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Citizen science in Marine Litter Research: A review

Abstract

Citizen science (CS) can help to tackle the emerging and worldwide problem of marine litter (ML), from collecting data to engaging different stakeholders. We reviewed what and how the scientific literature is reporting CS on ML to identify possible gaps to be improved. The 92 search results (separate occasions when 48 different CS initiatives were discussed across 85 publication records) revealed an under-representation of studies in developing regions. Most search results focused on the science of ML, while information regarding citizen scientists was commonly vague or missing, preventing critical analysis of good practices on this aspect. The studies concentrated on the shoreline and did not harmonize types and sizes of items collected, thus precluding data meta-analyses. The standardisation of CS methods and approaches and the detailed report of aspects related to citizen scientists are essential to support the science we need for the advances in CS efforts to face ML.

Keywords: public participation in science, assessment, volunteering, ethics in citizen science, clean-up

1 Introduction

To understand and tackle the numerous socio-environmental issues facing our world, we need three main factors: (1) the science to understand the causes, impacts, and potential solutions, (2) society's understanding, will, and ability to act and push decision making, and (3) political will to get science and society on-board to discuss, design, implement and evaluate public policies (Voelker et al., 2021). Consequently, to reach the United Nations' Sustainable Development Goals, a synergy between these factors is needed (ICS, 2017). Citizen science (CS) can be seen as a process to bring these factors together, particularly science and society, having the potential to contribute to the wealth of research under scientific inquiry, as well as engage society directly with socio-environmental issues

(Bonney et al., 2009; Jordan et al., 2016). This engagement, in turn, is hoped to increase knowledge and concern, and ultimately translate into actions (e.g., from changing individual behaviours to supporting pro-environmental policies; Hartley et al., 2015; Nelms et al., 2017; Wyles et al., 2017). There is a growing expectation that CS will help to understand and contribute to solving complex social-environmental issues, such as marine litter (GESAMP, 2019). However, some important aspects related to the application of citizen science in the context of marine litter still need to be assessed and analysed to advance this field of knowledge. In this context, this paper examines how these different aspects are being reported in the scientific literature that address citizen science initiatives related to marine litter: what type of citizen science is currently being undertaken, what contributions are they explicitly noting for science, and what, if any, are they reporting in terms of their citizen engagement. With this knowledge, we can then identify challenges and opportunities to further advance citizen science to ensure that we maximise these benefits for both science and society.

1.1. Citizen science

Citizen science (CS) is a process that involves the public in *doing* science (Bonney et al., 2009; Haklay et al., 2021a). The practice goes back to the National Audubon Society's annual Christmas bird count, which began in 1900 (Cohn, 2008), or even before if we consider the flowering records of the cherry trees in Japan, which dates back to 1401 (Primack and Higuchi, 2007). CS may help gather good quality scientific data (Hidalgo-Ruz and Thiel, 2013; van der Velde et al., 2017) and broaden researchers' spatial or temporal coverage, especially in terms of working in contexts with limited human access or financial resources (Bonney et al., 2009; Cohn, 2008). In addition, CS projects can improve the flow of information among scientists, the public, and decision-makers (McKinley et al., 2017). At the same time, they can have impacts on the individuals involved: increasing their understanding of scientific processes and the environment, making them feel recognised and appreciated for their contribution, and potentially making participants more sensitive to and aware of certain socio-environmental issues, developing a sense of agency that may encourage further action (Brossard et al., 2005; Cunha et al., 2017; Dickinson et al., 2012; Eastman et al., 2014; Freitag and Pfeffer, 2013; Kruse et al., 2020a; Oturai et al., 2022; Theobald et al., 2015; Turrini et al., 2018). These multiple benefits make CS suitable for different scientific disciplines and societal issues, and its use has consequently been seen to increase in popularity (Freitag and Pfeffer, 2013).

Although CS approaches can be well designed and produce good-quality data, they can also face numerous challenges and critiques. Common issues facing CS initiatives are the credibility and validity of the data according to scientific standards (Kosmala et al., 2016), as well as the ethical issues related to the partnership between scientists and citizens (e.g., data availability, sharing, attribution, and confidentiality; feedback and acknowledgement to citizen scientists). Thus, nine key steps and ten principles for the development of comprehensive CS projects have been proposed (Bonney et al., 2009; Robinson et al., 2018). Both these steps and principles highlight aspects of CS that should be considered when designing, conducting, and reporting this scientific approach, from identifying appropriate research questions and recruiting, training, and evaluating citizen scientists to disseminating results, making data/results openly available or accessible (taking into account possible embargo periods and ethical issues), and acknowledging all contributors. A key emphasis for these steps and principles is to run CS projects that engage and benefit both science and citizen scientists. However, the extent to which we are formally reporting and critically analysing these aspects in our scientific publications may preclude advancing the science behind CS (Vohland et al., 2021). This is especially relevant given the peculiarities of CS in certain environmental issues, such as marine litter (GESAMP, 2019).

1.2. Marine litter

Marine and coastal anthropogenic litter (or debris) consist of solid waste produced by humans (UNEP, 2009), of which plastic is a major component (Napper and Thompson, 2020). It is a global and ever-increasing issue that causes great concern due to its negative impacts on the environment, economy, and society (Bergmann et al., 2017; Hammer et al., 2012; Newman et al., 2015; UNEP, 2016). For example, estimates suggest that every ton of marine plastic waste entering the world's ocean results in between US$3,300 and $33,000 costs to society, from direct impacts to sectors such as tourism and fishing (GESAMP, 2020), to indirect costs by harming the ecosystem services the ocean would usually provide (Beaumont et al., 2019).

A series of global, regional, national, and subnational policies have been created to address the marine litter problem (Karasik et al., 2020). Following the Honolulu Strategy (UNEP, 2011), several action plans to combat marine litter incorporated "conducting education and outreach on marine litter" (Karasik et al., 2020). Communication was emphasised as a relevant aspect to engage society to help tackle marine litter (SAPEA, 2019). In parallel, monitoring and assessing sources and hotspots of marine litter emerged as key aspects to guide policies and evaluate their effectiveness (GESAMP, 2019). In this context, CS can be considered a promising approach to merge both science and societal aspects related to marine litter.

1.3. Marine litter and Citizen science: the need for a review

In the context of the proposed Integrated Marine Debris Observing System (Maximenko et al., 2019), the Guidelines for Monitoring and Assessment of Marine Litter and Microplastics (GESAMP, 2019), and the emerging United Nations Environmental Assembly resolutions and regional and national action plans to combat marine litter (see Karasik et al., 2020), citizen scientists are acknowledged as vital players to widen our understanding of the occurrence and trends of marine litter. CS thus emerges as a combined approach to promote education and communication whilst simultaneously allowing the production of data for local-to-global monitoring of marine litter (UNEP, 2021). Many CS initiatives related to marine litter exist worldwide, often striving to reach three key goals (1) to collect valuable scientific data to help understand this socio-environmental issue (e.g. Hidalgo-Ruz and Thiel, 2015), (2) to remove litter from the natural environment (e.g. Martin, 2013), and (3) to engage society in the scientific process and/or foster environmental awareness (e.g. Eastman et al., 2014; Merlino et al., 2015).

As the use and reporting of marine litter CS is on an upward trajectory, it is becoming more important to review and reflect on what is currently being done and reported, and more proactively, identify gaps that need to be addressed to help further advance this approach to benefit science and society. Here we will review the CS scientific literature in the context of marine litter to understand (1) general aspects of the studies (i.e. the objectives of the studies, the geographical location and coverage of the initiatives being reported, the accessibility of the data and results being produced; the acknowledgment of citizen scientists contribution); (2) what is being reported regarding marine litter data (e.g. if litter is recorded and/or removed, which environments are being studied and types and sizes of litter being reported); (3) what is being reported within the citizen dimension of these works (e.g. who the citizen scientists are, how they are recruited, trained and involved, and if impacts on these individuals are assessed), and (4) what are the challenges and opportunities to improve CS based on empirical evidence.

2 Methodology

2.1. Selecting of articles and book chapters

For this review, we considered marine litter (ML) citizen science (CS) initiatives as a case study (Yin, 2005). The term "citizen science" was considered as the activities in which non-professional scientists are actively involved in one or more steps of the scientific research (Bonney et al., 2009; Dickinson et al., 2012; Theobald et al., 2015). The term "marine litter" was considered as "any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment" (UNEP, 1995). Peer-reviewed articles and book chapters related to or describing citizen science initiatives focused on marine litter were surveyed on Web of Science and ScienceDirect platforms (until August, 04th 2021). This could be in the context of reporting empirical research (presenting results from or about a citizen science initiative), communication-based articles, or review articles. Abstracts from conference proceedings and grey literature (e.g., non-peer-reviewed reports, thesis, and dissertations) were not considered for the present analysis. The two platforms were searched using keywords for both "citizen science" and "marine litter", including their synonyms (e.g., "collaborative monitoring" AND "marine debris", see Supplementary Material - Table A for all keywords used).

