Using Citizen Science to Understand Plastic Pollution: Implications for Science and Participants

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Plastic pollution is ubiquitous in aquatic environments around the world, such as in lakes, rivers, and oceans, and the presence and accumulation of plastic litter in coastal environments has become a topic of high priority for policymakers. The proliferation of plastic litter is mostly driven by an increasing production of synthetic-based polymers combined with poor waste management strategies (Moore 2008). An estimate of 8 million metric tonnes of macroplastic (plastic debris > 5 mm) and 1.5 metric tonnes of microplastic (plastic debris < 5 mm) enter the oceans annually (Jambeck et al. 2015; Boucher and Friot 2017), and these values have been projected to double by 2050 under a business-as-usual scenario (Lau et al. 2020). Plastic pollution can be detrimental to marine ecosystems due to the potential hazardous effects on biota and ecosystem functions, potentially affecting life history of (commercial) fish species and degrading habitats. The estimate of environmental damage to marine ecosystems is 13 billion US dollars per year, including financial losses incurred by fisheries and tourism as well as time spent cleaning up beaches (UNEP 2014). Beaumont et al. (2019) estimated that each metric tonne of plastic discarded in the marine environment has an economic cost of 3,300−33,000 US dollars per year. To assess the current extent of plastic litter in the environment, surveys and monitoring programs have been implemented, but remain challenging due to the geographical extent and persistent nature of plastic pollution, which leads to accumulation of litter items, combined with often limited financial and time resources (GESAMP 2019). Citizen science has, however, the potential to address data gap related-issues, by using participants as "sensors" and simultaneously increasing the public awareness towards plastic pollution.

Citizen science projects related to marine sciences are popular (e.g., current estimate of 500 marine coastal projects actively running in Europe, Garcia-Soto et al. (2021)), including projects in the field of plastic pollution, which have recently increased in number (Rambonnet et al. 2019). For example, of 127 citizen science projects active in the North Sea in 2020, 17 percent focused on marine pollution, including plastic debris observations (van Hee et al. 2020). According to current guidelines and best practice suggested by the European Citizen Science Association (ECSA), in citizen science projects participants are included in one or more stages of the research process, and projects should have scientific outcomes, which are genuinely open access (ECSA 2015; Heigl et al. 2019; Haklay et al. 2021). Citizen science initiatives, related to the observation and mitigation of plastic pollution, actively involve the public in scientific research and in the policy-making process (Lippiatt et al. 2013; GESAMP 2019; Garcia-Soto et al. 2021). The benefits of citizen science are multifold. Firstly, data acquired by citizen scientists can fill in gaps in existing data and information about plastic pollution levels due to resource constraints (time, staff, etc.), and enables sampling over larger geographical areas (Rambonnet et al. 2019). Secondly, the data acquired by citizen science participants, obtained either by school-children and/or adults, is often of equivalent quality to that collected by experts (Falk-Andersson et al. 2019; van der Velde et al. 2017). Consequently, such initiatives contribute significantly to obtaining information on plastic debris distribution (GESAMP 2019). For example, data acquired by citizen science can be instrumental in rapid assessment surveys, i.e., in obtaining an initial "snap-shot" of the distribution and abundance of marine litter (GESAMP 2019). Finally, plastic pollution data obtained by volunteers can also be further useful to evaluate the effectiveness of mitigation actions and local environmental policies, such as recycling initiatives (Harris et al. 2021; Lippiatt et al. 2013). However, while the benefits for scientific outputs have been well described, the impact for the participants in citizen science projects are less known.

Citizen science projects have per definition a strong component of public engagement in the scientific process, and some studies suggest that participation can lead to increased awareness of environmental issues, such as plastic pollution. For instance, participation in citizen science projects has a positive impact on the public's scientific literacy in several ways. Volunteers report a positive shift in their attitude towards science and gain an increased understanding of the nature of science. Participants also obtain topic-specific knowledge of the project and the steps of the scientific method (Bonney et al. 2009; Cronje et al. 2011; Aristeidou and Herodotou 2020; Peter et al. 2021). Further reasons and motivation to participate include enhancement of career competencies, environmental concerns, and interest in science (West et al. 2021). Recent reports further indicate that volunteers working outdoors experience a sense of enjoyment and of satisfaction when participating in citizen science projects as well as an increased connection to people and nature (Peter et al. 2021). Regarding activities specifically related to plastic pollution, Locritani et al. (2019) demonstrated that school students change their perception on beach debris causes, sources, transport, and consequences after participating in citizen science projects. For young adults (e.g., university students), participation in beach clean-up activities have been associated with positive mood, pro-environmental intentions, and higher marine awareness (Wyles et al. 2017).

The impact of public participation in citizen science related to plastic pollution on health and well-being is largely unknown. We define the term health as the overall absence of illness, injury, or pain and well-being as "a state of happiness and contentment, with low levels of distress, overall good physical and mental health and outlook, or good quality of life" (American Psychological Association 2021, n.p.). To date, there is little knowledge on how public beach clean-ups and plastic surveying activities promote human health and well-being as well as the participants' ocean literacy compared to other recreational visits to the coast. From an Ocean and Human Health perspective, a meta-discipline that explores the link between the health of the ocean and that of humans, citizen science projects have an important role in promoting ocean literacy. Besides, they offer an excellent opportunity to explore the benefits and risks for the participants' health and well-being after their interaction with the ocean and other water features (blue spaces) (H2020 SOPHIE Consortium 2020).

The goal of this chapter is to review the current knowledge on the impact of citizen science activities related to plastic pollution (e.g., beach clean-ups, plastic surveying, etc.) on participants, specifically science literacy, awareness of plastic pollution, public health, and well-being. We further discuss the benefits of the citizens' participation in plastic pollution related projects from an Ocean and Human Health perspective.

