Biological Conservation 225 (2018) 176–186

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

The threefold potential of environmental citizen science - Generating knowledge, creating learning opportunities and enabling civic participation

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ARTICLE INFO

Keywords:
Environmental citizen science
Public participation in scientific research
Environmental education
Learning
Civic participation
Citizen science funding

ABSTRACT

Citizen science offers significant innovation potential in science, society and policy. To foster environmental and conservation goals, citizen science can (i) generate new knowledge, (ii) enhance awareness raising and facilitate in-depth learning as well as (iii) enable civic participation. Here, we investigate how these aims are realised in citizen science projects and assess needs and challenges for advancing citizen science and stimulating future initiatives. To this end, we conducted a quantitative, web-based survey with 143 experts from the environmental and educational sector in Germany, Austria and Switzerland. Our findings show that citizen science project managers pursue goals related to all three areas of potential impact. Interestingly, enabling civic participation was considered slightly less important in relation to generating new knowledge and creating learning opportunities. Different areas of necessary action emerge from our analysis. To fully realize the potential of citizen science for generating knowledge, priority should be given to enhance capacities to more effectively share research results with the scientific community through publication, also in scientific journals. Systematic evaluation is needed to gain a better understanding of citizen science learning outcomes, for which criteria need to be developed. Fostering project formats that allow participants to get involved in the whole research process – from posing the study question to implementing results – could enhance the transformative aspect of citizen science at a societal level. Important structural aspects that need to be addressed include adjustments in funding schemes, facilitation of communication between citizens and academia-based scientists, and offers for training, guidance and networking.

1. Introduction

Citizen science bridges science and society by involving members of the public in scientific discovery across disciplines (Bonney et al., 2014; Kullenberg and Kasperowski, 2016; Theobald et al., 2015). Although it can be implemented in all areas of research, citizen science has gained relevance particularly as a tool to address environmental and conservation issues (Forrester et al., 2017; Newson et al., 2017; Pocock et al., 2017; Zapponi et al., 2017). By enabling people to engage with scientific inquiry, environmental citizen science can contribute to realizing goals in three important areas. First, it provides opportunities to generate knowledge and insights which are new for and relevant to science, society or administration and management, especially with respect to nature conservation (Chandler et al., 2016; Danielsen et al., 2014; Weise et al., 2017). Second, it can contribute to learning about science and the environment as individuals can acquire knowledge which is new to them and gain skills as well as scientific and environmental literacy through involvement in citizen science projects (Bela et al., 2016; Bonney et al., 2014, 2016; Forrester et al., 2017). Third, citizen science can allow for empowering citizens by providing scope for civic participation and involving people in policy-relevant debates and decision-making processes (Dillon et al., 2016; Jordan et al., 2012; Trimble and Berkes, 2013). By offering the potential to merge these three components, citizen science is embedded at the interface of science and knowledge generation, learning and civic participation (Fig. 1).

The emphasis on the generation of new knowledge and addressing authentic scientific objectives is necessarily key to citizen science as expressed in the 'ten principles of citizen science' (Robinson et al., 2018). This needs to be included in design and planning of citizen science projects (Bonney et al., 2014). With regards to knowledge generation, citizen science has been remarkably successful in producing

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https://doi.org/10.1016/j.biocon.2018.03.024
Received 10 December 2017; Received in revised form 14 March 2018; Accepted 20 March 2018
Available online 17 July 2018

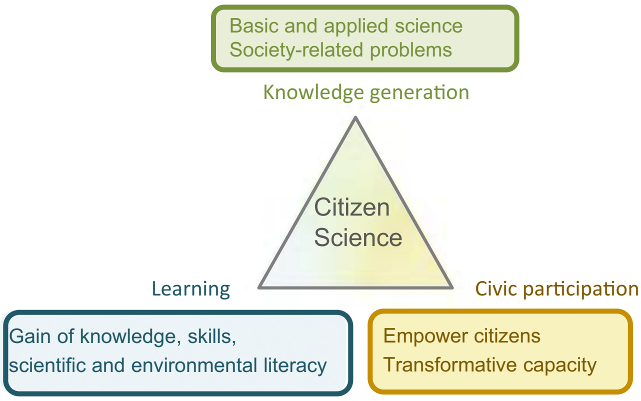

Fig. 1. The threefold potential of citizen science for generating new knowledge (green), creating learning opportunities (blue), and enabling civic participation (yellow). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

large amounts of data, especially data spanning large spatial or temporal extents, which would otherwise be laborious and costly or even impossible to obtain (Dickinson et al., 2012; McKinley et al., 2017). These data can form the important basis for analyses of trends and drivers of environmental change (Chandler et al., 2016; Devictor et al., 2010) and support local and international environmental monitoring, nature conservation, land-use planning and administration (Theobald et al., 2015).

Next to generating new knowledge, citizen science is often promoted as a valuable means to create opportunities for in-depth learning. By engaging members of the public in research endeavours, citizen science holds the promise to enhance their learning experience and motivation to acquire new knowledge and skills needed to solve authentic problems, thereby fostering their understanding of both science and scientific processes (Wals et al., 2014). Furthermore, environmental citizen science endeavours often aim at encouraging participants to increase their awareness of environmental problems and gain ecological stewardship (Ballard et al., 2017; Bonney et al., 2014; Shirk et al., 2012). However, while citizen science is naturally regarded as a means to combine scientific and educational purposes, studies systematically evaluating learning outcomes of citizen science projects are still rare and finding evidence for specific learning outcomes of citizen science has been challenging (Ballard et al., 2017). In general, it has been easier to demonstrate that participants of citizen science projects have improved their knowledge or skills than showing that they have enhanced their scientific and environmental literacy or changed their attitudes and behaviours (Bonney et al., 2016; Brossard et al., 2005; Evans et al., 2005; Jordan et al., 2011; Merenlender et al., 2016). One possible reason is that the latter achievements are more complex constructs that are more difficult to measure. But it also likely plays a role that citizen science projects in the fields of environmental protection and nature conservation mainly attract individuals that already have a positive attitude towards these fields in the first place, so no further increase can be detected during the course of a citizen science project (Forrester et al., 2017).

The educational goals pursued within citizen science projects strongly overlap with those of traditional education programs both in formal and informal settings. For example, science education aims at teaching scientific knowledge and skills, while environmental education incorporates goals like raising the participant's awareness for environmental problems and fostering eco-friendly values and behaviours (Wals et al., 2014). The element that distinguishes citizen science from mere educational approaches is that it additionally adds the element of generating new scientific knowledge.