Initially, we found 8,139 publication records using the search keywords. After removing duplicates, we screened the remaining 1,251 publication records by title, excluding 864 results that were unrelated to citizen science and marine litter (e.g., records related to chemical soil pollution, engineering, design etc.). Then, we read the abstracts of the remaining 387 publication records (Figure 1). If no clear information related to a citizen science initiative or marine litter was found in the abstract, we searched for the keywords "volunteer", "participant" and "citizen science" in the main text to seek any indication that a citizen science process was described, resulting in a further 268 publication records being excluded. In the last stage, we read the remaining 119 publication records and selected those that explicitly (1) described citizen science initiative(s) (i.e., presenting the protocols, process etc.) and/or (2) presented the results of the citizen science initiative(s) (either the results regarding marine litter data or results evaluating aspects related to the citizens). Publication records describing studies in which the participation of citizens in the scientific process was not reported (e.g., not stating how citizens were involved), or in which the citizens were the subjects of the scientific inquiry (e.g., measuring citizens' memories and opinions) were excluded. After this process, the final sample consisted of 85 publication records (including articles and book chapters, which will be referred to as *publication records* thereafter, see Figure 1).

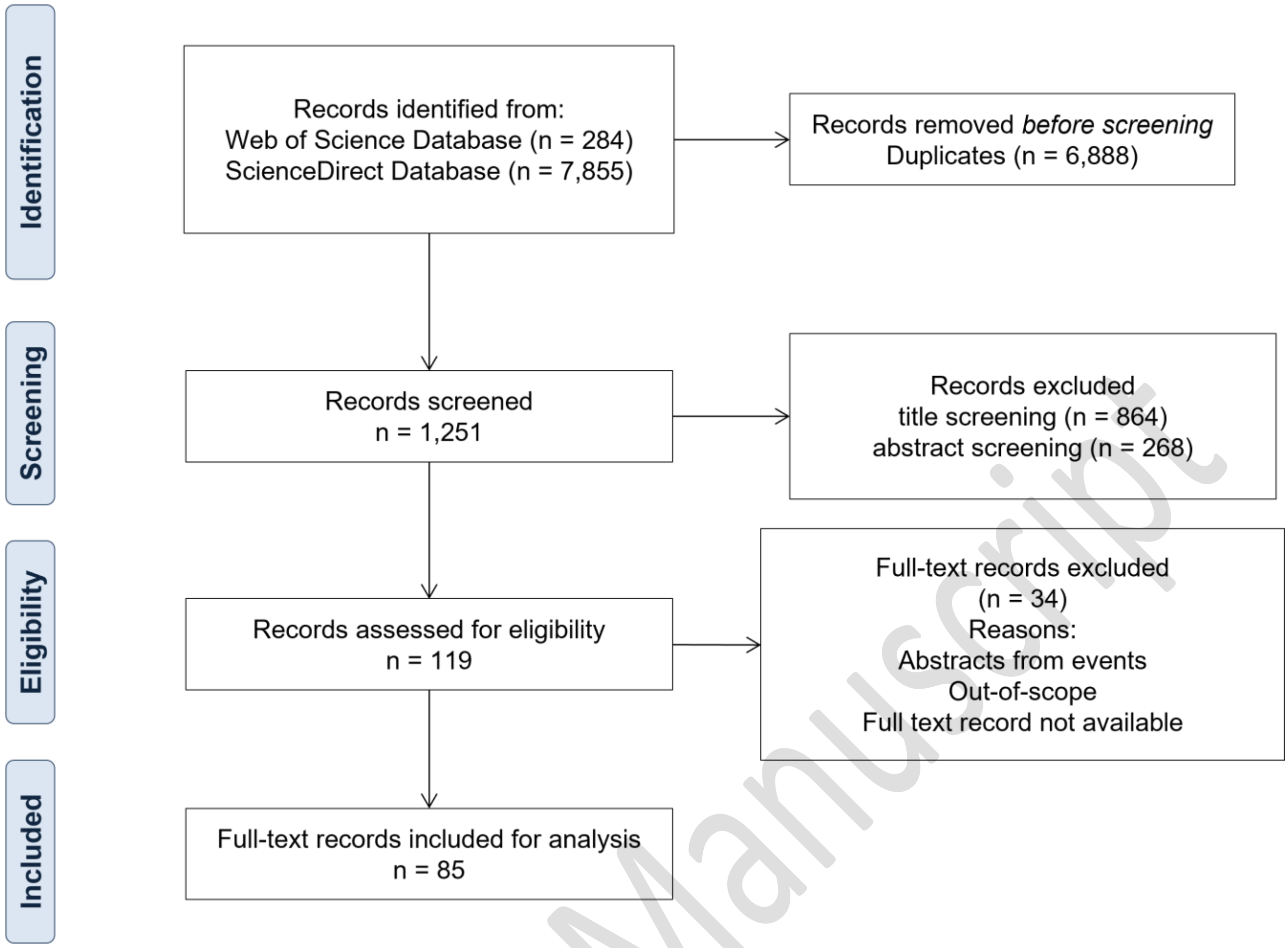

Figure 1. Search flow of full-text articles and book chapters (publication records) included in the review (based on PRISMA flow - Moher et al., 2009).

Across these 85 publication records, 48 different citizen science initiatives were reported (thus some were reported multiple times). Since some of publication records described more than one CS initiative, each initiative described for each record was analysed independently and considered as a *search result*, resulting in 92 *search results* across these 85 publication records. For example, the publication record of Mioni et al. (2015) described two initiatives (Blue Paths and SeaCleaner), so each initiative was analysed as an independent search result. All percentage calculations performed in the present work were based on these 92 search results, except for the analysis regarding the articles and books chapters' objectives (see *section 2.2.1 Coding of general aspects*) and the analysis of citizen scientists' acknowledgement (see *section 2.2.3 Coding of the Citizen Dimension*), which were based on the 85 publication records selected (see Supplementary Table B - Ghilardi-Lopes et al., 2022 - with all search results and categorisations).

2.2. Coding schemes

Inspired by the existing recommendations and principles that guide citizen science practice and research (Robinson et al., 2018), we examined thirteen aspects in each search result: four related to general characteristics of the studies, four related to marine litter data, and five related to the citizen scientists (see a detailed description below). For each aspect, we coded the results into categories, which were either based on categories already in existence in the literature (using a top-down approach) or that emerged from the reading of the search results (a bottom-up approach identifying recurring themes; Bardin, 2016). These simplified categories were then summarised into frequencies of occurrence.

All authors read the same five publication records (representing a sample of 5.9% of the records) to discuss and review the categories and codes until there was consistency in code assignment. All the names of the categories and their definitions were defined *a priori* and the authors fulfilled, independently, a table coding those categories for the publication records of the sample. After this step, the authors shared their results and discussed the inconsistencies obtained in code assignment so that a consensus was reached and a fully shared understanding of how to categorise the search results was reached. If a new category not previously considered was identified during the reading of the full publication records, the authors discussed how to include it (see Supplementary Tables C-I for the final list of categories and their respective definitions) and a revision of all other publication records already coded was performed to look for the possible presence of this new category. As the focus of this analysis is how citizen science initiatives were being reported within the peer-reviewed scientific literature, we did not consider our previous knowledge about the initiatives and only considered information explicitly reported within or that could be obtained from the publication records.

2.2.1. Coding of general aspects

(01) Articles and book chapters' objectives - To understand the overall focus of the 85 publication records, their objectives were summarised, retrieved from the abstract and introduction/objective section. The articles and book chapters' objectives (rather than the initiatives' general objectives) were summarised into 11 categories. They could have more than one objective, from reporting novel insights on marine litter (e.g., its composition or distribution) to assessing impacts on the citizen scientists and/or presenting new protocols, thus the sum of the objectives' frequencies could be higher than 100%. For the full list of categories and their respective definitions, see Supplementary Material - Table C.

(02) Geographical scale - To understand the geographical context of the initiatives being reported in each of the 92 search results, we examined both the geographical scale and socio-political regions used in these initiatives, retrieved mainly from the methodology section. In terms of geographical scale, we framed the search results into one of six categories based on the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services framework and Hothi (2005): Local, Subnational, National, Regional, Interregional or Global (see Supplementary Materials - Table D for the full definitions). The socio-political regions considered were: Latin America and the Caribbean, North America, Africa, Europe, the Middle East, Asia, and Oceania.

(03) Access to data and results - One important CS principle is allowing access to data and results, including to citizen scientists themselves (Robinson et al., 2018). Thus, the availability of data and results as explicitly noted within the 92 search results was summarised into five categories: a) if raw data were openly available, b) if results were openly available, c) if both data and results were openly available, d) if neither data nor results were openly available, and e) not stated/unknown (see Supplementary Materials - Table E for all categories and definitions). We only considered data/results as openly available if the search result was published in an open-access format or if the search result stated a website or database where data and/or results were made available.

