Marine Pollution Bulletin 222 (2026) 118747

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Marine litter pollution on Amazonian beaches: A risk assessment study with focus on non-urban beaches

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ARTICLE INFO

Keywords:
Marine litter
Risk assessment
Non-urban beaches

ABSTRACT

To better understand the impacts of marine litter, this study focused on the development and application of the Macro-Litter Risk Index-MLRI using two Amazonian beaches, rural and village beaches. This index facilitates comparisons between different beaches, offering a detailed classification of risks and contributing to impact assessment and mitigation through the formulation of appropriate public policies. The MLRI is based on five sub-indices, of which two were adapted for non urban beach settings to ensure its applicability. No weighting was assigned to the sub indices, reinforcing their equal importance in the final result. Each sub-index was rated on a scale from 1 (Very High risk) to 5 (Very Low risk), with the MLRI value calculated as the arithmetic mean of these ratings. On each beach, macro-litter was manually collected in four pre-defined areas, each measuring 400 m^2. These areas were located within the intertidal zone, with their upper boundary set at the high tide line. The items were quantified and characterized according to marine litter survey and monitoring protocols. According to the MLRI, the rural beach was classified as Low risk (score 4) due to its low level of impact, while the village beach was classified as Moderate risk (score 3), indicating moderate environmental, public health, and economic impacts. The results highlight the vulnerability of each beach according to the sub-indices and emphasize the need for public policy implementation. Overall, this index can be applied to any non-urban beach worldwide, providing valuable insights to support the development of public policies.

1. Introduction

Anthropogenic marine litter (AML) includes all solid materials discarded or abandoned in the marine environment (Gall and Thompson, 2015; Portman and Brennan, 2017; Novikov et al., 2021; UNEP, 2021; Mugilarasan et al., 2023). It includes all materials discharged directly into the sea or indirectly transported by rivers, sewage discharges, currents, winds, ships, offshore installations, among others (Prevenios et al., 2018; Williams and Rangel-Buitrago, 2019; Andriolo and Gonçalves, 2024).

The increased presence of marine litter has shown a detrimental impact on the environment (Gracia et al., 2018; J. Campbell et al., 2019; M.L. Campbell et al., 2019; Woods et al., 2021; Andriolo and Gonçalves, 2024; Torn et al., 2024). These impacts include: (i) changes in ecological processes such as natural features, nutrient cycling, and human well-being (Campbell et al., 2016; Carvalho-Souza et al., 2018; Castro et al., 2020); (ii) the entanglement of animals caught in abandoned nets, fishing lines, ropes and ribbons (Torn et al., 2024); (iii) ingestion by marine biota (Compa et al., 2022; Budihardjo et al., 2025); and (iv) the release of pollutants of diverse chemical compositions that can be harmful to living organisms (Geyer et al., 2017; Adyel, 2020; Torn et al., 2024).

Plastics account for approximately 80 % of AML (Galgani et al., 2015; Gall and Thompson, 2015). This type of debris is a growing concern due to its detrimental effects on marine life and the food chain (Al-Mosawi et al., 2017; Andriolo et al., 2021; Póvoa et al., 2021, 2022; Zalewska et al., 2021; Sokolova et al., 2023). Unfortunately, around 8 to 10 million tons of plastic enter the oceans annually, accumulating on the

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https://doi.org/10.1016/j.marpolbul.2025.118747
Received 26 December 2024; Received in revised form 28 August 2025; Accepted 19 September 2025
Available online 29 September 2025

seabed, entangling marine organisms, and being ingested by species across the food web, with an annual input projected at 13–37 million tons per year by 2040 (Adyel, 2020; UNEP, 2021).

With respect to the impacts on biota, the presence of plastics causes problems related to ingestion, entanglement, impaired movement, loss of habitat and feeding, reduced reproduction, laceration, and death (Gall and Thompson, 2015; Schnurr et al., 2018). Additionally, plastics serve as carriers for toxic chemicals, increasing the risks to ecosystem health and potentially human health through the bioaccumulation of contaminants (Galloway et al., 2017; Li et al., 2020; Wang et al., 2021; Rafa et al., 2024).

In coastal areas, sandy beaches are highly valuable environments, supporting a range of leisure and anthropogenic activities due to the numerous goods and services they provide (Munari et al., 2016; Rangel-Buitrago et al., 2020; Thushari and Senevirathna, 2020; Ford et al., 2022; Lincoln et al., 2022). Unfortunately, marine litter has been linked to a decline in the economic growth of various beach locations (Williams et al., 2016; Wilson and Verlis, 2017; Corraini et al., 2018; Hahladakis, 2020; Mugilarasan et al., 2021). Consequently, addressing the marine litter issue requires the implementation of monitoring and management programs to provide immediate solutions (Nobre et al., 2015; Simeonova and Chuturkova, 2020; Lima et al., 2022; Póvoa et al., 2024).

Most studies on marine litter conducted in beach environments focus on monitoring both quantitative and qualitative data and address the origins of the problem (Haarr et al., 2022; Bettencourt et al., 2023). In this context, special attention should be given to non-urban beaches, as these environments often lack infrastructure and essential services. This makes continuous monitoring crucial (NOAA, 2024) to support the development of effective mitigation strategies through public policies.

In an attempt to monitor and assess the impact of marine litter, several marine litter indexes have been widely used in coastal environments, each with specific approaches and focuses (Ramirez-Llodra et al., 2013; FEE, 2024). These indexes have proven to be an effective tool, as they facilitate comparisons between different regions and beaches, highlighting local and global pollution pattern variations. They also serve as a starting point for adapting intervention strategies to the specific characteristics of each region.

The literature highlights the existence of indexes that evaluate the cleanliness of coastal environments in various parts of the world. The EA/NALG 2000 protocol was developed to trace the sources of litter. The Clean Coast Index (CCI) (Alkalay et al., 2007) and the Marine Litter Index (Ryan et al., 2009), both of which assess pollution status solely based on the number of litter items. The Environmental Status (ES), unlike others, does not consider waste density and categorizes pollution into four general groups, offering less detail (Rangel-Buitrago et al., 2019a).

Other examples include the Plastic Abundance Index (PAI) (Rangel-Buitrago et al., 2021a, 2021b), the Pellet Pollution Index (Fernandino et al., 2015), and the Cigarette Butt Pollution Index (CBPI) (Torkashvand et al., 2021), which analyze only the quantities of plastics, pellets, and cigarette butts, respectively. The Hazardous Items Index (Rangel-Buitrago et al., 2019c) quantifies solely sharp and cutting items. Most limitations of these indexes lie in their specific application to only one type of litter, highlighting the need to adapt protocols to the "litter fingerprint" of each region (Kühn et al., 2015; Falk-Andersson, 2021; Heravi et al., 2024). While these indexes fulfill the purposes for which they were created, they also have limitations, particularly in terms of scope.

Based on this, this study emphasizes the importance of considering the specific characteristics of non-urban beaches. Therefore, it focuses on the development and application of an index—the Macro-Litter Risk Index (MLRI)—which was used as a case study on two Amazonian marine beaches. The MLRI was designed specifically for non-urban beaches, as some sub-indices were adapted to address the unique characteristics of these environments. In this context, applying the MLRI aims to understand the extent of marine pollution on non-urban beaches, and it can be implemented on any non-urban beach worldwide.

2. Methods

2.1. Development of the Macro-litter Risk Index (MLRI)

The Macro-Litter Risk Index (MLRI) was developed to assess environmental and public health risks associated with litter accumulation on non-urban recreational beaches. The adaptation of certain sub-indexes for beach settings with less urban development is crucial to ensuring the applicability of the MLRI to non-urban environments. The index consists of five sub-indexes, each playing a vital role in evaluating distinct factors that determine the presence and effects of macro-litter (Table 1). These sub-indexes are: (i) General Cleanliness sub-index (GCsi), which assesses the overall cleanliness of the beach by considering the visible presence of debris; (ii) Cleaning and Maintenance Services sub-index (CMSsi), which examines the quality and frequency of cleaning and maintenance services performed on the beach; (iii) Debris Decomposition Time sub-index (DDTsi), which analyzes the decomposition time of waste materials, considering their environmental persistence; (iv) Environmental Risk sub-index (ERsi), which assesses the risks associated with litter accumulation, including its potential impacts on local fauna and flora; and (v) Human Health Risk sub-index (HHRsi), which evaluates human health risks resulting from exposure to waste and potential contaminants.