Third, in addition to the scientific knowledge generation and the possibilities it offers for individual learning, citizen science also holds significant potential for civic participation and thereby outcomes at a systemic level, i.e. at the level of institutions, organizations and the society. On the one hand, citizen science can democratize the processes of agenda setting and knowledge generation in research by including the perspectives of citizens, thereby making science more societally relevant (Bela et al., 2016). On the other hand, citizen science can empower members of the public to get involved in policy-relevant processes and to gain the knowledge that is needed to do so, thereby fostering deliberative decision-making in societally relevant processes (Ballard et al., 2017; Jordan et al., 2012).

As such, the potential of citizen science to empower citizens at a systemic level is highly linked to the opportunities it creates for individual learning, which fosters competent citizens who are able to make informed decisions (Bela et al., 2016). These goals are also embedded in the concept of education for sustainable development (ESD; de Haan, 2010). Building such problem-solving capacities within communities is especially important with respect to societal issues that are highly relevant, and at the same time markedly complex and ambiguous, concerning multiple stakeholders with potentially conflicting perspectives as it is often the case with environmental and conservation issues ('wicked problems'; Dillon et al., 2016). The timeliness of facilitating civic participation in research and policy is also highlighted by the fact that in recent years the objective to do so has entered political agendas (Federal Ministry of Science 2016; Owen et al., 2012; Rodríguez et al., 2013; Thorn, 2015). However, in contrast to project learning outcomes at the individual level, transformative effects at a systemic level of enabling civic participation (for example, a change in routines and norms of conducting research) is difficult to measure, and researchers have only recently begun to explore possible ways to do so for citizen science programmes (Bela et al., 2016; Jordan et al., 2012).

It is a unique feature of citizen science that it provides opportunities to align scientific inquiry with creating opportunities for learning about science and environmental issues and getting involved in societally relevant processes. While the goal to generate new knowledge is inherent to citizen science (as otherwise it would not qualify as science), educational goals and the goal to empower citizens are also key aims of many citizen science projects. The relative importance of these three goals within citizen science projects has, however, not yet been investigated systematically.

People that have a managing or coordinating function in citizen science projects play a key role in shaping this rapidly expanding field and realizing its potential for science, education and social transformation. Therefore, in this study we asked: (i) What relative importance do managers of citizen science projects attribute to the goal of creating new knowledge versus educational goals versus the goal to enable civic participation? (ii) How are these goals reflected within the structure of citizen science projects? Furthermore, we wanted to assess the potential of citizen science to become more broadly implemented. To this end, we investigated: (iii) What are the challenges and needs that arise during existing citizen science projects? (iv) What are barriers to and needs for the establishment of future projects and the involvement of institutions and organisations that are currently not engaged in citizen science?

To answer these questions, we conducted a quantitative web-based survey among 143 experts from environmental education, science, and nature conservation. Based on our analyses, we explored fields of activity to overcome the identified challenges to fully harness the potential of environmental citizen science for generating knowledge, creating learning opportunities and enabling civic participation in environmental protection and conservation.

2. Material and methods

To systematically investigate the realized and unrealized innovation potential of citizen science, we conducted a web-based survey across Germany, Austria and Switzerland. We invited experts focusing on environmental topics (e.g., conservation or sustainable development), working in educational, scientific, administrative or management sectors. Experience in managing a citizen science project was not a prerequisite for participation, so we could also survey the potential for future citizen science projects coordinated by organisations currently not engaged in citizen science.

2.1. Online survey

The web-based questionnaire was composed of 44 questions in total, out of which 25 were analysed for this paper. The remaining questions referred to aspects outside the scope of this paper and were hence not included in the analyses presented here. The analysed questions were composed of a mixture of different question types, with the multiple choice and matrix type being most common (see Appendix). The questionnaire included a branching logic, i.e. respondents were directed to subsections of the questionnaire depending on their self-reported experience with the management of a citizen science project. Before, they were introduced to our criteria for citizen science projects, which were as follows: (1) The project involves volunteers which actively contribute to the generation of new knowledge. The term 'volunteer' comprises everybody making this contribution outside the scope of their profession. This includes school children in classroom settings as well as participants in non-formal education settings. Often the citizen scientists collaborate with researchers affiliated with scientific institutions. (2) The knowledge generated within the project is new in the sense that it is previously unknown (in general, not only to the project participants), the research process is open with respect to findings, and the results are of interest to others, for example stakeholders in science, nature conservation practice, museums, planning and management, policy and politics, or to society. Depending on their experience with managing a citizen science project, the respective respondent groups are named hereafter 'CS managers' (respondents that had held a managing function within a citizen science project, including educators that had managed the participation of a group of learners at a citizen science project) and 'CS novices' (respondents that had never held an organisational function within a citizen science project).

Two questions were directly related to the three areas of potential impact of citizen science, i.e. knowledge generation, learning, and civic participation. Given that research in science and environmental education has shown that it is important to differentiate between different aspects of learning (Wells and Lekies, 2012), we disentangled different potential learning goals in the questionnaire to allow for an in-depth analysis of learning aspects within citizen science.

Recruitment of survey respondents was conducted online through e-mail invitation as well as through announcements in e-mail newsletters, in social media and on websites, circulated in Germany, Austria, and Switzerland in German language. Announcements were also widely communicated via two national citizen science platforms, 'Citizens Create Knowledge' (GEWISS) (buergerschaffenwissen.de; Germany) and 'Österreich forscht' (citizen-science.at; Austria), via the 'Association for Environmental Education' (Arbeitsgemeinschaft Natur- und Umweltbildung, ANU, Germany) and the science communication platform 'Science et Cité' (science-et-cite.ch, Switzerland). Finally, we asked > 140 organizations and institutions for support in distributing the invitation to the survey. These institutions were from sectors such as environmental protection or conservation practice, environmental or science education, education for sustainable development, or education in general, and science and environmental communication (for example non-governmental organizations or professional associations of teachers and of environmental experts). The survey was open for 6 weeks, and we used the software Survey Monkey (SurveyMonkey Inc., Palo Alto, California, USA).

2.2. Data processing and analyses

A total of 260 visitors to the survey website were registered. During data processing, we excluded all cases in which the respondents (1) had not answered the questionnaire at all or with < 50% completion or (2) had indicated a background which was not related to the environment in the widest sense (for example, history or linguistics). This left us with 143 cases for analysis. Out of these, 51 respondents indicated that they were experienced with managing a citizen science project. However, we reclassified 13 out of these as CS novices because their projects did not meet our criteria for citizen science (see above). This left us with 38 cases of CS managers (for a short characterisation of the respective projects see Appendix) and 105 cases of CS novices for analysis. As respondents could leave out non-mandatory questions, the sample size for individual questions varied (see indication of sample size in figures). In some cases where we had used the question type 'matrix' (a list with scores for each line ranging on a scale from e.g. '1-not important' to '6-very important'), some respondents left out lines while giving high values to the other lines, and in that case we assumed the lowest value (e.g., '1').

