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Review

Beach Litter Assessment: Critical Issues and the Path Forward

Seweryn Zielinski [1], Giorgio Anfuso [2], Camilo M. Botero [3,4] and Celene B. Milanes [5,*]

[1] Department of Hospitality and Tourism Management, Sejong University, 209 Neungdong-ro, Gwangjin-gu, Seoul 05006, Korea
[2] Faculty of Marine and Environmental Sciences, University of Cádiz, Polígono Río San Pedro s/n, 11510 Puerto Real, Cádiz, Spain
[3] Coastal Systems Research Group, Playas Corporacion, Calle 19 8-44, Santa Marta 050022, Colombia
[4] Rowe School of Business, Dalhousie University, 1266 Seymour St, Halifax, NS B3H 3M4, Canada
[5] Department of Civil and Environmental Engineering, GeMarc and GESSA Research Groups, Universidad de la Costa, Street 58#55-66, Barranquilla 080001, Colombia
* Correspondence: cmilanes1@cuc.edu.co

Abstract: Studies analyzing large-scale patterns or long-term trends in the amounts and composition of beach litter are often based on the analysis of several small-scale studies, which may provide an inaccurate picture if the methods and approaches used in those studies are not directly comparable. Moreover, most beach-litter review studies do not evaluate how the results are affected by a number of factors. Therefore, this paper analyzes empirical results from 62 beach-litter (BL) assessment studies published in the last decade (years 2010–2020) in peer-reviewed international journals. Both the results on beach litter (origin, composition, and density) and the utility of those findings to coastal managers are analyzed and discussed. The paper identifies strengths and weaknesses of different research designs, overall compatibility among the results of studies, and identification and means of eliminating those aspects that cause incompatibilities, inconsistencies, and high variability of data that cause low reliability of the results, among other issues. The results indicate that a global picture based on a number of small-scale studies cannot be drawn due to incompatibilities in sampling protocols and presentation of results, data analysis and interpretation, spatial and temporal differences, and the lack of understanding of factors influencing BL. This paper offers a critical view of many aspects of (BL) research in order to bring them to researchers' attention, at the same time recognizing the importance of previously published studies in making significant advancements in this field. Finally, it is also a call to move from limited data collecting and presentation in peer-reviewed journals to experimental designs, large data analyses, and testing of methods and solutions to the BL issue to advance understanding of beach-litter issues.

Keywords: beach; litter; debris; marine; coastal pollution; coastal management

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1. Introduction

Marine anthropogenic debris, also called marine litter, has been a worldwide issue in the last few decades [1,2]. The problem does not require any introduction, as it has been well documented in numerous recent papers [3,4], although the harm caused by marine debris is not yet totally understood [5]. According to empirical demonstrations, it is a multidimensional issue that ranges from degradation of ecosystem goods and services; reduction in recreational, aesthetic, or educational values of an area; to risks to humans, ecosystem health, and life of living organisms [6], and a number of comprehensive review papers dealing with this topic have been published [1,2,7–11].

Previous review and meta-analysis papers have demonstrated the increase in the number of papers published on a variety of topics related to marine debris from one in 1978 to 579 in 2018 [12], from around 90 between 2000 and 2005 to over 200 in the 2011–2013 period [11], and from around 20 in 2005 to more than 100 in 2013 [13]. Those publications encompassed all types of marine debris-related research. These results show a clear increasing trend in publications. Similar trends were also reported by review studies focused on specific regions such as Latin America and the Caribbean [14] and Indonesia [12]. Review studies usually focus on painting an overview of macro-debris, micro-debris, composition, sources, impacts, debris management, and mitigation. Some studies provided an overview of the marine-litter issues, the state of research, and identified priority knowledge gaps [2,15]. Although many review studies focused on a variety of topics within marine-litter research, this paper focuses strictly on the characterization of beach meso- and macro-litter, hence excluding studies of characterization of deep-sea litter, floating litter, seafloor litter, dune litter, microplastic litter, or the socio-economic and environmental impacts of debris, including impacts on living organisms.

Review studies regarding beach litter and specifically focusing on composition, distribution, and sources of litter usually use either a descriptive way to demonstrate their general findings without providing detailed numerical data or a comparison table of basic parameters (usually litter density, percentages of materials, etc.) [1,2,7]. Most studies have attempted to summarize large-scale patterns or long-term trends in marine debris through a descriptive analysis of published data [9], which definitely provided a general overview of the problem and pushed governments to implement policies and solutions. Most have not, however, evaluated how a number of factors, such as sampling methods, affect the measures obtained [13,16]. A global synthesis of spatial patterns and trends in the amounts and composition of BL based on the analysis of several small-scale studies are often not accurate if the methods and approaches used in the different studies are not directly comparable.

This research analyzes different aspects of beach-litter assessment studies published in the last decade between 2010 and 2020 in peer-reviewed international journals. On one side, empirical results on the origin, composition, and amount/density of beach litter were extracted from BL assessment studies to present an overview on this issue. Although it was possible to obtain a very preliminary overview, further analysis put the reliability of a comparison into question due to the usage of non-standardized sampling methods and a number of other factors discussed in this paper. On the other side, the need for BL characterization (origin, composition, and amount/density) studies has often been justified by the utility of the information gathered for appropriate coastal-management issues, specific site management, and strategic planning to tackle litter sources [17–28], reduce litter impact [19,29], or evaluate the efficiency of policies targeted at reducing litter input into the oceans [30].

Therefore, besides the basic data analysis, the main aims of this research are the identification of (i) the main factors that inhibit drawing a quantitative global picture of beach-litter distribution; (ii) the factors that cause incompatibilities among studies, influencing the reliability of BL data; and (iii) whether the reviewed studies propose real management strategies and which ones, and whether those studies used the data to test either hypotheses or the effectiveness of policies and/or management strategies. Last, it is also important to stress that this paper offers a critical view of many aspects of BL research in order to spark a debate about its strong and, more importantly, weaker aspects that require further research, at the same time recognizing the importance of previously published studies in making significant advancements in the field.

2. Materials and Methods

The study was developed in various stages. In the first stage, the standard requirements of systematic reviews were used [31]. The identification of the peer-reviewed papers, despite when they were published, was carried out through the Web of Science (WoS) database search integrated into the Endnote X9 that automatically discards duplicates. The search was performed using a combination of the keywords "beach," "marine," "coastal," "litter," "debris," "pollution," "cleaning," "contamination," "waste," and "cleanup" in title, keywords, and abstract (Table 1). The initial step of the search was kept wide with the purpose of capturing most of the studies on the topics. An additional search was carried out through other sources such as Google Scholar and Scopus using the same combination of keywords. Because of the wide approach, only the Endnote search turned out 1003 viable papers.

Table 1. No. of papers founds in the WoS database.

Keywords	No. Found	Total Cumulative after Discarding Duplicates
Beach litter	115	115
Marine litter	181	265
Beach debris	98	359
Beach pollution	132	484
Beach clean	41	515
Beach contamination	61	571
Marine debris	378	898
Beach waste	30	922
Beach cleanup	7	927
Coastal litter	95	1003

During the second stage of this investigation, the title and abstract of each paper selected in the first stage were analyzed. The title screening allowed for quick rejection of papers that were not clearly related to beach litter. In some cases, it was impossible to identify from the title whether the research addressed beach litter or other related topics. Abstract analysis was carried out on 181 papers, discarding papers dealing with deep-sea litter, floating litter, seafloor litter, dune litter, microplastic litter, metal concentration, and plant or animal ecology, as well as economic valuation, chemical and microbiological pollution, geomorphology, sedimentology, and light pollution, among other topics. Papers identified through other sources followed the same process. Finally, a snowball technique was employed to identify additional papers found in the list of references in the collected papers until no new references were found.