Methodology

Systematic Literature Review

We performed a systematic literature search on 19th May 2021, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement (Page et al. 2021, prisma-statement.org), using the abstract and citation database Scopus (www.scopus.com; Elsevier) (Tab. 1, Appendix A). The goal of the literature search was to retrieve peer-reviewed publications on citizen science activities, related to plastic pollution (Search 1), with an additional discussion on scientific literacy and attitudes and behaviors towards marine litter (Search 2) (Tab. 1). The queries used Boolean operators, and the selected terms were searched in the field "title, abstract, and keywords" (TITLE-ABS-KEY). Both searches were merged, and we obtained a result of 56 publications (Search 1, n = 37; Search 2, n = 19) (Fig. 1). After the exclusion of duplicates (n = 9), the remaining 47 publications were then manually screened. Publications that were further excluded (n = 13) from the results included those not focusing on citizen science activities (e.g., were about other educational interventions), reviews, and other non-research peer-reviewed articles (e.g., methods development). We obtained a final list containing 34 peer-reviewed research publications (Fig. 1).

Non-Systematic Literature Search

To assess whether citizen science studies further measured the impact of the activities on the participants, we performed an additional non-systematic literature free-text search using Google Scholar (freely accessible metadata of scholarly literature, scholar.google.com, Google) and Scopus. The non-systematic literature search retrieved four peer-reviewed articles (Tab. 1).

Data Visualization

All data was visualized using the package ggplot2 (Wickham 2016) from R (R Core Team 2020).

Tab. 1: Number of peer-reviewed articles retrieved in the systematic literature search (Search 1 and 2) and non-systematic search. Queries of Searches 1 and 2 used Boolean operators and terms were searched in the "title, abstract, and keywords" (TITLE-ABS-KEY) in Scopus (Elsevier, 19/05/2021), whereas the non-systematic search was done using free-text terms in Google Scholar and Scopus. See Appendix A for the flow of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).

Search	**No. of Results**	**Plastic Pollution related terms**		**Citizen Science terms**		**Ocean Literacy/ Education related terms**
Search 1	37	(TITLE-ABS-KEY ("plastic pollution") OR TITLE-ABS-KEY ("plastic litter") OR TITLE-ABS-KEY ("plastic debris") OR TITLE-ABS-KEY ("plastic cleanup") OR TITLE-ABS-KEY ("beach cleanup"))	+	TITLE-ABS-KEY ("citizen science")		
Search 2	19	TITLE-ABS-KEY ("plastic pollution") OR TITLE-ABS-KEY ("litter") OR TITLE-ABS-KEY ("beach cleanup")	+	TITLE-ABS-KEY ("citizen science")	+	TITLE-ABS-KEY ("awareness") OR TITLE-ABS-KEY ("education")
Non-systematic search	4	Free-text search(es)				

Results

Systematic Literature Review

The literature search retrieved a total of 34 studies (Appendix) published between 2013 and 2021 (Fig. 1) which targeted citizen science activities mostly in Europe (n = 16), e.g., in Norway (n = 5) and Denmark (n = 4), and North America (n = 9), e.g., USA (n = 5) (Fig. 2). Nine out of the 34 publications reported activities that took place in two or more countries. All studies used citizens as sensors or for surveying/monitoring purposes. In 31 of the 34 retrieved articles, citizens quantified coastal, marine or riverine litter items in a systematic way, following standard operating procedures (SOPs), specified or developed in each study (Tab. 2). These included beach cleanups (n = 8), boat sampling (n = 1), river shore sampling (n = 1), coastal shore sampling (n = 19), using social media records (n = 1), or thanks to an opportunistic and haphazard activity (n = 1) (Tab. 2). In 29 out of the 34 articles, quality control of the sampling procedure and/or established scientific standards for plastic sampling were discussed. Of the 34 articles, only nine specifically stated that the intervention targeted school children and adolescents (minors), whereas most of the retrieved articles did not specify the age of the citizen scientists (and we assumed that they were either adults or a mixed population of all ages) (Tab. 2).

In our results, only two of the retrieved studies assessed the impact of citizen science activities (in short term) on the participants using systematic methodologies. Of these two, one study acquired data via feedback from volunteers and case studies, in the form of online communication and interviews (Yeo et al. 2015). The work of Yeo et al. (2015) took place in Australia and New Zealand, and consisted of surveying persistent organic pollutants (POPs) using plastic resin pellets. The assessment of the citizen scientists' participation in the activity was done by collecting information via email and (online) feedback from the volunteers. The main conclusion of the study by Yeo et al. (2015) was that the participants reported feeling "empowered/encouraged", "grateful", and "more aware about the issue". The authors further concluded that "active participation in citizen science increases the participants' awareness of marine debris issues" (Yeo et al. 2015, 142, 144). The second impact assessment, a study that took place in the Italian coast, used questionnaires to acquire data from students as citizen scientists (Locritani et al. 2019). In their study, Locritani et al. (2019) performed a quantitative assessment of students' attitudes and behaviors towards marine litter before and after their participation in an educational and citizen science project for surveying macro- and micro-litter. The results of the study by Locritani et al. (2019, 320) demonstrated that the students (n = 87) “changed quantitatively their perception of beach-litter causes and derived problems”, and that the students “improved their knowledge about the main marine litter sources and the role of the sea in the waste transport and deposition along the coast”.