To examine differences in the importance CS managers attributed to different goals which they pursue within their projects, we ran a linear mixed effects model, assuming a normal error distribution and using the package 'lme4' (Bates et al. 2012) in R version 3.0.1 (R Core Team 2013). We fitted the model with 'score' (the score ranging from 1 to 6 attributed to the different goals) as response variable and the factor 'goal' (ten levels) as fixed variable, and included the survey respondent-ID as random factor. An overall difference between the goals was tested by comparing the model against the respective null model using ANOVA and maximum likelihood. We then performed a post-hoc analysis on the model using the 'multcomp' package (Hothorn et al., 2008) to obtain pairwise contrasts between all different goals calculated with Tukey tests (p values adjusted for multiple comparisons). Since several goals within our survey were related to different aspects of learning, in a second step we aggregated these learning goals and repeated the analysis to test for differences between the general overarching areas of knowledge generation, learning, and civic participation.

We then tested differences between scores attributed by CS managers to the added value of the citizen science approach in reaching these goals, different factors of success within their projects, and different challenges associated with their projects. For CS novices we tested for difference in scores attributed to different barriers potentially preventing them from integrating citizen science into their work. We aggregated categories to 'extrinsic barriers' (i.e., circumstances that could potentially be influenced by external policies or structures to support citizen science), 'internal barriers' (i.e., circumstances related to the respondent's personality or work environment), and 'attitude towards the citizen science approach' (i.e., expressions of doubt about citizen science in general).

Finally, for investigating differences between the scores attributed by survey respondents to requirements to strengthen their current citizen science work (CS managers), or to start a new citizen science project (CS novices), respectively, we fitted a linear mixed effects model with the factor 'score' as response variable and the factors 'requirement' and 'CS experience' as explanatory variables, and we included the interaction between these two factors. Again, the survey respondent-ID was used as random factor. We then compared models with and without the interaction and obtained pairwise comparisons of different factor-level combinations as described above.

Subsequently, we proceeded analogously to examine differences in the scores attributed by survey respondents to preferred characteristics of supporting funding opportunities for citizen science projects. Given that neither the interaction 'characteristics × CS experience', nor the factor 'CS experience' were significant, we applied the post-hoc analysis to the model containing only the significant factor 'characteristics'. All models were checked visually for normality of residuals and homoscedasticity and met these assumptions.

3. Results

3.1. Characterisation of survey respondents

Overall, we analysed the answers of 143 survey respondents from Germany (57% of all respondents), Switzerland (29%) and Austria (15%; all percentages rounded, also in the following), who were affiliated with a diverse range of institutions and organisations, namely scientific institutions (e.g., universities or research centres; 30%), non-governmental organizations (20%), governmental administrative offices (10%), schools (8%), business companies (8%), administrative offices of nature-protected areas (7%), public science education institutions such as museums, zoos, or botanical gardens (6%), student labs for teenagers (4%) and other organizations (8%). While some professional association with issues related to the environment, nature or sustainability was a prerequisite for taking part in the survey, 80% of survey respondents indicated that a thematic focus of their current professional work was on ecology and conservation and/or on environmental protection. The other options were selected as follows (multiple answers were possible): 57% biology in general, 56% social and cultural aspects of sustainability, 48% civic participation, 37% offering entertainment during leisure time, 28% economy, 27% technology and physics, 24% chemistry, 24% others (for example, climate change).

Out of the 38 survey respondents that were managing a citizen science project which met our criteria (see above), seven indicated that they had not been aware of or only vaguely familiar with the term 'citizen science' before taking part in the survey, and had therefore not used this term before to classify their work. Out of the 105 survey respondents without experience in citizen science, 45% indicated that they were familiar with the term 'citizen science', while 31% indicated that they had not heard the term before and 25% indicated that they had heard the term before but without knowing its exact meaning.

3.2. Potentials perceived by citizen science managers

3.2.1. Project goals and the added value of citizen science

Overall, CS managers attributed significantly different importance to different goals pursued with their projects (Chisq = 72.862, $p < 0.001$; $N = 38$ for all goals; for sample sizes of individual goals see Fig. 2A). Posthoc tests revealed that the most important goals were to generate new knowledge, as well as a gain of knowledge, specific skills or a positive attitude towards nature conservation by project participants, which all reached a mean score of importance above 4.7 (out of 6). The goal to enable civic participation reached a mean score of 3.51 ± 0.29SE. This was significantly lower than the mean score of the abovementioned goals, and similar to the goals that the project participants should develop eco-friendly behaviour, gain scientific literacy and an understanding of environmental politics, and be motivated for a career choice in science or environmental protection. When the different aspects of learning were aggregated to a single factor level, there was an overall difference between the goals of knowledge generation, learning and civic participation (Chisq = 19.3, $p < 0.001$, N = 38 for all). A posthoc test revealed that the goal to create possibilities for learning scored significantly lower than the goal to generate new knowledge, but significantly higher than the goal to enable civic participation (Fig. 2A).

With regard to the added value of the citizen science approach for reaching different project goals, there was an overall difference in the mean scores attributed to the different goals (Chisq = 68.34, $p < 0.001$, N = 38 for all goals). The CS managers felt that the citizen science approach was most beneficial for reaching the goals of generating new knowledge, and that the project participants should gain specific skills, followed by a gain in knowledge in project participants and the development of eco-friendly attitudes and behaviours as well as scientific literacy. When different learning aspects were aggregated, there was an overall difference between the three areas of knowledge generation, learning, and civic participation (Chisq = 24.53, p < 0.001, $N = 35$ for all goals), and the post-hoc analysis revealed that the goal to generate new knowledge scored significantly higher than the other two goals, which were similar to each other (Fig. 2B).

3.2.2. Successes and challenges within existing citizen science projects

Different factors of success for citizen science projects overall were attributed different scores (Chisq = 35.92, p < 0.001, N = 35 for all factors). The most important factor of success was intensive communication with participants (5.15 ± 0.21SE), followed by science experts within the project management team (4.83 ± 0.26SE), the enthusiasm of the participants, sufficient staff resources and collaborations with other institutions. Professional public relation work (3.62 ± 0.26SE) and the use of modern technologies (3.59 ± 0.36SE) scored lowest (Fig. 2C).

With respect to different challenges faced by CS managers, there was an overall difference between the scores attributed to the different challenges (Chisq = 106.94, p < 0.001, $N = 33$ for all challenges). Aspects regarding the shortage of financial and staff resources ranged among the most important challenges, with temporary instead of long-term funding scoring highest (3.62 ± 0.38SE). Interestingly, also recognition of citizen science by the professional scientific community was rated relatively high (2.91 ± 0.39 SE). Unexpected scientific findings and lack of access to the scientific literature scored lowest and were not perceived as major challenges (1.64 ± 0.22SE and 1.32 ± 0.22SE, respectively, Fig. 2D).

