Exploring scientists' perceptions of citizen science for public engagement with science

Stephanie A. Collins, Miriam Sullivan and Heather J. Bray

Abstract

It is often assumed that citizen science is inherently participatory in nature. However, citizen science projects exist along a continuum from data contribution to full co-creation. We invited 19 biologists to explore their conceptions of citizen science. Almost all participants defined citizen science as involving non-scientists in data collection. This definition acted as a barrier for scientists who did not see how citizen science could suit their research objectives. While interviewees perceived many societal and experiential benefits of contributory citizen science, deliberate design is needed to realise the full potential of citizen science for public engagement.

Keywords Citizen science; Public engagement with science and technology

DOI https://doi.org/10.22323/2.21070201

Submitted: 18th February 2022
Accepted: 2nd August 2022
Published: 14th November 2022

Introduction

In addition to contributing to the production of scientific knowledge, Citizen Science (CS) is viewed as a method for increasing public engagement with science [Bonney, Phillips, Ballard & Enck, 2016]. Many CS projects either explicitly or indirectly nominate goals for public engagement in their practice [Steven et al., 2019] and public engagement underpins CS policy in many locations [Hecker, Wicke, Haklay & Bonn, 2019] and best practice guidelines [Robinson, Cawthray, West, Bonn & Ansine, 2018; Skarlatidou & Haklay, 2021]. However, within many CS programs, the engagement is implied, with few studies describing how engagement is managed within CS programs [Phillips, Ballard, Lewenstein & Bonney, 2019]. Although Bonney et al. [2016] argue that not all CS projects should have public engagement goals, they also suggest that further support is needed to enable many projects to foster effective engagement.

Studies of scientists' attitudes to public engagement have shown that although scientists generally are willing to engage in outreach activities such as giving public talks or speaking with the media [Carr, Grand & Sullivan, 2017; Grand, Davies, Holliman & Adams, 2015], they may not necessarily consider involving the public in their own scientific research as a form of public engagement. In addition, some studies have shown that scientists' perceptions of the public's ability to understand science, both within CS contexts [Golumbic, Orr, Baram-Tsabari & Fishbain, 2017], and more broadly [Besley & Nisbet, 2013; Simis, Madden, Cacciatore & Yeo, 2016] may limit their willingness to see participatory modes of public engagement as desirable. Because the effectiveness of CS for public engagement relies on project design and management [Bonney et al., 2016; Phillips et al., 2019], ascertaining the perceptions and understandings of public engagement held by scientists involved in CS projects is important. Hence this study aimed to explore Australian scientists' perceptions of CS as a tool for public engagement with science.

1.1 Citizen science as a tool for public engagement with science

Citizen science can be viewed as contributing to the 'participatory turn' in public engagement with science and, as described by Strasser, Baudry, Mahr, Sanchez and Tancoigne [2019], has emerged from two different concepts of public participation in science. The first is arguably more aligned with public participation in science policy and ideas of science citizenship [Irwin, 1995, 2001; Mejlgaard & Stares, 2010]. The second focuses more on non-scientists participating in research projects and is more aligned with public understanding of science goals as well as enhancing scientific research capacity [Bonney, 1996; Bonney, Cooper et al., 2009]. Although numerous studies have demonstrated that non-scientist participants in CS projects learn about science [e.g. Bonney, Cooper et al., 2009; Brossard, Lewenstein & Bonney, 2005], and enjoy participating [e.g. Phillips et al., 2019], it is less clear whether, as an enterprise, CS has significantly shifted public engagement with science away from predominantly one-way engagement activities [Martin, 2017; Metcalfe, 2019]. CS is often promoted as being open to 'everyone', however it is likely that CS participants tend to resemble the demographics of mainstream science (termed homophily) [Cooper et al., 2021], and the extent to which projects are truly 'participatory' or 'empowering' is open to critique [Strasser et al., 2019]. Understanding scientists' attitudes towards using CS for public engagement with science is therefore important if CS is to be more inclusive and achieve public engagement with science goals.

CS is frequently described as a participatory form of research [e.g. Dean, Church, Loder, Fielding & Wilson, 2018; Dickinson et al., 2012; van de Gevel, van Etten & Deterding, 2020]. However, the level of participation of citizens (henceforth referred to as volunteers) is dependent on project design, objectives and resources. The term 'volunteers' has itself been critiqued as inherently implying that their main purpose is free labour and creating a power imbalance with scientists [Eitzel et al., 2017], but we use it here to distinguish participants in citizen science projects from the participants in our study. Skarlatidou and Haklay [2021] describe levels of engagement within CS projects, suggesting that the greater involvement volunteers have in setting project objectives and project design, the greater the engagement. While several typologies of CS projects have been suggested to map project diversity in terms of scientific, social, and other goals as well as the contribution and participation of volunteers [e.g. Bonney, Ballard et al., 2009; Hecker & Taddicken, 2022; Shirk et al., 2012; Haklay, 2013; Wiggins & Crowston, 2011; Strasser et al., 2019], we draw heavily on the three main types of projects described by Bonney et al. [2016]:

– Contribution, where volunteers primarily contribute data following a scientist's design;

– Collaboration, where volunteers contribute in other parts of the scientific process mainly the design, analysis, and information dissemination stages; and

– Co-creation, in which the volunteers and scientists work together to create a project.

Shirk et al. [2012] adds to these 'contractual' projects, where a community enlists a scientist to investigate an issue, and 'collegial' projects, where volunteers perform a scientific investigation without a professional scientist. CS projects therefore exist along a spectrum of the relative contributions of volunteers and scientists, depending on the objectives and design (see Figure 1). Hence, because they determine the level of participation of volunteers, CS project designers have a direct impact on whether CS projects achieve engagement goals.

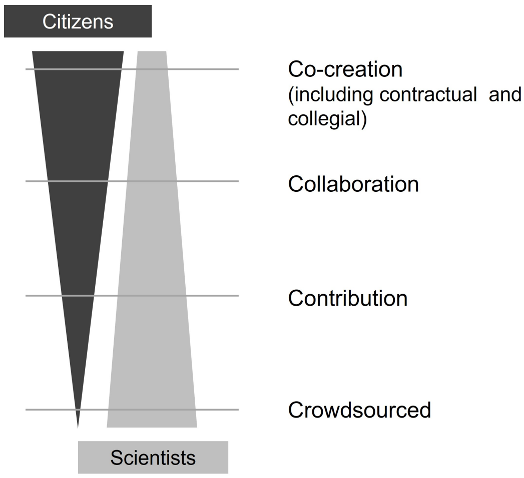

Figure 1. Diagram showing how typology determines the level of engagement for both citizens and scientists.

