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Critical Review

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Global Review of Beach Debris Monitoring and Future Recommendations

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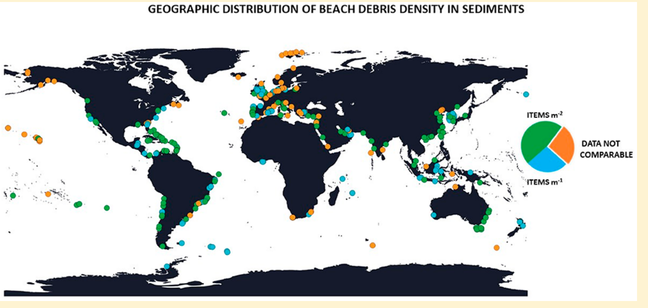
Supporting Information

ABSTRACT: Marine debris is distributed worldwide and constitutes an increasing threat to our environment. The exponential increase in the level of plastic debris raises numerous concerns and has led to an intensification in plastic monitoring and research. However, global spatial and temporal patterns and knowledge gaps in debris distribution, both on land and at sea, are relatively poorly understood, mainly due to a lack of comprehensive data sets. Here, we critically review the quality of the available information about beach plastic debris worldwide to highlight where the most urgent actions are required and to promote the standardization of reporting metrics and sampling methods among researchers. From a total of 174 studies evaluated, 27.0% reported marine debris densities in metrics that were not comparable. Some studies failed to report basic parameters, such as the date of the sampling (9.8%) or the size of the collected debris (19.5%). Our findings show that current research regarding beach debris requires significant improvement and standardization and would benefit from the adoption of a common reporting framework to promote consensus within the scientific community.



1. INTRODUCTION

Plastic products, especially single-use items, have become widespread in our society, and as a result, production and disposal have increased drastically in recent decades.[1,2] A lack of effective waste management and mitigation strategies, particularly in low- and lower-middle-income countries, has resulted in the accumulation of large amounts of plastic debris in the environment.[3−5] Often termed marine debris, it is defined as any persistent, manufactured or processed solid material made or used by humans and either deliberately or accidentally discarded, disposed of, or abandoned in the marine and coastal environment.[8] Monitoring of aquatic environments suggests the overall level of plastic (typically accounting for 61−87% of debris) is increasing,[4,6,7,9] with plastic production and consumption rates showing no signs of slowing.[10]

At present, plastic debris represents one of the most rapidly expanding and topical environmental hazards, due to the durability of plastic products and their diverse negative impacts on wildlife, habitats, and economies.[11−13] Most, if not all, marine environments (e.g., coastal zones, open ocean, and deep-sea sediments) are now contaminated by debris,[14,15] with significant quantities reported even in the most remote corners of the Earth.[16,17] Debris distribution is influenced by ocean currents, wind, and waves, all of which can fragment items and transport them over vast distances.[18]

Plastic debris can result from numerous human activities but is broadly categorized into either land- or marine-based sources.[19] Approximately 80% of all debris originates on land, being of particular concern in coastal ecosystems where it represents 60−80% of litter on beaches.[14,20] These same areas are important to local communities and tourism; therefore, debris has the potential to damage the aesthetic value of shorelines and, consequently, their economic value. Furthermore, the degradation of these habitats constitutes a major threat for the myriad marine and coastal species that rely on them.[21,22] The accessibility of coastal ecosystems, combined with the visible manifestation of debris on beaches, has led to the majority of data on debris being derived from beach surveys.[23]

In 2015, all United Nations Member States adopted the 17 Sustainable Development Goals (SDGs) as part of the "2030 Agenda for Sustainable Development".[24] Goal 14 aims to conserve and promote the sustainable use of the oceans, including the prevention and significant reduction in marine pollution by 2025. Additionally, in 2016 almost 200 countries united as part of the Convention on Biological Diversity to ratify the "Strategic Plan for Biodiversity 2011−2020", which

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includes Aichi Biodiversity Target 8 that aims to reduce all types of marine pollution by 2020.[25]

It is crucial to measure change and evaluate progress toward established international targets.[26] There has been significant investment in plastic monitoring and research, especially since 2013; however, our understanding of this environmental issue remains largely based on individual surveys reporting the abundance and type of beach debris at single locations.[27−30] In the dynamic marine environment, these one-off surveys provide no information about changes over time, something that can be overcome only with robust sampling at the same site over many years.

A handful of studies have reviewed the literature to identify factors that may influence the global distribution of beach debris[14,23,31−34] and have made recommendations for standardized reporting metrics.[32,35] However, assessing progress against global environmental policy targets remains difficult as the data generated through dozens of single-year, single-location beach debris studies undertaken in recent decades have not been reviewed. Therefore, there is an urgent need for a review and analysis of existing beach debris data so that researchers can better assess the global scale of this issue.