The inclusion of these sub-indexes is based on an approach that integrates various data collection methods to ensure accuracy and reliability. This approach includes a literature review, which identifies established criteria and previously studied parameters regarding beach litter, serving as the foundation for the index's development. Simultaneously, a checklist was applied to standardize the observation and classification of detected elements, ensuring consistency in data collection across different locations. To further enhance the assessment, photographic records were used to document beach conditions, validating collected data and support analytical comparisons over time. Additionally, researchers or volunteers directly observed field conditions, enabling real-time analysis and a contextual understanding of environmental and anthropogenic factors influencing macro-litter accumulation.

These data collection methods provide structured and reliable information, allowing each sub-index to accurately reflect beach conditions and macro-litter risks. Furthermore, no weighting was assigned to the sub-indexes, reinforcing the principle that each holds equal importance and exerts uniform influence on the final result. Each sub-index was rated on a scale from 1 (Very high-risk level) to 5 (Very low-risk level), as shown in Table 2. The MLRI value was calculated (Eq. (1)) using the arithmetic mean of the sub-index values. In this study, it was classified using the same principle applied to each sub-index (Table 2).

Table 1
Composition of the Macro-litter Risk Index (MLRI) with sub-indices, respective indicators, and data sources.

MLRI		
Sub-index	Indicators	Data sources
GCsi	Density of items *per* m^2	Field campaign, literature review
CMSsi	Quantify the cleaning and maintenance activities, both public and private	Field campaign, checklist, photographic images
DDTsi	Quantify the decomposition time of the material or how long it remains in the environment	Field campaign, literature review
Ersi	Quantify risks to the marine biota and macro-litter abundance	Field campaign, literature review
HHRsi	Quantify the risks to human health	Field campaign, literature review

Table 2
The limits, scores, and classification for the Macro-litter Risk Index - MLRI.

Index	Limits	Scores	Classification	Description
MLRI	1	1	Very high-risk level	Severe impacts on the beach, public health, and economic activities. Urgent measures to minimize and avoid new impacts.
	1.1–2	2	High risk level	Significant impacts on the beach, public health, and economic activities. Urgent measures to minimize and avoid new impacts.
	2.1–3	3	Moderate risk level	Moderate impacts on the beach, public health, and economic activities. Public policies are needed to avoid worsening impacts.
	3.1–4	4	Low risk level	Low impact. Monitoring and control of public policies are necessary.
	4.1–5	5	Very low risk level	Minimal impacts. Public policies are being effective; however, management control must exist.

This standardized scale ensures clear and consistent interpretation of the results.

$$MLRI = \frac{GCs\mathit{i} + CMSs\mathit{i} + DDTs\mathit{i} + ERs\mathit{i} + HHRs\mathit{i}}{5} \quad (1)$$

2.1.1. Sub-indexes details

2.1.1.1. General Cleanliness Sub-index (GCsi). The GCsi was based on macro-litter density (i.e., number of items *per* m^2). The data were obtained through field collection, as detailed in Section 2.2. It was adapted to non-urban beaches, as it was derived from a bibliographic review of 74 beaches that analyzed the density of marine litter on rural, remote, village, and resort beaches around the world.

The scores for this sub-index were defined from the averages of the mean and maximum density values obtained on those 74 non-urban beaches worldwide (see, ST1). This sub-index was categorized into five scores ranging from 1 (Very High risk) to 5 (Very Low risk), as shown in Table 3. Score 1 was assigned to macro-litter densities exceeding 1.93 items per m^2, the highest value recorded in Table S1; Score 2 (High risk) was the maximum limit of macro-litter densities (i.e., 1.93 items *per* m^2); Score 3 (Moderate risk) was the upper limit of the mean macro-litter density values (i.e., 0.42 items *per* m^2) found in Table S1; Score 4 (Low risk) represents the midpoint between Score 5 and the upper limit of Score 3 (i.e., 0.21 items per m^2), while Score 5 was assigned when no macro-litter was found (i.e., zero items per m^2).

2.1.1.2. Cleaning and Maintenance Services sub-index (CMSsi). The CMSsi quantifies public or private actions that contribute to maintaining cleanliness on beaches, particularly non-urban ones. For this study, governmental actions (cleaning, regular and selective waste bins, waste collection, selective collection, laws, and informational signs) and private initiatives (voluntary cleaning carried out by owners of inns and bars) related to integrated solid waste management were considered, as well as the involvement of society and various social actors (e.g., waste pickers and cooperatives). To document these actions or their absence, field campaigns, checklists, and photographic records were employed.

This sub-index was proposed and applied in this study, establishing that at least eight actions should be considered for non-urban beaches (Table 4). For the selection of these actions, the following criteria were considered: infrastructure (waste bins), cleaning and waste collection services, and governmental intervention (information, laws, etc.). Absent actions were assigned a value of 1, regularly and satisfactorily performed actions received a value of 5, and sporadically occurring actions were given a value of 3.

Therefore, the lowest value is eight and represents the scenario when no action is taken, while the highest value 40 when all actions are taken regularly and satisfactorily. Table 3 shows the limits, scores, and classification. Score 1 was assigned to "No action", Score 2 to "Minimal actions", Score 3 to "Actions of moderate and partial effectiveness", Score 4 to "Sufficient and effective actions," and Score 5 to "Fully effective actions".

2.1.1.3. Debris Decomposition Time Sub-index (DDTsi). DDTsi defines the decomposition time of marine litter, recognizing that its prolonged presence in the environment can lead to various impacts. According to OSPAR (2007) and Rech et al. (2014), the most common macro-litter found on beaches consists of plastic (bottles, bags, lids, PET, polystyrene, etc.), aluminum (cans, plates, etc.), and glass (bottles, jars, glasses, etc.). Additionally, coconut shells and paper materials were considered here because they result from recreational activities of anthropogenic origin. Other organic items (e.g., roots, leaves, algae, propagules, etc.) are also found (Macreadie et al., 2017; Gracia et al., 2018) but were not considered in these studies as they are of natural origin.

To calculate the DDTsi, the percentage of each decomposition time was multiplied by the corresponding specific weights (Table 5). The sum

Table 4
Action ranking for the Cleaning and Maintenance Services sub-index (CMSsi).

Sub-index	Actions	Scores		
		1	3	5
CMSsi	Waste collection	Absent	Alternate days	Daily
	Selective waste collection	Absent	Specific days	Daily
	Selective waste bin	Absent	–	Present
	Public waste bins	Absent	Few	Enough
	Public and private beach cleaning	Absent	Cleaning on days with a large influx of visitors	Daily
	Information boards	Absent	–	Present
	Municipal or state waste laws	Absent	–	Present
	Clean-up campaigns by NGOs, universities, etc.	Absent	Partially	Present

Table 3
Scores, limits, and descriptions for each sub-index of the Macro-Litter Risk Index (MLRI).

