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Contributions to publications and management plans from 7 years of citizen science: Use of a novel evaluation tool on Earthwatch-supported projects

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ABSTRACT

The use of citizen science to address global and local environmental challenges will depend on demonstrated evidence that it can lead to meaningful contributions to science, management, and social action. Systematic evaluation of citizen science projects is important yet lacking to date. We developed an evaluation tool and used it to conduct a meta-analysis of 51 Earthwatch projects over a 7-year period, assessing their ability to produce peer-reviewed publications and contribute to management plans and policies. The development and testing of an evaluation tool identified key factors to improve outcomes of citizen science projects, including deliberate design of projects through direct engagement with scientists. In turn, scientists increased their reporting of outcomes when outcomes were being used for program assessment and feedback to participants. Over this period, outcomes for the 51 projects consisted of: 333 peer-reviewed publications and 264 contributions to management plans and policies, with a mean of 1.6 peer-reviewed publications per project per year and 1.3 contributions to management plans per project per year. Across this period, projects averaged 6.5 publications and 5.2 contributions to plans and policies per project (range 0–26 contributions per project). Several other project attributes were found to lead to higher outcomes. We found that the creation of evaluation tools helped hold projects accountable for outcomes and highlighted to project managers and scientists the characteristics of projects that lead to improved outcomes. Elements of this approach could be transferred to other projects, helping to fulfill the potential of citizen science to address global challenges.

1. Introduction

Assessing global change and enacting environmental management plans and policies to address the scope and complexity of change require improved information systems, as well as increases in supporting science and public awareness (Collen et al., 2008; Pereira et al., 2012; Pimm et al., 2014). Engaging the public in scientific endeavor, hereafter referred to as citizen science, is one promising approach to address these global needs (Danielsen et al., 2014; Devictor et al., 2010; Dickinson et al., 2012; Pimm et al., 2014; Schmeller et al., 2008). Understanding where, when and how citizen science can most effectively contribute to increased knowledge generation and influence of management plans will assist in adopting strategic citizen science, and identifying synergistic areas with other complementary approaches (e.g., remote sensing) could be explored.

Citizen science is an umbrella term frequently used to encapsulate many forms of public participation in science, involving the public in various phases of the scientific process (e.g., design, data collection, interpretation of results Haklay, 2015; Shirk et al., 2012). A diversity of citizen science approaches has emerged (e.g., community-based monitoring, volunteer monitoring, crowdsourcing) at local and international levels (Miller-Rushing et al., 2012; Chandler et al., 2012). Citizen science has the potential to generate data and produce knowledge to help understand patterns of environmental change and assess progress towards global conservation goals (Chandler et al., 2016; Devictor et al., 2010; Pimm et al., 2014; Proença et al., 2016; Schmeller et al., 2008), among others. Indeed, citizen-collected data have contributed to regional and even global assessments of biodiversity, habitats, and impacts of global change (Amano et al., 2016; Cooper et al., 2014;

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Devictor et al., 2010; Loss et al., 2015; Parmesan et al., 1999; Pimm et al., 2014; Ries and Oberhauser, 2015; Schmeller et al., 2008), as well as provided input for management (Becker et al., 2005; Danielsen et al., 2005, 2014; Newman et al., 2016).

Nevertheless, large differences exist across citizen-science projects with regard to their ability to deliver on goals such as peer-reviewed publications, contributions to management plans, increasing public knowledge and scientific literacy (Cousins et al., 2009; Schmeller et al., 2008; Shirk et al., 2012). Many projects do not produce contributions to science (Kullenberg and Kasperowski, 2016; Theobald et al., 2015), management plans (Newman et al., 2016), or share their data with global repositories of data such as the Global Biodiversity Information Facility (Chandler et al., 2016).

Several attributes appear to be linked to increased delivery on these goals, which we refer to here as *outcomes* following the logic model (W.K. Kellogg Foundation, 2004) which incorporates a set of input criteria (e.g., citizen science participants and participant hours contributed), to outcomes (e.g., peer-reviewed scientific journal articles, data contributing to an implemented management plan), and impacts (e.g., recovery of an endangered species population). For example, citizen science projects that successfully produce publications tend to have one or more of the following attributes: larger in scale, longevity, affiliated with academic institutions, make data available, and associated with large web-based portals (Burgess et al., 2016; Kullenberg and Kasperowski, 2016; Theobald et al., 2015). Systematic evaluations of citizen-science projects for scientific and management outcomes are important but difficult because citizen science evaluation tools are lacking. In this paper, we report on the development of an evaluation tool and its application to assess scientific and management outcomes across a portfolio of citizen-science projects supported by Earthwatch Institute (hereafter referred to as Earthwatch).

Founded in 1971, Earthwatch is an environmental nonprofit that supports field-based citizen science projects to engage people worldwide in scientific field research and education to promote the understanding and action necessary for a sustainable environment (Chandler et al., 2012). Each year, Earthwatch helps to recruit over 2000 participants to support over 60 place-based citizen science projects in approximately 30 nations. The Earthwatch model consists of citizen scientist field crews of 4 to 12 public participants working directly alongside scientists for 1 to 2 weeks. Typically, several field crews (2 − 10) contribute to each project annually. Earthwatch participants receive training and then assist with data collection while being closely supervised by a scientist or field technicians.

Earthwatch citizen-science projects follow “deliberate project design” (sensu Shirk et al., 2012) that is, “thoughtfully employing a design strategy that will yield specific and measurable project outcomes”. Earthwatch staff work closely with project scientists affiliated with universities or independent organizations to design a participant field experience that provides structured data collection on specific research objectives, clearly articulated research outcomes, and a meaningful, safe, and enjoyable participant experience (Chandler et al., 2012). Each project must pass an external peer-review process, and must produce an annual field report that details progress on research goals. Previous assessment of outcomes from citizen science projects supported by Earthwatch focused on participants and their experience (Barker et al., 2011; Lawrence, 2006; Toomey and Domroese, 2013), data quality (Buesching et al., 2015; Newman et al., 2003), and, volunteer contributions (Brightsmith et al., 2008).

Earthwatch developed an evaluation tool that follows the Measures of Success model developed by Margolius and Salasfky (1998) that seeks to embed monitoring and assessment within an adaptive management cycle framework. We use this tool to evaluate outcomes from 51 Earthwatch projects over a 7-year period for their contributions to peer-reviewed publications, management plans and policies. Also assessed were project-level factors that influence both scientific and management outcomes. Both scientist team affiliation and collaboration have been shown to be important in influencing numbers of outcomes (Balme et al., 2014; Lee and Bozeman, 2007), with projects associated with academics (Dickinson et al., 2012; Burgess et al., 2016; Loss et al., 2015) and larger collaborations producing more publications (but see Theobald et al., 2015). Accordingly, here we test whether projects led by academics and projects that have larger collaborations produce more peer-reviewed publications and contributions to management plans and policies.