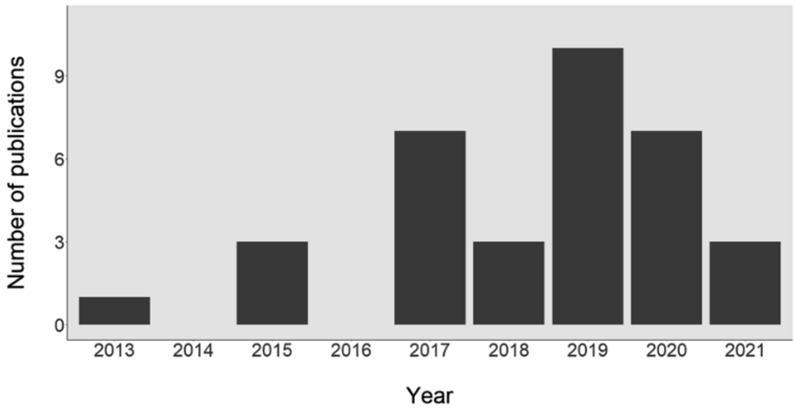

Fig. 1: Number of peer-reviewed articles per publication year on studies of citizen science activities related to plastic pollution retrieved using a systematic literature search (total n = 34 publications; search performed on 19/05/2021 using Scopus, Elsevier).

Non-Systematic Literature Search

In the non-systematic literature review, we retrieved four additional peer-reviewed articles published between 2017 and 2020 (Tab. 2), which assessed citizens’ perception, attitudes towards, and awareness of coastal litter in both children and adults. Of these four studies, two gave out questionnaires to beachgoers (coastal visitors) (Lucrezi and Digun-Aweto 2020; Rayon-Viña et al. 2018) to quantify the perception, awareness, and behaviors regarding coastal litter of participants undertaking citizen science activities (Rayon-Viña et al. 2019; Lucrezi and Digun-Aweto 2020). Wyles et al. (2017) assessed in university students (n = 90) from the UK, via pre- and post-intervention questionnaires, their marine awareness, behavioral intentions, mood, well-being, and perceived restorativeness of the coast. In their study, Wyles et al. (2017) observed that participants in beach cleaning activities reported a higher positive mood and pro-environmental intentions after the activity, with no significant differences to individuals who did activities such as rock pooling or coastal walks. Beach cleaning activities were further associated with higher marine awareness and were rated as most meaningful, but linked to lower restorativeness ratings of the environment (Wyles et al. 2017). Rayon-Viña et al. (2019) interviewed Asturian (Spain) adults and children before their participation in a coastal debris sampling campaign as well as non-participating beachgoers. In this study, Rayon-Viña et al. (2019) observed that, compared to non-participating beachgoers and adults, volunteers and children were more likely to erroneously attribute the main litter origin to beachgoers, and that volunteers perceived significantly more beached litter than non-volunteers, independent of the age group.

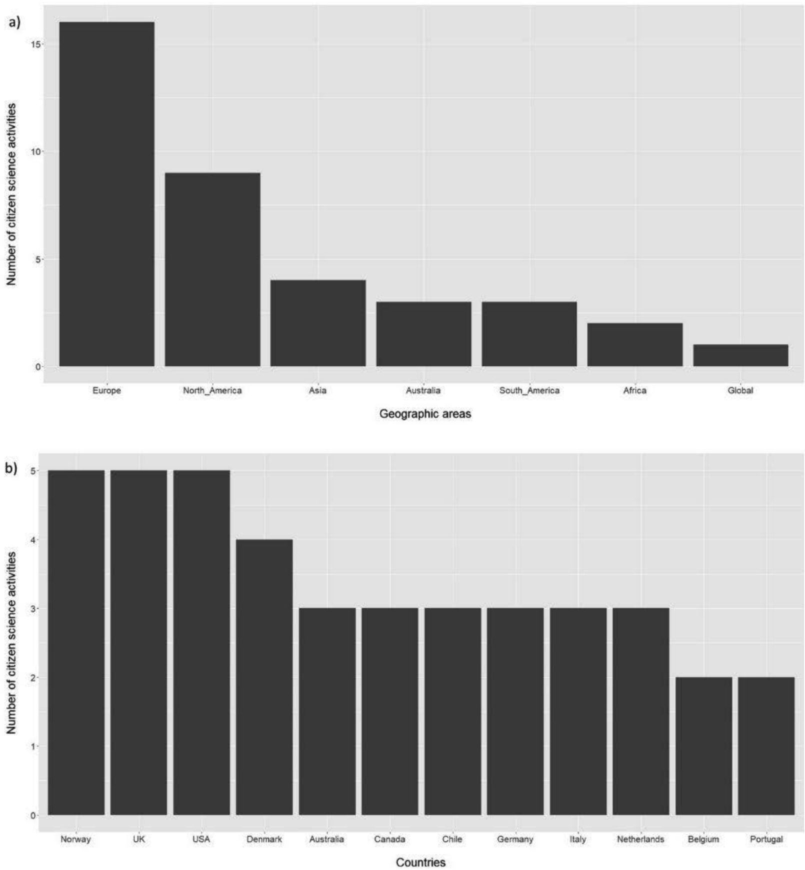

Fig. 2: Number of citizen science activities (absolute frequency) which took place a) around the world ("Global" included two or more geographic areas), and b) per country (only frequencies equal or above two were plotted), from studies retrieved using a systematic review approach [for details on systematic literature search see Tab. 1 and main text].

