or technical means (the so-called *pathways*) (Veiga et al., 2016). Land-based sources refer to activities in which waste is produced on land or on the coast, namely stormwater discharges, illegal dumping of garbage, littering, unprotected landfills, and industrial activities, whereas sea-based sources relate to the direct release of litter to the ocean, for example, by aquaculture, fishing, offshore platforms, recreational boats, and shipping (Allsopp et al., 2006; Sheavly and Register, 2007). Sewage systems, runoffs, rivers, ocean currents, and wind-blown are some of the potential pathways through which marine litter enters the marine environment (Veiga et al., 2016). Several million tons of waste are estimated to enter the sea annually. Most of this waste is plastic (Bhuyan et al., 2021). Without meaningful actions, it is predicted that the release of plastic waste into marine ecosystems will almost triple by 2040 (Hahladakis, 2020; UNEP, 2021). This accumulation of litter has a number of environmental, economic, social, and aesthetic consequences (Kühn et al., 2015; Potts and Hastings, 2011; Sheavly and Register, 2007).

Due to the importance of quantifying and measuring the types of marine litter, an increasing number of monitoring studies have been registered in recent years. Beach litter, benthic litter, floating litter, biota, and microlitter surveys are the basic types of marine

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https://doi.org/10.1016/j.rsma.2023.102991

litter surveys (Maes and Garnacho, 2013), being beach surveys the most common (Haarr et al., 2022) and the primary tool for quantifying the load of marine debris in coastal and marine systems (Cheshire et al., 2009). Monitoring beach litter contributes to perceiving its amount, composition/type, source and pathway, and how it varies over time. All this information enriches the understanding of the problem at different scales, as well as helps in the definition of measures to tackle the problem (NOAA, 2022). Several studies have demonstrated that beach litter analysis plays a key role in defining effective waste and coastal management actions and strategies (Kaviarasan et al., 2022; Rangel-Buitrago et al., 2017). Such strategies must rely on the 10R's principles (i.e. refuse, rethink, reduce, re-use, repair, refurbish, remanufacture, repurpose, recycle, and recover) which seek an ultimate circularity, where the product chain is closed so that materials are used over and over again (Morseletto, 2020; Potting et al., 2017). Different waste management measures (e.g., product charges, deposit-refund systems, extended producer responsibility, taxes, bans) complement this circularity strategy, as they impact waste quantities and composition (Newman et al., 2015; Pires et al., 2019). The relationship between waste management and marine litter characteristics hence strengthens the necessity of beach litter monitoring (Liu et al., 2013). Yet, to ensure data reliability and comparability, it is necessary to look for an appropriate and effective methodology—the 'standardisation of monitoring protocols is key to securing effective regulations and evaluating the results of implementation of measures' (Haarr et al., 2022, p. 153162) and, when necessary, adapt the protocols to the region's 'litter fingerprint' (Falk-Andersson et al., 2019).

Currently, several methods of monitoring and assessing marine litter are available. The OSPAR, NOWPAP, NMDMP, and AMDS are some of the existing protocols for beach surveys (Cheshire et al., 2009). OSPAR protocol is the 'most detailed protocol for monitoring beach litter' (Schulz et al., 2017, p. 167), being used in several worldwide studies (Álvarez et al., 2020; Binetti et al., 2020; Rangel-Buitrago et al., 2020). According to OSPAR guidelines, surveys must be carried out at regular intervals of three months (one in each season) in a 100-meter sampling area (OSPAR Commission, 2010).

Following the OSPAR protocol, macro-litter in Funchal's beaches was monitored. Funchal is the biggest city of Madeira (Portugal, NE Atlantic), a small oceanic island whose coastal areas have scenic, ecological, and economic value. The aims of the study were: (a) gather a comprehensive two-year dataset on the macro litter of beaches from an oceanic island; (b) compare the results of the two beaches subject to different user profiles and sources of litter; (c) suggest a cost-effective approach for managing marine litter on Madeira Island. Available data about marine litter in Madeira is scarce, with only one published study (Álvarez et al., 2020) reporting data in some parts of the island. As there is no available comprehensive macro-litter data on Funchal's beaches, the obtained information will allow the establishment of baseline knowledge of the actual litter situation, the comparison with other regions, and the identification of strategies to tackle the issue and help in decision-making actions. These points are important considering that beach cleanliness is regarded as one of the five most essential aspects for beach visitors according to the 'Big Five' parameters (Botero et al., 2021; Williams, 2011). This is particularly relevant in Madeira Island, as it is a tourist destination awarded eight times as 'Europe's Leading Island Destination'. Furthermore, Madeira can be studied as a model, as it is a small region easier to monitor. The proposed management approaches defined based on the sampled debris can be adapted to regions with similar marine litter and orographic profiles.

2. Methods

2.1. Beaches characterization

In this study, the field investigation was carried out in Funchal, located on the South coast of Madeira Island (Fig. 1). This municipality is the island's capital and has the more considerable number of inhabitants, about 105,795 people (DREM, 2021). In Funchal, there are ten coastal bathing water areas. Two beaches – 'Formosa' and 'Almirante Reis'– were selected as sampling areas since they were the only ones that meet the cumulative requirements: (1) are public, free-access zones (some of the beaches in the municipality are managed and operated by companies and their access is paid) and (2) can be sampled following OSPAR recommendations, as they are longer than 100 m in length, are exposed to the open sea, and are accessible all year (OSPAR Commission, 2010). The OSPAR guidelines also recommend that beaches should preferably not be subjected to regular litter collection activities. This criterion was not verified in 'Formosa' beach in some months, given that it is an accessible beach where cleaning actions are often carried out (although not always in the zone sampled in this study).

