EVALUATING THE USEFULNESS OF CITIZEN SCIENCE FOR NATURAL RESOURCE MANAGEMENT IN MARINE ENVIRONMENTS

Carla D Sbrocchi

Master of Science (Marine Science)

A thesis submitted for the degree of Masters by Research

University of Technology Sydney

School of Environment

January 2014

CERTIFICATE OF ORIGINAL` AUTHORSHIP

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Student:

Date:

ACKNOWLEDGEMENTS

Sincere gratitude to my supervisors Prof Bill Gladstone and Dr Tim Glasby who have provided continuous guidance, encouragement and support. I have been fortunate to receive financial support from the Sydney Metropolitan Catchment Management Authority and the Australian Geographic Society which was integral to having volunteers involved in my study: thank you SMCMA and Australian Geographic for your assistance in supporting the divers in my study and to Lesley Diver for making this happen. Thank you also to Skye Taylor and Peter Gibson from NSW Department of Primary Industry (Fisheries) and Glenn Courtenay for providing your expertise.

To all the questionnaire respondents across the country (who must remain anonymous), thank you for taking the time to contribute your thoughts. This thesis is based largely on what you told me, and I appreciate your candour. To Dave Thomas, Peter McGee, Karen Raubenheimer, Deborah Dickson-Smith, Scott Portelli, Mark Kitchen, Alice Forrest, Silke Stuckenbrock, David Massih, Elaine Kwee, Kate Tinson, John Turnbull: you are exemplars in the field of citizen science. Your commitment to marine monitoring and raising public awareness on marine issues is nothing short of inspiring – I am indebted to you and I am honoured to have the pleasure of working with you.

Thank you to all my friends and colleagues who have provided encouragement, enthusiasm and listening ears. I cannot express enough gratitude to Meg, John, Libby and Derek who been available to help at a moment's notice. And finally, to Adam, Aurora, Leif and Wren: you have walked this journey with me and have been ever gracious, ever understanding and ever loving. xo

This study has been approved by the University of Technology, Sydney Human Research Ethics Committee (UTS HREC REF NO. 2012-052A).

TABLE OF CONTENTS

CERTIFICATE OF ORIGINAL` AUTHORSHIP iii

Acknowledgements iv

Table of Figures viii

Abstract xiii

Chapter 1: Introduction 1

Chapter 2: Issues and Opportunities For Citizen Science In Natural Resource Management in Australia 5

2.1 Environmental Management Models 6

2.2 Models of Community Participation in Natural Resource Management 7

2.3 Citizen Science in Context 9

2.4 Outcomes of Citizen Science 11

2.4.1 Outcomes for Science 16

2.4.1.1 Factors influencing Science Outcomes 17

2.4.2 Outcomes for Individuals 19

2.4.3 Outcomes for Society 21

2.5 Conclusions 22

Chapter 3 Assessing the quality of data collected by citizen scientist SCUBA divers for monitoring seagrass condition 25

Abstract 25

3.1 Introduction 26

3.2 Methods 29

3.2.1 Study Site 29

3.2.2 Participants 30

3.2.3 Field experiment: hypotheses and sampling design 30

3.2.4 Lab experiment: hypotheses and sampling design 31

3.2.5 Influence of photo quality 32

3.2.6 Volunteers' attitudes and perceptions 32
3.2.9 Statistical analyses 33
3.3 Results 34
3.3.1 Field experiment 34
3.3.2 Lab experiment 36
3.3.3 Photo quality 41
3.3.4 Volunteer attitudes 42
3.4 Discussion 43
3.5 Conclusion 46
Acknowledgements 47
Supplementary Table S3.1 48
Supplementary Table S3.2 60
References 63
Chapter 4 67
Who Cares about Citizen Science? A Survey on the Utility of marine citizen science in Australia 67
Summary 68
4.1 Introduction 69
4.2 Methods 71
4.3 Results 72
4.3.1 General respondent information 72
4.3.2 Characteristics of Citizen Scientists 74
4.3.3 Characteristics of Data User Organisations 78
4.3.4 Uses of Citizen Science Data 81
4.4 Discussion 83
4.5 Conclusions 85
Acknowledgements 87

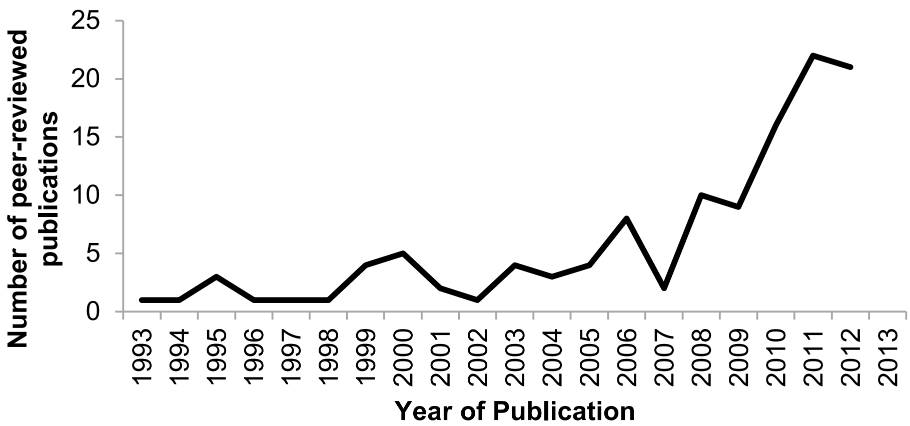
Appendix S4.1 Questionnaire ... 88
Appendix S4.2: Citizen Science Publications based on Australian Citizen Science Activities ... 96
References ... 104
Chapter 5: General Discussion and Conclusion ... 108
5.1 Introduction ... 108
5.2 Benefits of Citizen Science ... 108
5.3 Challenges to the Field of Citizen Science ... 109
5.3.1 Data Issues ... 109
5.3.2 Funding and support for Citizen Science ... 111
5.4 Citizen Science and Natural resource Management ... 113
5.5 Practical solutions for integrated citizen science ... 114
Appendix 1: Glossary ... 117
References ... 119

TABLE OF FIGURES

Figure 2.1. The number of peer-reviewed publications with the key word "citizen science" using web of science database. n=347 publications 1900-2013. 11

Table 2.1: Models of public-scientist interactions in citizen science (Shirk et al. 2012), in order (from top to bottom of table) of increasing public involvement. 12

Table 2.2: Evaluation of the five models of citizen science against outcomes for science, individuals and society (SYNTHESIZED FROM Lunney & Matthews 2002; Ely 2008b; Danielsen et al. 2009; Conrad & Hilchey 2011; Shirk et al. 2012). Models are in order of increasing public involvement (from top to bottom) as per Table 2.1. 13



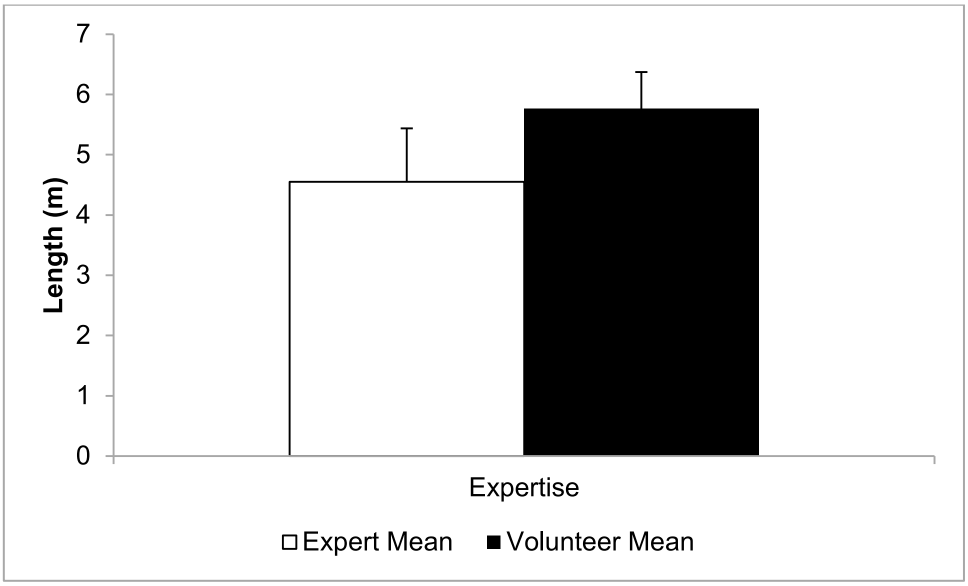
.... 28

Figure 3.1. Peer-reviewed publications implying use of citizen science for marine data collection, 1993 to 2012. Compiled list of references can be found in Supplementary Table S3.1. 28

Table 3.1. Questions asked of volunteers after a training session to assess their level of enjoyment with the data processing (lab) experiment. n=7 33

Table 3.2. Summary of PERMANOVAs testing for differences in estimates of mean leaf length of *Zostera* and *Posidonia* and of mooring scour lengths, measured by volunteers and experts. Estimates of variance components are included. Transformations are written above each analysis. *When Expertise x Site was non-significant (p>0.25), this term was pooled with the Residual to create new tests for the main factors. 35

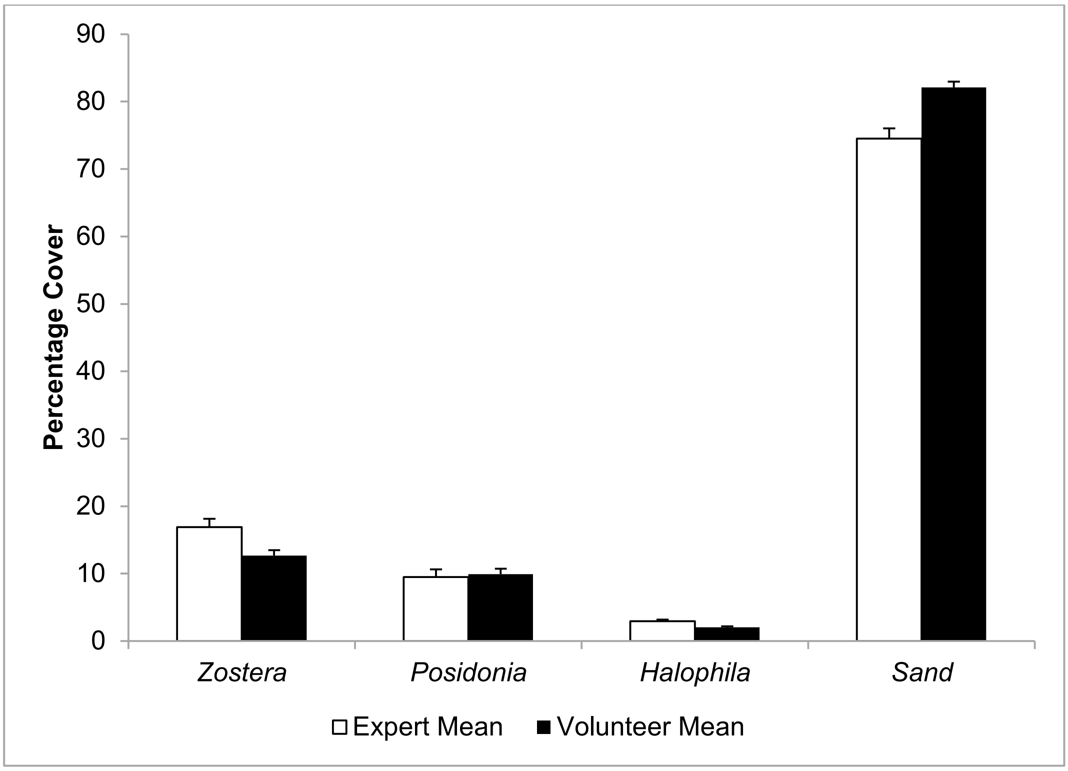
Figure 3.2. Estimates of Mean (+ Standard Error) leaf length of *Zostera* and *Posidonia* seagrass measured by experts and volunteers. 35



.... 36

Figure 3.3. Estimates of mean (+standard error) length of mooring scours from experts and volunteers. 36

Table 3.3. Summary of PERMANOVA results testing for differences between experts and volunteers in estimates of mean % cover of seagrass (*Zostera, Posidonia, Halophila*) and sand from photoquadrats. Estimates of variance components are included. Transformations are written above each analysis. *Adjusted Significance level of p=0.01 used because variances were heterogenous and could not be eliminated by transformations. 37



...38

Figure 3.4. Estimates of mean (+ standard error) of % cover of *Zostera, Posidonia, Halophila* and sand recorded by experts and volunteers. 38

Table 3.4. Results of pair-wise tests comparing Expert and Volunteer data for each site. *Adjusted significance level of *p*=0.01 used for *Posidonia* and *Halophila* because variances were heterogeneous and could not be eliminated by transformations. Significant *p*-values are in bold. 38

Figure 3.5: Estimates of mean % cover of seagrass (*Zostera, Posidonia, Halophila*) and sand recorded by each person at each site. Person 1-9 = volunteers, 10-13 = experts. Sites 1-4 are seagrass friendly moorings, Sites 5-8 are swing moorings, and Sites 9-12 are controls (i.e. no moorings).. 39

Table 3.5. Summary of PERMANOVA results testing for differences between experts and volunteers in estimates of mean % occurrence of seagrasses and sand from video transects Transformations are written above each analysis. Variance components are included. *Adjusted significance level of p=0.01 used because variances were heterogeneous and could not be eliminated by transformations. 40

Figures 3.6, 3.7, 3.8 (L-R). Photos demonstrating contribution of orientation and clarity to photo quality score. Quadrat is centred, square and clear (figure 3.6); figure 3.7

shows photo that is not square and taken at acute angle; 10% of quadrat missing from dull photo (figure 3.8). 41

Table 3.6. Quality scores of photos taken by volunteers. Letter denotes photographer. Site is denoted as Seagrass-Friendly Mooring (SFM), Swing (S) or Control (C). Shading indicates those moorings where significant differences were detected in % cover measured by experts and volunteers for *Zostera* (z), *Posidonia* (p) or sand (s). 41

Figure 3.9. Comparison of confidence in 8 volunteers in completing the computer-based activities, at the conclusion of the training workshop and after completing the task. 43

