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The role of citizen science in addressing plastic pollution: Challenges and opportunities

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ABSTRACT

Globally, the number of citizen science clean-up projects, such as beach cleans, is increasing in an effort to reduce the amount of plastic pollution in the environment. Such activities offer the opportunity to gather insightful data on plastic abundance, distribution and composition. This information is key for informing effective management strategies aimed at reducing input but little work has been conducted to examine the challenges faced by existing citizen science projects, or the potential opportunities for maximising their impact. Here, we present the results of a questionnaire survey and follow-up workshop to explore the opinions of representatives from 20 organisations that deal with the issue of plastic pollution in the environment. Our results show that, of the organisations that conduct clean-up activities in the United Kingdom (UK), the majority collect data on plastic pollution to some extent. To ensure these data are scientifically meaningful and the necessary levels of public engagement are maintained, participants felt that survey protocols should be standardised across organisations and data submission should be as simple and easy as possible. The participants considered communication, inclusivity and volunteer diversity to be key for enhancing citizen engagement and improving data quality. Many organisations were unclear about how the information they hold can be most effectively used to help inform policies relating to

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managing plastic pollution. Moving forwards, there is a clear desire from clean-up organisations to collaborate with other sectors, such as commercial, policy, waste and recycling, education and technology stakeholders, as well as other non-governmental organisations and scientific researchers, to enhance the value and impact of citizen science in tackling the issue of plastic pollution.

1. Introduction

Plastic pollution is a global societal concern due to its potential to cause ecological and socio-economic harm (Beaumont et al., 2019). Understanding its abundance, distribution and composition in the environment is important for informing, designing and implementing effective management strategies aimed at reducing inputs and the associated impacts. Yet, to identify sources, spatial patterns and temporal trends, large long-term datasets with broad spatial coverage are required, the collection of which can be expensive, time-consuming and labour intensive (Nelms et al., 2017). One option for achieving this is to involve members of the public as *citizen scientists*, whereby volunteers record information about anthropogenic litter (of which the majority is plastic pollution) during activities, such as beach cleans (Hidalgo-Ruz and Thiel, 2013; Nelms et al., 2017, 2020; Rambonnet et al., 2019). This method of collecting data is beneficial for a number of reasons. Firstly, utilising a volunteer workforce alleviates some of the logistical and financial constraints that would be incurred if professional scientists were employed to collect such large volumes of data (Nelms et al., 2017). Secondly, citizen science is particularly well-suited to investigating environmental issues which occur over broad spatial or extended temporal scales, and require members of the public to employ basic skills (e.g. counting items; Bonney et al., 2009; Silvertown, 2009; Dickinson et al., 2012; Wei et al., 2016). Thirdly, citizen science is highly appropriate for issues with public-policy implications because it can raise awareness, create an open discourse, engage with the public from the beginning, and encourage the public to take an active role in finding solutions (Dickinson et al., 2012; Bird et al., 2014; Zettler et al., 2017; Rambonnet et al., 2019).

There are, however, some constraints of using citizen science methods to collect data. For example, citizen science-derived data are often perceived as lower quality and less robust than those collected by professional scientists (Hyder et al., 2015; Kosmala et al., 2016). This is likely due to the propensity of citizen science data to experience variability/ error caused by differences in the skills of volunteer participants (Bird et al., 2014). Additional constraints are that citizen science datasets are coarse, experience biases from a variety of sources (e.g. sampling and observer bias, and detection probability) and can be a challenge to analyse and interpret (Bonney et al., 2009; Dickinson et al., 2012; Bird et al., 2014; Nelms et al., 2017). These constraints may affect the acceptance of citizen-science derived data by those who seek to use such information for developing plastic pollution management policies. It is possible, however, to mitigate many of these constraints by involving expertise from multiple disciplines in the project development, delivery and outputs (e.g.; Bonney et al., 2009; Zettler et al., 2017), employing simple and standardised data collection protocols (Silvertown, 2009; Bird et al., 2014), combining multiple datasets to enable fine-resolution examination of large-scale patterns (Bonney et al., 2009), and carrying out rigorous statistical analyses (Bonney et al., 2009; Bird et al., 2014).

The large number of existing, often long-running, projects represents a valuable resource in generating a better understanding of plastic pollution and their activities have great potential for gathering evidence (Bergmann et al., 2017; Nelms et al., 2017, 2020). Yet many were not originally designed with best-practice citizen science principles in mind but have instead evolved over time. Additionally, most clean-up organisations operate independently from one another and the data they hold are not directly comparable due to differences in collection methods and survey protocols. These factors currently limit the utility of citizen-science derived data for plastic pollution research and policy development and have been highlighted in previous work (see Nelms et al., 2017).

In this study, we sought to examine whether it is possible for existing projects to retrospectively adopt citizen science best practice principles and maximise the utility of their data. To do so, we invited representatives of organisations that work on the issue of plastic pollution in the United Kingdom (UK) to take part in a questionnaire survey and workshop discussion. Here we outline the challenges faced by clean-up organisations and the options available for future improvements.

2. Methods

2.1. Clean-up organisation identification

A web search for the keywords 'beach cleans' was carried out using the Google search engine to identify organisations which recruit volunteers to conduct clean-up activities (19 Sept 2019). Each returned result from the first 10 pages was examined for the name of organisations hosting beach cleans. Those organisations with a national (UK) and regional (southwest England) presence were recorded. This resulted in 25 potential organisations that may hold data about anthropogenic litter (including plastic pollution; hereafter, litter) in marine environment. A variety of techniques were employed to identify individual representatives who may be willing to participate in our questionnaire survey and workshop. These included using contact information from the organisation's website (either generic enquiry department or specific contact for beach clean events) and employing snowball sampling, whereby existing contacts were requested to recruit additional participants from among their colleagues and peers (Heckathorn, 2011; Illenberger and Flötteröd, 2012). This use of snowball sampling meant that multiple representatives from some organisations responded.