"Engagement" has been understood in different ways within CS research. Volunteer engagement is frequently explored using quantitative measures such as number of participants, time spent on the project, and retention/attrition rates that do not accurately reflect understandings of engagement more frequently used within fields related to public engagement with science [Phillips et al., 2019]. On the basis of qualitative work, Phillips et al. [2019] propose four "dimensions of engagement": behavioural activities, affective/feelings, learning/cognition, and social/project connections. However, their work is based on interviews with CS volunteers, and it is not clear whether these ideas of engagement are shared by CS project managers, or how these aspects of engagement are actively designed into projects.

Scientists' perceptions of using CS for engagement have received little scholarly attention. Golumbic et al. [2017] suggested that scientists who are not involved in CS may have negative perceptions of the public's ability to contribute to science. Scientists perceive that data from CS projects are of lower quality because of the knowledge and training of volunteer participants [Riesch & Potter, 2014] despite analyses showing that the data can be as valid as traditional research methods [e.g. Crall et al., 2011]. Hence volunteer training is considered a key part of CS management [Gardiner et al., 2012]. The assumptions made by scientist-managers about the capability of volunteers will ultimately be reflected in CS project design, which in turn may limit opportunities for engagement.

1.2 Research aims and objectives

This study explores scientists' perceptions of how CS is utilised for public engagement with science. We also explore what motivates scientists to use CS as a research method and the barriers to using CS. Finally, we examine how the CS volunteers are perceived by scientists. All these factors have the potential to affect how a CS project is designed, so developing a nuanced understanding can improve the design process and better support scientists considering using CS.

Methods

This research was approved by the University of Western Australia Human Research Ethics Committee (reference number 2019/RA/4/20/6153).

This study used qualitative research methods [Denzin & Lincoln, 2011] grounded in social constructivist approaches [Creswell, 2013] to explore scientists' subjective understandings of CS and public engagement. Qualitative methods reveal underlying motivations and attitudes that generally cannot be explored through surveys [Malhotra, 2006].

Scientists within the field of biology in Australia were invited to participate in this research via forty recruitment emails sent to professional associations and university departments for distribution on behalf of the researchers. The field of biology was chosen because of CS's usefulness in ecological studies [Dickinson et al., 2012]. Both scientists with experience with CS and no experience with CS were invited to participate. Interested scientists then completed a preliminary Qualtrics survey indicating their gender, research field, and career stage, to facilitate purposeful sampling to ensure diversity across the target population. Participants were not given any incentive to participate in the study, but were encouraged to forward the recruitment email to other scientists they felt might be interested.

Semi-structured interviews (see appendix A) were conducted between June 2020 and March 2021 using Zoom video conferencing software. The interview scripts consisted of 20 questions for scientists with previous citizen science experience and 17 questions for those with nil experience. The scripted questions stood as a guideline for the interviews, additional questions were asked or set questions were not asked based on the responses given by the participants. The scripted questions were piloted in five practise interviews performed between the first author and local biologists with and without experience in citizen science. The interviews were transcribed using a transcription app (otter.ai) and the first author to ensure accuracy. Transcripts were analysed thematically using NVivo (QSR International) using both deductive and inductive coding [Fereday & Muir-Cochrane, 2006; Metcalfe, 2019]. Data was initially coded by the first author who created a codebook. Inter-coder agreement (between first and second author) was 87%

which is above the generally accepted threshold for reliability [Hruschka et al., 2004; Lombard, Snyder-Duch & Bracken, 2004].

Results

1. Participant demographics. We received 24 responses to the Qualtrics preliminary survey, an additional 4 responses were emailed directly to the researchers. Four participants did not reply to follow-up contact and one participant did not progress to interview as we had already reached saturation for participants with citizen science experience. Overall, 19 scientists working in the field of biology in Australia took part in the interviews. Table 1 summarises participant's experience in CS and their self-defined career stage. Ten of the participants were male, and nine were female.

Table 1. Demographics of participants including their citizen science experience, career stage, field of study, and identifier number.

Identifier	Experience with Citizen Science	Career Stage	Field of Study
1	Yes	Late	Conservation Biology
2	Yes	Middle	Marine Biology
3	Yes	Early	Botany
4	Yes	Mid	Marine Biology
5	No	Early	Conservation Biology
6	Yes	Early	Marine Biology
7	No	Late	Agriculture
8	No	Early	Entomology
9	Yes	Middle	Zoology
10	Yes	Early	Conservation Biology
11	No	Early	Botany
12	No	Middle	Conservation Biology
13	No	Middle	Agriculture
14	No	Middle	Agriculture
15	Yes	Early	Ecology
16	No	Middle	Ecology
17	Yes	Middle	Marine Biology
18	No	Late	Agriculture
19	Yes	Late	Genetics

2. Thematic analysis. The analysis of the interviews revealed several key themes. Firstly, we present a summary of responses to questions asking the participant scientists to define both citizen science and engagement. Secondly, we discuss key themes regarding the participating scientists' motivations to participate in CS, and how these relate to their perceptions of the goals for CS. Barriers and motivations identified for not participating in CS are also presented here. Thirdly, we present key themes related to the participating scientists' perceptions of volunteers within CS projects.

3.1 *Defining CS and engagement*

3.1.1 Participants' understandings of "citizen science"

Eighteen of the participants defined CS as the involvement of non-scientists in science, and eleven made a direct reference to data collection.

> "I would define citizen science fairly broadly as a project that involves just using the general population to collect data". (18)

This suggests that most of the participants prioritise the research-related goals of CS. One participant stated that they did not feel the need to define it at all.

> "I think it's [citizen science] actually really quite difficult to define. And I actually feel there's too much emphasis on defining it. And actually, maybe better not to bother... I think it perhaps represents a range of phenomena" (4)

Only one gave a definition that expressed the values of driving scientific research through collaboration with the community, which included CS's role in promoting public understanding of science.

> "Teaming up with the community and for the purpose of driving forward research. And at the same time, engaged with the community and to improve awareness ... and generate enthusiasm and a better understanding of you know, the topic project is on." (19)

While some did acknowledge the co-creation or collaborative forms of CS later in interviews, it rarely featured in their initial description. One participant suggested that those types of CS were "overseas more so than in Australia." (10). Another noted the use of these categories for fulfilling local and specific needs.