Table 4.1. Questionnaire Themes 71

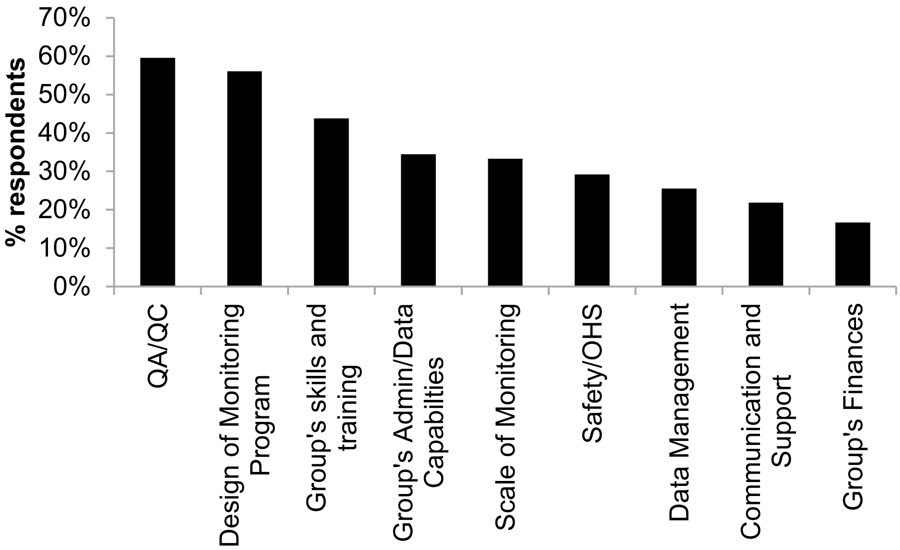
Table 4.2. Characteristics of respondents by organisation type, based on n=185 partially/fully completed surveys (percentages rounded to nearest whole number). 73

Table 4.3. Monitoring activities according to biotic, physical and social categories. Data are percentages of 73 ‘citizen scientist’ respondents. Percentages are rounded to nearest whole number. 75

Figure 4.1. Comparison of funding sources for citizen scientist respondents, showing (upper panel) proportion of respondents reporting all sources of funding (respondents could select more than one response so percentages may total >100); (middle panel) proportion of respondents reporting a funding source that made up more than 50% of their total operational budget; and (lower panel) proportion of respondents reporting a funding source that made up more than 90% of their total operational budget. N=60.. 76

Figure 4.2: Key factors that affect citizen scientists’ ability to provide data to organisations. Responses displayed for % respondents selecting top answer ('1'). ‘Volunteers’ describes the number of volunteers in the group and their technical skills, ‘funding’ refers to the financial support and partnerships the group maintains, ‘admin’ includes the capacity of the group to enter and store data, ‘communication’ is the amount of feedback the group receives from researchers or other project proponents, ‘QA/QC’ describes data quality and assurance protocols, and ‘safety/OHS’ relates to insurances and protocols for group monitoring activities. 77

Figure 4.3. Frequency distribution of time data users had engaged with citizen science (based on n=101 responses). 79



................80

Figure 4.4. Factors which contribute to a data user's decision to use citizen science data. Responses displayed are proportion of respondents selecting factor as top answer ('1' rank), n=90. 'QA/QC' describes data quality and assurance protocols employed by the group, 'Group's admin' includes the capacity of the group to enter and store data, 'Safety/OHS' relates to insurances and protocols for group monitoring activities, and 'Communication' is the amount of feedback the user provides to the citizen science groups. 80

Table 4.4. Perceived and known uses of citizen science data reported by citizen scientists and data users. Responses displayed are ranked, where 1 = top answer. (94 citizen science respondents, 97 data user respondents; 1=highest/most used rank, 9=lowest/least used) 81

Table 4.5. Outputs of citizen science programs, compiled from all respondents ((n=185)) as a measure of usefulness of citizen science data. 82

ABSTRACT

Management of marine natural resources and ecosystems is relying increasingly on the engagement of members of the public to collect environmental monitoring data for application in research and marine decision-making processes. Despite an accumulating body of work which discusses the potential benefits of engaging members of the public in marine environmental monitoring for better decision-making, there is no published analysis of whether, in fact the data collected by the public are used. The aim of this research was to assess the utility of citizen science data for marine natural resource management in Australia. This was accomplished by an investigation into the development of the field of 'citizen science' and its potential place within community participation frameworks for sustainability and environmental management. It also reviewed the perceived benefits and challenges to the use of citizen science in the natural sciences and discussed its potential uses and influence on environmental policy and management.

A validation study was undertaken to evaluate seagrass condition data collected by volunteers using field and computer-based sampling methods. Citizen scientists (volunteer SCUBA divers) did not differ from experts (professional marine scientists) in their estimates of % occurrence of seagrasses and sand (from video transects), however, they differed in a more complex task of estimating % cover of seagrass and other habitat features (from photoquadrats). Experts differed in their estimates of % cover from photoquadrats, indicating methods require review and may have contributed to volunteer results. Citizen scientists found the computer-based activities helpful in expanding their knowledge on scientific processes and essential for evaluating and modifying techniques used in their monitoring protocol. This evidence further supports the inclusion of volunteer SCUBA divers in scientific research (including seagrass condition monitoring) and highlights the importance of also validating professionals prior to training volunteers.

Results of a questionnaire distributed to researchers, managers, community support organisations and community members across Australia demonstrated that citizen science is being used for decision-making in Australia, as well as for high-quality research. More than 70% of respondents (n=185) reported having used citizen science-collected data for natural resource management decisions or research, with 53

programs producing 72 peer-reviewed publications and 110 technical reports. Where scientists and the public are working together, citizen science is a powerful research tool that has an added benefit of expanding the individual well-being of the participants involved. This study has also been able to demonstrate that citizen science is achieving its purported use of data for decision-making, and additional documented cases are likely to arise as the field gains trust.

CHAPTER 1: INTRODUCTION

Management of natural resources and ecosystems is relying increasingly on engaging members of the public in collecting environmental monitoring data (Pfeffer & Wagenet 2007; Holt et al. 2013) for application in decision-making processes (Antos et al. 2006; McIntyre 2008). Despite an accumulating body of work which discusses the potential benefits of engaging members of the public in environmental monitoring (Danielsen et al. 2005; Bonney et al. 2009b; Dickinson et al. 2010; Roy et al. 2012), there is no published analysis of whether, in fact, the data collected by the public are used for decision-making.

Coastal marine areas, specifically, are progressively affected by warming oceans, changes in storm frequency and intensity, increasing extractive activities and population pressures inducing accelerated degradation. Given the extensive scale coastal marine areas occupy, the financial resources required for comprehensive monitoring and the social complexities of decision-making, natural resource managers have been encouraged by governments to engage members of the public in environmental monitoring and management (Wilson 2002; Department of Environment Water Heritage and the Arts 2009; Department of Sustainability 2012). Validation of public monitoring data is identified as a concern for environmental researchers and managers (Darwall & Dulvy 1996; Underwood & Chapman 2002), and although validation studies of public monitoring data have taken place since the early 1990s, the contexts to date are generally constrained to freshwater and terrestrial investigations. In addition, no study of the impact on environmental decision-making of public involvement in environmental monitoring has yet been reported. This signifies a substantial gap in the knowledge required for researchers, policy makers and managers to further integrate the public into marine decision-making processes.

The general aim of the research reported in this thesis was to assess the utility of marine citizen science data for marine natural resource management in Australia.

The term citizen science has a variety of meanings and applications and is used in a variety of scientific disciplines, from astronomy to zoology. In the natural sciences, the term ‘citizen science’ can be applied to the actual process of managing natural resources; however, more often than not it is used to mean *the involvement of* *members of the public in scientific research and monitoring activities* (Miller-Rushing et al. 2012; Shirk et al. 2012) . Members of the public who participate in citizen science can be individuals or communities; they can be students, landholders, industry enthusiasts (such as recreational fishers, SCUBA divers), or community activists. They can initiate the activities or be asked to participate. They can be volunteers or can even be paying participants. The consistent element is that the intended outcome of citizen science is the provision of information for sound and informed decision-making for the better restoration, conservation and management of ecosystems and natural resources (Walker & Daniels 2001; Danielsen et al. 2005).

To achieve the aim above, Chapter 2 investigates the development of the field of ‘citizen science’ and its potential place within community participation frameworks for sustainability and environmental management. This will allow for an exploration of the nature of citizen science, as well as the roles of the various participants within the field. The chapter reviews the perceived benefits and challenges to the use of citizen science in the natural sciences and discusses its potential uses in, and influence on, environmental policy and management. The marine environment is used as a focus for this thesis, however, the concepts addressed have application in other scientific disciplines.

As validation of public data is identified as a primary concern to implementation of citizen science, Chapter 3 provides a validation test of volunteers in a specific context, not previously discussed in the available literature. Volunteer SCUBA divers participated in both field and computer-based data collection techniques that were validated against data provided by experts. By researching the validity of data collected by citizen scientists, this study will contribute to improvements for wider application of citizen science. It has been prepared in the format of an article for the journal Bulletin of Marine Science.

To examine the application of citizen science data, Chapter 4 will present the results of a questionnaire distributed to researchers, managers, community support organisations and community members across Australia that focused on the potential applications for, and actual uses of, citizen science data. The questionnaire covered topics ranging from motivations for monitoring, operational capacity, data capture, factors influencing use of data and evidence of impact of data collected by the public. It has been prepared in the format of an article for the journal Environmental Conservation.

The final chapter reviews the utility of citizen science for marine natural resource management in Australia by synthesizing findings of Chapters 2-4. This chapter also provides recommendations for better integration of citizen science in research and decision-making.

Chapter 2: Issues and Opportunities For Citizen Science In Natural Resource Management in Australia

Participation of the public in science is not new. Bonney et al. (2009b) and Miller-Rushing et al. (2012) provide some historical perspective to the field, recalling the observations of bird strikes by lighthouse keepers in the 1880s, a weather observer program initiated in 1890 and the annual Christmas Bird Count beginning in 1900. In fact, amateur research and specimen collection programs have existed for centuries (Brenna in Miller-Rushing et al. 2012), and much of the ecological monitoring undertaken throughout history has utilized amateur scientists as important participants in all aspects of a scientific study. In some cases they have quite successfully performed such studies independently of professional scientists. However, the professionalization of science in the early 20th century, that is, the rise of a niche of society paid to specialise solely on scientific issues (Bell et al. 2008), led to a decrease in the number of scientific enquiries jointly undertaken by members of the public and professional scientists (Miller-Rushing et al. 2012). As such, a paradigm developed where research rested with scientific bodies and natural resource management and policy rested with government – not the community. From the 1990s onwards, members of the public have taken an interest in 'democratising' science, making science available to all rather than allowing it to be a monopoly of a select few (Irwin 1995; Carr 2004). The public may have a desire for increased participation in science as it feeds into more well-considered and representative decision-making (Carr 2004; Pfeffer & Wagenet 2007). As this marked change in the dynamics of decision-making has emerged within the past two decades, an understanding of the current model of decision-making in natural resource, environmental and conservation management in Australia is required.

Citizen science is a growing field around the world, and much has been discussed regarding its potential for informing research and decision-making. Recent reviews on citizen science, however, have focused on activity in the United Kingdom, the USA and Canada (Bell et al. 2008; McIntyre 2008; Conrad & Hilchey 2011; Roy et al. 2012). Citizen science is active in Australia, yet there has been no comprehensive review of the place of citizen science within Australian environmental management contexts.

This chapter is a review of the issues and opportunities of integrating citizen science into Australian natural resource management. It will discuss the development of the field of ‘citizen science’ and its potential place within community participation frameworks for sustainability and environmental management. This will begin with an exploration of the models of environmental management in Australia, and the place of community participation within these models. Citizen science as an aspect of community participation will be discussed, highlighting the perceived benefits and challenges to its use in the natural sciences. Finally, the chapter will describe citizen science’s potential uses and influence on environmental policy and management.

2.1 Environmental Management Models

Legislative powers over the environment are not specifically dealt with in the Australian Constitution and are not the sole province of any one sphere of government (*Commonwealth Of Australia Constitution Act* 1900) . Government agencies at all levels (local, state and federal) are commissioned with management of natural resources within Australia. Internationally the term ‘natural resource management (NRM)’ tends to be used when discussing the sharing of resources/commodities, such as aquaculture, fisheries and forestry, amongst constituents (e.g. traditional owners, recreational fishers, commercial fishers, etc) whereas NRM in Australia is used in a broader context than what the term implies. It is used in Australia to mean the planning and direction of activities for conservation, restoration and management of ecosystems and natural resources (Commonwealth of Australia 2012).

Australia’s federal government has jurisdiction by legislation to manage threatened species (under the *Environmental Protection and Biodiversity Conservation Act 1999*), fisheries in Commonwealth waters (>3 nautical miles from shore) and environments governed by international agreements, for example, Ramsar-listed wetlands (United Nations 1971). Australia has also adopted the United Nations’ Agenda 21 for Environmentally Sustainable Development, one aspect of which aimed to encourage governments to incorporate communities in environmental activities for long-term sustainability (UN Dept of Economic and Social Affairs 1992). Sustainability is the capacity to maintain personal and societal well-being at a certain rate or level (adapted from UN Department of Economic and Social Affairs - Division for Sustainable Development 1992; Oxford Dictionaries 2013) which depends on the long-term maintenance of the natural world. Australia addressed this need in Section 4, Chapter 32 of its National Strategy for Ecologically Sustainable Development (Ecologically Sustainable Development Steering Committee 1992).

In Australia, each of the six states and two territories has responsibility for management of public assets such as 'national' parks and reserves, marine parks, and commodity-based resources (< 3 nautical miles from shore). Agencies of the state often work towards achieving an aspirational NRM target, which directs their management and research activities and provides a means of tracking progress on NRM issues. One example of an NRM target is the NSW State Plan which contains 7 targets relating to environment and communities (NSW Department of Premier and Cabinet 2011).