Tab. 2. Retrieved peer-reviewed articles, from a systematic (unshaded) and an unsystematic (shaded) search. Results were retrieved via Scopus (Elsevier) on 19/05/2021. SOP, standard operating procedure; NA, not applicable

Method for litter collection/observation	**Target geographic landform**	**Age group of participants**	**acquisition (surveys/ questionnaires)**	**Number of participants**	**Reference**
Search in social media mentions	NA	Not specified	NA	279 respondents	(Turner, Williams, and Pitchford 2021)
Cleanup	Beach	Not specified	NA	NA (meta-analysis)	(Earn, Bucci, and Rochman 2021)
Cleanup	Beach	Not specified	NA	NA (data analysis from eight citizen science shoreline cleanup organizations)	(Harris et al. 2021)
Following a sampling SOP	Coastal shore	School students (6 - 19 y/o)	NA	57,000 participants	(Syberg et al. 2020)
Following a sampling SOP	Coastal shore	Not specified	NA	Over three million person-days (a single individual doing an activity for any portion of a day) of recreational activity	(Uhrin et al. 2020)
Following a sampling SOP	River shore	Not specified	NA	Not specified	(Bernardini, McConville, and Castillo Castillo 2020)

Method for litter collection/observation	Target geographic landform	Age group of participants	Information acquisition (surveys/ questionnaires)	Number of participants	Reference
Cleanup	Beach	Not specified	NA	Not specified	(Roman et al. 2020)
Cleanup	Beach	Not specified	NA	Not specified	(Nelms et al. 2020)
Following a sampling SOP	Coastal shore	Not specified	NA	6,102 volunteers	(Chen et al. 2020)
Following a sampling SOP	Coastal shore	Not specified	NA	744 citizen scientists	(Tunnell et al. 2020)
Cleanup	Beach	Not specified	NA	2,139 volunteers	(Mayoma et al. 2019)
Following a sampling SOP	Coastal shore	Not specified	NA	37 surveyors	(Lee, Hong, and Lee 2019)
Cleanup	Beach	5–80 y/o	NA	85–183 average daily participants	(Cowger, Gray, and Schultz 2019)
Following a sampling SOP	Coastal shore	Not specified	NA	417 volunteers	(Ambrose et al. 2019)
Cleanup	Beach	Not specified	NA	Not specified	(Turrell 2019)

Method for litter collection/observation	Target geographic landform	Age group of participants	Information acquisition (surveys/ questionnaires)	Number of participants	Reference
Following a sampling SOP	Coastal shore	Not specified	NA	17 groups of citizen scientists	(Forrest et al. 2019)
Following a sampling SOP	Coastal shore	School children	NA	5,500 students	(Kiessling et al. 2019)
Following a sampling SOP	Coastal shore	Not specified	NA	Not specified	(Falk-Andersson et al. 2019)
Following a sampling SOP	Coastal shore	School children (nine– 17 y/o)	NA	1,383 students (supported by 80 teachers)	(Honorato-Zimmer et al. 2019)
Cleanup	Beach	Not specified	NA	498 volunteers	(Walther et al. 2018)
Following a sampling SOP	Coastal shore	Not specified	NA	214 participants	(Loizidou et al. 2018)
Opportunistic and haphazard	NA	Not specified	NA	Not specified	(Smith et al. 2018)
Following a sampling SOP (collection by manta trawls attached to standup paddleboards)	Baltic Sea	Not specified	NA	Two “adventurers”	(Gewert et al. 2017)

Method for litter collection/observation	Target geographic landform	Age group of participants	Information acquisition (surveys/ questionnaires)	Number of participants	Reference
Following a sampling SOP	Coastal shore	Not specified	NA	195 participants, including guests, crew and staff of cruises	(Bergmann et al. 2017)
Following a sampling SOP	Coastal shore	Not specified	NA	Not specified	(Lots et al. 2017)
Opportunistic and haphazard	NA	Not specified	NA	Not specified	(Colmenero et al. 2017)
Following a sampling SOP	Coastal shore	Not specified	NA	2,000–6,000 volunteers per year (estimate)	(Nelms et al. 2017)
Following a sampling SOP	Coastal shore	Not specified	NA	600+ volunteers	(Davis and Murphy 2015)
Following a sampling SOP	Coastal shore	School students and adults	Interviews and informal feedback	110 individuals or organizations	(Yeo et al. 2015)
Following a sampling SOP	Coastal shore	School students (eight– 16 y/o)	Informal survey	983 students (supported by 43 teachers)	(Hidalgo-Ruz and Thiel 2013)

Method for litter collection/observation	Target geographic landform	Age group of participants	Information acquisition (surveys/ questionnaires)	Number of participants	Reference
Following a sampling SOP	Coastal shore	School students (16–17 y/o)	Questionnaires: quant. assessment of attitude and behaviors twd marine litter before/ after participation	194 students (87 of which replied further to the post-survey questionnaire)	(Locritani, et al. 2019)
Following a sampling SOP	Coastal shore	School students (primary & secondary) and adults	NA	Not specified	(van der Velde et al. 2017)
Following a sampling SOP	Coastal shore	School students with an average of twelve y/o (other target groups: local resident children and adults)	Assessed perception and knowledge of local communities: 2x questionnaires and follow-up interviews	48 and 60 interviews per region	(Kiessling et al. 2017)
Following a sampling SOP	Coastal shore	School students/children	NA	Not specified	(Mioni et al. 2015)

Method for litter collection/observation	Target geographic landform	Age group of participants	Information acquisition (surveys/ questionnaires)	Number of participants	Reference
NA	NA	Mostly young adults	Quantitative, descriptive and non-experimental research design, structured questionnaire	512 beach visitors	(Lucrezi and Digun-Aweto 2020)
Following a sampling SOP	Coastal shore	Adults and children	Interviews before beach cleanups and survey	75 volunteers (and 133 beachgoers)	(Rayon-Viña et al. 2019)
Following a sampling SOP	Coastal shore	Adults	Survey about perception and awareness (open answers)	201 beachgoers	(Rayon-Viña et al. 2018)
Following a sampling SOP	Coastal shore	Undergraduate university students	Online surveys and paper surveys before activity, other measurements post activity	90 participants	(Wyles et al. 2017)