> "I think co design is especially important where a project has an incredibly strong attachment to a place [or] a strong attachment to a local issue." (4)

However, some did acknowledge that CS also included the ability to form dialogues with the volunteers as a part of the CS process;

> "it's like science communication at the same time as producing science." (13)
>
> "That's sort of partly why it's used in terms of, you know, a collaborative project, you're actually trying to give out information, but also open it up so people can ask their specific questions." (15)

3.1.2 Participants' understanding of engagement

Half of the participants described engagement as "getting the public involved and interested in science." (8) Education was often included with this description, "to get more people involved, to get more people interested, to educate people." (5) Participants also stated that engagement functions to allow "everyone to be able to access that knowledge" (15), and "taking the time to think about other people's perspectives and views on the concept" (2) improved the effectiveness of communication and accessibility of the science. Just over half of the participants noted that engagement was useful to fight misinformation and to build trust in science.

> "I think we are in that phase where expert advice has been ignored for a long time . . . I think having people look to experts for that is a vital part of public communication of science". (17)

Half of the participants who were experienced in CS also stated that CS was effective as engagement as it involved an active participation in the process, especially compared to traditional forms of engagement where audiences are given information with less chance for interaction.

> "I feel very strongly that this is the way of education and engagement is to actually say, to the community, you know, this is research we can do together, and then have a conversation about it." (19)

Scientists' motivations, barriers and outcomes towards using citizen science

Interviewees articulated their primary motivation for using CS as the need to collect data in large quantities or across large geographic regions. Another primary motivation was the lack of funding for data collection (and hence the need to recruit volunteers) and garnering public support to show value for publicly funded research. A summary of themes is provided in Table 2.

Some participants acknowledged the public as stakeholders in scientific research, e.g., "the community that really pays for science," (18) and "a lot of the funds for research in agriculture actually come from levies on farmers," (13). One notably stated that "I don't think we should be worrying about whether the public is happy with what we're doing or not" (11) as they did not find public support to be a strong motivator for performing engagement.

Participants with experience in CS expressed a need for support to run CS projects, usually in the form of experienced personnel who could help in communication, or other research adjacent factors like programming apps and websites.

Participants with no experience in CS stated that they did not pursue CS because the process did not fit the type of research they conducted, for example, if specific equipment or safety procedures were required and the data collection by volunteers was deemed unachievable. Participants stated a primary outcome, beyond the data collected which motivated them, is the connection to the community outside of science. All participants with experience in CS stated that

Table 2. Main themes present in interviews with scientists on their motivations, barriers, and outcomes of using citizen science.

Category	**Theme**	**Examples**
Scientists' motivation and barriers towards using citizen science	Ability to collect data that otherwise would be out of reach	"I think it's the part that would be most useful for scientists, because that's often very time consuming, and more people involved mean you get more data quicker and easier." – 11 "One is you can do projects, as I just mentioned, which are simply not feasible with a normal budget process." – 18
Scientists' motivation and barriers	Scientists need support in citizen science projects	"Having a little bit more support, so that we could grow it a little bit quicker, I would have liked because a lot of the things that I wanted to do felt too much of a distraction from my actual PhD to do instead." – 10 "More support? I know I was one person with many hats. And it's a lot to manage." – 12
	Data collected fits its intended use and may be unfit for others	"I don't see how it'd be useful for my own research." – 11 "I would definitely view it differently than I would if the data were collected by scientists, but also was designed differently for different purposes, it has a different context." – 2
	Funding and public support	"So, the government understands that if you've got a small but noisy component of the community that value participating in citizen science programs that are supported by the government and the government is happy to support those." – 1 "I think that's been largely driven by the fact that something bright and shiny and you can get funding for it." – 1 "Your research is funded from taxpayer's money, so you feel an obligation, you know, of interacting with the community and involving them in the research." – 19
Perceptions of citizen science outcomes for science and scientists	Citizen science is enjoyable for the scientist	"Sometimes you spend all your time surrounded by scientists, it can be refreshing to talk to people with different perspectives." – 8 "Interacting with people who are that keen to do something that they're willing to give all this time, it made me also realise how lucky I was that I could do this." – 6
	Citizen science helps connect science and the community	"Citizen science plays a crucial role in that that nexus between science and the community and helps to provide a bridge have that knowledge." – 3 "I think it helps to break down the barriers. This sort of ivory tower, if you like, because I think the ivory towers is a prison for both parties, you know, sort of keep science separated from most people." – 4 "I feel like for a lot of us, especially with wildlife conservation side of things, having a community that wants to encourage that wants to get involved in that is really, really important." – 5
	Citizen science has a positive impact on the public image and trust a of science	"I think it helps to establish a greater level of, of trust and also that that local relevance." – 13 "A very simple methodology that they at least understand how those results came. And then maybe that will improve that trust." – 14 "Just having people in the community that aren't scientists doing science, I guess that might do something for the public image of science and just making people more aware of it." – 2
	Citizen science is a good way to recruit people into science careers	"Students who are studying marine biology at the university ... field work will help them just learn more about their field of expertise." – 3 "Getting people involved, who are maybe considering going into science in the future, but they might be 16, they might, you know, just be finishing high school ... seeing if it's something that they want to pursue in the future as a job." – 8

they personally found running CS projects enjoyable, mostly because of the social interactions with citizens who are passionate about the topic, describing it as "great to be with, like-minded people, and having good time and sharing experience." (15). The benefits of these vary from broadening the scientific "ivory tower," (4), contribute to community identities, and build relationships.

Another common response given as a benefit to both science and the volunteers was that it provided an opportunity for the recruitment of people into science, particularly young people, by providing a unique opportunity for budding scientists or school-aged children to experience science and research and its potential as a career. It was also reported that CS provided a valuable training tool for students studying science to gain experience.

4.1 Trust in citizen science

Seventeen participants responded that they were trusting of CS data provided the study addressed appropriate research questions and had sound experimental design including quality control. Nearly all participants responded that they trusted the data produced by CS but that trust was dependant on the design and fit with the purpose of the project: "that depends on the question being asked." (17) Another interviewee suggested scepticism of all research data, rather than singling out CS.

> "I don't trust any data, whether that be citizen science or scientist until I've seen how they've done it." (6)

Aspects of a trustworthy design given by participants were the quality control or validation mechanisms included in the methods. Another concern was the potential for dishonesty by volunteers, whether brought about by a lack of interest or a lack of awareness for the importance of repeatability and null results in the scientific method. Participants commented on the level of trust of traditional science, "I think citizen science data is more trustworthy than data from scientists alone." (4). Another participant went as far as to say that "knowing certain people are involved" (7) was enough to distrust it.

A perceived negative stigma is still apparent in the science community, with many participants believing that other scientists would not be as trusting of the data.

> "They think that the data is less trustworthy. Or that's what the general science, you know, field sort of view it as." (11)

Some participants saw this as stemming from differences in industry cultures across working environments,

> "I think sort of straight up academia, like, universities have many-what I call academic snobbery problems. So I think citizen science is only one of them." (17)

Others experienced differences in the standards to which the research methods are held to within the science community as a manifestation of that negative stigma or mistrust.