Here, we provide an overview of the available information regarding beach debris abundance worldwide (a) to identify global geographic distribution trends and gaps in beach debris abundance and (b) to evaluate the performance of existing studies against established data standards. Through synthesizing research outputs and translating data into a common language (i.e., reporting metrics), we highlight where the most urgent actions are required to better understand the impacts of marine debris, enabling more effective mitigation policies to be developed.

2. METHODS

2.1. Literature Review. We conducted a systematic review following established methods.[36] An extensive search of the ISI Web of Knowledge database was conducted in April 2018 to search for publications using the following keywords: "beach debris OR beach OR beach litter" combined with "marine debris OR plastic debris OR marine pollution OR plastic pollution OR marine litter OR plastic litter OR plastic marine pollution OR marine plastic pollution OR marine plastic litter". Our search aimed to include all peer-reviewed papers published before December 31, 2017. However, the results missed some entries (see Discussion) and did not include records from the gray literature or popular media. The contemporary literature typically adopts five main categories for debris size; however, there is some disagreement regarding the categories used (e.g., micro- and nanoparticles). Therefore, we use only the two most common debris size categories: macro-debris (>5 mm) and micro-debris (0.2−5 mm).[14,37−40] We excluded all <0.2 mm debris.

On the basis of these search terms, we obtained 1060 publications from 1980 to 2017. Duplicate papers were removed as well as those in which the title or abstract was not related to plastic debris located in beach sediments [e.g., papers on ocean-based debris or chemicals adhered to debris (Figure 1)]. Following this first data filter, a total of 298 papers were considered for future reading, with information extracted from only those papers that included beach sediment debris density data, resulting in a final total of 174 papers (Figure 1). The final references can be found in the Supporting Information.

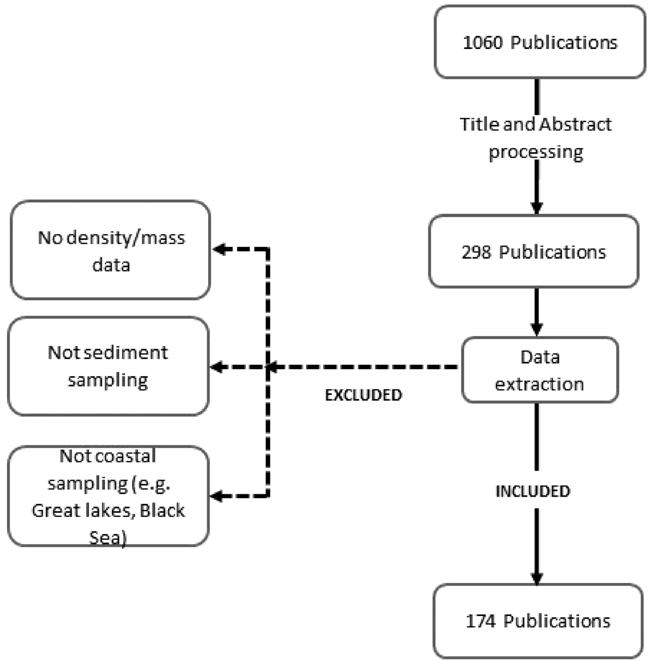

Figure 1. Flowchart showing the decision process for inclusion and exclusion of candidate beach debris literature identified using an ISI Web of Knowledge search.

From these 174 papers, the following information concerning beach debris was extracted, when available, for plastic and nonplastic items: (1) total debris abundance, (2) total debris density, (3) sampling location and year, (4) size class of the sampled debris [macro-plastics (≥5 mm) and micro-plastics (0.2−5 mm)], (5) sampling method [surface (0−2 cm) or buried debris (>2 cm)] with the corresponding depth when applicable, (6) reporting units, and (7) the most common debris item by mass and number. Some studies contained more than one sampling location, and where possible, the beach debris density/mass data were reported for each location independently; otherwise, a mean was reported for all locations combined. In rare instances in which data were reported from vegetated areas (e.g., dunes), it has been excluded from this review. Published values were converted to the same units (items per linear meter or items per square meter), when possible. Macro- and micro-debris densities were split and analyzed independently, because micro-debris densities tend to be much higher and, therefore, not comparable on the same scale with macro-debris densities.