A neo-conservative shift in the 1990s caused policy changes and cutbacks in funding for environmental agencies and research institutions in a number of countries, and led to the devolution of some environmental responsibilities to municipalities and the private sector (Burgin 2002; Lunney & Matthews 2002; Underwood & Chapman 2002; Pfeffer & Wagenet 2007; Kranjnc in McIntyre 2008). Within Australia this resulted in the creation of 56 regional NRM bodies which occur within state boundaries, operating in a variety of ways across the country, but having an overarching mandate to manage natural resources at the regional biogeographic scale through involvement of communities. Management of natural resources is directed by regional and local NRM issues, raised through community concern or identified prioritisation processes and documented in a regional NRM plan. Principles of 'awareness raising' and 'capacity building' are integral to many NRM strategies in Australia: a critical component to managing resources is the inclusion of the people that use the resource (Stepath 2000).

2.2 Models of Community Participation in Natural Resource Management

Community consultation and active participation by communities in planning and decision-making processes is becoming increasingly prevalent throughout the world, and at all levels of government (Wilson 2002; Department of Environment and Climate Change NSW 2008) as it is seen to be transparent, inclusive and representative and increases the community 'buy-in' and support of the decision. Numerous community participation models are available for use in NRM, depending on purposes of resource sharing, sustainability or research.

Management of commodity-based natural resources, such as fisheries and forestry, utilise community consultation processes to manage the distribution of the resource amongst the constituents (eg. constituents of a fishery might be traditional owners, recreational fishers, the various types of commercial fishing and conservation proponents). Community consultation processes also provide an opportunity for these stakeholders to be consulted about, and to influence, decision-making. Regional Forestry Agreements, for example, incorporate extensive scientific and social information from communities and experts to identify areas of forest that require protection and areas that can be used for commercial purposes (DAFF 2013).

Sustainability models of natural resource management have a strong basis in capacity building activities and raising awareness of environmental issues, as these activities will reinforce the role individuals and communities play in "informed and appropriate action" (Carr 2004; Thomsen 2008). This concept is so pervasive that philanthropic grants administrators in the US and Australia, who have stepped into this space because of the neo-conservative shift by government, require successful environmental research projects to include an 'outreach' component (Silvertown 2009). The philosophy of sustainability puts learning, capacity building and changed behaviours as its focus. It is argued that by improving community members' understanding of their role in sustainable ecosystems, their changed attitudes and behaviours may result in beneficial everyday actions (Stepath 2000; Thomsen 2008)

The Australian Government has run its environmental funding programs over the past two decades by the sustainability model of community participation. The aims have included increasing community awareness of current science in pure and applied environmental research, improving participation in the decision-making processes involved in management, and achieving locally-relevant on-ground results (Burgin 2002; Lunney & Matthews 2002; Department of Environment Water Heritage and the Arts 2009). The key assumption of the community participation model is that communities will gain an improved understanding of their role in sustainable ecosystems and will embrace long-term stewardship over the environment and the program in which they are involved (Weston et al. 2003; Department of Environment Water Heritage and the Arts 2009; Department of Sustainability 2012). In Australia, the devolvement of funds to communities has primarily been through one of two processes, either direct to community groups (including non-government organisations (NGO)) or through the regional NRM bodies.

It has been argued that volunteers, by participating in longer-term environmental activities, might play a key role as a potential solution to the cutbacks and downsizing experienced by research institutions and management agencies, and the new function given to other sectors (Antos et al. 2006; McIntyre 2008). This can be demonstrated, in part, by the amount of effort expended by volunteers in environmental restoration. The 'Caring for our Country Outlook' reported that between 2008 and 2013, over 200 private land managers helped to conserve over 47 000 hectares of threatened ecological communities, more than 30 200 farmers participated in over 450 projects to increase their uptake of sustainable farm and land management practices, and over 400 000 hectares of Ramsar wetland were protected through on-ground activities carried out by land managers, Indigenous and community groups and volunteers (Commonwealth of Australia 2012). The 'community' in community participation is not exclusive to communities of place – that is, those who live or work in a particular location. Community also includes 'communities of interest', that is, those people who take an interest in a particular issue. Ideally, community participation would comprise involvement from scientists, natural resource managers, government, industry and other members of the public to benefit mutual aims of conservation, restoration and management through contributions of experienced individuals from their respective communities (Burgin 2002; Lunney & Matthews 2002; Underwood & Chapman 2002). In this way, citizen science, as a form of community participation, could be the bridge between multiple stakeholders who can contribute equally in implementing positive change and better management of natural resources (Jacoby et al. 1997; Stepath 2000; Thomsen 2008).

2.3 Citizen Science in Context

The term citizen science has a variety of meanings and applications and is used in a range of scientific disciplines, from astronomy to zoology. A list of terms often associated with 'citizen science' is provided in Appendix 1. In the natural sciences, the term 'citizen science' can be applied to the actual process of managing natural resources; however, more often than not it is used to mean *the involvement of members of the public in scientific research and monitoring activities* (Miller-Rushing et al. 2012; Shirk et al. 2012). Members of the public who participate in citizen science can be individuals or communities; they can be students, landholders, industry enthusiasts (such as recreational fishers, SCUBA divers), traditional owners or community activists (Dickinson et al. 2010; Conrad & Hilchey 2011; Shirk et al. 2012). They can initiate the activities or be asked to participate. They can be volunteers or can even be paying participants. The consistent element is that the intended outcome of citizen science is the provision of information for sound and informed decision-making to enable better restoration, conservation or management of ecosystems and natural resources (Walker & Daniels 2001; Danielsen et al. 2005).

Lunney & Matthews (2002) described citizen science as the integration of community knowledge and support into research programs. The majority of citizen science involves volunteers working alongside professional scientists (usually biologists) on projects that have been adapted to give amateurs a role (Cohn 2008; Silvertown 2009). In the words of one researcher, "Citizen science represents a partnership between volunteers and scientists to answer real-world questions" (Cohn 2008). Citizen scientists may record observations, carry out physical tasks such as field data collection or submission of specimens (Bonney et al. 2009b; Roy et al. 2012), or undertake more complex tasks such as posing research questions, analyzing data, discussing, and disseminating results (Conrad & Hilchey 2011) .

The phenomenon of citizen science is growing (Benz et al. 2013), as substantiated by the rise and breadth of documentation in the field (Figure 2.1). In recent years there have been reviews on the current state of citizen science (Roy et al. 2012); the history of citizen science (Miller-Rushing et al. 2012); the development of frameworks for implementing citizen science programs (Danielsen et al. 2009; Shirk et al. 2012); considerations of the issues and opportunities in citizen science (Bonney et al. 2009b; CSIRO 2009; Dalton & Smith 2009; Dickinson et al. 2010; Conrad & Hilchey 2011; Stenekes & Sahlqvist 2011; Clarke et al. 2012); the development of best practice for engaging volunteers in citizen science (Mackney & Spring 2001; Bell et al. 2008; McIntyre 2008); and discussion of the associated social outcomes, such as increasing well-being (Koss & Kingsley 2010), a greater awareness of sustainability concepts (Thomsen 2003; Thomsen 2008) and participation in management activities (Carr 2004; Danielsen et al. 2009). A two-day conference solely dedicated to the topic

('Conference on Public Participation in Scientific Research,') was held in Portland, Oregon in 2012 and, in the same year, the academic journal Frontiers in Ecology and the Environment published a special edition entirely comprised of citizen science related articles (Volume 10, Issue 6 August 2012).

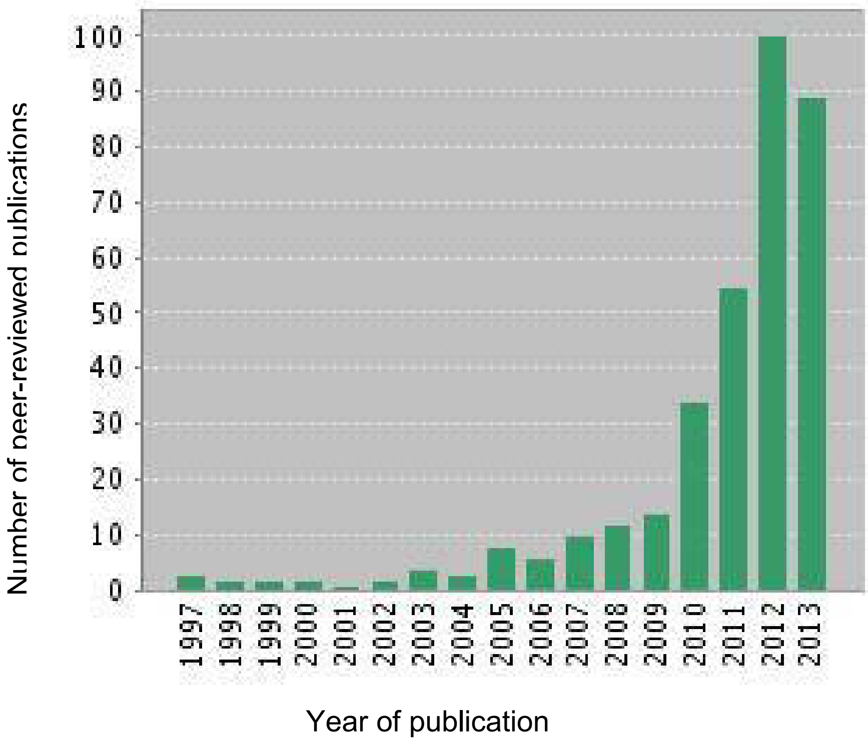


Figure 2.1. The number of peer-reviewed publications with the key word “citizen science” using web of science database. n=347 publications 1900-2013.

2.4 OUTCOMES OF CITIZEN SCIENCE

The reviews and discussions presented in the previous section have described citizen science as having varying levels of public participation (Danielsen et al. 2009; Dickinson et al. 2010; Conrad & Hilchey 2011; Shirk et al. 2012). Shirk et al. (2012) synthesized the descriptions of scientist-public interactions as a series of models (Table 2.1).

Table 2.1: Models of public-scientist interactions in citizen science (Shirk et al. 2012), in order (from top to bottom of table) of increasing public involvement.

Model	Role of the Public
Contract	Ask scientists to conduct a scientific investigation and report on results
Contribute	Asked by scientists to collect and contribute data and/or samples
Collaborate	Assist scientists in developing a study and collecting and analyzing data
Co-create	Develop a study and work with input from scientists to address a question of interest or an issue of concern
Colleagues	Independently conduct research that advances knowledge in a scientific discipline

Shirk et al. (2012) classified the outcomes of citizen science programs into three main categories: outcomes for science (e.g. scientific findings); outcomes for individual participants (e.g. acquiring new skills or knowledge); and outcomes for social-ecological systems (hereafter denoted as 'society', and examples include influencing policies, building community capacity for decision-making, taking conservation action). Each of the models described in Table 2.1 provide opportunities for each of the three outcomes, however, due to the nature of some of the interactions between the scientists and the public described in the models, some models are more likely to produce certain outcomes than others (Table 2.2). When community groups, scientists and managers consider the implementation of a citizen science program the benefits and challenges of each model would need to be evaluated against the project's desired outcomes (for science, individuals and society) to determine which model of scientist-public interaction would best achieve the project's goals. Additionally, certain implementation challenges that may impact on the use of a model would need to be considered.

Table 2.2: Evaluation of the five models of citizen science against outcomes for science, individuals and society (SYNTHESIZED FROM Lunney & Matthews 2002; Ely 2008b; Danielsen et al. 2009; Conrad & Hilchey 2011; Shirk et al. 2012). Models are in order of increasing public involvement (from top to bottom) as per Table 2.1.

Outcomes for Science	**Outcomes for Individuals**	**Outcomes for Society**	**Implementation Implications**	**Examples**
Contract: *Ask scientists to conduct a scientific investigation and report on results*				
Expands research from being driven solely by researcher interests to consider also community-relevant interests and questions.	Limited opportunities for public to participate	Under-represented members of society can bring concerns to scientists to investigate	Contracts are short term project-based. Requires community champions to communicate findings and source funding for additional research if required.	European Science Shops (European Commission n.d.), *see description next page;* Friends of Christie Creek, South Australia (Stuart Manson, *pers.comm.)*
Contribute: *Asked by scientists to collect and contribute data and/or samples*				
Potential for efficient data collection at large scale with high precision and accuracy; allows for coordination of large number of volunteers, spanning wide geographic area, the collection of large datasets, early detection of issues	Some stewardship action and behaviour changes; limited role for public participants	Limited stakeholder engagement and capacity; decision-making may be slow to result	Funding dependent and cannot continue without financial (often government) assistance; training and coordination/facilitation costs	OPAL; Earthwatch programs; BirdLife Australia programs; Feral or In Peril, South Australia
Collaborate: *Assist scientists in developing a study and collecting and analyzing data*				
Potential for efficient data collection at large scale with high data precision and accuracy; may need to choose between data collection for scientific validity and data collection for education and empowerment	Strong sense of stewardship, increased capacity and skills and appreciation of data collection concerns	Highlights local conservation issues and provides detailed local information	Resource intensive – volunteers participate in various tasks; researchers responsible for volunteer recruitment and retention, data analysis, interpretation and dissemination	Community-based monitoring of wetlands in Madagascar; BirdLife International's Important Bird Areas in Kenya; Sea Search Victoria

Table 2.2 cont'd

Outcomes for Science	Outcomes for Individuals	Outcomes for Society	Implementation Implications	Examples
Co-create: *Develop a study and work with input from scientists to address a question of interest or an issue of concern*				
Intermediate expectations of data precision and accuracy; intermediate capacity to inform large-scale monitoring schemes	Increased science process skills (refining questions and interpreting data)	Yields more decision-making power than other types of monitoring; High degree of decision-making relevance at biogeographical scale	High to establish, low to maintain; community must have commitment to goal setting, planning and implementation; For researchers, intensive support required to assist community in goal-setting, design,training and data analysis strategies	Watershed councils in Canada and USA, run by board; Ranger and community-based monitoring of resource use and wildlife in Phillipines; Eco Divers seagrass monitoring activities *(see description in Chapter 3)*
Colleagues: *Independently conduct research that advances knowledge in a scientific discipline*				
Amateurs become the 'experts' by carrying out work that otherwise might not transpire due to lack of resources, time, skills or inclinations in professional scientific community; interactions between citizens and scientists are likely only when findings are written and submitted for peer review and publication	Citizen scientists develop and extend their skills and knowledge in scientific concepts and processes; Focus of investigation is of high relevance to the individual	Allows investigations of issues where there may not otherwise be a political priority	Research is entirely self-funded by citizen scientists	Examples in fields of astronomy, physics, taxonomy and archaeology (Mims III 1999)

The spectrum of public involvement therefore places researchers, managers and communities at the nexus of shared decision-making. There are trade-offs and benefits to each of the approaches to citizen science, which these models make explicit. The use of one model over another will directly relate to the goals and aspirations of the communities, the level of support researchers and the managers can provide and the level of precision and speed of decision-making required. For example, where a high degree of precision in the data is required in order for a management decision to be applied, it may be more beneficial to employ a Contributory model of citizen science, which allocates scientists the highest level of control of the scientific process whilst still engaging the public, through collection of data. The Co-create model may be a good choice where the public have responsibility for management of natural resources, to ensure good quality science is used towards management decisions. In an example from the United States, a community group requested assistance from scientists to design a suitable monitoring program for the purpose of targeting critical areas for restoration and protection (Shirk et al. 2012): in this case, precision of data only needed to be high enough to triage restoration efforts. Contractual models can operate as an introduction to scientific process for members of the public. The expansion of 'Science Shops' across Europe (European Commission n.d.) provides socially marginalised communities with an opportunity to engage with scientists, who who provide low-cost or *pro bono* consulting services. The intent of these services is that knowledge generated is 'geared to the requirements of civil society' (European Commission n.d.).