Discussion

Scientific Relevance of Citizen Science Activities Related to Plastic Pollution

Citizen science activities related to plastic pollution have recently become popular and represent a global effort of engaging the public in collaborative scientific projects. In our review, we demonstrate that citizen science projects related to plastic pollution have led to scientific outputs, i.e., peer-reviewed scientific publications (ECSA 2015). Our data shows that a quarter (nine out of 38) of the assessed studies represented a collaboration between two or more countries, indicating an effort of covering larger geographical areas of sampling. The data on plastic litter acquired by the public are considered of high quality and of scientific value, and comparable to that obtained by trained professionals (e.g., Falk-Andersson et al. 2019). The promotion of data quality and interoperability standards in citizen science depends largely on the development of clear sampling methodologies, with transparency of data management and sharing principles, and methodologies that include quality control and assurance measures (European Commission 2020). Plastic data acquired via citizen science projects can be made available (open data) in non-commercial portals such as The European Marine Observation and Data Network (EMODnet) Chemistry [www.emodnet-chemistry.eu], LitterBase [litterbase.awi.de, (Tekman et al. 2021)] or via mobile apps, such as the Marine Debris Tracker [debristracker.org/data, National Oceanic and Atmospheric Administration, NOAA, USA]. Most of the reported projects in this chapter (76 percent) included a discussion on the quality control and assurance of the obtained data, and followed a systematic sampling protocol for plastic litter quantification (Tab. 2). The quality of surveyed data is key to produce datasets that have comparability and should be considered in the evaluation of such projects in terms of cost-benefits (GESAMP 2019). Even though training citizen scientists can be time-consuming and costly (Hidalgo-Ruz and Thiel 2015; GESAMP 2019), the public participation can cover large geographic areas (e.g., Colmenero et al. 2017; Lots et al. 2017; Turrell 2019; Roman et al. 2020) that would be difficult or expensive for technical staff to visit (Hidalgo-Ruz and Thiel 2015), leading to clear benefits for valuable scientific outputs.

Most of the reviewed studies in this chapter focused on activities that assessed larger marine plastic debris, macroplastics (> 5 mm), and only three studies have quantified microplastics (< 5 mm), a more technically challenging work. The surveying and collection of macroplastics requires easy-to-understand sampling methodologies that do not demand complex equipment nor extensive training (GESAMP 2019). As per our results, citizen scientists successfully engage in projects that use systematic plastic data collection and employ standardized protocols. The collection of microplastic data by citizen scientists requires however, that two important analytical challenges are overcome (Zettler et al. 2017), i.e., inclusion of additional quality control measures (e.g., incorporation of procedural blank samples to quantify background contamination) and avoidance of unintentional microplastics contamination (e.g., airborne fibers) (Forrest et al. 2019). In their work, Lots et al. (2017) combined the collection of beach sediment samples done by citizen scientists with the laboratory extraction of microplastics done by technically trained staff and in a controlled environment. Forrest et al. (2019) used a similar approach to sample microplastics from Ottawa River (Canada). In their work, volunteers filtered a volume of 100 liter of river water using a previously provided sampling kit and then had the samples processed in the laboratory (Forrest et al. 2019). In the case of Gewert et al. (2017), two Swedish "adventurers" provided extra sampling opportunities by collecting microplastics during a paddleboard expedition over the Baltic Sea using lightweight trawls and processing the samples in a laboratory setting. In these studies, the participation of the public enabled researchers to cover a broader geographical area for microplastics sampling: data was collected in 23 locations of 13 countries in Lots et al. (2017), in locations covering a 550 km river stretch in Forrest et al. (2019), and along a transect of 210 km in the Baltic Sea in Gewert et al. (2017). After performing the quality check, four drawbacks of citizen science microplastics sampling compared to researchers taking the samples were mentioned in the discussion sections. These drawbacks mostly related to volunteers not following the step-by-step instructions such as not recording metadata, not processing blank samples, not sampling the required number of replicates or by overestimating the volume of sampled water (Forrest et al. 2019). Even so, for both macro- and microplastics sampling, authors noted that their outputs were reliable and data replicable (e.g., Kiessling et al. 2019; Bernardini et al. 2020), and the collected data provided important indications of litter density and composition (e.g., Bernardini et al. 2020; Harris et al. 2021) to inform recommendations for local and international plastic waste and litter management (Hidalgo-Ruz and Thiel 2015; Bernardini et al.2020; Harris et al. 2021). A multistep data verification flowchart with multiple criteria to be reached as presented in Kiessling et al. (2019) is an excellent example on how to ensure the quality of the citizen science data, and which can assist future projects to report on their data acquisition.

A frequent claim of citizen science litter surveying projects and beach clean-ups is that the public engagement also leads to an increased awareness of plastic pollution, with potential impact on the volunteers' ocean literacy and pro-environmental behaviors (Zettler et al. 2017; GESAMP 2019). Increasing ocean literacy, i.e., the understanding of human impact on the oceans and of the ocean's impact on humans, has been considered to contribute to tackling waste management issues and to improve the understanding of local communities on the potential consequences of plastic (Westfall and Simantel 2019). Even though considerable work is being done on engaging volunteers in scientific projects, there is still a considerable knowledge gap on how plastic related projects impact citizen scientists. For example, in our work, of the 38 publications evaluated (systematic and non-systematic searches), only four studies have assessed the impact of the activity on the participants. The retrieved studies reported, for instance, that participants felt "more aware about the (plastic pollution) issue" (Yeo et al. 2015, 142), and "changed quantitatively their perception of beach-litter causes and derived problems" (Locritani et al. 2019, 320). However, the assessed aspects were not only restricted to the educational benefits and pro-environmental intentions of the activity. For instance, Yeo et al. (2015) and Wyles et al. (2017) further assessed aspects related to mood and well-being of the participants. As with other citizen science projects, plastic related activities are intrinsically transdisciplinary, and an active inclusion of social sciences and humanities questions and methodologies would benefit the understanding of the benefits and challenges of the interventions in the public (Tauginienė et al. 2020). In the following sections, we will discuss the educational and behavioral impact of citizen science as well as the potential psychological implications of the public participation in plastic pollution related projects from an Ocean and Human Health perspective.