(04) Citizen scientists' acknowledgement - To understand if the publications derived from CS initiatives that acknowledged the contribution of the citizen scientists, as recommended in guidelines for good practices in CS (Robinson et al., 2018), we searched whether the citizen scientists were explicitly thanked (individually, by the citation of their names; or as a group, being acknowledged only as "citizen scientists" or "volunteer contributors") in the acknowledgement section of the 85 publication records or not. We also searched for the words "thank" and "acknowledge" in the whole manuscripts to see if there was any kind of acknowledgement in other sections.

2.2.2. Coding of aspects related to marine litter data

(05) Removal/record of marine litter - As noted above, marine litter citizen science initiatives can focus on cleaning an environment locally *and/or* collecting data. We distinguished between search results (n = 92) that reported marine litter and also removed it and those that just recorded (without removal), based on the information available in the abstract and methodology section of the 85 publication records.

(06) Sampled environment - To understand if a certain environment is receiving more attention and, in turn, identify environmental locations in need of greater scientific attention, we categorised the sampled environment as either: shoreline (litter collected on the interface between land and sea – when the information was available we specified if the environment was a beach, a reef or a rocky shore), floating (litter collected in the water column and water surface), seafloor (litter collected underwater and on the bottom, including over the biota) or biota (litter entangled on or ingested by organisms); all categories according to GESAMP (2019). This information was obtained mostly from the methodology section of the 85 publication records and was identified for each 92 search results. Some search results reported multiple sampled environments; thus, the sum of all frequencies can be higher than 100%.

(07) Size of marine litter - To understand the profile of the marine litter being reported in the literature, we standardised and summarised the size of the litter. The scales of marine litter size were

not the same across the 92 search results, therefore, to compare them, we converted these different scales to the scale used in the GESAMP reports (2019, 2016): micro (<5 mm), meso (5 mm-2.5 cm), macro (2.5 cm-1 m), mega (>1m) or mixed (more than one of the categories). If the search result did not explicitly mention the size of the litter, but the category could be deduced from the description or images provided in the search result, the most appropriate category was selected. When examining the search results, we coded size based on both their sampling focus (what size(s) did the protocols concentrate on) typically derived from the methods sections, as well as noting if they explicitly examined the size of the litter as part of their scientific enquiry, reported within their results sections.

(08) Type of marine litter - Another important aspect to know is what types of litter are being reported within the literature. For this, we concentrated on the results sections of the 85 publication records and examined the findings of the 92 search results. There was a lot of variation on how this was being reported. First, there was a variation on how the items were described, for example by material or by item-type. Consequently, we summarised these categories into 9 material-type categories (e.g. plastic, glass, metal etc.) and 6 item-level categories (e.g. fishing materials, sanitary products, and cigarette materials - see Supplementary Material - Table F for all categories and definitions), based on Cheschire et al. (2009). Second, the number of types reported also varied, with some search results focusing on one specific type of litter (such as plastic resin pellets) whereas others examined a range of types. Consequently, the frequency of our summary categories exceeded 100%.

2.2.3. Coding of aspects related to the citizen scientists

(09) Profile of the citizen scientists - To summarise the types of populations that participated as citizen scientists, the 92 search results were first coded on whether this detail was reported ("present" or "absent/not reported"). Those that explicitly described the citizen scientists' profile were then summarised into five groups (school groups, university groups, general public, mixed groups or other; see Supplementary Materials - Table G for all categories and definitions). The categories emerged mainly from the reading of the content of the methodology and results section of the 85

publication records and was coded for each of the 92 search results. As some search results reported multiple populations, the sum of all frequencies could be higher than 100%.

(10) Recruitment - Considering that recruitment strategies can be determinant for the success of a citizen science initiative (Brouwer and Hessels, 2019), we summarised how the 92 search results had this aspect reported. Similarly, to the profile of the citizen scientists, the recruitment strategies were first coded as "present" or "absent/not reported". For those that explicitly described the recruitment strategies, 14 different categories emerged from the reading of the search results' content, mainly from the methodology section of the 85 publication records and was coded for each of the 92 search results. These recruitment strategies included face-to-face events, personal contacts (via an institution or via the project staff), courses, or dissemination in the media (social networks, television, radio, newspapers; see Supplementary Materials – Table H for all categories and definitions). If a search result reported more than one strategy, they were all considered in the analysis, thus exceeding 100%.

(11) Citizen scientists' involvement/tasks – To examine how the level of engagement was reported in the 92 search results, citizen scientists' involvement was coded in two ways. First, the involvement of the citizen scientists was categorised based on definitions by Wiggins & Crowston (2011): (a) *co-created* – citizen scientists participate in all stages of scientific inquiry, from defining a question to discussing results; (b) *collaborative* – citizen scientists participate mainly in data collection, sample and/or data analysis; sometimes they design the study, interpret data, draw conclusions and disseminate results; (c) *contributory* – citizen scientists mainly contribute with data; secondarily they can analyse data and disseminate results. Second, each task in which the citizen scientists participated, from defining a question to disseminating the results, was categorised based on Bonney et al. (2009) (see Supplementary Materials – Table I for all categories and definitions). If there was no mention in the search result regarding the involvement of the citizen scientists, we stated it as "not stated/unknown". This information was retrieved mainly from the methodology and results section of the 85 publication records and was coded for each of the 92 search results.

(12) Citizen scientists' training - As emphasised as a key step for CS by Bonney et al. (2009), we also summarised the training the citizen scientists reportedly undertook. It was categorised as "not stated/unknown", "formal" or "informal". When this aspect was explicitly reported in the search result, we categorised it as *formal training* when citizen scientists received mandatory training before the participation, receiving instructions via face-to-face training such as classroom courses or practical learning, demonstrations and/or support in the field. In contrast, *informal training* represented initiatives in which the citizen scientists received non-mandatory training, receiving instructions via guides, protocols, or other materials only. This information was retrieved mainly from the methodology and results section of the 85 publication records and was coded for each of the 92 search results.

(13) Citizen scientists' assessment - As a recommended step (Bonney et al., 2009) and a requirement that the activity should be beneficial to the individuals involved (Robinson et al., 2018), we examined the methodology and results sections of the 85 publication records to see whether any assessment of the impacts on the citizen scientists (learning or enjoyment/engagement outcomes) was reported for each search result. We categorised it as "explicit" when it was reported with evidence, reporting the methods used (e.g. application of assessment instruments as questionnaires and/or interviews followed by qualitative or quantitative analysis), or as "implicit" when the articles made some inference to the citizen scientists' experiences (e.g. enjoyed it, would do again) but without any evidence or reference to a data collection method (e.g. based on the description of coordinators impressions, citation of only some citizen scientists' impressions, or the indirect evaluation through the observation of citizen scientists engagement in the activities). Results that did not make any reference to an assessment were marked as "not stated/unknown". For those search results that reported on the assessment of citizen scientists with evidence, we also quantified the frequency of the main outcomes that were reported, using categories that emerged from the reading of their content.

3 Results

3.1. General aspects

The publication records found (n = 85) were published between 2006 and August, 2021, showing a clear increase in number from 2017 on (Figure 2).

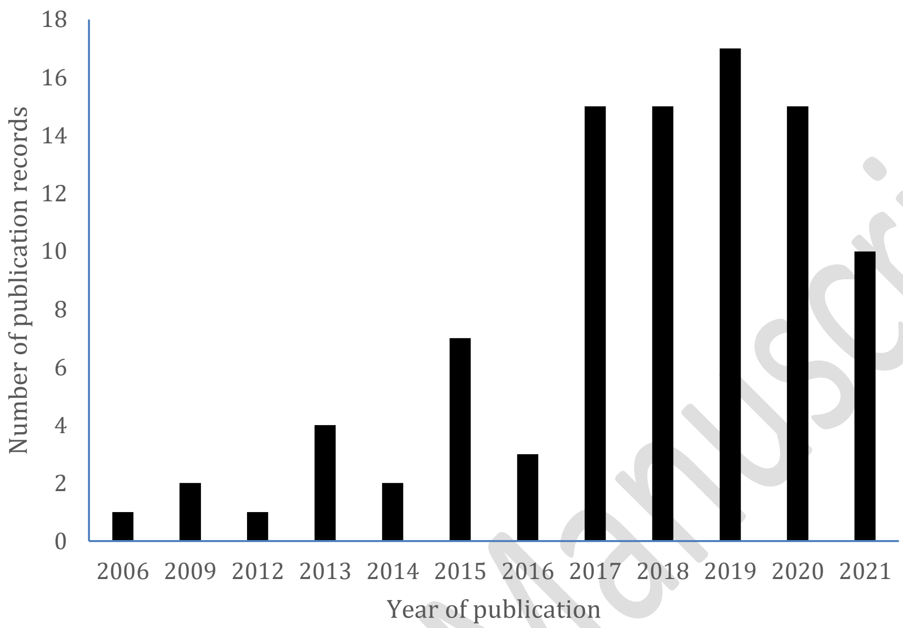

Figure 2. Number of publication records found per year of publication (n = 85).

