Article

How do New Zealand Marine Scientists perceive the benefits and limitations of Citizen Science?

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Public engagement with science in New Zealand adopted a more participatory approach with the 2014 launch of the Strategic Plan for Science in Society, joining the groundswell of citizen science research seen internationally. This study interrogates the views of scientists on the benefits and limitations of citizen science (CS) before and several years after the strategy was launched. Three groups of scientists were compared: NZ marine scientists with an international group of marine scientists around the time of launch, and NZ marine scientists four years later. At initial comparison NZ and international scientists held largely similar views on the benefits and limitations of CS, with only a few exceptions. Awareness of and involvement in CS projects were significantly higher in NZ four years later. Scientists with CS experience generally perceived more benefits, such as expanded data collection, community engagement and public awareness of science. The most frequently identified limitation was quality of data. Although this perception increased in the NZ cohort, the vast majority of scientists felt limitations could be overcome by careful project design and improved infrastructure support and professional recognition. These findings guide further recommendations for high level support systems to facilitate scientists' involvement in citizen science.

Introduction

Public engagement in science is expanding beyond traditional one-way communications (in which scientists inform non-experts) to include more interactive approaches that involve the public in doing science and facilitate mutual learning between scientists and the community (Rose et al., 2020). Although many scientists have considered engaging the wider community with their research as 'extra-curricular', this view is changing (Daelli et al., 2014; Hamlyn et al., 2015; Poliakoff and Webb, 2007). Participation in science communication is increasing particularly among young scientists, in part due to the increased use and accepted value of social media for communicating and promoting science (Collins et al., 2016) and increased training opportunities (Salmon and Priestley, 2015). Scientists increasingly recognize the value of contributing to the public awareness and understanding of science (Burchell et al., 2009; Davies, 2008; Golumbic et al., 2017). Such appreciation of science communication is positively associated with their previous experience (Poliakoff and Webb, 2007) and their awareness of the benefits of contribution (Besley and Nisbet, 2013). In contrast, factors that decrease scientists' involvement in science communication include lack of time and/or institutional support, limited confidence in their communication skills, as well as failure to see direct benefit to their research (Hamlyn et al., 2015; Mizumachi et al., 2011; Rose et al., 2020). Despite these concerns, scientist participation in public engagement activities is increasing, particularly among younger researchers (Cerrato et al., 2018; Rose et al., 2020).

Role of citizen science in public understanding of science

Citizen science (CS), or public participation in scientific research, is an increasingly popular method of actively engaging the public in science. Although there is great variation in CS practice (Eitzel et al., 2017), at base it involves members of the public collecting data to address a specific issue or question, often alongside scientists, in one or multiple steps of scientific practice (Miller-Rushing et al., 2012). Crowd sourcing typically involves large numbers of people processing and analyzing data, but the focus of this paper is on public involvement in data collection. Ideally CS provides opportunities for two-way communication between scientists and participants (Golumbic et al., 2017). CS is gaining recognition world-wide as a means to generate appreciation of science and/or interest in science careers (Martin et al., 2016); improve citizens' knowledge and understanding of science and its processes (Bonney, Ballard, Jordan, McCallie, Phillips, Shirk and Wilderman, 2009; Bonney et al., 2016; Phillips et al., 2014; Trumbull et al., 2000); improve their skills in conducting scientific studies (Crall et al., 2013; Lewis and Carson, 2021; National Academies of Sciences, Engineering and Medicine, ed. Pandya, Rajil, 2018); and/or change behaviours (e.g. relating to environmental conservation) (Haywood, 2016; McKinley et al., 2017). More specifically, marine CS projects are connecting people to the ocean and furthering global ocean literacy (Kelly et al., 2020). For the enterprise of science itself, it is increasingly recognised that CS can facilitate large-scale data collection at low cost

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across geographic and / or temporal scales (Bird et al., 2014; Devictor et al., 2010; Hadj-Hammou et al., 2017; Pocock et al., 2018; Sullivan et al., 2014). Ideally the data collected by the public is high quality and contributes to new scientific understanding, defines baseline conditions and / or is used to inform local management actions or policy decisions (Kosmala et al., 2016; Miller-Rushing et al., 2012; Savan et al., 2003). There can, however, be trade-offs between the quality of effect on public participants (e.g. extent of education or enhancement of scientific skills) versus the quality of the data collected (Chase and Levine, 2016), and these differ between approaches to CS described below. CS projects vary in the roles and degrees of control afforded to scientists vs participants (Parrish et al., 2018). Under a contributory model (Bonney, Ballard, Jordan, McCallie, Phillips, Shirk and Wilderman, 2009), scientists formulate the research question, set up well-defined and supported data collection methods, analyse the data, and interpret the results. In this top-down approach, participation essentially involves donating data (Devictor et al., 2010). On the other end of the participatory scale are co-created projects where citizens work alongside scientists in formulating the research question and data collection methods, and / or interpreting and sharing results (Bonney, Ballard, Jordan, McCallie, Phillips, Shirk and Wilderman, 2009). The level of public engagement often depends on how relevant a project is to citizens, and the ability of the scientist to design a project that appeals to a wide audience. Such appeal often entails flexible data collection protocols, which may contrast with protocols that provide the highest scientific value (Bonney, Cooper, Dickinson, Kelling, Phillips, Rosenberg and Shirk, 2009).

This tension between flexibility and scientific accuracy may explain some of the persistent reluctance within science to accept CS (Burgess et al., 2017; Golumbic et al., 2017; Theobald et al., 2015). Despite increasing awareness of CS methods, funding for research involving CS, and a concomitant rise in the number of CS projects and publications (Earp and Liconti, 2020). Repeatedly, scientists note concerns around CS data quality (Riesch and Potter, 2014; Santos-Fernandez and Mengersen, 2021) and specifically, lowered probability of publication related to potentially biased data (Burgess et al., 2017). Other perceived challenges of adopting CS, such as ownership of data and recruitment or retention of volunteers (Curtis, 2015; Riesch and Potter, 2014), or various other ethical issues of partnering with volunteers (Resnik et al., 2015), are raised less frequently. Some studies back up the concerns about data quality (Cox et al., 2012; Gillett et al., 2012; Kremen et al., 2011), showing a relationship between data quality and factors like the degree of difficulty and time required for the science methodology involved, and availability of training programmes and/or suitable sampling equipment. However, other CS studies have produced data with accuracy at levels on par with that of professionals (Albus et al., 2020; Canfield et al., 2002; Earp et al., 2022; Fore et al., 2001; Kosmala et al., 2016; Smith, 2019; Storey and Wright-Stow, 2017; van der Velde et al., 2017). There is improved awareness of the type of research questions suitable to be addressed by CS (Devictor et al., 2010) and strategies have been developed for designing CS projects to generate robust science outcomes (Fraisl et al., 2022; Parrish et al., 2018). Such strategies include specific participant training methods, and data validation methods, including increased replication and statistical modelling of systematic error (Kelling et al., 2019; Kosmala et al., 2016; Riesch and Potter, 2014). Despite these advances, a disjoint persists between the perceived values of CS as a means of public engagement in science versus as a methodology in scientific research (Golumbic et al., 2017; Riesch and Potter, 2014).