The presence of a well-structured and well-supported framework that considers the aims of a study, the intended outcomes, and the needs of the public is critical to ensuring provision of data that meets the intended outcome and increases the likelihood of mutual satisfaction in the outcome for scientists and citizens (Bell et al. 2008; Dickinson et al. 2010; Shirk et al. 2012). Satisfaction in citizen scientists relates to the level of participation they wish to maintain, their overall experience with the activity and the aspects of support they can expect, including choice of methodology, training, support and supervision (Lovell et al. 2009). When frameworks are not developed, aims are often not achieved and the quality of data is compromised. This is an area of new research (testing whether frameworks assist in achieving outcomes) and has been initiated by a small group of researchers based in the United States (Shirk et al. 2012), however in the past this concept has been addressed in part by ensuring some analysis of volunteer motivations have been incorporated into program design (Weston et al. 2006a; Bell et al. 2008; Conrad & Daoust 2008; Wolcott et al. 2008).

2.4.1 Outcomes for Science

Each of the five models of citizen science potentially have excellent outcomes for science. Reviewed citizen science programs mainly operate within the three models of Contributory, Collaborative and Co-create (Bonney et al. 2009a; Dickinson et al. 2010), which rely heavily on interactions between the public and professionals. Citizen science projects have progressed the scientific body of knowledge on trends in species ranges, distributions, abundances and diversity; the spread of disease or invasive species; changes in phenology or life-cycle events; and have advanced innovative techniques on the collection, analysis and management of data (see Dickinson et al. (2010) and Shirk et al. (2012) for further examples of these outcomes). From a professional's perspective, there are many potential benefits of these interactions with the public, including access to greater amounts of data, (e.g. data sets collected over long periods) often at a lower cost than if the data had been collected by professional scientists (Darwall & Dulvy 1996; Newman et al. 2003; Goffredo et al. 2008; Holt et al. 2013). There is also the ability to refine, extend and complement professionally-collected data (Pattengil-Semmens & Semmens 2003; Monk et al. 2008; Edgar & Stuart-Smith 2009; Gillett et al. 2012). Volunteers can supplement condition and trend information collected by natural resource management agencies (McKenzie et al. 2000; Zeller et al. 2001), can cover areas rarely or not visited by management agencies and can survey numerous sites simultaneously (Edgar & Stuart-Smith 2009; Finn et al. 2010; Stuart-Smith et al. 2013). The biodiversity of habitats, such as seagrass beds, can vary greatly among locations, days, seasons and years, and data collected by members of the public, because of the access to greater numbers of observers, may help in quantifying this variation (West 2006). Darwall & Dulvy (1996), for instance, were able to complete baseline subtidal surveys in Tanzania, possible only through the assistance of a large number of volunteers (200 individuals over more than 6000 dives). Volunteers can also provide a project with a much-needed source of cash (Cohn 2008; Lovell et al. 2009). As volunteers directly incur part of the costs to participate in the project there are significant cost-savings to the public and scientific community. For example, volunteer SCUBA divers in Europe provided seahorse sightings to researchers, a task which would have taken one professional scientist 20 years and would have cost > $1.3 million USD (Goffredo et al. 2004).

2.4.1.1 FACTORS INFLUENCING SCIENCE OUTCOMES

The focus of criticism from scientists, understandably, is the rigour in the data the citizens provide (i.e. the sampling design, methodologies used, and the data collection procedures) and is the primary source of concern with the field of citizen science (Underwood & Chapman 2002; Foster-Smith & Evans 2003). The factors believed to influence the quality of data provided by citizen scientists are generally consistent throughout the literature and focus on three main aspects: design and execution of sampling methods; training; and quality assurance/quality control processes.

Experimental design and performance of tasks are two areas that can affect the quality of data. Schmeller et al. (2009) suggest that, in assessing influences on the quality of data collected by volunteers, "the doubt should be cast on the designer of the study, as inaccuracies or the statistical value of collected data is generally related to problems in methodology, design, or poor communication within the program". A well-designed study will reduce the likelihood of inconsistencies in the data, and therefore maximise the likelihood of useful data being provided (Goffredo 2004). Accuracy of data collection is reduced where subjective observations are required or where a result may depend on the observer's level of experience (Halusky et al. 1994; Goffredo et al. 2004; Goffredo et al. 2008; Edgar & Stuart-Smith 2009). Tasks must be realistic and achievable and appropriate to the observer's level of experience (Foster-Smith & Evans 2003), as observer effects begin to infiltrate more complex tasks, reducing the usability of the data (Halusky et al. 1994; Mumby et al. 1995; Darwall & Dulvy 1996).

Training programs have been shown to reduce both observer bias (Wilson 2002) and attrition (Wilson 2002; Edgar & Stuart-Smith 2009). Effective training programs include the use of training aids, such as manuals or field identification sheets (Halusky et al. 1994; McKenzie et al. 2000) and a form of assessment to gauge mastery of skills (Mumby et al. 1995; McKenzie et al. 2000). In some cases, volunteers attain specialized accredited certification (Halusky et al. 1994; Turner 2006; Koss et al. 2009), and in others, volunteers must achieve a certain level of success before their results are accepted as part of the body of data used in the project (Darwall & Dulvy 1996; Wilson 2002; Edgar & Stuart-Smith 2009). Follow-up training may also be necessary to keep skills fresh (McKenzie et al. 2000)

Quality assurance protocols in fieldwork, such as the use of standards and field guides and in-field supervision, can reduce potential sources of error. Seagrass-Watch, a community seagrass monitoring program, uses a consistent set of methods and validation processes (McKenzie et al. 2000; Finn et al. 2010) as does Reef Life Survey, a citizen-science based reef monitoring program (Edgar & Stuart-Smith 2009). In-field supervision of volunteers by experts, at least at some point in the program development, is essential to allow researchers to provide detailed information to the volunteers and evaluate their progress. (Goffredo et al. 2004). Citizen scientists cannot improve in their data collection techniques or observations if they are unaware of issues relating to their performance and skills. Identifying a problem is not the only necessary step: citizen scientists must also be given assistance to find a solution to the identified issue. Mumby et al. (1995) found that when the feedback loop between scientists and volunteers was missing, divers did not improve with experience in their data collection abilities. Lovell et al. (2009), Edgar & Stuart-Smith (2009), Finn et al. (2010) and Koss et al. (2009) used a high ratio of experts to volunteers, in some cases 1:1, in continual field supervision to ensure correct identification of species and application of methods. This amount of interaction between experts and volunteers may not be possible on a continual basis, but it has been shown to be beneficial, at least in the initial stages of training, ensuring procedures are understood, followed and corrected as required. An alternative to in-field supervision is the use of photos and video, which can assist the expert to remotely evaluate the volunteers' actions and data and provide feedback where required (Finn et al. 2010). A quality assurance protocol in data processing is also necessary. Development of proformas for use in the field reduces transcription errors or omissions during data entry. Cross-checking data with photos or video can be a useful tool for the researcher to double check suspicious data sets (Finn et al. 2010).

By no means is the issue of valid data a problem only for citizen science programs (Kercher et al. 2003; Newman et al. 2003; Katsanevakis et al. 2012) but the issue is perceived to be greater where citizens are involved in the provision of data (Mumby et al. 1995; Newman et al. 2003). Although there is a growing number of studies demonstrating validation tests of citizen scientist data (Halusky et al. 1994; Fore et al. 2001; Engel & Voshell 2002; Bell 2006; Delaney et al. 2008; Lovell et al. 2009; Finn et al. 2010; Gollan et al. 2012) there are currently no validation studies conducted on citizen scientists outside of field-based sampling techniques. With the growing use of digital technology in environmental monitoring, using volunteers for computer-based tasks is likely and is already occurring in some fields (eg. Zooniverse, https://www.zooniverse.org; Fold it, http://fold.it/portal; Explore the Sea Floor, http://exploretheseafloor.net.au). Therefore there is a need to extend validation of citizen scientists to these types of tasks.

Validation primarily centres on the reliability of data citizens provide, comparing volunteers with each other (Halusky et al. 1994; Delaney et al. 2008; Ward-Paige & Lotze 2011) or with experts (sometimes called 'parallel testing'), with the implicit assumption that experts are relatively accurate (Mumby et al. 1995; Darwall & Dulvy 1996; Fore et al. 2001). However, few citizen science studies have provided assessments of expert accuracy: rather than relying on assumptions, conducting tests of expert accuracy should be included in all studies (Foster-Smith & Evans 2003; Kercher et al. 2003) against a standard where possible. This aspect of a citizen science program is important as it may expose sources of error outside of observer bias, such as in the methods, equipment or techniques (Newman et al. 2003). New methods have become available which assist in assessing these biases (Bird et al. 2013).

Ely (2008b) reported that volunteers were rarely involved in aspects of environmental research outside of data collection (the Contributory model). Engaging citizens in additional research activities beyond the collection of data, such as developing research questions, designing studies, analysing and interpreting data, is more likely to provide citizens with a better appreciation of the whole process of research (Newman et al. 2003; Ely 2008b; Wilderman in Conrad & Hilchey 2011; Roy et al. 2012). This, in turn, increases the potential for initiating localized, hypothesis-driven research (Foster-Smith & Evans 2003; Dickinson et al. 2010). To date, this potential remains largely unexplored.

2.4.2 Outcomes for Individuals

An outcome for Science is only one of the many potential reasons for engaging with volunteers, as participation by volunteers in research and monitoring programs may be beneficial to both the individuals involved and the public. As well as the potential for developing a deeper appreciation for scientific processes (see above), individuals involved in citizen science learn new skills (Foster-Smith & Evans 2003; Newman et al. 2003; Bell et al. 2008; Thomsen 2008) and have their eyes opened to new landscapes, species and ecosystems (Foster-Smith & Evans 2003; Bell et al. 2008)

Becoming more environmentally responsible requires a change in attitude (Stepath 2000), and is not just the result of exposure to new information. Volunteer monitoring programs have been shown to lead to changed behaviour relating to environmental issues and personal responsibility (Saunders 2002; Foster-Smith & Evans 2003; Thomsen 2008; Koss & Kingsley 2010), including conducting small conservation projects inspired by their experiences in the study (Gladstone et al. 2006; Lovell et al. 2009), joining conservation groups (Newman et al. 2003), and participating in other social movement activities (Lovell et al. 2009). As Tofler (in Wilson 2002) noted, “members of a small group working together to bring about some change in the ecological condition of their community…will find they must learn something about science, economics, sociology and politics, as well as the communicative skills required to define the difficulties, outline alternative solutions, and persuade others.” Working towards a long-term goal (for example, a long-term data set) may not be sufficiently engaging for participants' ongoing participation. Thomsen (2003) highlights the social and interactive aspects of citizen science and the importance of rewarding and enjoyable social processes in ensuring continued participation of volunteers. By giving the scientific and social aspects of a project equal focus, the maximum benefit of community participation can be achieved (Saunders 2002; Foster-Smith & Evans 2003; Thomsen 2003; Overdevest et al. 2004). This indirectly benefits the agency as, apart from the acquisition of data, these social benefits contribute to the longer-term sustainability of the project (Foster-Smith & Evans 2003). Individuals and community groups with an interest in their local environments often have a detailed knowledge of and expertise in particular environmental features. Development of this expertise, along with scientific support, can enable comprehensive monitoring in local areas and increased understanding of local environments for communities, managers and scientists (Jacoby et al. 1997; Wilson 2002; Overdevest et al. 2004).

It is important to consider the support needs of the volunteers as they contribute their freely given time, effort and personal funds (Stepath 2000; Newman et al. 2003; Edgar & Stuart-Smith 2009; Finn et al. 2010). The voluntary nature of citizen science demands that 'rewards' other than monetary ones must be fostered (Thomsen 2003). Volunteer monitoring generates feelings of personal satisfaction and enjoyment through contribution and socialising with others (Overdevest et al. 2004; Koss & Kingsley 2010). The richer the experience, the less turn-over and attrition will result which, in turn, reduces the demand on the research team for training and administrative management tasks, a very common issue with volunteer monitoring programs (Underwood & Chapman 2002; Danielsen et al. 2009).

2.4.3 Outcomes for Society

Although there is a growing number of documented cases of positive science outcomes (eg. scientific findings) from citizen science programs (Smith & Edgar 1999; Goffredo et al. 2004; Edgar & Stuart-Smith 2009; Huveneers et al. 2009; Clemens et al. 2010; Ward-Paige & Lotze 2011; Iwamura et al. 2013) and the literature increasingly is capturing the outcomes of citizen science for individuals (Newman et al. 2003; Overdevest et al. 2004; Bell et al. 2008; Thomsen 2008; Koss & Kingsley 2010) documentation on societal outcomes is evident, but less explicit, and limited in the type of outcomes discussed. Identified outcomes for society include partnerships between the public and scientists and managers (Jacoby et al. 1997; McKenzie et al. 2000; Wilson 2002; Goffredo et al. 2008); conservation and management actions (Jacoby et al. 1997; McKenzie et al. 2000; Danielsen et al. 2005; Seak et al. 2011) and increased public engagement in policy processes (Carr 2004; Overdevest et al. 2004; Thomsen 2008).