'Formosa' is the biggest beach in Funchal, in a tourist zone. Along the beach is a walkway and a stream nearby, making it a bustling area all year round (Fig. 1a). The sampled beach area - 5,267.29 m^2 (coordinates near the sea: 32.641990° N, −16.957850° E and 32.641500° N, −16.956870° E; back of the beach: 32.642350° N, −16.957650° E and 32.642190° N, −16.956650° E) - is mainly composed of sand and pebbles and is known by some inhabitants as 'Praia Nova'. 'Almirante Reis' beach is in the city's heart, near the cruise ship harbor, a wastewater treatment station, and three streams. It has a C-shape (Fig. 1b) and an area of 2,417.41 m^2 was sampled (coordinates near the sea: 32.64638° N, −16.902410° E and 32.64654° N, −16.90147° E; back of the beach: 32.64677° N, −16.90268° E and 32.64675° N, −16.901480° E). Despite the water not being classified as bathing water, the place is often frequented by residents and tourists. It is entirely composed of pebbles. Due to the beach's shape (curved) and composition (rocky), it was challenging to select replicate sections (Schulz et al., 2021), so one sampling area per beach was defined.

2.2. Macro-litter sampling and categorization

OSPAR guidelines (OSPAR Commission, 2010) were used to quantify and characterize macro-litter found on the two sampled beaches. Four annual clean-up actions took place in the recommended seasons (winter, spring, summer, and autumn) for two years, always on the same 100 m sampling unit (defined by OSPAR as the fixed section of the beach covering the area between the water edge and the back of the beach). The sampling started one hour after the high tide and occurred between July 2020 and April 2022 (8 surveys per beach over the two years). Despite most studies on stranded beach litter occurring within a single year (Haarr et al., 2022), a longer period was adopted for a better understanding of the marine litter situation and of the seasons' influence on the composition of the items. Some of the sampling actions counted on the participation of the general population or students to raise awareness for the theme of marine litter and ocean preservation.

Marine litter found in the sampled areas was collected, weighted, counted, and sorted using the OSPAR material categories: plastic| polystyrene, metal, cloth, paper| cardboard, wood, rubber, glass, pottery| ceramics, sanitary waste, medical waste, and faeces (OSPAR Commission, 2010). Yet, four alterations to OSPAR guidelines were made: (1) cigarette butts were categorized as an independent group and not in the paper category

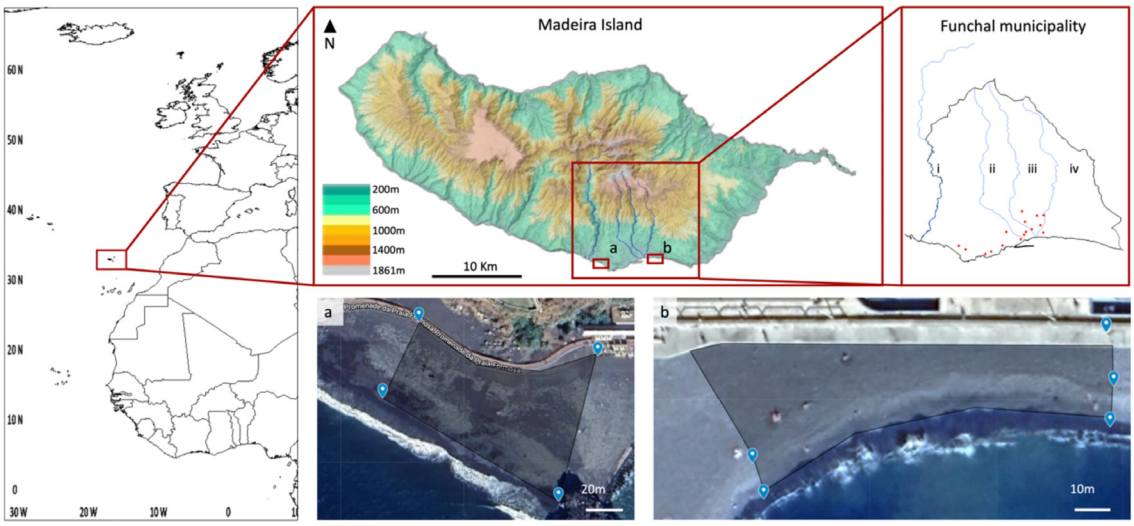

Fig. 1. Location of the study site: Madeira archipelago on the Northeast Atlantic (left), topographic map of Madeira Island denoting the streams and surveyed beaches (top center), and Funchal municipality with the streams (i – Socorridos, ii – São João, iii – Santa Luzia, and iv – João Gomes) that are available in the area (top right). Data from Antunes (2015). Location of the majority of the ATMs (marked with a red dot - top right; number of ATMs in the area as an indicator of the high population density) and aerial views of (a) 'Formosa and (b) 'Almirante Reis' beaches and respective surveyed areas (down).
Source: ATMs locations and images from Google Maps.

as proposed in OSPAR guidelines because cigarette butts filters are made from cellulose acetate (a synthetic polymer) (Araújo and Costa, 2019), an option already followed in other studies (Araújo and Costa, 2021; Becherucci et al., 2017; Ma et al., 2021); (2) Tetra Pak packages were included in the plastic category instead of paper since in Portugal these packages go to the plastic recycling container, thus avoiding confusing the volunteers who participated in the litter categorizations; (3) a category for COVID-19 items was created, which included face masks, disposable gloves, and alcohol bottles (Ammendolia et al., 2021); (4) 'others' group for items that did not fit in the above-referred categories.

2.3. Data analysis

The monitored surface areas (Section 2.1.) were used to calculate the amount of litter per m^2(calculated by the number of items divided by the sampled area). Marine litter items sources (i.e., land-based, sea-based, and uncertain sources) were determined following Pasternak et al. (2017) procedure. The appearance of the objects (e.g., type of product, user profile, labeling, barcode) and characteristics (e.g., presence or absence of marine fouling, like algae, barnacles, and bryozoans (Póvoa et al., 2021)) were used to identify its possible sources, thus contributing to the definition of management approaches and educational actions that could be adopted to curb the marine litter issue on Madeira Island.

To assess the seasonal variation of the main marine litter items categories (cigarette butts, plastic, metal, and paper), a chi-square test of independence was performed (considering a significance level of .05). In other words, the chi-square test of independence was used to determine if two categorical variables (in this case, season and each marine litter category) are likely to be statistically significantly related.

