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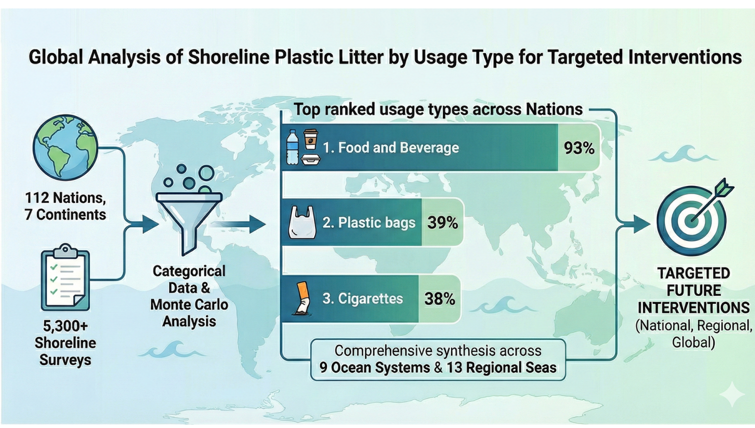
Food and beverage plastics dominate global shorelines: A harmonized rank-based assessment of usage types to guide interventions

Graphical abstract



Highlights

- Food and beverage plastics, plastic bags, and cigarettes dominate global shorelines
- Food and beverage plastics are a top three pollutant in 93% of studied nations
- Monte Carlo analysis provides a confidence-weighted index for 112 nations
- Findings advocate for sectoral, upstream interventions to reduce plastic leakage

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In brief

Plastic pollution is a pervasive environmental crisis, yet global mitigation is often hindered by a lack of item-specific data across diverse regions. This study analyses over 5,300 shoreline litter surveys across 112 nations to provide the first granular global index of macroplastic pollution by usage type. By identifying food and beverage plastics as a dominant pollutant in 93% of nations, this research shifts the focus toward targeted, sectoral interventions and upstream production reduction strategies.

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Food and beverage plastics dominate global shorelines: A harmonized rank-based assessment of usage types to guide interventions

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SCIENCE FOR SOCIETY Our planet faces a growing crisis as plastic debris accumulates in every corner of the ocean. This pollution undermines the health of marine ecosystems, threatens food security, and imposes great financial burdens on coastal communities, particularly in lower-income nations. While we know the problem is vast, a major uncertainty remains: which specific products are the primary culprits on a global scale? Consequently, interventions remain fragmented. We analyzed shoreline litter across 112 nations, representing 86% of the world's population, to identify the most common items by their usage. We show that food and beverage items are nearly universal as a top pollutant, highlighting a clear, high-priority target. These findings mean society can move beyond "one-size-fits-all" solutions. By prioritizing the reduction of specific high-impact items at national and global scales, through targeted legislation and sectoral shifts, we can more effectively safeguard environmental and human health.

SUMMARY

Plastic pollution represents a pervasive global environmental challenge. However, the lack of globally harmonized monitoring hinders the development of targeted interventions. Here, we develop a rank-based approach combining over 5,300 shoreline surveys and Monte Carlo analysis to present a confidence-weighted global assessment of marine litter across seven continents, nine ocean systems, 13 regional seas, and 112 nations, representing 86% of the global population. The analysis shows that food and beverage plastics dominate shoreline debris globally, ranking among the top three most abundant usage types in 93% of nations, followed by plastic bags (39%) and cigarettes (38%). Specifically, plastic food packaging, caps/lids, and plastic bottles were among the top-ranked individual items in over half of all nations. By pinpointing the most prevalent items across national and regional scales, our framework provides critical policy-relevant evidence and associated levels of confidence, indicating the need for targeted upstream responses focused on short-lived plastics.

INTRODUCTION

Plastic pollution is a global environmental problem. Around 460 million metric tons of plastic are produced annually,[1] with cumulative production projected to reach 20,000 million metric tons by 2040.[2] While negative effects are evident along the entire supply chain, they are especially pronounced for end-of-life products, with approximately 20 million metric tons of plastics entering the environment annually.[3] By 2060, the total accumulation of plastic in the ocean is projected to reach 145 million metric tons.[1] This debris has major detrimental impacts on the environment,[4] ecological processes,[5] wildlife,[6] economies, and human health[7,8] and imposes a substantial financial burden,[9] which falls disproportionately on some of the lowest-income nations.[10]

Recent global models indicate that the problem cannot be addressed by waste management alone and that supply-side measures will be essential.[11] Consequently, developing effective solutions to mitigate the impacts requires an urgent focus on identifying and confirming the primary sources of specific plastic items.

While several previous studies have estimated the global magnitude of the problem using either plastic mass or numerical abundance, these macrolevel approaches typically lack the granularity needed to identify the specific sources, such as distinct sectors, usage types, and individual items. This lack of harmonized, high-resolution data represents a critical knowledge gap that severely hinders the development of targeted responses. Lack of clear source attribution represents a substantial barrier to deploying effective upstream measures, including changes in product design, bans, taxation, and extended producer responsibility (EPR) frameworks,[12,13] because policymakers cannot definitively identify which sectors and behaviors are the primary drivers of pollution in their specific region.

In contrast, while there are a multitude of localized, within-nation studies examining marine litter by product category, synthesizing this wealth of data has historically proven challenging.[14] Surveys using a consistent methodology at multiple locations across a nation are scarce and typically rely on localized citizen science programs.[15–18] Consequently, the inability to compare these localized datasets has prevented reliable, global-level understanding of plastic pollution by usage type, leaving international agreements and national action plans without the granular evidence base required to drive specific sectoral interventions.[2]

This gap is a crucial obstacle to addressing plastic pollution. The majority of studies quantifying plastic litter in the environment have focused on items from beaches.[14] While these data reflect a mix of local (e.g., tourism and coastal populations) and distant (e.g., transported by ocean currents) sources, studies have demonstrated that the composition of shoreline litter closely mirrors that of adjacent urban settings and waterways, indicating that beach debris is frequently a reflection of local terrestrial inputs.[19,20] Beaches have also been a focal point for understanding the impact of plastic pollution on wildlife, human well-being, and economies.[21,22] This wealth of shoreline litter data could therefore, provide a valuable, representative index of plastic pollution at national, regional, and global scales.

Here, we present a global assessment of shoreline marine plastic litter by usage type to inform and guide the design and placement of interventions across policy, industry, and society. To overcome the historical limitations of methodological variation among individual studies, we develop and validate a rank-based framework combined with Monte Carlo simulation analysis. By categorizing data from over 5,300 shoreline litter surveys across 112 nations, we identify the top three most prevalent types of plastic debris by usage type for each nation and calculate an associated level of confidence.

RESULTS

Methods summary

Using the Scopus search engine, we identified an initial set of 2,471 litter studies along shorelines by searching across 161 individual nations and territories (Table S2; referred to as nations herein). We then developed and tested a ranking approach that overcomes issues of intercomparability between studies by recording the top three items in each study and then aggregating the data to generate a list of the top three items in each nation. Item descriptors were adopted from the OSPAR (Oslo and Paris Convention) marine litter monitoring guidelines[23] and harmonized into 35 individual item types to align the varying descriptors and terminology used in previous studies (Table S1). Studies that grouped plastic under a single category without identifying the individual plastic items or recorded only one type of litter were removed from the analysis. As fragments cannot easily be attributed to sources, they were also omitted. However, since fragments often result from the breakdown of larger macroplastics,[24] subsequent interventions would, in the longer term, also help reduce the accumulation of microplastics.