The papers had to meet at least one of the following criteria to be eligible: (1) Present empirical findings from a beach-litter assessment (amount/sources/density) based on specific sampling methods, and (2) analyze or use findings from beach-litter studies, including secondary sources, to inform management, education, or policy-making. Both of these criteria were chosen based on the objectives of the research. The former criterion corresponds directly with the main focus of the research (meta-analysis of beach-litter assessment), whereas the latter criterion was necessary to analyze the utility of beach-litter studies. Regarding the first criterion, 99 studies were found (Figure 1), and 57 studies were found that met the second criterion. Because the objective of the research was to assess the current state of beach-litter studies, only the papers published in the 10-year period between January 2010 and March 2020 were considered. Although 79 studies gathered some sort of litter data, 17 of them were discarded because they did not follow clear and rigorous sampling protocols (many beach clean-up studies and citizen science projects fell in this category) or did not provide data about litter materials, sources, density of litter, etc. In consequence, 62 studies met criterion 1 and 57 criterion 2. Out of the 62 studies, the majority (61%) were published in *Marine Pollution Bulletin*, 10% in *Ocean and Coastal Management*, and the rest (29%) in one of the remaining 13 journals presented in Table 2 (full list is available in Appendix A).

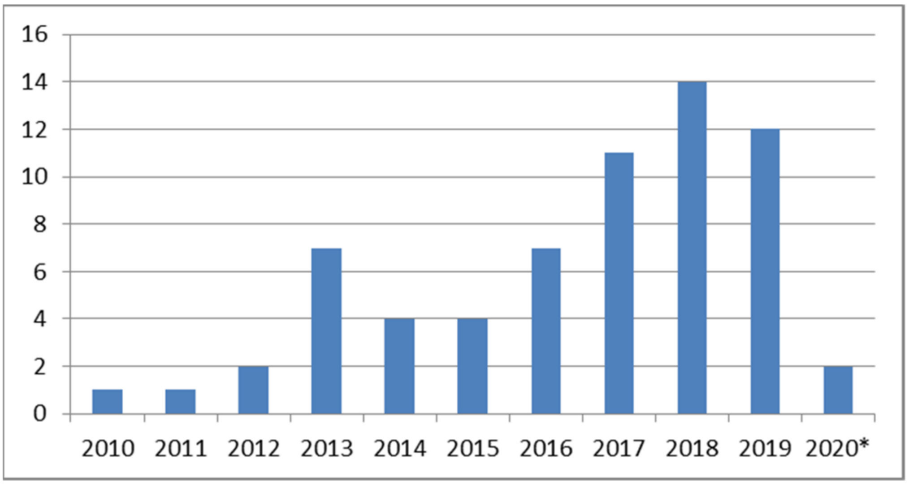

Figure 1. Beach-litter assessment studies published between January 2010 and March 2020 (*).

Table 2. Journal sources of analyzed papers.

Journal	Count	Total
Marine Pollution Bulletin	38	61%
Ocean and Coastal Management	6	10%
Environmental Pollution	2	3%
Marine Environmental Research	2	3%
Regional Studies in Marine Science	2	3%
Waste Management	2	3%
Turkish Journal of Fisheries and Aquatic Sciences	2	3%
Others [1]	8	14%

[1] Detailed list in Appendix A.

3. Results

3.1. BL Meta-Analysis: What Is the Issue?

The original premise of this paper is to give an overview on the results of published papers. It is not surprising that plastic items were identified by all but one of the 63 studies as the most commonly found litter material, ranging from 27.4% [32] to 98% [33] of all items, averaging 75.1% or 79.2%, depending how it is calculated, which is relatively accurate with the global approximations of 60–80% [1], 61–87% [34], or 70% [2] (Figure 2). The results are consistent independent of the type of beach and geographic region, with even remote beaches receiving a considerable amount of plastic litter [2,35,36]. Other materials were found to be more dependent on local conditions, except cloth/fabric, which showed relatively high consistency (0.1–3.0%) with two outliers. Among the common items found on all beaches, many researchers identified cigarette butts to be the most common items [24,37–40] and a major litter problem that is very difficult to remove manually and mechanically due to its size [41]. The proportion of cigarette butts ranged from 13.84% [42], to 38% [43], to 45.6% of the total items [35] and 35.4% and 30% of total plastic items [29], with some studies reporting an almost complete absence of this type of litter on some beaches [24,42,44,45]. Unfortunately, previous numbers may not be consistent and comparable because cigarette butts were considered plastic or reported within a separate category.

Although many studies focus principally on the types of materials, a more recent trend is to categorize litter according to its origin or use, as that is thought to lead to a better understanding of its sources and pathways into the environment and therefore is seen as a step to implement strategies preventing waste from entering the oceans [27,29,46]. The most commonly quoted global ratio for land-based and sea-based sources of marine litter is 80% and 20%, respectively [18,19,47–50]. According to 12 out of 62 studies that provided this estimate, the ratio between land-based and sea-based sources averaged 59%

and 27.2%, respectively. Many papers provided a single list of specific items as advised by the most commonly used manuals (OSPAR, EP/IOC, NOAA, EU MSFD TGML) or alternatively categorized the items by their category of use (between 4 and 18 categories), or did both. Eighteen studies identified fishing-related items (mean = 10.6% of all items), 15 studies tourism- and recreation-related items (mean = 43.9% of all items), and 8 studies smoke-related items (mean = 26.9% of all items) (Appendix B). Less-common categories found in a smaller number of studies were "shipping," "medical waste," "household," "sewage," and "construction," among others.

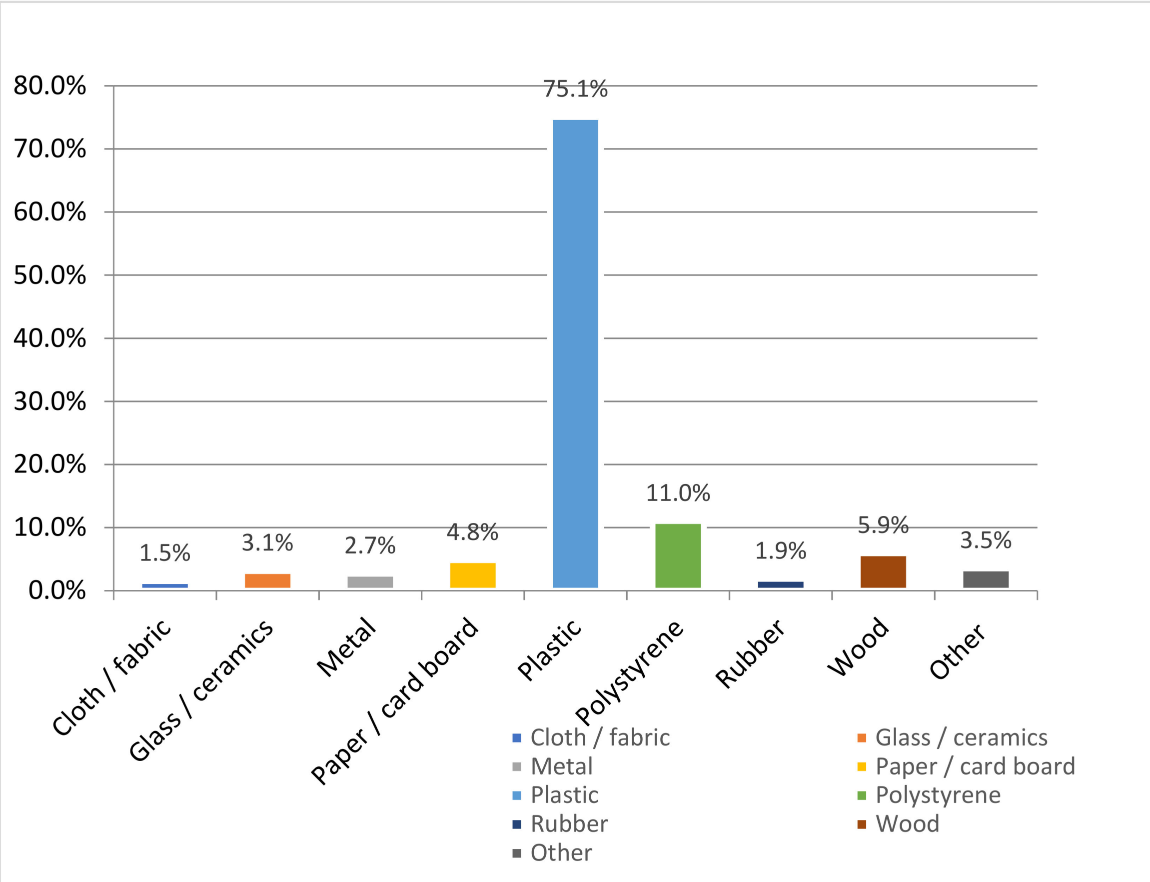

Figure 2. Average composition of items by type of material.