The Educational and Behavioral Impact of Citizen Science

Citizen science has important benefits in the development of scientific literacy, beyond the facilitation of data collection or data analysis to reach a specific research outcome. The term scientific literacy can refer to either knowledge of scientific processes, concepts, or situations (OECD 2006) or to awareness of one's role in the local environment (Conrad and Hilchey 2011). In the case of knowledge and awareness of ocean and human interactions, the more common term of "ocean literacy" is used; however, ocean literacy and scientific literacy are seen as interdependent as "one cannot be considered 'science literate' without being 'ocean literate'" (Strang et al. 2007, 7). Enhancing ocean literacy encompasses several processes, such as educating on marine environmental issues, increasing awareness and sensitivity, and developing a connection as well as pro-environmental attitudes and behaviors towards the ocean (Kelly et al. 2022). A study by Ashley et al. (2019) demonstrated that ocean literacy initiatives led to an increased awareness, knowledge, and attitudes, supporting sustainable actions to marine environmental issues that were considered key predictors of behavior change, which is the goal of ocean literacy.

Considering today's context of marine plastic pollution, it would be beneficial to evaluate the capabilities of citizen science interventions to improve knowledge, awareness, and attitudes essential to addressing the problem. Citizen science is already regarded as being of educational value to the participants, however increasing knowledge or awareness is insufficient to predicting actual behavior change (Hines et al. 1987). Changes in attitudes and behavioral intentions are necessary additional predictors of behavior change (Ashley et al. 2019, see also Grünzner and Pahl in this volume), but are often overlooked during evaluation of citizen science interventions (Toomey and Domroese 2013). As per our results, only four studies from the (systematic and non-systematic) literature search assessed the impact of citizen science activity on the participants, although there is an increased effort of the scientific community in recent years to assess the public perception of plastic pollution related issues (Catarino et al. 2021). More investigation on the educational and behavioral effects of citizen science is therefore necessary, to establish the impact of the citizen's participation in sampling campaigns in tackling the plastic pollution problem.

To assess the educational and behavioral impact of citizen science, researchers follow social science methodologies (e.g., questionnaires, interviews, etc.), that can be applied in studies related to plastic pollution. One method that has been implemented by mostly social scientists in numerous studies is a quantitative pre- and post-assessment via a questionnaire (Hartley et al. 2015; 2018; Locritani et al. 2019; Wyles et al. 2017). This type of within-subject design allows to concisely assess the short-term impact of the activity on the participants and thereby evaluating its effectiveness. For example, specific questions regarding knowledge, awareness, attitudes, and behaviors towards marine litter are developed and typically piloted before being used on the participants. Participants then complete the questionnaire before and after the citizen science activity (Breakwell et al. 2006). Another methodology, applied by Rayon-Viña et al. (2019), compared participants taking part in beach clean-ups with non-participants and evaluated potential differences in perception and awareness of marine litter by means of a survey. This between-subject design resembles that of a typical interventional design employed in social sciences with one group undergoing the "intervention" and the other remaining as "control group", enabling to tease out the unique effect of the activity (Breakwell et al. 2006). Notably, the intervention group (i.e., citizen science participants) may differ from the control group in many ways (e.g., demographic, psychological), which may confound the envisioned effects, despite efforts to ensure equal variability in both groups via randomization Another example is the methodology employed by Yeo et al. (2015), i.e., the use of qualitative methods to investigate the impact of the science communication of their program on the volunteers. The researchers analyzed feedback from the volunteers that was sent via email, conducted on-site interviews, and implemented case studies including participant observation (Yeo et al. 2015). This type of methodology provides an open access to the participants' thoughts and feelings concerning the citizen science activity. Although applying qualitative methods does not enable to test a specific effect, it does enable to indicate potentially undiscovered effects that could be interesting to pursue and further test with quantitative methods (Taylor 2005).

According to the results of the presented literature research, there are indications that participation in citizen science activities can affect volunteers. In the study conducted by Wyles et al. (2017), marine awareness and pro-environmental behavioral intention increased significantly after the citizen science activity and remained higher than baseline after one week, suggesting a short-term effect. Additionally, the study's results imply a positive spillover effect, as participants not only expressed a stronger intention to engage in beach clean-ups, but also reported a higher intention to adopt more general pro-environmental behaviors (Wyles et al. 2017). This supports the notion that engaging in one conservation act can induce individuals to undertake other pro-environmental behaviors (Grønhøj and Thøgersen 2012). The effectiveness of citizen science also seems to vary by age group. Essentially using the same questionnaire as Hartley et al. (2015) for ages between eight to 13 years, Locritani et al. (2019) state differences in the effects of their citizen science activity on the adolescent participants, aged 16 to 17 years. The results from Locritani et al. (2019) indicate that adolescents had a higher baseline knowledge and awareness of marine litter pollution, thereby leading to less significant changes between pre- and post-activity. Alongside these results, children aged ten to 16 years had a higher awareness of the problem of marine litter compared to adults in another study, even though this was not linked with a higher litter perception (Rayon-Viña et al. 2019). This suggests that although increasing children's awareness is a priority, there remains a lack of knowledge about marine litter. Although participation in citizen science related activities might affect specific age groups differently, the educational value of engaging in such activities should not be discarded. For example, by directly empowering educators to teach about marine litter, as suggested by Hartley et al. (2018), and by including adults in citizen science projects, knowledge transfer to children can be indirectly promoted.