This approach to synthesizing the existing literature provided 355 studies describing the prevalence of specific macroplastic items across 94 nations, encompassing over 5,300 shoreline survey locations between 1992 and 2024 (91% were published in the last decade). We evaluated the level of confidence in our findings at a national level using Monte Caro simulation analysis.[25,26] We also interpolated outcomes, at a reduced level of confidence, in a further 18 nations where the amount of data was more limited. Collectively, this consistent approach provided a unique synthesis of the most prevalent plastic item types, with an associated level of confidence, across 112 nations representing 86% of the global population (Table S2). This highlights the potential impact and broad reach of our findings, offering a global analysis of marine plastic litter by usage type.

Global prevalence and distribution by plastic item type

When the data were aggregated across nations, 22 plastic item types were recorded within the top three most prevalent items (Figure 1). Food packaging represented the dominant type of litter, recorded as a top-three-ranked item in 53% of the 112 nations and in 45% of the 355 individual studies. Caps/lids were the second most prevalent item (51% of nations and 38% of studies), followed by plastic bottles (51% of nations and 34% of studies), plastic bags (40% of nations and 26% of studies), cigarettes (38% of nations and 35% of studies), and fishing and shipping gear (34% of nations and 31% of studies) (Figure 1).

When the data were then aggregated by continent or ocean system (Table S2), trends in the proportion of plastic item types were relatively consistent (Figure 1), although some regional-scale variation was apparent. For example, the highest proportion of food packaging items was reported in Oceania, accounting for 25% of the top-three-ranked plastic item types when aggregated by continent. In contrast, food packaging did not appear among the top three items in any of the five studies conducted around the South Shetland Islands in Antarctica (Figure 1). Notably, food packaging was identified as a top-three item in the Arctic Ocean, likely reflecting the presence of small, relatively isolated communities that potentially have very limited access to waste management, compared with Antarctica, where habitation is limited to research stations operating under rigorous waste management protocols. The nations included within each ocean region are listed in Table S2, following the ocean boundaries defined by the Flanders Marine Institute.[27]

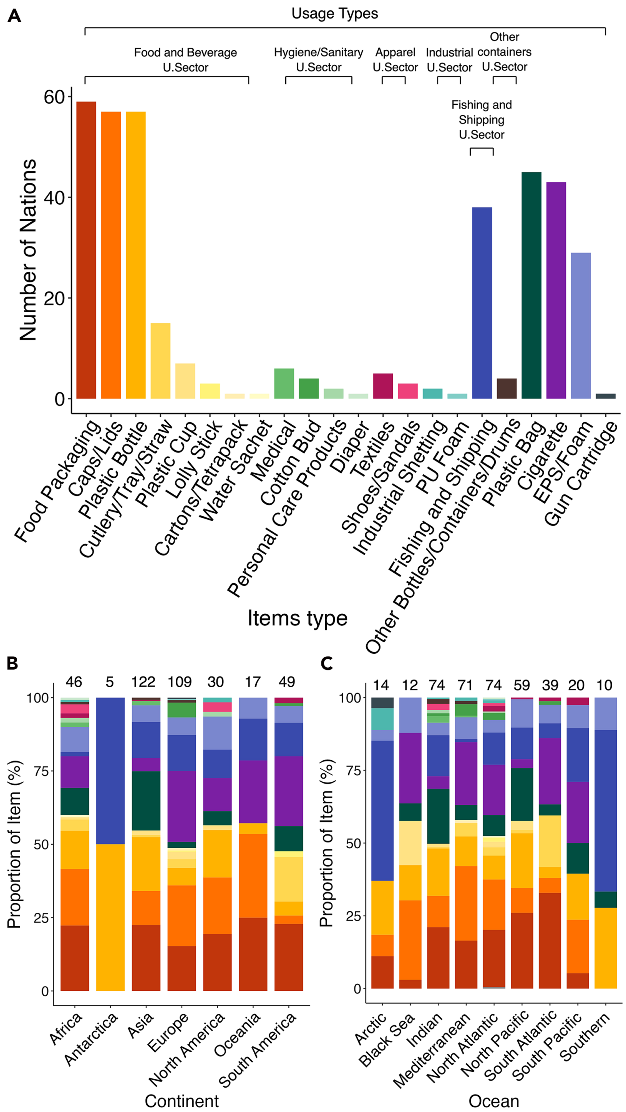

Figure 1. Global prevalence of plastic litter on shorelines

(A) The number of nations (n = 112) where each plastic item was recorded within the top three most frequently found item types; the items are also grouped into relative proportions by (B) continent and (C) ocean system. Item types were subsequently grouped (depicted by horizontal black lines in A) into usage sectors (U.Sector) or left as individual item types when no master grouping was logical. Collectively, these usage sectors and individual item types are referred to here as usage types. Bar colors and labels are consistent throughout. The numbers above the bars (B and C) represent the total number of data points aggregated from all studies. The top three items in each nation, the associated level of confidence, and ocean boundaries are presented in Table S2.

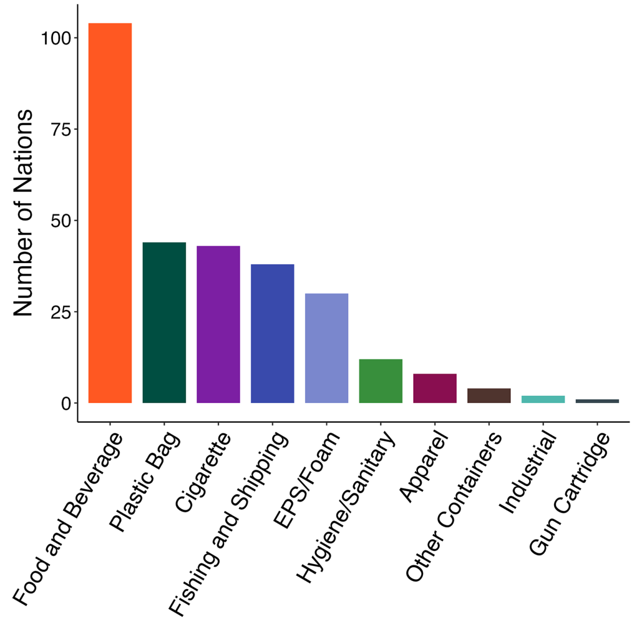

Figure 2. The prevalence of plastic items grouped by usage type

The number of nations (n = 112) where each usage type was recorded within the top three most frequently reported is shown. Usage types with grouped plastic items that are presented include the following usage sectors: food and beverage (food packaging, caps/lids, plastic bottles, cutlery/trays/straws, plastic cups, cartons/Tetra Paks, water sachets, and lolly sticks), hygiene/sanitary (medical, personal care products, diapers, and cotton buds), apparel (clothing and shoes/sandals), industrial (industrial sheeting and PU foam), fishing and shipping items, and other containers (other bottles, containers, and drums).

Similarly, the highest proportion of cigarettes was found in Europe (24% of the top-ranked items), and these were not recorded as a top-three-ranked item for Antarctica or the Arctic (Figure 1). Conversely, fishing and shipping gear, while present on the shorelines of every continent, had the highest proportions (56% of the top-ranked items) on shorelines in the Southern Ocean (including Antarctica, Heard Island, Macquarie Island, and South Georgia and the Sandwich Islands) and the Arctic Ocean (including Canada, Greenland, Iceland, Norway, and Russia) (55% of the top-ranked items) (Figure 1). These distinct spatial patterns demonstrate that, while domestic food packaging and consumer items dominate globally, buoyant marine-related items such as fishing gear are disproportionately prevalent in remote polar regions.

Global plastic pollution by usage type

To provide actionable insights for sector-specific interventions, we categorized the identified litter into broad usage types (Table S1) to evaluate their relative prevalence on a global scale. Groupings for plastic item types identified as being in the top three at the national level are also shown in Figure 1A. The most abundant usage type was food and beverage, which was ranked as a top three usage type in 93% of nations (Figure 2), including the top five most populated nations (India, China, United States, Indonesia, and Pakistan, Figure 3). Plastic bags were the second most dominant usage type, recorded as a top-three-ranked usage type in 39% of nations, followed by cigarettes (38% of nations), fishing and shipping gear (34% of nations), and expanded polystyrene (EPS)/foam (27% of nations) (Figures 2 and 3). The consistent dominance of the food and beverage sector across diverse demographic and geographic scales highlights it as the primary contributor to plastic pollution worldwide.