Sub index	Very high risk (score 1)	High risk (score 2)	Moderate risk (score 3)	Low risk (score 4)	Very low risk (score 5)
GCsi	>1.93 (very high amount)	0.43–1.93 (high amount)	0.22–0.42 (moderate amount)	0.01–0.21 (low amount)	0 (none)
CMSsi	8 (no action)	9–16 (minimal actions)	17–24 (moderate and partial effectiveness actions)	25–32 (sufficient and effective actions)	33–40 (fully effective actions)
DDTsi	2 (very high number of debris items with long decomposition time)	2.1–3.0 (high number of debris items with long decomposition time)	3.1–4.0 (moderate number of debris items with short decomposition time)	4.1–5.0 (low number of debris items with long decomposition time)	5.1–6.0 (very low number of debris items with long decomposition time)
ERsi	1 (severe impacts)	1.1–2 (significant impacts)	2.1–3 (moderate impacts)	3.1–4 (few impacts)	4.1–5 (negligible impacts)
HHRsi	1 (unsafe - heavy presence of hazardous items)	1.1–2 (unsafe - a lot of hazardous items)	2.1–3 (moderately safe - some hazardous items)	3.1–4 (safe - few hazardous items)	4.1–5 (safe - no hazardous items)

Table 5
Items, decomposition time, and weights for the sub-index DDTsi.

Sub-index	Category of items	Decomposition times	Weights
DDTsi	Cigarette butts, paper, textile, painted wood, coconut shells[a]	Months to a few years	0.3
	Styrofoam fishing float, styrofoam kite, plastic bags[b]	Decades	0.25
	Cans and can seals of soft drinks or beer, beer cap[c]	Few hundred years	0.2
	Plastic in general (strow, disposable diaper, food packaging, cups, plates, disposable cutlery, pet (polyethylene terephthalate) bottles, caps), fishing line and rope[d]	From 400 years	0.15
	Glass, rubber[e]	From 1000 years	0.1

[a] Landim et al. (2016), Dobaradaran et al. (2019), and Arshad and Mujahid (2011).
[b] van-Sebille et al. (2015),
[c] Santos and Yoshida (2011) and van-Sebille et al. (2015).
[d] Santos and Yoshida (2011), Marsh and Buguso (2007), Thompson et al. (2004), Ivar do Sul and Costa (2014), Santos et al. (2012), Foresti et al. (2020), Chamas et al. (2020), and Lavers et al. (2014).
[e] Landim et al. (2016).

of these weights was classified into five categories. Weights were assigned to the decomposition time, ranging from months (0.30) to thousands of years (0.10), as shown in Table 5. This assignment considers the persistence of these materials in the environment and their ability to affect ecosystems over an extended period. Items made of paper, cardboard, textiles etc., are in the same category due to their short decomposition time (months to a few years) and are given a higher weight (0.30), because their presence in the environment is temporary and poses a lower risk of prolonged pollution. Items made of styrofoam, plastic bags, etc., have a decomposition time of decades (0.25) and cans and can seals of aluminum and beer caps have a decomposition time of a few hundred years (0.20). These weights were assigned because waste that remains for decades or centuries has a lasting and cumulative environmental impact, reflecting its contribution to long-term pollution.

The limits were established by multiplying the weight by 100 % and dividing by 5 (the number of item categories). Accordingly, the maximum limit was set at 6, which means the highest weight (0.3) was multiplied by 100 % and divided by 5 (the number of item categories) for category 1 (Very low number of debris items with long decomposition time). Meanwhile, the minimum limit was set at 2, which means the lowest weight (0.1) was multiplied by 100 % and divided by 5 (the number of item categories) for category 5 (Very high number of debris items with long decomposition time). The limits were then divided into equal intervals to ensure a balanced and systematic classification, as shown in Table 3. Eq. (2) was applied to determine the score for this sub-index.

$$\mathrm{DDTsi} = \left(\frac{(\mathrm{W1}\times\%1)+(\mathrm{W2}\times\%2)+(\mathrm{W3}\times\%3)+(\mathrm{W4}\times\%4)+(\mathrm{W5}\times\%5)}{5}\right) \tag{2}$$

where, W is the weight and % is the percentage of each category of items within the sample. The numbers are the item categories.

2.1.1.4. Environmental Risk sub-index (ERsi). The Environmental Risk sub-index (ERsi) was obtained from the average of the Macro-litter Abundance Risk (MAR) and Marine Biota Risk (MBR) scores (Table 6). The results can be interpreted as shown in Table 3, where the intervals were distributed into scores (1 to 5), according to other indicators, ranging from Very High (Severe impacts) to Very Low risks (Negligible impacts).

2.1.1.4.1. Macro-litter Abundance Risk (MAR). Regarding the Macro-litter Abundance Risk, the values were obtained from the PAI (Plastic Abundance Item) and OAI (Other Abundance Item), the latter of which is proposed for the first time in this study. The PAI was developed by Rangel-Buitrago et al. (2021a, 2021b) and determines the abundance of plastic items *per* m^2 relative to the total marine litter. It was calculated using the following equation:

$$PAI = \left[\frac{\left(\frac{\sum plasticlitter}{log10 \sum totallitteritems}\right)}{Area}\right]*20 \tag{3}$$

where, PAI considers the existing relationship between plastics and the log-transformed number of all marine litter items observed within the sampled area.

The limits used in PAI were the same as those adopted by Rangel-Buitrago et al. (2021a, 2021b), which estimated the total number of plastics, with categorization ranging from 'absence/very low abundance' to 'very high abundance.' Specifically, very low abundance/absence is $0 < \mathrm{PAI} < 1$, low abundance is $0.1 < \mathrm{PAI} < 1$, moderate abundance is $1.1 < \mathrm{PAI} < 4$, high abundance is $4.1 < \mathrm{PAI} < 8$, and very high abundance is $\mathrm{PAI} > 8$.

It should be noted that other items (rubber, glass, metal) described in the literature are harmful and pose risks, although they are less frequently present. Here, it was designated as Other Abundant Item (OAI), and the same calculation method and categorization ranges as PAI were used to define its values from Eq. (4):

$$OAI = \left[\frac{\left(\frac{\sum otherlitter}{log10 \sum totallitteritems}\right)}{Area}\right]*20 \tag{4}$$

where, OAI allows categorization in terms of the presence of litter (except plastic).

The MAR values were obtained from the sum of the PAI score and OAI score multiplied by their corresponding weights (Eq. (5)). As plastic debris is considered one of the main threats to global marine biodiversity (Soto-Navarro et al., 2021), with 80–90 % found among debris in wildlife, a weight of 0.8 was assigned to PAI and, consequently, a weight of 0.2 was assigned to OAI.

$$MAR = (PAIscore*0.8) + (OAIscore*0.2) \tag{5}$$

2.1.1.4.2. Marine Biota Risk (MBR). The Marine Biota Risk indicator defines the risks of accidents of the macro-litter to the marine biota. According to the studies by Gall and Thompson (2015), who analyzed 294 papers, two main categories of impacts on biota were identified: entanglement (87 %) and ingestion (84 %). To attribute scores to these two sub-indicators, five classes of categories of items were defined for both (Table 6), according to the percentage of accidents found in the

Table 6
Scores, limits, and descriptions for each indicator of the Environmental Risk sub-index (ERsi).

Sub index	Indicators	Very high risk (score 1)	High risk (score 2)	Moderate risk (score 3)	Low risk (score 4)	Very low risk (score 5)
Ersi	MAR (PAI and OAI)	>8 (too much debris items)	4.1 to 8 (a lot of debris items)	1.1 to 4 (moderate number of debris items)	0.1 to 1 (low number of debris items)	0 (no debris items)
	MBR (RI and RE)	2 (extremely harmful)	2.1–3.0 (high risk of damage)	3.1–4.0 (visible hazards and damage)	4.1–5.0 (presence minimal of danger)	5.1–6.0 (minimal risk)

studies of Gall and Thompson (2015).