From each study, we also recorded (1) the orientation of the sampling location [leeward (LW) or windward (WW)], (2) whether the sampling was conducted on an island or mainland locality, (3) whether it was a community science study, (4) the duration of the study (number of years: single-year vs multiyear studies) and if the respective multiyear studies went back to the same site (repeated sampling), (5) the number of locations sampled, and (6) if the study recorded information regarding polymer types, colors, types of sediment, and potential debris sources (Table 1). Additionally, to identify possible convenience in selecting the sampling sites, the country of affiliation for the first and last author (i.e., institution where the authors are based) was also recorded. In a few instances, the extraction of specific information (e.g., size of the items and sampling frequency) was only possible due to being suggestive along the reading (e.g., reported as

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Table 1. Proportions of Publications and Sampling Sites Included in This Review with the Reported Factors Known To Influence Marine Debris Densities (174 publications, 715 sites; 1980−2017)

variable	reported metrics	% of publications	% of sites sampled
density	items per linear meter	26.4	36.1
	items per square meter	47.2	42.8
	volume	2.8	3.2
	mass	5.6	5.9
	total items	10.1	4.6
	others[a]	7.9	7.4
size	macro	58.4	67.6
	micro	22.2	19.8
	both	10.8	5.9
	not reported	8.6	6.7
sediment	sandy	54.6	49.4
	mix	18.9	18.7
	others	7.0	4.2
	not reported	19.5	27.8
sampling depth	surface (<3 cm)	68.9	75.2
	buried (≥3 cm)	16.9	15.9
	not reported	14.2	8.9
provenance of items (source)	reported	46.9	47.8
	not reported	53.1	52.2
duration of the study	≤1 year	67.2	52.4
	2−5 years	14.9	22.3
	≥6 years	8.0	17.0
	not reported	9.8	8.2
no. of sampling sites	1	17.8	–
	2−5	32.8	–
	≥6	49.4	–
location	mainland	51.1	41.1
	island	46.7	58.3
	both	2.2	0.6
type of sampled debris	all debris	71.2	75.7
	only plastic	28.8	24.3
item categorization (some examples of the categories used by authors are provided)	material type (e.g., wood, plastic)	55.3	42.5
	use (e.g., footwear)	7.3	14.6
	both (type and use)	26.8	33.3
	only one item (e.g., pellet)	5.6	3.2
	not reported	5.0	6.3
beach orientation[b]	leeward	31.9	31.5
	windward	52.4	59.4
	both	15.7	9.1
polymers identified	yes	14.9	13.
	no	85.1	87.0
colors reported	yes	11.5	7.7
	no	88.5	92.3
community participation	yes	18.4	–
	no	81.6	–
standing stock removed	yes	16.1	8.4
	no	83.9	91.9
transect/quadrat location (e.g., high tide)	yes	71.4	70.0
	no	28.5	30.0
dimensions reported (e.g., transect size)	yes	89.1	85.9
	no	11.4	14.1
no. of replicates reported (e.g., transects)	yes	51.4	39.3
	no	48.0	60.7
frequency of sampling	once (single event)	46.2	23.4
	twice	17.6	17.7
	specific number (>2)	11.5	3.8
	daily	5.5	2.6
	weekly	1.1	1.5
	fortnightly	1.6	1.1
	monthly	2.2	14.8
	bimonthly	15.9	0.3
	seasonally	1.1	3.6
	annually	5.5	3.2
	irregular	3.8	3.3
	not reported	3.3	24.5

[a] A range of other units were used to report the debris density; for example, some studies reported per weight (e.g., items per kilogram) or per unit time (e.g., item grams per day). See Figure 2. [b] Note that only 46.0% of published papers included in this review reported beach orientation; in cases in which this was not reported, the orientation was determined by the authors of this paper.

"visible debris") but not explicitly reported in the evaluated publication.

2.2. Statistical Analysis. A χ^2 test was performed to investigate the relationship between author affiliation location and study location. Kendall's τ coefficient was run to determine the strength of the association between affiliation country of the first and last authors and the sampling country. Both first and last authors are considered to be the most important contributors to each study[41] and were included in our analysis. Three studies were excluded from this analysis because the first author had more than one country of affiliation. Statistical analyses were performed in R 3.5.0 (R Core Team, 2018). Results were considered significant when $p < 0.05$, and data are presented as means ± the standard error.

3. RESULTS

3.1. Geographical Patterns of the Studies. Most papers referring to beach plastic debris were published in recent years, with half of the publications before 2014 (1980−2013) and the other half between 2014 and 2017. The 174 publications considered here contained data from 717 sampling sites in 71 countries (Figure 2), of which only four countries had >10 publications (Australia, Brazil, United Kingdom, and United States). The United Kingdom was the most sampled country, with 64 sampling sites from 17 publications. It was closely followed by the United States (54 sites, 18 publications), Australia (50 sites, 11 publications), and Brazil (48 sites, 18 publications). These same countries also had the highest number of study sites, followed by Indonesia [5 studies, 63 sites, of which 59 were from a single publication[42] (Figure 2)]. Most countries benefitted from only one or two studies of