> "I feel like it's we're discriminated against. They find all kinds of problems with what we're doing that might not be questioned otherwise." (6)

Scientists' perceptions of volunteers

Interviewees perceived the two primary motivators for volunteers were pre-established interest and the desire to contribute to efforts to resolve environmental issues. Participants, especially those later in their careers, noted that the volunteers are often already engaged (i.e. they had previous knowledge and an active interest). Other respondents, predominantly early in their career, responded that CS could be a way to engage people who are not already interested. However, they did not cite specific examples of reaching new audiences in their own projects. Others responded with the caveat that reaching the un-interested was difficult or almost impossible and not worth the effort. Having volunteers with a preestablished interest was seen as preferred by participants with CS experience as they are seen as more invested and thus more likely to give honest answers.

> "if you were encouraging people that we're not so keen to do it, maybe there will be more prone to errors because they wouldn't be so genuine about it and wouldn't care so much." (15)

The responses regarding the perceived benefit to the volunteers covered three main categories, social, knowledge, and experiential (Table 3). The participants included the facilitation of social interactions and community building as a positive outcome for all parties. Knowledge uptake was described as both the research topic guided by discussion with scientists, and the scientific process through exposure to the process. Though this is often represented as a passive process, "just being involved in a research project, you'll like, start thinking about research methodology." (2) Some participants perceived volunteers as uninterested in being involved in the scientific process further then the data collection stage. Participants also perceived that the volunteers may experience attitudinal and behavioural changes that align with the conservation efforts of many of the projects. Finally, the experience of volunteering provides the volunteers with a sense of contribution both to science and to resolving environmental issues.

Table 3. Main themes present in interviews with scientists on their perceptions of the outcomes for and motivations of citizen science volunteers.

Category	Theme	Examples
Perceived volunteer outcomes	Citizen science has beneficial social impacts (Societal)	"I think they are actually quite fundamental part of social activity, and the sense of purpose and belonging and achievement amongst a group." – 4 "You're actually working together, even if you don't know it. And so some of the community members have sort of connected as well." – 17
	Citizen science is enjoyable for the volunteers (Experiential)	"It's usually like a nice day out. Like, people would enjoy it, it can help bring, I don't know, inspire passions to people, like if they go out and have a really good day." – 5

Continued on the next page

Table 3. *Continued from the previous page.*

	Experiencing science methodology increases the volunteers understanding (Knowledge-based)	"They learn about how to do things very precisely and systematically; they learn about the difference between good data and bad data." – 8 "They're effectively being trained in the philosophy of science and how science works they probably will be trained as well almost by default in the rigour involved in coming to a scientific conclusion." – 18
	Participating increases a feeling of ownership and responsibility in the environment (Experiential)	"They develop that ownership. And this is what citizen science can do. They can get deeply involved in and say, well, that's my creek." – 7 "That they should all be aware that as a community, they need to be responsible as well for managing it." – 9
	Volunteering can lead to attitude and behavioural changes (Knowledge-based)	"I think it also could make them change the, their habits and ways they might interact with the environment or know that they're involved in a citizen science project that's talking about emissions, they might decide to drive less." – 11
	Volunteers enjoyed contributing to science and efforts to resolve issues (Experiential)	"I think they enjoyed being able to contribute to science, and also to conservation." – 2 "Being able to contribute to, you know, feeling like they can have a role to play in supporting the health of natural ecosystems." – 3
	Volunteers learn about the topic (Knowledge-based)	"They also get more information about the natural world." – 15 "They are thought that they increase their knowledge and increase their appreciation of the natural environment through this activity." – 6
Perceived volunteer motivations	Non-scientists do not care about science methodology	"I'm not sure whether the citizens would be liking to participate in the part of science, it's actually quite dry." – 18 "A lot of people couldn't give two hoots about how the data is being used and don't care. And they're not particularly interested and don't want to be bothered and fettered by that." – 4
	Motivation is interest-driven	"So it appealed to people who are interested in this species." – 11 "Someone who's really pursuing a passion, and has found citizen science as a way of either organising and teaching themselves and learning faster." – 4
	Giving back and contributing to conservation efforts	"In general, have a strong passion for their local environment and want to participate in some way or form in the management and improvement of their local waterways." – 1 "Getting more active in providing, you know, making a difference, giving something back having a role to play in supporting management." – 3
	Citizen science helps to engage people that are not already engaged	"I think it's important to spread the word to get people that maybe they wouldn't have otherwise been engaged with it because they're not scientists." – 5 "We get people that aren't necessarily like science people really start to get engaged, and we can capture that sort of audience." – 10
	Citizen science does not engage people who are not already in engaged	"They have to be interested enough to actually want to participate." – 17 "It's unlikely just your average citizen will just do it, I think it already has to be somebody's got a bit of a passion for the topic." – 18 "I think a lot of it comes back to preaching to the converted." – 7
Perceived wider community outcomes	Scientific research and new knowledge	"They're benefiting whatever research outcomes that they may have." – 2 "Society will probably benefit from citizen science project as a whole because of the manpower the power that is brought by every single person taking off." – 6
	Volunteers can disseminate information	"I can definitely trickle all around, it can spread, and I think it can make changes." – 11 "These people are possibly amenable to explain to other people and ripples in the community." – 15

Continued on the next page

Table 3. *Continued from the previous page.*

	Influence's policy and decision making	"It also gives people the power to then go to their MP or their local member and put the pressure on specific local environmental matters." – 16 "There's quite a few local government citizen science programmes. And obviously that will feed back into like Policy and Governance, and I guess more environmental management, etc." – 2

In addition to individual benefits, participants identified three positive outcomes of CS for the wider community. Firstly, the information dissemination power of the volunteers can help to spread the knowledge the volunteer's uptake and influence the attitudes of their social circles. Secondly, the support shown by the volunteers for issues, particularly in environmental issues, can influence policy and decision makers into adopting more evidence-based policies. Lastly, the most common answer given, was that the knowledge and benefits achieved through the research was benefit enough to the community. For example, new insights into the ecology of areas being considered for conservation measures.

Discussion

6.1 Scientists' understandings of citizen science and engagement

Participants understanding of CS revealed an emphasis on volunteers participating in data collection to achieve scientific research outcomes. The definitions given by participants fit best with those described by Bonney et al. [2016] as contribution-type projects. This definition maintains the scientists' power and control over the scientific process, but acknowledges that CS can be used to educate and increase public understanding of science. Only one participant reflected the sentiments in the definition by Irwin [2001], identifying collaboration as a key aspect of CS.