To evaluate the beaches' cleanliness and compare them with other regions, the Clean-Coast Index (CCI) is frequently used (Alkalay et al., 2007). The index is calculated by dividing the total number of plastic parts by the sampled area, then multiplied by a coefficient for statistical and convenience reasons (K, whose value = 20). The results indicate the beach status: 'very clean': 0–2; 'clean': 2–5; 'moderate': 5–10; 'dirty': 10–20; and 'extremely dirty': 20 and higher. Yet, this index only includes plastic items as an indicator of beach cleanliness. Considering that Funchal's beaches have a lower percentage of plastic items (according to the results of the two-year study presented in this research) than other regions, this way of calculating the index would bring underestimations about the beaches' cleanliness. To surpass this limitation, the total number of items from all categories was used to determine the concentration of debris (Lippiatt et al., 2013) instead of just accounting for plastic items. Marin et al. (2019) refer to this as the General Index and Sibaja-Cordero and Gómez-Ramírez (2022) as the modified CCI. Regardless of nomenclature, the equation accounting for all types of debris has been applied in different studies (Mokos et al., 2020; Mugilarasan et al., 2021; Rangel-Buitrago et al., 2021) and also in this study.

3. Results and discussion

3.1. Marine litter composition and temporal distribution

Marine litter found on the beaches was classified as described in Section 2.2. A total of 14,265 items (totalizing more than 185 kg) were collected over the two years on both beaches (16 surveys), Figs. 2a and 3a. Spring 2022 was the period with the highest records (n = 2083 items, 24.7%) on 'Almirante Reis' beach (Fig. 2b) and autumn 2020 was the season with more debris (n = 1685 items, 28.9%) on 'Formosa' beach (Fig. 3b). Such values may be justified by a lower frequency of cleaning (in comparison to the bathing months) and by rain and wind events that drag objects that settle on the beaches. In winter, many of these objects are washed out by the agitated sea, decreasing their number on beaches.

Concerning the composition of the marine litter, cigarette butts and plastic items were the most common objects on the surveyed beaches, an observation in line with studies in other locations (Araújo and Costa, 2021; Munari et al., 2016). Paper/cardboard and metal items were also frequent in some sampled seasons, similar to litter found on Brazilian beaches (Andrades et al., 2020). The 'others' category was very diverse, given that it included items with a mixed composition (e.g., plastic and paper bags) and/or that did not fit any of the OSPAR categories. In this category, napkins and electric wires were the most common items; the less usual ones were citric acid packages,

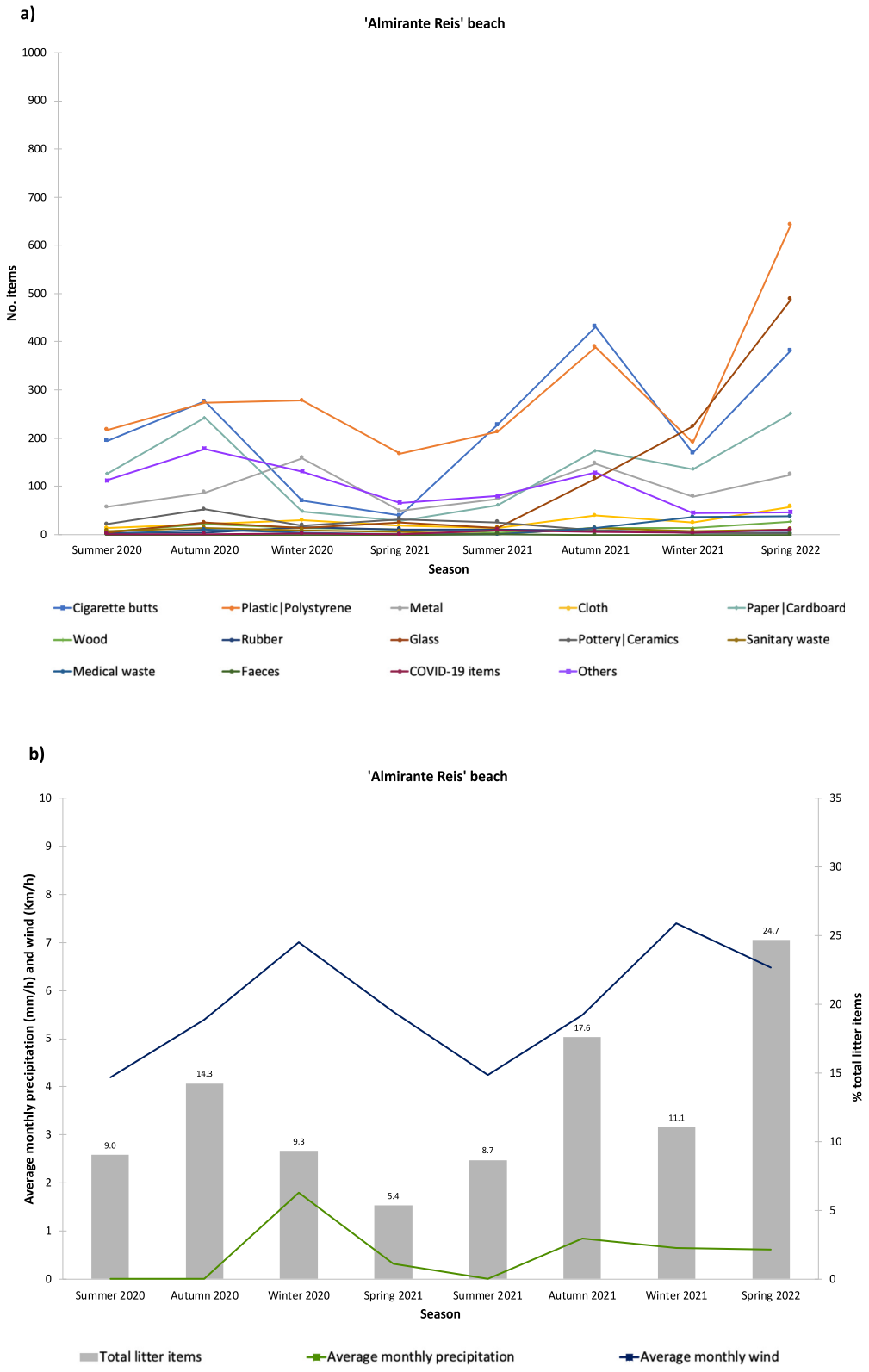

Fig. 2. Number of items of each category (a) and average monthly precipitation (mm/h), wind (Km/h), and total litter items (%) in the sampled area of 'Almirante Reis' beach (b) in different seasons over two years (summer 2020 to spring 2022 – 27/07/2020; 24/09/2020; 09/12/2020; 05/04/2021; 08/06/2021; 21/09/2021; 13/12/2021; 28/04/2022).