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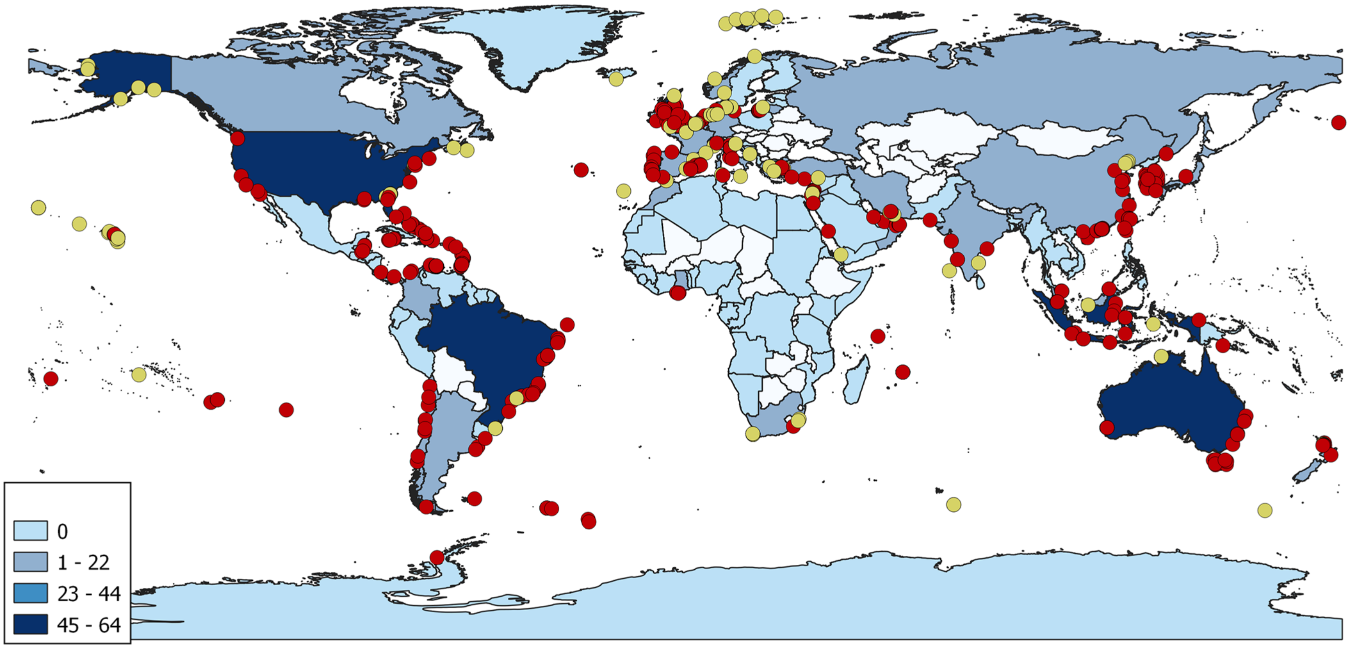

Figure 2. Geographic distribution of studies of beach debris density in sediments using a Web of Knowledge search that were included in this review (174 publications, 717 sites, circles). Yellow circles represent studies that reported their data as items per kilogram (10 publications, 42 sites), items per unit time (4 publications, 12 sites), items per volume (5 publications, 23 sites), or mass per unit area (e.g., grams per square meter; 9 publications, 40 sites). Also represented by the yellow circles are studies that reported the total number of items across all sites (18 publications, 33 sites). Red circles represent the studies that reported the number of debris items per linear meter or items per square meter (131 publications, 566 sites). Countries for which studies are available (n = 71) are colored blue, and countries without any beach debris studies are colored white. The different tones of blue represent the number of sites (darker blue for more publications). Countries without coastline are also colored white (n = 42).