However, the large variety of not only the sampling methods, but also litter categories and other considerations (size, ability to detect the type of litter, among others), would make direct comparisons of the data highly inaccurate. Hence, the results presented are just a very basic approximation, as this aspect is not the core of this paper (Appendix B). The comprehensive review carried out of the studies revealed a myriad of other factors that considerably influence the results obtained, shifting the main focus of the paper. These factors are further discussed in following sections of this paper.

Almost all of the studies focused their discussion on comparing their results with those obtained in other studies. The authors justified their decision by geographical proximity of beaches under investigation, i.e., because they dealt with the same country or region, or because of the similar methods used for sampling and/or categorizing litter. The main question is whether these results were compared in a systematic way or not. Perhaps the second and third most important questions are: Are these results representative? What is the value of the data taken without strict considerations? Hence, the following sections of this paper are focused on a review of factors that make any comparison extremely difficult, if possible at all, indicating the measures that should be taken during research design and data collection. The different principal issues were grouped under five categories: (1) litter-sampling protocols and result presentation, (2) data analysis and interpretation, (3) spatial and temporal factors, (4) understanding of factors influencing BL, and (5) solutions to the litter problem.

3.2. Issue 1: Litter-Sampling Protocols and Result Presentation

The first critical issue that effectively complicates comparison of data is the fact that even recent studies often used a variety of sampling methods that are not always cross-compatible. Fifty-two distinctive methodological arrangements were identified in papers published between 1981 and 2020 with sampling and quantification methods either developed by the author(s) or partially adopted from established, preexisting methodologies (Appendix D). This number decreased only slightly to 45 when the period between 2010 and 2020 was taken into account, which indicated that although the sampling methods matured and achieved at least a certain level of standardization, studies still often adopted item categorization from two or more different methodologies and/or used non-standardized transect sizes for sampling. Only in a few cases was the variety of sampling designs and methods adopted justified to reach specific required aims.

Although the early studies date back to the 1960s, more recent studies had significantly improved sampling methodologies [51]. Sampling using belt transects between the low-tide mark and the beginning of vegetation, dunes, or artificial barriers quickly became the most common method promoted in litter monitoring and assessment manuals of the UNEP/IOC [52], OSPAR [53], NOAA [54], and EU [8]. Although the length of transects (i.e., the length of beach surveyed in an alongshore direction) has been standardized to either 50 m [23] or 100 m in opposite directions from the main entrance to the beach, with sporadic usage of 20 m [55] or 60 m [56] up to 1000 m [57], many studies did not differentiate between the width of transects along which surveyors moved and the total width of the surveyed area. The total surveyed width (i.e., the cross-shore dimension of surveyed beach) ranged from 2 m (1 transect 20 m long and 2 m wide) [36], 3 m (3 transects 1 × 1 m) [58], 5 m (surveyed area of 100 × 5 m) [18], 10 m [59], 20 m [60], 50 m [32], and 100 m [57] up to the maximum width of the beach [61,62]. Indeed, most of the recent studies (post-2013) tended to employ the universal method of beach sampling (100 m × maximum width of the beach) proposed by the abovementioned protocols (OSPAR, NOAA, EU). Following standardized protocols is an important step in data gathering to establish regional long-term trends [63,64]. Details about the area used and the transect number and dimensions used in the reviewed studies are presented in Appendix D.

The final methodological consideration that disqualifies comparison among some studies is the removal (or not) of litter before the first sampling or after each sampling. Besides the obvious consequence of removal, there is one that is less obvious. According to an experiment carried out by Schernewski et al. [63], the action of picking up litter results in an increase in the total number of found items by 32–75% due to the ability—when bending down—to spot smaller items that are not clearly visible from an upright stance. Most studies followed the recommendation of removing gathered litter and, therefore, their results might not be comparable with those studies that removed litter. There is also an obvious human factor involved when litter is collected by a large number of different people at each sampling time and/or location, which "introduces a level of uncertainty and variability into any data set and often makes robust statistical analysis difficult" [26]. This aspect should be accounted for by researchers when designing a project, although it cannot be easily removed from the equation.

Besides the differences in methodologies, the presentation of the results may also complicate any meta-analysis (e.g., items per beach in 100 m length [42,65] or more commonly used square meters). Results may also be expressed by weight (e.g., kg per 100 m and gr per m^2, etc.), proportions of items (percentage), or just the number of items, some of which may be recalculated to be used in a comparison analysis, whereas others cannot. The more recent trend that most studies tended to follow is to use square meters as the measurement of litter density and the number and proportion of litter categories or specific items.

The methods used to categorize litter have varied considerably as well. Previous studies classified litter into 4–18 general material categories (Figure 3) (Appendix D). Moreover, many studies adjusted the item lists and categories [35] to suit their specific local conditions or because the litter types were not always easily identifiable and classifiable. It is immediately noticeable from the data gathered (Appendix C) that even recent papers on top of the variety of sampling methods employed sometimes very different ways to categorize litter and therefore data presentation. This, once again, often disqualifies comparison. For example, some studies separated between different specific categories of material (e.g., ceramics and glass, organic and vegetation debris), whereas others integrated them into one category (e.g., glass or glass/ceramics). It is most evident in the case of "plastic," which sometimes included polystyrene or polyutherane, or cigarette butts, and sometimes did not and, in some cases, it was not even clearly stated. A considerable number of studies followed the recommendation of the most common guidelines, namely, UNEP/IOC [52], OSPAR [53], NOAA [54] and EU MSFD TGML D.10 [8], in order to avoid the miscategorization of litter items. A considerable number of studies (n = 35) used such exhaustive lists with between 28 and 165 items for beach macro-litter only. Because the lists used different scales ranging from very general to very detailed, the only way to compare the results is by selecting studies that used the same list or by finding the common denominator (the most general list of items).

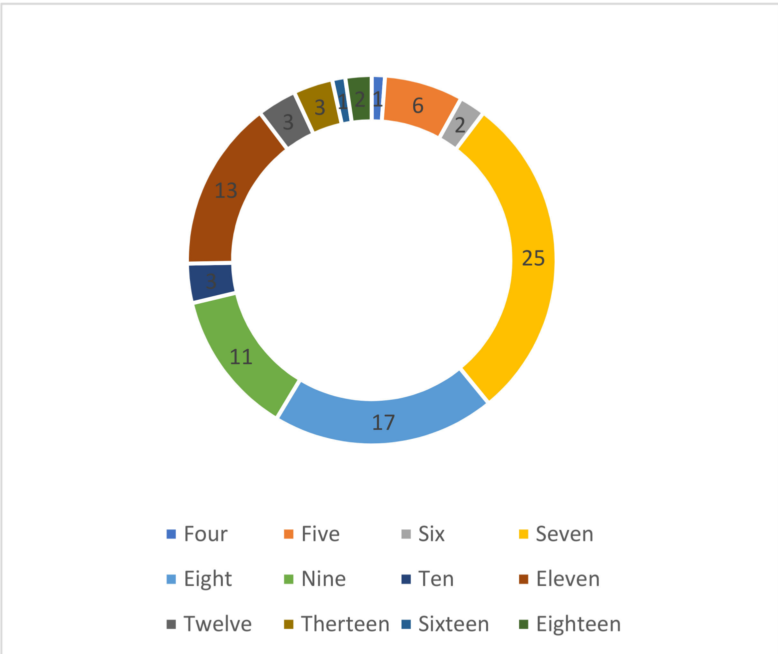

Figure 3. Frequency of studies shown by the number of material categories used.