Overview of this study

There has been significant growth of CS in New Zealand (NZ) particularly since the government's release of the Strategic Plan for Science in Society (SPSS), *A Nation of Curious Minds – He Whenua Hiriri i te Maha* (Ministry of Business, Innovation and Employment, 2014). Its trifold aims include enhancing: (1) the role of science education, (2) public engagement with science and technology, and (3) science sector engagement with the public. A participatory science platform was devised as an integrating action that attended to all aims, and this has been piloted in three regions (Dunedin, South Auckland, and Taranaki) from 2015-24. Further contestable funding has been available since 2016 for projects that involve both community groups and scientists in research that is relevant to the local community, harnesses local knowledge and provides learning experiences for participants while producing robust scientific outcomes (https://www.curiousminds.nz). Scores of CS projects have resulted, many within environmental science, and as might be expected for an island nation, many with a marine focus.

So far there has been limited review of the perceived value of citizen science to science in NZ; however in 2015, Peters et al. noted that while CS participants acknowledged the value of the relationships they developed with scientists, scientists were most concerned about data quality and lack of institutional systems for using the data. Our study examines NZ scientists' awareness and attitudes about CS before and after the initiation of the SPSS scheme, and interrogated scientists' perceptions of CS both as a science research method and as a tool for public engagement in science. Two groups of NZ marine scientists were surveyed (four years apart) and at the initial time point they were also compared with an international group of marine scientists. Notably, the latter was comprised of attendees at an international conference of marine mammalogy, a discipline which has a particularly long history of employing CS to collect data (Earp and Liconti, 2020). Recommendations drawn from this study help inform future development of CS in NZ, supporting the motivated involvement of scientists as well as the participating public.

Methods

An on-line survey consisting of short answer and multichoice questions was implemented using Survey

Monkey. Multichoice questions queried respondents' scientific position, nationality and how they ranked their awareness of and previous involvement with CS. Open-ended, free response questions further addressed previous involvement with CS, as well as perceived benefits and limitations of CS to science, personal motivation to participate in CS as a scientist, and recommendations to increase participation of scientists in CS and the value of CS to science (all questions supplied in Supplementary Table 1).

Three groups of marine scientists were surveyed including scientists attending the 20th Biennial Conference of the Society for Marine Mammalogy (Dunedin, NZ, December 2013). Roughly 1000 conference registrants were emailed a survey invitation several weeks before the conference, with respondents hereafter referred to as the International Group. Note there were some NZ scientists in the group as the conference was held in NZ. An NZ group was surveyed within eight months of the former group and involved marine scientists attending an annual NZ Marine Sciences Society (NZMSS) Conference (Nelson, NZ, August 2014). Again, survey invitations were emailed several weeks prior to the conference to approximately 250 delegates (respondents hereafter, NZ Year 1 Group). A second NZ group was surveyed four years later (NZ Year 4 Group) at another NZMSS conference (Napier, NZ, July 2018), where a survey invitation was included in the conference digital app and emailed to NZMSS members (whether attending the conference or not). For all groups, incentives were provided for participants completing the survey including draws for an ecotourism boat tour, local pottery, and NZ marine-related books.

Respondents' awareness about CS was assessed via a Likert scale (using a 1 = low to 4 = high scale), with independent sample t-tests used to compare results between groups. Although a Kolmogorov-Smirnov test for normality of data distribution suggested an unequal distribution, violations of normality with a sample size larger than 30 (as were our sample sizes) is not typically problematic (Ghasemi and Zahediasl, 2012). Nonetheless, nonparametric Mann-Whitney U Tests were also implemented, yielding results not different in significance from parametric (thus only t-test results are reported). Statistical comparisons focused on NZ Year 1 vs. International Groups, and NZ Year 1 vs. 4 Groups, and Open-ended questions answered in free text responses were analysed according to their emergent themes using a grounded theory approach (Sbaraini et al., 2011), with all responses coded into categories of response by two independent coders. Although there was an initial 4-22% discrepancy between the two coders for some questions, discussion and agreed clarification of each emergent category description led to 100% congruence in a second coding event with no new categories emerging. For each category only two response options were possible (category identified = 1, or category not identified = 0), and if the same category emerged more than once in the text response, it was recorded only once. Data from these questions were analysed using the Chi Squared Test for independence with Yates' Continuity Correction. All respondents expressed their consent for the academic use of the data, with names anonymized to maintain privacy (as approved by the University of Otago Human Ethics Committee; application references D13/380 and D18/235). Qualitative extracts quoted in the results are identified with a unique respondent number as well as their survey group.

RESULTS AND DISCUSSION

Within International Group respondents (n=89), the majority were from the USA (47%), with the remainder from NZ (13%) Australia and the South Pacific (8%), Asia (6%), South America (6%), Soviet Union (4%) and Europe (2%). Roughly half were practicing scientists (52%) from universities, government agencies, private research firms, commercial organisations (e.g. marine mammal tour operations) and science education centres (e.g. museums and aquariums). The remaining 48% were university postgraduate students. The NZ Year 1 Group (n=96; all from NZ) was composed predominantly of practicing scientists (67%), with 33% postgraduate students. The NZ Year 4 groups (n=59; all from NZ) was similarly 69% practicing scientists and 31% postgraduate students.

Awareness of and Involvement in Citizen Science

Most scientists in all groups were at least moderately aware of CS (Table 1) and a very low proportion expressed no awareness of it (2-8%). Significantly more International Group scientists were aware of CS as a method of scientific research than NZ Year 1 scientists; however, NZ awareness increased significantly in Year 4 (Table 1). Further, those NZ scientists expressing no awareness of CS decreased from 7% for year 1 to 2% for Year 4. Within groups, the awareness between the practicing scientists and postgraduate students was similar, except for the NZ Year 1 group, where the practicing scientists were significantly more aware than the postgraduate students (Table 1). Thus, although less aware of CS than their international peers at the first time point, this was no longer the case four years after the launch of the *Curious Minds* strategy (Ministry of Business, Innovation and Employment, 2014).

Similarly, the proportion of scientists involved in CS, as a scientific advisor and / or participant, was also higher for the International Group (54.7%) than the NZ Group in year 1 (40.6%). The higher awareness and involvement of the International Group scientists (47% of which were from USA) aligns with a review of marine citizen science projects worldwide (Earp and Liconti, 2020), which showed that not only did the USA have a much higher number of marine CS projects than NZ, but marine mammals were the most popular taxa studied. Marine mammal CS also yielded the highest number of scientific publications of all marine CS research reviewed, and many were long-running projects, with the majority established prior to 2008 (Earp and Liconti, 2020).