rings, and matches. Fishing-related items from sea-based sources were scarce on the surveyed beaches. One fishing line with a hook, a fluorescent light stick tube, and sporadically some ropes were found. Since fishing activities occur near the study sites, a higher percentage of fishing-related items on the sampled beaches was expected. Yet, although maritime ropes have already

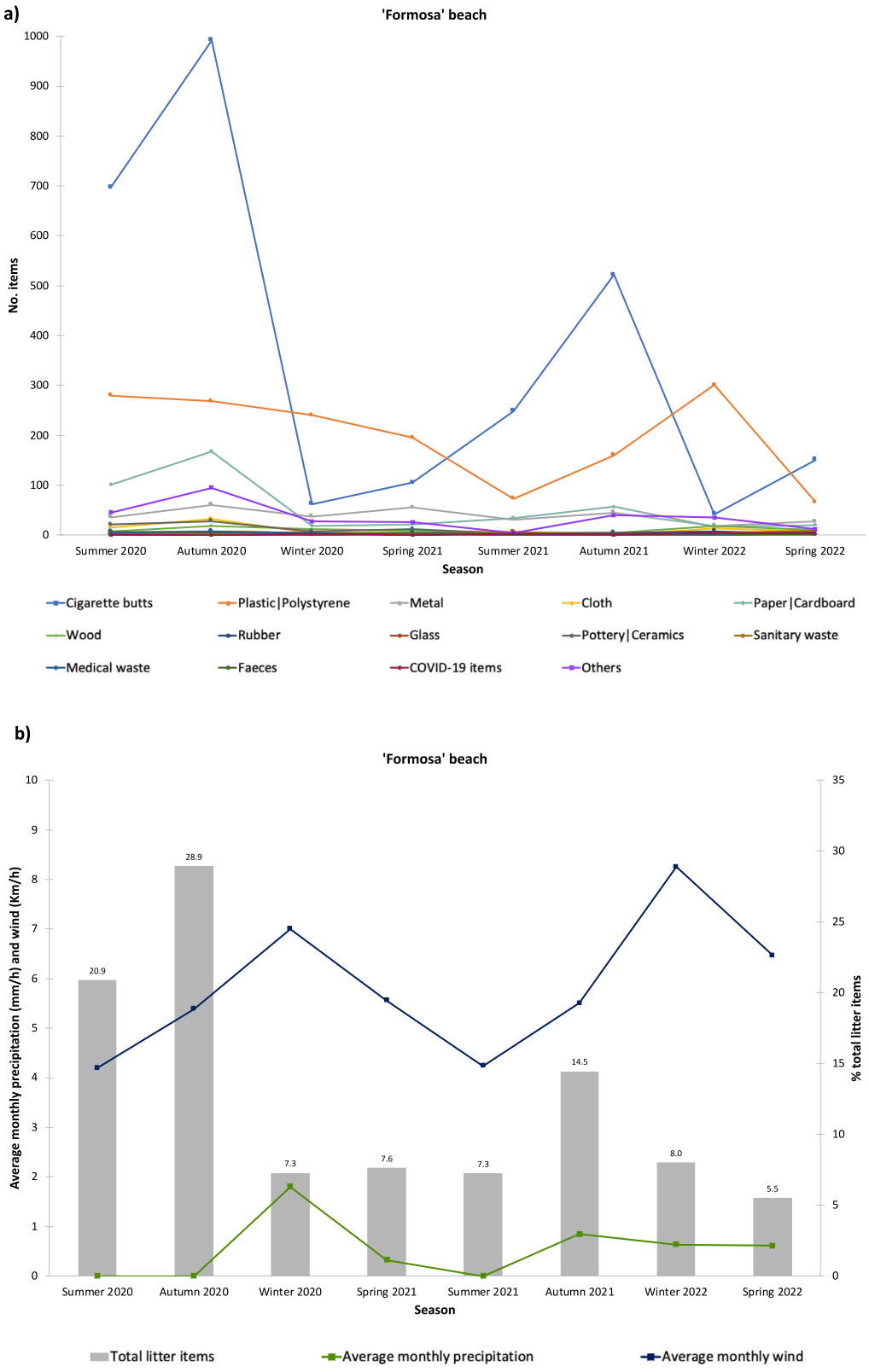

Fig. 3. Number of items of each category (a) and average monthly precipitation (mm/h), wind (Km/h), and total litter items (%) in the sampled area of 'Formosa' beach (b) in different seasons over two years (summer 2020 to spring 2022 – 13/07/2020; 11/09/2020; 10/12/2020; 20/04/2021; 18/06/2021; 21/09/2021; 12/01/2022; 29/04/2022).

been described on Madeira Island rocks (Ehlers et al., 2021), it is believed that higher amounts of fishing gear and other fishing-related items are on the seafloor, as previously described for other Portuguese oceanic regions (Rodríguez and Pham, 2017). The presence of objects from the COVID-19 category (mean 0.4%) was equally reduced. Nonetheless, despite the low percentage of COVID-related items on the surveyed beaches, it is believed that a group for these objects (including personal protective equipment)

Fig. 4. Items collected on 'Almirante Reis' beach in the autumn 2021 survey: (a) plastic; (b) paper| cardboard; and (c) metal objects.

should be created and standardized (Canning-Clode et al., 2020; Prata et al., 2020). Up-to-date methodologies must accompany emerging topics and areas, as is the case of COVID-19.