3.3. Characteristics of existing citizen science projects

3.3.1. Participation of different actors

The majority (90%) involved the citizens in data collection ($N = 30$ projects). In contrast, participation during other phases of the scientific research process was much less pronounced. Only 42% of the projects involved citizens in sample analysis, and in all other phases of the research process citizens were involved in < 40% of projects. In only 10% of projects citizens took part in defining the research question, and while in 26% they were involved in non-scientific publications, they were part of scientific publications in only a single case (< 3%). In 23% of the projects citizens were involved in implementing the research results with respect to a practical problem. For 32% of projects, however, survey respondents indicated that implementation of results was not an integrative part of the project (Fig.3).

During every stage of the research process, project coordinators were involved in at least 35% of the projects. Fundraising, logistical planning, data interpretation, and publication in non-scientific media involved coordinators in > 60% of the cases. Similarly, for all phases of the research process, scientists were involved in at least 30% of the projects, with a main focus in data analysis (71%) followed by data interpretation (58%; Fig. 3).

3.3.2. Publication of results

The knowledge generated within the citizen science projects was often published on websites (80%), in newspapers (77%) or reports (77%). However, while non-scientific publications were part of most projects, publications of results in scientific journals were indicated by 50% of the respondents as not a part of the project. In 27% of projects publication of a scientific paper was planned, and in 23% of projects this had already been realized (Fig. A1, $N = 30$ projects).

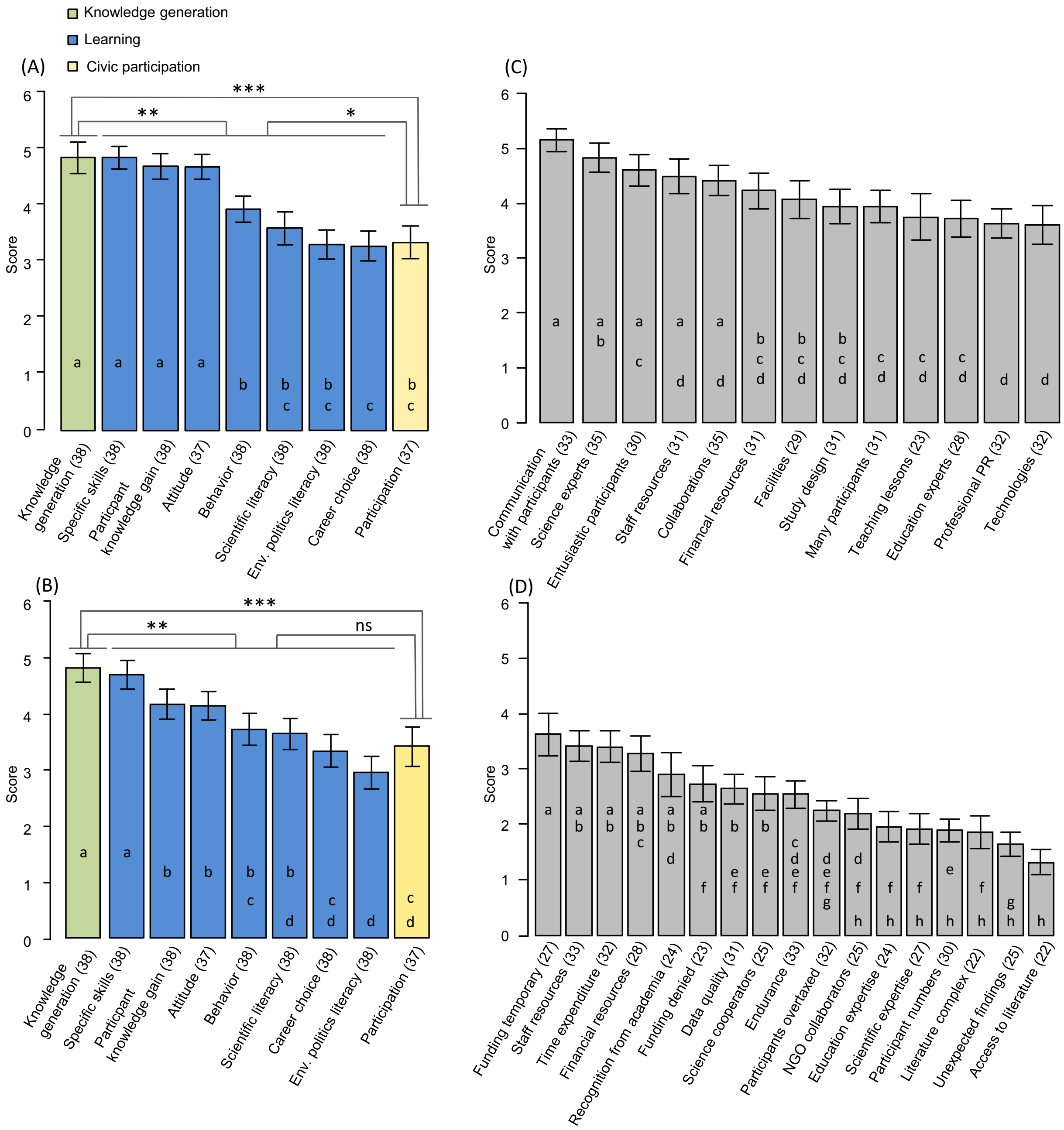

Fig. 2. A–D. Importance (mean ± SE score on a scale from 1 to 6) attributed by managers of citizen science projects (CS managers) to (A) different goals pursued within CS projects, (B) the added value of the CS approach in reaching these goals, (C) factors of success within CS projects, and (D) challenges within CS projects. Results from post-hoc pairwise comparisons exercised on linear mixed effects model are indicated. Within bars, different letters display significant ($p < 0.05$) differences between the single categories, and in (A) and (B) differences between aggregated overarching groups of categories are indicated above bars. Numbers within brackets indicate sample sizes. In (A) and (B) bars represent different goals, and colours differentiate between the three different overarching groups of goals: generating new knowledge (green), creating opportunities for learning (blue), and enabling civic participation in societally or policy-relevant processes (yellow). The specific learning goals (blue) are as follows: project participants should gain specific skills, knowledge, an eco-friendly attitude, eco-friendly behaviour, scientific literacy, an understanding of environmental politics, and interest in a career in science or environmental protection. In (C), bars represent different factors of success: intensive communication with participants, science experts within project team, enthusiasm of participants, sufficient staff resources, collaborations with experts outside own organisation, sufficient financial resources, adequate facilities, simple study design, high participant numbers, additional teaching lessons, experts for education/didactics within project team, professional public relations work, use of technologies. In (D), bars represent different challenges: funding temporary, insufficient staff resources, high time expenditure, generally insufficient financial resources, low recognition by scientific community, funding denied, low data quality, low interest within scientific community to cooperate, participants have low endurance, tasks overtax participants, low interest within NGOs to cooperate, missing education/didactics expertise within project team, missing scientific expertise within project team, low participant numbers, scientific literature too complex, unexpected findings, no access to scientific literature. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