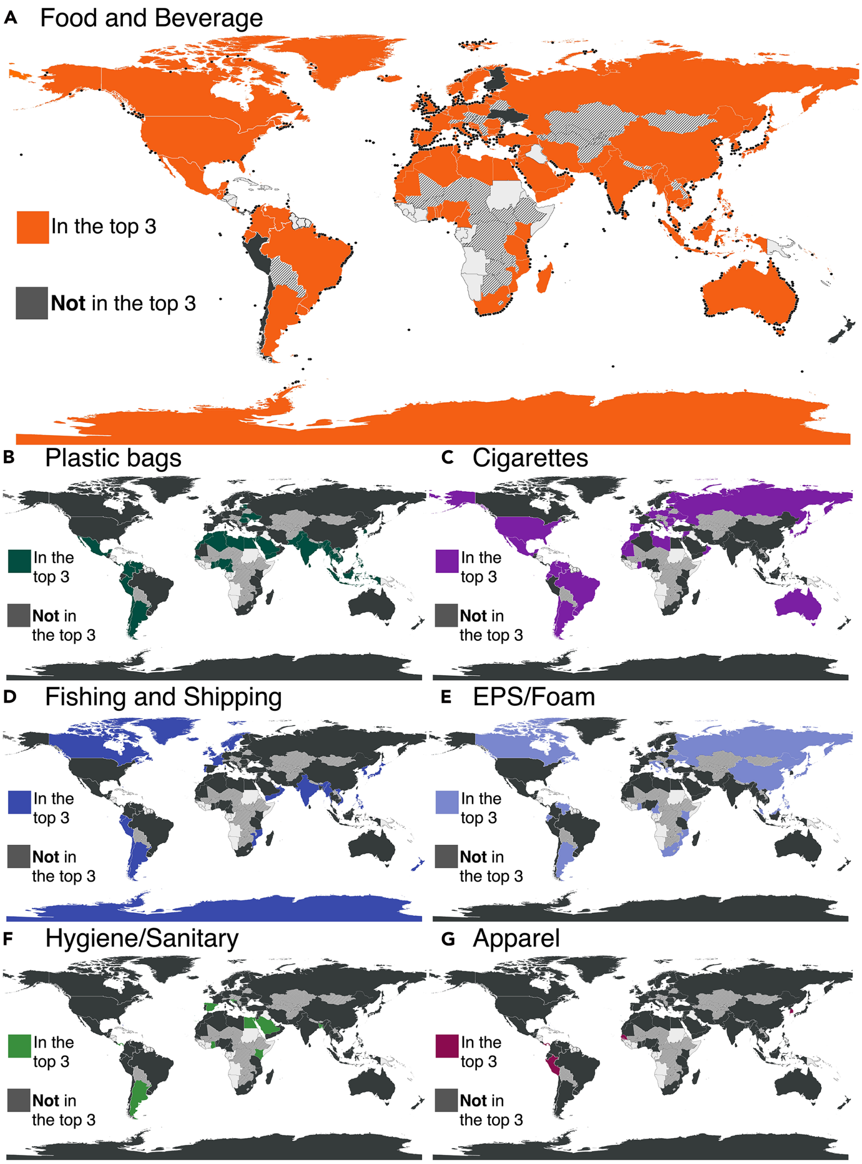

Figure 3. Global patterns of plastic litter by usage type

The ranked abundance from 355 shoreline litter studies across 112 nations and presented by usage type in order of global dominance: (A) food and beverage, (B) plastic bags, (C) cigarettes, (D) fishing and shipping, (E) EPS/foam, (F) hygiene/sanitary, and (G) apparel. Each graphic highlights nations where the respective usage type ranks within the top three for that nation (colored), while nations where the usage type does not rank in the top three are shown in dark gray. Nations with no data (n = 49) or no coastline are shown in light gray or dashed gray lines, respectively, throughout all graphics. Black dots (A) indicate the locations of survey sites (n = 5,342, with overlapping dots representing multiple surveys in the same area) across all nations (same for A–G).

National and regional analysis of plastic debris

To facilitate targeted interventions at both national and regional levels, we provide a comprehensive, ranked-abundance dataset of shoreline litter spanning 112 nations, developed using a consistent approach with a high level of confidence. To guide strategies in individual nations, we present these data at a granular level, detailing the top-ranked items from all studies within each nation across all 35 item types (Table S3).

Building on these national data, we then grouped nations according to the European Union (EU) and United Nations (UN) regional seas programs to identify 28 individual plastic item types for regional-level actions (Figure 4; groupings are highlighted in Table S2). These groupings show the top-ranked items across all of the studies within the North-East Atlantic (OSPAR Convention, n = 44 studies), the Baltic Sea (HELCOM Convention, n = 26 studies), the Mediterranean (Barcelona Convention, n = 86 studies), the Black Sea (Bucharest Convention, n = 26 studies), West Africa (Abidjan Convention, n = 8 studies), the Caribbean Sea (Cartagena Convention, n = 26 studies), the East Asian Seas (Coordinating Body on the Seas of East Asia "COBSEA," n = 55 studies), the Western Indian Ocean (Nairobi Convention, n = 17 studies), the North-West Pacific (Northwest Pacific Action Plan, n = 21 studies), the South-East Pacific (Lima Convention, n = 15 studies), the South Asian Seas (South Asia Co-operative Environment Programme, n = 31 studies), the Red Sea and Gulf of Aden (Jeddah Convention, n = 4 studies), and the South Pacific (Noumea Convention, n = 14 studies).

This presentation revealed trends in the types of items and usage types across regions. For example, plastic bags were consistently prevalent across all Asian regions. The industrial usage sector was most prevalent within EU regional seas (including Black Sea, Baltic, and North-East Atlantic) and the North-West Pacific. EPS/foam was consistently prevalent throughout all regions, excluding the Red Sea and Gulf of Aden, and proportionally highest in the North-West Pacific, accounting for 17% of the top-ranked items recorded. The highest proportion of apparel was in the South-East Pacific and East Asian Seas regions, and the highest proportion of hygiene/sanitary-related items were in the West Indian Ocean and Red Sea and Gulf of Aden. However, the most dominant usage type across all regions was the food and beverage sector (Figure 4). This regional categorization revealed that, while there is evidence of local variability, the composition of shoreline litter remains remarkably consistent across different regional seas.