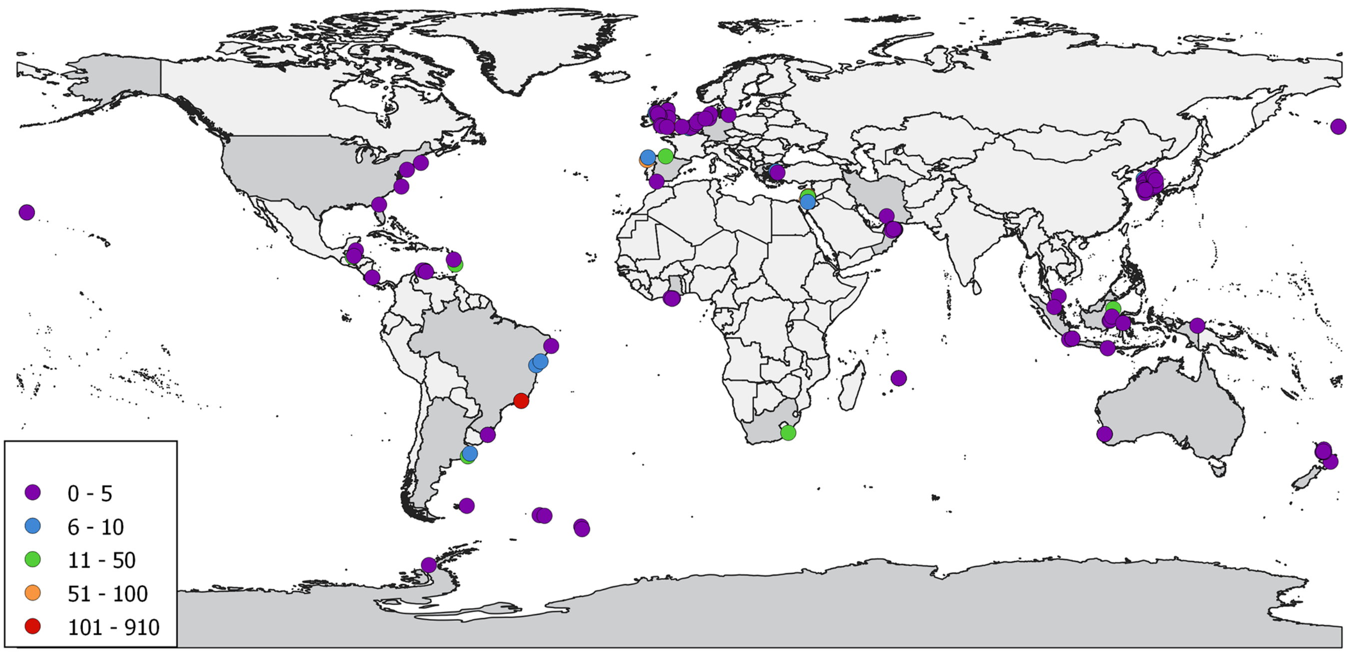

Figure 3. Average density of macro-debris reported in items per linear meter for each site considered in this review (38 publications, 235 sites) between 1980 and 2017. The color spectrum reflects different beach debris densities with red indicating a higher density and purple lowest densities at each site. Countries for which publications were available (n = 28) are colored gray, and countries that lacked beach debris studies are colored white.

beach debris [72.6% (Figure 2)]; for example, Canada has only two studies (both from Nova Scotia[43,44]) despite having the longest coastline in the world, and Antarctica has only one.[45] Only a handful of studies were completed in Africa (6 publications, 17 sites). Islands (417 sites, 86 publications) were represented with more sites than mainland (294 sites, 94 publications), but both had approximately the same number of studies (Table 1).

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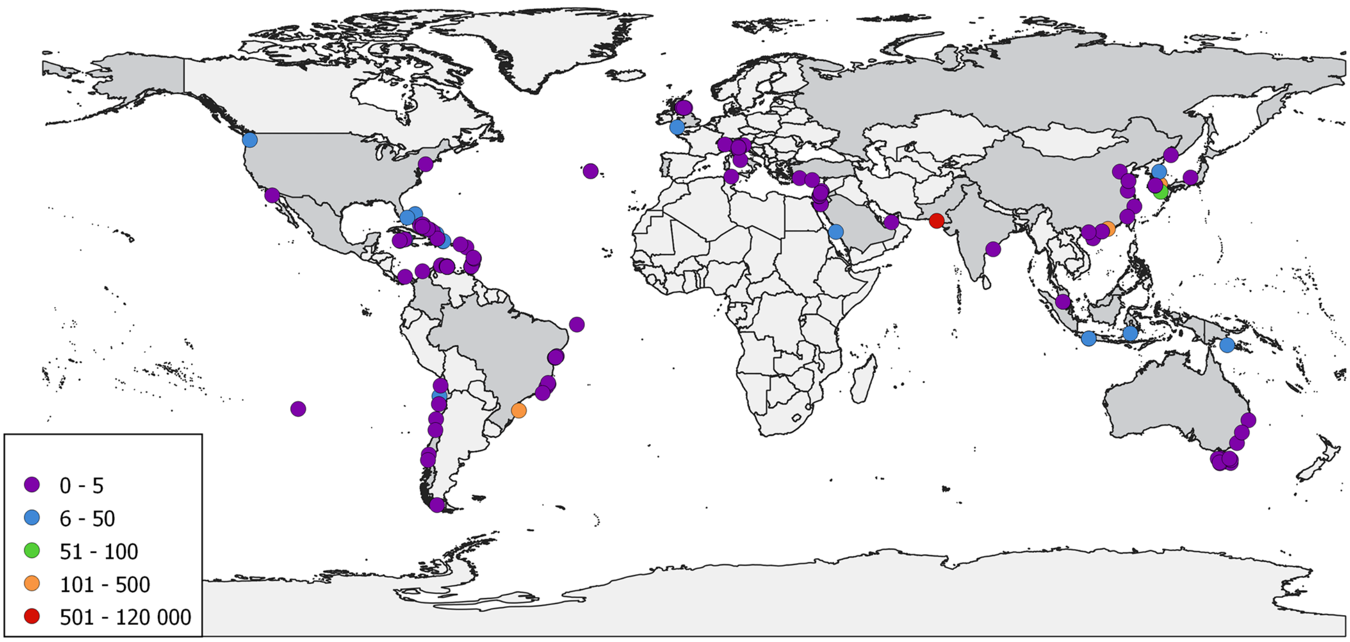