Partnerships are well discussed in the literature. When collecting data across a wide geographic region the use of partner organisations in regional and local areas is essential to manage data, minimize duplication of effort and maintain data quality (McKenzie et al. 2000; Silvertown 2009). Partnerships are essential when engaging a wider sector of the public: a citizen science program in Italy which used recreational divers to collect marine biodiversity information resulted in increased participation of businesses and agencies to further develop regional initiatives and productive environmental consortiums (Goffredo et al. 2008). People benefit from and place value on contributions from scientists and other experts. A comprehensive survey undertaken by Alexandra et al. (1996) showed partnerships were actively sought and highly valued by community volunteers undertaking community-based monitoring. Partnerships also provide the opportunity for scientists and natural resource managers to work together to develop and frame questions in a measurable way, to promote prioritization and to meet agreed outcomes between science and management (Lindenmayer & Likens 2009). Partnerships allow volunteers and facilitators to access support from a variety of sources and develop networks for learning and shared decision-making (Thomsen 2008).

Policy, conservation or management outcomes are fairly well documented in developing countries (Danielsen et al. 2005; Seak et al. 2011) where citizen science activities directly feed into natural resource management practices, but are less well documented in developed countries. This could be due to the time lag between research, management action and determining the impact of the action (Shirk et al. 2012), or could be due to a lack of communication of the results of studies using citizen science (Cohn 2008; Ely 2008a; Benz et al. 2013). It is, however, recognized that projects designed primarily by the public (the Collegial model) have fewer opportunities to build trust with managers and researchers, which affects the probability of their use for decision-making (Burgin 2002; Saunders 2002; Fernandez-Gimenez et al in Shirk et al. 2012). In any case, the lack of documented cases of these societal outcomes presents a serious gap in the knowledge of scientists for any further integration of citizen science into research and decision-making.

2.5 Conclusions

Governments in Australia have a range of mechanisms available for managing natural resources. Community participation is seen to be the predominant paradigm, whereby 'communities' are integrated with natural resource management through sustainability concepts of education and capacity building, and management activities of planning, environmental restoration, conservation, monitoring and decision-making. This paradigm, a shift from a previous top-down management approach consisting almost exclusively of experts, has created in some contexts a tension between 'scientists' and 'citizens'. It has been suggested that citizen science provides a bridge between multiple stakeholders who can contribute equally in implementing positive change and better management of natural resources (Jacoby et al. 1997; Stepath 2000; Thomsen 2008).

A series of models, synthesized by Shirk et al. (2012) from a range of work by practitioners in the field of citizen science, provides a way of conceptualizing the different types of interactions between the public and scientists, ranging from Contractual, where citizens engage scientists to research and report on a specific issue, through to Collegial, where amateurs make their own discoveries and may become experts in the field. The models of predominant focus to citizen science practitioners are Contributory, Collaborative and Co-create, which exhibit the highest levels of interaction between scientists and citizens. Peer-reviewed literature on citizen science is concentrated on the Contributory model.

Quality assurance and quality control are identified as factors in the use of citizen science data by researchers and managers (Darwall & Dulvy 1996; Delaney et al. 2008; Dickinson et al. 2010). Validation studies have been undertaken within many fields of environmental research, with citizen science capabilities closely scrutinized. Trust in data generated by citizen scientists may be gained if the data satisfy appropriate statistical analysis considerations, although new methods provide greater flexibility and inferential opportunity (Bird et al. 2013).The vast majority of validation studies centre on potential benefits and challenges to using citizen scientists for data collection, with multiple studies finding that, with adequate training, volunteers can perform tasks as competently as experts (Fore et al. 2001; Foster-Smith & Evans 2003; Newman et al. 2003; Pattengil-Semmens & Semmens 2003; Edgar et al. 2004; Goffredo et al. 2004; Delaney et al. 2008; Gollan et al. 2012) The majority of these validation studies focus entirely on in-field tasks. With use of and advances in digital technology in ecological studies, data processing, as a part of research, will be required as much or more than fieldwork, and volunteers are already showing interest in being involved in these types of tasks. There is therefore a need to extend validation of citizen scientists to computer-based tasks in addition to the traditional fieldwork activities. Validation studies, although recognizing the need for a quantitative assessment of expert precision alongside the analyses of the citizen scientists, often do not provide such an evaluation and thus highlight a need to incorporate this aspect more widely in studies of citizen science.

Citizen science is described as having three general outcomes: for science, for the individual, and for society (inferring decision-making applications) (Shirk et al. 2012). Much of the recent discussion on the topic of citizen science focuses on its contribution to science (Foster-Smith & Evans 2003; Newman et al. 2003; Dickinson et al. 2010; Roy et al. 2012) with limited discussion of the benefits to individuals (sustainability learning, Thomsen 2008; well-being, Koss & Kingsley 2010). However, not currently present in the literature is an analysis and discussion on the usefulness of citizen science for decision-making purposes, often the third intended outcome of citizen science programs (Walker & Daniels 2001; Danielsen et al. 2005). The imbalance in published records of scientific vs societal or individual outcomes is perhaps due to the actual or perceived notion that research specific for local management is less ‘publishable’ in traditional journals. However, if science is to be useful to society, it is essential to understand the current uptake of citizen science by decision-makers and the factors they consider to be of greatest influence on their choice to use citizen science in their decision-making processes.

CHAPTER 3* ASSESSING THE QUALITY OF DATA COLLECTED BY CITIZEN SCIENTIST SCUBA DIVERS FOR MONITORING SEAGRASS CONDITION

Carla Sbrocchi[1], Tim Glasby[2], William Gladstone[1]

[1] School of the Environment, University of Technology Sydney, Sydney NSW

[2] Port Stephens Fisheries Institute, Department of Primary Industries, Taylors Beach, NSW

ABSTRACT

For environmental managers and researchers to use the data provided by citizen scientists, they must be able to trust its quality (i.e. accuracy, precision and reliability). The aim of this study was to test the accuracy and precision of citizen scientists of varying levels of experience in resource monitoring. This was done by field and lab experiments that compared data on seagrass condition collected by citizen scientists (volunteers) with data collected by professional scientists (experts). Data on subtidal seagrasses collected by citizen scientists using SCUBA-based field and computer-based sampling methods were not significantly different from those collected by professional scientists for two field tasks, measurements of leaf lengths and mooring scours. Citizen scientists did not differ from experts in their estimates of % occurrence of seagrasses and sand (from video transects), however, they differed in a more complex task of estimating % cover of seagrass and other habitat features (from photoquadrats). Experts differed in their estimates of % cover from photoquadrats, indicating methods require review and may have contributed to volunteer results. Citizen scientists found the computer-based activities helpful in expanding their knowledge on scientific processes and essential for evaluating and modifying

* This chapter has been formatted for submission to the journal Bulletin of Marine Science. Material from Chapter 2 may be repeated here as this chapter is intended to stand alone.

techniques used in their monitoring protocol. This evidence further supports the inclusion of volunteer SCUBA divers in scientific research (including seagrass condition monitoring) and highlights the importance of also validating professionals prior to training volunteers.

Key words: marine biodiversity, citizen science, natural resource management, public participation in scientific research, seagrass condition assessment, validation, SCUBA, volunteer

3.1 INTRODUCTION

The term 'citizen science' is most often used to mean the involvement of members of the public in scientific research activities (Miller-Rushing et al. 2012; Shirk et al. 2012). The phenomenon of citizen science is growing, substantiated by the growth in number and diversity of relevant publications (Benz et al. 2013). In recent years there have been reviews on: the current state of citizen science (Roy et al. 2012); the history of citizen science (Miller-Rushing et al. 2012); the development of frameworks for implementing citizen science programs (Danielsen et al. 2009; Shirk et al. 2012); considerations of the issues and opportunities (Mackney & Spring 2001; Bonney et al. 2009b; CSIRO 2009; Dalton & Smith 2009; Dickinson et al. 2010; Conrad & Hilchey 2011; Stenekes & Sahlqvist 2011; Clarke et al. 2012); the development of best practice for engaging volunteers in citizen science (Bell et al. 2008; McIntyre 2008); and discussion of the associated social outcomes, such as increasing well-being (Koss & Kingsley 2010), a greater awareness of sustainability concepts (Thomsen 2003; Thomsen 2008) and participation in management activities (Carr 2004; Danielsen et al. 2009). The range of activities citizen scientists undertake is broad, with over 200 groups participating specifically in marine citizen science in Australia alone, gathering information about reef health, shorebird presence, turtle nests, marine mammal behaviour, exotic species occurrence, water quality and resource use (C Sbrocchi, University of Technology Sydney, unpubl data).

One of the intended outcomes of citizen science is the provision of information for sound and informed decision-making for the better restoration, conservation and management of ecosystems and natural resources (Walker & Daniels 2001; Danielsen et al. 2005). It has been suggested that for environmental managers and researchers to use the data provided by citizen scientists for decision-making and to test hypotheses, respectively, they must be able to trust it (Mumby et al. 1995; Newman et al. 2003; C Sbrocchi, University of Technology Sydney, unpubl data). Trust may be gained if the data satisfy appropriate statistical analysis considerations, although new methods provide greater flexibility and inferential opportunity (Bird et al. 2013). Data quality incorporates aspects of accuracy (how close an estimate is to the true value), reliability (consistency in accuracy and data provision over time) and precision (similarity of estimates among observers) (Andrew & Mapstone 1987). It is important to note that accuracy and precision are independent of one another – data can be precise (all estimates are similar to each other, i.e. minimal variability among samplers), yet inaccurate (the estimates are far from the true values) (Andrew & Mapstone 1987; Underwood 1997). By no means is the issue of data quality relevant only for citizen science programs (Kercher et al. 2003; Newman et al. 2003; Katsanevakis et al. 2012), but it is perceived to be more of a potential problem in cases where citizens provide data (Mumby et al. 1995; Newman et al. 2003). Thus, it is important to audit samplers to quantify both the precision and accuracy of the data they produce.

Validation studies usually focus only on the precision of citizens, by comparing data with each other (Halusky et al. 1994; Delaney et al. 2008; Ward-Paige & Lotze 2011) or with professional scientists (i.e. 'parallel testing'), with the implicit assumption that experts are relatively accurate (Mumby et al. 1995; Darwall & Dulvy 1996; Fore et al. 2001). Rather than relying on assumptions, tests of expert accuracy should be included in all studies (Foster-Smith & Evans 2003; Kercher et al. 2003) against a standard where possible. This aspect of a citizen science program is important as it may expose sources of error outside of observer bias, such as in the methods, equipment or techniques (Newman et al. 2003).

Citizen science is experiencing growth in the marine sciences (Figure 3.1, also Supplementary Table S3.1) with 124 papers published over a period of 19 years.

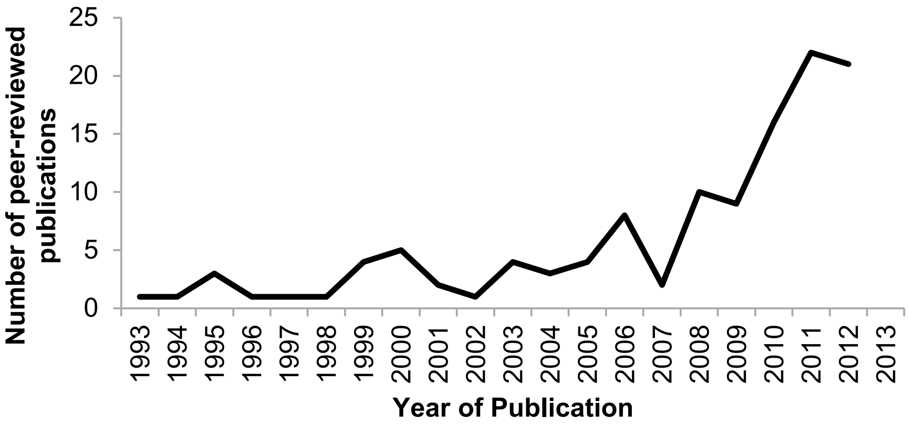


Figure 3.1. Peer-reviewed publications implying use of citizen science for marine data collection, 1993 to 2012. Compiled list of references can be found in Supplementary Table S3.1.

A sample of 12 papers, randomly selected from the 124 papers (~10% sample, Supplementary Table S3.1), revealed that parallel tests were performed in 11 (92%) studies but scientists' results were validated only in 3 (25%) studies (Supplementary Table S3.2). This study will provide a validation of data collected by professional scientists to provide context to the results of the parallel test between citizen scientists and professional scientists.

Validation studies on volunteer data have shown that data provided by volunteers is not usually demonstrably different from professional scientists for a range of data types, including fish length estimates, species identification, water quality parameters, and percentage cover estimates (Halusky et al. 1994; Pattengil-Semmens & Semmens 2003; Delaney et al. 2008; Edgar & Stuart-Smith 2009; Finn et al. 2010) However, given the growing use of digital technology in environmental monitoring, there is potential to engage volunteers in computer-based tasks and this is already occurring in some contexts (e.g. Zooinverse, Explore the Sea Floor). There is a need to extend validation of citizen scientists to tasks outside of field-based sampling techniques to include computer-based tasks.

There are numerous operational models that characterize the level of interaction between scientists and members of the public as part of a citizen science program. These can range from scientist-led studies in which volunteers participate to community initiatives that engage scientists in development of study aims, design and data analysis (summarised in Shirk et al. 2012). However, citizens are rarely involved in aspects of environmental research outside of data collection, with fieldwork being the implied mode of participation (Ely 2008b). By engaging citizens in additional research activities, such as developing research questions, designing studies, data processing, analysis and interpretation, they may become more engaged in the process of research and natural resource management (Newman et al. 2003; Ely 2008b; Wilderman in Conrad & Hilchey 2011; Roy et al. 2012). To date, this potential remains largely unexplored.