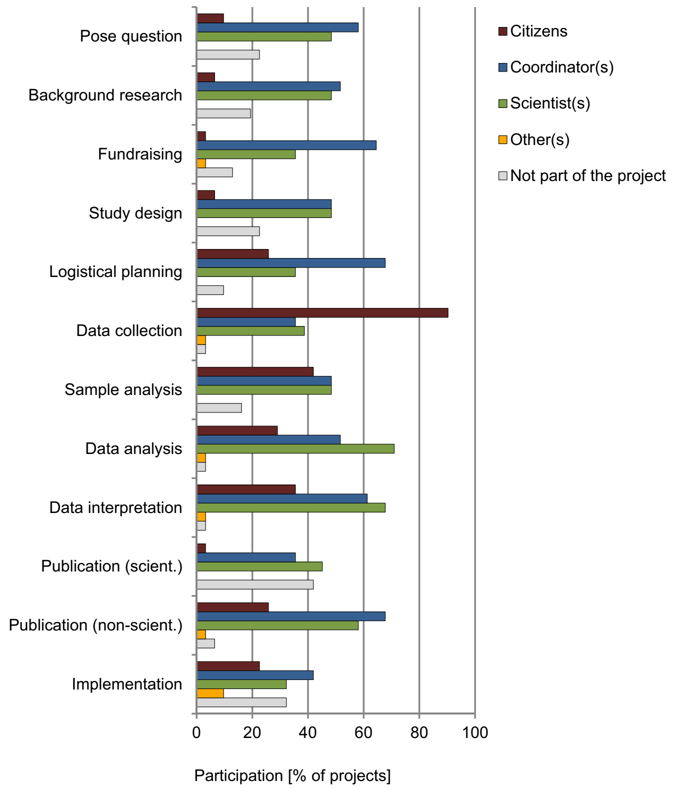

Fig. 3. Involvement of different actors in the different steps of the research process within citizen science projects ($N = 31$ projects). Note that multiple answers were possible (hence bars do not sum up to 100%). *Abbreviations:* scient., within scientific journals; non-scient., within non-scientific media.

3.3.3. Collaborations

The majority of CS managers (97%; $N = 31$) collaborated with at least one other institution. On average, CS managers collaborated with four partners out of nine possibilities open for option, which were schools, students' labs (for teenagers), scientific institutions, museums/zoos/botanical gardens, nature protected areas, NGOs, governmental institutions, business companies, and others. A statistical analysis of the most common combinations of collaborators was not meaningful due to the high diversity of possible combinations.

3.3.4. Evaluation of citizen science learning outcomes

The majority of CS managers (92%) used informal feedback for assessing the learning outcomes of their citizen science projects, and for half of CS managers (49%) their own personal assessment was important for evaluating the success of their project. Half of the project managers (51%) applied more elaborated forms of evaluation, namely a systematic personal assessment on the basis of defined criteria (16%), an evaluation of project participants with a simple survey (19%), or an evaluation of project participants with a before-after survey (16%; $N = 37$ for all evaluation forms, multiple answers possible, Fig. A2).

3.4. Opportunities for citizen science perceived by citizen science novices

3.4.1. Attitude towards the citizen science approach

CS novices were generally very interested in citizen science. For the potential of integrating citizen science approaches into different education formats, they attributed high scores to three different possibilities, namely a mean score of 5.22 ± 0.11 SE to 'extracurricular education programs with children', a mean score of 5.16 ± 0.10 SE to 'extracurricular education programs with adults', and a mean score of 5.17 ± 0.12 SE to 'formal education at schools'. When asked if they would like to integrate the citizen science approach into their own work in the future, they attributed a mean score of 4.89 ± 0.15 SE. All these four mean scores were similar to each other (Chisq = 7.27, $p = 0.06$, $N = 87$ for all formats incl. own work, Fig. A3).

3.4.2. Barriers to engaging in citizen science

CS novices attributed different importance to different barriers for getting involved in citizen science (Chisq = 421.47, $p < 0.001$, $N = 76$ for all barriers). The highest scores were given to three external factors, namely shortage of financial and staff resources and time constraints. These were followed by insecurity about how to find collaborators, a lack of personal autonomy within the own work setting, and doubts about the target group's discipline (e.g., sustained and high quality engagement in citizen science activities). When factors were aggregated to three overarching groups of barriers, namely 'extrinsic barriers', 'intrinsic barriers or personal factors', and 'attitude towards citizen science approach', the analysis revealed an overall difference (Chisq = 282.73, p < 0.001, N = 76 for all barriers), and the posthoc-analysis showed that 'external barriers' scored significantly higher than

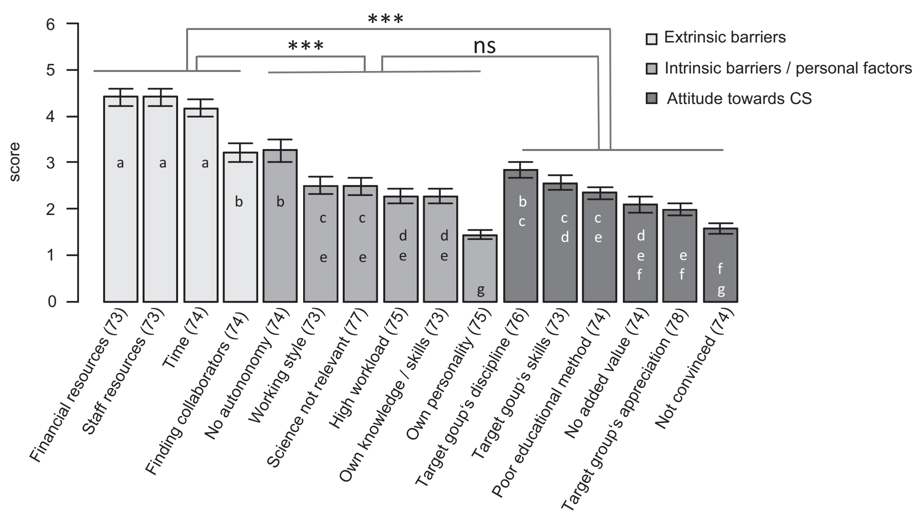

Fig. 4. Importance attributed by survey respondents without previous citizen science (CS) experience (CS novices) to different barriers potentially preventing them from starting a CS project (mean ± SE score on a scale from 1 to 6). Bars represent different barriers; shading differentiates between different overarching groups of barriers. Results from post-hoc pairwise comparisons exercised on linear mixed effects model are indicated. Within bars, different letters display significant ($p < 0.05$) differences between the single barriers, and differences between aggregated overarching groups of barriers are indicated above bars. Reasons related to extrinsic structures and policies (light grey): lack of financial resources, lack of staff resources, lack of time, lack of knowledge how to find collaborators. Reasons related to intrinsic structures or personal factors (medium grey): no autonomy for starting a citizen science project, CS approach does not fit own working style, scientific research is no relevant topic for my work, shying away from high workload associated with managing a CS project, lack of knowledge or skills to manage a CS project, CS approach does not match with own personality. Reasons related to the respondent's attitude towards the CS approach (dark grey): Doubts about target group's discipline, doubts about target group's skills, CS not considered as a suitable approach to reach educational goals, doubts about added value of CS for own work, doubts about target group's appreciation, not convinced by CS in general. Abbreviation: CS, citizen science.