A number of papers adopted items/categories from different sampling protocols and, in consequence, created new lists that included stand-alone individual items as categories (e.g., cotton-bud stick, can, lollipop stick, wet wipes) and material categories from other protocols (e.g., cloth, paper) in one list of categories. Because those papers presented items and materials in one list, it was unclear whether the items made of specific material were counted in both categories or just in one (e.g., "cans" counted both as specific "items" and as "metal" material, or just once as "cans" and the "metal" category included other, possibly difficult to identify "metal" items). The reason for presenting data in such a manner is perhaps due to the inability of identifying specific items or to present the results in a more concise manner. In some cases, material categories also included item groups based on their origin or use, such as medical, sanitary, or construction rather than the material they were made of (for example, needles were counted as "medical" rather than "metal" in the material list). For more clarity in data presentation, it is our hope that future studies will strictly adhere to one of the established protocols that use 77 (UNEP/IOC), 112 (OSPAR), 42 (NOAA), and 165 (EU MSFD TGML D.10) items.

Although the recommendation is to use specific items to identify their origin and act at the source of pollution, many studies used several items (of different composition, size, etc.), which were considered all together within a broad category, relating them to specific activities/uses (e.g., smoking, fishing from the beach, construction, etc.) and their potential sources (land- or sea-based) [17]. The problem with this approach is once again the variability of chosen categories that are not cross-compatible and that often are not clearly defined. Since those can come from various sources, the results may be compromised. In this way, most studies separated sources such as "shipping" and "fishing" [39,46,63,66], whereas other integrated them into one category ("ocean/waterway" [67]) or included all items coming from the sea in one category ("boat/fishing/farming activities" [29]). A similar case can be observed with the separation/integration of "medical" and "sanitary" sources [46,67,68] and of "smoking-related" items from "tourism/recreation-related" litter [29,68,69], or the exclusion of the "household/domestic" category and the categorization of some of those items under "other" [69] and the integration of "tourism/recreation" and "household" into one category ("shoreline and recreational activities" [29]). Finally, some studies included sources such as "household," "sewage," "construction," "dumping," and "foreign sources," whereas others did not. Technically, there is nothing wrong with neither of these approaches as long as the authors clearly explain which specific items are included in each category, which is not always the case due to limited space given to journal papers. Most of such differences are linked to the methodologies used that are not cross-compatible—this introduces another layer of complexity to carrying out a comparison analysis. The only simple solution to those issues is to strictly follow one of the most common established methodologies that have clear guidelines and sampling protocols.

3.3. Issue 2: Data Analysis and Interpretation

There are many obstacles in analyzing and interpreting the data that significantly lower the reliability of the results obtained. Although some of them are inherit limitations of all litter studies and hence cannot be avoided, various measures can be taken to improve the reliability. One of the unavoidable issues that researchers face is the inability to identify items due to their decomposition and/or fragmentation [26]. As a result, the contribution of items described as "unsourced," "general," "unknown," or "mixed source" is significant ranging from 25–30% [25,70–72], 34% [19], 42% [63], 43–61% [26], and 52% [24] to 76–88% [65] of all items in most BL studies. In this context, as pointed out by Watts et al. [26], many studies concluded that certain types of litter or sources are greatest contributors, despite their findings being heavily driven by unidentifiable plastic pieces. "This highlights a key issue with litter categorization (. . .) such that the way in which litter is assigned during analysis can heavily skew the subsequent conclusions" [26] (p. 421).

A significant number of factors determine litter content and amount, including natural processes such as erosion, local tidal range [73–75], currents and storm occurrence [24,27,30,37,58,64,76,77], beach characteristics [78,79], and wind direction and strength [24,27,30,36,46,58,64,65,73,80–82]. Significant positive correlations were observed in the abundance by number of items with rainy days, rainfall, and river discharge [17,32,58,81,83–87] and runoff [46,81,83]. Anthropogenic factors are also considered to be significant for abundance of beach litter. Ocean-based sources such as shipping and fishing [24,32,35,65], illegal dumping of waste at sea [83], the vicinity of ports [44,65], and human activities related to beach use (e.g., tourism) [32,60,65,88] have been identified to be driver of the total amount of beach litter. Furthermore, the amount of marine debris is considered to be inversely related to its geographical distance to a population center and directly to the number of users [39,46,55,60,61,86,89–91].

Because of the huge number of factors determining litter content and amount, researchers have to work with concrete assumptions, hypothesizing the different factors that increase or decrease the amount of litter. When explaining the sources or factors that influence litter abundance, most authors used words such as "probably" [24,42,46,68], "likely" [23,27,88], "may" [18,29,30,33,39,92], and "could" [27], and defined litter origin based on speculations, local conditions, and their knowledge of the area [24,28,46,81,83,93]. Researchers often looked for explanations to fit to their data, rather than provide data-driven confirmation for the results. In this way, the presence of a river mouth nearby, a city, or tourism activity were usually listed as major sources. Even though they are likely to be the major sources, the result is more of an educated guess than a claim supported by data. Accounting for the diverse range of factors that individually influence debris densities is a significant challenge, as they often occur together and act synergistically [36]. Many studies came to conclusions about the main sources of litter by correlating two variables (e.g., number of litter items with population density, beach type, vicinity of port), but correlation does not imply causation in an environment influenced by many more factors that were not accounted for.

In theory, indicator items should be easily related to a specific group of users or sources [52]. Indeed, this works well in the case of linking nets or buoys to fisheries or cotton buds to the presence of sewage [24], but this is not the case when different sources can coexist [94]. Typically, items such as cotton-bud sticks, wet wipes, tampons, etc., are associated with river sources or direct sewage [35,81]. However, as rightly noted by Wessel et al. [27], the actual origin of some of the items is still very much unknown. Items typically considered to be left by tourists (usually floatable plastic items such as bottles or plastic food containers) could have been transported by rivers, wind, municipal drainage systems, etc. There are examples of items associated with tourists (e.g., plastic bottles, food containers, caps, lids) found on remote, difficult-to-access beaches [17,36,73]. It is difficult to assess whether they accumulated over time, which is a common occurrence on remote beaches that receive small number of tourists [36], or were transported by the sea currents and waves from elsewhere [73]. According to Schulz et al. [95], the development of a more reliable attribution of litter types to sources is currently in progress in OSPAR.

A relevant aspect to be considered in beach-litter assessment is the influence of beach clean-up activities. Many studies face the issue of sampling beaches with regular [29,88,91,96] or irregular cleaning regimes [39]. Beach cleaning is a factor that may invalidate the results if sampled beaches receive irregular cleaning or if sampling of regularly cleaned beaches is inconsistent. Some studies only mentioned that some beaches from their sample were cleaned sometimes but did not provide when and how often. A few studies sampled beaches at different times of the day or different days of the week, sometimes before cleaning and sometimes after. In consequence of varied cleaning regimes, the differences between high and low season can be very significant. Sometimes beaches are cleaner during the high season because of cleaning operations [66,88], and sometimes they are cleaner during the low season because of lack of tourists. The opposite can also be true, when ineffective cleaning regimes are implemented on tourist beaches and when litter slowly accumulates during winter on beaches without any cleaning service (remote beaches) [36]. Such studies produced highly unreliable results, as cleaning introduced a significant spatial and temporal bias.

Cleaning operations can be factored into a study if they follow regular patterns and are synchronized with sampling times, but those studies should be automatically disqualified from comparison with other beaches. OSPAR [53] guidelines state that monitoring beaches should "ideally not be subject to any other litter collection activities." To isolate the issue introduced by beach cleaning, it is advisable to eliminate this factor from the equation by selecting either those beaches that are not cleaned or those that have a clear and transparent cleaning regime that can be factored into the analysis by adjusting beach-sampling times. This, however, was often not done, which begs a question about the reliability of the results. On the other hand, due to the public character of many beaches as principal spaces for leisure, beach-litter monitoring can be a very complex task that has to deal with aforementioned limitations. It should be noted, however, that the results of such studies should be treated as a snapshot of the local litter situation providing data about the state of cleanliness or cleaning-regime effectiveness, and therefore should not be used for comparison with other beaches whose cleaning regime is different.