A mean of 353 (41.4%) and 224 (20.3%) units of cigarette butts and filters were found on the sampled area of the 'Formosa' and 'Almirante Reis' beaches, respectively. Globally, the mean percentage of cigarette butts is in line with that reported by other authors: 31% in Germany (Haseler et al., 2018), 30% in Bulgaria (Simeonova and Chuturkova, 2019), and more than 22% in Brazil (Silva et al., 2018), being reported that a higher number of cigarette butts is found on urban beaches (Asensio-Montesinos et al., 2021). Over the two-year monitoring, it was possible to observe a temporal trend: cigarette butts accumulation increases in the summer–autumn months and decreases in winter–spring. Such a pattern was observed on both beaches. This was expected, as smoking on the beach is a recognized source of these debris, especially during the high season. Nevertheless, it is known that cigarettes are not always smoked *in situ*. The butts of cigarettes can be transported via roads, pavements, and drains, thus ending up on beaches and in the ocean, a frequent situation in urban areas due to greater anthropogenic pressures, selling points, and smokers (Araújo and Costa, 2019; Novotny et al., 2009). Winter was the period with fewer cigarette butts (mean 42 items – 9.0% in 'Formosa' and 70 items – 8.9% in 'Almirante Reis'), not only because there are fewer bathers, but also because cigarette butts are washed directly to the sea by strong winds and rain, rather than being stranded on the beaches. Kolitari and Gjyli (2020) surveyed Albanian beaches in winter and the percentage of cigarette butts and filters found (3.7%) was similar to the registered in this study.

Plastic items (Fig. 4a) were the most abundant objects in nearly all winter and spring samplings. Yet, despite its ubiquitous distribution, no rigorous accumulation trends could be defined, similar to other studies (Martínez et al., 2020). Plastic items decreased from the summer to autumn months and increased from the autumn to winter months (there were exceptions in 2021 monitoring). Other authors equally reported higher litter rates during the winter months (Rosas et al., 2021). Plastic/polystyrene pieces with 2.5–50 cm, crisp/sweet packets, foam sponges, Styrofoam, and PVC pieces belong to the list of common items. Further objects, such as construction sign tapes, wrapping straws, caps/lids, bottles, food containers, bags, cigarette lighters, and security lockers of sunscreen bottles, were found less frequently. These last two objects were found mainly during the bathing season, suggesting that their presence is primarily attributed to bathers. Overall, plastic was available in quantities lower than usually reported. The mean of plastic items on both beaches in the two years was 30.7%, a value inferior to that described by Álvarez et al. (2020) (>80%) for beaches on the South-East and North coast of Madeira Island and by Orthodoxou et al. (2022) (86.3%), Gaibor et al. (2020) (75.9% and 64.8%), and Verlis and Wilson (2020) (58%) for other islands. As high percentages of plastic objects suggest items were transported through the sea, mainly via gyres or currents, to the oceanic islands, we can infer that plastic litter items found on Funchal beaches were primarily from local sources (Gaibor et al., 2020; Honorato-Zimmer et al., 2019).

Paper and cardboard items (Fig. 4b) have been registered with high abundance in different months (mean 9.2% over the two years), not following a linear accumulation pattern over the seasons. Small unidentified pieces of paper/cardboard were the most common. Chewing gum wrappers, cigarette packs, labels (especially from beer), invoices/receipts, straws, and scratch cards were frequently found. The first three items appeared to have been left directly on the beach or nearby. Most invoices/receipts were attributed to coffee shops and ATM bank cash machines located near the sampled areas (see Fig. 1, where some Funchal ATMs are marked), mainly with issue dates in the weeks before the sampling. Sibaja-Cordero and Gómez-Ramírez (2022) also reported the presence of sales slips on beaches. However, it is not an item frequently described in beach monitoring studies. Cardboard straws mainly appeared in the last 2021 and 2022 sampling months, replacing the plastic straws initially found. This change is due to the transition from plastic to cardboard straws, which occurred in most commercial establishments over the year prior to the study. Yet, people's unsustainable straw disposal behaviors endured, indicating that material modification from plastic to cardboard was insufficient to prevent waste from reaching beaches and the marine environment. Several scratch cards

were found on 'Almirante Reis' beach during surveys. As this is not a common object found on beach clean-ups, no references that could explain its presence were found in the literature. It is believed that the presence of these scratch cards stems from the fact that there is a cabstand nearby the beach, and games of chance are popular among taxi drivers that queue nearby.

Metal objects (Fig. 4c) appeared on the beaches in all seasons. Much of this garbage accumulates in the mountains and streams of the region (e.g., through the incorrect disposal of objects in these locations) and is dragged to beaches and sea by adverse weather conditions and rain. This observation is particularly true for 'Almirante Reis' beach, which contains the end of three water streams in the vicinities (see Fig. 1) and where 158 metal objects (20.0%) were collected in the winter of 2020. Despite being challenging to assign items to a source and pathway with a robust level of accuracy, it is possible to point out streams as possible litter pathways (following the guidelines for rivers, as there is no information available for streams). The nature of these metallic objects found contributes to this prediction, as they are objects that are not typically found in bathing areas (e.g., part of an iron, part of a gas cylinder, metals longer than 50 cm) nor disposed directly on the sea (i.e., sea-based source). Furthermore, the items allocated to this source are frequently parts or fragments of products (most of the objects collected fit this criterion) and highly variable in quantity, with meteorological events (such as rainfall) contributing to litter peaks (González et al., 2016). In Chile, 8% of riverside litter was found to be metal, partly attributed to illegal dumping and upstream sources, whereas in Germany metal accounted for 11.5% of the total debris (Honorato-Zimmer et al., 2021; Kiessling et al., 2019). Kiruba-Sankar et al. (2023) reported that 14.5% of the litter found was metal. Coupled with streams, some of the metal objects were predicted to arise from construction works near the beaches and public littering on beaches (especially the metallic crowns of beer bottles). Such building activities and beach users have equally been ascribed as a source of litter in previous studies (Asensio-Montesinos et al., 2020). With these results, it is possible to reinforce that land-based sources go far beyond littering and disposal of litter by bathers and recreational visitors. It is necessary to adopt holistic measures to fight marine litter.