The aim of this study was to test the accuracy and precision of volunteers of varying levels of experience in resource monitoring. This was done using field and lab experiments that evaluated the quality of data collected by citizen scientists and comparing these with data collected by professional scientists. This study used data collected during fieldwork and computer-based techniques, and it therefore extends the scope of previous research on quality assessments of citizen scientist-collected data.

3.2 METHODS

3.2.1 STUDY SITE

The field component of this study was undertaken in Manly Cove, Sydney Harbour, New South Wales, Australia (-33.801372, 151.285649). The site is sandy and shallow (2-4 m) with generally very good underwater visibility and low swell. The site comprises a mix of seagrass species (*Halophila* spp., *Zostera muelleri* spp. *capricorni* and *Posidonia australis*). The site has been the subject of recent study (Gladstone 2010; 2011, 2012) which assessed the impacts of moorings on seagrass meadows. Traditional moorings consist of a block (usually of concrete), chain rope and mooring buoy (hereafter called swing mooring). Ebb and flow of the tide as well as variations in wind strength and direction cause the chain to drag along the seabed in response to movements of the attached boat, removing seagrass and other organisms. As a result, a scour develops and further action of the chain prevents seagrass from recolonising the area (West 2011; Demers et al. 2013). Replacing these swing moorings with seagrass-friendly moorings aimed to remove the constant pressure on the sediment and seagrass meadows from the scouring action of chains, and thereby allow seagrasses to recolonize the scours. The outcomes of this were monitored (NSW Department of Primary Industries Fisheries 2009; Gladstone 2010).

3.2.2 PARTICIPANTS

This study involved a group of citizen scientists, Eco Divers, who had initiated and participated in volunteer marine assessment and monitoring activities (including seagrass monitoring) for four years at the time this study commenced. The field experiment involved four participants from Eco Divers, all of whom had previously participated in seagrass monitoring. The lab experiment involved seven participants, five from Eco Divers and two from other dive research clubs, none of whom had any experience in the particular lab techniques prior to this study (although the group included several participants from the field experiment). The field experiment also involved three professional marine researchers from the NSW Department of Primary Industries (DPI), all of whom had >7 yr of experience (range 7–20 yr) monitoring seagrasses and other subtidal habitats using a variety of techniques. The lab experiment involved four professional marine researchers that comprised two of the researchers from DPI involved in the field experiment and two from the University of Technology Sydney. The professional marine researchers had >4 yr experience (range 4-15 yr) in the techniques employed.

3.2.3 FIELD EXPERIMENT: HYPOTHESES AND SAMPLING DESIGN

The field study tested the null hypothesis that measurements of mooring scour lengths and seagrass leaf lengths collected by volunteers and experts would not differ. All divers measured the dimensions of mooring scours and leaf lengths at 12 sites, comprised of 4 traditional swing moorings, 4 seagrass-friendly moorings and 4 control sites (seagrass meadows with no moorings). Data were collected by the Eco Divers citizen scientists (hereafter called ‘volunteers’) and professional scientists (hereafter called ‘experts’) in March-May 2012.

Divers used two fibreglass tapes to lay out 10 m transects at the four cardinal compass points intersecting at the midpoint of the mooring, or through an assigned midpoint at a control site. Volunteer divers recorded video of the transects, first in the north-south direction, then in the east-west direction, to be used in quantifying the biotic attributes of each site (see next section on lab experiment). Two 0.5x0.5 m quadrats were placed along each transect at assigned distances and photographed for estimates of % cover of seagrass (see next section on lab experiment). The diver selected the 10 longest leaves of *Zostera muelleri* spp. c*apricorni* (hereafter called

Zostera) and *Posidonia australis* (hereafter called *Posidonia*) within each quadrat and recorded their length to the nearest 1 mm. Scour lengths in the four cardinal directions were measured from each transect to the nearest 1 cm at 8 sites (four seagrass friendly moorings and four swing moorings). Divers generally worked in teams of three: the first diver deployed the transects and quadrats, the second diver recorded the video transects and photoquadrats, and the third diver recorded the measurements. Divers changed roles at different sites.

3.2.4 Lab experiment: hypotheses and sampling design

The lab experiment tested the null hypothesis that estimates of the % cover of seagrasses and sand (from photoquadrats) and % occurrence of seagrasses and sand (from video transects) would not differ between volunteers and experts. The lab experiment also tested the null hypothesis that experts would not vary significantly in their estimates. Volunteers participated in a day-long training workshop in June 2012 where in-depth instruction on use of the computer-based sampling techniques (given the term 'data processing' when used with the volunteers) was given by one of the professional scientists. Although the volunteers all had some experience in underwater sampling (range 1-4 years), none had previously been involved in computer-based environmental sampling.

Four experts and seven volunteers used the photo-quadrat images, taken by the volunteers, to assess the % cover of the following features: *Halophila*, *Zostera*, *Posidonia*, algae or sand. Algae were sampled but not analysed because they occurred so infrequently. The photograph taken of each quadrat was overlaid with a 100-point grid. The identity of the feature underlying each point on the grid was recorded and the total number of records of each feature summed to provide an estimate of its % cover in the quadrat.

The % occurrence of seagrass and sand at each site was quantified from the video transects by two experts and seven volunteers. Along each transect, the video was paused at 10 evenly-spaced time intervals and the presence-absence of each feature (*Halophila*, *Zostera*, *Posidonia*, sand, algae) in the image was recorded ('1' for present, '0' for absent). The number of occurrences of each feature from the 10 pause positions along each transect was recorded and % occurrence calculated. Photo-quadrats and video transects are among the suite of standard methods that are used to estimate seagrass cover and occurrence (Lanyon & Marsh 1995; Duarte & Kirkman 2001; McDonald et al. 2006).

As part of the training session, volunteers were given time to work on the tasks and receive feedback and assistance. Where volunteers could not complete the tasks within the training session, the remainder of work was completed on the volunteer's own time and submitted on a USB drive via postwithin six weeks of the training session.

3.2.5 INFLUENCE OF PHOTO QUALITY

The quality of the photoquadrat images taken by the volunteers that had been used in the lab experiment was assessed by one of the professional scientists using criteria based on clarity, lighting, the angle at which the photo was taken, and whether the photo was centred. Each image was given a 'quality score' between 1 (very poor) and 5 (excellent). These scores were used to determine whether photo quality was a contributing factor to variation in estimates of % cover of the variables assessed.

3.2.6 VOLUNTEERS' ATTITUDES AND PERCEPTIONS

To test the hypothesis that participating in activities other than traditional field-based data collection improves understanding of scientific processes, volunteers completed a questionnaire that asked them to rank (on a Likert scale from 0-5) their experience with the computer-sampling exercises. The questionnaire examined their confidence in performing the task immediately after the training session and after completing the task, the usefulness of the feedback received during the training session, the usefulness of the activity to their overall understanding of the scientific research process and their role in particular as a volunteer (Table 3.1). Although all of the volunteers had previously participated in some underwater monitoring activities, four of the seven volunteers had specific seagrass monitoring experience. None of the volunteers were experienced in computer-based sampling techniques. Results of the questionnaire were analysed by descriptive statistics (frequencies and percentages). Volunteers were also asked to provide an estimate of the time taken to complete the tasks.

Table 3.1. Questions asked of volunteers after a training session to assess their level of enjoyment with the data processing (lab) experiment. n=7

Question	Possible responses
Please circle the number that best describes how you felt immediately after the training session: how confident did you feel that with the described methods you could undertake the task? (1 = did not feel confident, 5= felt confident in most tasks)	1, 2, 3, 4, 5
Please circle the number that best describes how you felt once you had completed the task: how confident were you that you had completed the task in the way the methods described? (1 = did not feel confident, 5= felt confident in most tasks)	1, 2, 3, 4, 5
If you were given assistance or feedback while undertaking the task, how useful was the feedback? (1= 'not useful', 5 = 'very useful')	1, 2, 3, 4, 5
Please tick the statements that describe how you feel about the data processing aspect of this study:	o The data processing activity enhanced my overall experience of participating in research. o The data processing activity improved my understanding of how research works and what scientists do. o The data processing activity improved my understanding of volunteers' contribution to research. o I would prefer not to participate in this aspect of research again. o I would like to participate more in this aspect of research.

3.2.9 Statistical analyses

Field experiment

The experimental design consisted of two factors: Expertise (fixed, 2 levels: expert, volunteer) and Site (random, with n=9 levels for test of leaf length measurements and n=8 levels for test of scour length measurements). For scour length measurements, control sites were not relevant. The type of site (control, swing and seagrass-friendly mooring) was thus not included as a factor, as a comparison of Expertise across numerous sites was the focus of this study.

Although the field experiments consist of univariate measurements, PERMANOVA, (Anderson 2001; McArdle & Anderson 2001) a multivariate permutational program, was used to test the null hypotheses as PERMANOVA allows unbalanced design and produces estimates of components of variance.

PERMANOVAs were based on a Euclidean distance similarity matrix, with significance determined by permutation (9999 permutations under a reduced model). Analyses were undertaken with PRIMER 6 & PERMANOVA+ software (Primer-E).

Leaf length measures in each quadrat were averaged with n=8 values per person per site. *Posidonia* leaf length data were log(x+1) transformed to remove heterogeneity of variances (tested by Conchran's C-test). Four replicates of scour length measurements per site were used.

Lab experiment

Factors included in the PERMANOVA model used to compare % cover estimates of seagrass species among volunteers and experts were: Expertise (fixed, 2 levels: expert or volunteer), Person (random, 11 levels, nested within Expertise; 7 volunteers and 4 experts) and Site (random, 12 levels), with n=8 replicates per site. Heterogeneity of variances for *Posidonia* and *Halophila* percentage cover analyses could not be removed, thus untransformed data were analysed for these variables, however, significance levels were reduced to 0.01.

PERMANOVA was also used to test the hypothesis relating to the % occurrence of seagrasses and sand at each site. Factors included in the PERMANOVA model were Expertise (fixed, 2 levels: expert, volunteer), Person (random, 9 levels, nested within Expertis; 7 volunteers and 2 experts), and Site (random, 12 levels). Percent occurrence values in each transect were averaged with n=4 values per person. Heterogeneity of variances for *Posidonia* and *Halophila* percent occurrence analyses could not be removed; thus untransformed data were analysed for these variables, however, significance levels were reduced to 0.01. PERMANOVAs were based on a Euclidean distance similarity matrix, with significance determined by permutation (9999 permutations under a reduced model). All other details were the same as above.

3.3 Results

3.3.1 Field experiment

Means of measurements for leaf length and scour length are displayed in Figures 3.2 and 3.3. Results of PERMANOVAs of mean leaf length measurements for *Posidonia* and *Zostera* and mean scour length measurements for volunteers and experts are summarised in Table 3.2. No significant differences were detected for either variable between experts and volunteers, although differences were apparent among sites. The residual variance components were always larger than the variance components associated with the other factors, indicating that variation among replicate units was important.

Table 3.2. Summary of PERMANOVAs testing for differences in estimates of mean leaf length of *Zostera* and *Posidonia* and of mooring scour lengths, measured by volunteers and experts. Estimates of variance components are included. Transformations are written above each analysis. *When Expertise x Site was non-significant (p>0.25), this term was pooled with the Residual to create new tests for the main factors.

Source	df	MS	F	p	Variance component
a) *Zostera* leaf length	No transform				
Expertise	1	66.46	0.85	0.35	0.00
Site	8	337.19	4.33	<0.001	4.02
*Expertise x Site	8	77.84			0.00
Residual	126	80.02			8.82
b) *Posidonia* leaf length	Ln(x+1)				
Expertise	1	0.02	0.01	0.91	0.00
Site	8	7.00	5.70	0.001	0.60
*Expertise x Site	8	1.22			0.00
Residual	126	1.29			1.11
c) Scour length	No transform				
Expertise	1	23.21	2.37	0.13	0.65
Site	7	30.68	3.14	<0.01	1.62
*Expertise x Site	7	6.35	0.65		0.00
Residual	48	10.28			3.13

Figure 3.2. Estimates of Mean (+ Standard Error) leaf length of *Zostera* and *Posidonia* seagrass measured by experts and volunteers.

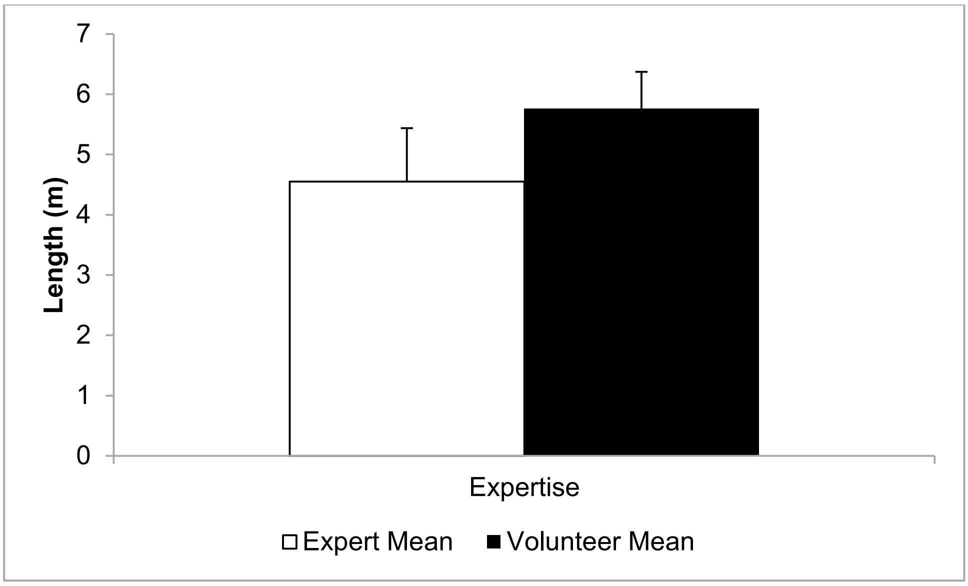


Figure 3.3. Estimates of mean (+standard error) length of mooring scours from experts and volunteers.