In NZ, the level of involvement of scientists in CS increased significantly from year 1 (41%) to year 4 (59%, see Table 2), suggesting an impact of the *Curious Minds* strategy (Ministry of Business, Innovation and Employment, 2014) and associated funding for projects

		International Group (n = 89)	NZ Year 1 Group (n = 96)	NZ Year 4 Group (n = 59)
Awareness of CS	All respondents	$\mathbf{\bar{x} = 2.82 \pm 0.85}$[1]	$\bar{x} = 2.53 \pm 0.81$	$\mathbf{\bar{x} = 3.07 \pm 0.72}$[2]
	Practicing scientists	$\bar{x} = 2.92 \pm 0.84$	$\bar{x} = 2.66 \pm 0.84$	$\bar{x} = 3.12 \pm 0.68$
	Post-graduate students	$\bar{x} = 2.72 \pm 0.85$	$\bar{x} = 2.28 \pm 0.68$	$\mathbf{\bar{x} = 2.94 \pm 0.85}$[3]

Table 1: Level of awareness of CS methods by practicing scientists and post-graduate students

Significant differences in bold: [1]($\bar{x} = 2.82 \pm 0.85$ *vs.* $\bar{x} = 2.53 \pm 0.81$; $t(183) = 2.38$, $p = 0.02$); [2]($\bar{x} = 3.07 \pm 0.72$ *vs.* $\bar{x} = 2.53 \pm 0.81$; $t(134) = -4.31$, $p < 0.001$); [3]($\bar{x} = 2.66 \pm 0.84$ *vs.* $\bar{x} = 2.28 \pm 0.68$; $t(94) = -2.19$, $p = 0.031$) (*Likert scale 1-4, Independent Samples T Test*).

		International Group (n = 89)	NZ Year 1 Group (n = 96)	NZ Year 4 Group (n = 59)
Involvement with CS	All respondents	54.7%	40.6%	**59.4%**[1]
	Practicing scientists	25.6%	30.2%	45.8%
	Post-graduate students	29.1%	10.4%	13.6%
Type of Involvement	Participant	48.9%	32.5%	**17.1%**[2]
	Scientific advisor	25.5%	42.5%	34.3%
	Both participant and advisor	21.3%	15.0%	48.6%
	Other	4.3%	5.0%	0%

Table 2: Previous involvement in CS by practicing scientists and post-graduate students

Significant differences in bold: [1]($\chi^2(1, n = 155) = 4.398$, $p = 0.036$, $phi = -0.18$); [2]($\chi^2(3, n = 74) = 10.855$, $p = 0.013$, $phi = -0.383$).

through the Unlocking Curious Minds and the Participatory Science Platform contestable funds[1]. It is of note that a concomitant increase in the proportion of postgraduate students involved in CS in the Year 4 group was not significant, suggesting less rapid uptake from this cohort.

The type of previous involvement in CS also varied between groups. International scientists had previous experience predominantly as participants, whereas NZ scientists in both years had greater experience as scientific advisors (Table 2). The breadth of involvement in CS was significantly higher for NZ Year 4 scientists, with nearly 50% having both advised and participated (Table 2).

Perceived Benefits of CS to Science

The vast majority of scientists in all groups identified at least one perceived benefit of CS (>98%), and by all NZ Year 4 scientists. Eight different types of benefits were articulated, some pertaining more directly to scientific research and others to society more broadly (Table 3). The most frequently expressed included: *expanded data collection*, *community engagement* and *public understanding of science*, each noted by >40% of respondents in each group; Figure 1. Expressed by 12-24% of respondents in each group were the benefits of: *supporting research funding* and *increased application of science*. Far less frequently expressed (by 11% of respondents), were benefits such CS providing: *new viewpoints*, *increased science skills / thinking* and *interest in science careers*. Differences between groups in their perceived benefits of CS are discussed further below.

[1]https://www.mbie.govt.nz/.../curious-minds/

Expanded data collection was the main benefit of CS identified by all groups (52-68%) and was the most frequently identified by the NZ Year 4 group, with a marked increase of 16% between years. (Figure 1). This viewpoint was typified by comments like: "*It also provides scientists with an enormous pool of enthusiasts to draw on for help in collecting baseline data*" (NZyr4#34). The dominance of this perceived benefit is convergent with international studies e.g. (Miller-Rushing et al., 2012; Parrish et al., 2018; Theobald et al., 2015) as well as within NZ (Peters et al., 2015; Valois et al., 2020). The former study confirmed that many CS projects in NZ involve environmental monitoring work, which is regarded as a significant subset of CS (Eitzel et al., 2017) that is heavily reliant on data collection extended over time and space. Storey and Wright-Stow (2017) also noted NZ scientists' acknowledgement of the value of CS to agency-led monitoring programmes specifically because of participant's connection to local study sites (i.e. expanded geographic data collection). CS data has been widely recognized to increase the number of sites surveyed and amplify data sets at minimal cost, stretching science budgets further (Miller-Rushing et al., 2012). The current study identified similar perceptions, for example: "*the opportunity to engage local communities and volunteers can be a cost-effective way to scale up projects*" (NZyr4#38), "*it allows data to be gathered across larger areas saving time and money for scientists*" (NZyr1#73) and even "*collection of data that would otherwise unlikely be obtained*" (NZyr4#24).

Although the most frequently observed benefit of CS served the enterprise of science, most scientists

Category	Description
Expanded data collection	Includes a wider geographic and temporal scope and volume of data collected
New viewpoints	A broadened scope of science, that may include 2-way learning
Support research funding	Increased attractiveness of grant applications to funders, expand public support for science funding, decreased manpower costs to collect data
Increased application/uptake of science	The science is of relevance, leading to wider support of scientific endeavours. The data may be useful for management of the local environment or for wider policy.
Interest in science careers	Includes reference to future employment or study pathways in science
Increased science skill/thinking	Increase in the community's ability to carry out science related tasks and use evidence-based thinking
Community engagement	Refers to participation of the wider community at variety of levels but may not specify the result of the engagement. Includes developing a connection between academics and the wider community. (The wider community refers to both local communities and interest groups.)
Public understanding of science	Extends from general understanding of science to increase awareness of specific issues (e.g. threatened species, environmental concerns) and improved science education.
No benefits specified	includes no response (participants had to enter N/A in order to move to the next question).

Table 3: Perceived benefits of CS to science

Benefits emerging from content analysis of free-text responses. The first three pertain to direct benefits to scientific research, and the later to society more broadly.

also perceived benefits to society through community engagement (perceived by 40 − 54%) and public understanding of science (43-51%; Figure 1). Benefits to the former centered around enhanced interest, passion, pride and ownership conducive to societal change, and sustainability, e.g. "*Getting the community involved and interested in science and how it relates to the environments around them. If the community is passionate and aware of environmental issues, then there is more momentum for societal change*" (NZyr4#25) and "*Getting local people involved in understanding their environment will hopefully lead to a sense of pride and ownership which will translate into more sustainable behaviour in the natural world*" (NZyr4#34). Such perceptions are also in line with evidence from other studies showing positive effects of CS on community engagement including the utilisation of new knowledge for political and civic action (Danielsen et al., 2014; Golumbic et al., 2017). Although arguably linked with public engagement, understanding of science may exist as a separate benefit (Bela et al., 2016). It can enrich an understanding of the functioning of one's built or natural world, e.g. to "develop an interest in science which they might not have realised they had" (International#2). Participants also noted the power of co-created understanding, or knowledge, for instance: "*People will be more receptive to messages coming to them from a scientific perspective if they feel like they helped create those messages. They'll also probably be more receptive to thinking critically about news that doesn't have scientific backing*" (NZyr1#53). Enhanced understanding of science was also linked to increased trust in science: "*The inclusion of the public with the scientific process helps the layperson feel connected to science and builds up trust between the public and the scientific community*" (NZyr4#41). As we are increasingly aware, trust may lead to better support of science whether it is social licence, compliance or funding, and mistrust of science is of real concern to many contemporary societal issues (Soleri et al., 2016).