Confidence levels in identifying top plastic item types

To assess the robustness of our ranking approach across diverse datasets, we utilized Monte Carlo simulation analysis[25,26] to assess the probability of accurately identifying the

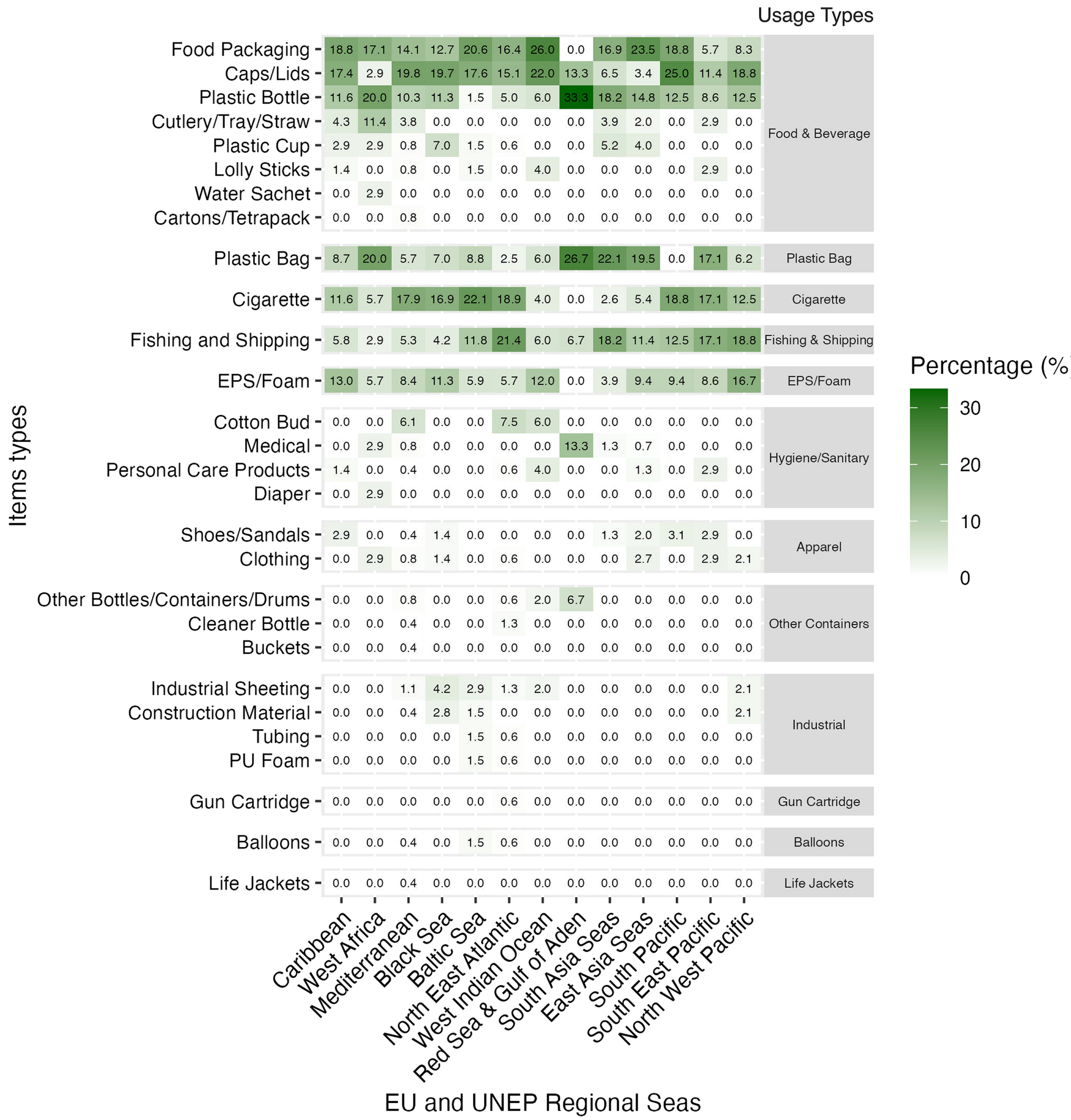

Figure 4. Prevalence of plastic litter across EU and UNEP regional seas

The percentage of instances (%) in which each item type appears in the top three items across all studies in a regional sea, divided by the total occurrences of all top three items in the same regional sea, multiplied by 100 (displayed numerically and in a green color scale). Usage type groupings are presented in gray boxes, and nations within each regional sea convention are presented in Table S2.

top three item types per nation based on the available number of studies. For instance, the number of within-nation studies in our global dataset (n = 355 studies) ranged from 1 to 27, with an average of one study for every 333 ± 69.5 (SE) km of coastline, globally. This analysis showed that there was greater confidence in determining the top-three-ranked item types for nations with a greater number of studies, which often corresponded to countries with larger populations. For example, our approach indicated >90% confidence for 11 nations containing 33% of the global population and >50% confidence for 40 nations containing 65% of the global population (population data from the UN[28]). Conversely, nations where we were less confident, with fewer studies, were often less populated. For example, 38 nations had less than 20% confidence, yet they collectively represented only 10% of the global population (Table S2). Consequently, our methodology yields the highest confidence in heavily populated nations with extensive datasets, while highlighting critical data gaps in less populated regions.

DISCUSSION

Global plastic pollution by usage type

The overarching objective of this study was to combine marine debris datasets from multiple individual studies in order to provide greater clarity on the key usage types and sectors to help guide interventions. Across all 355 studies encompassing 35 item types, plastic litter accounted for 97% of the litter items recorded from over 5,300 survey locations, clearly justifying our focus on plastics (any non-plastic items are shown in Tables S2 and S3). The most abundant usage type was food and beverage, which was ranked as a top-three usage type in 93% of nations (Figures 2 and 3). Within this dominant category, the individual items most responsible were food packaging, caps/lids, and plastic bottles, which were among the top-ranked individual items in over half of all nations. Plastic bags were the second most dominant usage type, recorded as a top-three-ranked usage type in 39% of nations, followed by cigarettes (38% of nations), fishing and shipping gear (34% of nations), and EPS/foam (27% of nations).

Our findings broadly align with data on both the quantities of plastic usage types produced and those reported within waste management systems. For example, conservative estimates indicate that food and beverage packaging accounts for up to 20% of all plastics produced,[29] the majority of which are for single use,[30] which accounts for around half of the global plastic waste that is generated.[13] Additionally, short-lived plastic products account for approximately 70% of the total volume of plastic waste globally.[1] Mass production of short-lived plastics, population density, and urbanization are the likely primary factors driving the high prevalence of the food and beverage sector across global shorelines.

These results further reinforce the direct link between plastic production volumes and environmental pollution.[12] The global consistency of shoreline debris according to usage type (Figure 3) provides the critical evidence needed to guide targeted interventions under the emerging UN Global Plastics Treaty and national-level action plans. Critically, our findings provide direct evidence of items that are prevalent as litter in the environment and could therefore be proposed for inclusion in the treaty's annexes of "problematic and avoidable plastic products" (e.g., Annex B).[31] The global dominance of food and beverage plastics, as described here, emphasizes the need for upstream measures, including production reduction strategies aimed at high-production, single-use items.

Other usage types appeared in much lower abundances. Although some recent localized studies have shown an elevated abundance of medical-related litter associated with the COVID-19 pandemic,[32,33] collectively, hygiene/sanitary occurred as a top-three usage type in only 11% of nations (Figures 2 and 3). Similarly, the prevalence of apparel was also low (7% of nations). While our study included EPS/foam items that were >25 mm and reallocated any identifiable EPS/foam products to their respective usage types (e.g., food packaging or fishing and shipping gear; Table S1), the prominence of EPS/foam may be partially driven by its high friability. This suggests that EPS/foam counts are inflated by fragmentation, masking the material's original source. While some reports indicate that fragments are more likely to be underreported in beach surveys,[34,35] our emphasis on larger items is a reflection of the mass of plastic debris that will ultimately become fragments. From the perspective of intervention prioritization, any size-related detection biases are unlikely to influence the relative importance of larger intact items on which our analysis is focused. Other potential biases might include the disparity of beach cleaning events between regions. These could introduce variability among datasets used in the analysis; however, the strength of the trends identified indicates the extent of any such biases to be relatively small.

Regional trends and targeted interventions

While universal drivers, such as mass production, high consumption, and short usage life, dictate the broadly consistent composition of shoreline pollution globally, as highlighted above, some distinct regional-level differences and spatial variations (Figure 4) highlight the influence of ocean transport and local geography. Although previous studies have established that shoreline debris is generally representative of local terrestrial waste generation,[19,20] the extent to which beach litter reflects purely local drivers varies geographically.