3.1.1. Articles and book chapters' objectives

The majority of the publication records (n = 85) aimed to report the assessment of one or more litter indicators, such as their features (e.g., type of material, chemical composition, size, shape, and/or other physicochemical features – 56.5%), abundance (48.2%), distribution (31.8%), and sources (24.7%). Only a few of them aimed at reporting on the assessment of the impacts of the CS initiatives on the citizen scientists (engagement; attitudes and behaviours; awareness – 8.2%), on the validation of protocols (3.5%) or on the assessment of the CS initiatives themselves (3.5%) (Figure 3). The majority of the publication records presented a clear focus either on the quantification of litter or on the assessment of citizen scientists, and only two publication records (Kiessling et al., 2017; Yeo et al., 2015) aimed to quantify the litter and also to assess citizen scientists. The assessment of the CS initiatives was the unique objective on those publication records that presented it.

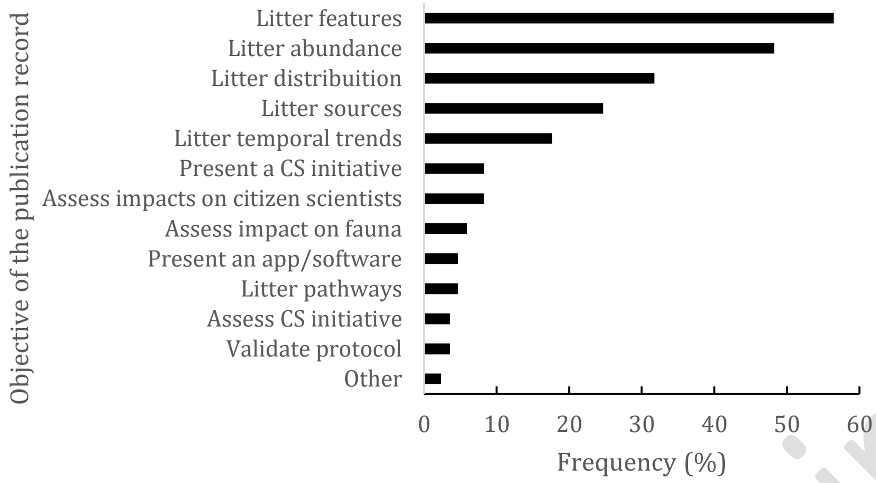

Figure 3. Frequencies (%) of the objectives stated in the analysed publication records (n = 85). Note: See details in section *2.2.1 Coding of general aspects*; studies could have multiple objectives (all publication records had at least one clearly identifiable objective and up to a maximum of six objectives).

3.1.2. Geographical scale

The search results reported mainly subnational (28.3%) and local (26.1%) CS initiatives, most of them undertaken in developed regions, especially Europe and North America, with an under-representation of studies in Africa and the Middle East (Figure 4).

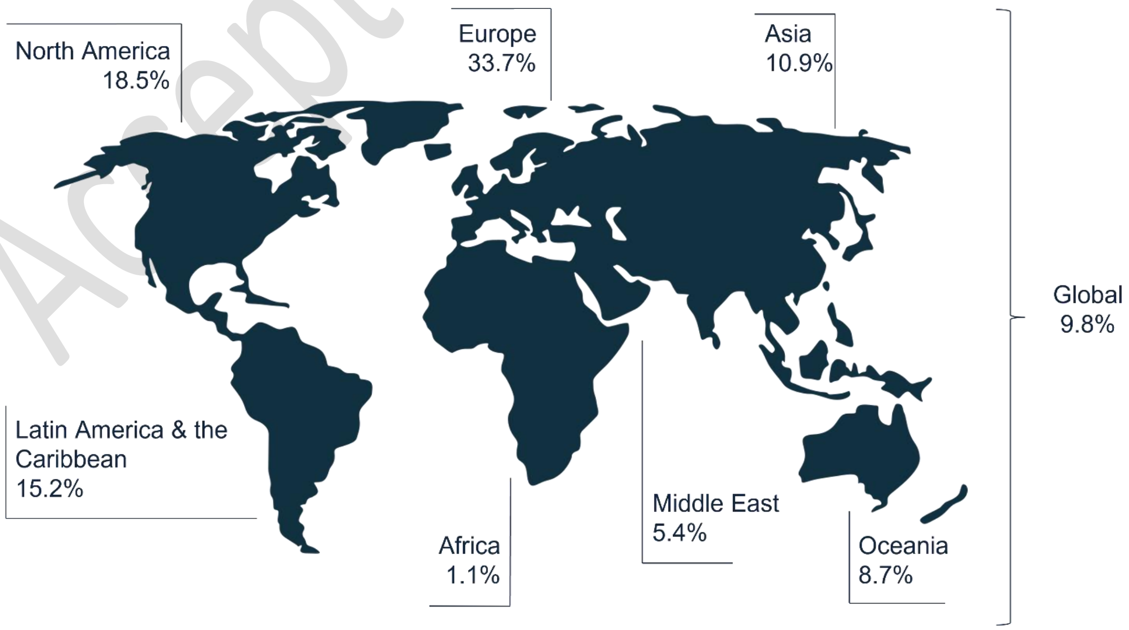

Figure 4. Socio-political region where the search results were undertaken (n = 92). The search results could encompass more than one region, so that the sum is higher than 100%.

3.1.3. Access to data and results

Many search results did not make any reference to the accessibility of the data or results and conclusions for citizen scientists and/or the general public (43.5%). The results and conclusions (31.5%) or the data (12.0%) of some search results were openly available, but only 9.8% of them provided both data and findings to the public. Some search results (3.3%) stated that data was available by requesting the project coordinators.

3.1.4. Citizen scientists' acknowledgement

Most (73.9%) publication records acknowledged the citizen scientists, but 23.7% did not have an explicit thank-you note to the citizen scientists for their contributions to the research. In 2.4%, acknowledgement to citizen scientists was not applicable: one search result was a paper that presented a software (Schattschneider et al., 2020) and the other reported the results of interviews with CS project's coordinators (Rambonnet et al., 2019).

3.2. Aspects related to marine litter data

3.2.1. Removal/record of marine litter

The recording of litter was a major aspect reported by most of the search results (92.4%). The removal of the litter from the environment was also reported in most of them (77.2%), but in 15.2% of the search results, there was no reference to what happened to the litter after the scientific study concluded. In 7.6% of the search results, litter was not removed from the environment because they were online initiatives.

3.2.2. Sampled environment

Most search results reported on litter collected on shorelines (71.7% - Figure 5), mainly on sandy beaches (68.5% - see Supplementary Table B - Ghilardi-Lopes et al., 2022).

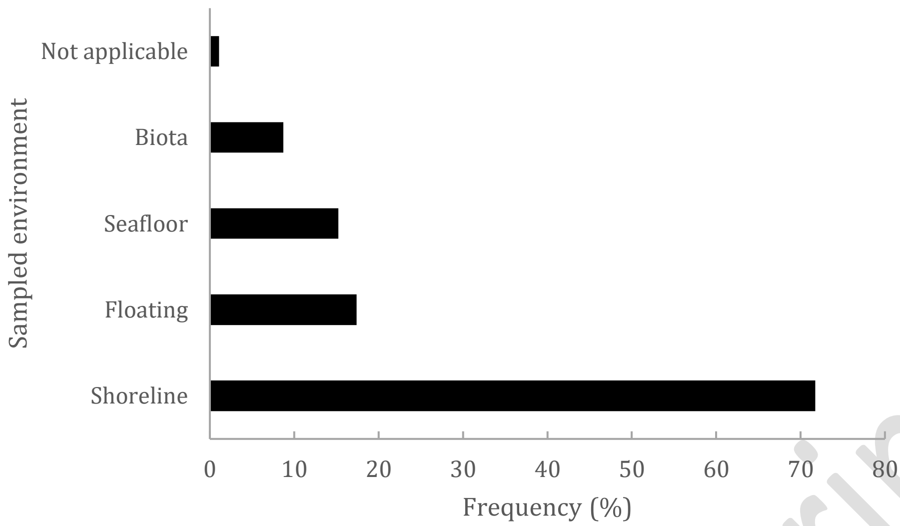

Figure 5. Sampled environment reported in the search results (n = 92). The search results could encompass more than one environmental category, so that the sum of all categories is higher than 100%.