2.2. Questionnaire

An online questionnaire survey, consisting of 20 questions and sub-questions (see Appendix) relating to litter collection and disposal, beach clean data and citizen engagement with plastic pollution, was hosted by the secure platform, onlinesurveys.ac.uk. The questions were of various types (e.g. direct and short open-ended, yes/no and multiple-choice) depending on the desired resulting information.

The identified organisations were contacted via email and invited to complete the survey using a link to the password-protected questionnaire, between 21 Oct 2019 and 6 Dec 2019. Prior to taking part, participants were informed that they had the option of omitting questions they did not wish to answer and if published, their responses would not be identifiable as theirs. Qualitative response data from the online questionnaire were manually coded and themes from the responses identified (thematic analysis; Braun and Clarke, 2006). Quantitative data were explored using Excel.

2.3. Workshop

Following the questionnaire survey, participants were invited via email to take part in a face-to-face workshop on 30 Jan 2020, hosted by the University of Exeter (UoE), where the topics outlined in the questionnaire could be further discussed.

The participants were divided in to two groups with one UoE staff member in each to facilitate discussion (outlining discussion topics,

time-keeping and ensuring equal opportunity for all attendees to participate). The workshop consisted of two sessions (1.5 h each) where four pre-determined themes (based on topics covered in the questionnaire) were discussed in each (see below);

Session 1: Challenges.

i) Barriers to collecting scientifically meaningful data
ii) Maximising citizen engagement

Session 2: Opportunities

i) Engaging with other sectors
ii) Building capacity

Both groups discussed all topics concurrently during the two sessions. During the workshop, discussions were recorded on dictation devices, consent for which was requested beforehand. At the end of each session, groups were asked to summarise their discussions as a written list of points. These notes were then typed up into an electronic format to assist in the identification of themes during analysis. For those who were not able to attend, the same questions were posed via email (two participants). After the workshop, recorded discussions were transcribed using Google Docs Speech-to-Text tool, and reviewed for accuracy.

The discussion transcripts for each workshop session were coded using NVivo (QSR 2020). Broad themes were identified during the first coding pass and, if present, sub-themes were identified during the second coding pass (Braun and Clarke, 2006; Newing et al., 2011). Each theme and sub-theme is presented to comprehensively illustrate the range of participant views and discussion topics.

3. Results

3.1. Questionnaire responses

Of the 25 organisations contacted, 22 responses were received from 20 organisations (more than one staff member from some organisations participated). The majority of these organisations focus their clean-up efforts in the southwest of England (Cornwall, Devon, Dorset and Somerset) but some have a national (England and United Kingdom) and international (global) coverage. The number of volunteers taking part in beach cleans annually with each organisation varies between 5 and 90,000. Combined, the 20 organisations manage an estimated 201,000 volunteers, though this figure likely includes individuals who volunteer with more than one organisation.

3.1.1. Anthropogenic litter collection and disposal

The organisations reported the amount of litter collected during clean-ups using different metrics, by weight (kilograms) and number of bags (bin and carrier bags). They estimated that volunteers remove approximately 314,803 kg, 961,638 bin bags and 24,752 carrier bags of litter from beaches annually. If we conservatively assume the two bag types (bin and carrier) weigh 3 kg and 0.25 kg respectively, this equates to a minimum overall estimate of 3205 metric tonnes of litter collected per year.

The litter collected during beach cleans is disposed of in a variety of ways, with several respondents stating they employ more than one disposal method ($n = 14$). The most common was recycling (40% of responses; $n = 16$), followed by landfill (25%; $n = 10$), outreach and education (e.g. for publicity, art, and school activities; 20%; $n = 8$), reuse or repurpose (7.5%; $n = 3$), incineration (5%; $n = 2$) and removal by local authority (2.5%; $n = 1$; Fig. 1). Recycling methods included domestic kerb-side schemes run by local authorities, collection by commercial waste contractors, and contribution of suitable items to circular economy projects for recycling into specific products (e.g. Odyssey Innovation - fishing nets into kayaks; www.odysseyinnovation.com; last accessed 24 July 2020).

3.1.2. Beach clean litter data

Most (71%; $n = 15$) of the participants said that data on litter are collected during beach cleans and, of these, the majority (60%; $n = 9$) said that the data are kept within the organisation for their own purposes. The remaining participants (40%; $n = 6$) said the data were sent elsewhere to be added to datasets of other organisations (such as Marine Conservation Society, Surfers Against Sewage or Keep Britain Tidy). For those who said data were not collected during beach cleans (29%; $n = 6$), two main reasons were given. Firstly, the difficulties of coordinating volunteers to record data when litter removal is carried out on an ad hoc or individual basis (i.e. the organisation does not run formal beach clean events). Secondly, because data collection is not the primary purpose of beach cleans (main aims are to engage the community and remove litter).