Plastic bottles, for instance, were present on shorelines in every ocean system, with their relative proportion increasing toward the poles. Plastic bottles accounted for 50% of the top-three-ranked plastic item types in Antarctica (Figure 1B), 18% in the Arctic, and 28% across the shorelines of all nations in the Southern Ocean (Figure 1C), compared with 12% of the total items recorded globally. Plastic bottles can travel substantial distances,[36] and global analyses of floating marine litter indicate that macroplastic items, including fishing- and shipping-related items, contribute the greatest proportion of positively buoyant marine plastic by mass in the open ocean.[37,38] Therefore, the combination of low population densities and high transport potential for buoyant litter in circumpolar currents are likely the main factors explaining the greater prevalence of fishing- and shipping-related items and plastic bottles across polar shorelines (Figure 1).

The high capacity for positively buoyant items to be transported between regions introduces potential error when using shoreline data to represent national-level consumption and littering patterns. This effect is likely to be more pronounced for sparsely populated locations situated within large ocean systems or in proximity to ocean circulation features, such as gyres, that are known to concentrate debris.[39] As a result, for small oceanic islands, including many small island developing states (SIDSs), linking beach data to local drivers of pollution may be particularly challenging.

Our analysis also revealed some outlier items such as life jackets and gun cartridges, which represent very specific sources of litter and were found as top-three-ranked items only in Greece and Iceland, respectively (Table S3). The underlying drivers for the prevalence of these items may require further investigation to help guide national-level policy intervention. For example, the globally unique prevalence of abandoned life jackets on Grecian shorelines may reflect journeys made by migrants in small boats, but more detailed information on specific locations and circumstances would be needed to confirm this.

Policy measures on specific items have already been shown to be highly effective in some countries, indicating the data provided here could be of considerable value in guiding the focus of national legislation in other locations. For example, with plastic bags, strategies such as taxation have proven effective in driving reductions (e.g., UK and Ireland), reinforcing the utility of fiscal levers[40] and indicating the need to prioritize the waste hierarchy via the promotion of reusable alternatives over single-use

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disposable options. It is also important to recognize that, in certain essential contexts, such as the provision of potable water in regions with inadequate water utility infrastructure, single-use formats may remain a critical, affordable solution.

The scale of pollution from cigarettes remained high in the Mediterranean, despite a general decline in global smoking prevalence. For both cigarettes and plastic carrier bags, a switch to alternative materials with enhanced biodegradability is widely suggested and may offer potential as a policy intervention. However, there is a growing body of evidence that some of these formulations do not readily degrade in the open environment.[41] Hence, while our data can help indicate priority items for intervention, it is of key importance to ensure that any alternatives and substitutes are adequately tested before they are promoted in order to avoid the risk of regrettable substitutions.[42,43] With cigarettes, a focus on sustained behavior-change initiatives, including public health campaigns that align health and environmental goals, likely represents a more robust and systemic intervention pathway.

Framework for global data harmonization

Source attribution is a key step toward effective intervention. However, individual studies typically lack the granularity required to inform targeted interventions aimed at particular items or usage types. For example, from the initial Scopus search, which identified 2,471 studies on shoreline litter, only 355 provided data on specific item types. The ranking approach developed here addresses this limitation by enabling comparison among the most prevalent types of litter by usage type across multiple different studies, geographies, and nations even where different sampling methods and efforts have been used. Therefore, our approach overcomes the previously outlined limitations of comparing patterns in litter data across highly variable studies.[44]

Furthermore, we utilize existing data grounded in the primary literature and determine an associated level of confidence for each nation via Monte Carlo analysis, thus reducing the necessity for additional and costly harmonized large-scale datasets and increasing policy-level confidence to act on existing data. The top-ranked items we have identified globally are similar to those reported by the International Coastal Cleanup (cigarette butts, plastic bottles, bottle caps, and food wrappers), highlighting agreement with large-scale citizen science projects.[18] These data could help reinforce and supplement our global dataset in regions where peer-reviewed information is limited, notably among the nations where confidence in item rankings is low (Table S2).

The utility of our rank-based framework could potentially extend beyond marine plastic pollution to other disciplines, where data comparability remains a critical bottleneck.[45] For example, in ecological surveys of species abundance, methodological approaches can vary widely, ranging from direct observation to remote sensing and the use of artificial intelligence, or between quadrat surveys with a defined spatial extent and timed searches delimited by survey duration. Similarly, in global fisheries and marine biodiversity monitoring, synthesizing stock assessments or bycatch rates is historically confounded by regional variations in gear types (e.g., trawl nets vs. acoustic surveys), distinct catch units (e.g., catch per unit effort vs. total biomass), and differing temporal scales.[46] Applying a ranking and confidence-testing methodology to these datasets could allow researchers to identify trends in dominant species assemblages or global prevalence of invasive species or to prioritize conservation targets across regions where raw data intercalibration is deemed challenging.[47]

A limitation of the available data, which our approach cannot address, is the absence of quantitative data to compare actual numerical abundance between item types. Therefore, while our analysis reveals the usage types on which to focus interventions, monitoring the success of any interventions will ultimately require a more quantitative approach, ideally monitoring close to the source of the item or the intervention and aligned with baselines and targets. For example, plastic bags, which were a key item of beach litter identified in this study (Figure 3), have been a target for national bans, taxes, and voluntary initiatives. Since 2003, over 30 African nations have implemented plastic bag bans.[48,49] While the primary focus of our study was to help prioritize future intervention points, it is interesting to note that some nations without such bans (e.g., Egypt, Algeria, and Nigeria) had plastic bags among the top three item types. In contrast, four nations with bans (Kenya, Tanzania, Mozambique, and Madagascar; Figure 3) do not. However, four nations with bans (Morocco, Tunisia, Senegal, and Cameroon) did have plastic bags as a top-ranked item. Legislative measures introduced in these nations range from 2003 in South Africa to 2020 in Tunisia, potentially indicating a lack of enforcement (South Africa) or a lag between implementation and outcome (Tunisia). Thus, while our methodology highlights the specific targets for policy, these variations underscore the concurrent need for robust enforcement.

Conclusion

Our results demonstrate that shoreline debris offers a robust barometer of debris composition by source and sector across national and global scales, thereby providing a strong evidence base by which to prioritize interventions. Our analysis consistently identified food and beverage items, plastic bags, cigarettes, and fishing and shipping as priority usage types for interventions. Specifically, plastic food packaging, caps/lids, and plastic bottles were among the top-ranked individual items in over half of all nations. We suggest that substantial global reductions in plastic pollution could therefore be achieved by adopting a sectoral approach tailoring interventions toward these specific product categories. Prioritizing measures within the food and beverage sector offers substantial potential to reduce levels of plastic pollution nationally, while including food and beverage items, plastic bags, cigarettes, and fishing and shipping debris as problematic items within annexes to the UN plastic treaty provides the potential to prioritize measures addressing plastic pollution on a global scale.

METHODS

Collating and ranking existing data

The Scopus search engine was used with search terms in English: Plastic OR Litter OR Debris AND Beach AND ‘nation of interest’ to identify research articles describing litter on shorelines for 161 nations with a coastline (including 9 non-independent nations; Table S2). This returned an initial 2,471 research articles.

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Although the search terms yielded a predominance of data from sandy beaches, the dataset also encompassed mangroves, rocky shores, tidal flats, and estuaries (Table S2). Consequently, the collective term "shoreline" is used throughout to reflect this habitat diversity. As is typical of marine litter monitoring data, while individual papers used consistent "*within*" study methods, both the methods and the units of measurements varied "*between*" studies. To overcome the issue of differing sampling methods, we developed an approach using ranks to evaluate trends in the prevalent item types across the individual studies within each nation. For each individual study, the three most abundant items of litter (including plastic and non-plastic items) were determined, based on the quantification method used in that particular study. This then allowed subsequent comparison of the top-three-ranked items across all studies within each nation.