A chi-square test of independence was performed to assess the seasonal variation of the most common marine litter groups (cigarette butts, plastic, paper, and metal). The results indicated that, for both beaches, the number of items was significantly related to the season (for 'Formosa' and 'Almirante Reis' beaches, $p < .001$). For example, autumn was one of the more prone seasons for litter accumulation on both beaches compared to other seasons. This goes in line with what was previously stated about post-summer months having more debris due to less frequent beach clean-up actions. It is also interesting to realize that litter accumulation varied in a sinusoidal relationship with the season in 'Almirante Reis' beach. On the other hand, 'Formosa' beach had a more stable litter variation through the seasons. Indeed, although litter varies statistically significantly among seasons in both beaches, each beach has its profile due to its users and location.

3.2. Litter densities and beaches cleanliness

There were differences in the marine litter densities recorded on each beach. The average litter density was 0.44 items/m^2 in 'Almirante Reis' and 0.14 items/m^2 in 'Formosa' beach. These values are in the same order of magnitude as in other worldwide studies (Table 1). Still, it should be noted that sampling methods and the size of the collected items vary among the studies. Also, the number of surveyed beaches was reduced compared to other regions, as in Funchal only the two selected beaches met the cumulative criteria to be sampled using OSPAR guidelines.

The index values (Table 2) indicated that 'Almirante Reis' is a moderate to dirty beach (the exception was spring 2021, classified as clean). 'Formosa' was aesthetically classified as very clean in most seasons, considering the calculated CCI. Moderate is the intermediate level in beaches cleanliness classification and was the most obtained status (6 times out of a total of 16) during the survey, reinforcing that management approaches to curb marine litter need to be adopted in Madeira Island.

3.3. Management approaches to curb marine litter on Madeira Island

Characterizing the beach litter is essential as 'measures to address and subsequently prevent the problem can be taken only if a source is identified, and those perpetrating the pollution can be targeted' (Poeta et al., 2016, p. 232). Analysis of the type of item and respective brand suggests that litter found in this study is mainly local, from land-based sources. The absence of litter from other countries (e.g., determined considering the barcode, telephone number, or 'made in' information) and marine fouling in the collected items indicates that sea-originated debris objects were rare (Pasternak et al., 2017), having been assigned to the sea-based sources only a few fishing-related items. Results also showed that the two analyzed beaches in the same municipality have different marine litter profiles: despite human land-based activities have contributed to most of the debris found on both beaches, in 'Formosa' part of the litter was attributed to beach visitors and people walking along the beach promenade, whereas in 'Almirante Reis' water transport channels played an important role in the accumulation of debris. Veiga et al. (2016) reported that 'the closer the surveyed site is to a potential source, the more likely it is that part of the litter originates from that source' (Veiga et al., 2016, p. 30). In 'Almirante Reis' beach, together with the influence of streams, its location (in an urban area) and beach users are also potential litter contributors (Poeta et al., 2016). Unfortunately, there are no estimates of the type and number of annual users on those beaches to support this discussion (Direção Regional do Ambiente e Alterações Climáticas, 2021).

Cigarette butts were common on both beaches, present in all seasons and with a clear temporal accumulation trend. Funchal municipality heavily invests in raising awareness for this issue, frequently promoting environmental campaigns and placing public ashtrays in popular places. The city is also a partner of the project 'O mar começa aqui' [translation: The sea starts here], where students make drawings on schools' gutters to get the attention that the garbage placed there will end up in the ocean through the rain drainage systems. Yet, it does not seem enough since cigarette butts were the most found items (average 30.9%). Raising awareness of cigarette butts' composition and the time it takes to degrade in the ocean is necessary. If people realize there are over 5000 compounds in cigarettes (some of them with carcinogenic and mutagenic potential) and that the filter material is a synthetic polymer (the compounds in the filter are very toxic, contaminating the soil after leaching by rainwater and the aquatic environment via urban runoffs), they can easily recognize cigarettes' ecological risks, thereby acknowledging the improper disposal as a pollution source (Araújo and Costa, 2019; Green et al., 2014; Slaughter et al., 2011). Furthermore, the perception of biodegradability will influence littering behavior, as sometimes cigarette butts are assumed to be made from paper and consequently expected to degrade quickly (Torres et al., 2019). Fees on cigarette packs and fines for cigarette butts' improper disposal are economic disincentive measures to be explored to reduce the number of smoked cigarettes and butts deposited on the

Table 1
Reported beach litter densities for different locations.

Location (country)	Litter density (items/m^2)	No. surveyed beaches	No. surveys/ beach	Reference
Bay of Durres and Bay of Lalzi (Albania)	0.14	5	2	Gjyli et al. (2020)
Pernambuco (Brazil)	2.3–6.3	9	1	Araújo et al. (2018)
Gulf of Nicoya (Costa Rica)	1.5	14	1	Sibaja-Cordero and Gómez-Ramírez, 2022
not defined (Cyprus)	0.36	9	2	Loizidou et al. (2018)
Mo'orea and Tahiti (France)	0.83	16	1	Verlis and Wilson (2020)
Corfu Island (Greece)	0.08–0.91	4	32	Prevenios et al. (2018)
Chennai-Puducherry coast (India)	0.24	6	1	Kaviarasan et al. (2022)
Rosh HaNikra-Zikim (Israel)	0.12	8	14–19	Pasternak et al. (2017)
Po River Delta Parks and Natura 2000 Italian network (Italy)	0.2	5	1	Munari et al. (2016)
Tangier, Martil, O. Laou, Jebha, Al Hoceima, Nador, and Saïdia (Morocco)	0.05	14	4	Nachite et al. (2019)
not defined (Slovenia)	1.25	6	1	Laglbauer et al. (2014)
Alicante (Spain)	0.062 and 0.12	56	2	Asensio-Montesinos et al. (2019)
Cilician Basin (Turkey)	0.92	13	1	Aydin et al. (2016)
Funchal (Portugal)	0.29	2	8	This study

ground and in wastewater and rain drainage systems (Barnes, 2011). Finally, as the summer and autumn months registered a high number of cigarette butts on beaches, portable ashtrays can be provided in these places. This strategy is advocated to reduce cigarette butts in the environment (Araújo and Costa, 2019), particularly in the high season, where bathers are the primary source of this item. Altogether, these measures can contribute to smarter product use and manufacture through refuse, rethink, and reduce strategies (Potting et al., 2017), but also via recycling (Mohajerani et al., 2020), Table 3.