The influence of particular project characteristics on outcomes is also tested; namely, whether greater Earthwatch support (i.e., number of volunteers, number of volunteer hours, years of Earthwatch support, and the nature of Earthwatch funding) increases the number of project outcomes. Finally, citizen science projects are often challenged to simultaneously maximize different goals (e.g., educational, scientific, management; Crain et al., 2014; Pocock et al., 2015), which appear to create trade-offs between producing both scientific publications and management action (Habel et al., 2013; Knight et al., 2008; Prendergast et al., 1999). We examine whether these trade-offs exist as a general rule across the 51 citizen science projects assessed in this study.

2. Methods and analysis

2.1. Data collection and evaluation tool development

In 2005, Earthwatch initiated the development of the Measures of Success (MoS) evaluation tool to assess outcomes from its citizen science projects. Demand for a more systematic evaluation tool was both internal (i.e., staff and board) and external (e.g., funders). Design and deployment of the Earthwatch MoS tool followed an established logic model (W.K. Kellogg Foundation, 2004) and adapted for environmental sustainability projects. The highest Earthwatch impact level included maintaining or increasing biodiversity, habitats, ecosystem services, livelihoods, and safeguarding cultural heritage (see Appendix A). The initial set of MoS criteria were tested on 25% of Earthwatch projects. Further improvements were gained by an external review by scientists leading citizen science projects and peers in the field of citizen science. This resulted in a final set of 12 MoS criteria that have been applied across Earthwatch citizen science projects fielding since 2008 (Appendix A).

A review of the 12 MoS criteria scored for each project at the outset of the data analysis revealed inconsistencies in how variables were interpreted by those scoring the projects. Thus, for the purposes of this paper, we restricted our assessment to the two MoS criteria related to peer-reviewed publications (MoS 1.2), and contributions to management plans and policies (MoS 4.1) as they are more direct outcomes derived from the data or project and consistently reported on by principal investigators (PIs).

We initially compiled counts and MoS scores on 62 research projects for the period of 2008–2014. After a first set of analyses, we observed that projects reported few outcomes (both numbers of publications and contributions to management plans) during the first two years. We did not include the first two years of Earthwatch support of a project when testing for the effect of explanatory variables on project outcomes, which eliminated 11 projects because they had only been operating for two years. This allowed for a more consistent analysis across projects which had been operating for different lengths of time and resulted in a total of 51 projects being analyzed.

Field reports submitted by PIs annually were the main source of information used to score each Earthwatch-supported project on their contributions to MoS criteria. Initial scoring challenges included a low field report submission rate (55% in 2008), which improved (to >90% in 2014) with increased understanding by PIs on the use and value of reporting on MoS criteria.

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2.2. Project assessment of peer-reviewed publications and contributions to management plans and policies

To assess the number of peer-reviewed publications that Earthwatch projects produce, we reviewed all annual field reports submitted to Earthwatch, documenting peer-reviewed publications produced by project PIs, co-PIs, and graduate students whose theses were based on Earthwatch support. Scientific publications have been an expected outcome for projects since the organization's founding in 1971. To address potential gaps in publication data, we conducted web searches for peer-reviewed publications using the Google Scholar search engine as our primary resource, augmented with the ISI Web of Science electronic database. Only publications based on Earthwatch support were included in this analysis. We did not include publications that were published after Earthwatch support ended since annual reporting is no longer expected, and lack of reporting could have created a bias. Our informal tracking of post-support publications reveals publications acknowledging Earthwatch support decades after our support had ended. As such, the numbers we report within this analysis represent a conservative proxy for the total number of publications that may stem from our support. For each project, we scored both the actual numbers of publications in peer-reviewed publications, as well as a MoS score using the rubric described in Table 1.

To assess a project's contributions to environmental management plans and policies, we searched all annual field reports for the following keywords: convention, IUCN, treaty, policy, policies, plan, management, protected, and MPA. We scored both the count (i.e., numbers) of contributions to management plans or policies irrespective of their scale or type, and also created a MoS 4.1 score based on kinds of contributions to management plans and policies as described in Table 1.

Differences across citizen science projects were assessed in terms of outcomes (i.e., contributions to publications and management plans) using six explanatory variables. These variables included number of participants (per project-year), number of participant hours (per project-year), project duration (years of support), PI affiliation, project leadership, and source of funding, all described in Table 1. The data for these variables were derived from our Earthwatch project tracking database. Given the increasing response rates in submitting field reports between 2008 and 2014 (noted above), we also included a "year of evaluation" variable (values ranging from 1 to 7) in preliminary analyses to account for this variability in reporting, and assess potential improvement of model goodness of fit.

2.3. Inter-coder reliability and data analysis

Four Earthwatch staff members, each familiar with the project-level information, compiled and drew insights from available project documents. To eliminate bias in coding our observations, we standardized our observations assessments using verbal and written discussion. To test for inter-coder reliability, we identified at least 30 projects and independently coded the different variables. For two variables that appeared to be prone to different interpretations, we also calculated

Table 1
Response and explanatory variables assessed for Earthwatch-supported research projects.

Response variable (impacts)	Type	Units/categories	Definition
Peer-reviewed publications	Counts (continuous)	Number of peer-reviewed publications	Peer-reviewed publications published from projects that are based on and acknowledge Earthwatch support. Source: Annual field reports submitted by scientists, Web of Science and Google Scholar searches.
	MoS 1.2 score	Low = 15	Low (1) = Scientist(s) have published 1–2 articles over the past 3 years in low impact factor (IF ≤ 2) journals
		Medium = 3	Medium (3) = Scientist(s) have published 2–3 articles over the past 3 years in medium impact factor (IF 2–4) journals;
		High=	High (5) = Scientist(s) have published at least 1 article over the past 3 years in a high impact factor (IF ≥ 4) journal AND publish routinely in lower impact factor journals.
Policy impacts	Counts (continuous)	Number of authentic contributions to management plans and policies	High level contributions to management plans, policies, conventions, treaties or creation of protected area. Source: Annual field reports submitted by scientists.
	MoS 4.1 score	Low = 1	Low (1) = Over the past 3 years, the project team contributed data to ecological/cultural resource management plan(s) or policy makers or managers;
		Medium = 3	Medium (3) = Over the past 3 years, the project team contributed to at least 1 policy/management plan that is currently being considered at the state/national level;
		High = 5	High (5) = Over the past 3 years, the project team has contributed to at least 1 policy/management plans that have been adopted or enforced and continue to provide up to date research to policy makers.