When asked how better quality data could be gathered during beach cleans, a shared database where all organisations could deposit their litter data was the most common suggestion (30%; $n = 7$; Fig. 2a). This was followed by both, a need for standardised data collection methods and an easier way to input and collate data such as an 'App' (26%; $n = 6$ for each). More training of beach clean volunteers to record data and identify litter items was suggested (9%; $n = 2$), as was coordination of beach clean events with other organisations to avoid temporal and

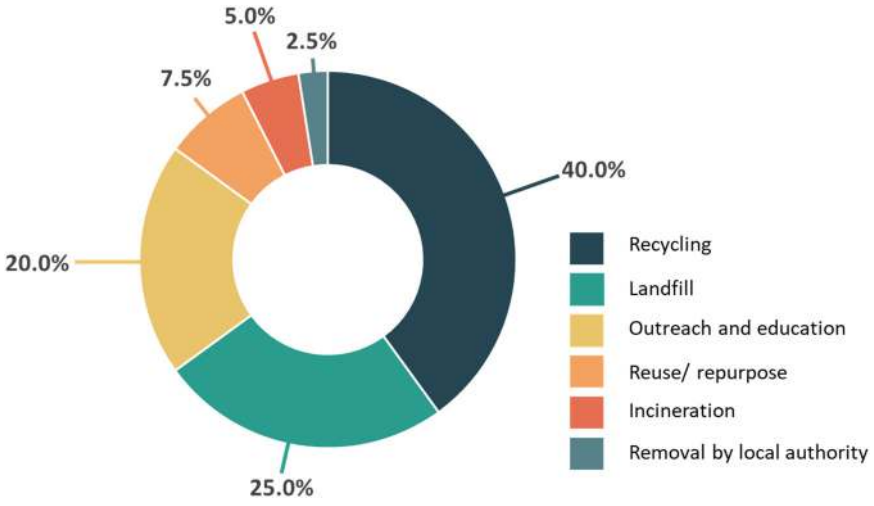

Fig. 1. Doughnut plot showing the methods organisations use to dispose of litter collected during beach cleans based on the number of questionnaire responses for each method.

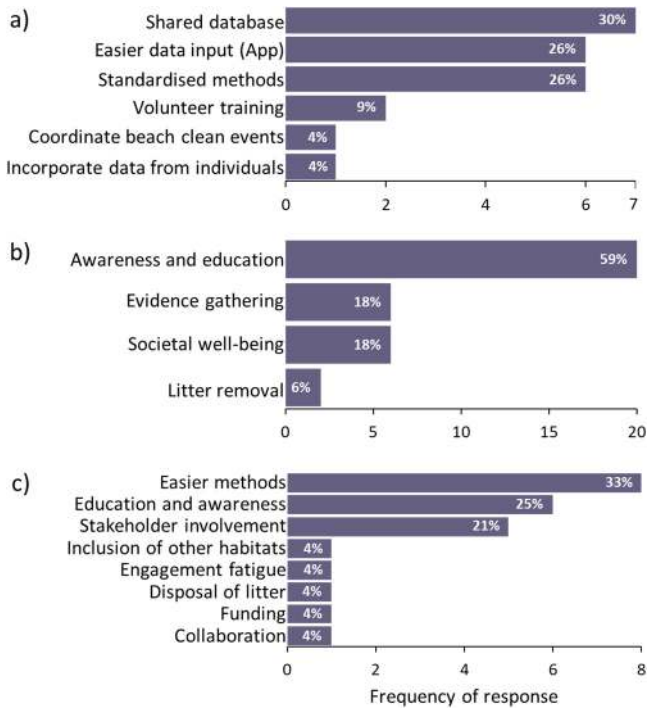

Fig. 2. Histograms showing questionnaire participant responses when asked (a) how better beach clean data could be gathered and (b) what are the benefits of citizen engagement to the issues of beach litter and plastic pollution and (c) what key issues need to be resolved/discussed to maximise the benefit of citizen engagement to the plastic pollution problem.

spatial overlap, and incorporating data collected by individuals who record litter when not taking part in an official beach clean (both 4%; $n = 1$).

3.1.3. Citizen engagement with plastic pollution through beach cleans

When asked what the benefits of citizen engagement are to the issue plastic pollution, the most common response of participants was awareness and education (59%; $n = 20$; Fig. 2b). In particular, participants felt that beach cleans allowed volunteers to see the effects of litter on the marine environment, which in turn might inform their behaviours relating to plastic use and disposal. Evidence gathering and societal well-being were both discussed equally (both 18% of responses; $n = 6$ each). For the former, benefits focused on observing trends and patterns in plastic pollution and contributing to policy changes. Well-being benefits included mental and physical health, empowerment of individuals and communities and socialising. Perhaps surprisingly, plastic pollution removal was the least discussed benefit (6%; $n = 2$). Environmental and socio-economic factors (e.g. impacts on maritime industries, such as fisheries and other boat users) were listed.

In response to being asked what key issues should be resolved or discussed to maximise the benefits of citizen engagement to the plastic pollution problem, the need for easier methods of collecting, recording and accessing beach clean data was the most mentioned (33%; $n = 8$; Fig. 2c). This was followed by education and awareness (25%; n = 6) and involvement from other stakeholders, such as fishers (21%; $n = 5$). The need for collaboration between organisations (e.g. knowledge sharing and co-ordination of activities) and funding, concerns over how best to dispose of beach litter and how to avoid engagement fatigue were listed, as was the need to include other habitats (e.g. rivers, and urban areas) in clean-up activities (each 4%; $n = 1$).

3.2. Workshop discussion

Themes that emerged during the workshop discussion are presented in detail below. The workshop was attended by 20 representatives from 18 of the 20 organisations who responded to the questionnaire (from the 25 initially contacted). Quotes are presented that represent the clearest examples of the topics discussed. A summary of discussion topics can be found in Fig. 3.