3.2.3. Size of marine litter

Macro (0.25m-1m) and mega-litter (> 1m) were reported more frequently as the focus of the CS protocols presented in the search results (Figure 6). When it came to the scientific enquiry of the search results, 18.5% presented some kind of analysis (e.g., quantification, comparisons) related to the sizes of the litter found by citizen scientists (see supplementary Table B - Ghilardi-Lopes et al., 2022).

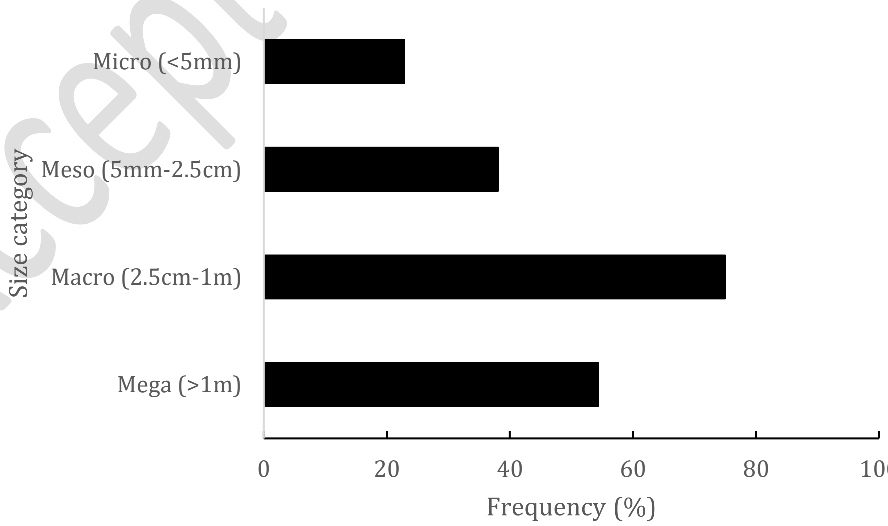

Figure 6. Size categories reported in the search results (n = 92) as being the target of the CS protocols. The protocols could encompass more than one size category, so that the sum of all categories is higher than 100%.

3.2.4. Type of marine litter

Most search results (79.3%) explicitly reported the types of marine litter in their findings, but there was a lot of variation on how this was being reported. For instance, they varied in how the items were described: most search results used material-level categories, such as glass, paper or plastic, but some used very specific item-type categories, such as derelict crab traps or high-density polyethylene.

When it came to the materials, fragments and items made of plastic were reported by the majority of the search results (78.3%), along with fragments, and items made of metal (43.5%) and glass (41.3%). To a lesser extent, paper and cardboard (30.4%), natural or processed wood (29.3%), rubber (21.7%), ceramic waste (8.7%) and organic waste (7.6%) were noted. When it came to coding based on item-type, fishing items were commonly reported (e.g., nets, lines, lures, and buoys – 45.7%), along with cigarette materials (29.3%), clothing and textile (such as fabrics, clothes, and shoes – 27.2%), sanitary waste (such as tampons, sanitary pads, and diapers - in 16.3%) and medical waste (5.4%).

3.3. Aspects related to the citizen scientists

3.3.1. Citizen scientists' profile

Most search results (77.2%) specified the citizen scientists' profile (Figure 7). School children (5.4%) and undergraduate students (4.3%) were often included in the initiatives, and it was also common to find citizen scientists with different profiles participating in the same initiative. The most frequent profiles reported were the general public (27.2%) and mixed groups (17.4%, e.g., dog and beach walkers, natural resource management professionals, members of recreational clubs, and corporate participants).

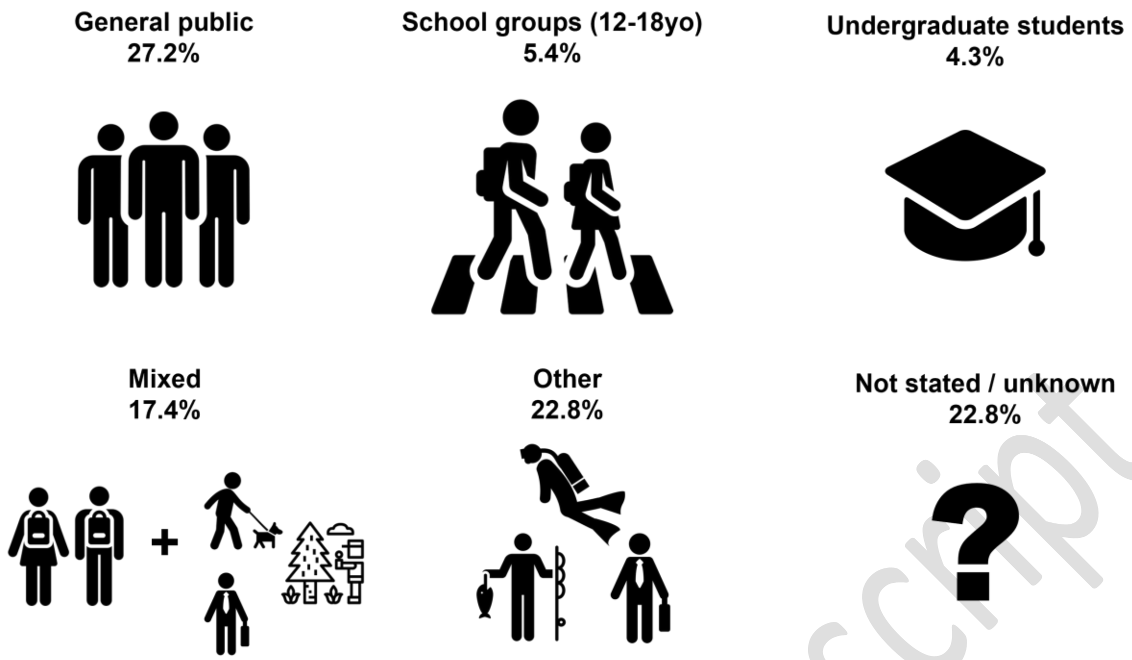

Figure 7. Profiles of the citizen scientists participating in marine litter citizen science initiatives reported in the search results (n=92). The category "other" included workers or members from a specific group, company or institution, fishers, SCUBA divers and snorkelers, specific local communities, and Facebook users. Icons designed by Freepik and Nikita Golubev from Flaticon.

3.3.2. Citizen scientists' recruitment

Just over half of the 92 search results mentioned the ways citizen scientists were recruited (53.3%). The most common was via organisations or social associations (15.2%) that were partners or coordinated the initiatives, followed by schools or universities (13.0%), in which the initiative was mostly mandatory and part of the teaching program. Online recruitment via social media, email, websites, and apps (12.0%), personal contact (7.6%) and recruitment via press coverage (TV, radio, newspapers, and journals – 6.5%) were also used. It is noteworthy that a large sample of search results (46.8%) did not mention how citizen scientists were recruited.

3.3.3. Citizen scientists' involvement/tasks

The involvement of citizen scientists in the initiatives reported was mostly contributory (87.2%), in which citizen scientists contributed to data collection, and secondarily they could analyse data and disseminate results. Collaborative (8.5%) and co-created (2.3%) processes, in which citizen scientists not only collect data but participate in other steps of the scientific method too, were not well represented.

Almost all search results (97.8%) that specified citizen scientists' involvement included data collection as part of their activities and in 80% of the search results, data collection was the only step of the scientific inquiry in which citizen scientists were involved. Also, when involved in multiple steps, the contribution of citizen scientists, as declared in the search results, was concentrated in collecting and analysing samples (Figure 8).

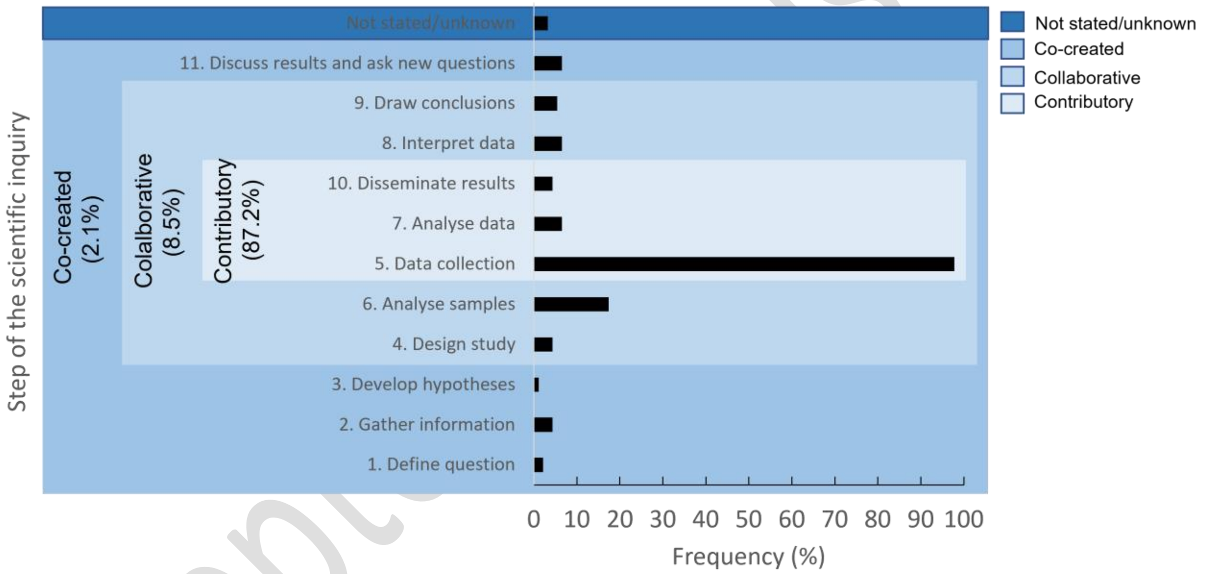

Figure 8. Steps of the scientific inquiry in which citizen scientists were involved in marine litter citizen science initiatives reported in the search results (n = 92). Steps 1 to 11 are included in the "Co-created" category; steps 4 to 10 are included in the "Collaborative" category; and steps 5, 7 and 10 are included in the "Contributory" category.