3.4. Issue 3: Spatial and Temporal Factors

Because of the great number of factors that influence litter abundance, the monitoring studies that sampled the same set of beaches in time intervals should deliver more consistent data, uncovering temporal trends in litter accumulations [97]. On the contrary, a one-time sampling of a site is a snapshot that, because of the large number of factors influencing litter amount and content, likely provides an inaccurate depiction of the normal situation. Nonetheless, according to Browne et al. [13], about a third of all papers dealing with beach litter are based on a single survey per site. Our own analysis of 62 papers confirms this, as we found that 33.8% of all published studies were based on one-time sampling, although in the case of four of those studies (6%) this was justified by a specific-hypothesis testing (Table 3).

Table 3. Summary of spatial and temporal factors.

Factors	% of Studies
Studies based on one-time sampling per beach	33.8
(Temportal trends/accumulation) One-time sampling per season	12.3
Studies based on data collected during one year or less	56.9
Studies based on data collected during more than one year	43.1

Extra care also has to be taken when interpreting and comparing the results of studies that focus on temporal trends and accumulation rates. Eight studies (12.3% of all studies) focused on temporal trends presented data from one-time sampling per season without sampling seasons over a number of years. Because of this, seasonal change cannot be distinguished from random temporal variation [13]. In many studies, the intervals between times of sampling were not always specified or varied during the study. Some studies even compared two one-time seasonal samples taken years apart. According to a review carried out by Browne et al. [13], 40% of papers are based on data collected during one year or less and only 38% are based on data collected during more than one year. In our review, these proportions were 56.9% and 43.1%, respectively (Table 3). Studies based on a single survey per year over one or two years (49.2%) may show very different results from one year to another. For example, Zhou et al. [96] reported densities of litter of 0.02 items/100 m^2 in one year and 0.3 a year later (over one order of magnitude of difference). Therefore, such temporal distribution of surveys is perhaps the least-adequate solution, as the differences can be significant and patterns are not identifiable. According to Schulz et al. [95], a minimum of three, and optimally four to five years, is required to reach a reliable baseline on litter amount and content in an area. In fact, the OSPAR and MSFD protocols recommend a six-year beach-litter assessment period. In theory, the benefit of those short-lifespan studies is to make the data available to other researchers and to provide a baseline for further research, but in reality, with the exception of Zhou et al. [96], none of the one-time sampling studies has published a follow-up study or has been used for other research except for comparison of the results, which is inadequate by its own account. Most likely the decisions to accept those limitations were dictated by the academic nature of these studies and time/budget constraints.

In terms of accumulation rates, the abovementioned studies comparing one-time seasonal samples taken in the same year or across two or more years did not provide reliable information, and which leads to a large underestimation of the litter problem [73]. Recent research shows that measuring shorter time scales results in higher accumulation rates [27,36,90,98], as part of the litter accumulated is not detected because it is blown away, buried, or taken away by waves and currents and reappears later [13,73,90,92,98,99]. Various studies demonstrated that daily collection may give an average value about 10 times that of monthly collection [73,100]. Similarly, Ryan et al. [101] reported daily accumulation rates to be 100–600% greater than values based on weekly sampling. Hence, daily sampling is advocated as a standard approach for measuring accumulation rate and accurate quantification of beach litter, and it requires the same amount of field work (seven daily samples vs. seven weekly samples). More importantly, daily monitoring facilitates isolation of factors and correlation of potential factors that influence accumulation of litter because the entire set of environmental factors such as wind and tides is less likely to differ substantially on a daily basis than on a monthly basis. In this way, Eriksson et al. [73] were able to identify winds and tides as the main factors of litter accumulation, which would not be possible if the samples were collected on a monthly basis.

3.5. Issue 4: Understanding of Factors Influencing BL

The review of published papers demonstrates that it has been a common practice to compare the results of one study (density of litter items) with those of similar studies [30], even though they were carried out in other areas, regions, and, often, countries. This practice begs a question about the purpose of this exercise if even beaches that are relatively close to each other cannot be compared due to different conditions that determine litter accumulation [25]. Many studies have reported a significant difference in the abundance of litter in beaches located relatively close to each other [25,42,46,87]. Schernewski et al. [63] analyzed the results of a large number of studies and concluded that even on remote neighboring beaches with similar structure, orientation, morphology, and exposure to pollution, small-scale spatial variability is very high and cannot be explained: It was not possible to detect any trend during the four years at any beach investigated. Nelms et al. [39] and Schulz et al. [77] concluded, in two separate studies, that even time series of 10 years would hardly allow for the detection of trends in item numbers. Schulz et al. [102] came to a similar conclusion even after analyzing 25 years of beach macro-litter data series for eight German North Sea beaches. This high variability may be a limiting factor for the detection of temporal trends even if monitoring could be maintained over decades. The solution proposed by Schulz et al. [102] is to average out regional results. Extensive and systematic monitoring of BL pollution for four to five years with limited variation in the methodology is necessary to identify long-term trends [26,77].

Because of the above-mentioned findings, long-term monitoring may seem like a lost cause without taking this particular approach to analyze the data. Moreover, if temporal trends cannot be clearly identified due to a large number of conditions that influence the abundance of litter on any given day, then there should be more research effort dedicated to understanding relationships among the variables that influence litter abundance (understanding of baselines). However, detection of these conditions can be achieved only by following experimental methods. The reliability of litter research can be increased by controlling or "isolating" the conditions that introduce uncertainty [27,97], which is often not the case, even in most recent BL studies. It is clear that it is impossible to control all variables, but at a minimum, an effort should be made to minimize bias caused by beach clean-ups [19,30,92] and surveyors' error [46,63], and to increase general reliability by surveying two neighboring transects (replica) [63]. In comparison studies, an extra effort should be made to ensure similar exposure to sources, wind, and currents, and thereby degrees of pollution, rather than based on topographical position (two or more beaches in the same area or within a close distance) [64,82].

Another aspect requiring more attention is selection of the area for sampling. Because of topography and wind, different beaches accumulate litter in different zones, including the foredunes. Most of the established methodologies recommend placing 50 m-long transects in opposite directions from the entrance to the beach, usually in the central area, away from the areas that may record major accumulation rates because of natural factors [13,65].

Hence, a study may inaccurately assess the amount of litter, over-representing litter left by beach users and underrepresenting litter coming from the sea or blown by the wind.

It is surprising that a very limited number of litter studies tended to follow the experimental approach, designing their methods to specifically control those variables that could be isolated. Although knowledge of local conditions may help in identification of the BL sources [24,28,46,81,83,93], it may also lead to false assumptions not supported with hard data. Although a portion of studies looked beyond assumptions based on observation and knowledge of the area, statistical correlation of the results with other data—usually wind direction, currents, density of beach users, and distance from rivers or urban centers—is more often an afterthought rather that a deliberate design to test specific hypotheses. Perhaps it is because sites are chosen out of convenience, necessity (priority sites), ecological relevance, anthropogenic activities [2], or time and budgetary restrictions.

Although the global value and contribution of monitoring and baseline studies for painting a picture of the litter issue and driving national and regional policies is undeniable (e.g., EU plastic strategy) [4,8,103], it is argued that more researcher' attention should be paid to test the hypothesized influence of specific factors as they advance the understanding of BL dynamics and hence provide more information to management to address the issue. For example, rivers are often identified as the primary sources of litter on coastal beaches [81,104], but studies deliberately testing this hypothesis are few and far between [87]. Rech et al. [87] removed some uncertainties by controlling certain conditions and focusing on isolated effects. They were able to identify tendencies for individual rivers. The need for increased reliability in BL studies was called out by Wessel et al. [27], who pointed out that experimental designs that compare places of sampling (upper vs. lower beach) [60] or two areas with different densities of bathers [60,63] increase certainty in the determination of the main sources of litter. There is an overall need for more BL-related studies that test specific hypotheses instead of providing litter-quantity data with limited utility, unless they are part of long-term monitoring programs to serve as a baseline for consequent studies or provide the data for other studies to use.