Although engagement was not included in the initial definitions provided by participants, they do see CS as a tool for public engagement with science. It is unclear whether the participants see engagement as part of the CS process or an end result, or by product of CS. The participants' definition of engagement with science is similar to their definition of CS, however, their responses reveal that scientists view the purpose of engagement as primarily educational, even though they recognised volunteers had pre-existing knowledge of the topic already. While this is not inherently wrong it fails to take into account the complexity of knowledge uptake and attitudinal change and does not accurately reflect the objectives of true engagement [Phillips et al., 2019] or recognize the potential of CS for community empowerment [Eitzel et al., 2017]. CS is seen by the scientists in this study as effective engagement because it provides the volunteers with an opportunity to be actively involved with and therefore learn about the science. Participants who had more experience with CS or public engagement recognised that making citizens views heard is integral to effective engagement.

Participants also refer to CS as an active form of engagement, and while it is more active than a lecture or piece of written communication, the action of the volunteers is primarily based in data collection and many volunteers only collect a few points of data. This project structure fails to give volunteers any democracy or decision-making power within the scientific process. The idea that CS is participatory research is also prevalent in the literature [Dean et al., 2018; Dickinson et al., 2012; English, Richardson & Garzón-Galvis, 2018; Metcalfe, 2019; van de Gevel et al., 2020], however, the descriptions of engagement within CS given by participants more closely resemble the knowledge exchange in dialogue models of engagement [Reincke, Bredenoord & van Mil, 2020]. CS can only be considered as participatory engagement if the volunteers are participating in the generation of new information, and as such are active in some form of decision making in the scientific process [Shirk et al., 2012]. Collecting a single point of data, or even a few points, especially for those not already highly engaged with science, does not fulfil the promise of public engagement with science offered by CS [Martin, 2017], can leave volunteers disappointed with their experience [Roche, Rickard, Huguenard & Spicer, n.d.] and is unlikely to promote the types of engagement recommended by Phillips et al. [2019]. Volunteers have the capacity to contribute intellectually, behaviourally, and socially in various ways that can improve projects [Eitzel et al., 2017; Phillips et al., 2019]. It is important to note here that the expertise of scientists is not diminished in these relationships, but the citizens' own expertise of their community, environment, and needs are acknowledged and can help drive research.

6.2 *Trust in citizen science*

Issues with data quality has been identified in the literature as a key concern for scientists in CS projects and a barrier to participation for some. In this study, well-designed CS project was described by participants as having simple and clear volunteer instructions which are tested with volunteers beforehand, as well as a system in which volunteers work in teams, as they can regulate themselves. Participants' suggestions for well-designed projects included adequate training and clear, simple instructions along with quality control as a standard and are aligned with recommendations in the literature [e.g. Isaac, van Strien, August, de Zeeuw & Roy, 2014; Kosmala, Wiggins, Swanson & Simmons, 2016; Wiggins, Newman, Stevenson & Crowston, 2011].

While no participants said that they did not trust CS research, there was a perceived negative stigma around CS projects in the scientific community. This disconnect can be explained by a higher standard being placed upon the CS projects when compared to a more traditional research method, as experienced CS participants reported their methods being questioned more. Previous studies confirm that distrust amongst scientists can be a barrier to running CS projects [Golumbic et al., 2017; Riesch & Potter, 2014; Alabri & Hunter, 2010; Gilfedder et al., 2018]. As participants responses reflect what is established as trustworthy CS design and show they can regard the CS research as trustworthy, focus should be put on supporting project managers and methods of best practise. Designing for engagement within the scientific community can be included to build trust if deemed necessary.

6.3 Motivations to participate in citizen science

The primary motivation reported by our participants to use CS was the ability to collect data that would not be able to be collected using other methods, namely data that covers large areas and ecological monitoring. Other motivators included obtaining funding and increasing public support, especially in environmental and conservation research. The participants in this study expressed support for public engagement. No participants gave responses that showed reluctance in attempting engagement because they felt it unimportant, but they did give examples of other scientists they viewed as unwilling or reluctant to take part in engagement attempts. All participants who had previous experience in CS found engaging with the volunteers enjoyable and worthwhile.

Concerns regarding engagement stemmed from the reported lack of time and resources or lack of support in the form of qualified professionals to help with engagement and communication, or the funds to hire them, was a barrier for extending existing projects. The main barrier that participants with no CS experience reported was that CS did not fit with their research objectives. This contradicts previous studies which found the two main factors in scientists' disinterest in CS stems from either a lack of value given to using CS or a distrust of the data [respectively Golumbic et al., 2017; Riesch & Potter, 2014]. While the literature on scientists' perspectives is limited it does not reflect the beneficial outcomes reported by the participants in this study. Aside from data collection and personal enjoyment the participants also reported beneficial outcomes for the science community, such as the recruitment of young volunteers into science careers, the opportunity for scientists in training to get experience in the fieldwork, and for early career scientists to gain experience while running projects.

The participants were able to recognise positive outcomes for both the volunteers and the wider community. The participants observations on volunteer outcomes fall into three categories: knowledge-based, societal, and experiential, which correspond to three of the four areas of engagement identified by Phillips et al. [2019]. The experiential outcomes include stewardship and the satisfaction from contributing to efforts for environmental issues. The societal outcomes include community building and overlap with the societal benefits for science and scientists. Many of these outcomes are also found in the literature; studies show that CS can increase knowledge of the topic, the scientific process and stewardship of the volunteers [Brossard et al., 2005; Merenlender, Crall, Drill, Prysby & Ballard, 2016]. In addition to these individual outcomes the participants also consider new research as the primary benefit to the wider community. Other benefits include information dissemination and the potential to inform policy and decision making, which also aligns with the literature [Newman et al., 2017; Warner, Lowell, Timme, Shaftel & Hanner, 2019; Villaseñor, Porter-Bolland, Escobar, Guariguata & Moreno-Casasola, 2016].

The participants' perceptions of volunteer motivations overlapped with the outcomes, including interest in the topic and interest in environmental issues. Participants disagreed on whether CS increases engagement among previously unengaged individuals or only reaches people who are already engaged with science outreach. The literature shows volunteers are motivated by their pre-existing interest in the topic and concern for the environment [Domroese &

Johnson, 2017; Rotman et al., 2014]. Martin [2017] found that individuals with high levels of existing engagement in science are more likely to volunteer in CS projects. The responses that aligned with the literature on motivations belonged predominantly to participants in the later stages of their careers, who also thought that pre-existing interest was beneficial for volunteer commitment and honest in data collection. This argument is supported by Rosenblatt et al. [2022], who found highly experienced recreational birdwatchers contributed more data and were more likely to be retained in their citizen science project. For less experienced interviewees who believed they could engage new audiences, their idealised reach may be greater than their actual reach. There is a clear need for evaluative practises in CS to determine the reach and impact on volunteers, such as Day et al.'s [2022] analysis of 73 CS 'expeditions' which showed that those designed with collaboration between volunteers and scientists had the strongest impact on conservation intentions.