3.3. Challenges

3.3.1. Barriers to collecting scientifically meaningful data

The workshop participants raised six challenges for collecting scientifically meaningful data on plastic pollution, ranging from logistical to behavioural barriers (Fig. 3).

'*Complexity of data collection and submission*' was one of the most commonly discussed themes. This included specific issues, such as labour-intensive collection methodologies, complicated recording forms, some volunteers and beach clean leaders having a lack of scientific understanding, and lack of incentive to submit data after beach cleans. For one participant, engaging the public to collect detailed data is a challenge;

> *'It's that balance of getting people engaged and getting robust data - we're struggling with both.'*

'*Data quality' was another key theme*, with some participants expressing concern over the potential biases in data collected by citizen scientists. For example, one participant said;

> *'One thing we've noticed is that people are quite biased to picking up things that they find interesting……. We've done a beach clean looking specifically for Lego and that was the biggest beach clean we've ever done because people are interested in that. They're not going to pick up polystyrene cups if they can find something more interesting.'*

Other topics included the lack of ability of some volunteers to correctly identify and categorise litter items, and problems ensuring volunteers follow the survey methodology correctly. Additionally, the number of volunteers and volume of data requiring management can be a practical barrier for some organisations;

> *'The size [of beach cleans] and the volume of people involved is a barrier. It's not impossible; it's just looking at a clever way of how we can consolidate data.'*

'*Motivation*' is another barrier to collecting scientifically meaningful data. Many participants felt that volunteers are not driven by the need to collect data, particularly if it is labour-intensive;

> *'Most of them [volunteers] just want to clean the beach rather than understand there are 50 items of polypropylene and 20 items of polystyrene* etc.*'*

Factors such as inclement weather, complexity of data collection and submission, and lack of tangible impact from their efforts can also negatively affect volunteer motivation.

The need for '*Standardisation*' of data collection methodologies and recording forms among the different organisations was frequently discussed, with some participants highlighting that disparities in techniques mean that data from multiple sources cannot be combined for detailed analysis;

> *'We're all doing different things differently and recording different things, like width of beach, beach length, number of volunteers and things like that.'*

Examples of countries where governments coordinate the various beach clean organisations to use standardised methodologies (e.g. Spain) were discussed but some participants highlighted that this is easier to implement when organisations first begin collecting data. In the UK, organisations have been collecting data using similar, but not the same, methods for many years (e.g. the Marine Conservation Society

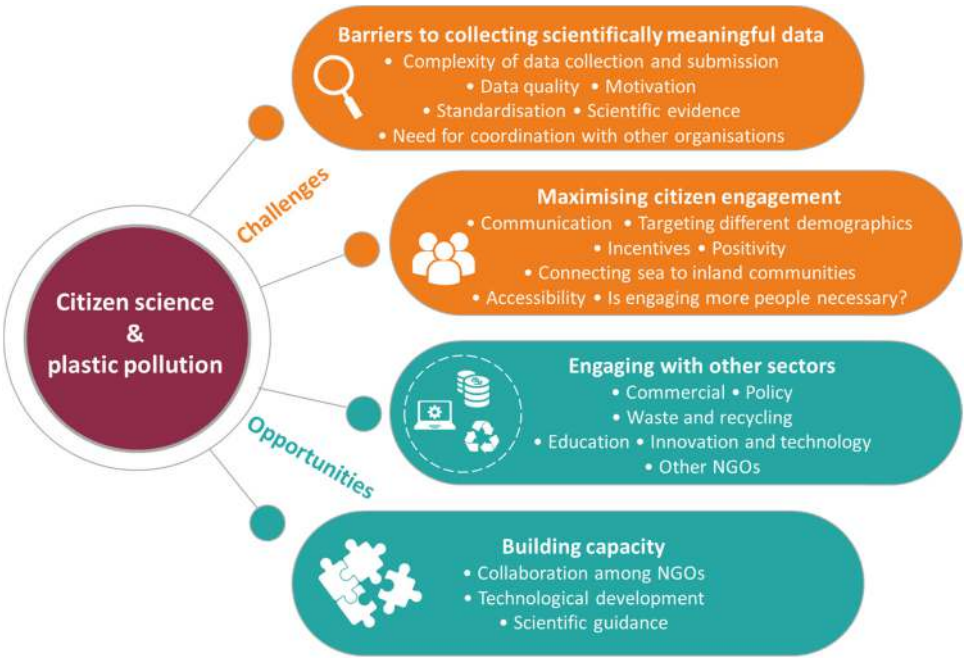

Fig. 3. Summary of themes identified during workshop discussion relating to four topics within two sessions (challenges and opportunities).

began running beach cleans in 1994). Within this theme, the varying methods of recording data were also discussed. For example, differences in item classification and metrics (i.e. weight versus counts) between different beach clean projects.

Discussions around '*Scientific evidence*' focused on questions regarding the quality and type of data needed by policy makers, with many participants unsure as to what standard of data is required;

'What [data] do we need to collect to inform policy?'

Lastly, participants felt there was a '*Need for coordination with other organisations*' to share data and avoid duplicating effort and skewing datasets, e.g. by cleaning the same beaches, but had *'Concerns over data ownership'*.

'If there was one system [for coordinating beach cleans] this could be great because we could record when beach cleans were happening [and avoid overlap].'

'Ownership [of data] may be a barrier because different organisations want to be recognised for what they're doing. That can cause a barrier through competition.'