Understanding and trust of science are often still a step removed from actioning that in specific behaviours. A smaller proportion of scientists (12-20%) perceived that CS could lead to increased public uptake of science (Figure 1). Some believed that CS could increase understanding and application of science in ways that benefit compliance, management strategies and policy. For example: "*Better understanding of science behind conservation leading to better support/compliance of conservation projects, protected areas etc.*" (NZyr1#77); "*Greater uptake of ideas, management strategies etc.*" (NZyr1#76); and "*Potential increased ability to affect change in e.g. policy*" (NZyr4#40).

A similar proportion of respondents linked the impact of CS on raising awareness and understanding of science on funding for science (17-24%, Figure 1). For instance: "*Raises public awareness of issues faced by scientists and may help with future pressure on the government to fund us*" (NZyr1#15), and "*Helps the general public learn more / get involved. When there is larger support for science, it is easier to get funding*" (International#65). Help with research funding in other cases also referred to the low cost of labour to collect the data: "*It is extremely beneficial to scientific research in developing countries where funding is very limited*" (International#63). Thus, such benefits of CS provide particular advantage in underfunded sectors. In NZ more than 60% of community groups involved in CS were found to use their data to support funding applications to continue their CS work (Peters et al., 2015).

Far fewer scientists identified CS as beneficial for

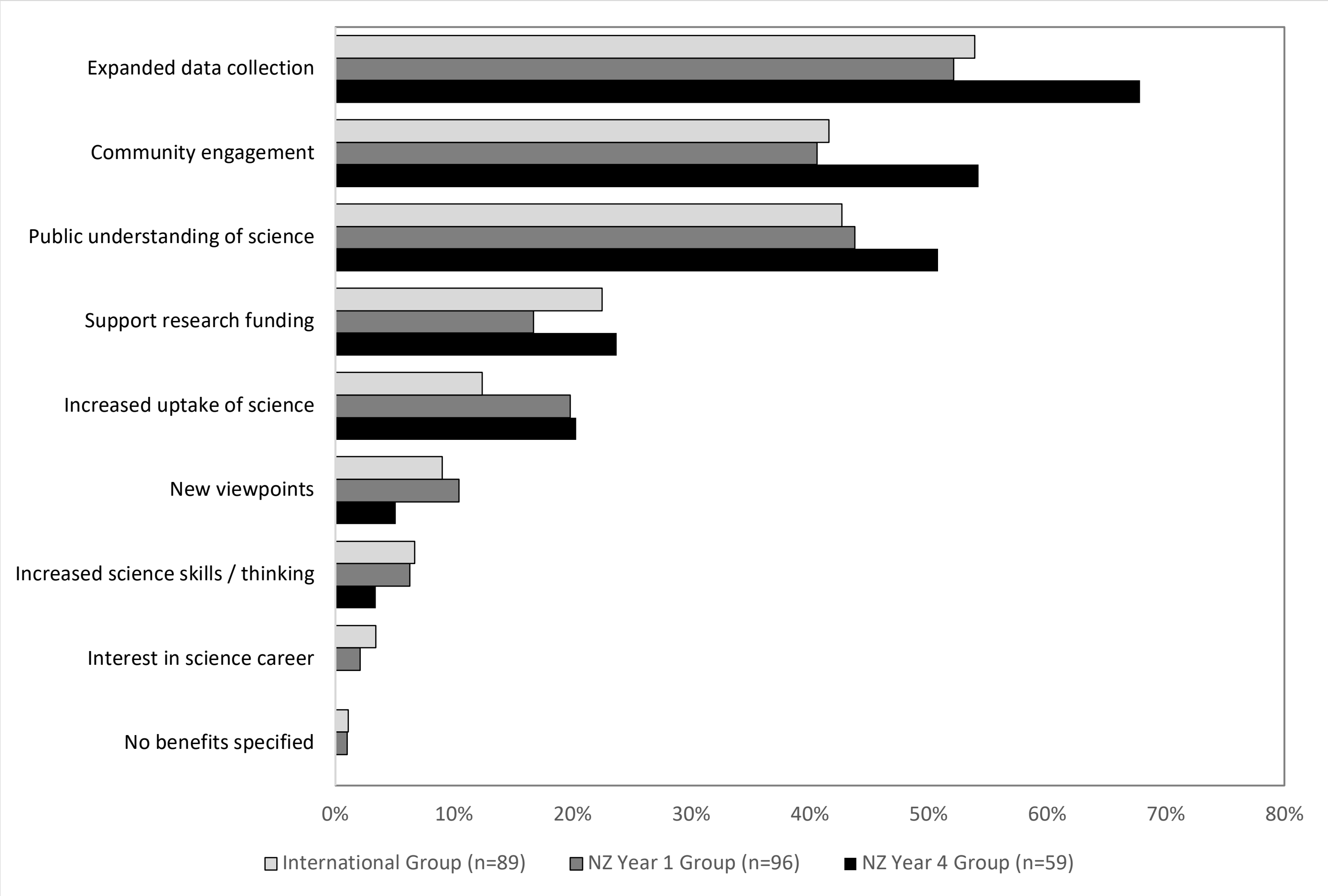

Figure 1: Key Benefits of Citizen Science as described by scientists.
Expanded data collection approached significance between NZ Year 1 and NZ Year 4 Groups ($\chi^2(1,\ n = 155) = 3.088,\ p = 0.079\ phi = 0.155,$ *chi squared test for independence with Yates' Continuity Correction*).

science in providing new viewpoints (5-10%, Figure 1). Where noted it was seen to contribute a greater breadth and diversity of experiential knowledge including local understanding. These ideas were articulated in comments like: "*allows for a broader range of ideas to be explored*" (International#74); "*interactions and collaborations for reciprocal learning*" (NZyr4#8); and "*Opportunities to gather more data specific to sites and solve local problems. Bring local knowledge in developing and executing research projects*" (NZyr1#70). A variety of studies have also highlighted that community input helps researchers design more interesting research projects and can open up new areas and approaches for investigations (Hepburn et al., 2019; Jensen et al., 2008). Arguments have specifically been made for involvement of indigenous communities and landowners in less accessible places who have valuable insights that CS should acknowledge (Danielsen et al., 2018; Kennett et al., 2015). Scientists' relatively low awareness of such potential for reciprocal learning has long been discussed as a feature of CS that needs to be further considered (Bonney, Cooper, Dickinson, Kelling, Phillips, Rosenberg and Shirk, 2009; Lukyanenko et al., 2016) and this appears unchanged in our NZ context. Facilitating greater two-way communication may be addressed through training workshops to raise awareness about the wider benefits of CS (Bonney, Cooper, Dickinson, Kelling, Phillips, Rosenberg and Shirk, 2009; Concannon and Grenon, 2016; Crall et al., 2013), and of the co-creation of scientific knowledge (Bela et al., 2016; Golumbic et al., 2017).