Similar to DDTsi, a weight was assigned to each category of items, with 0.10 for the highest risk of ingestion or entanglement and 0.30 for the lowest risk of both. This weighting criterion considered, respectively, the percentages of the highest and lowest frequencies of accidents reported by Gall and Thompson (2015). The limits for each score were also similar to those of DDTsi, reaching a maximum of 6 (i.e., 100 % multiplied by 0.3 divided by 5, very low risk) and a minimum of 2 (100 % multiplied by 0.1 divided by 5, very high risk). The limit ranges were then divided into equal intervals to ensure a balanced and systematic classification. Eqs. (6) and (7) were used to obtain the values for each item comprising these indicators, ingestion, and entanglement, respectively. The MBR value was defined as the average of the two categories (entanglement and ingestion), and Table 6 shows the limits, scores, and risk levels for this indicator.

$$RI = \left(\frac{(W1 \times \%1) + (W2 \times \%2) + (W3 \times \%3) + (W4 \times \%4) + (W5 \times \%5)}{5}\right) \tag{6}$$

$$RE = \left(\frac{(W1 \times \%1) + (W2 \times \%2) + (W3 \times \%3) + (W4 \times \%4) + (W5 \times \%5)}{5}\right) \tag{7}$$

where, *RE* is the risk of entanglement and *RI* the risk of ingestion; W is the weight, and % is the percentage of each item within the sample. The numbers (1 to 5) indicate the category of items shown in Table 7.

2.1.1.5. Human Health Risk sub-index – HHRsi. HHRsi was developed to assess risks to human health associated with marine litter and includes various types of debris with potential adverse impacts. HHRsi is essential for effective marine waste management and to protect public health. The indicators used in this sub-index were faeces, debris related to personal hygiene (toilet paper, sanitary napkins, etc.), the remains of construction materials (such as iron, bricks, and ceramics, as well as their fragments), and the Hazardous Items Indicator (HII) which was established by Rangel-Buitrago et al. (2019b, 2020). These indicators together make the Human Health Risk sub-index (HHRsi) more robust.

Faeces were classified as present or absent, while personal hygiene and construction material items were categorized based on limits established by EA/NALG (2000). In addition, the HII refers to the number of hazardous items *per* m^2, considering the proportion between hazardous items and the log 10 of the total number of all items *per* m^2 (Eq. (8)), according to Rangel-Buitrago et al. (2019c). The HII classifies sharp items, such as broken glass, light bulbs, and drink and medicine containers, into five classes: I, II, III, IV and V, which were redistributed within the scores to align with the study methodology (see Table S2).

$$HII = \left[\frac{\left(\frac{\sum hazardourlitter}{log10 \sum totallitteritems}\right)}{Area}\right] * 20 \tag{8}$$

Table 7
Items of Marine Biota Risk (MBR) and respective weights for ingestion and entanglement sub-indicators.

Indicator	Ingestion	Entanglement	Weights
MBR	1-Plastic fragments >5 mm	1-Ropes and nets	0.10
	2-Intact items and packaging	2-Other fishing items (lines, pots, styrofoam, etc.)	0.15
	3-Other fishing items (lines, pots, styrofoam, etc.)	3-Intact items and packaging	0.20
	4-Ropes and nets, other and unknown	4-Other (e.g. rubber) and unknown	0.25
	5-Glass, metal and paper	5-Plastic fragments >5 mm, glass, metal paper	0.30

where, HII allows categorization in terms of Hazardous Items.

The scores for each indicator were divided into 1, 3, and 5 (see Table 8). The HHRsi was calculated from the average of these four indicators, as shown in Eq. (9). The final result of the HHRsi can be interpreted according to Table 3, in which the risks range from 1 (Unsafe - heavy presence of hazardous items) to 5 (Safe - no hazardous items).

$$HHRsi = \frac{Fae + PH + CMI + HII}{4} \tag{9}$$

2.2. Field campaigns

The field samplings were similar on both beaches under study. Marine litter collection took place between 9 am and 4 pm, depending on the tide range, in four pre-defined areas, each measuring 400 m^2 (20 m wide and 20 m long). These areas were located within the intertidal zone, with their upper boundary set at the high tide line. The high tide line was defined as the boundary because this zone tends to accumulate a larger amount of litter compared to other areas of the beach.

In each area studied, all macro-litters (≥2 cm, UNEP, 2009) were collected manually. The materials were quantified and characterized following the document guidelines for surveying and monitoring marine litter (UNEP, 2009; OSPAR, 2009). Additionally, a checklist was applied by an expert during the field campaigns to verify the existence of services, infrastructures and signage related to waste management. Photographic images were also taken during the field trips.

3. Study area

The coastline of the state of Pará is part of the Brazilian Amazon coast and represents 8.6 % of the state's total area (Fig. 1). This long coastline (>2000 km) is divided into five sectors: (i) Western Marajó, where a large part of the population is composed of traditional and riverside communities; (ii) Eastern Marajó, where the most visited beaches of Marajó Island are located, adding great ecological and economic importance to the region; (iii) Continental Estuarine, where the state capital, Belém, and the municipalities corresponding to its metropolitan region are located, being the most populous sector; (iv) Fluvial Maritime, whose economic activities are sustained through agriculture, fishing, family farming, and tourism; and (v) Atlantic Coast, consisting of different environments (e.g., dune fields, beaches, mangrove areas, etc.), where numerous economic activities are developed, such as fishing, tourism, etc. (Pereira et al., 2016; Sousa et al., 2017a, 2017b; Pessoa et al., 2019).

In the Atlantic Coast sector, hydrodynamics is characterized by semi-diurnal macrotides, with tide elevations ranging from 5 to 6 m during spring tides and 3.5–4.5 m during neap tides (DHN, 2024). The tides are asymmetrical, with periods of flood-tides shorter than ebb-tides (Pereira et al., 2016), resulting in higher tidal currents during flood-tides, which can reach speeds up to 1.5 m s^{-1} (Pereira et al., 2013). The significant wave heights (H_s) are modulated by the tides and can vary from 0.0 to 0.5 m, during low tides to almost 2 m during high tides (Pereira et al., 2014).

Local climate consists of two distinct seasons: the rainy season, from January to June, and the dry season, from July to December. The average annual rainfall is 2400 mm, of which 80–85 % falls during the

Table 8
Indicators of the Human Health Risk sub-index (HHRsi).

Sub-index	Indicators	Scores		
		1	3	5
HHRsi	Faeces	Present	–	Absence
	Personal hygiene	25	1/24	0
	CMI	25	1/24	0
	HII	IV-V	II-III	I