3.3.2. Maximising citizen engagement

When asked to discuss how to deal with difficulties of involving unengaged citizens, the workshop participants highlighted seven key points (Fig. 3).

Firstly, '*Communication*' was heavily discussed and can be broken down into three sub-themes;

i) Science communication: It was felt that effective science communication is important to inform the public about the issue of plastic pollution and why collecting data is needed. For example,

'.nothing in science is really written in English. It's not accessible to the general public so it has to be an easily understandable story.'

ii) Raising awareness: Clean-up activities can provide an opportunity to discuss how the public's behaviour and actions affect the environment. For example,

'Every time I speak to a group of people and I say, "We can go and litter pick in the park so it doesn't get to the ocean and choke whales and dolphins and turtles and sharks and whatnot", and they go "Yeah that's a great idea, let's do that". Then we go out and they feel good about it so you need to tell them that they are actively doing something which really has a positive effect on the environment and the animals and the ecosystems and the sea, and afterwards they are smiling.'

iii) Social media: It is useful for organisations to tailor their communication to specific demographics via social media. For example,

'Social media is amazing. If someone, who is of a certain demographic in our database, posts something on social media via *the app, we know how to respond to that person because we need to talk to them and their friends. Actually understanding social media at an intricate level is so important to us all.'*

The need for '*Targeting different demographics*' to ensure that a wide audience is engaged and volunteers from all backgrounds and ages are included was another key theme. Some participants noted a gender bias towards more women taking part in beach cleans, and possible solutions for addressing this were discussed;

'We have a massive issue, everyone who comes on our beach cleans is always female.'

'You have to give an incentive, which is why we planned the LEGO beach clean and we had more boys [attend].'

Some participants also observed challenges with enlisting volunteers from certain age brackets but the age brackets were not always the same among organisations. There was some suggestion that overall coverage of the volunteer age spectrum might be achieved when all the organisations are considered together;

'…different age groups *and different audiences need different approaches and [have] different challenges for each of them and making the connection.'*

Participants discussed '*Incentives*' as a means to increase levels of beach clean engagement, both in terms of financial and health and well-

being benefits;

'They have done something similar in Germany for long-term unemployed where they have brought in one euro jobs where they go litter picking, for example, and they are responsible for a stretch of street or park or whatever and they get paid for it and they get all of the benefits.'

'You [volunteers] can help, you are empowered, you are part of the solution if you come and help us. We can make it all sound as if they can come and make new friends and have a cup of tea and a cookie and clean the beach and can still engage if they want to.'

The participants felt that '*Positivity*' is a key way to engage with more people, and optimism is important for helping people to feel empowered;

'One thing to keep in mind is that the message needs to be positive. People disengage when it's all doom and gloom and people know it is bad and they just disengage. So if you want to engage you need to make it positive.'

'Connecting the sea to inland communities' was seen as an important way to involve people who do not live on the coast in helping to tackle the issue of plastic pollution, both in terms of reducing plastic input and removing it from the environment;

'Trying to connect the sea to the land is a good way of engaging people, making them go to the beach and get people to see that connection.'

Related to this was '*Accessibility*'. It was felt that access to the marine environment, and engagement with environmental issues, may be constrained by socio-economic barriers and public perceptions:

'We assume everybody is like us and loves it [the beach] and everyone will at least go there on their holidays but they don't, they go to shopping centres on their holidays. So it's the majority of your population you're wanting to engage, not people who are already on the beach walking their dogs and doing beach cleans.'

'We need to make this a 'cool' thing to do. Litter picking is still seen as a negative, particularly in schools where it is often used as a detention or community service punishment.'

Finally, the question, '*Is engaging more people necessary?*' was raised with some participants feeling that the number of volunteers taking part in beach cleans is sufficient. While others pointed out the need for diversity, good geographic coverage and the need to future-proof the volunteer workforce:

'We've just been talking about how massive our beach cleans are, how many volunteers we have, let's just focus on what is already being done and make it better. Because it can be made better as we're all highlighting and collect better data'.

'Don't forget that we might have a lot of people now but some of these people will get too old or will disengage so we need to always be engaging to keep young people and new people coming in.'

3.4. Opportunities

3.4.1. Engaging with other sectors

When asked which sectors should be engaged with to tackle plastic pollution, six main categories were identified (Fig. 3).

The most commonly discussed sector was *'Commercial'* with discourse focusing on the following sub-themes:

i) Accountability and corporate responsibility from specific sources (e.g. manufacturers, tourism, fisheries, supermarkets and big retail brands). For example,

'We're collecting data around what customers are finding really annoying [about plastic packaging] when they're going round the shops and then the idea is that we can use that to go to supermarkets to show them.'

ii) Methods of reducing plastic consumption and environmental leakage (e.g. extended producer responsibility, bottle deposit return schemes, incentive-based initiatives/ charters, circular economy approaches, Fishing for Litter). For example,

'We need to engage people with expertise in business and circular economy.'

iii) Pitfalls to be wary of when engaging with business (e.g. greenwashing). For example,

'How do we check the level that those businesses are actively participating in the schemes and aren't just greenwashing it using it to make more money?'

The *'Policy'* sector was also frequently discussed. Many organisations were unclear about how the information they hold on plastic pollution in the environment and the levels of engagement from the public can be most effectively used to help inform policies relating to managing the problem. Particular concerns related to the types of information (data) needed, timescales of when to supply this information, who requires it and how to involve the correct people. There was, however, a clear desire for organisations to engage with policy makers on the issue;

'Where are these policy drivers, what's going on at the scenes behind parliament and Westminster and where is the interest, because then we can actually target our actions.'