Among those studies that make a significant contribution are the ones that tested the efficiency and reliability of data between shorter and longer time scales of sampling [73,90,100], power analyses of large datasets to find trends [77], studies testing systematic differences between single persons and a team carrying out the survey and between counting litter with and without picking it up while counting [63], testing the method to assess the origin–indicator items [19], testing hypotheses about the origin of litter and the position of litter on the coast [21,105], making a comparison of the effectiveness of cigarette-collection devices and manual collection methods [106], and testing the influence of runoff by comparing litter at urban outfalls and storm drains with beach-survey data (proposed by [97]).

Equally important is to approach the social side of BL. Besides the need for assessment and monitoring of socio-economic harm that has been highlighted for targeted research [2,15], there is also a need for more advanced behavioral research, moving from descriptive beach-user attitude measurements to qualitative and quantitative studies explaining how these attitudes are formed (for example, through structural-equation modelling). In this respect, Rayon-Vina et al. [44] found that BL attitudes are not always based on the objective reality but on past observations, beliefs, and preconceptions that may influence how reality is perceived. Moreover, Slavin et al. [40] found that certain populations are more likely to experience feelings of guilt about beach litter and/or more likely to do something about it. Both studies indicate that beach-user perception studies could integrate litter sampling to increase the robustness of the findings and test common assumptions. Despite a significant body of research on pro-environmental behavior, studies exploring behavioral psychological constructs are almost non-existent in the marine-litter domain.

3.6. Issue 5: Solutions to the Litter Problem

Although it is recognized that it is not the scope of every BL paper to propose any management strategies, the majority of the 62 analyzed publications proposed a number of solutions to address issues identified in their papers (82%). However, the majority of those 53 studies (64%) proposed only the most "generic" management strategies applicable to any beach at any place in the world (Figure 4).

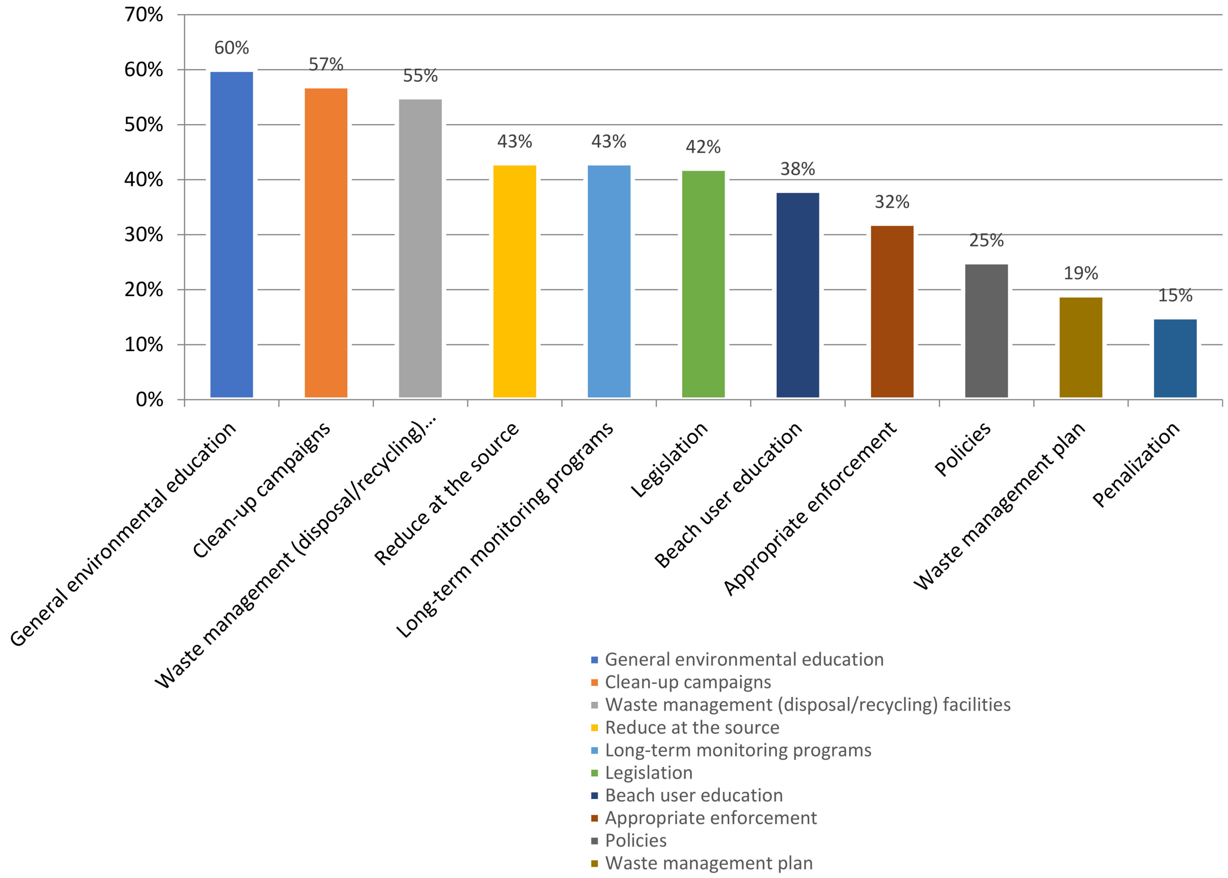

Figure 4. Frequencies of management strategies proposed in the reviewed papers.

Although general strategies are known and well documented in the literature [9,107], specific strategies targeting sources or items of ML need to be developed, proposed, and tested at the local scale to fit the particular conditions. Despite the need, only 36% of analyzed studies proposed either one or two more specific strategies to address either the sources or types of BL based on the results of their research. These strategies ranged from specific cleaning regimes (time and place) [19,42,81], number and placement of garbage bins on the beach [60], portable ashtrays and reusable drink containers [55], container design [18,88], and technological solutions to limit the amount of litter from rivers [58], to specific legislation in the country/area to address particular BL items [18,35,68,81].

Appropriate actions and strategies in beach-litter management must be based on deep understanding of the factors that explain why specific approaches, legal institutions, and policies designed to prevent pollution are more successful in one context than in another [22,108]. Specific solutions and existing or new governance arrangements are needed but their effectiveness has to be tested [15]. Scholars often propose "generic" ML management strategies, but studies that test their effectiveness in different context are rare. In line with the need for research on factors that influence the abundance of ML, there is also a need for comparison studies that test commonly proposed solutions in either different locations or before/after implementation.

4. The Way Forward

The main question that has been at the center of this paper is asking what we are really learning from marine-litter studies and what is needed to advance the knowledge. There are two main objectives for generating BL data. One is to provide an overview, a snapshot, or a trend of the problem to serve as scientific proof of the issue and to spark an impulse to act when necessary. The long-term regular-monitoring programs fall in this category, as they have undeniable importance in driving regional and national BL-related policies (e.g., EU plastic/packaging directives, California microbeads ban, etc.). Data from those programs are usually freely accessible through project reports and online databases for further analysis. The second objective, one that is not always reached, is to advance scientific knowledge about the factors that influence the abundance of BL, explain the sources, and facilitate the detection and understanding of BL dynamics. These studies usually require a careful study design to control as many variables as possible to test hypotheses, and they pave the way for further studies that want to take the topic to the next level. The results of those studies are published in international peer-reviewed journals for the benefit of the scientific community. The number of these types of papers published in peer-reviewed journals is still low, but they contribute the most to the body of knowledge. The premise of this paper is to bring all the items presented to researchers' attention (especially to those in the early stages of their career) and to encourage them to make a deliberate attempt to avoid the issues discussed, design experimental studies, carry out large data analyses, test existing methods, and develop new ones. Indeed, it is not easy to take into account all factors presented in this paper to design appropriate BL research surveys and monitoring programs useful to enhancing future investigations and sound management strategies, but attempts have to be carried out in this direction in the near future.