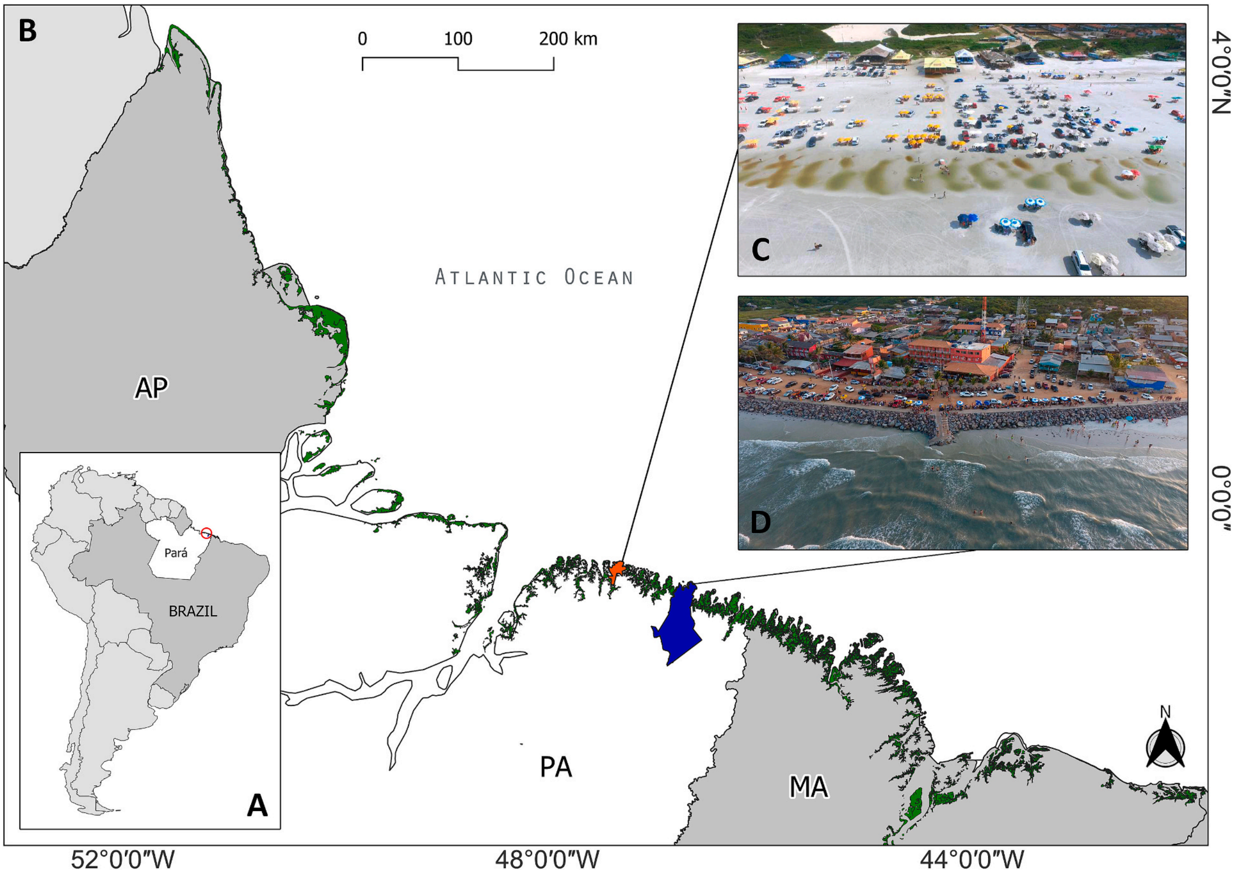

Fig. 1. Study area. A. South America, highlighting Brazil, the state of Pará, and the northeastern region of Pará in a red circle. B. Brazil's Amazon coastal zone, with the municipality of Salinópolis highlighted in red and the municipality of Bragança in blue. C. Atalaia beach at low tide and D. Ajuruteua beach at high tide. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

first semester (INMET, 2024). The average air temperature is 27 °C and the difference between the minimum and maximum averages is around 2 °C (INMET, 2024).

Due to the strong seasonality, July marks the beginning of the summer in this equatorial zone. This month represents a period of intense tourism on the beaches of Pará, including those in the Atlantic sector (Pereira et al., 2014, 2016, 2018). During this month and throughout the second half of the year, especially on long weekends or holidays, some sandy beaches are subject to strong human pressure, increasing the presence of marine litter (Assis et al., 2023; Monteiro et al., 2024). The most popular beach is the Atalaia beach (Fig. 1C), located in the municipality of Salinópolis, followed by Ajuruteua beach (Fig. 1D), located in Bragança.

Atalaia offers the most efficient infrastructure and services for coastal tourism in the state of Pará. It has a NW–SE orientation, with a total length of 12 km and a width of 200–400 m (Pinto et al., 2011). The western sector is occupied by holiday homes that sit on cliffs (Barreiras Formation), while the eastern sector is characterized by many bars and restaurants housed in wooden stilt buildings built on sand-dunes and intertidal zone (Sousa et al., 2011; Pinto et al., 2011). The intertidal zone has a gentle slope, fine to very fine granulometry, and is delimited by frontal and permanent dunes, and sandbanks on the coastline (Ranieri, 2014). The beach is located adjacent to an Integral Protection Area, the Atalaia Natural Monument.

Ajuruteua is a rural beach located between two canals (Chavascal and Barca), bordered by adjacent mangroves and the Caeté-Taperaçu Extractive Marine Reserve. Its economy is based on artisanal fishing and its growing tourist potential, with an increasing number of second homes, bars, restaurants, and inns. It is a dissipative beach formed by sandy barrier-beach ridges, consisting of fine to very fine sand. It has a total length of 2.5 km and a width of 300 m during low spring tides.

4. Results

The result of applying the Macro-litter Risk Index is shown below and in Fig. 2. The GCsi calculated the number of marine debris on both beaches. Considering the four transects at each beach, a total of 1988 items was collected in 3200 m^2, where 33 % of the debris was found in Ajuruteua (density of 0.41 items *per* m^2, Fig. 2C) and 67 % in Atalaia (density of 0.83 items *per* m^2, Fig. 2C). Regarding General Cleanliness (GCsi), these results place Ajuruteua in the “Moderate risk” category (Fig. 2B) and classify Atalaia as “High risk” (Fig. 2B).

Concerning CMSsi, in the state of Pará, many measures to combat debris can be highlighted, such as a ban on the use of plastic straws (State Law No. 9.229/2021) and a ban on the distribution of plastic bags in commercial establishments (State Law No. 8.902/2019). More specific laws, such as Ordinary Law No. 10381, prohibit the sale, consumption, permanence, circulation, or availability of non-returnable glass containers, such as long neck bottles, in beach areas. For infrastructure, both beaches have garbage collection services campaigns promoted by the government that reinforce beach cleanliness with educational measures on hygiene and ecological disposal, which also exist on each beach but are restricted to the July period (school vacations).

At the municipal level and according to the checklist applied, Ajuruteua presented more effective measures to combat garbage on its beach (Table S3), such as selective garbage collection, the presence of information signs, a ban on the circulation or permanence of vehicles on the beach strip (Municipal Law No. 4.148/2011). On this basis, Ajuruteua beach was classified as “Low risk” (i.e., sufficient and effective actions)

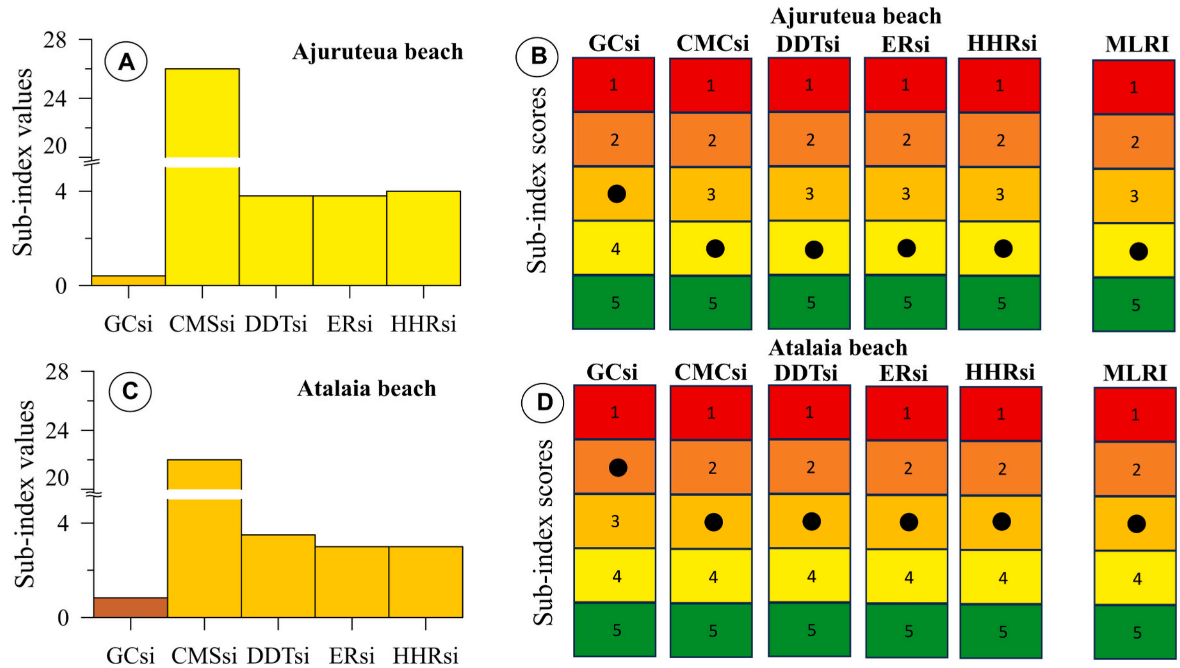

Fig. 2. Sub-index values and sub-index score in Ajuruteua (A, B) and Atalaia (C, D) beaches.

because the actions taken to keep the beach clean appear sufficient and effective. At Atalaia, there are not enough litter garbage collectors, no information signs, and cars are allowed to circulate on the stretch of beach (Table S3). There, the measures do not seem to be as effective, classifying this beach as "Moderate risk" (i.e., partially effective).