3.3.4. Citizen scientists' training

About two thirds of the search results (65.2%) mentioned that the reported initiatives provided some kind of training to citizen scientists. The training was reported as mandatory prior to citizen scientists' participation in less than half of search results (*formal training* – 42.4%). This included face-to-face training, such as classroom courses or practical learning, demonstrations, and/or support in the field to citizen scientists. Some of those search results that mentioned formal training did not specify exactly how it was conducted (23.3%). *Informal training* for the citizen scientists was explicitly mentioned in 22.8% of the search results. In this category, the citizen scientists were mostly asked to read protocols, guidelines, or similar materials, or had the possibility to contact the initiative's coordinator via online communications, chat, or email. In 6.5% of the search results, it was explicitly stated that no training was provided, and in 28.3% of the search results there was no mention regarding the training of citizen scientists.

3.3.5. Citizen scientists' assessment

The majority of the search results did not report any evaluation or assessment of impacts on the citizen scientists (78.3%). In 10.9%, the citizen scientists' experience was reported without evidence and in 10.9% it was reported with some form of evidence (Figure 9). In those that briefly noted the citizen scientists' experience without evidence, some of them considered the project coordinators' or researchers' impressions (7.3%). For example, they stated citizen scientists generally participated with enthusiasm in the initiative or that the participation in the initiative influenced citizen scientists' behaviour/engagement (e.g. some citizen scientists started discussing how the marine litter problem could be mitigated and initiated corporate changes to reduce the environmental footprint, and some search results simply stated the citizen scientists' behaviour changed, without additional information) or inferring the citizen scientists enjoyed the project because they remained on it for further activities or the research team was invited to continue the study (4.2%). Also, some search results stated that some citizen scientists spontaneously reported their positive impressions about the initiative (5.2%), as reporting a sense of achievement, ownership, and empowerment, and a desire to change behaviour and educate others.

If we consider only those search results (n = 10) that assessed the citizen scientists with evidence (e.g., using questionnaires, measures, or indexes), their main findings were that the participants presented an increase in behavioural intention (50.0%) and in knowledge or awareness (40.0%) (Figure 10).

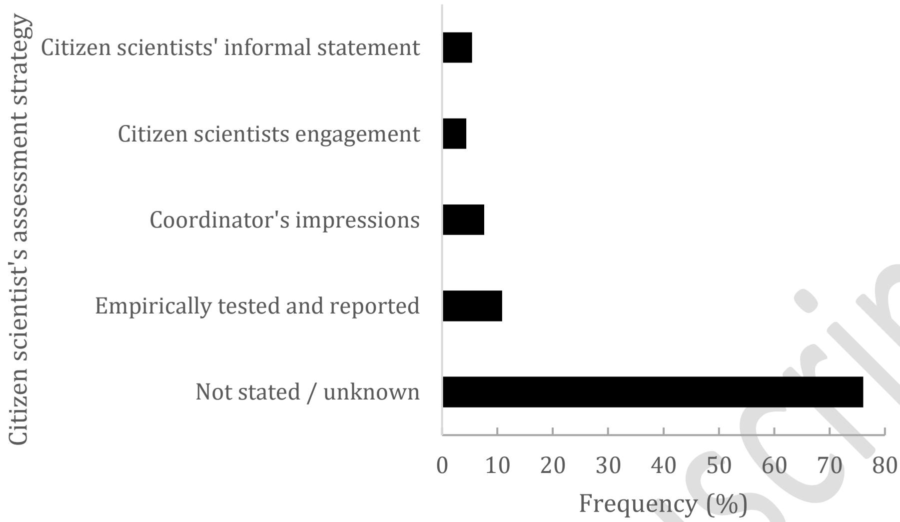

Figure 9. Frequency (%) of assessment strategies of citizen scientists' experience reported in the search results (n = 92). Search results could report more than one strategy, so that the sum of all categories is higher than 100%.

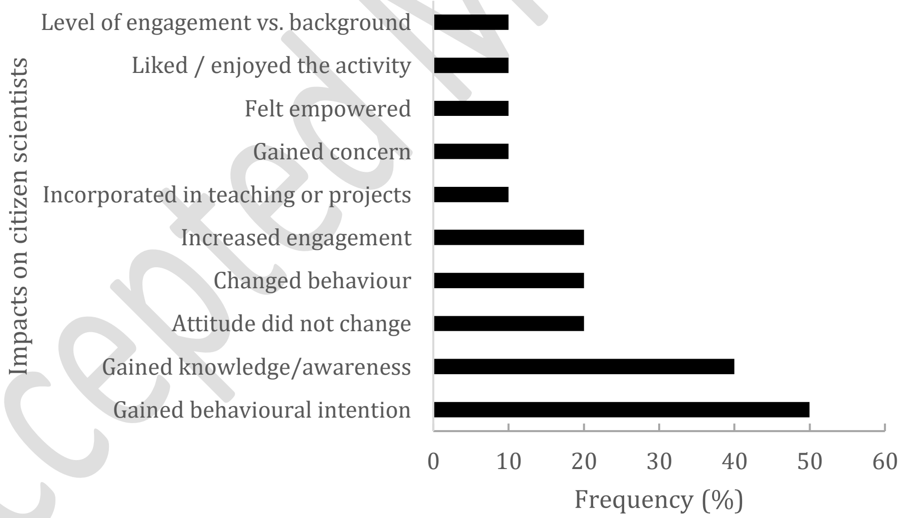

Figure 10. Search results' main findings (%) from citizen scientists' assessment with evidence (n = 10 search results that presented the assessment as an objective).

4 Discussion

To our knowledge, our analysis provides the first overview of how citizen science initiatives are being reported in the scientific literature within the context of marine litter. Specifically, we examined important aspects related to CS practice and research that might further advance the field.

The 85 publication records published between 2006 and August 2021 showed an increase in the number per year after 2017, corroborating the tendency observed in previous studies that showed CS studies significantly increased after the beginning of the 21st century (Kullenberg and Kasperowski, 2016). Whilst the uptake and reporting of CS has grown in popularity, our analysis also identified gaps in this field and thus opportunities for future work.

4.1. General aspects

Our literature review returned 92 search results (reporting on 48 different initiatives across 85 publication records), and our in-depth analysis of these showed that most of the studies aimed at reporting aspects related to marine litter (e.g., composition, abundance, distribution, trends and sources of litter) and few of them aimed at reporting on the assessment of the impacts of CS initiatives on the citizen scientists (e.g., research related to engagement; motivations; attitudes and behaviours; awareness or perceptions), evidencing a gap to be filled. In one of the articles that assessed the impacts of a CS initiative on the citizen scientists, the authors state "We think that the assessment of the societal/educational aspect of citizen science requires the same scientific attention that is devoted to the evaluation of the data collected for research purposes" (Locritani et al., 2019, p. 325) and our findings and earlier work (Bonney et al., 2009; Phillips et al., 2018; Robinson et al., 2018) agree with this point of view. The lack of formal analysis of the aspects related to citizen scientists may preclude improvements in its practice and be a consequence of the lack of formal reporting in the scientific literature, as we will discuss below.

Our results demonstrated that most search results reported on local and subnational initiatives, a similar pattern reported by Hidalgo-Ruz and Thiel (2015). Moreover, most search results were based in developed countries, with very few taking place in developing countries and only one in Africa. This contrasts with one of the main roles of CS in terms of widening the capacity to acquire data to feed monitoring and assessment schemes (GESAMP, 2019; Maximenko et al., 2019; Requier et al., 2020). This is a gap that needs further attention to expand CS influence in both research and management. Incentives for citizen science initiatives based in the Global South (in terms of human and financial resources), as well as incentives to publish the results from these initiatives (e.g., calls for thematic issues in journals and granting discounts/waives on publication fees for authors from these localities) can help in this regard.