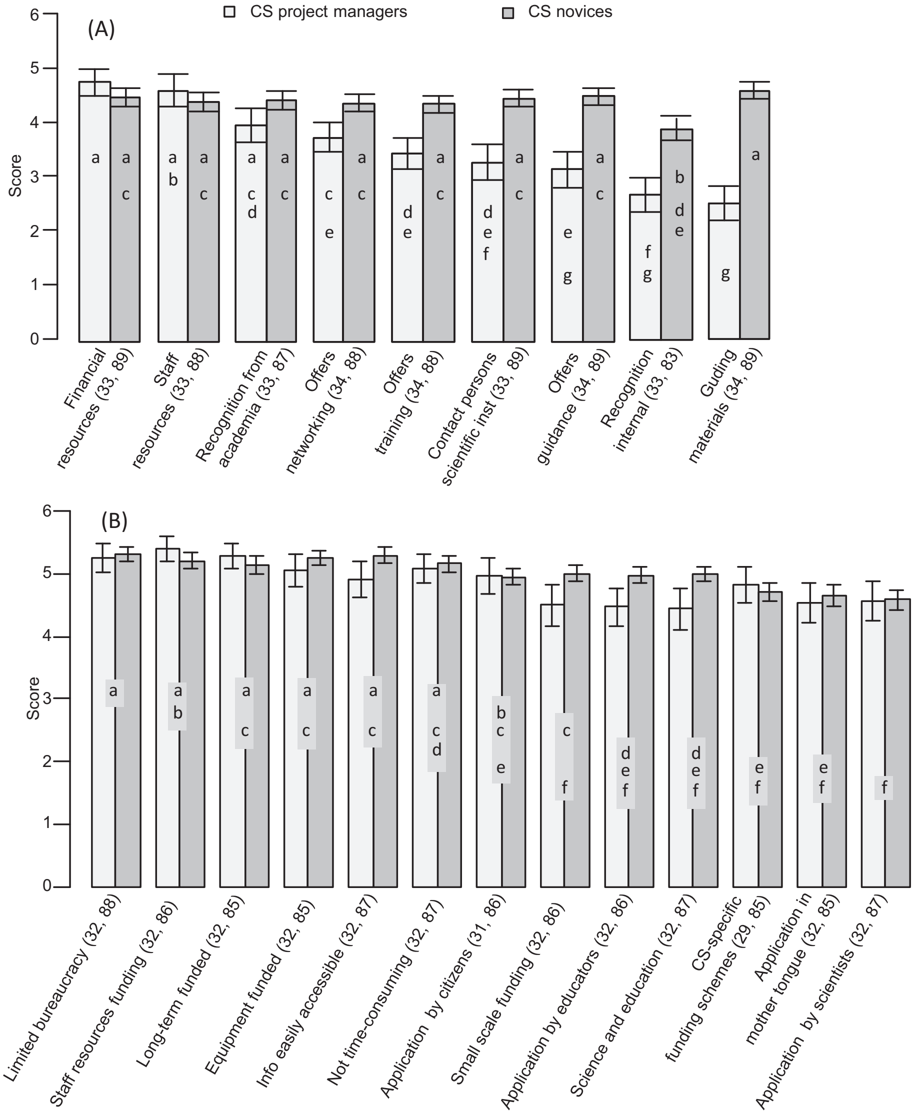

Fig. 5. Importance attributed by survey respondents (mean ± SE score on a scale from 1 to 6) to (a) requirements to strengthen their CS work (CS project managers, light grey), respectively conditions that would motivate them to start a CS project (CS novices, dark grey): more financial resources, more staff resources, recognition from scientific community for CS, offers for networking within CS community, offers for training in CS, contact persons for CS at scientific institutions, offers for guidance (counselling) for CS project managers, recognition within own organisation for CS, guiding materials (e.g., manual for CS). And (b) desired characteristics of funding possibilities for citizen science: limited bureaucracy, staff resources can be funded, long-term funding warranted, costs for equipment can be funded, information on funding possibilities easily accessible, application not too time-consuming, citizens can apply, application for small amounts of funding possible, educators can apply, criteria for funding incorporate both scientific and educational aspects, citizen science-specific funding schemes available, application possible in German language, scientists can apply. Results from post-hoc pairwise comparisons exercised on linear mixed effects model are indicated, with different letters displaying significant ($p < 0.05$) differences and numbers within brackets indicating sample sizes (CS managers, CS novices). In (b), there was no significant difference between survey respondents with and without citizen science experience, therefore post-hoc results from a model containing only the factor "requirement" are shown. Abbreviation: CS, citizen science.

the other two groups, which were similar to each other (Fig. 4).

3.5. Needs in order to strengthen citizen science

The requirements expressed by CS managers to strengthen their current work differed from the requirements expressed by CS novices that would motivate them to engage in a citizen science project. This was indicated by a significant interaction 'requirement × citizen science experience' with regard to the score attributed to different requirements (Chisq = 66.88, $p < 0.001$, $N = 34$ CS managers, 89 CS novices for all requirements). CS novices attributed equally high scores (mean > 4.38) to all requirements except for 'more recognition for citizen science inside own organization', which scored lower (3.88 ± 0.20). In contrast, CS managers attributed high scores to financial and staff resources as well as to measures of recognition for citizen science from the professional scientific community, but relatively lower scores to overarching structures for support and guidance. Nevertheless, with regard to the latter, offers for networking, training, and guidance as well as contact persons at scientific institutions still scored above 3. The factor 'recognition within own organization' scored relatively low in CS managers (Fig. 5A).

3.5.1. Needs with regard to funding

The scores attributed to different characteristics for funding instruments in order to strengthen citizen science were generally high, with the lowest score being 4.44 ± 0.32 for 'requirements for funding should take into account both scientific and educational aspects' given by CS managers. There was no significant interaction 'characteristics × citizen science experience' (Chisq = 16.26, $p = 0.18$, $N = 32$ CS managers, 88 CS novices for all characteristics), i.e., the answers of survey respondents with and without previous experience in citizen science were similar. There was an overall difference in the importance survey respondents attributed to different characteristic for funding instruments open for option (Chisq = 70.55, $p < 0.001$, N = 32 CS managers, 88 CS novices for all characteristics). As most important, the respondents indicated that the funding process should not be too bureaucratic and time-consuming, that information on funding possibilities should be easily accessible, and that funding needs to include long-term options and cover both staff resources and equipment. Interestingly, other factors rated as important were options for small-scale funding and possibilities for citizens, educators and scientists to apply for funding (Fig. 5B).