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Appendix A

Table A1. Journal sources of analyzed papers.

Journal	Count	Total
Marine Pollution Bulletin	38	61%
Ocean and Coastal Management	6	10%
Environmental Pollution	2	3%
Marine Environmental Research	2	3%
Regional Studies in Marine Science	2	3%
Waste Management	2	3%
Turkish Journal of Fisheries and Aquatic Sciences	2	3%
Aquatic Ecosystem Health & Management	1	2%
Environmental Monitoring Assessment	1	2%
Estuarine, Coastal and Shelf Science	1	2%
Journal of Coastal Research	1	2%
Journal of the Marine Biological Association of the United Kingdom	1	2%
Global Journal of Environmental Science and Management	1	2%
Plos One	1	2%
Science of the Total Environment	1	2%
	62	100%

Appendix B

Table A2. Litter sources identified in studies. ** Calculated the average value when differences were not large. * Medical + sanitary.

Reference	Country	No. of Beaches	Fishing Related	Tourism and Recreation	Smoke Related	Medical Waste	Household	Sanitary Waste	Shipping	Land Based	Ocean Based	Unsourced
[89]	Brazil	3								93.6% *	2.4%	39.8–51.2%
[109]	Brazil	8										
[17,35]	Spain	56			45.6%			0.6%		86.0%	3.0%	11%
										>80%	<4%	16.0%
[66]	Turkey	1	18.0%	15.0%					13.0%	62.0%	38%	18.0%
[37]	Argentina	2										
[92]	South Africa	5										
[81]	Brazil	8										
[60]	Brazil	2										
[55]	Brazil	3										
[73]	Australia	2	22.0%									
[83]	Italy	11										
[32]	Colombia	26										
[65]	Germany	4										
[65]	Various EU	29										
[68]	South Korea	20	35.3%	12.4%		0.4%	20.1%			50.8%	49.2%	
[110]	Malaysia	2										
[67]	India	1		74.5%								
[18]	Taiwan	4										
[69]	Cyprus	9	0.4%	18.9%	59.7%							
[111]	Brazil	25										
[106]	USA	1										
[42]	Morocco	14										
[29]	Italy	5	32.4–59%	37.9%	25.5%							
[61]	Morocco	14		60.5%								
[39]	UK	736	15.0%	36.0%		0.2%		5.0%	3.0%	42.0%	18.0%	40.0%
[48]	Turkey	1	0.8%	1.7%				12.5%				33.8%
[72]	Israel	8	1.5%					2.1%		60.0%	5.0%	
[19]	Portugal	2								44.0%	56.0%	
	Portugal	2										
[86]	Italy	1										

Table A2. *Cont.*

Reference	Country	No. of Beaches	Fishing Related	Tourism and Recreation	Smoke Related	Medical Waste	Household	Sanitary Waste	Shipping	Land Based	Ocean Based	Unsourced
[88]	Israel	1										
[46]	Greece	4	7.4%			0.7%		5.5%	1.6%	49.2%		35.2%
[112]	Colombia	26										
[20]	Colombia	8										
[21]	Colombia	1		60%	0.5%	6% *						
[22]	Colombia	25	1.0%									
[43]	Chile	1		62%	38%							
[44]	Spain	9	12.0%									
[87]	Chile	36			9.5% *							
[75]	Midway	4										
[30]	Portugal	42										
[97]	USA	12										
[113]	Iran	1	2%	94%		1.0%		1.0%				
[57]	Bulgaria	8										
[105]	Aruba	10										
[114]	Indonesia	1										
[63]	Germany and Lithuania	35	7%	50%					10%			
[64]	Europe	8										
[16]	Caribbean (various)	42										
[23]	Australia	16										
[100]	Australia	1										
[58]	India	3										
[115]	Chile	1										
[24]	Turkey	10	0.5%									
[25]	Various	31	5.3%			1.0%		9.7%	1.1%	33.4%	6.3%	0.1%
[33]	Brazil	5										
[116]	China	9	7.3%	56.7%	12.0%			1.0%		95.0%	5.0%	
[96]	China	4	13.5%	61.3%	7.3%			1.3% **				
[26]	UK	9	32.0%	18.0%					4.0%			46.0%
[27]	USA	6										
	USA	6										
[117]	UK	45										
[28]	Spain	20										

Appendix C

Table A3. Litter-material composition identified in published studies. * Values calculated by the researchers from the data provided in the paper.

Reference	Country	No. of Beaches	Cloth/Fabric	Glass/Ceramics	Metal	Paper/Card Board	Plastic	Polystyrene	Rubber	Wood	Other	Density (m^2)
[89]	Brazil	3					80.8%					
[109]	Brazil	8	4.8%	11.3%			77.3%					
[17,35]	Spain	56	2.3%	4.9%	3.2%	5.6%	82.6%		0.6%	0.5%	0.3%	0.062
			1.6%	1.7%	2.6%	8.6%	83.6%		0.5%	0.9%	0.4%	0.062–0.116
[66]	Turkey	1					87.5% *					1.22–4.2
[37]	Argentina	2					72.9%					
[92]	South Africa	5	0.1% *	0.3% *	0.5% *	0.7% *	96.8% *		0.8% *	0.3% *	0.4% *	
[81]	Brazil	8					95.9% *					0.29
[60]	Brazil	2			7.5%	11.0%	72.0%	5.0%		3.0%	1.5%	
[55]	Brazil	3					82.4%					0.91
[73]	Australia	2		2.7%	0.5%		94.5%			1.1%		
[83]	Italy	11	0.6%	0.2%	0.3%		89.1%	6.7%	0.5%	0.3%	0.7%	1.06
[32]	Colombia	26	0.4%	1.6%	1.1%	0.6%	27.4%	3.5%	3.0%	1.1%	0.2%	2.9
[65]	Germany	4		3.7%		3.6%	82.7%					
[65]	Various EU	29	3.0%	5.0%	4.0%	12.0%	69.0%		3.0%	2.0%	2.0%	
[68]	South Korea	20	2.4%	7.9%	2.6%	1.7%	58.1%	16.9%	0.6%	8.4%	1.1%	
[110]	Malaysia	2				12.0%	55.0%	16.0%			12.5%	0.38
[67]	India	1	1.0%	1.3%	2.4%		44.9%		1.6%	28.9%	19.8%	
[18]	Taiwan	4		1.8%	0.5%	10.3%	55.0%	20.6%	1.3%		9.2%	0.9
[69]	Cyprus	9										
[111]	Brazil	25	1.1%		0.3%	1.6%	69%	13.9%			3.7%	
[106]	USA	1	1.4%	1.7%	3.9%		88.6%		1.0%	2.2%		
[42]	Morocco	14	0.5%	5.0%	17.0%	4.1%	66.8%	2.4%	0.1%	2.6%	1.5%	4.94
[29]	Italy	5		3.9%		7.0%	81.1%	3.3%	1.4%	1.2%		0.14–0.57
[61]	Morocco	14	1.4%	2.1%	4.0%	5.9%	83.3%		0.3%	2.5%	0.6%	0.001–0.15
[39]	UK	736					66%	10.0%				
[48]	Turkey	1	1.3%	1.5%			95.6%				1.6%	
[72]	Israel	8		1.0%	1.0%	2.0%	90.0%		3.0%	3.0%		0.12
[19]	Portugal	2	0.3%	4.9%	0.3%		93.1%		0.8%	0.2%	0.2%	
	Portugal	2	0.4%	3.3%	0.2%		95.4%		0.3%	0.2%	0.1%	