Explanatory variable	Type	Units/categories	Definition
Number of participants	Continuous	Number of participants/project per year	The number of people participating on project each year
Number of participant hours	Continuous	Hours/year	The number of field research hours contributed by citizen science participants
PI affiliation	Categorical	-University NGO -University + NGO -Government	Type of institution or organization with which the PI is affiliated.
Project leadership	Categorical	-Single PI -Two collaborating co-PIs - >2 co-PIs or single PI with 2 or more PhD students	Composition of staff leading the research project, includes PIs, co-PIs, and graduate students
Source of funding	Categorical	-Public	Public = Primary source (>80%) of Earthwatch project support is derived from self-paying volunteers (i.e. "Public");
		-Philanthropic	Philanthropic = primary source (>80%) of funding from Earthwatch is derived from third parties including charitable organizations (e.g. Foundations) or corporations;
		-Both	Both = Projects receive significant (at least 20%) Earthwatch support derived from *both* public and philanthropic sources

Krippendorf's alpha using the "kalpha" macro in SPSS for the independently coded project subsamples (Hayes and Krippendorff, 2007). The inter-coder reliability statistics for the MoS score for contributions to management plans before convening to discuss was alpha = 0.74, and after rescoring post convening was alpha = 0.97. The inter-coder reliability statistic for PI affiliation was similarly high post convening (alpha = 0.89).

Varying years of support for each project (1–7 years) resulted in unbalanced samples from which predictor variables were drawn, and did not support assumptions of equal variance of the residuals. A preliminary analysis of our count-based response variables (publications and plans) also revealed over-dispersion issues in each, so we employed a negative binomial regression to correct for that skewing of the data. Our two direct project outcome models are:

Log (Number of peer-reviewed publications) = Intercept + b_1 (Years of support) + b_2 (PI affiliation) + b_3 (Project leadership) + b_4 (Source of funding) + b_5 (Number of participants) + b_6 (Number of participant hours); and,

Log (Number of contributions to management plans and policies) = Intercept + b_1 (Years of support) + b_2 (PI affiliation) + b_3 (Project leadership) + b_4 (Source of funding) + b_5 (Number of participants) + b_6 (Number of participant hours)

We hypothesize that publications are primarily driven by longer periods of support, PIs affiliated with universities, larger research teams (with respect to project leadership), and more diverse sources of funding (which may still provide sufficient support when volunteer recruitment does not reach project targets). We also predict that projects with larger numbers of participants, as well as higher numbers of contributed hours toward research tasks will result in more publications.

To test these same independent variables against our MoS scoring process, and given the ordinal nature of that scoring metric, we assessed those data against the assumptions associated with a proportional odds regression analysis. The variables failed to conform to assumptions of proportional odds, as assessed by a full likelihood ratio test, comparing the fit of the proportional odds model to a model with varying location parameters (Chi-Square = 63.485, df = 44; $p = 0.029$). As such, we employed a multinomial logistic regression model, which provided the most robust assessment available given the constraints of the data. We conducted all statistical analyses using PASW (SPSS) Statistics (Version 18).

3. Results

Across the larger portfolio of 62 projects in our first assessment, the mean number of years of support for an Earthwatch project was 8.8 years (range 1–39 years, median = 7, SE 0.91; Fig. 1). Over 25% of projects were supported for 12 years. Each year, Earthwatch citizen science projects had a mean of 43 participants (range 2–141, SE 1.45, Table 2), who cumulatively contributed a mean of 2234 h per year (range 204–9729, SE 84.01, Table 2) in the field helping with research activities. These 62 projects averaged 5.5 publications (range 0–41 publications per project) and 4.8 contributions to plans and policies per project (range 0–26 contributions per project) throughout this seven-year period.

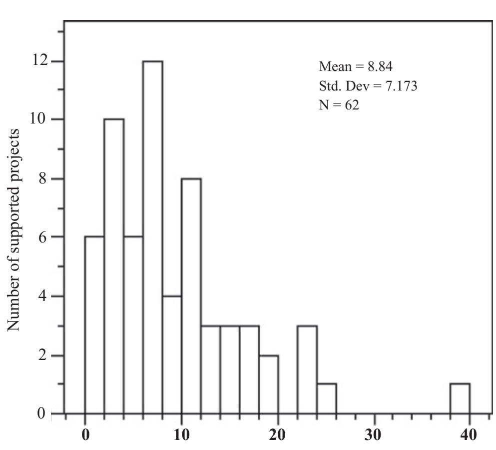

Fig. 1. Number of years of Earthwatch support for the 62 projects included in this paper. First two years of all projects excluded from full analysis (first bin), resulting in a total of 51 projects assessed for factors that influence project impacts.

3.1. Project contributions to peer-reviewed publications and management plans

3.1.1. Contribution to peer-reviewed publications

Citizen science projects supported by Earthwatch published regularly and often in peer-reviewed literature. A mean of 64% of projects published results in peer-reviewed journals each year, with 82% of the 51 projects publishing at least once throughout the 7-year period. These projects generated a mean of 1.6 (SE = 0.15; range 0–16) articles each year in peer-reviewed journals, including contributions to many high impact journal publications (e.g., *Ecology*, *Nature*, *PNAS*, *Conservation Biology*, *Biological Conservation*: Table 2).

We found convincing evidence of a positive relationship between years of support and publication rates (Fig. 2), with "years of support" variable strongly contributing to the overall model of project publication rate (Wald Chi-Square 12.047; df = 2; $p = 0.002$). Projects supported for between 3 and 5 years published about 63% fewer peer-reviewed publications than projects supported for 10 or more years (Exp(B) = 0.356; Wald Chi-Square 11.98; df = 1; $p \leq 0.001$; Fig. 2a. A similar result was found when using the publication MoS score, with year of support significantly contributing to the model (Multinomial logistic regression-Likelihood Ratio Test; Chi-Square = 20.857, $p = 0.002$; Fig. 2b).

This effect of "years of support" was particularly pronounced for the first two years ("Low") of a project's operations, where 31% of projects reported publishing during this period, for a mean publication rate of 0.2 publications/year. This increased to 39% of projects producing at least one publication in their third or fourth year ("Med-Low"), 80% of assessed projects producing at least one publication in years five through nine of support ("Med-High"), and 88% of projects producing at least one publication with ten or more years of support ("High"). Analyses to test for project-level effects on publication rate were performed on data taken from reports at year three of their Earthwatch support, which we considered an "established" project.

PI affiliation also had a significant model effect on contributions to publications (Wald Chi-Square 12.189, df = 3; $p = 0.007$; Fig. 3a), with PIs having an exclusive university affiliation producing 5.7 times the publications produced by government-affiliated scientists (Exp(B) = 4.535; Wald Chi-Square 4.148, df = 1; $p = 0.042$). The strength of the PI affiliation held true for MoS scoring as well, significantly contributing to the model (Multinomial logistic regression-Likelihood Ratio Test; Chi-Square = 50.896, df = 9; $p < 0.001$; Fig. 3b), a difference driven by the low scores associated with government-affiliated researchers.