In addition to cigarette butts, certain plastic items, broken glasses, and aluminum drinking cans have been linked to public littering, the recreational use of beaches, and proximity to food or drink outlets (Binetti et al., 2020). In Portugal, beer is generally sold in glass bottles (vs. aluminum cans in other countries); hence it was common to find beer bottles on the surveyed beaches. Also, only one local brand has a deposit-return scheme, thus discouraging the return of glass bottles. Further schemes of this nature for the remaining beer brands but also for the aluminum cans and PET bottles could be a successful measure, as there is proven evidence that adding monetary value to the products prevents them from ending up as mismanaged waste on the coasts (Schuyler et al., 2018) and contributes to the recovery of resources and energy (Pires et al., 2019). Other economic policy instruments, such as taxes, are widely used to reduce plastic usage (Heidbreder et al., 2019). The introduction of a plastic bag tax in Portugal led to a 74% reduction in disposable plastic bag consumption and an increase of more than 60% in the use of reusable plastic bags (Martinho et al., 2017). The same tax had previously shown positive effects in other sites (Convery et al., 2007; Hermann et al., 2011; Xanthos and Walker, 2017). A similar approach or even a ban could be applied to single-use plastic items and Styrofoam to address part of the marine litter problem on Madeira Island. While product taxes and charges discourage the use of certain products, landfill taxes disincentivize the improper disposal of waste through the promotion of recycling and recovery. They should therefore be also explored as a measure to reduce plastics found in the marine environment (Newman et al., 2015). The previously proposed instruments must be complemented with education and raising-awareness initiatives so that behavior intentions and attitudes change consciously and marine litter reduction is achieved following the R's strategies (Table 3).

Paper and cardboard items had representativeness in the number of objects collected on the Funchal's beaches, yet no clear accumulation trend could be identified. As the type of objects indicates, most were incorrectly disposed of on beaches (e.g., ice cream wrappers) or littered by people/carried by the wind (e.g., gum wrappers, cigarette packs, scratch cards). These observations confirm that there is still low awareness and perception of the marine litter problem among the population, not favoring ocean preservation (Bettencourt et al., 2023). Indeed, awareness-raising campaigns and educational initiatives are needed to promote sustainable actions and ensure a transition toward a more circular economy. Several actions promoted by governmental entities, companies, schools, and science centers are underway on the island and have reached many people, especially the younger ones. It is necessary to continue to invest in education and awareness-raising activities given their recognized value (Hartley et al., 2015; Kusumawati et al., 2020; Locritani et al., 2019), but also to extend their action ray to different audiences and promote more sustainable behaviors and practices through a critical thinking approach (Bettencourt et al., 2021). Besides, taxes can encourage

Table 2
Coastal Clean Index (CCI) and beach cleanliness status of 'Almirante Reis' and 'Formosa' beaches in different seasons. Scale adapted from Alkalay et al. (2007), accounting for all types of debris.

'Almirante Reis' beach			'Formosa' beach		
Season	CCI	Beach cleanliness	Season	CCI	Beach cleanliness
Summer 2020	6.30	Moderate	Summer 2020	4.62	Clean
Autumn 2020	9.95	Moderate	Autumn 2020	6.40	Moderate
Winter 2020	6.53	Moderate	Winter 2020	1.61	Very clean
Spring 2021	3.74	Clean	Spring 2021	1.69	Very clean
Summer 2021	6.06	Moderate	Summer 2021	1.61	Very clean
Autumn 2021	12.30	Dirty	Autumn 2021	3.20	Clean
Winter 2021	7.72	Moderate	Winter 2022	1.77	Very clean
Spring 2022	17.23	Dirty	Spring 2022	1.22	Very clean

CCI	0-2	2-5	5-10	10-20	20+
Beach cleanliness	Very clean	Clean	Moderate	Dirty	Very dirty

recycling. If the costs of landfill increase, people will look for other forms of waste treatment, such as rethinking, reducing, recycling, and reusing (Newman et al., 2015; Potting et al., 2017).

Some of the items found on the sampled beaches were identified as having been possibly transported through the island's streams (Table 3). This hypothesis stems from: (a) the object's composition (i.e., items that are not often abandoned on the beach nor littered in the urban streets but dumped on streams or zones close to streams and water channels, such as the part of an iron or car brake discs found), (b) the items' state (typically parts or fragments instead of the whole object, compatible with the very pronounced and extremely rugged relief of Madeira Island and respective pathway through the stream to the beach), and (c) the seasonal variation in the amount of the items (e.g., debris flushed away by heavy rainfalls and wind vs. accumulation in low precipitation periods), reinforced by the locations of the surveyed sites (i.e., close to streams) (González et al., 2016; Schirinzi et al., 2020; Veiga et al., 2016). In Madeira, streams behave similarly to rivers, which have a high abundance of debris near river mouths (Binetti et al., 2020; Rech et al., 2014). 'Almirante Reis' beach has the end of three water streams in the vicinities: the 'São João' stream which has an average slope of 13.5%, the 'Santa Luzia' stream which has an average slope of 13.9%, and the 'João Gomes' which has an average slope of 13.9%. For such streams, the efficiency of dams containing solid material has been described to be 11.6%, 23.9%, and 32.7% respectively (Reis, 2015). 'Formosa' beach has the influence of effluents from the 'Socorridos' stream, which has been identified as a potential source of pollution by the Regional Directorate for the Environment and Climate Change (Direção Regional do Ambiente e Alterações Climáticas, 2021). Yet, Madeira streams are poorly gauged and hydrological data at the river outlets are not available, hampering the validation of hydrological models (Rosa et al., 2022). Together with the geological and geomorphological streams' characteristics (Oliveira et al., 2011), the diffuse waste management collection system over the island municipalities (that promotes the improper disposal of waste on public roads and near streams, including metal and electrical/electronic equipment—sometimes the so-called bulky waste 'monsters'), must be considered. Similar debris patterns are described in other islands: in the Solomon Islands, the sources of litter are mostly local, with the river being used by the population for waste disposal (Binetti et al., 2020), and in Awaji Island, the rise of the local river causes the outflow of internal debris (Shimizu et al., 2008). A circularity strategy relying on the refuse, rethink, reduce, re-use, repair, refurbish, remanufacture, and repurpose principles must be adopted (Potting et al., 2017). The creation of more free collection spots strategically located, running of cleaning actions at the deposition sites, application of landfill taxes, reinforcement of awareness-raising initiatives focusing on behavior change, and adoption of extended producer responsibility are some of the measures that can be explored to reduce waste input into the ocean (Pires et al., 2019). Extended producer responsibility is claimed to be a cornerstone of waste policy, as producers are co-responsible for the impacts of their products and look for the eco-design of products. Introducing clear labels guiding the sampling processes, reducing mixed packaging in daily-use products, and lessening the unnecessary use of plastic products can improve waste flows (Pires et al., 2019; UNEP, 2021). This is particularly relevant for the bakery bags and coffee cups with mixed composition (i.e., paper and plastic) and for the food and cigarette packages, all frequently found on the monitored beaches. Companies' and producers' responsibility over products' end-of-life impacts also positively affects their destination. This responsibility is essential in items like iron, lamps, glasses rims, and electronic components collected on Funchal's beaches.