Figure 4. Average density of macro-debris reported in items per square meter for each site considered in this review (50 publications, 183 sites) between 1980 and 2017. Red indicates a higher density of debris, and blue a lower density of debris. Countries for which publications were available (n = 35) are colored gray, and countries that lacked beach debris studies are colored white.

The country in which the study was completed along with the country of the first author's affiliation were highly related (χ^2 = 20806; n = 627; p < 0.001), as was the study country and the country of the last author's affiliation (χ^2 = 21577; n = 627; p < 0.001). There was also a strong and positive correlation between the affiliation of the first (G = 0.62; n = 627; p < 0.001) and last author (G = 0.71; n = 627; p < 0.001) with the sampling country, which was statistically significant.

3.2. Overall Patterns and Reproducibility of Reporting Metrics. Most studies (n = 126; 71.2%; 543 sites) included different types of beach debris, not solely plastic. The proportion of plastic in beach debris among all studies was 70.1% (89 publications, 263 sites). Of the studies that spanned ≥2 years (22.9%; n = 40), nine (22.5%) did not return to the same site for subsequent sampling events (i.e., these "multi-year" studies sampled different regions or countries in different years). The reported metrics and respective proportions are listed in Table 1.

Overall, 131 papers (73.6%) covering 566 sites (78.9%) reported debris density either by linear meter (items per linear meter; 47 publications, 259 sites) or per unit area [items per square meter; 84 publications, 307 sites (Figure 2)]. These units are not comparable; therefore, the results are presented separately below.

3.3. Global Distribution and Patterns of Macro-Debris. *3.3.1. Reported Unit: Items per Linear Meter.* The mean linear density among all sampling sites (n = 259) was 17.97 ± 4.34 items m^{-1}, with both the maximum (906.35 items m^{-1}[146]) and minimum (0.01 items m^{-1}[147]) recorded in Brazil.

Of the studies reporting beach debris per linear meter, the majority sampled only macro-debris items [80.9%; 38 publications, 235 sites (Figure 3)] with a mean density of 18.36 ± 4.77 items m^{-1}. The highest densities of macro-debris were found in Curaçao (253.30 items m^{-1}[129]), Belgium (217.44 items m^{-1}[149]), Israel (126.56−201.42 items m^{-1}[150]), and New Zealand [129.38 items m^{-1}[151] (Figure 3)]. The lowest densities were distributed across the globe and ranged from 0 to 5 items m^{-1} at many sites [68.3%; 36 publications, 177 sites (Figure 2)].

A small number of studies reported both micro- and macro-debris (10.6%; 5 publications, 15 sites). Publications that did not mention the size of the debris sampled (6.4%; 3 publications, 8 sites) were excluded from this analysis.

3.3.2. Reported Unit: Items per Square Meter. The average density of macro-debris across all sampling sites (50 publications, 182 sites) was 1264.92 ± 529.72 items m^{-2}. The highest densities were reported for Pakistan (82964.47 items m^{-2}[52]), South Korea (237.0−238.0 items m^{-2}[53]), China (163.0 items m^{-2}[54]), and Brazil (102.0 items m^{-2}[55]). The lowest densities were widely distributed across the globe and ranged from 0 to 5 items m^{-2} representing 64.2% of the sites [48 publications, 197 sites (Figure 4)].

Most studies that reported debris densities per unit area included only macro-debris [54.9%; 50 publications, 183 sites (Figure 4)] reporting an average of 463.87 ± 455.82 items m^{-2}. Some reported both micro- and macro-debris together (13.1%; 12 publications, 23 sites), and some did not mention the size of debris items sampled (8.8%; 8 publications, 30 sites). Therefore, these were excluded from this analysis.