Both the number of volunteers per year and the number of participant hours per year provided significant support for MoS 1.2 scores (volunteers-Likelihood Ratio Test; Chi-Square = 9.358, df = 3; $p = 0.025$; hours-Likelihood Ratio Test; Chi-Square = 18.265, df = 3; $p < 0.001$), but not in the model of actual counts of publications. The lowest peer-reviewed publication rates (both counts and MoS scores) were for projects that had PIs affiliated with government agencies. No other factor had a significant effect on numbers of publications produced, nor the associated publication MoS scores (Table 3).

Table 2
Metrics from 51 Earthwatch-supported field projects supported between 2008 and 2014.

Measures of success		Total[a]	Total project-years[a]	Average outputs[b]	Range[b]	SE [b]
MoS 1.1	Number of participants	8872	207	42.9	2–141	1.7
	Number of hours contributed	465,830	207	2250.1	204–9729	93.3
MoS 1.2	Number peer-reviewed publications	333	207	1.6	0–16	0.15
MoS 4.1	Management plans/policies informed	264	207	1.3	0–6	0.10

a – across 51 projects supported 2008–2014.
b – per project per year.

3.1.2. Contribution to management plans and policies

The great majority of citizen science projects using the Earthwatch model also made frequent contributions to management plans and/or policies. A mean of 62% of projects made contributions each year to plans (e.g., for Protected Areas/National Parks) and international conventions (e.g., CITES, IUCN Red List, IPCC country reports), with 81% of the 51 projects contributing at least once within the 7-year period. These projects generated a mean of 1.3 (range 0–6; SE = 0.10) contributions to management plans and/or policies each year (Table 2). Common contributions included sharing data with managers and policy makers, performing analyses based on data collected to shape a management plan, and PIs being part of the development and implementation of a management plan or policy.

Assessing project characteristics with respect to contributions to management plans and policies revealed different patterns than with publications. The source of funding provided the sole significant effect within the count-based model (Wald Chi-Square = 12.464, df = 2, $p = 0.002$; Fig. 4c). Projects supported solely by philanthropic funding sources contributed to 38% of the plans and policies of those funded through a combination of public participation in the research and philanthropic resources (Wald Chi-Square = 10.506, df = 1; $p = 0.001$; Fig. 4c), whereas projects supported solely through public participation contributed to just over half of the

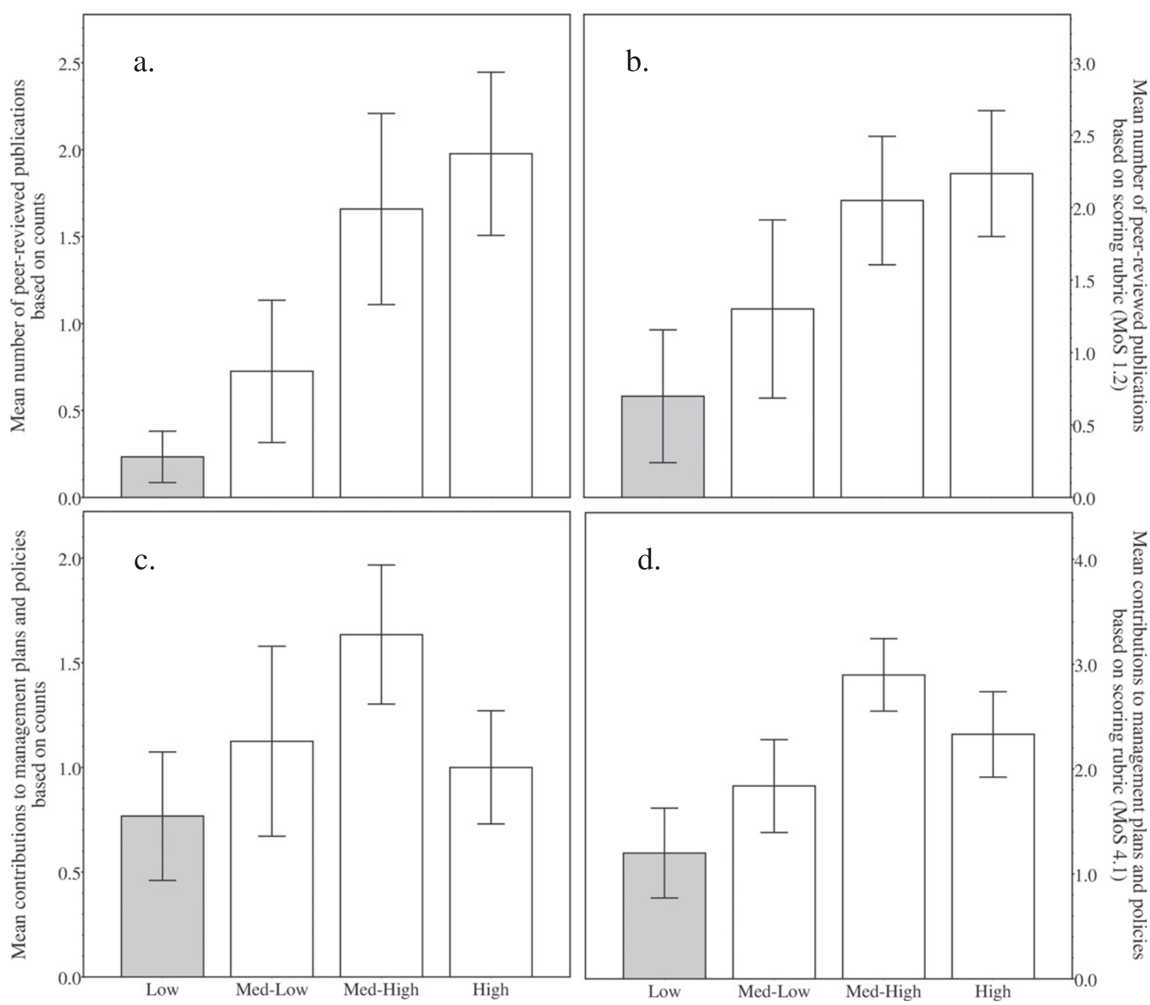

Fig. 2. Mean project impacts by years of support (binned), with significance of contribution to model indicated, a. based on counts of publications (Negative binomial regression-Wald Chi-Square = 12.047; df = 2, $p = 0.002$); b. based on MoS 1.2 scoring rubric (Multinomial regression-likelihood ratio test-Chi-Square 20.857; df = 6, $p = 0.002$); c. based on counts of contributions to management plans and policies (Negative binomial regression - Wald Chi-Square = 4.165; df = 2, $p = 0.125$); d. based on MoS 4.1 scoring rubric (Multinomial regression-likelihood ratio test-Chi-Square 34.778; df = 10, $p < 0.01$). First two years shown for relevance (gray), but excluded from full analysis. n = 51 projects, representing 207 project-years of support. Error bars-95% CI.