Table A3. *Cont.*

Reference	Country	No. of Beaches	Cloth/Fabric	Glass/Ceramics	Metal	Paper/Card Board	Plastic	Polystyrene	Rubber	Wood	Other	Density (m^2)
[86]	Italy	1					79.4%	15.0%				
[88]	Israel	1	5.4%	0.9%	0.9%	2.4%	78.1%	3.1%	0.3%	5.6%	3.3%	5.1
[46]	Greece	4			2.3%	1.1%	93% *					0.08–0.91
[112]	Colombia	26	1%	2%	1%	1%	27%	3%	3%	1%		
[20]	Colombia	8		3.9%	2.2%		63.8%	9.7%	14.4%	3.4%		4.7/1.4–12.6
[21]	Colombia	1	0.0%	4.2%	2.9%	0.0%	88.6%		1.0%	1.0%	1.0%	2.87
[22]	Colombia	25	1.0%	1.0%	1.0%	1.0%	58.0%	30.0%	4.0%	1.0%	1.0%	3.5
[44]	Spain	9					64.0%					0.31
[87]	Chile	36	0.9% *	1.1% *	1.1% *	3.5% *	54.5% *	14.8% *	0.7% *	11.4% *		
[75]	Midway	4					91.0%	7.2%	1.6%			
[30]	Portugal	42		3.0%		3.0%	87.0%				7.0%	0.62
[97]	USA	12				5.0%	41.0%	41.0%		5.0%		0.8–2.5
[113]	Iran	1	2.0%	3.0%	1.0%	7.0%	81.0%		0.0%	4.0%		
[57]	Bulgaria	8					84.3%					0.03–0.045
[105]	Aruba	10					79.5% *					0.55 *
[63]	Germany and Lithuania	35	2.3%	7.2% (9.5%)	4.4%	12.5%	63.8%		2.8%	3.1%	0.6%	
[64]	Europe	8	0.9%	3.7%	3.1%	2.9%	74.0%			9.2%	5.4%	
[16]	Caribbean (various)	42					90.0%					6.34
[23]	Australia	16		10.0%	6.0%		73.0%					0.015–0.330
[100]	Australia	1	2.7%	0.6%	2.0%	0.8%	91.4%		1.6%	0.8%	0.1%	
[58]	India	3										up to 246.5
[114]	Indonesia	1					75.0%					16.8–41.6
[115]	Chile	1	0.8%	0.6%	0.8%	1.6%	83.1%	3.0%		8.0%		
[24]	Turkey	10					78.5%	4.3%				0.92
[25]	Various	31	1.1%	3.2%	1.5%	1.4%	91.1%		0.6%			0.67
[26]	UK	9		0.3%	3.0%	4.1%	89.0%				3.6%	
[27]	USA	6	1.0%	4.3%	3.5%		87.9%		1.7%	1.6%		
	USA	6	1.1%	0.9%	1.1%		92.7%		3.8%	0.4%		
[33]	Brazil	5			0.5%		98.0%			1.0%		0.1
[117]	UK	45										
[28]	Spain	20	1.2%	5.2%	10.9%	6.2%	69.7%		0.6%	3.5%	0.0%	
[116]	China	9	3.7%	2.4%	1.4%	4.2%	48.6%	6.6%	4.4%	33.7%	1.6%	0.1
[96]	China	4					20.0%	11.8%		58.7%	16.8%	0.25

Appendix D

Table A4. Beach-litter sampling methods used in the reviewed studies.

Protocol Used	No. of Categories/Origin or Use	No. of Items	Count/Weight	Area Sampling (1) or No. of Transects/Length/Width	Reference
Dixon and Dixon (1981)	-/9 (origin of containers only)	-	Y/N	3/5 m/–	[118,119]
NOAA–NMFS	8/-	59	Y/N	1/500 m/–	[75]
Modified NOAA–NMFS	11/-	-	Y/Y	10/2 m/2 m	[120]
Modified Dixon and Dixon (1981) and NOAA–NMFS	10/6 (plastic containers)	18	Y/N	3/5 m/–	[104]
Willoughby (1986)	7/-	-	Y/N	1/50 m/1–5 m 5–20/10 m/1 m	[121] [122]
			Y/Y	3/100 m/20 m	[60]
	5 (plastics)/-	-	Y/N	3/2 m/2 m	[114]
Caulton and Mocogni (1987)	?? 18/- 5/-	-	Y/N	5/100 m/1 m 2–9/100 m/1 m	[123] [124] [44]
IOCARIBE (1990)	9/-	-	Y/Y	3/5 m/–	[125]
Marine Conservation Society (MCS)	12/6	132	Y/N	1/100 m/1 m	[126]
EA/NALG (Earll et al. 2000)	-/7	-	Y/N	1/100 m/–	[17,20,28,32,35,42, 62,81,93,112,117, 127–129]
Cunningham and Wilson (2003)	10/6	-	Y/N	27/50 m/5 m	[130]
Araújo et al., 2006	18/16	-	Y/N	varying/20 m/–2 m each transect (to cover the entire width)	[24]
National Marine Debris Monitoring Program (NMDMP) (Sheavly, 2007)	8/5	-	Y/N	1/100 m/5 m	[18]
OSPAR (OSPAR, 2007, 2010)	11/5 13	112	Y/N Y/Y	1/100 m/–	[26,30,63–66,77,95,102,112]
NOAA data sheet (Lippiatt et al., 2013; Opfer et al., 2012)	7/5 8 8	46	Y/Y	1/100 m/–	[19,27,67]
Modified NOAA Opfer et al., 2012	7/-	61	Y/N		[105,131]
EU MSFD TGML D.10 (Galgani et al., 2013)	8/- 8/3 8/7 8/5	165	Y/N	1/100 m/– 2/100 m/10 m 4/50/??	[46,61,86,88] [25,48]
	8/	167	Y/Y	3/1000 m/up to 100 m	[57,132]
Modified EU MSFD TGML D.10, OSPAR, UNEP	9/-	33	Y/Y	variable	[83]

Table A4. *Cont.*

Protocol Used	No. of Categories/Origin or Use	No. of Items	Count/Weight	Area Sampling (1) or No. of Transects/Length/Width	Reference
Tangaroa Blue Foundation (www.tangaroablue.org, 2013)	8/4	28	Y/N	3–4/50 m/–	[23]
UNEP/IOC (Cheshire et al., 2009)	9/3	77	Y/N	1/100 m/– 1/20 m/– 2/50 m/–	[29,55,58,72]
	9		Y/Y	3/1 m/1 m	
Items from Cheshire et al. (2009)	9				[92]
Modified UNEP/IOC	8/3	-	Y/Y	3/10 m/–	[37]
Rech et al. (2014)	11	-	Y/N	1/100 m/50 m 4/3 m/3 m	[87]
International Coastal Cleanup (ICC) Protocol (Ocean Conservancy, 2017; Sheavly, 2007)	5/-	41	Y/N	1/–/–	[69]
Modified ICC Protocol	12	94	Y/Y	1/100 m/–	[68]
Center for Marine Conservation’s National Marine Debris Database	5	Over 50	Y/Y	1/50 m/1 m	[133]
	8	-	Y/Y	1/60 m/high tide	[134]
	7/-	-	Y/Y	5/10 m/–	[135]
	11		Y/N	3/3 m/–	[136]
	6	-	Y/N	1/50 m/–	[137]
	10/-	60	Y/N	6/100 m/1 m	[138]
	7/-	-	Y/N	1/–/–	[139]
	7/-	-	Y/N	1/47–818/4 m	[140]
	5/-	-	Y/N	4/10 m/–	[141]
	9/-	-	Y/N	79/10 m/–	[59]
	8/5 (plastic only)	-	Y/N	1/8 km/1 m	[142]
	8	-	Y/Y	5/50 m/2 m	[33]
	11			1/30 m/20 m	[143]
	13	-		2/50 m/5 m	[97]
	9/	-	Y/N	4–20/1.7–48.8 m/–	[89]
	12/-	101	Y/N	1/100 m/–	[39]
	5/6	-	Y/N	1/20 m/2 m	[16]
	5/-	-	Y/N	2–6/3 m/3 m	[90]
	16/			1/50 m/2 m	[111]
					[110]
				5/30 m/2 m	[109]
					Removing litter, no transect design
					[106]
					[73]
					[115]

Area of sampling: –/– refers to the entire length or width of the beach.

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