Plastics are the most representative items (>60 %) on both beaches, followed by paper (19 % in Ajuruteua and 12 % in Atalaia), and metal, glass, organic material, and others, each accounting for less than 10 % (Fig. 2A, B). The DDTsi showed a predominance of items with a decomposition time of more than 400 years (60 %) on both beaches (Fig. 3C, D). Most of the debris items were classified as plastic, and unfortunately, single-use items such as disposable cups, cutlery and plates, and food packaging, among others. Items with a decomposition time of months to a few years (e.g., cigarette butts, paper, fabrics, coconut shells) occupy the second place with 22 % in Ajuruteua and 17 % in Atalaia. Items made of glass accounted for only 3 % in Ajuruteua and

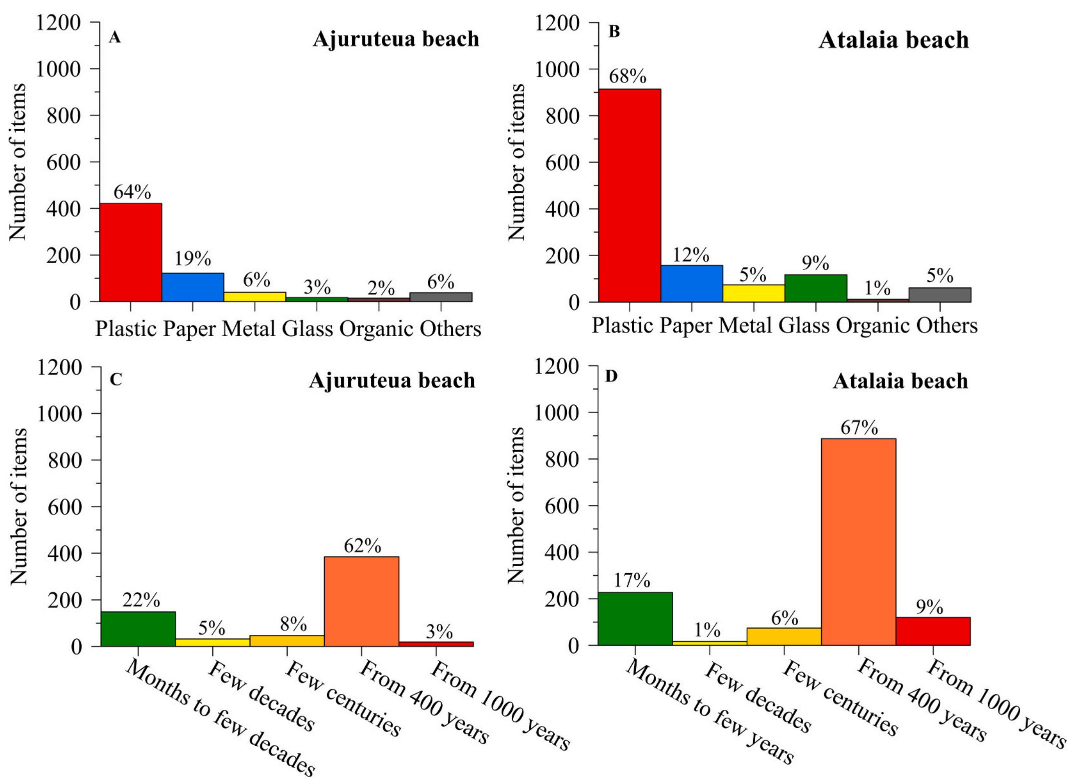

Fig. 3. Number and percentage of litter types by beach (A, B), and number and percentage of items categorized by decomposition time by beach (C, D).

9 % in Atalaia (e.g., long neck bottles, light bulbs, etc.), while metal items accounted for 6 % in Ajuruteua and 5 % in Atalaia (e.g. cans, seals and caps). With this data, it was possible to classify Ajuruteua as "Low risk" (i.e., High amount of debris items with low decomposition time) and Atalaia as "Moderate risk" (i.e., Moderate amount of debris items with low decomposition time).

The results of the Environmental Risk sub-index were obtained from MAR and MBR indicators. The MAR indicated a "High risk" for Atalaia due to the presence of much debris, while Ajuruteua represented a "Moderate risk". These results were in line with the PAI and OAI indicators. On both beaches, plastic presented a predominance of more than 60 % of the total debris items (Fig. 3), and the PAI was classified as a "Moderate risk" in Ajuruteua and a "High risk" in Atalaia. Single-use items such as disposable plates and cups, packaging, and lids dominated the samples and were the representatives that contributed the most to risk. The results for OAI showed that Ajuruteua beach offers a "Low risk" for these types of debris items and Atalaia beach a "Moderate risk" dominated by textiles, glass, coconut shells, and metallic seals in the samples (Fig. 3).

Complementing the ERsi, the MBR rated both beaches as "High risk" (i.e., with High risk of damage) since 90 % or more of the items collected fell into the category of items at risk of ingestion and entanglement. Regarding the risk of ingestion and entanglement, intact items, and packaging comprised a large quantitative contribution of items, with more than 50 % on both beaches (Fig. 4). Ropes and nets, considered the most harmful items, represented only 4 % for ingestion and 1 % for entanglement in Ajuruteua, despite 42 fishing-related items, such as styrofoam and motor oil packaging, which indicate fishing activity and improper disposal of these items. Atalaia also had a low contribution, with less than <3 % of fishing items (Fig. 4). Finally, the result of the Environmental Risk sub-index (ER_{SI}) showed "Moderate impacts" for Atalaia and "Few impacts" for Ajuruteua beach.

The HHRsi results indicated that Ajuruteua offered a "Low risk" to human health due to the absence of both, non-human faeces and personal hygiene debris (Table S4). In addition, Atalaia beach was rated as "Moderate risk". On this beach, human faeces and construction debris such as bricks, processed wood, and ceramics were found, indicating improper disposal (Table S4). The Hazardous Items Indicator (HII) was 0.1 (Ajuruteua) and 0.5 (Atalaia) and categorized into Class II. A total of 117 sharp items were found in Atalaia and 17 in Ajuruteua.

According to the Macro-litter Risk Index, Ajuruteua beach was classified as "Low risk" due to its low level of impact, but it still requires monitoring and public policy control (Fig. 2B). Conversely, Atalaia was classified as "Moderate risk" indicating moderate impacts on the environment, public health, and economic activities (Fig. 2D). For this beach, public policies are essential to prevent worsening impacts.

5. Discussion

5.1. Macro litter risk index (MLRI) for non-urban beaches: advantages, limitations, and applicability

The growing concern regarding marine pollution and environmental degradation in coastal zones underscores the importance of implementing monitoring and management tools capable of assessing the risks associated with solid waste accumulation on beaches. Within this context, the Macro-Litter Risk Index (MLRI) emerges as a strategic instrument for understanding, classifying, and guiding mitigation efforts, especially in non-urban beaches that, although less anthropized, remain vulnerable to external influences and the lack of adequate management.

The primary advantage of the MLRI lies in its multidimensional approach, based on the integration of various sub-indices that evaluate different types of risks (environmental, human health and waste management services). This structure makes the index sensitive to local specificities, capturing nuances that more simplified methods tend to overlook. Additionally, its application can provide valuable insights to public managers, environmental agencies, and local communities by translating complex data into clear risk classifications.

However, like any tool, the MLRI presents limitations that must be considered. The reliability of the results depends directly on the accuracy of the data collected, the technical knowledge involved in its application, and the ability to integrate contextual variables such as seasonality, recreational dynamics, and spatial usage patterns. Moreover, certain indicators—such as socioeconomic, cultural, geomorphological, hydrodynamic, and ecological variables—were not included, which may require methodological enhancements in future assessments.