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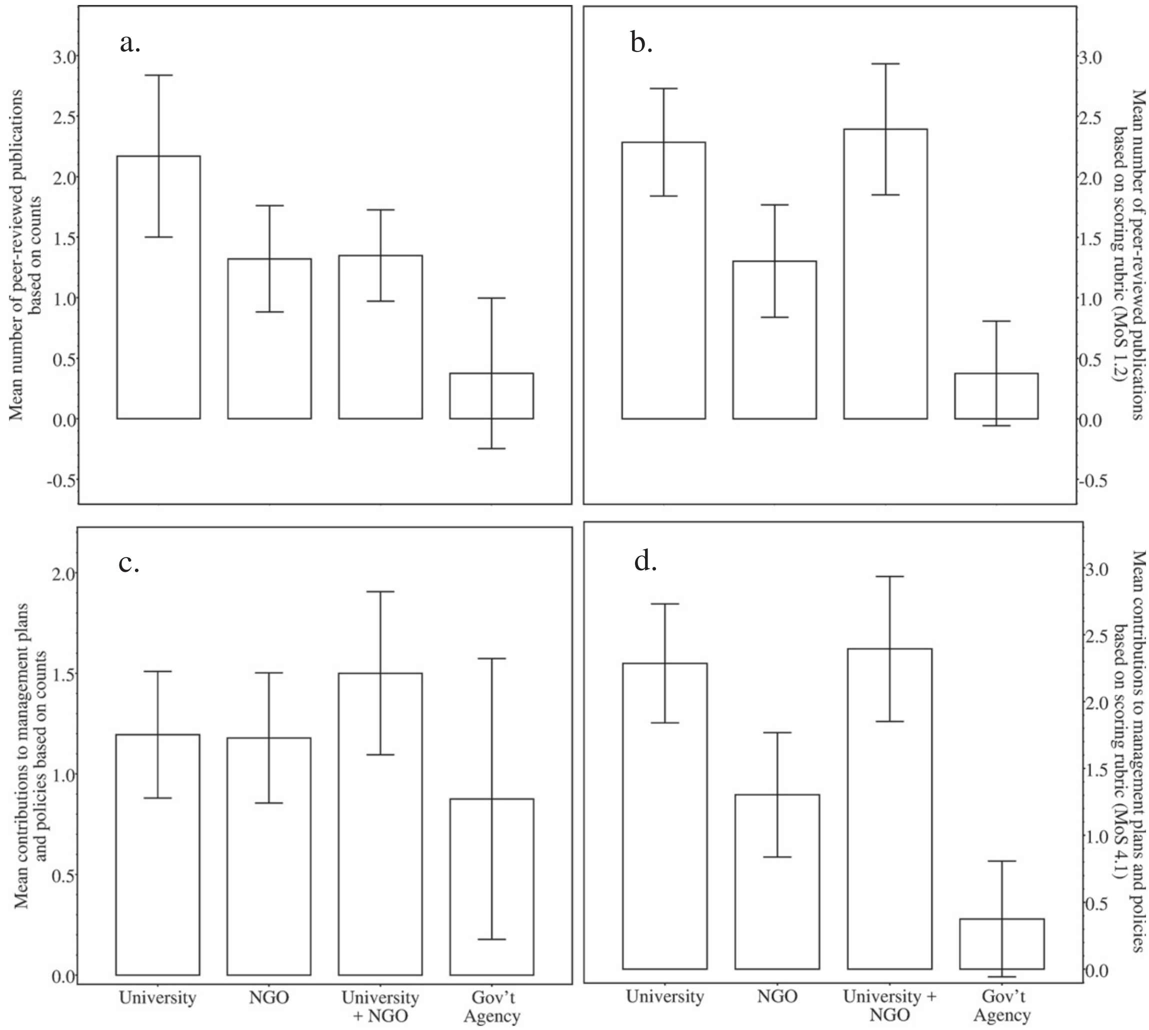

Fig. 3. Mean project impacts by PI affiliation with significance of contribution to model indicated, a. based on counts of publications (Negative binomial regression-Wald Chi-Square = 12.189: df = 3, $p = 0.007$); b. based on MoS 1.2 scoring rubric (Multinomial regression - likelihood ratio test-Chi-Square 50.896; df = 9, $p < 0.001$); c. based on counts of contributions to management plans and policies (Negative binomial regression-Wald Chi-Square = 0.723; df = 3, $p = 0.868$); d. based on MoS 4.1 scoring rubric (Multinomial regression-likelihood ratio test - Chi-Square 37.452; df = 15, $p < 0.001$). n = 51 projects, representing 207 project-years of support. Error bars-95% CI.

Table 3
Means and sample sizes for project attributes across 51 citizen science projects supported by Earthwatch between 2008 and 2014. Statistical differences across means are also included.

			Peer-reviewed publications				Contributions to management plans/policies			
			Count		MoS 1.2 Score		Count		MoS 4.1 score	
Variable category	Predictor variable	Sample size	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Project years-bins[b,d]	Low[a] (1–2 years)	43	0.23	0.07	0.70	0.23	0.77	0.15	1.20	0.21
	Med-low (3–4 years)	40	0.73**	0.20	1.30**	0.30	1.13**	0.22	1.84**	0.22
	Med-high (5–9 years)	82	1.66	0.28	2.05	0.22	1.63**	0.17	2.90**	0.17
	High (>10 years)	85	1.98**	0.24	2.24**	0.22	1.00**	0.14	2.33**	0.20
Project leadership[d]	Single PI	17	0.71	0.21	1.47	0.42	0.76	0.22	1.71	0.42
	PI + Co-PI *or*.PI + PhD student	61	1.89	0.39	1.95	0.27	1.43	0.19	2.37	0.19
	≥3 Co-PIs *or* PI + ≥2 PhD students	129	1.60	0.16	2.06	0.18	1.27	0.13	2.60	0.16
PI affiliation[b,d]	University	77	2.17*	0.34	2.29**	0.22	1.19	0.16	2.33	0.21
	NGO	56	1.32	0.22	1.30*	0.23	1.18	0.16	2.49	0.20
	University + NGO	66	1.35*	0.19	2.39**	0.27	1.50	0.20	2.56	0.22
	Governmental agency	8	0.38	0.26	0.38**	0.18	0.88	0.30	2.63	0.56
Funding source[c]	Public	115	1.76**	0.23	1.97	0.19	1.18**	0.13	2.40	0.16
	Philanthropic	37	1.76**	0.41	2.24	0.37	0.70**	0.17	1.65**	0.26
	Combination	55	1.20**	0.17	1.82	0.26	1.84**	0.20	3.01**	0.23

* Significant difference in means based on negative binomial or multinomial logistic regression test, with $p \le 0.05$; ** with $p \le 0.01$.
a. Means for first two years of support reported here (gray), but excluded from other analyses.
b. Significant contribution to model with counts of publications and MoS 1.2 scores at $p < 0.05$.
c. Significant contribution to model with counts of management plans and MoS 4.1 scores at $p < 0.05$.
d. Significant contribution to model with MoS 4.1 scores at $p < 0.05$.