Two further benefits of CS, although perceived at low frequency, included enhanced science skills and evidence-based thinking for the public, and CS serving as a pathway to a scientific career (3-7% and 2-3%, respectively). Although understanding the process of science is well promoted in formal science education, only a few scientists extended this benefit to the public involved in CS. Where noted, some expressed this idea generally as "*teaches skills to untrained individuals*" (International#12) and "*training the public in scientific thinking*" (NZyr4#19). Others gave more explicit examples such as: "*More 'educated' eyes on the water [i.e. for] ecotour companies and fishermen who spend more time on the water than we do*" (International#10). Involvement in CS was also occasionally identified as

Key Benefits	International Group		NZ Year 1 Group		NZ Year 4 Group	
	Involved in CS (n = 47)	Not Involved (n = 42)	Involved in CS (n = 39)	Not Involved (n = 57)	Involved in CS (n = 35)	Not Involved (n = 23)
Expanded data collection	**34.8%**[1]	19.1%	25.0%	27.1%	39.0%	28.8%
Community engagement	24.7%	16.9%	16.7%	24.0%	32.2%	20.3%
Public understanding of science	27.0%	15.7%	18.8%	25.0%	21.9%	24.5%
Support research funding	**16.9%**[2]	5.6%	9.4%	7.3%	11.9%	11.9%
Increased uptake of science	10.1%	2.2%	9.4%	10.4%	16.9%	3.4%
New viewpoints	5.6%[1]	3.4%	5.2%	5.2%	3.4%	1.7%
Increased science skills / thinking	4.5%[1]	2.2%	2.1%	4.2%	3.4%	0.0%
Interest in science career	3.4%	0.0%	0.0%	2.1%	0.0%	0.0%
No benefits specified	0.0%	1.1%	0.0%	1.0%	0.0%	0.0%

Table 4: Comparison of key benefits of CS perceived by scientists based on previous involvement in CS.

Significant differences in bold: [1]($\chi^2(1,\ n = 89) = 4.816$, $p = 0.028$, $phi = -0.255$); [2]($\chi^2(3,\ n = 89) = 4.014$, $p = 0.045$, $phi = -0.247$).

guiding career pathways, e.g. "*Encouraging younger people into observation and rigorous thinking*" (NZyr4#42). Again, scientists' lack of awareness of this benefit is at odds with what is readily acknowledged within formal education, where hands-on science experience is a well-known pathway to science careers. For example, Golumbic et al. (2017) demonstrated that youth participation in science can have long-term educational benefits and that the increase in students pursuing a scientific career is of benefit to scientists. Indeed, one of the key objectives of NZ's *Curious Minds* strategy is to have more students choosing STEM-related career pathways. NZ scientists' more recent failure to link the two (none in 2018 perceived this) is worth further investigation.

Effect of CS experience on perceived benefits

It might be expected that the perceived benefits of CS will be influenced by a scientist's own level of previous involvement in CS. For example, Poliakoff and Webb (2007) found that scientists who have previous public engagement experiences are more likely to have future intentions to participate. In our study, none of the scientists who saw *no benefits* to CS had previous involvement (Table 4). In almost all cases, scientists that had been involved in CS had higher frequencies of perceiving each benefit (with some exceptions in 2014, (Table 4). For the International Group with previous CS involvement, these differences were significantly higher for benefits including *expanded data collection* (35% with experience vs 19% without) and *supporting research funding* (17% with experience vs 6% without) (Table 4).

Perceived Limitations of Citizen Science to Science

Limitations of CS were noted by virtually all scientists surveyed. Six themes emerged from their free text responses including: limitations that could compromise the utility of the data (*variable data quality* and *limited education / training*); limitations associated with the effort involved (*low value of the project / data to science*, *limited funding / time*, *low engagement* and *concerns about meeting health and safety guidelines*) (Table 5).

Scientists were primarily concerned about the quality of CS data; more than 57% of every group expressed this (Figure 2). The NZ Year 4 Group were particularly concerned (78%, a significant increase from 58% in the NZ Year 1 Group). Specific difficulties in maintaining consistency and accuracy were mentioned as well as bias in sampling, e.g.: "*Patchiness of data and samples biased towards populated areas. Samples biased towards problem areas (e.g. for water quality). Samples biased towards quality areas (e.g. for birds sightings)*" (NZyr1#66) and "*bias toward populated areas; potential inaccuracies [...]; potentially biased towards species easier to identify; potentially biased towards widespread/common species; potentially hard to capture effort properly*" (NZyr4#26). The ramifications of poorer data quality were multiple, as articulated by one scientist, it "*May entail a lot of 'cleaning up' after data collection for the scientists. It may limit the type of analysis that can be done on the data collected*" (International#23). Poor data was also perceived to constrain publication: "*Most scientists (academics anyway) are only going to be interested if data are publishable. Training them [citizen scientists] to point of usefulness and managing them may take longer and be more hassle than*

Themes	Description
Low engagement	Refers to low engagement of the citizens and /or the scientist for a variety of reasons (e.g. non charismatic species, low media awareness of scientists, ineffective advertising to citizens).
Limited funding / time	Refers to low levels of funding and time for the scientist and / or the citizen. Limitations on equipment available is also related to low funding.
Low value to science	Lack of relevance or mandate of the project to science.
Limited education / training	Low skill level or insufficient training of the citizen.
Data quality	Poor quality control measures, accuracy of the data collected is questionable; also, poor recognition of the potential quality of the data.
Health and safety	Regulations around health and safety difficult to meet.
No limitation specified	Includes no response, N/A (participants had to enter N/A to move to the next question)

Table 5: Limitations of CS Projects to Science

doing it yourself" (NZyr4#18). Support for this view comes from Theobald et al. (2015) who found only 12% of 388 CS projects were linked to peer-reviewed scientific publications. In contrast, some scientists held the view that issues with CS data were due to a lack of recognition of their quality, e.g. "*There is a negative [attitude] from the academy to recognize it as valid sources of information*" (International#31), and "*scientific managers [not] taking the work done by citizens seriously, when in fact, these volunteers have just as much capability, and often more time, to get the job done right*" (International#45).

There is much debate about the quality of CS, with concerns about consistency and reliability of data highlighted by multiple studies (Bird et al., 2014; Fore et al., 2001; Gillett et al., 2012; Kosmala et al., 2016; Kremen et al., 2011; Theobald et al., 2015) including in NZ (Peters et al., 2015; Smith, 2019; Storey and Wright-Stow, 2017). Although acknowledging the value of CS data in some form, many call for improvement of data quality through better refined protocols e.g. through analysis at a higher taxonomic level (Kremen et al., 2011), or better training (Edgar and Stuart-Smith, 2014; Fore et al., 2001; Newman et al., 2010). However, other studies have demonstrated that the reliability of data collected by scientists versus CS participants are comparable and biases are problematic only for some types of study (Bird et al., 2014; Fore et al., 2001). Indeed, Riesch and Potter (2014) conclude that concerns about data quality may more often be anticipated than actually encountered.