4. Discussion

4.1. Current realization of the threefold potential of citizen science

Our analysis of the answers given by managers of environmental citizen science projects shows that they perceive all three potential components of their work as important, (i) generating new knowledge as a key outcome for scientific advancement, (ii) creating learning opportunities for members of the public and (iii) enabling civic participation in scientific research as a societal process. Also, they feel that adopting the citizen science approach is of added value for achieving these goals. Viewed in relation, however, knowledge generation and specific learning aspects were considered of greater importance by the respondents than enhancing civic participation.

Generating new scientific knowledge is the key element that differentiates citizen science from mere educational formats (Robinson et al., 2018). Nevertheless, survey respondents most often reported to make the results of their research public via grey literature or informal online media only (e.g. reports, blogs, newspapers), which is congruent with recent findings from other studies (Burgess et al., 2017; Kullenberg and Kasperowski, 2016; Theobald et al., 2015, but see Chandler et al., 2017). Although knowledge published in grey literature may reach relevant local stakeholders, a lack of scientific publication precludes citizen science from really fulfilling the goal of advancing science as well as gaining grounds in more traditionally oriented research organisations.

One potential barrier to scientific publishing could be insufficient access to scientific literature; however this was seen only as a minor problem by survey respondents. Instead, four other possible reasons for the lack of scientific publications emerge from our analysis. First, managers of citizen science projects may lack the intent to publish in peer-reviewed journals in the first place, as this was often stated to be not an explicit part of the project. Second, there might not be enough capacities in terms of staff and time for producing scientific papers, as these factors were rated as most challenging by citizen science managers, together with a lack of sufficient funding, especially on the long term, which is at the basis of staff and time scarcities. This assumption is also supported by a meta-analysis that found that citizen science projects that received financial support over a longer time period had a higher output of scientific publications (Chandler et al., 2017). Third, a low recognition by the professional science community as experienced by survey respondents may hamper the publication of citizen science findings in peer-reviewed journals. Finally, a lack of awareness or skills of citizen science actors may play a role. The latter is contradicted, however, by the fact that many respondents indicated scientific expertise within project teams to be an important factor of success for their citizen science project. On the other hand, a lack of awareness for scientific tools within the citizen science community may also be indicated by the fact that almost one quarter of respondents who had originally stated that they were experienced with managing a citizen science project actually referred to projects which did not fulfil the requirement of genuine research. To fully exploit the potential of citizen science for generating scientific and policy-relevant knowledge (Danielsen et al., 2014; Theobald et al., 2015) and to fulfil the principle of genuine scientific endeavour (Robinson et al., 2018), efforts should be made to promote scientific literacy among all citizen science actors and to improve the dissemination of results in scientific journals.

Creating learning opportunities as a second key element of citizen science was perceived as essential by project managers. The most important learning goals were to foster specific skills and knowledge in citizen science participants, as well as to encourage them to adopt a positive attitude towards the environment. Based on the self-evaluation of project managers, the citizen science approach was beneficial for realizing learning outcomes (as compared to a regular educational program). Interestingly, the added value of citizen science was most pronouncedly perceived with respect to learning of specific skills (like identifying species). This reflects other studies which found that citizen science learning outcomes that go beyond a gain in knowledge and skills, namely the adoption of pro-environmental attitudes and behaviours and an increase in scientific literacy, are much more difficult to be realized (Crall et al., 2013; Jordan et al., 2012; Merenlender et al., 2016). However, there are also hints that these outcomes tend to increase with deeper involvement of citizens in more than one phase of the scientific process (Bonney et al., 2016; Trimble and Berkes, 2013). This calls for participation of citizens throughout the research process, as in our survey citizen science participants were reported to be mainly involved in data collection.

Developing formats that involve participants in the whole scientific process may finally also help to better harness potential synergies between the areas of citizen science and science and environmental education (Bonney et al., 2016; Wals et al., 2014). To date, especially synergies of citizen science and formal education are underexplored, as citizen science activities take place mainly outside of curricular settings and involve mostly adults. Nevertheless, exemplary projects have successfully employed citizen science at schools (e.g., Alexander and Russo, 2010; Ballard et al., 2017; Blackawton et al., 2011; Miczajka et al., 2015; Zárybnická et al., 2017) and in Austria, for example, a whole research programme of the Federal Ministry of Science, Research and Economy was dedicated to involving schools in scientific endeavour (www.sparklingscience.at/en).

While our results fortify the assumption that citizen science can be a beneficial approach to reach specific learning goals, this awaits further empirical proof as it is evident from our survey that systematic evaluation has not gained currency yet among citizen science actors. Reasons might be that citizen science project managers lack the time or the means for evaluation. In order to advance our understanding of citizen science learning outcomes, it will be crucial to build capacities for establishing systematic evaluation as an integrative part of citizen science (Jordan et al., 2012; Kieslinger et al., 2017), and based on coherent evaluation schemes that take into account insights gained from environmental and science education. This will allow for disentangling realized from inferred outcomes (Shirk et al., 2012), and will also facilitate the comparison of results from different citizen science projects (Wells and Lekies, 2012).

Enabling civic participation in societally relevant processes was seen as the least important goal by survey respondents in our study. In line with this, the participation of citizens in the surveyed projects was predominantly realized through data collection. The additional potential of co-creating and co-designing research projects was rarely harnessed. This is unfortunate, because if there are ambitions to democratize science and environmental policy (Dillon et al., 2016), it is essential to enable the public to influence which questions should actually be addressed with scientific inquiry. Also with respect to the management of natural resources and endangered species, projects that are co-created by private stakeholders, scientists and governments hold great potential for changes at a systemic level leading to more sustainable practices in the use of natural resources (Trimble and Berkes, 2013). Finally, societal transformation interacts with individual learning (Bela et al., 2016; Jordan et al., 2016), and to induce learning processes that ultimately empower citizens, a deeper involvement in several project stages is necessary (Bonney et al., 2016; Danielsen et al., 2014).

A major reason for the dominant approach of involving citizens in data collection only (see also Kullenberg and Kasperowski, 2016; Theobald et al., 2015) may be that these projects are easier to design and conduct, and that they allow for engaging a larger number of participants. Also, developing co-created projects may require capacities and experiences that still need to be established within the scientific, educational, and environmental communities (Dillon et al., 2016; Hecker et al., 2018; Shirk et al., 2012; Trimble and Berkes, 2013). At the same time, it will be of utmost importance to tackle structural problems if we want to promote formats with deeper involvement of the public in the scientific process, in particular during the project planning phase. Most importantly, funding programs and their evaluation measures need to be realigned (Kieslinger et al., 2017).