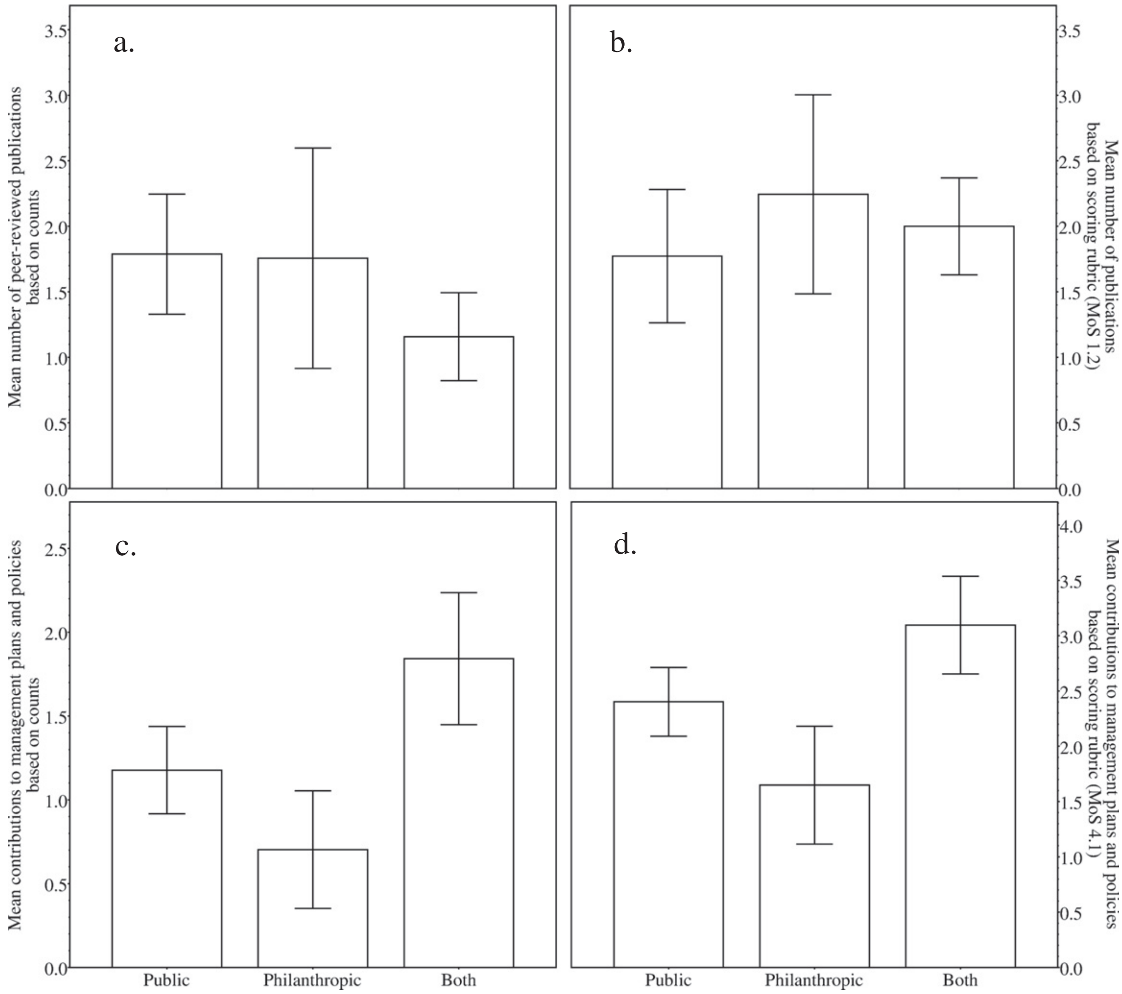

Fig. 4. Mean project impacts based on the source of funding with significance of contribution to model indicated, a. based on counts of publications (Negative binomial regression-Wald Chi-Square = 3.142: df = 2, $p = 0.208$); b. based on MoS 1.2 scoring rubric (Multinomial regression-likelihood ratio test-Chi-Square 10.726; df = 6, $p = 0.097$); c. based on counts of contributions to management plans and policies (Negative binomial regression-Wald Chi-Square = 12.464; df = 2, $p = 0.002$); d. based on MoS 4.1 scoring rubric (Multinomial regression-likelihood ratio test-Chi-Square 23.757; df = 10, $p = 0.008$). n = 51 projects, representing 207 project-years of support. Error bars-95% CI.

plans and policies as the combined funding approach (Wald Chi-Square = 6.760, df = 1, $p = 0.009$; Fig. 4c).

As noted above, the effect of years of support on contributions to management plans was not significant in direct counts (Wald Chi-Square = 4.165, df = 2, $p = 0.125$; Fig. 2c), but was for the associated MoS (4.1) score, driven by differences in project outputs supported for three to four years (Med-low) with those supported between five and nine years (Med-high; Wald Chi-Square = 7.527, df = 1; $p = 0.006$; Fig. 2d). Annual contributions to management plans and policies appeared to peak earlier than publications at 5–9 years ("Med-high") of support for both counts of contributions to plans (mean annual contribution to plans = 1.63, K-W test, $p = 0.008$; Fig. 2c) and the weighted management plans MoS score (mean score = 2.90, K-W test, $p = 0.004$; Fig. 2d).

Although projects were less productive during the first two years supported through Earthwatch, the effect was less pronounced than for publications; 69.2% of projects reported contributing to at least one management plan during the first two years of operation with a mean project contribution rate of 0.77 management plans and policies per year.

There were significant effects of sources of funding support on the contributions to management plans MoS score. Projects funded by a combination of self-paying volunteers and philanthropy contributed significantly higher to management plans based on both mean counts and MoS scores than projects solely funded by philanthropy (Table 3; Fig. 4d; Multinomial logistic regression- Exp(B) = 0.102; Wald Chi-Square 6.840, df = 1; $p = 0.009$). There was a significant but very slight effect when the number of participant hours was considered with projects with more participant hours contributing to more management plans ($R2 = 0.022$, $p = 0.031$). Funding source also strongly influenced the model MoS scoring for these contributions (Multinomial logistic regression-Likelihood Ratio Test; Chi-Square = 23.757, df = 10; $p = 0.008$; Fig. 4d), though in this case, all other independent variables also significantly contributed to the model (all p values < 0.05; Table 3).

3.1.3. Interaction between publications and management plans

We looked for a relationship between a project's contributions to publications and management plans to assess whether a science to management gap existed (Habel et al., 2013; Prendergast et al., 1999). We found no significant relationship between the project's contributions to publications and its contributions to management plans, whether looking at contributions using counts ($R2 < 0.001$, $p = 0.95$) or MoS scores ($R2 = 0.004$, $p = 0.34$; Fig. 5a & b). While some projects focused on either publications or management plans, this analysis did not support the idea that there are project-wide constraints to focus on either contributions to management plans or publications, with some projects successfully achieving both.