3.4. Global Distribution and Patterns of Micro-Debris. Only one study reported micro-plastic items per linear meter (2.1%; 1 publication, 1 site) finding 2.96 items m^{-1}.[48] Of studies reporting items per unit of area, 23.1% reported densities of micro-debris (21 publications, 71 sites). The average reported micro-debris density was 4174.74 ± 1942.23 items m^{-2}, ranging from 0.0 to 119182.0 items m^{-2} [21 publications, 71 sites (Table 1)]. The highest densities of micro-debris were found in South Korea (119182.0−8205.0 items m^{-2}[56,57]), Jordan (43947.0 items m^{-2}[58]), China (6675.0−3242.0 items m^{-2}[54,59]), and Japan (2610.0 items m^{-2}[60]), while the lowest densities were recorded in Brazil where no micro-plastics were detected.[61]

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4. DISCUSSION

Overall, from the 174 publications included in this review, we obtained 717 data points, covering a total of 71 countries. Reporting units for the beach debris density data were variable; most contemporary studies reported the density per square meter, while studies undertaken before 2000 typically reported their data per linear meter. For the latter, a lack of information about survey methods means that these studies cannot be reproduced, as there is limited or no information about the actual area sampled. Such a fundamental problem precluded any temporal or spatial comparisons of beach debris, despite considerable effort in the field.

A handful of previous studies strived to understand spatial and temporal patterns in marine debris, identifying the challenges of comparing the available data due to the lack of standardized methods and reporting metrics.[33,62−64] Even with increasing interest among researchers resulting in a growing number of beach debris studies, we were unable to analyze or predict spatial or temporal patterns at large scales with the available information. Below, we highlight the most common challenges and provide suggestions for possible solutions that can help us to move toward a common goal.

4.1. Geographical Patterns of the Studies. Spatially, the research effort to describe beach debris (measured as either the number of publications or number of sites) is focused on only a handful of countries [e.g., United Kingdom (Figure 2)], with most countries represented by data from <10 sites (Figure 2). The limited spatial coverage of studies makes it difficult to understand patterns and trends at a larger scale, which is urgently required. The strong relationship between authors' affiliation and study country suggests convenience is often a key driver in selecting sampling sites, likely influenced by funding limitations, the desire to engage with local research communities, or local research priorities. Consequently, current monitoring efforts for plastic debris may not accurately reflect priority locations (e.g., countries with few or no data regarding marine debris), representing a mismatch in the information that is available and the information that it is required to be able to fill the current gaps and address this global issue.

4.2. Reproducibility and Comparability of Reporting Metrics. A fundamental principle in science is that research should be reproducible. Despite this central tenet, we found a wide range of problems while extracting information regarding the studies' methods and results. For example, some publications did not report the precise sampling location within the chosen site (e.g., berm or high strandline), a critical piece of information as local topography and geographic position (e.g., orientation) play a significant role in where and how marine debris accumulates.[29,65−67] Some studies have previously shown that different areas within the same beach can represent different densities of marine debris.[30,40,56] Although the high strandline is the most common area used for micro-plastic sampling, this area contains higher densities of micro-debris compared to the berm.[30] In contrast, Besley et al. suggested the sampling area may not affect the obtained densities for the beach. These opposing results highlight the importance of detailed sampling information; depending of the sampling area, the obtained densities may not be representative of the actual beach pollution status.

Information regarding the sampling depth (superficial or buried) or even the sediment type (e.g., sandy or rocky) was also lacking in some cases, or not reported for all sites (Table 1).[42,68] Both parameters can significantly alter study results and interpretation. For example, more debris, especially micro-plastics, accumulates in finer sediments,[18,69] and there is often considerably more debris reported buried in the sediment, as it is less affected by wave action and daily tides than superficial debris.[16,70] Therefore, a consistent depth, usually the top 5 cm of sediment, should be sampled across studies, to maintain temporal and spatial comparability.[62]

Reporting the size or size class of the collected debris is imperative; however, 19.5% of publications did not report this information (Table 1), or in some cases, data for both micro and macro items were pooled together.[72,73] Defining a minimum size is fundamental to interpretation. When the same volume of sediment is passed through filters of varying mesh sizes and items below a given threshold are discarded, meaningful comparisons depend on knowing the minimum mesh size. Similarly, in beach debris studies, reporting the minimum size detected (and ideally with some discussion of detection probability) is fundamental to meta-analyses and cross-study comparisons. A common agreement about the definition of debris size categories is also required, as suggested by previous studies, as some categories (e.g., meso-debris) lack a consensus among researchers.[40,71,74]

While debris size is frequently reported among studies (Table 1), this information should also be presented alongside other metrics, such as the shape, origin (provenance), type (e.g., fragment or rope), and chemical composition (polymer type). Polymer identification provides useful information regarding the possible age or origin of the collected items but often requires specialized equipment that is not always available or affordable. The color of debris items can provide useful information about the origin or duration of time spent in the environment through weathering.[75] However, when debris is categorized by color, it is crucial that researchers adopt the standardized color categories that have been developed to ensure data are comparable over time.[63,64] The same can be said for plastic type with standardized type categories having been developed.[76−79]

We found that only 29% of the studies merely focused on plastic debris and therefore did not report all types of debris (e.g., wood) or different plastic categories (by type or use). Only 62.6% of publications categorized their debris by type (Table 1), but in some cases, the range of categories used (or vague descriptions) made it impossible to distinguish between plastic and other types of debris. For example, in some studies rubber or polystyrene was assigned its own category, while other studies pooled this debris in with general plastic or under the category "other".