Another perceived limitation, which was linked to data quality but generally articulated as a separate concern, was CS participants' limited scientific education/training (noted by 20-40%, Figure 2). The International Group identified this significantly more than NZ scientists, which may be linked to the intensive training required to master marine mammal identification techniques. Scientists expressed specific concerns that participants might neglect to record important contextual observations, e.g. "*Using basically untrained people to try and get precise measurements. Often people with little experience in what they are doing don't take notice of other things going on around them or in the area, which might have significant impacts to the data that they are collecting, whereas a trained and experienced scientist/researcher is always watching out for and recording things like that.*" (NZyr4#27); "*methods must be simplified to make them accessible to the public, training effort/regulatory framework required can require a lot of time and resources*" (International#9). Others noted how lack of training also restricted how CS participants might contribute: "*Data analyses and interpretation may be beyond the scope of participants*" (NZyr4#24). Doubtlessly, scientific methodologies vary in their complexity and training requirements and thus suitability for CS, which will impact each science discipline's concerns about CS. It is interesting to note that no comments were related to the lack of training for scientists in how to carry out CS work, which has been identified as a major barrier to scientist participation by other studies (Cerrato et al., 2018; Hamlyn et al., 2015; Shugart and Racaniello, 2015).

Despite the aforementioned concerns, few scientists felt CS had limited value to science (expressed by only 16-24%), and this concern also decreased for NZ scientists over time (24% vs. 19%, Figure 2). Justification for this perceived limitation centered on the idea that when the methodological complexity of a project was reduced (as might be required for enhanced engagement and/or quality of data), CS may not have any real value to science: "*Quality and complexity usually traded off against quantity*" (NZyr1#71). Others expressed concern about an often highly local focus of CS: "*focus on local projects that in the bigger picture are not contributing effectively to conservation or science*" (International#29). It was also noted that only limited kinds of science benefited: "*Some topics do not lend themselves to having data collected by those that are not skilled in a procedure*" (International#22) and "*Topics that are complex for lay people to understand may be avoided.*" (NZyr1#78). These findings are in line with other studies observing that CS might never lead to significant science contributions (Riesch and Potter, 2014), and that not everything can be easily monitored through CS (Chase and Levine, 2016). Clearly, the intrinsic variability across science disciplines means not only must each be assessed for its suitability for CS, but each CS dataset should be assessed individually according to project design and application, and not assumed to be substandard simply because volunteers generated it (Kosmala et al., 2016;

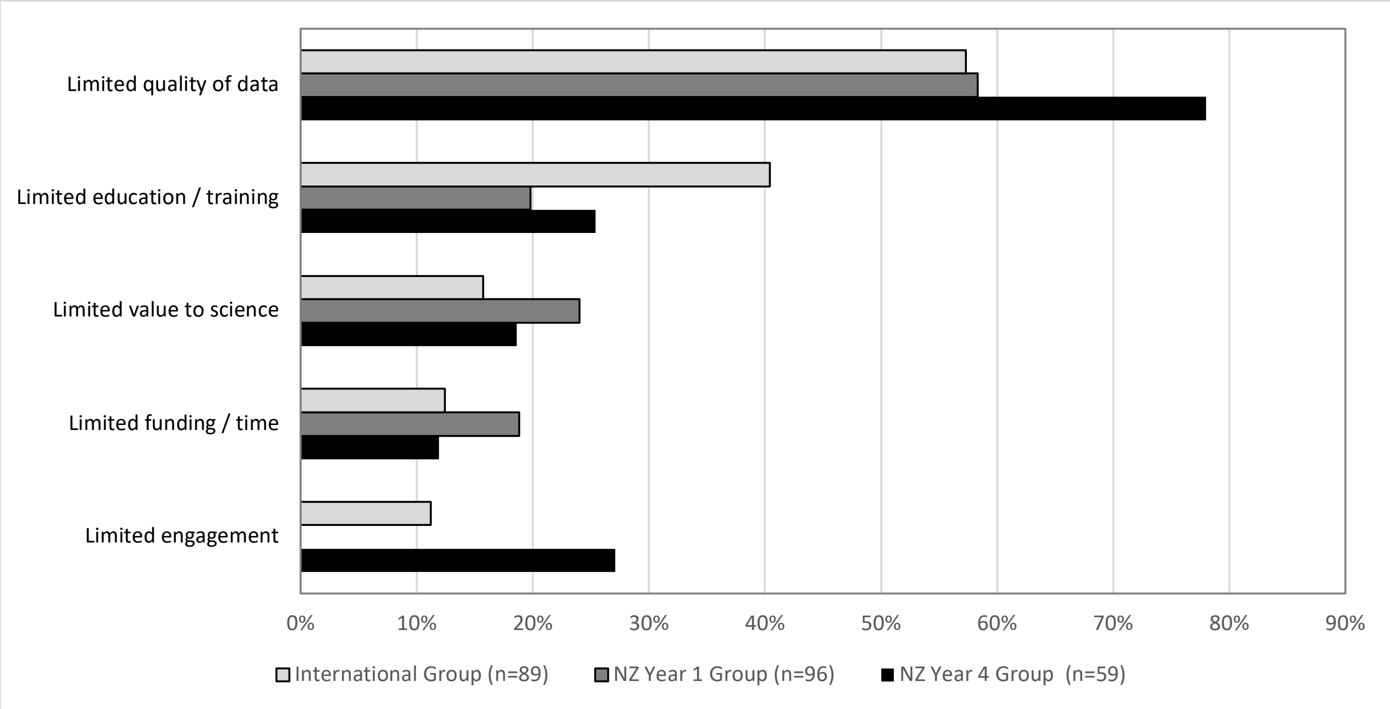

Figure 2: Limitations of Citizen Science for Science

Significant differences were found for limited quality of data between NZ Year 1 group to Year 4 group ($\chi^2(1, n = 155) = 5.417, p = 0.02\, phi = 0.201$) *and limited education or training between International group and NZ Year 1 group* ($\chi^2(1, n = 185) = 8.471$, $p = 0.004\, phi = -0.226$, *chi squared test for independence with Yates' Continuity Correction*).

Parrish et al., 2018). As one scientist put it "*Ironically, the limitations are that we don't know the limitations because there are so few evaluations. So it is more that we lack knowledge of the value [of] these projects*" (NZyr4#38).

Limitations of funding and time for scientists to integrate CS into their work was raised as a barrier by a small proportion of respondents (12-19%, Figure 2). Some noted a lack of time for reading about CS work, while others viewed CS as a short-term investment that was not worth the time and money: "*so much time must be spent training citizens who want to be more than just "cogs in the wheel" of a project. However, they have no commitment to stay with a project long term. With that level of my energy and time input, I'd rather have someone who will stay the course of a project, such as a graduate student...*" (International#11). In contrast with this sentiment, Theobald et al. (2015) argue that when the true value of CS volunteer effort is calculated, the financial cost of engaging a large number of volunteers may be more than acceptable.

Science funding agencies internationally are increasingly expecting to see public engagement included in research project goals (Daelli et al., 2014; Pearson, 2001) and in some cases they motivate scientists to include CS specifically (Golumbic et al., 2017). However, community-driven projects with smaller funding sources who seek to involve scientists often do not have funding to financially support them as evidenced here: "*Much of the time I give to these projects is unpaid which reduces my ability and keenness to participate*" (NZyr4#47). It is of note that fewer NZ scientists in the Year 4 Group saw time and money as an issue, after dedicated funding had recently been made available by the NZ government (Ministry of Business, Innovation and Employment, 2014). However, this funding strategy encourages CS projects to be community-led with the involvement of scientists, yet the funding does not support compensation for scientists' time under current overhead models or provide any training in CS methods.