Health Impacts of Coastal Citizen Science Activities

By participating in citizen science projects, the public can experience benefits to their health and well-being. Two studies in our systematic review reported changes in the health or well-being of the participants (Wyles et al. 2017; Yeo et al. 2015), a key aspect in establishing the link between ocean health and human health. The impact of plastic surveying and beach clean-ups has only been marginally investigated compared to other and more common activities in coastal areas, such as walking or other leisure coastal activities (Maguire et al. 2011; White et al. 2013; Wyles et al. 2014). More specifically, health and well-being aspects that were investigated in these two studies retrieved from the current literature review can be categorized as having an emotional or cognitive origin. The studies reported emotional changes in the participants, including feeling more "empowered/ encouraged" and "grateful" (Yeo et al. 2015, 142), as well as a better mood and higher meaningfulness (Wyles et al. 2017). However, negative aspects were also reported, such as a lower cognitive restoration in response to beach cleaning compared to walking or rock pooling (Wyles et al. 2017), indicating that beach cleaning may affect the participants self-perception of their relaxation status.

The citizen science participants can experience key benefits or shortcomings that can affect their emotions and cognitive restoration from actively participating in plastic surveying and beach clean-up activities. For example, the blue gym concept explains the mechanisms behind the health benefits potentially experienced by citizen science participants' exposure to blue spaces (water features, including coastal areas). The blue gym refers to the use of coastal environments that promotes health and well-being, thanks to physical activity, stress reduction, and by building a community spirit (Sea Change 2018). Participants in plastic pollution surveying and beach clean-up activities are exposed to an outdoors setting (e.g., natural coastal landscape, clean air), participate in a physical activity (e.g., via plastic collection, walking for surveying purposes), and can experience positive social interactions (with friends, family, and other community members). Research from the fields of environmental health and psychology suggests that spending time in a natural setting, such as a beach or coastal environment, can result in better mood (Peng and Yamashita 2016), less stress (Triguero-Mas et al. 2017), and decreased depressive symptoms (Dempsey et al. 2018). However, the relative absence of cognitive restoration from citizen science activities compared to other beach activities found by Wyles et al. (2017) can be attributed to the exposure and focus on the plastic litter. For example, litter seems to negatively impact the perceived restorative potential of a landscape when shown via pictures (Wyles et al. 2016; Hooyberg et al. in prep). Wyles et al. (2016) additionally showed that the litter decreased the preference for the shown environment. Recent research indicates that this effect is especially relevant in natural landscapes compared to urban landscapes and is higher than the impact of other anthropogenic disturbances such as cars (Hooyberg et al. in prep). The fact that citizen science activities related to plastic pollution imply exposing the public to litter may limit the restorative characteristics of the activity. Future research should verify and elucidate these effects in detail.

In contrast with the anticipated positive effects, the participants of citizen science projects have at some occasions reported pessimism, anxiety, and other negative emotions. For example, in an online survey given to participants across 63 biodiversity citizen science projects, the majority of which focused on insects and birds, a small portion of these participants reported a pessimistic outlook regarding the future of the environment after participation (Peter et al. 2021). This is in line with research displaying the negative consequences of environmental education such as pessimism and eco-anxiety, referring to the "chronic fear of environmental doom" (Sheppard 2004; Clayton et al. 2017; Pihkala 2020). As such, there is a small but existing risk for participants in citizen science to develop negative emotions. To make it even more complex, pessimistic emotions and views towards the future can be constructive, in the sense that the more negatively one perceives a future situation, the more likely one will be encouraged to act preventively in the present, as demonstrated by Kaida and Kaida (2016). Further research on the potential negative outcomes of participating in citizen science should be conducted, as addressing these issues could improve the positive outcomes of citizen science projects (Peter et al. 2021).

The repeated exposure to plastic litter during beach clean-ups and other plastic pollution related activities, whether being it in the context of citizen science or not, may induce further psychosocial impacts. Such impacts may arise from coastal users or citizen science participants perceiving that other coastal visitors are responsible for littering, which may in turn impact their social relationships (Wyles et al. 2014). For instance, coastal users have identified activities such as walking to be detrimental to the environment, as they perceived that other coastal visitors are responsible for littering (Wyles et al. 2014). As the perceived restoration of the landscape moderates the effect on pro-environmental behaviors (Berto and Barbiero 2017), a similar outcome can be expected for people participating in citizen science activities related to plastic. The same impact on citizen scientists' perception can occur in the interactions between health-related effects (e.g., restoration) and literacy-related effects. Currently, the health and well-being benefits of citizen science plastic-related activities are poorly quantified, but recent reports indicate that complex psychological, social, and physical factors can jointly and interactively play a role in determining the health benefits of the citizen science plastic activity.

Socio-Economic and Socio-Demographic Representation

There is an inherent bias in the socio-economic and socio-demographic representation of the participants of citizen science activities (Haklay 2013), questioning whether societal and environmental benefits are evenly distributed (Cooper et al. 2021; Pateman et al. 2021). Most participants are from middle to high income backgrounds, with access to education, technical skills, resources, and infrastructure that facilitate engagement in citizen science projects (Haklay 2013; Cooper et al. 2021; Pateman et al. 2021). There are further concerns on how diverse citizen science participants are (Cooper et al. 2021; Pateman et al. 2021). For example, in the UK, participation in environmental citizen science projects is particularly low among women from minority groups and people who are unemployed or from lower socio-economic groups (Pateman et al. 2021). At the same time, the participating population in citizen science activities in the US does not reflect the demographics of this country, mostly excluding individuals from groups that have been historically underrepresented in science (e.g., African Americans, Latinx, American Indigenous Communities) (Pandya 2012; Trumbull et al. 2000). It has been demonstrated, however, that more social deprived communities in the UK have the highest health benefits when living in close proximity to the sea (i.e., blue spaces), potentially thanks to increased opportunities for stress reduction and physical activity (Wheeler et al. 2012). It is critical to further understand whether the participation of lower socio-economic groups in citizen science activities related to plastic pollution would provide additional health and educational benefits to such communities, to promote projects that account for diversity, equity, and inclusion dimensions.