'We're just assuming the level of understanding that they [policy makers] need to create change but we need to understand what they need from us to drive forward legislation and policy change.'

Many participants felt that engaging with the '*Waste and recycling*' sector was important for both reducing the amount of plastic reaching the environment, and disposing of waste collected during beach cleans.

'An opportunity to engage with business or plastic recyclers will help manage the waste and make more of a circular economy'

'Education' was seen as an important method of engaging with people to raise awareness of plastic pollution and, more broadly, to enhance ocean literacy;

'There are 1000 kids in each school (approx.). If every year group does a beach clean once a year, you've got hundreds of thousands exposed and, if you do it right, engaged.'

The opportunities offered by '*Innovation and technology*' were discussed, particularly for enhancing data collection, levels of engagement and impact on policy;

'I think technology in terms of scalability for what we're all doing. It has the ability to provide a level of unification and scalability outside of our normal groups of influence.'

Within this theme, developing new tools, which enable society to reduce the levels of plastic used, was also discussed. For example, alternative materials for storing and dispensing food, such a refill stations and bulk-buy shops.

Finally, some participants recognised the need for the '*Non-governmental organisation (NGO)'* sector to work together more to create a clearer and more impactful message:

'Being able to get together to have a louder voice, rather than lots of individuals shouting in a crowded room. We need to get together cohesively, to be able to have a unified voice that this is the direction that we want to go in.'

3.4.2. Building capacity

When asked what they need to build capacity, the participants discussed three main themes (Fig. 3).

'*Collaboration among NGOs*' was seen an important aspect (to share knowledge and data, ensure a strong shared message and to avoid duplicating beach cleaning effort):

> *'Communication between the groups about where and when the [beach] clean is happening, and to enable data sharing….'*

> *'We need a central database so that everybody's data is compiled.'*

There were concerns, however, about the need to maintain brand identity, particularly because many are charities and rely heavily on attracting competitive funding:

> *'I guess it's striking a balance about everybody [NGOs] working together but everyone maintaining their own identity. We're all working in different places and capturing different audiences. You'd have to keep that balance between that diversity but also that collaboration.'*

'Technological development' was discussed as a potential solution to make data collection and sharing easier:

> *'Another thing that would be useful in the whole [data] collection thing is getting whatever it is, an app or a database, to actually work out the figures for you at the end. It's so time consuming, gathering all this data.'*

Lastly, *'Scientific guidance'* regarding the level of detail and robustness needed regarding data was discussed, as well as a desire to understand the direction of scientific research so organisations could assist in data collection:

> *'A website where scientists could list specific things they're interested in getting help from people out in the field.'*

4. Discussion

Engaging with volunteers to collect and/ or analyse data is a rapidly growing research tool and citizen science is now widely recognised and valued by national governments, funders, policy makers and the scientific community, due to its potential to advance our scientific understanding of environmental change and enhance public involvement with important societal issues (Silvertown, 2009; Bonney et al., 2014; Hyder et al., 2015).

Recently, citizen science-derived data have increasingly been utilised to understand the abundance, distribution and potential sources of plastic pollution in a variety of environments, such as beaches, sea surface water, rivers and lakes (Hidalgo-Ruz and Thiel, 2013, 2015; Wang et al., 2015; Bergmann et al., 2017; Bosker et al., 2017; Nelms et al., 2017, 2020; Vincent et al., 2017; Zettler et al., 2017; Chiu et al., 2020). Even so, challenges remain and overcoming them requires a collaborative and multidisciplinary approach. Here we present the integrated learnings from representatives of 20 UK-based organisations that coordinate thousands of volunteers to tackle plastic pollution, and make recommendations for maximising the utility of existing citizen science projects to tackle plastic pollution.

4.1. Collecting scientifically meaningful data

Collecting information on litter is a common practice for many organisations that conduct clean-up activities but a variety of barriers hamper efforts to make the data robust and scientifically meaningful, an important consideration if endeavours are to truly be citizen 'science'. There is a strong link between the complexity of collection methodologies and data quality and easier tasks have been found to result in higher levels of accuracy with minimal bias (Parsons et al., 2011; Kosmala et al., 2016). Designing appropriate protocols that are easy to follow, and providing training, can enable volunteers to collect robust data, which is of equal quality to those produced by professional scientists (Bonney et al., 2014; Rech et al., 2015; Kosmala et al., 2016). For example, Hidalgo-Ruz and Thiel (2013) demonstrated that the accuracy of data on small plastic debris collected by schools, did not differ from subsequent laboratory re-counts conducted by scientists and Rech et al. (2015) found no difference in litter densities of rivers as recorded by volunteers when compared to professionals.

A significant barrier to obtaining comparable data from across the various organisations is the lack of standardisation in survey design and data collection protocols. For example, clean-up events where data are collected (surveys) may occur in transects with defined areas or on whole beaches where volunteers are free to clear the areas they prefer. The surveys may involve a set number of volunteers or may be open to anyone who turns up on the day. This variation in sampling effort can have a significant impact on data reliability if it is not accounted for (Nelms et al., 2017). The data may be recorded on paper sheets or mobile devices and the litter item categories available for data input, and the terminology used to classify them, vary among the organisations. The litter may be recorded as count data (individual items) or as weights (either for individual items or collated for each survey). During the workshop, the representatives of clean-up organisations expressed a willingness to consider the concept of aligning litter survey methods with those of other organisations to enhance the amount of data available for analysis and therefore enhance its ability to inform research and policy.