In cases where studies had conducted surveys across multiple nations and/or coastlines, rank data were extracted for each and used as separate data points as depicted in Figures 1A and 1B (and identified in Table S2). As the vast majority (86%) of global literature uses count rather than mass when recording the quantities of litter,[14,44] when an individual study had used both count and mass to quantify abundances, count data were used. Therefore, our synthesis reflects trends in litter types based predominantly on count data. Ranks determined by mass were used only when a study had quantified item prevalence exclusively by mass (<5% of studies).

Studies that grouped plastic under a single category without identifying the individual plastic items, or recorded only one type of litter, were removed from the analysis. Studies that described shoreline litter on lakes were also removed to provide consistency in our approach across all data. While unidentifiable plastic fragments frequently rank among the most abundant items in raw shoreline counts globally,[34] fragments and microplastics were excluded from our rankings. Not only are they challenging to reliably enumerate during visual *in situ* surveys but their difficult source attribution makes it difficult to design and facilitate targeted interventions. However, because the majority of these fragments result from the breakdown of larger macroplastics,[24] prioritizing macrodebris provides clear, actionable targets. Consequently, subsequent interventions will also help reduce the long-term accumulation of microplastics.

Although exact exclusion counts were not systematically subcategorized during full-text screening, a retrospective keyword analysis of our initial search pool indicated that approximately 26% of the retrieved literature focused explicitly on microplastics. Additionally, some reports indicate fragments are more likely to be underreported in beach surveys.[34,35] However, our emphasis on larger items is a reflection of the mass of plastic debris that will ultimately become fragments. From the perspective of intervention prioritization, any size-related detection biases are unlikely to influence the relative importance of larger intact items on which our analysis is focused.

For our analyses, we focused primarily on the peer-reviewed literature obtained through our Scopus search to mitigate some concerns raised on whether citizen science data are sufficiently robust to guide decisions on appropriate interventions.[50,51] Hence, we included citizen science data only when it was explicitly referenced within a peer-reviewed study for a specific nation. The datasets where this is the case are listed in Table S2, corresponding to the respective nations (references 99, 114, 334, 336, and 337 in the Table S2 file).

From the initial 2,471 studies, 355 encompassing 5,342 shoreline litter surveys (4 studies did not indicate the number of field sites highlighted in Table S2) across 94 nations contained data that could be used in our analysis. Item descriptors were initially selected from the 121 OSPAR marine litter categories[23] and then harmonized to align the varying descriptors and terminology used by authors of the publications in the global dataset we had created. This returned 35 different item types across all 355 studies (Table S1). As plastic litter accounted for 97% of the litter items recorded from over 5,300 survey locations, we removed non-plastic items from our analyses across Figures 1, 2, 3, and 4. Instances where top-ranked non-plastic items were recorded within the top three ranks for a nation are shown in Tables S2 and S3.

Across the global dataset we compiled, studies often employed a variety of internationally recognized protocols for characterizing marine litter, including those developed by the UN Environment Programme (UNEP), OSPAR, the National Oceanic and Atmospheric Administration (NOAA), the International Union for Conservation of Nature (IUCN), the Ocean Conservancy, and the Commonwealth Scientific and Industrial Research Organisation (CSIRO).[52] While these protocols share broad objectives, they differ in their item categorization systems and labeling approaches and often distinguish between plastic and non-plastic item types. As a result, the datasets are not uniformly designed to focus exclusively on plastics, which is reflected in the data gathered here.

Source attribution

An overarching objective of this study was to combine multiple marine debris datasets from multiple individual studies to provide greater clarity on the key usage types and sectors. Therefore, we further combined the 35 item types identified across all 355 studies to give seven usage sectors (food and beverage, apparel, hygiene/sanitary, industrial, fishing and shipping, other containers, and non-plastic), with six remaining individual item types (plastic bags, cigarettes, EPS/foam, gun cartridges, balloons, and life jackets) for which further grouping was not appropriate. Collectively, these usage sectors and individual item types are referred to here as usage types to understand the sources of litter (Table S1). Groupings for the plastic item types identified as the top three item types at national and regional levels are also shown in Figures 1A and 4, respectively.

For example, from the perspective of potential interventions according to usage type, it was logical to group food packaging, caps/lids, plastic bottles, cutlery/trays/straws, plastic cups, cartons/Tetra Paks, lolly sticks, and water sachets into a usage sector of food and beverage. Additionally, we grouped clothing items and shoes/sandals under apparel and medical items, personal care products, diapers, and cotton buds within a hygiene/sanitary usage sector, and industrial sheeting and polyurethane (PU) foam were grouped within the industrial usage sector. Fishing- and shipping-related items were grouped as a usage sector from the outset, as these items (e.g., ropes, lines, and nets) were often aggregated together within individual studies. In this approach, items attributed to the fishing and shipping usage sector could then be compared across individual studies. However, for items such as gun cartridges and cigarettes there was no logical master grouping, and so these were left as individual item types to attribute the specific source.

Expanding on the specific groupings, industrial sheeting, PU foam, construction materials, and plastic tubing were grouped within an industrial usage sector, as these materials can have multiple functions across different industries, including agriculture, manufacturing, packaging, and construction. Item types including corks, foils, glass bottles, metal cans, metal pegs, ceramic items, and processed wood, which accounted for 3% of item types, were also grouped into a non-plastics usage sector and presented in Tables S2 and S3 to enable individual nations to identify the most prevalent litter items in their datasets regardless of material type.

Plastic item types that did not fit within a logical grouping were presented individually to attribute the specific source, including plastic bags, cigarettes, gun cartridges, balloons, and life jackets (Table S1). For example, plastic bags are presented individually; although related to packaging, they are used for transporting other goods, in particular, single-use carrier bags for shopping, and therefore require different interventions compared with food and beverage packaging. If plastic bags were added within the food and beverage usage sector, it would only make the patterns in our analysis appear stronger (Figure 3) and we would lose granularity in the data. Thus, plastic bags were left as an individual litter type.

Gun cartridges are a very specific source of litter and ranked within the top three for only one nation (Table S3). Similarly, balloons are also a specific source of litter and can be manufactured from both plastic and rubber polymers and occurred as a top-three-ranked item in only two individual studies. Thus, gun cartridges and balloons were left as an individual litter types.

EPS/foam was presented as one of the following: (1) an individual material type, since when EPS/foam is fragmented and degraded in the environment, the specific usage type can be difficult to identify; (2) where an individual study in our dataset described EPS/foam as fast food containers, the item was categorized as food packaging; (3) EPS/foam described as insulation used for the transportation of fish or used as buoys to suspend nets was grouped into fishing and shipping. Thus, if we were able to identify the source of all the EPS, it would likely further increase the prevalence of the food and beverage and fishing and shipping usage types.

Evaluating the level of confidence for national trends

The number of within-nation studies in our global dataset (n = 355 studies) ranged from 1 to 27, and across all data, there was an average of one study for every 333 ± 69.5 (SE) km of coastline. To assess how the number of studies available influenced the probability of finding the top-three-ranked item types for a nation, we used Monte Carlo simulation analysis.[25,26] This analysis focused on the four nations with the greatest number of studies (Indonesia, n = 19; Spain, n = 16; India, n = 23; and Brazil, n = 27; Table S2), representing diverse socioeconomic structures with high (India, 1.42 billion people) to medium (Spain, 47.56 million) populations. Thus, nations represented by fewer than 15 studies were omitted from the Monte Carlo analysis to avoid confidence estimates driven by insufficient sampling rather than true underlying patterns.

This approach provided robust baseline data, enabling us to predict the confidence level of our findings for all other nations in the dataset. For example, Indonesia is the largest archipelago nation in the world, spanning 34 provinces, including over 7,000 districts and 83,000 administrative villages[53] encompassing 270 million people[54,55] and diverse economic sectors, including tourism, agriculture, fisheries, manufacturing, trade, automotive, and mining.[56–58] India has the second largest population in the world,[28] Brazil is the fifth largest country by land mass (8.5 million km^2 area),[59] and Spain is within the top five GDP nations in the EU.[60] Therefore, we are confident our approach, including subsequent confidence level adjustments described below, can return robust outcomes (the confidence level of finding the top three item types) across additional nations with varying populations, land mass, and socioeconomic settings.