The dimensions or number of transects/quadrats used, together with the number of total surveys, or the frequency of sampling, are also fundamental to the reproducibility of a study. In some cases, we noted an attempt to follow standard reporting protocols. For example, 89.1% of the publications reported the dimensions of their transect/quadrat, but almost half (48.0%) did not provide any information about the number of units of replication (Table 1). As a result, the density of debris could not be calculated on the basis of the limited information provided. Although sampling frequency can determine at fine temporal scales different estimates of the accumulation of debris on beaches, this information is still not uniformly reported within the scientific community.[80−82] The

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sampling frequency varied significantly among studies, spanning daily to yearly sampling intervals.

Although publications reported different metrics (Figure 2), most of the recently reported densities are per square meter [46.6% (Table 1 and Figure 4)], which does not allow us to compare with records from pre-2000s [mostly items per linear meter; 26.4% (Table 1 and Figure 3)]. Although units of items per linear meter were frequently reported, this metric does not provide an accurate measure; therefore, we strongly recommend that future studies present items per unit area as a standard metric (see Table 2). Those studies reporting their data per unit area could therefore be viewed as priority locations for follow-up sampling. However, of the 84 publications that did report debris per unit area, 57.1% [n = 48 (Figure 4)] did not provide the necessary information for the study to be repeatable (e.g., sampling depth and exact sampling location). Unfortunately, only 20.7% [n = 36 (see the Supporting Information)] of all studies appear to be reproducible. Depending on the density metric used, different debris "hot spots" would also be identified: using items per linear meter would identity countries such as Brazil and New Zealand (Figure 1) as being the most heavily polluted, while Pakistan, South Korea, and China would be flagged if items per square meter were used (Figure 2). Very few studies [16.0% (Table 1)] undertook a cleanup of the beach prior to beginning data collection. Removal of the "standing stock" of debris can be important, depending on the research question, as this debris that has accumulated over an unknown period of time may cause misinterpretation of the results.[23,42] Studies that aim to identify patterns in debris density over time should therefore discard data collected during the first sampling period so that subsequent sampling events occur only when a known amount of time has elapsed.

Table 2. Basic Requirements To Include in Future Beach Debris Studies

date of the sampling
GPS coordinates of the precise locations
specific size of the collected debris
specific depth of sampling
item categorization (type and use): best to present data for each category individually
reporting metric per area of sampling (or the total area covered)

Finally, some studies [9.8% (Table 1)] failed to report extremely basic parameters, such as the date of the sampling. This important information impedes our ability to measure change over time, a critical component of assessing performance against local, national, and international environmental agreements and pollution reduction schemes. Also, most of the studies covered by this review were never repeated (i.e., one year or less), being single records in time. We were also able to identify among the multiyear studies a lack of replication. Furthermore, from all of the publications, only 31 came back to the same exact site in multiple years.

5. PERSPECTIVES AND OUTLOOK

To address issues with global impacts, such as plastic pollution, big data sets with an adopted framework can play an important role. In addition, sharing the existing knowledge among researchers and working together can be keys for future research (e.g., open online libraries). Current monitoring and mitigation efforts for plastic debris may not accurately reflect priority issues or locations, representing a mismatch in the information that is available and the information that is required to address this global issue. The standardization of the sampling methodology and of the reporting metrics was identified by Vegter et al.[83] as one of the keys to understanding rates and patterns of dispersal, accumulation, and abundance of plastic debris in our environments. Despite the abundance of data currently available (717 sites spanning 1980 to 2017), the available data (quantity and quality) regarding marine and plastic pollution abundance cannot be used for comparison. Therefore, future research urgently requires a significant improvement and standardization. Researchers' efforts should be more strategic in the future if we want to really understand the global patterns of distribution regarding marine pollution and evaluate progress against international environmental policy targets. Therefore, a framework, such as that recently suggested by Besley et al.[62] and Hartmann et al., would be crucial to overcome some of the challenges identified in this review by promoting consensus within the scientific community (see Table 2). However, as important as such information may be for future research, gathering these data can be time-consuming and requires considerable effort. Acknowledging this, we emphasize there is a crucial need to report such metrics in a standardized way among studies.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.est.9b01424.

List of beach debris references used in performing the study presented here (PDF)

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Notes

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SUPPORTING INFORMATION

Global review of beach debris monitoring and future recommendations

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This supporting information contains 13 pages, including an extensive list of references analysed in the present study. (*) represents the 36 studies considered in this global review (n = 174) that appear to be reproducible as mentioned in the discussion.

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