Methodological standardization is also highly important. For instance, comparisons of litter density across different studies may be compromised by variations in the sampled areas—particularly when involving restricted sectors versus full beach transects. The beaches under study have more than 2000 m of extension, and in this case, we adopt four transects of 20 × 20 m each, expanding spatial coverage and contributing to a more representative assessment of the variability present along the coastal strip. Nevertheless, caution remains necessary when comparing results with studies that employ substantially different sampling scales, reinforcing the need for methodological standardization and for contextualizing the results within the spatial limits of each approach.

The results obtained using the current MLRI indicators provide valuable insights into the risks and the (in)effectiveness of waste management on non-urban beaches, accurately reflecting the local context in which they were applied. For a better understanding, non-urban beaches are classified in several ways: rural, remote, village, and resort (Dodds and Holmes, 2019; Mugilarasan et al., 2023) and, in the present study, two of them were highlighted: rural and village beaches. The comparison between Ajuruteua and Atalaia beaches clearly illustrates how specific site conditions influence performance outcomes and risk classifications within the index framework.

Ajuruteua, classified as a rural beach, showed a significantly lower debris density and fewer persistent materials. These quantitative results were supported by effective management strategies, such as selective waste collection and informative signage. Thus, although macro-litter density was categorized as a moderate risk, the sub-indices CMSsi, DDTsi, ERsi, and HHRsi predominantly indicated "low risk," demonstrating relative effectiveness in waste management and a reduced threat to environmental and public health (Fig. 2).

Such results are consistent with expectations for rural beaches, which typically have fewer permanent residents and limited accessibility—factors that reduce direct anthropogenic pressure (Araújo et al., 2018). However, this does not render these environments immune to external factors. The vulnerability of these areas to challenges such as inadequate waste disposal infrastructure, irregular seasonal cleaning schedules (Akindele and Alimba, 2021), and the influx of marine litter carried by currents (Assis et al., 2023) can significantly affect their risk profile. In addition, hydrodynamic and climatological conditions may also act as external drivers of litter transport, deposition, and exposure (Hatje et al., 2021). Although these indicators were not considered in this study, macro-tidal conditions (typically between 5 and 6 m) and local climate dynamics (strong winds, usually exceeding 4 m s^{-1} in the second half of the year, and heavy rainfall level in the first half, with accumulations often above 2000 mm for the period) may contribute to increased debris density in the study area. This analysis reinforces the idea that MLRI results should not be interpreted solely through a local lens, but rather in light of broader regional influences that may compromise ecosystems that appear well managed.

In contrast, Atalaia presented a higher debris density, with significant quantities of long-lasting plastic materials—such as disposable cups, cutlery, and packaging—as well as infrastructural deficiencies, including the absence of signage, inadequate waste collection services, and the circulation of vehicles along the beach strip. These factors resulted in "moderate" and "high" risk classifications in sub-indices such as GCsi, ERsi, and HHRsi, indicating more severe impacts and an urgent

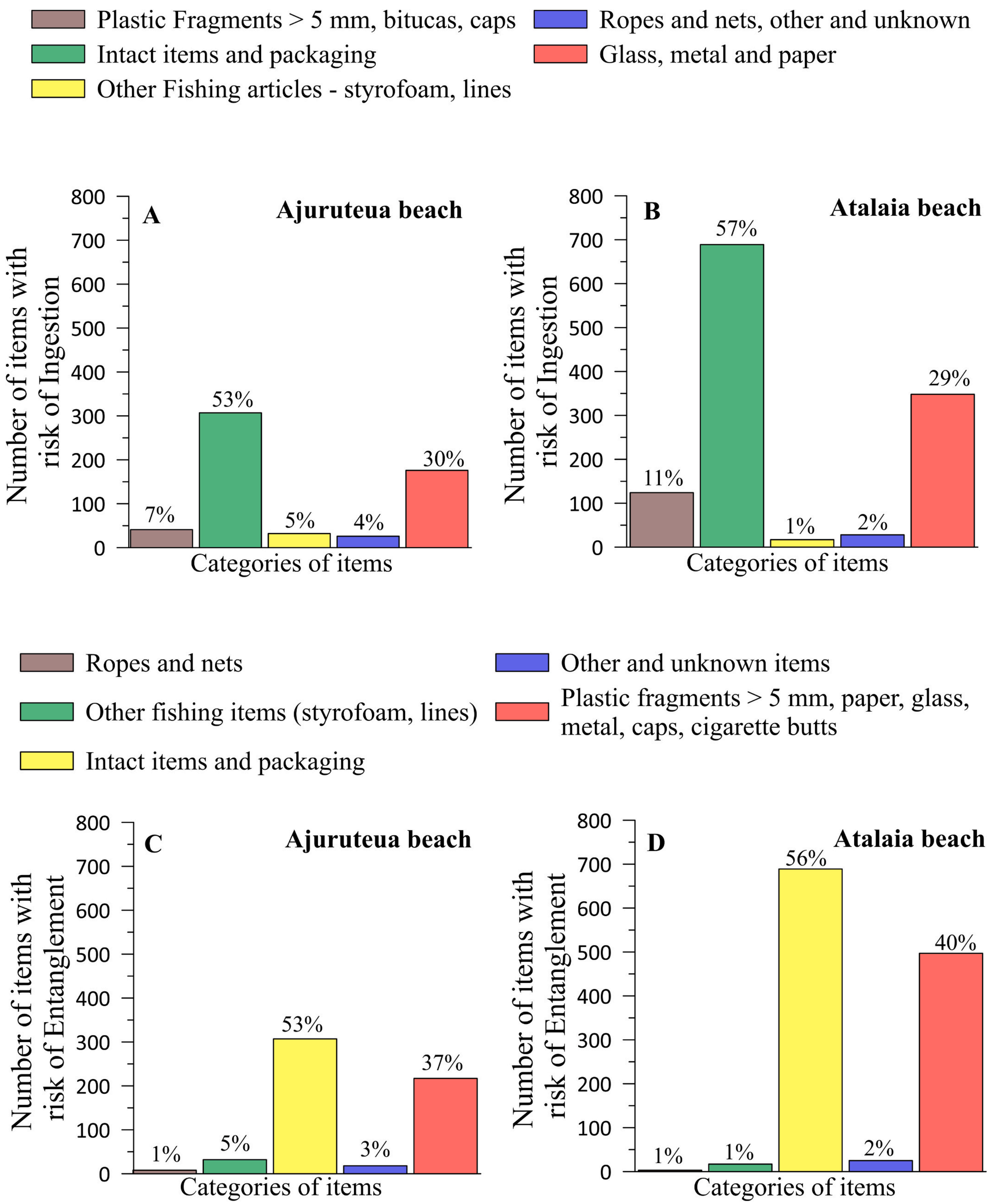

Fig. 4. Number and percentage of categories of items and their risk of ingestion (A, B) and entanglement (C, D) in Ajuruteua and Atalaia beaches.

need for corrective measures (Fig. 2).

These results are also consistent with expectations, considering that village-type beaches generally have few permanent residents and may retain rustic features while remaining relatively preserved in certain areas. However, they tend to have more developed infrastructure, including hotels, resorts, inns, bars, restaurants, and local businesses (Asensio-Montesinos et al., 2019a). Although this type of beach is expected to carry out more effective public cleaning initiatives (Leite et al., 2014), in Atalaia, the high number of visitors combined with the lack of a suitable solid waste management system led to the opposite outcome (Silva, 2014; Pereira et al., 2016, 2018).

Ultimately, the MLRI demonstrated that the growing demand for recreational activities in non-urban coastal zones may require more robust and continuous management strategies, especially during peak periods, when the sharp increase in beachgoers leads to a greater volume of waste and heightened pressure on the environment and existing cleaning systems (Becherucci et al., 2017). These findings accurately reflect the reality of the study areas; however, given the intensification of recreational demand, both beaches require enhanced control measures and the implementation of strategic actions to prevent the escalation of risks. In addition, it is essential to consider other external factors that contribute to the transport and deposition of marine litter, such as climatological and hydrodynamic conditions, as previously mentioned.