A final limitation expressed by a small proportion of scientists involved the inability of some CS projects to generate the public engagement required (11-27%, Figure 2). This limitation was noted most frequently by the NZ Year 4 Group and perhaps reflects some frustration in achieving the CS work they had anticipated under the new funding scheme. Some specifically questioned the time that volunteers had available and whether it was sustainable long term for participants: e.g. "*Time and costs to communities. Most work full time after externally funded projects cease*" (NZyr1#70) and "*The seasonal and location replication is often too expensive and laborious for a citizen science project*" (NZyr4#8). The reliability of participation has also been identified as an issue by other studies of CS (Riesch and Potter, 2014) but here again this varies with scientific discipline. Issues with engagement were less frequently highlighted by marine mammal scientists, which may suggest that participation levels reflect subject popularity, or as articulated by one respondent: "*low participation* *for less charismatic projects*" (NZYr1#12). Others felt popularity would be driven by the intensity of science skills required: "*Many members of the public are scared of "real" science and thus are hard to engage*" (NZyr4#34). Other challenges to engaging participants include enabling them to reach sampling sites (e.g. offshore sites in particular). It was further observed that participants need to see the personal and/or community benefits of their involvement as outcomes of their work: "*Public may not always feel they gained anything from a project and may be deterred from future participation*" (NZyr4#56).

The most infrequently raised limitation was around health and safety, which was only noted by NZ scientists, and more often in Year 4 (1% vs 5%). Health and safety regulations were identified as putting additional stress on science organisations, as community groups might not have the systems in place to deal with the responsibility: '*'H&S limitations are difficult to overcome unless the organiser accepts some level of accountability for public/participant H&S*" (NZyr4#33). The concern is not surprising and may be expected to heighten; risk assessment is becoming an increasingly important component of designing CS projects (Van Haeften et al., 2021).

Effect of CS experience on perceived limitations

Unlike when identifying benefits (where perceived CS experience typically increased the likelihood of their identification), identifying limitations appeared to be less dependent on previous experience (Table 6). Although in many cases, scientists previously involved in CS identified each type of limitation more frequently than those not involved, a few of these were significant differences. NZ Year 1 scientists with previous involvement expressed significantly more concern about *limited value to science* (15% vs 9%) and *limited funding and time* (13% vs 6%). The NZ Year 4 scientists with experience were significantly more concerned about the lack of engagement (22% vs 5%) and limited funding and time (12% vs 0%, (Table 6). Involvement clearly heightened awareness of time and funding limitations and this concern remained even after the roll out of dedicated funding. It is hopeful that the value of CS to science is becoming clearer over time, and that concerns are turning to effectiveness of engagement.

Scientists intended future involvement with CS and solving its limitations

Scientists' intended future involvement

Scientists were asked if they would consider participating as a CS leader or participant in the future. The overwhelming majority (91 – 95%) said yes and indicated this was largely because of personal enjoyment, as well as for the greater good, e.g.: "*I like working with the public. People are generally excited, and it helps get the word out about marine mammal conservation*" (International#58). The small percentage that said no typically identified a lack of time and/or concerns about poor data quality, e.g.: "*too much time for too little reliable data*" (International#84). Combined with the results of this study, they also point to necessary institutional change to support such work within research science.

Future design of projects and tools for implementation

Despite the diversity of limitations perceived about CS, the vast majority of scientists felt they could be overcome (78-85%, the highest proportion being NZ Year 4; (Table 7) with a small proportion giving a mixed response (3-15% said yes and no, suggesting that only some issues could be solved). Recommendations for how limitations might be overcome coalesced into three themes: (1) design of projects and tools for implementation, (2) infrastructural support and (3) recognition of the scientist and the science.

Many scientists called for design of clear protocols and validation methods to maintain the reliability of the data. Key phrases repeated were: "*clear protocols*"; "*standards of practice*"; "*standardized data sheets*"; "*monitoring of data collection*"; "*observer reliability*"; "*decrease citizen error*"; and "*rigorous review of data*". Better education and training of participants was seen as a logical step to ensure the quality of the data, and this could be developed via scientist-supported workshops and field days along with well-developed guide materials: "*extend education of the crowd that is to participate in these projects, try to make preparational material (e.g. flyers explaining details) as good and detailed as possible to minimise error rate*" (International#74). Other project design elements included: simplification either by limiting the number of participants or in minimising the science goals, e.g. "*By reducing the complexity of the question making it easier for citizens to collect reliable data, at the risk of robustness of the project*" (NZyr1#56). On-line tools were also suggested as a means to improve long term data storage and data quality: "*Through survey design and data capture apps that undertake basic check for inaccuracies (e.g. species seen in an area where not known to occur)*" (NZyr4#26). Although concerns around data quality appear central to scientists' reservations about CS, they also do not appear to be insurmountable. Indeed, they may drive much of methodological innovations within CS (Riesch and Potter, 2014) especially when failures as well as successes in data quality practices are shared (Balázs et al., 2021).

Suggestions for project design were also given that attended to increasing public engagement, and these focused on having objectives relevant to participants as well as scientists (e.g. addressing both local and larger scale issues): "*need to target projects that are relevant to the general public and if they aren't directly relevant, we need to try to make them relevant - make connection between peoples' everyday lives and the research (e.g. recreational uses of estuaries and ecosystem services)*" (NZyr1#76). This might be facilitated by having local champions who are well trained and able to decide what was of relevance: "*selection of good on-the-ground people as 'champions' for the work who are both engaged and have sufficient technical skills*" (NZyr1#38).

Designing projects via inclusive discussion networks

Key Limitations	International Group		NZ Year 1 Group		NZ Year 4 Group	
	Involved in CS (n = 47)	Not Involved (n = 42)	Involved in CS (n = 39)	Not Involved (n = 57)	Involved in CS (n = 35)	Not Involved (n = 23)
Limited quality of data	34.8%	22.5%	28.1%	30.2%	45.8%	32.2%
Limited education / training	22.5%	18.0%	6.3%	13.5%	16.9%	8.5%
Limited valuie to science	11.2%	4.5%	**14.6%**[1]	9.4%	13.6%	5.1%
Limited funding / time	9.0%	4.5%	**12.5%**[2]	6.3%	**11.9%**[3]	0%
Limited engagement	4.5%	6.7%	6.3%	11.5%	**22.0%**[4]	5.1%
Health and safety issues	0.0%	0.0%	1.0%	0.0%	3.4%	1.7%
No limitation specified	0.0%[1]	0.0%	1.0%	0.0%	0.0%	0.0%

Table 6: Comparison of key limitations of CS perceived by scientists based on previous involvement in CS.

Significant differences in bold: [1]($\chi^2(1,\ n = 96) = 4.095,\ p = 0.043,\ phi = -0.255$); [2]($\chi^2(3,\ n = 96) = 4.971,\ p = 0.026,\ phi = -0.231$); [3]($\chi^2(3,\ n = 59) = 3.701,\ p = 0.054,\ phi = -0.304$); [4]*approaching significance* ($\chi^2(3,\ n = 59) = 3.216,\ p = 0.073,\ phi = -0.272$).