Conclusion

CS is considered by the scientists that participated in the study primarily as a tool for data collection, and then secondarily as a method for engagement with the objective of education. Engagement is approached by the participants as a discussion and a chance for the volunteers to ask questions, but volunteers have limited influence beyond data collection. The scientists in this study do not include activities such as defining research questions, designing procedures, data analysis, and interpretation of results as aspect of their work that could or should involve non-scientist volunteers. Participation in these stages, especially research question development is an important part of participatory science as it allows the volunteers power within the scientific process. It is also a missed opportunity to fully utilise volunteers' pre-existing knowledge and experience. Given this, it may be inaccurate to categorise some types of CS as participatory and may better fit the dialogue model of engagement [Metcalfe, 2019].

Participants expressed a willingness to participate in engagement practises and while they did not see it as a barrier to using CS, they felt that more support was needed to accomplish it. The most common barrier for biologists not using CS was whether citizen data collection was fitting for their research question. When CS is narrowly defined as citizens being involved in data collection it prevents efforts being made to include the public in stages of research where the citizens have more power, such as research question development.

The social aspect of CS was found to be a beneficial outcome to all parties involved, as it is worthwhile to scientists; a major positive outcome for the volunteers; and helps to open the scientific community to the wider community. CS can help in contributing to the community identity and making science more accessible. The participants of this study clearly understand, at least to some extent, the complexities of volunteer motivations and outcomes. As the understanding of the nuances of engagement appears to grow with experience level, it may be pertinent for early-career scientists to train in public engagement strategies or take on communication specialists to assist with project design.

While not all CS projects must have public engagement with science as an objective, all CS projects rely on interactions with volunteers and their needs should be clearly understood. Our results suggest that CS project managers see engagement as something that 'happens', rather than something that needs proactive design, management, and evaluation. For those projects with public engagement as a goal, or where public engagement is crucial to achieving scientific goals, for example the collection of data over the medium-to-long-term, specific training for project managers in public engagement with science or collaboration with those with expertise in this area is recommended. Ongoing evaluation against engagement goals, for example surveying participants or informally collecting feedback, in addition to monitoring the scientific aspects of CS projects should also considered standard practice. In projects where funding is granted on the premise of public engagement with science, engagement processes should be considered as important as the scientific aspects of CS projects and managed appropriately.

Acknowledgments

The authors would like to thank the participants for their contribution to this research.

Appendix A. Interview guide

Thank you for participating in this study. I will remind you that this interview is recorded, but all data will be de-identified during analysis. Please answer all questions as honestly as you can. Before we start do you have any questions for me?

– How do **you** define citizen science?
– Have you conducted any form of citizen science during your career as a scientist? (If yes go to part A, if no go to part B)

Part A

1. What type of citizen science projects have you been involved in?
2. What types of audiences were involved?
3. What scale was your project aiming for?
4. What role did you play in the citizen science project/s?
5. What level of interaction did you have with the citizen participants in your project?
6. What did you most want to get out of your citizen science program? [Alt] What was your objective?
7. What, if anything, would you change about your citizen science program? (or how programs are run in general?)
8. Do you have any concerns regarding performing citizen science? If so what?
9. What did you find most beneficial about citizen science to you as a scientist?
10. Did you have any personal benefits to performing citizen science?
11. In your opinion, does citizen science have any benefits for the citizen participants? If yes what are they?
12. In your opinion, does citizen science have any benefits to the community?
13. Do you trust the data generated through citizen science? Why or why not?
14. How do you define engagement and the role it plays in science?
15. Do you feel that your citizen science project engaged the participants?
16. How do you feel about transparency in science?
17. Do you have any final comments or thoughts you want to add?

18. Was science communication included in your science education or training? If so to what extent?
19. Are you encouraged to do public engagement at your workplace? If yes, are you encouraged to do citizen science?

Part B

1. Is citizen science something that you have considered before?
2. What has prevented you from pursuing it?
3. What interests, or doesn't interest, you about citizen science?
4. If something was to convince you to pursue citizen science what would it be?
5. Do you have any concerns regarding citizen science? If yes what are they?
6. What would you expect to get out of citizen science if you did use it?
7. Do you see any potential benefits of citizen science to you as a scientist? If yes what?
8. In your opinion, does citizen science have any benefits for the citizen participants? If yes what are they?
9. Do you trust the data generated through citizen science? Why or why not?
10. What, if anything, would you change about citizen science if you were to conduct a program?
11. How do you define engagement and the role it plays in science?
12. Do you feel that your citizen science project engaged the participants?
13. How do you feel about transparency in science?
14. Do you have any final comments or thoughts you want to add?
15. Was science communication included in your science education or training? If so to what extent?
16. Are you encouraged to do public engagement at your workplace? If yes, are you encouraged to do citizen science?

References

Alabri, A. & Hunter, J. (2010). Enhancing the Quality and Trust of Citizen Science Data. In *2010 IEEE Sixth International Conference on e-Science*. doi:10.1109/escience.2010.33

Besley, J. C. & Nisbet, M. (2013). How scientists view the public, the media and the political process. *Public Understanding of Science 22* (6), 644–659. doi:10.1177/0963662511418743

Bonney, R. (1996). Citizen science. A lab tradition. *Living Bird: For the Study and Conservation of Birds 15* (4), 7–15.

Bonney, R., Ballard, H., Jordan, R., McCallie, E., Phillips, T., Shirk, J. & Wilderman, C. C. (2009). *Public Participation in Scientific Research: Defining the Field and Assessing Its Potential for Informal Science Education* [A caise inquiry group report]. Center for Advancement of Informal Science Education (CAISE). Washington, D.C., U.S.A. Retrieved from http://www.informalscience.org/public-participation-scientific-research-defining-field-and-assessing-its-potential-informal-science

Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V. & Shirk, J. (2009). Citizen Science: a Developing Tool for Expanding Science Knowledge and Scientific Literacy. *BioScience 59* (11), 977–984. doi:10.1525/bio.2009.59.11.9

Bonney, R., Phillips, T. B., Ballard, H. L. & Enck, J. W. (2016). Can citizen science enhance public understanding of science? *Public Understanding of Science 25* (1), 2–16. doi:10.1177/0963662515607406

Brossard, D., Lewenstein, B. & Bonney, R. (2005). Scientific knowledge and attitude change: The impact of a citizen science project. *International Journal of Science Education 27* (9), 1099–1121. doi:10.1080/09500690500069483

Carr, A. E., Grand, A. & Sullivan, M. (2017). Knowing me, knowing you. *Science Communication 39* (6), 771–781.