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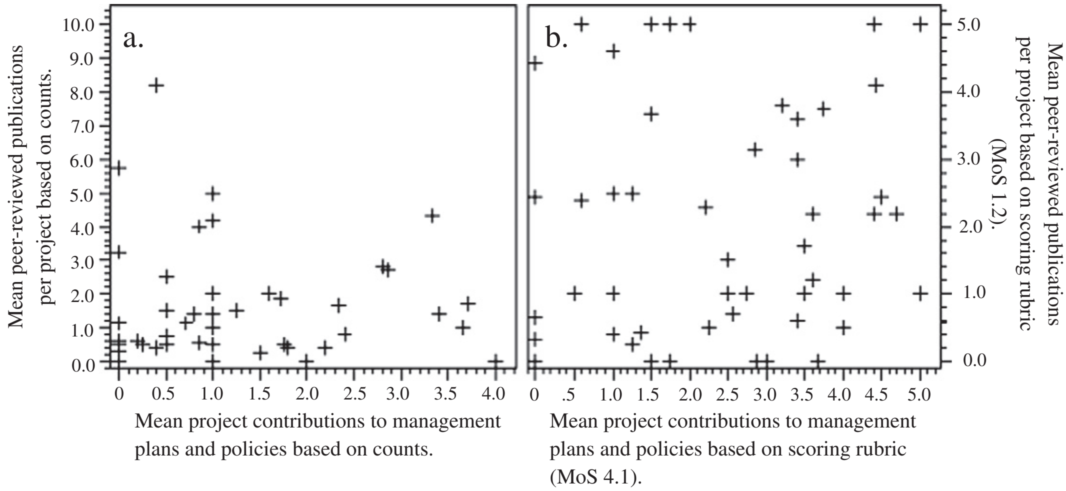

Fig. 5. Comparison of mean peer-reviewed publications per project and mean contributions to management plans and policy per project, based on: a. counts (R2 = 0.025, $p = 0.86$), and b. MoS scoring rubrics (R2 = 0.005, $p = 0.61$). n = 51 projects in each.

4. Discussion

Citizen science has the potential to contribute to increased understanding, monitoring, and management of the world's biodiversity (Amano et al., 2016; Devictor et al., 2010; Newman et al., 2016; Schmeller et al., 2008; Theobald et al., 2015). Moreover, there is aspiration for these citizen science projects to contribute data to scientific publications, management plans and global conservation agendas (Newman et al., 2016; Theobald et al., 2015). For example, Theobald et al. (2015) found that 97% of the 388 projects surveyed had an explicit goal to contribute to scientific publications, and Newman et al. (2016) found that 89% of the 113 projects surveyed also had an intention to contribute to management plans. Yet data of many, if not most, citizen science projects remain underutilized (Chandler et al., 2016; Theobald et al., 2015). Drawing from our findings and a review of the literature, we discuss a number of factors linked to increasing citizen science project outcomes including the model of citizen science, longevity of projects, participant input, and deliberate design.

4.1. Model of citizen science

Theobald et al. (2015) found 12% of the 388 projects assessed provided data to scientific publications, and Kullenberg and Kasperovsky (2016) found only 16% of the 490 projects surveyed contributed to publications. In contrast, our survey found that the contributory (sensu Bonney et al., 2009) and place-based (Newman et al., 2016) model of citizen science supported by Earthwatch leads to over 60% of projects annually producing scientific publications as well as input to management plans and/or policies. In a survey across several groups of citizen-science projects, Newman et al. (2016) found the contribution to management plans to be between 14% for CitSci.org projects and 50% for The Stewardship Network New England projects. The higher percentage for the community based monitoring projects may reflect their collaborative or co-created approach, blending the monitoring of local interests (e.g., status of an extracted resource) with broader and more external interests (e.g., carbon stocks), and thereby often providing direct input into local and larger-scale management plans (Conrad and Hilchey, 2011; Danielsen et al., 2005, 2014). Although contributory projects such as Earthwatch supported citizen science are mostly not co-created with the participants; project scientists often do work with local communities to incorporate their needs and local knowledge, as well as include them in other aspects of data collection and interpretation of the project results (Chandler et al., 2016, in press). Indeed, place-based (rather than large-scale or extensive) programs can lead to substantial local outcomes including local management plans (Becker et al., 2005; Chandler et al., 2016, in press; Newman et al., 2016), especially if they sample more intensively or are part of field research programs (Proença et al., 2016).

Several studies have identified factors that predict why some projects had higher outcomes (Kullenberg and Kasperowski, 2016; Loss et al., 2015; Theobald et al., 2015): projects that operate over larger spatial and longer temporal scales, share their data openly (often online), include some aspect of data collection training (e.g., species identification) or operate their projects on large web-based portals (e.g., eBird, Christmas Bird Count) published more frequently. Earthwatch-supported citizen science projects share some but not all of these characteristics. Almost all citizen science projects supported by Earthwatch tend to operate at local scales (<100 km) and data are generally not openly available (although often shared directly with collaborating scientists or management agencies). Moreover, Earthwatch supported citizen science projects are strongly place based (sensu Newman et al., 2016), which has been found to increase uptake of project results into management plans (Newman et al., 2016). Similar to other studies (Balme et al., 2014; Burgess et al., 2016), projects supported by PIs with affiliations to academic institutions have higher rates of publication. The results of this study also support the finding of Loss et al. (2015) that projects which define clear research questions also have increased outcomes. Earthwatch-supported projects also have rigorous training protocols, on-site scientists who can monitor and provide additional support during the course of the project, factors which enhance likelihood of publication (Burgess et al., 2016).

The low rate of peer-reviewed publications by government affiliates has been found elsewhere (Balme et al., 2014) and may be accounted for by the fact that we do not count or score technical reports in the same category of outcomes as peer-reviewed publications, although this may need to be reconsidered. Such outcomes from government scientists may become the foundation for government-based policies and agendas, and indeed, mean scores for such outcomes (based on the MoS 4.1 rubric) were the highest for government-affiliated PIs (though not significantly different from the other groups; Fig. 3d; Table 3).

The higher contributions of projects funded through the combination of public and philanthropic sources suggest the importance of varied funding strategies to increase such policy contributions, and may be driven by the joint expectations of high project impacts held by Earthwatch and the external funders who support our work.

4.2. Longevity of citizen science projects

Project duration has been found as a strong predictor of likelihood to publish (Burgess et al., 2016; Theobald et al., 2015). We found that project productivity, for both publications and management plans depended on the number of years of support for the project. Most projects surveyed for this analysis began generating outcomes by the end of year two, first for contributions to management plans, and later for contributions to peer-reviewed publications (Fig. 2). Contributions increased over time, peaking for management plans and policies at 6–8 years, which was earlier than contributions to publications which peaked between 7 and 9 years of support. Thus, we find a strong effect of project longevity on outcomes, although high rates of publication could be achieved within 5 years before appearing to peak closer to 10 years of operation. It should be noted that while the sampling period of project evaluation is 8 years, many projects begin operation prior to evaluation, thus operate for longer than 10 years by the end of the sampling period.