In addition, over a quarter of our search results did not acknowledge the citizen scientists' contribution. Whilst this may have been translated via other mediums (e.g., direct contact with the citizen scientists or project websites), arguably this should be equally transparent in the reporting of these initiatives in the scientific literature. Expressing appreciation to participants and sharing with them the impact and results of their contributions in new scientific insights, policies or management decisions improve the likelihood of citizen scientists to continue engaging in the initiative and even contributing to disseminate results to different stakeholders (Rambonnet et al., 2019; Resnik et al., 2015; Strauss and Rager, 2017; Zettler et al., 2017).

Finally, more than a third of our search results did not make any reference to the accessibility of the data or results. This is an issue that should be considered in the scientific literature related to CS. Citizen science is a key component of open science (EU, 2022, 2019; UNESCO, 2021), playing an important role in the endeavour of democratizing knowledge. However, there can be some barriers for taking full advantage of this feature of citizen science, such as the lack of organized and interoperable open databases and the already mentioned high fees charged by many journals for open access publications.

4.2. Aspects related to marine litter data

As noted before, the vast majority of search results fully reported specific aspects related to marine litter. The present review did not intend to evaluate the quality of the data produced by citizens, i.e., the quality of the science derived from data, or the decisions based on them, but specifically, the results here reveal what the literature was explicitly reporting on. The surveyed studies in general reported on litter features or abundance. The composition of litter evidenced by

CS initiatives is seen as vital, for example, to evaluate the effectiveness of policies directed to specific items such as plastic bags and straws (GESAMP, 2019). While high density items (e.g., glass or metal) may suggest local sources or beach littering, predominance of plastic fragments (reported in 78.3% of our search results) may indicate an oceanic origin of items that are being degraded (and fragmented) for a long time (Honorato-Zimmer et al., 2019; Krelling and Turra, 2019). Characterization of litter features by CS initiatives may also inform sources and pathways, although the latter was rarely reported in the survey results.

When the size of the litter targeted was reported, it revealed a strong skewness to large-sized items (>2.5 cm) and an under-representation of meso and microlitter. Moreover, the results showed an emphasis on the shoreline sampling, mainly beaches (68.5%) and an under-representation of studies targeting floating or seafloor litter or the interactions between litter and the biota. The study of Melvin et al. (2021) also indicated gaps regarding the types of environments being studied for plastic pollution, such as coarse sediment and snow or ice. The interest of citizen scientists, as well as safety concerns or the amount of labour involved in field and sample processing activities, may explain such under-representations in sizes and sampled environments whilst simultaneously highlighting contexts that CS initiatives could broaden into in the future. One important aspect to be considered when planning a citizen science initiative is the level of professionalism and training (Haklay et al., 2021b) needed to participate. Protocols that present no assumption about expertise or do not need significant training are better suited for citizen scientists to perform, as is the case of those protocols targeted at macrolitter or mesolitter items on easily accessed sandy beaches.

The relevance of all information regarding litter is enhanced when data can be compared among locations or dates, helping in the identification of hotspots or trends of litter accumulation to address, for example, differential risks to societal policy concerns or effectiveness of public policies (GESAMP, 2020, 2019). This kind of application is strongly dependent on the reliability and comparability of the data acquired from citizen science approaches (Hidalgo-Ruz and Thiel, 2015; Rambonnet et al., 2019). As stated in the ten principles of citizen science (Robinson et al., 2018), citizen science initiatives produce genuine scientific data (principle 2) and have limitations and biases that should be considered and controlled for (principle 6). Generally, the validity of citizen science produced data is verified through pilot testing of protocols or comparisons between the results obtained by citizen scientists and specialists. Our results showed that only 3.5% of the publication records aimed at validating protocols or the data produced by citizen scientists. This does not mean that the protocols currently being used are not scientifically validated, but it is advisable that the studies that report on the results of the application of CS protocols explicitly inform the readers about the reliability of the data being reported (see, for example, the data verification flowchart presented in the work of Kiessling et al., 2019). This is important because the more reliable the data, the more accurate would be the comparisons of litter abundance across different spatial and temporal scales. The comparability of data can be achieved through the use of standardised (or harmonized) protocols, as well as the standardisation of measurement scales (Ambrose, 2021; Balázs et al., 2021; Barcelo and Pico, 2020; Freitag et al., 2016; Newman et al., 2011; Wiggins et al., 2011). As demonstrated in our findings, measures (such as size classifications) were highly variable amongst the search results and can prevent, for example, the production of synthesis and meta-analysis which would give us a broad and integrated view of the issue (Ottinger, 2010; Zettler et al., 2017), thus further highlighting an opportunity for future development. Comparison among different localities can also be achieved by large-scale studies if adopting a more standardised approach.

4.3. Aspects related to the citizen scientists

Whilst our findings support previously noted research gaps as well as highlight new challenges related to marine litter aspects, they also highlight a gap in the scientific reporting of some basic aspects related to the citizen scientists. For CS research to truly advance, the scientific aspects of the environmental issue should not be considered independent from those related to the citizen scientists, as they both rely on each other. For example, the sampling scale will depend on recruitment strategies and who is engaged, and the quality and type of the data recorded will be reliant on the training of the citizen scientists. Thus, it is necessary to understand if and how those aspects are currently being reported within the literature, which in turn will aid comparisons and replication to support further improvements in citizen science initiatives with marine litter.

Although most of our search results mentioned the profile of citizen scientists, there was little information in this regard, with almost one-third of them describing their participants only as "general public". Similarly, almost half of the search results did not mention how they recruited citizen scientists. This vague information may prevent the identification of the target audience, their interests, background (education, profession etc.), and motivations (as in McAteer et al., 2021). This gap in reporting consequently makes it difficult to learn from prior work. For example, having further information may help maintaining engagement of individuals in the initiatives (i.e. knowing and supporting their motivations), identifying strategies and populations that can be successful in CS (i.e. could start identifying which profiles are better suited for different objectives and tasks), as well as identifying novel groups to target to further improve the inclusivity of this CS approach (Aristeidou et al., 2017; Brouwer and Hessels, 2019; Hermoso et al., 2021; Lucrezi and Digun-Aweto, 2020). Thus, similarly to the lack of standardised protocols and measures, not reporting this information may prevent science from being able to replicate and advance this approach.

Knowing who the citizen scientists are may help to better develop and improve training, which is another aspect that was vaguely reported in our search results. Some initiatives did not train their citizen scientists, and for the majority of the initiatives, it was not mandatory prior to their participation. There is evidence in the literature that training can improve data quality (Bonney et al., 2016, 2009; Crall et al., 2017; Danielsen et al., 2014; van der Velde et al., 2017). Data errors and biases can be caused by differences in participants' abilities (e.g., identification, detection, estimation; Dickinson et al., 2010; Kosmala et al., 2016) and experience (Kosmala et al., 2016). The task difficulty may also influence data quality and, consequently, initiatives with more complex tasks should require greater attention/dedication to the training development and assessment (Kosmala et al., 2016; Rambonnet et al., 2019). For instance, van der Velde et al. (2017) found differences in data collected by primary school students trained by teachers who received a one-day training from those who received multi-day intensive training. The primary school students supervised by teachers with multi-day intensive training found significantly more marine litter during quadrat search than did other groups (e.g., secondary school students and adults). In this sense, knowing details of the protocol and how the training was conducted is important to assess the confidence in the findings, to allow reproducibility of the study, and for further improvements.

Training also has an important role in the scientific and environmental education of citizen scientists but having a training program is not a synonym of learning outcomes. It is common to find studies affirming that participating in the initiatives improved the citizen scientists' environmental and/or science education (Peter et al., 2019). However, the report of learning outcomes supported by data is uncommon in the literature and we could confirm this with our results.

In addition to the lack of evidence that learning outcomes have been achieved, this review also identified that other impacts on the citizen scientists have not been reported and/or assessed. According to the ECSA's principles, CS initiatives should aim to benefit (and to assess those benefits on) the citizens and society more broadly. Marine litter initiatives often intend to be enjoyable, interesting, and to promote more pro-environmental behaviours, but our review demonstrates that this was rarely reported. Those that reported an assessment on citizen scientists (with evidence), however, did demonstrate that experiential learning through the participation in a CS activity can foster environmental engagement (Hidalgo-Ruz and Thiel, 2013), positively influence knowledge and behaviour (Owens, 2018; Pahl and Wyles, 2017), or inspire citizen scientists to pursue academic environmental-related carriers (Yeo et al., 2015). However, it has also been noted that the way citizen science experiences make people feel may be more important for fostering future environmental engagement than factual-based learning (Dean et al., 2018). Moreover, educational level and social status may determine a volunteer's level of understanding of scientific terms, current issues, and global versus local issues (Hermoso et al., 2021; Yeo et al., 2015), thus linking back to different needs for training noted above (Haklay et al., 2021b).