	International Group (n = 89)	NZ Year 1 Group (n = 96)	NZ Year 4 Group (n = 59)
Yes	78.0%	79.2%	84.7%
No	6.0%	2.1%	3.4%
Yes & No	15.0%	3.1%	8.5%
No response	0.0%	15.6%	3.4%

Table 7: Scientists' perception of whether the limitations could be overcome.

among science interest groups was also identified as another means: e.g. "*Encourage collaboration between the community, universities and government organisations*" (NZyr4#25). It was noted that such collaborative design would also allow consideration of how to make projects more suitable for science and allow for discussion of research methods best suited for CS. Other practical recommendations included establishing a directory of scientists available for citizen science projects, as well as a centralized database of CS resources to help with design, execution, and evaluation of projects. Ultimately, networking and co-design of CS projects was seen as a way to build dialogue to help resolve wider science and society disjoints that impede CS, e.g. "*Many scientists still seem to have an attitude that the general public can't be trusted or aren't smart enough to contribute to science (and, incidentally, the general public often has a perception of scientists as thinking they are superior, so it's a problem that goes both ways)*" (NZyr1#40). The suite of aspects requiring intentional design of CS span from inception to completion: "*Ease of participation, importance of project, usefulness to the involved community and potential outcomes need to be clear and maximised*" (NZyr4#56).

Infrastructural support and professional recognition

Better infrastructural support for scientist involvement was a clear and consistent recommendation, including dedicated staff for coordinating CS, facilitation of governance and stronger partnerships, support from home institutions and improved operational systems. At the smallest scale (within individual projects), support for project management was highlighted as particularly important: e.g. "*Needs a dedicated paid individual to manage the logistics and communicate with the volunteers to keep them keen & organised etc.*" (NZyr4#18). But higher level support was also called for: "*Getting top echelons of science politicians, VC's DVC's PVC's to support, recognise and fund citizen science*" (NZyr4#36). Better management at the national level was also suggested, e.g.: "*Better leadership and coordination of CS in NZ. Clearer understanding of govt agency roles in Citizen Science - who leads the govt's role - DOC, MBIE, Councils, MfE?*" (NZyr4#33), as well as specialist support positions: "*Reliable team of "interpreters" to liaise between specialist scientists and the public*" (NZyr4#12).

Generally, it appeared there was appreciation of a diversity of roles in CS beyond the scientist, from orchestration to participation (e.g. "*organisers, funders, creators, participants, promoters, coordinators, data managers*" NZyr4#33) and that there could be enhanced coordination at levels higher than individual projects. It was suggested that such support could help projects reach different demographics (such as senior citizens) or provide better support for communicators to: "*disseminate results back to the public and thus increase participation*" (NZyr4#12). Communication was also seen as important for supporting the involvement of the scientists: "*There needs to be a clearer framework that outlines the key steps involved in undertaking citizen science projects for researchers. This should include case studies of where citizen science has helped augment or been incorporated into more traditional-science projects*" (NZyr4#24). These findings echo other studies that have identified a lack of institutional commitment and support for professional training as one of the main obstacles of scientist outreach activity (e.g. in science communication, (Hamlyn et al., 2015; Shugart and Racaniello, 2015). Just as it has been proposed that better networking and developing an institutional culture of support would foster involvement of scientists in science communication (Cerrato et al., 2018), it appears the same argument could be made for CS. Other studies have noted that it is early career researchers that are often more interested in CS and engaging with the public (Golumbic et al., 2017; Hamlyn et al., 2015) and some scientists in the present study noted that consideration needs to be given to how young scientists, in particular, can be better supported: e.g. "*More incentives for young researchers, better advertising of opportunities to contribute, better defined end goals*" (NZyr4#6). This aligns with the wider recommendation that it is critical to the field of CS to expose scientists to CS methods early in their career (Golumbic et al., 2017).

Scientists also recommended that there be better recognition of the scientist and the science. Specifically, it was felt that this needed to include recognising the additional workload CS involved: "*The amount of work necessary to ensure the citizen scientists are doing a quality job is high, but the recognition (in terms of service/research/teaching) is low*" (NZyr4#1). Practical suggestions offered by the scientists to increase recognition mostly addressed publications, e.g. "*Encourage multi author write up of results in scientific journals so there is an output for scientists to claim on*" (NZyr4#47).

Conclusions on the future of CS in NZ

Although the literature is glowing on the benefits of CS, concerns have been raised that it has been too enthusiastic and optimistic about what CS can deliver for science (Riesch and Potter, 2014). From this study it seems clear that the enthusiasm for CS by marine scientists in NZ is held concomitantly with concerns about its scientific contribution. These potential conflicting views are mediated by a viewpoint that limitations can be overcome given the right project design and support. The optimism expressed by scientists towards the use of CS and its value is particularly encouraging as it was often expressed by those with previous experience with CS. However, fundamental challenges around institutional support were raised that need to be resolved before CS is going to reach its full potential in NZ.

This study is timely, as the Science and Society Strategy 2014-2024 (Ministry of Business, Innovation and Employment, 2014) is approaching a review period. To better reach its goals of "science engaging with the public" and "participatory science", further feedback from scientists needs to be collected and considered. Scientists in this study articulated that their involvement in CS was generally desirable and can be fostered by:

1. Improved tools, resources and infrastructure - to make the best use of the scientist's time, maintain data quality and accessibility, enhance project design and management, and support recruitment and networks to facilitate ease of involvement.

2. Supported scientist involvement - through appropriate funding and institutional recognition. In particular, scientists and science organisations need financial support to trial and develop CS research methods. and networks/platforms to encourage sharing of experience and outcomes.

A recent survey of 322 scientists identified high priority research questions for the future of marine science in NZ (Jarvis and Young, 2019). Marine guardianship was one of the nine themes identified and key questions asked how to: *improve public awareness and understanding; use engagement to better connect New Zealanders with their marine heritage; use citizen science to maximize observation of changes in the marine environment; and use community monitoring to inform local management and behaviour change.* These research priorities clearly identified the need to build effective partnerships and strengthen Māori, community, and citizen guardianship of the marine environment.

Indeed, in NZ, there are higher expectations of contemporary CS platforms linked with constitutional obligations, which add extra emphasis to the value of infrastructural support. Here, the development of CS platforms is expected to engage the community, including Māori, and where appropriate to incorporate mātauranga Māori methods. This necessitates a more collaborative approach with iwi, with an openness to new viewpoints, and resourcing significant time to develop these relationships.

For CS to be effective, both scientists and the wider community need to recognize its limitations and opportunities. A review of what has been achieved through the *Curious Minds* funding would provide valuable insight on this and Salmon et al. (2021) has provided a model to assess the contributions and motivations of the multiple roles needed for a successful project. Clearly scientists need to be smart about identifying projects that are suitable for CS, and devise methods to ensure quality data is collected. But they also must consult with community about what questions and issues are important to them. Community leaders in CS equally must recognize that their data may only supplement a science project, and that scientists are increasingly constrained by institutional overhead structures. Funders must realize that their funding needs to allow fuller for scientific and community (including iwi) participation. Recognition of the potential of CS projects to develop science skills and raise youth awareness of study pathways and careers, must also be acknowledged and nurtured.

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