Given the longevity of support needed to produce project outcomes, a key challenge for citizen science project PIs is maintenance of long-term financial support for programs, particularly when funding cycles often operate on shorter periods (Brightsmith et al., 2008). The strong time lag seen between the start of a project and its peak outcomes also points to a significant challenge for citizen science project PIs who need to communicate feedback about outcomes to participants, funders, and stakeholders early on in order to sustain engagement and support. Feedback about the value of the data collected is often important in sustaining participant involvement over the long-term (Conrad and Hilchey, 2011; Geoghegan et al., 2016).

4.3. Participant input

In their review of European-based citizen science projects that monitor biodiversity, Schmeller et al. (2008) found that increased participant numbers did increase outcomes, in part by sampling more sites. In our study, the level of participant effort, as measured by both the number of participants and the number of participant hours, had a negligible effect on project contributions to publications or management plans and policies, despite notable variation in participants (2 to 141 participants/year) and hours contributed by participant to each project (204–9729 h/year). The citizen science projects supported by Earthwatch are framed around specific research questions and are designed to produce outcomes based on a projected number of participants. These “intensive” projects may therefore be less sensitive from an outcomes perspective to having more participants than projects designed for more extensive sampling (sensu Couvet et al., 2011; Schmeller et al., 2008).

Theobald et al. (2015) in their survey of over 400 field-based projects (excluding some of the largest online global programs such as Zooniverse and eBird) found a median estimate of 50 participants, each contributing 21–24 h per year, which is comparable to Earthwatch projects (average 43 participants each contributing around 52 h per project; Table 2). Earthwatch-supported projects train and engage participants continually over the course of 7–14 days rather than spread across a year. This more intensive training allows Earthwatch PIs to provide a greater variety of, and more complex, training across research tasks. Moreover, with scientists being present onsite to train and oversee data collection efforts, data quality is often higher (e.g., Buesching et al., 2015; Dickinson et al., 2010). With regard to contributions to global biodiversity monitoring efforts, these intensive field research programs can provide complementary kinds of biodiversity data to those collected by more extensive monitoring found in many other citizen science projects (Devictor et al., 2010; Proença et al., 2016).

4.4. Deliberate design

Optimizing delivery of individual projects to achieve a wide range of societal goals (e.g., useful data for science, applicable results, and meaningful participation) remains challenging for a number of reasons (Geoghegan et al., 2016; Shirk et al., 2012). Limited resources, capacity, and potential trade-offs can lead to projects focusing on one set of objectives rather than all (e.g., prioritizing science outcomes or public engagement, but not both; Crain et al., 2014; Pocock et al., 2015, but see Lawrence, 2006). There is evidence that many of the citizen science projects assessed in this study manage to balance these multiple demands to achieve different goals, showing that projects contribute to both publications and management plans.

Earthwatch supported programs may also have high rates of publication or contributions to management plans because continued support by Earthwatch is contingent on each project demonstrating outcomes, assessed via the MoS evaluation rubric. In other words, the evaluation tool itself may itself create incentives for project leads to publish their results or mobilize their data to influence management plans and policies.

Projects designed with input from the lead scientists alleviate some perceptions, stigma and real challenges identified within the scientific community around trustworthy citizen science data (Burgess et al., 2016; Loss et al., 2015). Creating a comprehensive evaluation tool for citizen science projects in general that integrates assessment across multiple goals might help achieve a common understanding and language, thereby building trust and confidence across scientists, resource managers, and communities, including citizen scientists, invested in a particular project (Margolius and Salafsky, 1998; Stem et al., 2005).

5. Conclusion

The field of citizen science is increasing in prevalence in part due to the exigency of the conservation and natural resources issues faced today. While citizen science has the potential to generate highly useful data that can inform management plans and policies, there are wide differences across this field in the ability of projects to deliver impactful work (Newman et al., 2016; Theobald et al., 2015). The development of a systematic MoS evaluation tool and associated database to evaluate project outcomes has enabled Earthwatch to track progress of individual projects as well as outcomes for the organization as a whole. Equally important, it has facilitated a dialogue with project PIs about expected goals covering a range of possible outcomes including input to management plans, local activities and writing scientific publications.

Since implementing the MoS tool, Earthwatch has seen improved reporting by project PIs, and an increase in the number of, and detail about, outcomes achieved by the projects. This has fed positively into increased feedback to participants. Despite these benefits, the ongoing development of this tool has been highly labor intensive in terms of staff time, as well as requiring additional input from PIs. Many challenges remain in the continuing implementation and refinement of this tool, including development of consistent and rigorous definitions of MoS criteria. It has been hard to sustain internal funding for programmatic evaluation beyond base-level assessments. In the case of the MoS tool, sustainability to date has been maintained because it has become part of an integrated (adaptive) program management system that embeds the MoS criteria (e.g., need to publish, provide input to management plans) in the full life cycle of the citizen science project, namely proposal development, proposal evaluation, annual reporting by PI on activities and renewal of project support.

In sum, we found the MoS tool to be a highly promising means of assessing and guiding the impact of citizen science. Through the deployment of the tool, project leads have been able to demonstrate the positive impacts of citizen science back to participants, existing and prospective principal investigators and funders. Furthermore, it has assisted to validate the intensive and deliberate project design and

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development approach taken, balancing the needs for a quality participant experience with clear scientific and management objectives. This paper presents one approach to building systematic evaluation of projects. By leveraging experiences and methodologies found across many citizen science projects, more effective projects may be developed that help to fulfill the potential of citizen science to address global challenges can be realized.

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Appendix A. Earthwatch Measures of Success (MoS)

MoS 1. Increasing scientific knowledge to facilitate and disseminate world class scientific field research

- MoS 1.1 Number of people and number of person hours dedicated to collecting scientific data
- MoS 1.2 Peer reviewed publications
- MoS 1.3 Popular publications and outreach events

MoS. 2. Engaging people in transformational learning experiences that promote environmentally sustainable action

- MoS 2.1 Education: individuals engaged and developed increased capacity

MoS 3. Enabling organizations and business to become more sustainable

- MoS 3.1 Partnerships: organizations actively engaged

MoS 4. Informing environmental policies, agendas, management plans and government policies

- MoS 4.1 Contributions to conventions, agendas, policies, and management plans
- MoS 4.2 Pro-environment actions taken at the research project site

MoS 5. Enhancing natural and socio-cultural capital to create a sustainable environment

- MoS 5.1 Taxa of conservation significance enhanced
- MoS 5.2 Natural habitats enhanced
- MoS 5.3 Ecosystem services enhanced
- MoS 5.4 Cultural heritage components enhanced
- MoS 5.5 Livelihood assets enhanced

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