Volunteer motivation can affect the quality and quantity of data collected and submitted. This can be overcome by examining what key factors drive volunteer involvement. For example, de Vries et al. (2019) found that motivation can be enhanced by sharing data and findings with volunteers as it demonstrates that their efforts are valuable in creating tangible outcomes.

Sceptics of citizen science often cite concerns about biases, but many of those found in citizen science datasets are also present in professionally produced data and can be dealt with by applying appropriate statistical tools (Kosmala et al., 2016). Care should be taken, therefore, when interpreting citizen science data as simple statistical analyses may misrepresent the data. For example, if volunteer effort (number of participants, time spent searching and area covered) cannot be standardised during data collection, it should be recorded and accounted for in statistical analysis (Kosmala et al., 2016; Nelms et al., 2017, 2020).

4.2. Citizen engagement

Recruiting and retaining volunteers is key to citizen science activities and effective communication through a variety of engagement methods is essential. For example, a combination of digital (e.g. webinars and social media) and face-to-face (e.g. public lectures, education and outreach) communication encourages uptake by a diverse audience and elicits greater participation (Zettler et al., 2017). During the recent coronavirus (Covid-19) pandemic, many organisations significantly increased their use of digital engagement methods in response to restrictions on movement and social distancing measures. In some cases, this resulted in substantially higher numbers of people attending online events than would have been possible on a face-to-face basis. It is therefore probable that digital interactions will become more mainstream in the future. It is not known, however, whether the increase in quantity of virtual interactions has the same benefits as 'real-world' interactions in terms of quality and impact.

Retention of volunteers helps to improve data quality because experienced participants are often able to gather more accurate data, and can help train new recruits. Clear scientific objectives, which are communicated throughout, enable volunteers to understand the purpose of the project and increase their support for it (de Vries et al., 2019). The 'Ten Principles of Citizen Science' underline the importance of communicating project findings to participants and acknowledging their

involvement (European Citizen Science Association, 2015). In many cases, volunteers prefer communication of tangible results more than recognition or reward (Silvertown, 2009; Alender, 2016; Zettler et al., 2017; de Vries et al., 2019).

During the workshop, participants noted that effective science communication was an important factor in engaging with citizen scientists but also a challenge to deliver, particularly in relation to education on why collecting robust data is important. In the future, this could be overcome through greater involvement from policy makers and researchers. For example, public engagement events, such as talks, may offer the opportunity for the public to better understand how the data have real-world application for evidence-gathering.

4.3. Engaging with other sectors

There is a desire from organisations that conduct beach cleans to engage with policy makers on how citizen science can be best used to gather evidence on plastic pollution and inform management actions designed to reduce it. Indeed, it is an essential next step if the potential of citizen science data is to be realised (Hyder et al., 2015). Yet, concerns about data quality, accuracy and precision, robustness and access likely affect the uptake of citizen science data by policy makers and some may even be unaware that it exists (Bonney et al., 2014; Hyder et al., 2015). Some policy makers and environmental regulators consider citizen science outputs only when the data have been professionally analysed and published in peer-reviewed journals, demonstrating a need for robust scientific methods and academic linkage. Moving forwards, greater collaboration between clean-up organisations, scientific researchers and policy makers will provide the opportunity to make the most of citizen science data.

Clean-up activities, such as beach cleans, remove significant volumes of litter from the environment and the organisations involved in this study alone collect approximately 3000 metric tonnes of litter per year. The results from our questionnaire survey and workshop indicate that organisations would like to see greater collaboration with the waste and recycling and commercial sectors to better manage the litter they remove. As a solution to the plastic pollution problem, clean-up activities have a significant role to play and support from other sectors would facilitate progress towards the waste hierarchy goal of reducing the amount of waste entering landfill (https://ec.europa.eu/environment/topics/waste-and-recycling/waste-framework-directive_en; last accessed 22 Apr 2021).

4.4. Building capacity

To further increase the power of citizen science data, collaboration among clean-up organisations would be of great benefit to both scientific research and litter removal operations (Zettler et al., 2017). For example, a shared database where organisations aggregate their litter records would help develop a better understanding of litter abundance, distribution and re-accumulation rates (Zettler et al., 2017), and information on the location and timing of clean-up activities would direct effort to where it is most needed. One method that may facilitate input into a shared database is the use of a mobile application ('app') to record data collected during organised clean-up events and by individuals. Apps are commonly used for citizen science purposes because they facilitate quick, easy and often real-time data submission (Luna et al., 2018). They can also improve the accuracy of spatial information, capture data collected by individuals who are not part of organised events and improve levels of engagement (Jambeck and Johnsen, 2015; Luna et al., 2018). Currently, a variety of different apps for recording litter in the environment are available, some of which have significant levels of user engagement. By amalgamating data through a shared recording tool, such as an app, clean-up organisations could generate a volume of information that enables data reuse and meta-analyses by a diversity of users (Newman et al., 2012; Wang et al., 2015). This, however, would require some consideration of how all participating organisations could adopt the same standardised sampling protocols, agree upon an approach to data 'ownership' issues, maintain brand identity and address the challenge of managing the data (Newman et al., 2012). Nonetheless, developing and improving open-source data management technologies and analysis tools are crucial for driving citizen science forward, and data sharing and storage are key considerations for the future (Newman et al., 2012; Bonney et al., 2014; Zettler et al., 2017).