For each of these four nations, the top three item types were first identified by frequency of occurrence across all studies within each respective nation. Monte Carlo analysis[26] then consisted of 5,000 random simulations (Rstudio; version 2023.06.0+421) where studies were consecutively removed at random during each simulation until the items listed as the top three changed. The minimum number of studies required to consistently identify the same top three item types (in any order) was recorded across the 5,000 simulations, with each representing a potentially different random sampling. The likelihood of finding the top three item types could then be calculated for each possible outcome (minimum number of studies required to find the same top three items) across each nation and then averaged across the four nations (Figure S1). This provided the average probability (confidence level) of correctly identifying the top three item types for any given number of studies.

The level of confidence, presented in 10% confidence level bands, was then determined for each of the 94 nations, based on the number of studies available. For example, a nation with 8–10 studies gave a confidence level of 80%–90% (Figure S1) in correctly identifying the top three item types. Although our approach offers a valuable confidence measure to guide decision-makers in assessing the potential efficacy of targeted interventions, future investigation could consider the use of weighted analyses that adjust for disparities in sample size and methodological design and may provide an even more robust depiction of abundance patterns and reduce biases associated with ranking or presence-absence data.

Confidence level adjustments

While Monte Carlo analysis was the primary method for assessing confidence level bands, to account for the influence of spatial and temporal variations in the available data for each nation, confidence level adjustments (between +5% and −5%) were subsequently developed and applied to all nations (highlighted in Table S2). The use of 5% increments was to ensure that changes to a nation's confidence band (in 10% intervals) would require at least two of the three developed conditions to shift consistently in either a positive or a negative direction. This threshold allowed us to account for data quality indicators without overweighting any single factor.

(1) Concordance: the degree of consistency in the top three items across studies within a nation was used as a measure of concordance, indicating whether multiple studies identified similar item types. This was calculated as

Number of studies × 3/*total number of ranked items identified across all studies*.

This highlights the total possible number of items if each study provided different top-three-ranked items divided by the actual number of top-ranked items recorded across all studies within a nation. Nations that had a high similarity (concordance >2.5) between individual studies had a confidence adjustment of +5% (n = 16), as this indicated more studies were finding the same top-ranked items. Nations with a lower similarity (concordance <1.5) had a confidence adjustment of −5% (n = 8). Nations with only one study were not included in these adjustments.

(2) Extent of total coastline covered: a confidence level adjustment was applied to account for spatial variations in data distribution along a nation's coastline. Lower confidence was attributed to cases with sparse data coverage across extensive coastlines, while higher confidence was assigned to cases with concentrated data coverage along the coastlines of smaller nations. This was calculated as

Length of a nation's coastline/number of survey locations.

Nations with at least one survey within every 50 km of their coastline had a confidence adjustment of +5% (n = 31), while nations where surveys occurred at distances >200 km apart had a confidence adjustment of −5% (n = 32). Nations with one survey in every 50–200 km stretch of coastline had no change. The length of each nations' coastline was obtained from the US Central Intelligence Agency (CIA) database (https://www.cia.gov/the-world-factbook/field/coastline/).

(3) Age of data: a confidence level adjustment was applied to account for how recently the data were collected in each nation. A confidence adjustment of −5% was given (n = 18 nations) to nations where >50% of the studies were more than 6 years old (i.e., published before 2019), reflecting a lower confidence in identifying the current top three items on shorelines in that nation.

Interpolating outcomes for nations without primary data

For nations without any relevant shoreline litter studies from which we could extract ranked litter data (n = 67; Table S2), data were interpolated from two or more neighboring nations for which data were available (highlighted in Table S2). The top-three-ranked items were derived by aggregating frequency of occurrence data for each item type recorded across studies within neighboring nations. The initial confidence level for the interpolated nations was calculated as the mean confidence across the neighboring nations, and then a confidence level adjustment of −10% was applied as the outcome was interpolated (Table S2). This provided top-three-ranked item predictions for an additional 18 nations for which no primary data were found in Scopus. Monaco, The Gambia, and Bahrain were also included in the 18 nations for which data were predicted from only one, much larger, nation that surrounded it (France, Senegal, and Saudi Arabia, respectively) for which data were available. These 18 nations were included in the presentation of global patterns of marine litter (112 nations in total). Therefore, from the Scopus literature search including 161 nations with a coastline, data were available for 94. For the remaining 67, it was possible to interpolate outcomes for 18, leaving 49 for which we show no data (Table S2).

RESOURCE AVAILABILITY

Lead contact

Requests for further information and resources should be directed to and will be fulfilled by the lead contact, Max Kelly (max.kelly@plymouth.ac.uk).

Materials availability

This study did not generate new unique reagents.

Data and code availability

All data are available in the main text or the supplemental information. R code and raw data files used in our Monte Carlo analysis are accessible via Zenodo[26]: https://doi.org/10.5281/zenodo.14046868.

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AUTHOR CONTRIBUTIONS

Conceptualization, M.R.K. and R.C.T.; methodology, M.R.K., R.C.T., and P.S.; investigation, M.R.K. and R.C.T.; visualization, M.R.K.; funding acquisition, S.J., R.C.T., and M.R.C.; project administration, S.J.; supervision, R.C.T., S.J., and M.R.C.; writing – original draft, M.R.K. and R.C.T.; writing – review and editing, S.J., M.R.C., M.R.K., and R.C.T.

DECLARATION OF INTERESTS

R.C.T. is an unpaid coordinator of the Scientists' Coalition for an Effective Plastics Treaty.

SUPPLEMENTAL INFORMATION

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Supplemental information

Food and beverage plastics dominate global shorelines: A harmonized rank-based assessment of usage types to guide interventions