Cooper, C. B., Hawn, C. L., Larson, L. R., Parrish, J. K., Bowser, G., Cavalier, D., . . . Wilson, S. (2021). Inclusion in citizen science: The conundrum of rebranding. *Science 372* (6549), 1386–1388. doi:10.1126/science.abi6487

Crall, A. W., Newman, G. J., Stohlgren, T. J., Holfelder, K. A., Graham, J. & Waller, D. M. (2011). Assessing citizen science data quality: an invasive species case study. *Conservation Letters 4* (6), 433–442. doi:10.1111/j.1755-263x.2011.00196.x

Creswell, J. W. (2013). *Qualitative inquiry & research design: choosing among five approaches* (3rd ed.). SAGE Publications.

Day, G., Fuller, R. A., Nichols, C. & Dean, A. J. (2022). Characteristics of immersive citizen science experiences that drive conservation engagement. *People and Nature 4* (4), 983–995. doi:10.1002/pan3.10332

Dean, A. J., Church, E. K., Loder, J., Fielding, K. S. & Wilson, K. A. (2018). How do marine and coastal citizen science experiences foster environmental engagement? *Journal of Environmental Management 213*, 409–416. doi:10.1016/j.jenvman.2018.02.080

Denzin, N. K. & Lincoln, Y. S. (Eds.) (2011). *The Sage Handbook of Qualitative Research* (4th ed.). Thousand Oaks, CA, U.S.A.: SAGE Publications.

Dickinson, J. L., Shirk, J., Bonter, D., Bonney, R., Crain, R. L., Martin, J., . . . Purcell, K. (2012). The current state of citizen science as a tool for ecological research and public engagement. *Frontiers in Ecology and the Environment 10* (6), 291–297. doi:10.1890/110236

Domroese, M. C. & Johnson, E. A. (2017). Why watch bees? Motivations of citizen science volunteers in the Great Pollinator Project. *Biological Conservation 208*, 40–47. doi:10.1016/j.biocon.2016.08.020

Eitzel, M. V., Cappadonna, J. L., Santos-Lang, C., Duerr, R. E., Virapongse, A., West, S. E., . . . Jiang, Q. (2017). Citizen science terminology matters: exploring key terms. *Citizen Science: Theory and Practice 2* (1), 1–20. doi:10.5334/cstp.96

English, P. B., Richardson, M. J. & Garzón-Galvis, C. (2018). From crowdsourcing to extreme citizen science: participatory research for environmental health. *Annual Review of Public Health 39* (1), 335–350. doi:10.1146/annurev-publhealth-040617-013702

Fereday, J. & Muir-Cochrane, E. (2006). Demonstrating rigor using thematic analysis: a hybrid approach of inductive and deductive coding and theme development. *International Journal of Qualitative Methods 5* (1), 80–92. Retrieved from http://ejournals.library.ualberta.ca/index.php/IJQM/article/view/4411

Gardiner, M. M., Allee, L. L., Brown, P. M. J., Losey, J. E., Roy, H. E. & Smyth, R. R. (2012). Lessons from lady beetles: accuracy of monitoring data from U.S. and U.K. citizen-science programs. *Frontiers in Ecology and the Environment 10* (9), 471–476. doi:10.1890/110185

Gilfedder, M., Robinson, C. J., Watson, J. E. M., Campbell, T. G., Sullivan, B. L. & Possingham, H. P. (2018). Brokering Trust in Citizen Science. *Society & Natural Resources 32* (3), 292–302. doi:10.1080/08941920.2018.1518507

Golumbic, Y. N., Orr, D., Baram-Tsabari, A. & Fishbain, B. (2017). Between vision and reality: a case study of scientists' views on citizen science. *Citizen Science: Theory and Practice 2* (1), 6. doi:10.5334/cstp.53

Grand, A., Davies, G., Holliman, R. & Adams, A. (2015). Mapping public engagement with research in a UK University. *PLoS ONE 10* (4), 1–19. doi:10.1371/journal.pone.0121874. PMID: 25837803

Haklay, M. [Muki] (2013). Citizen Science and Volunteered Geographic Information: Overview and Typology of Participation. In D. Sui, S. Elwood & M. Goodchild (Eds.), *Crowdsourcing Geographic Knowledge: Volunteered Geographic Information (VGI) in Theory and Practice* (pp. 105–122). doi:10.1007/978-94-007-4587-2_7

Hecker, S. & Taddicken, M. (2022). Deconstructing citizen science: a framework on communication and interaction using the concept of roles. *JCOM 21* (01), A07. doi:10.22323/2.21010207

Hecker, S., Wicke, N., Haklay, M. & Bonn, A. (2019). How does policy conceptualise citizen science? A qualitative content analysis of international policy documents. *Citizen Science: Theory and Practice 4* (1), 32. doi:10.5334/cstp.230

Hruschka, D. J., Schwartz, D., St.John, D. C., Picone-Decaro, E., Jenkins, R. A. & Carey, J. W. (2004). Reliability in Coding Open-Ended Data: Lessons Learned from HIV Behavioral Research. *Field Methods 16* (3), 307–331. doi:10.1177/1525822x04266540

Irwin, A. (1995). *Citizen Science: a Study of People, Expertise and Sustainable Development* (1st ed.). doi:10.4324/9780203202395

Irwin, A. (2001). Constructing the scientific citizen: science and democracy in the biosciences. *Public Understanding of Science 10* (1), 1–18. doi:10.1088/0963-6625/10/1/301

Isaac, N. J. B., van Strien, A. J., August, T. A., de Zeeuw, M. P. & Roy, D. B. (2014). Statistics for citizen science: extracting signals of change from noisy ecological data. *Methods in Ecology and Evolution 5* (10), 1052–1060. doi:10.1111/2041-210x.12254

Kosmala, M., Wiggins, A., Swanson, A. & Simmons, B. (2016). Assessing data quality in citizen science. *Frontiers in Ecology and the Environment 14* (10), 551–560. doi:10.1002/fee.1436

Lombard, M., Snyder-Duch, J. & Bracken, C. C. (2004). A Call for Standardization in Content Analysis Reliability. *Human Communication Research 30* (3), 434–437. doi:10.1111/j.1468-2958.2004.tb00739.x

Malhotra, N. (2006). *Marketing research: an applied orientation* (3rd ed.). Pearson Education Australia.