3.3.2 LAB EXPERIMENT

PERMANOVA was used to compare variation between volunteers and experts for the variables % cover and % occurrence, summarised in Tables 3.3 and 3.4. Significant differences were detected for % cover of all parameters (seagrass species and sand; Table 3.3, Figure 3.4). Pairwise tests revealed that estimates of mean % cover of experts and volunteers differed significantly at some but not all sites (Table 3.4), and the number and identity of sites where differences occurred was different for each variable. Significant differences between experts and volunteers in % cover estimates occurred at three sites (*Zostera*), one site (*Posidonia*) and six sites (sand). Estimates of mean % cover by experts were higher than volunteers for two variables (*Zostera* and *Halophila*) and lower for two (*Posidonia* and sand) (Figure 3.5).

Table 3.3. Summary of PERMANOVA results testing for differences between experts and volunteers in estimates of mean % cover of seagrass (*Zostera, Posidonia, Halophila*) and sand from photoquadrats. Estimates of variance components are included. Transformations are written above each analysis. *Adjusted Significance level of p=0.01 used because variances were heterogenous and could not be eliminated by transformations.

Source	df	MS	F	p	Variance component
a) *Zostera*	No transform				
Expertise	1	4369.10	4.60	<0.01	2.67
Site	11	5916.50	72.15	<0.001	8.46
Person(Expertise)	9	691.59	8.43	<0.001	2.52
Expertise x Site	11	275.84	3.36	<0.001	2.18
Person(Expertise) x Site	99	82.00	0.18	1	0.00
Residual	924	446.87			21.13
b) *Posidonia*	No transform*				
Expertise	1	230.74	2.71	0.05	0.56
Site	11	2911.30	301.33	<0.001	5.96
Person(Expertise)	9	28.86	2.99	<0.001	0.44
Expertise x Site	11	59.91	6.20	<0.001	1.11
Person(Expertise) x Site	99	9.66	0.11	1	0.00
Residual	924	91.58			9.57
c) *Halophila*	No transform*				
Expertise	1	189.97	3.11	0.04	0.52
Site	11	195.63	46.63	<0.001	1.53
Person(Expertise)	9	33.44	7.97	<0.001	0.55
Expertise x Site	11	28.90	6.89	<0.001	0.77
Person(Expertise) x Site	99	4.20	0.73	0.98	0.00
Residual	924	5.72			2.39
d) Sand	No transform				
Expertise	1	13509.00	7.61	<0.01	4.91
Site	11	14601.00	124.95	<0.001	13.33
Person(Expertise)	9	1186.30	10.15	<0.001	3.34
Expertise x Site	11	603.15	5.16	<0.001	3.46
Person(Expertise) x Site	99	116.86	0.22	1	0.00
Residual	924	528.67			23.03

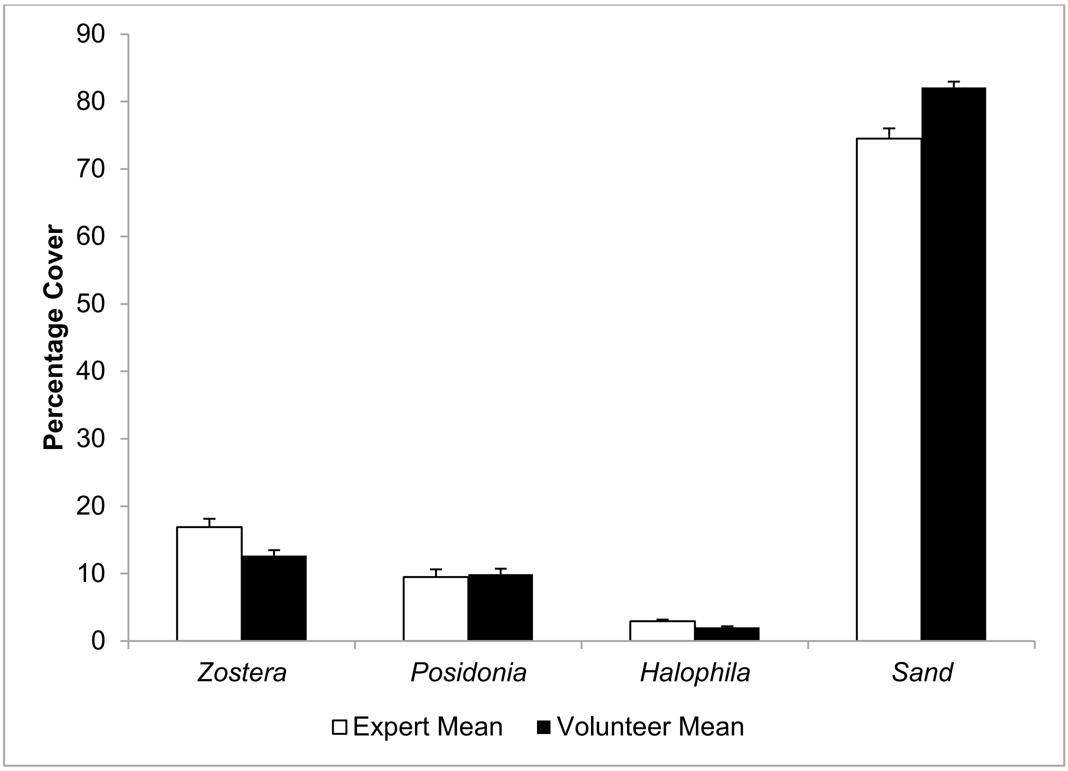


Figure 3.4. Estimates of mean (+ standard error) of % cover of *Zostera, Posidonia, Halophila* and sand recorded by experts and volunteers.

Table 3.4. Results of pair-wise tests comparing Expert and Volunteer data for each site. *Adjusted significance level of *p*=0.01 used for *Posidonia* and *Halophila* because variances were heterogeneous and could not be eliminated by transformations. Significant *p*-values are in bold.

Site	a) *Zostera*		b) *Posidonia*		c) *Halophila*		d) Sand	
	t	*p*	*t*	*p**	*t*	*p**	*t*	*p*
1	1.25	0.27	0.00	**0.00**	0.12	1.00	1.11	0.28
2	2.36	**0.04**	3.42	0.01	0.71	0.53	3.52	**0.01**
3	0.13	0.90	1.14	0.50	1.23	0.40	0.21	0.84
4	1.77	0.16	1.11	0.41	0.73	0.49	1.41	0.19
5	1.77	0.11	0.74	1.00	1.79	0.13	2.42	0.05
6	0.79	0.45	3.49	0.01	2.14	0.04	2.11	0.08
7	2.83	**0.02**	1.07	0.42	0.17	0.87	2.84	**0.02**
8	1.97	0.08	0.77	0.65	2.31	0.04	2.77	**0.02**
9	1.93	0.09	3.09	0.02	2.39	0.04	3.67	**0.01**
10	2.99	**0.01**	2.39	0.04	2.45	0.03	2.83	**0.01**
11	2.32	0.05	2.13	0.07	2.25	0.05	2.94	**0.02**
12	1.02	0.31	0.30	0.81	2.96	0.02	2.11	0.07

Additional pairwise tests were performed to investigate the significant term Expertise x Site. Demonstrated in Figure 3.5, all variables were recorded quite differently amongst people (both experts and volunteers). Within volunteers (person 1-9), sand was recorded differently at 10/12 sites, *Posidonia* was noticeably recorded by only one volunteer at one site (site 8) and not recorded by two volunteers at another site (site 11), *Zostera* was recorded differently at four sites, and *Halophila* at six. Within experts (person 10-13) the main sources of variation seem to be with how sand is recorded (particularly by one expert at all sites, *Posidonia* at one site (site 6) but also *Zostera* at four sites (sites 6,7,11,12). The components of variance associated with the residual are always larger than those associated with Expertise or Person, indicating that variation amongst samples, replicates and sites is important.

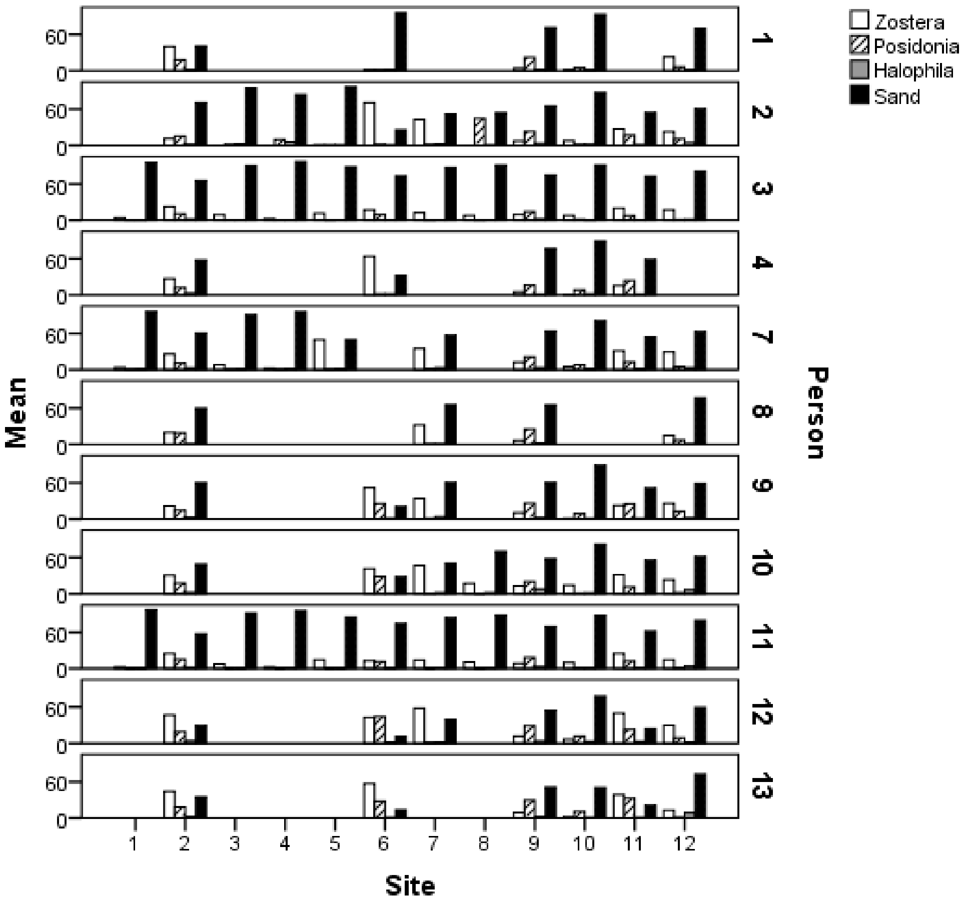


Figure 3.5: Estimates of mean % cover of seagrass (*Zostera, Posidonia, Halophila*) and sand recorded by each person at each site. Person 1-9 = volunteers, 10-13 = experts. Sites 1-4 are seagrass friendly moorings, Sites 5-8 are swing moorings, and Sites 9-12 are controls (i.e. no moorings).

Experts and volunteers did not differ significantly in their estimates of the mean occurrence of any of the seagrasses or sand using the video transect technique (Table 3.5). Components of variance reveal there was some variability among people within levels of expertise for *Halophila,* and sand, however, there is more variation due to sites and individual replicates. There was no difference amongst people within levels of expertise for *Zostera* and *Posidonia*. Post-hoc comparisons indicated the cause for the significant Person(Expertise) term for *Halophila* was due to differences among the volunteers, not between the two experts. For sand, the cause of the significant Person(Expertise) could not be determined from the pairwise comparisons.

Table 3.5. Summary of PERMANOVA results testing for differences between experts and volunteers in estimates of mean % occurrence of seagrasses and sand from video transects Transformations are written above each analysis. Variance components are included. *Adjusted significance level of p=0.01 used because variances were heterogeneous and could not be eliminated by transformations.

Source	df	MS	F	p	variance component
a) *Zostera*	No transform				
Expertise	1	2.88	0.23	0.75	0.00
Site	11	147.70	89.63	<0.01	2.42
Person(Expertise)	7	12.76	1.92	0.07	0.35
Expertise x Site	11	0.95	0.57	0.83	0.00
Person(Expertise) x Site	77	1.65	0.25	1	0.00
Residual	324	6.65			2.58
b) *Posidonia*	No transform*				
Expertise	1	4.18	1.50	0.278	0.00
Site	11	119.59	160.16	<0.01	2.18
Person(Expertise)	7	2.78	0.61	0.75	0.00
Expertise x Site	11	0.56	0.74	0.67	0.00
Person(Expertise) x Site	77	0.75	0.16	1	0.00
Residual	324	4.55			2.13
c) *Halophila*	No transform*				
Expertise	1	50.02	1.21	0.28	0.23
Site	11	165.66	34.44	<0.01	2.54
Person(Expertise)	7	41.50	7.51	<0.01	0.86
Expertise x Site	11	3.61	0.75	0.67	0.00
Person(Expertise) x Site	77	4.81	0.87	0.76	0.00
Residual	324	5.53			2.35
d) Sand	No transform				
Expertise	1	0.08	0.97	0.49	0.00
Site	11	0.01	0.35	0.90	0.00
Person(Expertise)	7	0.08	2.49	0.01	3.2
Expertise x Site	11	0.01	0.35	0.90	0.00
Person(Expertise) x Site	77	0.04	1.06	0.28	2.23
Residual	324	0.03			0.18

3.3.3 PHOTO QUALITY

Four volunteers took the photos at the 12 sites that were used in the lab experiment. A large proportion (41%) of photos had an issue that potentially could make analysis of the photos difficult: 26/98 photos (27%) had parts of the quadrat (which were not straight) missing from the photo and an extra 14/98 quadrats (14%) were just not straight (Figures 3.6-3.8).

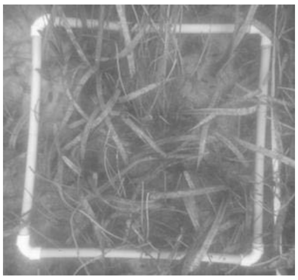


Figure 3.6. Score = 5.

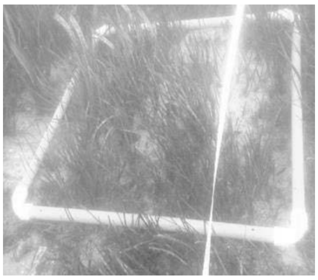


Figure 3.7. Score = 2

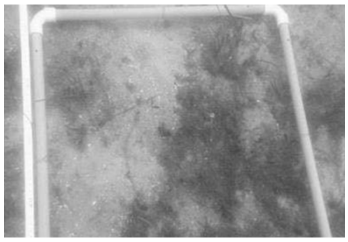


Figure 3.8. Score = 2.