Overall, the management measures and economic policy instruments proposed here can be replicated in oceanic islands and other regions with similar debris profiles, ensuring marine ecosystems' sustainability.

3.4. Study limitations

The present study aimed at gathering a comprehensive dataset on the macro litter of Funchal's beaches, identifying litter quantity, composition, and probable sources/pathways and respective management actions. The sampling was restricted to two beaches as they were the only ones whose profiles fulfilled the criteria of suitable OSPAR monitoring beaches. The lack of available data regarding the number of beach items/m^2 in other Madeira municipalities and further oceanic islands difficulted the comparison and discussion of the results among regions with similar landscape profiles. Also, OSPAR litter categories did not entirely fit with the local reality. Such limitation was overcome with the adjustment of the Tetra Pak packages category and the creation of a separate group for cigarette butts and COVID-19-related items.

As beach litter monitoring schemes offer the most comprehensive data on individual litter items, standardization of the

Table 3
Most common marine litter items of Funchal's beaches, sources, pathways, and possible strategies and waste management measures to reduce their presence in the ocean and coastal environments. Strategies and waste management measures based on Pires et al. (2019) and Potting et al. (2017).

Marine litter items	Sources and pathways	R's strategies	Waste management measures
Cigarette butts	Land: beaches; public littering; wind and/or runoff; wastewater and rain drainage systems	Refuse; rethink; reduce; recycle	Fines; product charges; improve number and convenience of collection points (e.g., portable ashtrays); education and raising-awareness initiatives
Plastic	Land: beaches; public littering; streams; wind and/or runoff	Refuse; rethink; reduce; re-use; repair; remanufacture; repurpose; recycle	Deposit-refund systems; product charges; landfill taxes; education and raising-awareness initiatives
Paper and cardboard	Land: beaches; public littering; wind	Rethink; reduce; re-use; recycle	Landfill taxes; education and raising-awareness initiatives
Metal and electronic objects	Land: beaches; public littering; streams	Refuse; rethink; reduce; re-use; repair; refurbish; remanufacture; repurpose	Improve number and convenience of free collection points; landfill taxes; cleaning actions at the deposition sites; extended producer responsibility; education and raising-awareness initiatives

methods and item categories is hence crucial in future works so that global information can be compiled and easily compared (Galgani et al., 2015). Furthermore, it is necessary to ensure the replicability of the OSPAR surveys, namely through using replicate surveys, preferring raw data of such replicate surveys, and following the recommended survey intervals (more than 2 months) (Schulz et al., 2021).

4. Conclusions

This study presents the first data on a two-year monitoring of marine litter on Funchal's beaches. A profile of the main marine litter items, sources, pathways, and possible actions to curb their increase is provided.

Cigarette butts and plastics were the dominant litter categories in the sampled beaches, followed by paper/cardboard and metal items. Products of smoke-related activities and dumping were identified as the main marine litter sources, whereas streams were perceived as important litter pathways. 'Formosa' beach was classified in most seasons as 'very clean', whereas 'Almirante Reis' status changed among 'clean', 'moderate', and 'dirty' using the adapted CCI. Results support the need for waste management measures to prevent ocean pollution, such as adding monetary value to some items and taxing/banning others. In addition to these economic instruments, it was defined that more accessible waste collection points, improvement of product ecodesign, extended producer responsibility, and circularity strategies that rely on different R principles must be put into practice, also based on the common items of marine litter found in the sampling beaches. Furthermore, findings reinforced that the management of marine litter needs to start at the root of the problem, preventing the accumulation of debris through informed and sustainable behaviors. For that, raising awareness and educating the whole population is a priority axis to prevent litter input from land-based activities.

Altogether, the collected data about the abundance and distribution of marine litter contributed to improving the state of knowledge about the island's beaches' cleanliness and suggesting waste management improvements. The effect of future implemented approaches to curb marine litter on Madeira Island can be assessed through comparison with the data series provided here and the same approach can be replicated and used in other regions.

CRediT authorship contribution statement

Sara Bettencourt: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Carlos Lucas:** Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Sónia Costa:** Investigation, Supervision, Validation, Writing – review & editing. **Sandra Caeiro:** Supervision, Validation, Writing – review & editing.

Declaration of competing interest

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

Data availability

No data was used for the research described in the article.

Acknowledgments

The authors thank Diogo Freitas for statistical analysis support, all the volunteers who participated in the marine litter samplings over the two years, and the Portuguese Institute for Sea and Atmosphere (IPMA) for kindly providing the meteorological stations data.

Funding

This research was supported by the Fundação para a Ciência e Tecnologia (FCT), Portugal [grant SFRH/BD/147085/2019 to Sara Bettencourt]. Also had the support of FCT, Portugal through the strategic projects (UIDB/04292/2020 awarded to MARE and UID/AMB/04085/2019 to CENSE) and through project LA/P/0069/2020 granted to the Associate Laboratory ARNET, Portugal and financing of Fundo Azul do Ministério do Mar, Portugal through the project ALIMAR – Ação Lixo Marinho! (FA_06_2017_081).

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