Currently, funding bodies usually request a proposal that already includes a detailed project plan (e.g. EU Horizon 2020: http://ec.europa.eu/research/participants/data/ref/h2020/wp/2016_2017/main/h2020-wp1617-swfs_en.pdf; Sparkling Science, Austria: http://www.sparklingscience.at/en/ausschreibungen.html; Federal Ministry of Education and Research, Germany, https://www.bmbf.de/foerderungen/bekanntmachung-1224.html; Earthwatch, USA: http://earthwatch.org/Research-Funding/Apply-for-Funding). Involving citizens in posing the research question and throughout the whole research process as meaningful participants and partners would require an explicitly funded scoping phase, however. In addition, funding evaluation schemes could also take into consideration to which degree a citizen science project enables civic empowerment, next to assessing its scientific and educational purposes (Jordan et al., 2012; Kieslinger et al., 2017; Rowe and Frewer, 2005). At current, however, to our knowledge there is no evaluation scheme available for measuring the degree of civic empowerment in citizen science projects.

4.2. Structural needs for strengthening and expanding citizen science

Our research reveals that despite being a rapidly emerging field, citizen science has not gained broad recognition in relevant sectors yet, as only one third of citizen science novices were familiar with the term 'citizen science'. Interestingly, even several citizen science managers were not familiar with the term and had not used it before to describe their work. However, our results suggest that the potential for citizen science to be adopted more broadly is very high, as citizen science novices expressed great belief that citizen science can be successfully employed both in curricular and extracurricular settings, and they were interested in doing so in their own work environment. Potential barriers were most strongly related to external, i.e., structural aspects, namely financial and staff resources, which interact with limited time available. As other potential barriers, a lack of capacities or existing networks to find collaborators, a lack of autonomy of respondents to shape work routines within their institutions, and doubts about the necessary discipline of participants to conduct sound scientific research emerged from our survey.

These results highlight the importance of structures facilitating capacity building and networking for citizen science actors. In particular, these seem to be crucial for attracting new environmental and education experts into the field, because especially citizen science novices indicated that they would appreciate offers for training and guidance as well as guiding materials. This underlines the importance of initiatives to develop such structures, for example in the form of guides (e.g., Pettibone et al., 2016; Phillips et al., 2014; Pocock et al., 2014; Tweddle et al., 2012), frameworks from official institutions (Wagenet and Pfeffer, 2007) and online platforms (see http://www.birds.cornell.edu/citscitoolkit/toolkit; www.buergerschaffenwissen.de, www.citizen-science.at), as well as the need to promote their prominence among current and potential future citizen science actors.

A key issue emerging from our survey is communication, in particular between citizen science actors and academia-based scientists. Citizen science managers indicated that recognition from the professional science community is currently poor, but would be important for their work. Citizen science novices indicated that one of the most important barriers to starting their own project would be that they don't know how to find collaborators, and also agreed that contact persons at scientific institutions and offers for networking would be very helpful. Furthermore, collaboration with scientific experts ranged among the most important factors of success in existing citizen science programs as indicated by citizen science managers.

Initiatives for platforms facilitating networking arose in many countries during the last years, for example in Germany (*Bürger schaffen Wissen*), Austria (*Österreich forscht*, *Zentrum für Citizen Science*) and Switzerland (*Schweiz forscht*). Our results highlight the importance of such initiatives, but also the need to make them more broadly recognized. In addition, while existing platforms mainly focus on supporting networking within the citizen science community and with interested members of the public, it might be rewarding to establish people and structures that adopt a catalyst function for the communication with academia-based scientists that not only have the knowledge and skills to support citizen science projects, but are also interested in doing so. Ultimately, this might also promote the publication of citizen science research finding in in peer-reviewed scientific literature, which in turn might feedback to raise the recognition of the professional science community for citizen science. Other efforts to raise the awareness and recognition of academics for citizen science could include the establishment of training how to engage the public in research for students in higher education.

The availability of adequate resources is key for applying citizen science (Chandler et al., 2016; Theobald et al., 2015). Our results clearly show that the demand for well-suited funding schemes that meet the special needs of citizen science practitioners is high. This is also directly related to staff resources, for which survey respondents expressed a high need and which they rated among the most important factors of success for citizen science projects. Furthermore, they indicated that citizen science funding pools should allow for diverse citizen science stakeholder groups to act as applicants (academics, educators, and citizens) and that the application process should not involve too much bureaucracy or be too time-consuming. Furthermore, information on funding possibilities and procedures should be easily available. Long-term funding of different resources (staff, equipment) should be provided, as well as explicit funding of project scoping phases.

Very recently, special funding schemes for citizen science endeavours have been introduced in several countries, for example in Germany (Federal Ministry of Education and Research: https://www.bmbf.de/foerderungen/bekanntmachung-1224.html) and Austria (Sparkling Science and Top Citizen Science: http://www.sparklingscience.at/en/ausschreibungen.html). It will now be interesting to follow-up their impact in order to gain an in-depth understanding of the effectiveness of different funding tools in fostering public participation in scientific research.

4.3. Conclusions

Our results suggest that citizen science can be successfully employed to achieve multiple goals of generating new knowledge, enabling learning at the individual level, and promoting transformation at the societal level. They also, however, reveal areas for improvement and point to necessary efforts both by the citizen science community itself and by policy makers.

First, systematic evaluation indicators need to be developed and applied systematically as an integrative part of citizen science to better understand whether citizen science programs are meeting their goals. Second, capacity for publishing in scientific journals should be enhanced, and awareness for the importance of doing so should be raised. Third, the development of more citizen science formats that involve the public into the whole scientific process could foster innovation at a systemic level. Fourth, funding schemes need to be developed or better aligned with the needs of citizen science practitioners. Fifth, advice, guidance and training offers need to be established as an important prerequisite especially for inspiring future citizen science initiatives. Finally, facilitation of networking and the communication between citizen science actors and the professional scientific community are important. Measures to develop and strengthen necessary capacities and structures may help to fully unleash the threefold potential of this emerging field.

Acknowledgements

We thank all survey respondents for sharing their expertise and time. We thank our collaborators who circulated the invitation to the survey, especially Pia Viviani from the Swiss foundation 'Science et Cité' and Annette Dieckman from the German Association for Environmental Education (ANU). A special thanks goes to Jens Schuhmacher for providing statistical advice. This study was inspired by a dialogue forum on citizen science in January 2015 in Osnabrueck (Germany), hosted by the German Federal Environmental Foundation (Deutsche Bundesstiftung Umwelt, DBU) and organized by the consortium 'Citizens Create Knowledge' (GEWISS) that was funded by the German ministry of education and research (BMBF, grant no 01508444).

Competing interests

The authors declare to have no competing interests.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2018.03.024.

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