5. Conclusion

In many ways, plastic pollution and citizen science make an ideal combination for increasing research capacity and enhancing knowledge, while simultaneously providing societal and environmental benefits (Wyles et al., 2016; Zettler et al., 2017; Den Broeder et al., 2018). As a highly visible issue, plastic pollution has the levels of public interest and engagement needed to instil action from large numbers of people, and 'science by the people' (Silvertown, 2009) has the power to gather large volumes of data over broad temporal and spatial scales. From our study, it is clear, however, that many challenges must be overcome if citizen science is to reach its potential for informing our understanding of plastic pollution. Looking forwards, we feel that greater collaboration and support from researchers and policy makers will help to fill in the gaps and maximise the impact of clean-up organisations and their activities.

CRediT authorship contribution statement

Sarah E. Nelms: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Project administration, Funding acquisition. **Emily Easman**: Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Project administration. **Nichola Anderson**: Writing – review & editing. **Madeleine Berg**: Writing – review & editing. **Sue Coates**: Writing – review & editing. **Abigail Crosby**: Writing – review & editing. **Sonja Eisfeld-Pierantonio**: Writing – review & editing. **Lauran Eyles**: Writing – review & editing. **Tony Flux**: Writing – review & editing. **Emily Gilford**: Writing – review & editing. **Claire Giner**: Writing – review & editing. **Jasper Hamlet**: Writing – review & editing. **Neil Hembrow**: Writing – review & editing. **Jessica Hickie**: Writing – review & editing. **Peter Hopkinson**: Writing – original draft, Writing – review & editing, Funding acquisition. **Dan Jarvis**: Writing – review & editing. **Jonathan Kearsley**: Writing – review & editing. **Justine Millard**: Writing – review & editing. **Fred Nunn**: Writing – review & editing. **Emily Pollitt**: Writing – review & editing. **Avril Sainsbury**: Writing – review & editing. **Sue Sayer**: Writing – review & editing. **Rory Sinclair**: Writing – review & editing. **Amy Slack**: Writing – review & editing. **Pat Smith**: Writing – review & editing. **Rebecca Thomas**: Writing – review & editing. **Jen Tyler**: Writing – review & editing. **Richard Walker**: Writing – review & editing. **Claire Wallerstein**: Writing – review & editing. **Mark Ward**: Writing – review & editing. **Brendan J. Godley**: Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: All of the co-authors except SN, EE, PH and BG were participants of the questionnaire survey and/or workshop. They were not involved in collecting or analysing the data and, therefore, did not contribute to identifying themes within the discussion. This limits the potential for bias to occur. For further transparency, we also outline the roles that each author played in the creation of this manuscript: SN and BG conceptualised the study; SN, BG and EE designed the questionnaire, hosted

the workshop and, with PH, wrote a draft of the manuscript. All other authors contributed to subsequent iterations.

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Appendix

Online questionnaire survey (hosted by onlinesurveys.ac.uk)

The role of citizen science in understanding plastic pollution

Page 1:

The widespread contamination of global marine and coastal environments by anthropogenic litter is of growing concern. An increasing body of evidence demonstrates that synthetic and persistent materials, such as plastic, have the potential to cause ecological and socio-economic damage. Understanding the abundance, distribution and composition of litter along coastlines can be instrumental in designing and implementing effective management strategies aimed at reducing future inputs. Beach litter surveys are a well-known technique for gathering such information but considerable time and resources are required to collect meaningful data, which have the spatial coverage to enable the detection of patterns and trends. Litter survey programmes that enlist volunteers - or citizen scientists – are capable of generating useful data on the state of the marine environment. During this questionnaire, we would like to garner information on citizen science litter removal programmes operating around the UK. Should you wish to participate, please note;.

- Your participation is voluntary.
- You have the option of omitting questions you do not wish to answer.
- Data will be treated with full confidentiality, and if published, will not be identifiable as yours.
- The collected data will be retained for a maximum of 5 years.
- You have the right to withdraw your data.

Thank you in advance for your participation!

Page 2:

Name:

Organisation:

Email address:

Page 3:

We are sending this survey questionnaire to the following organisations who are involved in litter clean ups in the South West and nationally (click 'More info' below). Do you feel we have captured all the relevant organisations?

- Yes.
- No.

If no, who have we missed? Please list.

Page 4:

How many paid staff are currently in your organisation in total?

How many of those paid staff work in roles relating to beach litter?

Page 5:

Roughly how many members does your organisation have (if applicable)?

Page 6:

Roughly how many people volunteer for your organisation per year?

How many of those are beach clean volunteers?

Page 7:

What is the geographic scale of your organisations work? For example, all of UK, regional (please specify) or local (please specify).

Page 8:

When did your organisation start doing beach cleans?

Page 9:

When did your organisation first become interested in plastic pollution?

Page 10:

Why did your organisation become interested in plastic pollution?

Page 11:

Roughly how much litter do your staff and volunteers collect per year (e.g. number of items, bags, kilos)?

Page 12:

What happens to the litter gathered during your clean ups?

Page 13:

Do you collect data on litter during the clean ups?

- Yes.
- No.

If Yes, what happens to the data?

- Send to the Marine Conservation Society.
- Send to Surfers Against Sewage.
- Send to Keep Britain Tidy.
- Keep it for own analysis.

Other.

If other, please explain.

If not, please explain why.

Page 14:

What do you think are the benefits of citizen engagement to the issues of beach litter and plastic pollution?

Page 15:

What do you think are the key issues that need to be resolved/discussed to maximise the benefit of citizen engagement to the plastic pollution problem?

How do you think we could gather better data on beach litter?

Page 16:

Thank you for your participation!

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