The current literature review highlights that most of the retrieved publications have reported on activities that took place in Europe and North America (Fig. 2), where countries are mostly classified as middle to high-income economies (The World Bank 2021), with Africa as being the continent with the lowest number of reported projects (Fig. 2). We were unable to assess the socio-economic background of the participants in the literature reviewed, as such data are rarely recorded in citizen science outputs (Pandya and Dibner 2018; Pateman et al. 2021). The lack of participation of people from specific geographic areas or from specific communities may imply that certain areas are not considered in environmental datasets and are excluded from prioritization in policies (Pandya and Dibner 2018; Pateman et al. 2021), for example, to prevent and mitigate plastic pollution. Furthermore, members from these communities will not have access to the benefits in terms of skills and literacy gained by participating in citizen science projects, such as having direct contact with scientists or exposure to scientific literacy (Pandya and Dibner 2018; Pateman et al. 2021). Projects such as the Citizen

Observation of Local Litter in Coastal ECosysTems (COLLECT) (Partnership for Observation of the Global Ocean 2021) and the WIOMSA (Western Indian Ocean Marine Science Association) Marine Litter Monitoring Project (Western Indian Ocean Marine Science Association 2021), among others, are important contributors in working towards data acquisition on plastic debris distribution and abundance on the coasts of African countries, by training citizen scientists and promoting knowledge transfer between local communities and researchers. Additionally, COLLECT further aims to evaluate shifts in the pro-environmental attitude of participants towards coastal plastic litter, as well as on their well-being, filling an important knowledge gap on the health and educational impacts of citizen science initiatives in Africa. Overcoming underrepresentation of entire geographic areas and/or of underprivileged and minority groups in plastic pollution related citizen science should be considered in projects, as it is a missed opportunity to empower local communities in taking part in the development of a successful plastic circular economy, via perception and behavior shifts, and via active participation in decision-making.

Conclusions and Outlook

Citizen science projects related to plastic pollution, such as beach clean-ups and litter surveying, have increased in popularity and have produced valuable scientific outputs. The participants in citizen science projects can follow standardized methodologies for data acquisition, and allow to cover a wider geographical range for sampling than conventional observational and monitoring efforts. Even though the scientific advantages of citizen science plastic related projects are well documented, only a limited number of studies have reported on the educational and behavioral effects on participants. There are however indications of the positive educational value for the public in participating in beach clean-ups and plastic surveying activities as well as positive impacts in terms of ocean literacy, pro-environmental behaviors, higher meaningfulness, and general well-being. Some negative impacts have also been suggested, such as induced changes in the participants' emotions, which limit restoration of their cognitive abilities. An important finding of our systematic literature review is that both positive and negative impacts on participants of citizen science plastic projects have barely been explored, and that there is a gap in the knowledge of whether the public experiences pessimism and eco-anxiety feelings. We further identified a limited socio-economic and socio-demographic representation of the participants of citizen science activities in plastic pollution projects. Plastic related projects involving citizen scientists should broaden their collaborative scopes to include geographic areas overlooked in current projects, consider the inclusion and empowerment of diverse groups of participants (and beneficiaries), to deepen the projects' impact, and to avoid important data gaps due to the exclusion of participants due their socio-economic and -demographic status. Future surveying programs of plastic pollution involving citizen scientists should consider a collaboration between natural and social science professionals, to evaluate in depth the educational and psychological benefits to the participants, and that best practices should include mechanisms to engage across diverse publics, including access to activities by underrepresented socio-economic and socio-demographic groups.

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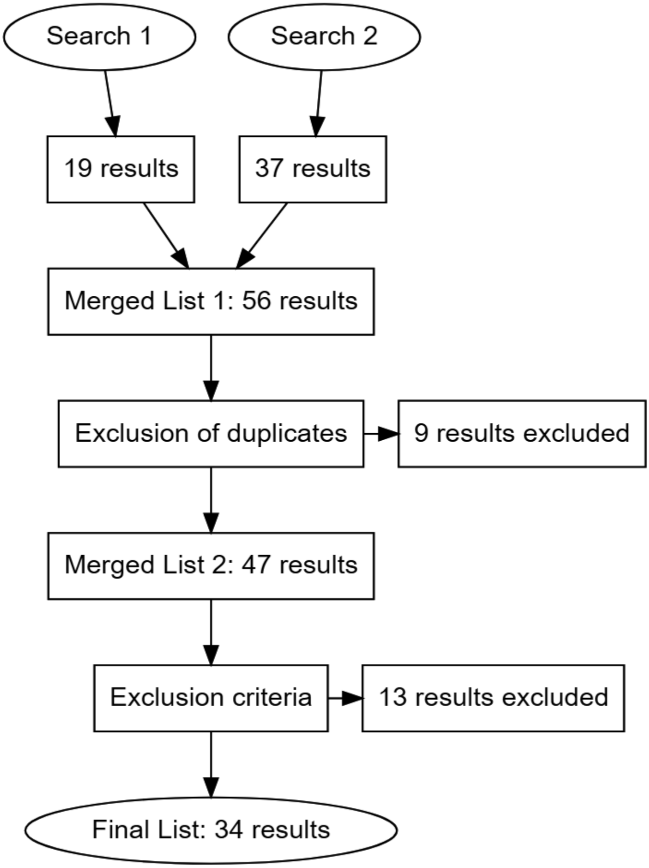
APPENDIX A



Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram [for search terms please refer to Tab. 1, for exclusion criteria please see main text]. Results were retrieved via Scopus (Elsevier) on 19/05/2021 and merged lists were managed using Mendeley (Elsevier). The final list of results consisted of 34 scientific peer-reviewed articles is available in Tab. 2.