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Supplemental Information

Supplementary figures

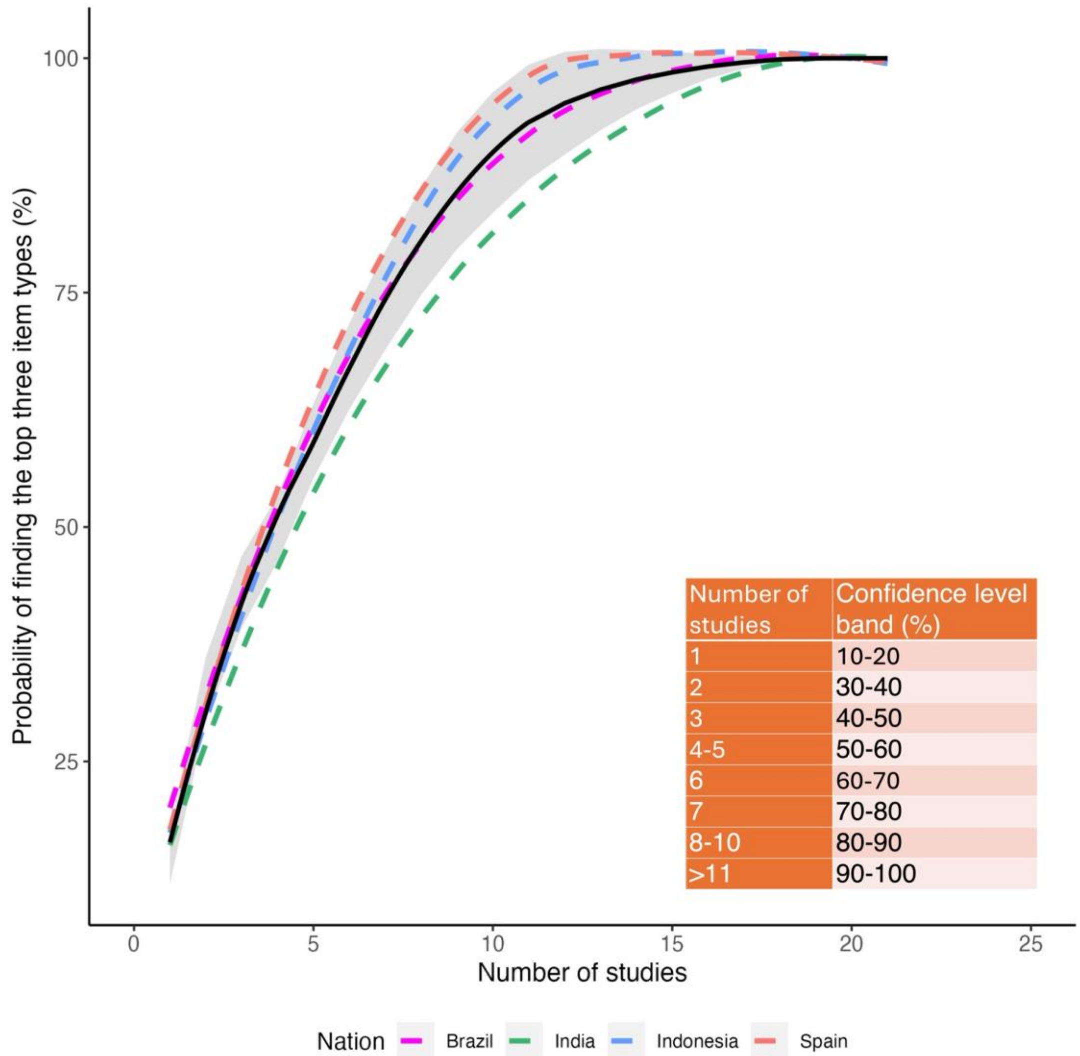

Figure S1. The probability (%) of correctly identifying the top three most prevalent item types from available publications. Derived from 5000 Monte Carlo simulations for each nation (Brazil, India, Indonesia and Spain), indicating how the number of studies available influenced the probability of finding the top three ranked item types. The mean probability across the four nations is represented by the solid black line, with the standard deviation indicated by grey shading. This mean probability was then used to establish confidence levels, categorized in 10% confidence bands (table inset), for each nation based on the number of available studies. For instance, a nation with either 4 or 5 studies had a confidence level within 50-60%. Confidence levels were then further developed to account for the influence of spatial and temporal variations in the available data (see confidence level adjustments in supplemental information).

Supplementary Tables

Table S1. Item types and usage type categorisation. Item descriptors were adopted from the OSPAR marine litter monitoring guidelines[1] and harmonised into 35 individual item types to align the varying descriptors and terminology used by authors in the global dataset of 355 studies (highlighted in column 3). Items are presented by usage type groupings (column 2).

Item Type	Usage type grouping in this analysis[a]	Item classification with reference to OSPAR
Caps/Lids	Food & Beverage	Both are often used interchangeably between different studies or grouped as here (OSPAR ID 15).
Cartons/Tetrapack	Food & Beverage	OSPAR ID 118 and 62.
Cutlery/trays/straws	Food & Beverage	OSPAR ID 22. Though most commonly referring to straws, which was often used as an individual item category in this dataset.
Food packaging	Food & Beverage	Including all rigid and film plastic products when explicitly related to food packaging, such as plastic sachets, and Styrofoam fast food containers (including OSPAR ID 6 and 19, excluding lolly sticks as used a separate category below).
Lolly stick	Food & Beverage	Most commonly related to plastic lolly sticks and used as a category in isolation (not incorporated with crisp/sweet packets, unlike OSAPR ID 19).
Plastic bottles	Food & Beverage	Including any plastic drinking bottle (OSPAR ID 4).
Plastic cups	Food & Beverage	Any type and size of plastic cup (OSPAR ID 22).
Water sachet	Food & Beverage	No OSPAR equivalent.
Cotton Bud	Hygiene/Sanitary	OSPAR ID 98
Diaper	Hygiene/sanitary	No OSPAR ID.
Medical	Hygiene/Sanitary	Including surgical N95 face masks, gloves (OSPAR ID 113), hazard suits, face shields, syringes (OSPAR ID 104) and swabs (OSPAR ID 105).
Personal care products	Hygiene/Sanitary	Including cosmetic items such as shampoo (OSPAR ID 7), wet wipes (other sanitary items, OSPAR ID 102) and household products

		including dishwashing soap and detergent packaging.
Clothing	Apparel	Discarded clothing and fabric (including OSPAR ID 59, 21 and 54).
Shoes/Sandals	Apparel	Included all footwear types (OSPAR ID 44).
Other bottles, Containers and Drums	Other Containers	OSPAR ID 12
Buckets	Other Containers	OSAPR ID 38.
Cleaner Bottle	Other Containers	OSPAR ID 5.
Construction material	Industrial	Including any type of construction material (excluding wood). Not only related to ceramics as described in OSPAR ID 94.
Industrial sheeting	Industrial	OSPAR ID 40
Polyurethane (PU) foam	Industrial	OSPAR category 45. When explicitly stated and not referring to EPS/foam.
Plastic Tubing	Industrial	No OSPAR equivalent.
Plastic bags	Plastic bags	Including any size of plastic bag. E.g. small freezer bags and shopping bags (i.e. OSPAR ID 2 and 3).
Cigarette	Cigarette	Including cigarette butts (OSPAR ID 64), lighters (OSPAR ID 16) and packs (OSPAR ID 63). Most often reporting individual cigarette butts.
Fishing and shipping	Fishing and Shipping	Included synthetic items when explicitly stated for use in fishing or shipping practices including fishing lines, nets, rope, buoys/floats and string/cord.
Expanded polystyrene (EPS) /Foam	EPS/Foam	Items >25 mm were considered. Presented as either: a) an individual material type as when EPS/Foam is fragmented and degraded in the environment the specific usage type can be difficult to identify so not included; b) food packaging, when a study described EPS/Foam as fast food containers; C) fishing and shipping, when a study had described the use of EPS/Foam for the transportation of fish or used as buoys to suspend nets in the ocean.
Gun Cartridge	Gun Cartridge	OSPAR ID 43.

Balloons	Balloons	OSPAR ID 49.
Life Jackets	Life Jackets	No OSPAR equivalent.
Corks	Non-plastic	OSAPR ID 68.
Foils	Non-plastic	No OSPAR equivalent. Foil food wrappers (OSPAR ID 81 incorporated into food packaging above).
Glass bottle	Non-plastic	OSPAR ID 91.
Metal cans	Non-plastic	OSPAR ID 76 and 78 as the function is not always indicated by authors.
Metal pegs	Non-plastic	Referring to tent pegs. No OSPAR ID.
Other ceramic	Non-plastic	OSPAR ID 96.
Processed wood	Non-plastic	Excluding natural drift wood.

[a]Colored labels correspond to the colored bars in Figs. 1, 2 and 3 (in the main text). Usage type labels without colors are shown in either Fig. 4 (main text) or tables S2 and S3.

Table S2. Global dataset for all 112 nations. Data used within our analysis across all nations including location, continent and ocean systems, top three item ranks, number of studies, Monte Carlo results, confidence level adjustments, population and length of coastline.

- Attached as a separate excel file - table S2

Table S3. National rankings for all 35 item types. Total list of all item ranks, including non-plastics across 112 individual nations. Data aggregated by finding the top three ranks in all individual studies within a nation.

- Attached as a separate excel file - table S3

Supplementary References:

1. Wenneker, B., and Oosterbaan, L. (2010). Guideline for Monitoring Marine Litter on the Beaches in the OSPAR Maritime Area. Edition 1.0.