Looking at the volunteering literature more broadly, citizen science initiatives have a great potential to benefit individuals' physical and mental health. Insights from the behavioural sciences show that if individuals enjoy an activity, understand the problems and associated solutions, have a sense of agency, and have a positive attitude towards a socio-environmental issue, they are more likely to continue that activity (i.e., increasing retention of volunteers) and engage in related behaviours (e.g., perform other pro-environmental behaviours; see Gifford and Nilsson, 2014; Kruse et al., 2020b; Oturai et al., 2022). Thus, assessing and understanding if or how these initiatives could affect behaviour would help maximize retention of participants within the initiative itself; increase experience and knowledge among the citizen scientists, further improving the quality of the data collected; and could have a broader impact by encouraging pro-environmental behaviours in other contexts. Yet, our review highlights this as being a major gap in this current field. This gap does not seem exclusive to marine litter. Peter et al. (2019) only found 14 studies out of a sample of 62 describing citizen scientists' outcomes in biodiversity-focused initiatives. Deguines et al. (2020) highlight that participating in citizen science initiatives has the potential to directly benefit local biodiversity "if such experience of nature leads to biodiversity-friendly behaviours in volunteers. However, whether engagement in nature-based CS programs promotes individual behavioural changes remains poorly known". In a review of climate change-focused initiatives (Groulx et al., 2017), only one study focusing on citizen scientists' assessment was found and it included non-empirical evidence in their analysis, which indicates the need to incorporate citizen scientists' assessment in the initiatives or report on it. In recent studies that evaluated the influence of the participation in citizen science activities on the promotion of pro-environmental behaviour, Wichmann et al. (2022) and Oturai et al. (2022) showed that school children did not show a significant change in perception of marine debris problem and in environmental behaviour after their participation in a plastic litter citizen science project. It is important to notice, however, that those school children already presented a high perception and involvement regarding plastic marine debris right in the beginning of the study, which was evidenced by the pretest that was applied by the authors.

Other studies that reported on the assessment of citizen scientists rarely did it in a systematic way, often relying on individual accounts and/or the researchers' impressions. Whilst this provides some insight, it does not demonstrate whether the act of engaging in these CS initiatives truly had an impact on the citizen scientists themselves. Optimally, the target impacts (be it changes in mood, literacy, or behaviour) should be measured before and after the initiatives using reliable and standardised measures to assess if there have been any changes (Pahl and Wyles, 2017; Phillips et al., 2018). This highlights the importance of combining expertise from different disciplines: (i) natural sciences to ensure good quality research is conducted, educators to ensure the learning outcomes are met, and (ii) social sciences to help maximise the benefits to citizen scientists and encourage greater engagement and retention.

Feedback from citizen scientists seems to be an even greater gap than the assessment. Most initiatives involve citizen scientists in a contributory way, reporting mainly on their involvement in data collection and rarely showing their contribution in other aspects of the scientific research, preventing valuable insights this kind of reporting might provide (Stevens et al., 2014). It is possible that in some cases the citizen scientists are satisfied by only participating as data collectors. However, we cannot be sure if we do not ask them. In fact, participation in scientific projects can provide citizen scientists an opportunity to expand their personal knowledge, to make them feel recognised and appreciated for their individual contributions to science, to see the impact of their work on their local community, and to better understand the issues pertaining to environmental policy that affect them (Brouwer and Hessels, 2019; Rotman et al., 2012), opening doors to a wider range of potential outcomes (Brouwer and Hessels, 2019; Crall et al., 2017; Merenlender et al., 2016; Shirk et al., 2012).

4.4. Filling the gaps

Overall, it is evident that citizen science has made a valuable contribution to the field of marine litter, in terms of collecting vital data, engaging the public, and ultimately impacting society. However, to maximise these benefits, some improvements are recommended in the science behind citizen science (Table 1), mainly related to standardisation and coverage of the results related to marine litter as well as the incorporation, better reporting, and explicit analysis of aspects related to the citizen scientists. First, the standardisation of data collection methods and in the way the results are reported (e.g., using same size scales or comprehensive categories of litter) is fundamental to allow for the comparison across different locations and periods of time, which will ultimately allow a broader view of the issue and guide decision making. Second, the expansion of geographical coverage, with the inclusion of more initiatives in Africa is also urgent. Third, since the advance in CS ultimately depends on its social dimension, publications featuring marine litter CS initiatives should report not only the results related to the litter (e.g., types, sizes, abundance, sources, and pathways) but also basic and general information about the citizen scientists with more detail (e.g., demographics and profile of citizen scientists, recruitment and training strategies, level of involvement in the scientific inquiry). Moreover, it is highly advisable that, whenever possible, marine litter citizen science initiatives adopt already well-stablished methodologies for the report of sociological aspects (e.g., educational, and behavioural impacts on participants), and that the publication of such results in scientific journals is encouraged to foster the development of frameworks and standards on CS research and practice. The scientific context required for these studies is probably so extensive that they must be reported in separate publications. However, we encourage these evaluations since they will not only provide important insights for strengthening the citizen science approach, but they will also help to significantly enhance the societal impact of citizen science initiatives by facilitating positive behavioural change. It is possible that some initiatives are already doing this but publishing elsewhere. Scientific journals that publish articles on CS that are related to marine litter could, for example, give some space for the reporting of these aspects related to citizen scientists, increasing the scope of existing good practices, especially those from empirical studies that are based on social or educational sciences methodologies and theories; authors should also use the opportunity to provide extensive information about these aspects in the electronic supplementary space offered by most scientific journals. This information is necessary for future comparative studies and meta-analyses, which in turn would help to advance this approach.

Table 1. Main recommendations derived from the systematic review of marine litter citizen science literature.

Aspect	Recommendation
Geographical coverage	The planning and implementation of more initiatives in the Southern Hemisphere, especially in Africa, is urgent. Integration of the results of initiatives from different localities could broaden the scope and the impact of the results of current subnational and local initiatives. Financial incentives are recommended.
Data and results/conclusions availability	There is a need to increase the accessibility to data and the results/conclusions of the initiatives to the general public, for example, through the use of open web-based citizen science platforms.
Acknowledgement	It is mandatory that all scientific publications that relied on citizen science data somehow acknowledge the participation of citizen scientists.
Removal of litter	All marine litter citizen science initiatives should remove the litter, and report on its removal from the environment, after the recording process.
Litter sizes	Standardization of the size scales adopted in the protocols is recommended to allow comparisons and meta-analyses. The development and validation of objective and simple citizen science protocols for the study of meso and microlitter are possibilities.
Types of litter	Standardization of the names of litter categories across different protocols and the use of comprehensive categories is recommended to allow comparisons and meta-analyses.
Report on citizen scientists	At least basic demographics and the profile of the participants; recruitment and training strategies; and the level of participants' involvement in the scientific inquiry should be reported by all scientific publications involving marine litter citizen science.
Assessment of citizen scientists	It is advisable that citizen science initiatives consider the assessment of perceptions, learning outcomes and behavioural changes of the participants. It is also recommended that scientific journals that encourage citizen science publications to open some space for the authors to include such aspects of citizen scientists' assessment in the articles.

5. Conclusion

As citizen science is a tool to connect two groups (scientists and citizens), it is necessary to acknowledge and report these approaches in a holistic manner, reporting both the aspects related to the environmental issue and those related to the citizen scientists themselves. Reviewing a rapidly growing area of citizen science approaches within marine litter, this paper examined what is currently being reported within the scientific literature and if this is fit for purpose to help advance this approach. Whilst the results were able to identify some gaps related to the report of marine litter aspects, a key finding was the lack of comprehensive reporting of aspects related to the citizen scientists. Thus, to address the overarching goal of the United Nations Decade of Ocean Science for Sustainable Development (IOC/UNESCO, 2020), this paper provides recommendations that may help build the *science* we need for the *citizen science* we want and, consequently, the *citizen science* we need for the *ocean* we want.

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Authors' contributions: Author 1: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data Curation, Writing- Original draft preparation, Visualization. **Author 2:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data Curation, Writing- Original draft preparation, Writing- Reviewing and Editing, Supervision. **Author 3:** Conceptualization, Methodology, Validation, Writing- Reviewing and Editing. **Author 4:** Conceptualization, Methodology, Validation, Investigation, Writing- Reviewing and Editing, Project administration, Funding acquisition.

Data availability statement: The data that support the findings of this study are openly available in Mendeley Data at DOI: 10.17632/t2gjt7kpk6.1 (URL: https://data.mendeley.com/datasets/t2gjt7kpk6/1).

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