Martin, V. Y. (2017). Citizen science as a means for increasing public engagement in science. *Science Communication 39* (2), 142–168. doi:10.1177/1075547017696165

Mejlgaard, N. & Stares, S. (2010). Participation and competence as joint components in a cross-national analysis of scientific citizenship. *Public Understanding of Science 19* (5), 545–561. doi:10.1177/0963662509335456

Merenlender, A. M., Crall, A. W., Drill, S., Prysby, M. & Ballard, H. (2016). Evaluating environmental education, citizen science, and stewardship through naturalist programs. *Conservation Biology 30* (6), 1255–1265. doi:10.1111/cobi.12737

Metcalfe, J. (2019). Comparing science communication theory with practice: an assessment and critique using Australian data. *Public Understanding of Science 28* (4), 382–400. doi:10.1177/0963662518821022

Newman, G., Chandler, M., Clyde, M., McGreavy, B., Haklay, M., Ballard, H., . . . Gallo, J. (2017). Leveraging the power of place in citizen science for effective conservation decision making. *Biological Conservation 208*, 55–64. doi:10.1016/j.biocon.2016.07.019

Phillips, T. B., Ballard, H. L., Lewenstein, B. V. & Bonney, R. (2019). Engagement in science through citizen science: moving beyond data collection. *Science Education 103* (3), 665–690. doi:10.1002/sce.21501

Reincke, C. M., Bredenoord, A. L. & van Mil, M. H. W. (2020). From deficit to dialogue in science communication. *EMBO reports 21* (9). doi:10.15252/embr.202051278

Riesch, H. & Potter, C. (2014). Citizen science as seen by scientists: Methodological, epistemological and ethical dimensions. *Public Understanding of Science 23* (1), 107–120. doi:10.1177/0963662513497324

Robinson, L. D., Cawthray, J. L., West, S. E., Bonn, A. & Ansine, J. (2018). Ten principles of citizen science. In S. Hecker, M. Haklay, A. Bowser, Z. Makuch, J. Vogel & A. Bonn (Eds.), *Citizen science: innovation in open science, society and policy* (pp. 27–40). London, U.K.: UCL Press. Retrieved from http://www.jstor.org/stable/j.ctv550cf2.9

Roche, A. J., Rickard, L. N., Huguenard, K. & Spicer, P. (n.d.). Who's Tapped Out and What's on Tap? Tapping Into Engagement Within a Place-Based Citizen Science Effort. *Society & Natural Resources 35* (6), 667–683. doi:10.1080/08941920.2022.2056668

Rosenblatt, C. J., Dayer, A. A., Duberstein, J. N., Phillips, T. B., Harshaw, H. W., Fulton, D. C., . . . Wood, C. L. (2022). Highly specialized recreationists contribute the most to the citizen science project eBird. *Ornithological Applications 124* (2), duac008. doi:10.1093/ornithapp/duac008

Rotman, D., Hammock, J., Preece, J., Hansen, D., Boston, C., Bowser, A. & He, Y. (2014). Motivations Affecting Initial and Long-Term Participation in Citizen Science Projects in Three Countries. In *Proceedings of iConference 2014* (pp. 110–124). doi:10.9776/14054

Shirk, J. L., Ballard, H. L., Wilderman, C. C., Phillips, T., Wiggins, A., Jordan, R., . . . Bonney, R. (2012). Public Participation in Scientific Research: a Framework for Deliberate Design. *Ecology and Society 17* (2), 29–49. doi:10.5751/ES-04705-170229

Simis, M. J., Madden, H., Cacciatore, M. A. & Yeo, S. K. (2016). The lure of rationality: why does the deficit model persist in science communication? *Public Understanding of Science 25* (4), 400–414. doi:10.1177/0963662516629749

Skarlatidou, A. & Haklay, M. [Mordechai] (2021). Citizen science impact pathways for a positive contribution to public participation in science. *Journal of Science Communication 20* (06), A02. doi:10.22323/2.20060202

Steven, R., Barnes, M., Garnett, S. T., Garrard, G., O'Connor, J., Oliver, J. L., . . . Fuller, R. A. (2019). Aligning citizen science with best practice: Threatened species conservation in Australia. *Conservation Science and Practice 1* (10). doi:10.1111/csp2.100

Strasser, B. J., Baudry, J., Mahr, D., Sanchez, G. & Tancoigne, E. (2019). "Citizen science"? Rethinking science and public participation. *Science & Technology Studies 32* (2), 52–76. doi:10.23987/sts.60425 van de Gevel, J., van Etten, J. & Deterding, S. (2020). Citizen science breathes new life into participatory agricultural research. A review. *Agronomy for Sustainable Development 40* (5). doi:10.1007/s13593-020-00636-1

Villaseñor, E., Porter-Bolland, L., Escobar, F., Guariguata, M. R. & Moreno-Casasola, P. (2016). Characteristics of participatory monitoring projects and their relationship to decision-making in biological resource management: a review. *Biodiversity and Conservation 25* (11), 2001–2019. doi:10.1007/s10531-016-1184-9

Warner, K. A., Lowell, B., Timme, W., Shaftel, E. & Hanner, R. H. (2019). Seafood sleuthing: How citizen science contributed to the largest market study of seafood mislabeling in the U.S. and informed policy. *Marine Policy 99*, 304–311. doi:10.1016/j.marpol.2018.10.035

Wiggins, A. & Crowston, K. (2011). From Conservation to Crowdsourcing: a Typology of Citizen Science. In *Proceedings of the 44th Hawaii International Conference on System Sciences (HICSS-44)* [Kauai, hi, u.s.a.](pp. 1–10). doi:10.1109/HICSS.2011.207

Wiggins, A., Newman, G., Stevenson, R. D. & Crowston, K. (2011). Mechanisms for data quality and validation in citizen science. In *2011 IEEE seventh international conference on e-science workshops*, 5th–8th December 2011 (pp. 14–19). Stockholm, Sweden. doi:10.1109/esciencew.2011.27

Authors

Stephanie A. Collins recently completed her Master of Science Communication at the University of Western Australia.

scicommsteph@gmail.com.

Miriam Sullivan is Team Leader of the Learning Advisers at Edith Cowan University. Her research focuses on science communication and evaluation of teaching.

m.sullivan@ecu.edu.au.

Heather J. Bray is a Lecturer in Science Communication at the University of Western Australia. She has over 20 years of experience in science communication as a practitioner, scholar, teacher, and researcher. She coordinates the Master of Science Communication course which includes a unit on Citizen Science (SCOM5309).

heather.bray@uwa.edu.au.

How to cite

Collins, S. A., Sullivan, M. and Bray, H. J. (2022). 'Exploring scientists' perceptions of citizen science for public engagement with science'. *JCOM* 21 (07), A01. https://doi.org/10.22323/2.21070201.

ISSN 1824-2049. Published by SISSA Medialab. jcom.sissa.it