Although the MLRI was originally designed for non-urban environments, with sub-indices adapted to their specific conditions, its methodological framework is sufficiently flexible to allow application to urban beaches—provided that certain sub-indices are adapted to reflect the unique characteristics of urban settings. Sub-indices requiring adjustment include the General Cleanliness Sub-index (GCsi), which measures the density of litter per square meter, and the Cleaning and Maintenance Services Sub-index (CMSsi), which quantifies both public and private cleaning and maintenance activities. These adaptations are necessary due to the typically higher visitor traffic and more intensive tourism infrastructure found in urban beach environments. Conversely, the Debris Decomposition Time Sub-index (DDTsi), Environmental Risk Sub-index (ERsi), and Human Health Risk Sub-index (HHRsi) do not require modification, as they are intrinsically linked to the nature of the waste itself. These sub-indices consider degradation time and the associated risks to biota and human health—factors that remain consistent regardless of whether the beach is situated in an urban or non-urban context.

In summary, the MLRI stands out as a promising tool for environmental monitoring and management of non-urban beaches. Its ability to capture diverse realities and guide targeted interventions underscores the strategic value of indicators as facilitators in reducing the risks associated with marine litter.

5.2. Environmental and human health risks of marine litter: origin, composition, and impact

The comparison between the data from Ajuruteua and Atalaia beaches, based on the results obtained from the sub-indices, reveals important differences in terms of environmental and human health risks. In both beaches, the results indicated a high risk to marine biota, with over 90 % of the items classified in the categories of ingestion and entanglement. In the case of Ajuruteua, where fishing activity is more prevalent, more fishing-related items were found—such as nets, lines, and ropes—that can cause asphyxiation, serious injury, or death in marine animals (Kühn et al., 2015; Murphy et al., 2017; Steer et al., 2017). However, the volume of such materials is still lower than in high-pressure fishing beaches like those in the Mediterranean region (Asensio-Montesinos et al., 2019b), suggesting that despite the relevance of fishing in Ajuruteua, the direct disposal of these items remains relatively controlled.

On the other hand, Atalaia displayed a predominance of plastic debris, especially those linked to local recreational activities, including disposable cups, packaging, and plastic utensils (Campani et al., 2013; Wright et al., 2013; Romeo et al., 2015). This type of waste poses a significant threat to marine fauna due to its potential to cause gastrointestinal blockages, malnutrition, and death by accidental or secondary ingestion (Gall and Thompson, 2015; Remy et al., 2015; Vandermeersch et al., 2015; Alomar et al., 2016; Gusmão et al., 2016; Digka et al., 2018). The presence of these materials underscores the environmental vulnerability of the beach, particularly during peak tourist seasons, and highlights the need for public policies targeting single-use waste.

With regard to human health, the results pointed to a specific concern at Atalaia beach, where various sharp objects, such as fragments of long-neck bottles, were found. Although they do not account for a large proportion of the total waste, these items pose a direct risk to beachgoers and are associated with improper disposal during leisure activities. Previous studies (Whiting, 1998; Abu-Hilal and Al-Najjar, 2004) have reported this type of hazard on several beaches around the world, and its inclusion in health risk indicators has been considered limited, focusing mainly on sharp objects (Ivar do Sul and Costa, 2007).

Thus, the data reveal that Ajuruteua concentrates ecological risks linked to fishing, while Atalaia demonstrates risks to the environment, biota and public health due to disorganized recreation and lack of waste management. The analysis of debris types and their implications reinforces the importance of integrated management measures that take into account not only the volume of waste but also its origin, composition, and impact on ecosystems and coastal populations.

5.3. Implementation of public policies

The formulation and implementation of public policies aimed at solid waste management in coastal areas represent a critical strategy in addressing the growing environmental and public health impacts caused by macro-litter accumulation. In this context, the Macro Litter Risk Index (MLRI) emerges as a valuable tool for diagnosing environmental and human health risks, while also guiding governmental interventions, particularly in areas characterized by deficient infrastructure and limited visibility of ecological challenges.

The application of the MLRI on the beaches of Ajuruteua and Atalaia, for example, demonstrated the index's ability to differentiate socioeconomic contexts and waste generation patterns. While in Ajuruteua a significant portion of the waste is linked to artisanal fishing activities—although recreational practices also play a role—Atalaia exhibits a distinctly tourist-oriented profile, with a high input of waste stemming from unregulated leisure activities. These findings illustrate the diverse origins of marine litter, yet they also reveal a common point between both cases: the urgent need for public policies focused on continuous monitoring and the integration of local specificities into management processes.

Accordingly, these policies must include the implementation of selective waste collection programs, educational campaigns to raise public awareness, environmentally sound waste treatment, periodic clean-up operations, strict enforcement, the development of legal instruments to promote recycling, and cooperative mechanisms between public authorities and the private sector to enable funding and execution of initiatives.

To expand the effectiveness of the MLRI in varying contexts, especially in areas with limited primary data, it is advisable to develop a flexible protocol for application. Such a protocol should consider factors like seasonality, peak visitation periods, usage patterns, and sociocultural and economic dynamics specific to each location. The use of remote sensing and Geographic Information Systems (GIS) can enable the identification of critical waste deposition areas and support decision-making based on high-precision geospatial evidence.

Ultimately, adopting an integrated approach to coastal management—anchored in effective regulation, industrial innovation in material production and disposal, and active consumer engagement—is essential to significantly reducing the impacts of marine litter. This tripartite model is crucial not only at local and regional levels but also with regard to global implications for the conservation of coastal environments and the protection of human health.

6. Conclusions

The conclusions of this study demonstrate that the MLRI results enabled comparisons between beaches with different levels of development, providing a detailed classification of risks and contributing to the assessment and mitigation of environmental impacts. The sub-index results also showed that it is possible to formulate effective guidelines for the development of adequate public policies. In this context, the application of the index revealed that the rural beach of Ajuruteua has more efficient management actions and, as a consequence, presents a lower amount of waste, with a shorter decomposition time, as well as debris with lower environmental and public health risks compared to the waste found on the village beach of Atalaia. Despite Ajuruteua being classified as "Low risk," indicating lower environmental impact, the implementation, monitoring, and control of additional public policies are necessary to ensure beach quality. Conversely, Atalaia was classified as "Moderate," presenting environmental, public health, and economic impacts, which require urgent action to prevent further degradation. Through the analysis of sub-indices, several strategies to minimize impacts can be outlined on both beaches, including environmental education programs to raise awareness among beachgoers about proper waste disposal; installation of more garbage bins to reduce waste dispersion on beaches; increased waste collection frequency, especially during peak tourist seasons; stricter measures to reduce plastic use, such as restrictions on disposable items like cups, plates, and cutlery; prohibition of long-neck bottle sales on beaches to minimize glass waste (specifically in Atalaia); restriction on vehicle circulation in the intertidal zone (specifically in Atalaia), among others. Additionally, adjustments to the classification limits of the first two sub-indices (GCsi and CMSsi) enable the MLRI to adapt to any type of beach, regardless of urbanization levels, making it a versatile and widely applicable tool across different environmental contexts.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2025.118747.

CRediT authorship contribution statement

Ingrid Padilha de Souza: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Luci Cajueiro Carneiro Pereira:** Writing – original draft, Supervision, Resources, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Brenda Ribeiro Padilha da Silva:** Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Rauquírio Marinho da Costa:** Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization.

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.

Acknowledgements

The authors are grateful to the Brazilian National Council for Scientific and Technological Development (CNPq) and Brazilian Federal Agency for Support and Evaluation of Graduate Education CAPES for financial support. The first author was supported by CNPq (141818/2020-4), Silva BRP by CAPES (88887.627073/2021-00). The authors Pereira LCC (314037/2021-7) and Costa RM (314040/2021-8) would also like to thank CNPq for their research grants.

Data availability

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

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