Figures 3.6, 3.7, 3.8 (L-R). Photos demonstrating contribution of orientation and clarity to photo quality score. Quadrat is centred, square and clear (figure 3.6); figure 3.7 shows photo that is not square and taken at acute angle; 10% of quadrat missing from dull photo (figure 3.8).

Table 3.6. Quality scores of photos taken by volunteers. Letter denotes photographer. Site is denoted as Seagrass-Friendly Mooring (SFM), Swing (S) or Control (C). Shading indicates those moorings where significant differences were detected in % cover measured by experts and volunteers for *Zostera* (z), *Posidonia* (p) or sand (s).

	Photographer											
Site/ Quadrat	A	A	B	C	C	A	B	D	C	B	D	B
	1-SFM	**2-SFM**	**3-SFM**	**4-SFM**	**5-S**	**6-S**	**7-S**	**8-S**	**9-C**	**10-C**	**11-C**	**12-C**
1	3	2	4	4	4	2	3	4	4	4	4	3
2	3	2	3	3	3	2	3	2	3	4	4	5
3	4	3	5	3	5	3	3	5	4	4	4	4
4	3	4	3	2	4	4	4	3	3	2	5	2
5	4	3	4	3	5	4	4	5	5	3	4	3
6	3	3	4	3	5	3	3	3	4	1	4	3
7	4	4	4	5	3	2	5	4	5	2	3	4
8	3	4	3	3	4	4	5	3	5	3	3	3
		z,s,p				*p*	*z,s*	*s*	*s*	*z,s*	*z,s*	
Mean quality score	3.38	3.13	3.75	3.25	4.13	3.00	3.75	3.63	4.13	2.88	3.88	3.38

The mode of photo quality scores was 3 (Table 3.6), although each photographer scored a 1 or 2 (very poor quality) at least once. Two sites at which significant differences were detected for *Posidonia* (sites 2, 6) showed up to three photos of very poor quality. Sites where significant differences were detected for *Zostera* show multiple poor quality photos at some sites (sites 2, 10). The quality of photo is not likely to have affected the sand percentage cover estimates.

3.3.4 VOLUNTEER ATTITUDES

Volunteers estimated the time taken to complete the data processing tasks at home ranged from 6 to 14.5 hr (median=10 hr). This included analysis of photoquadrats and video trasects, data entry, and checking of data entry. Two experts completed half the tasks and data entry in 5 hr, and the other two experts completed all tasks in 9-12 hr (median = 10.5 hr), demonstrating there is no difference between the time taken for volunteers and experts to undertake the data processing tasks. When asked whether they thought involvement in the lab experiment enhanced their overall experience in scientific research, 50% of volunteers answered yes. All volunteers reported that their understanding of 'what scientists do' had been enhanced, and 75% thought their involvement in the activity had improved their understanding of how volunteers can contribute to different aspects of research. Volunteers' confidence about their abilities in the use of computer-based data collection techniques was evaluated immediately after the full-day training workshop and upon completion of data processing. The majority of volunteers reported their confidence and abilities had remained the same or increased (74%) while 2/8 volunteers (24%) reported a decrease in confidence in their ability to complete the activity (Figure 3.9). Two (2/8) of the volunteers expressed interest in continuing to participate in computer-based data collection.

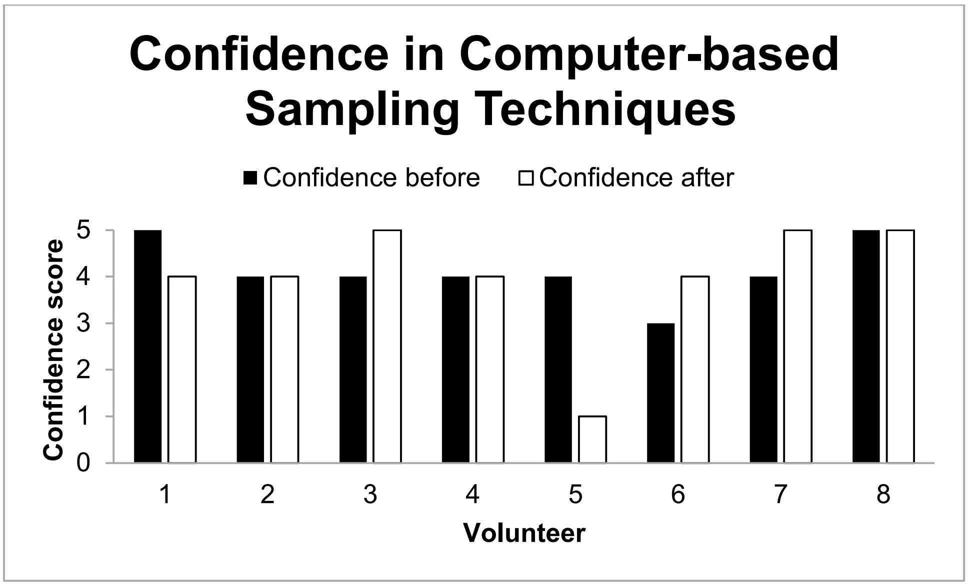


Figure 3.9. Comparison of confidence in 8 volunteers in completing the computer-based activities, at the conclusion of the training workshop and after completing the task.

3.4 DISCUSSION

The null hypothesis that experts and volunteers did not differ for two in-field tasks that involved measuring seagrass leaf lengths and the length of mooring scars is supported. Measuring leaf lengths and scour lengths were relatively simple tasks and each of the divers involved had previous experience with these specific field-based activities. This supports a growing number of studies where no difference for field data collection techniques between experts and volunteers has been observed where volunteers are experienced in the techniques (McKenzie et al. 2000; Foster-Smith & Evans 2003; Pattengil-Semmens & Semmens 2003; Edgar & Stuart-Smith 2009). Estimates of components of variance demonstrate that the variation in level of expertise is less than the variation due to site. A high residual result indicates there is high variation within replicates. This could indicate the replicates and sites are naturally variable, or that there are not enough replicates within the study design. We suggest that the number of replicates is sufficient, and the more likely cause of a high residual result is variability within replicates, as, for example, some quadrats within a scour had leaf length measures of 0 cm (no seagrass) and others had >50 cm.

The null hypothesis that experts and volunteers did not differ in % cover estimates is rejected, as although there was no overall effect of expertise on the estimates of % cover of seagrasses and sand collected from photo-quadrats, there was an effect that depended on the site being sampled. This occurred for 4/12 sites for

Zostera % cover, 6/12 for sand, and 2/12 for *Posidonia*. Contributing sources of error could potentially arise from photo quality or experience in applying the techniques. Assessing % cover can be subjective, and where subjective observations are required or where a result may depend on the observer's level of experience, accuracy and precision can be reduced (Halusky et al. 1994; Goffredo et al. 2004; Goffredo et al. 2008; Edgar & Stuart-Smith 2009).

The null hypothesis that experts and volunteers did not differ in their assessments of the occurrence of seagrass and sand from data collected from video transects is supported. Video transect processing technique involved a relatively simple protocol (noting presence/absence of a species), whereas photoquadrat estimates required careful counting of multiple species within an area. This may suggest that volunteers may be more suited to this rather than the photo quadrat tasks, or that more training may be required for volunteers to achieve a sufficient level of experience and precision. Foster-Smith & Evans (2003) found that tasks must be realistic and achievable and appropriate to the observer's level of experience, as observer effects begin to infiltrate more complex tasks, reducing the usability of the data (Halusky et al. 1994; Mumby et al. 1995; Darwall & Dulvy 1996). Components of variance support the results, indicating that there is some variation in the data individual people provide, however it is relatively low compared to the variability amongst sites. There is more variation due to sites and individual replicates than between levels of expertise or people within a level of expertise.

Photo quality may have had an impact on percentage cover estimates as lower quality photos (scores of 1 or 2) were generally observed at sites with differences between levels of expertise (Table 3.6). Poor quality photos may result from either poor photographic technique, low-quality equipment, poor lighting or poor diving technique (buoyancy control). Using experienced divers to conduct the sampling work will reduce the error from poor diving technique, and photographic technique can be ameliorated provided feedback is given to the divers involved. Prior to this study, these volunteers were previously unaware how much the quality of photographs affected the type and quality of analysis that can be performed. The volunteers committed to taking more care with their photographic techniques in the future. In future, photos should be checked for quality prior to forwarding on to the scientist involved, and the scientist should check photos following receipt to ensure quality is sufficient. Further work may be required to assess the contribution of photographic equipment to photograph quality and resulting quality of analysis arising from these photos.

Experience with applying computer-based techniques may also have been a contributing factor to differences between experts and volunteers, or within these groups. None of the volunteers had previous experience in such activities. A quarter of the volunteers were not confident in their ability to complete the activity (Figure 3.9) likely due to the unfamiliarity with this type of task. There may also be some interaction between a diver's level of experience in seagrass monitoring and the accuracy of data supplied in the computer-based sampling activities. That is, his or her experience in monitoring seagrass may better equip the volunteer to assess photo and video evidence. It is not possible, however, to determine how much of a factor this may have been without more examples (larger sample size of novices and more experienced volunteers).

Members of each group (Expert, Volunteer) were equally variable in certain tasks. For estimates of percentage cover, for example, of the four experts, only 2 were highly correlated. As we would expect the results of experts of similar experience to be more highly correlated (less variable), it would suggest that methods and instructions require review to reduce any subjectivity in interpretation.

Dickinson et al. (2010) suggest that citizen science must extend volunteers beyond the collection and submission of field data to uncover mechanisms underlying ecological patterns – that the process of engaging volunteers in more meaningful and insightful aspects of research will allow more novel hypotheses to be presented and explored. All of the volunteers participating in this study had previously been involved in other monitoring activities, exclusively as field data collectors. The majority of volunteers reported their involvement in the additional data processing activity as part of this study enhanced their overall experience in scientific research, improved their understanding of scientific research processes, and improved their understanding of the role volunteers can and do play in environmental research. Two volunteers reported a desire to seek out more of these opportunities. The time commitment the volunteers made was not insignificant: volunteers estimated the time taken to complete the computer sampling tasks at home was about 10 hours, which is over and above the 6 hours they spent in a training workshop. Experts were no quicker, thus revealing volunteers are capable of equal efficiency. However, as volunteers, the element of time may influence the degree of commitment and level of interest for this type of task held by these volunteers over and above their interest in the marine environment. Although divers on the whole may not be interested in data-processing and analysis, there is a cohort of other volunteers increasingly becoming involved in scientific research through computer-based, web-enabled activities (fold it, http://fold.it/portal/; Zooniverse, https://www.zooniverse.org/).

A high proportion of marine citizen science programs operating in Australia rely on SCUBA-based volunteers (authors' unpublished findings). A potential barrier to using SCUBA divers in Australia is the introduction of a national standard for dive operations (AS/NZS 2299.2:2002 Occupational Diving Operations and NSW Work Health & Safety Regulation 2011) which defines volunteers who participate in research or contribute data to a research or management organization as 'workers'. As such, volunteers must be qualified to a professional dive qualification level (scientific diver or above), must have a valid first aid and CPR ticket and must undergo an annual medical by a certified Diving Physician. As volunteers are not paid workers, there are significant funding shortfalls to gain and/or maintain these certifications. Divers in this study were subsidized by a government agency to obtain the necessary certifications so that they might be able to contribute to this and other research in the region.

3.5 Conclusion

Data on subtidal seagrasses collected by citizen scientists using field and computer-based sampling methods were not significantly different from those collected by professional scientists for two field tasks, measurements of leaf lengths and mooring scours. Volunteers did not differ significantly from experts in the results provided for % occurrence of seagrasses and sand (from video transects), however, there were differences detected, often dependent on site, for a more complex task of estimating percentage cover of seagrass and habitat features (from photoquadrats). Photographs taken by the volunteers and used in the study potentially could be the cause of the significant differences for some of the percentage cover estimates: volunteers, as a result of participation in this study, have committed to reviewing their photographic techniques to ensure the provision of high quality data into the future. Variation was present in the data collected by experts in the computer-based percentage cover tasks, indicating methods require review and may have contributed to volunteer-expert differences. Inaccurate technique and interpretation of methods may have contributed to variation in volunteer results as well. Despite some of these contributing factors, estimates of variance components show that variation amongst sample replicates is consistently higher than the estimates of variance due to expertise and person, which are relatively small.

To our knowledge, this study provides the first example of validation of citizen scientists undertaking computer-based sampling activities for natural resource condition monitoring. Involving volunteers in these aspects of research, additional to field data collection, provides them with a better appreciation of the whole process of research and monitoring (that might flow back to improved field practices – our experience) and provides an opportunity for researchers to build on personal skills and interests of volunteers through their participation in field work. This type of task also provides the opportunity for non-diving participants to contribute to marine projects (eg. Explore the Sea Floor, http://exploretheseafloor.net.au/).

The evidence supports the inclusion of SCUBA divers in scientific research, as they have been shown to be capable of providing reliable and accurate data in a wide variety of contexts. Harnessing the effort of these volunteers benefits long-term provision of data, including the comparison of current data with historical observations to determine change (Ward-Paige & Lotze 2011), designation of priority conservation areas (Smith & Edgar 1999) and measuring the relative success of different management strategies for protection of at-risk locations or species (Edgar & Stuart-Smith 2009).

ACKNOWLEDGEMENTS

Thanks first and foremost to all the divers who participated in this study, without whom this research would not be possible. Thanks to Skye Taylor, Peter Gibson and Brooke McCartin (NSW DPI Fisheries); Glenn Courtenay; Peter McGee, Silke Stuckenbrock, Karen Raubenheimer, Dave Thomas, Deb Dickson-Smith, Scott Portelli, Mark Kitchen and Alice Forrest (Eco Divers); David Massey, Elaine Kwee and John Turnbull (URG); and Kate Tinson (CHUG) for your patience, perseverance and commitment. The project relied upon the use of facilities at the Sydney Institute of Marine Science. We are very grateful for financial support from Sydney Metropolitan Catchment Management Authority, Australian Geographic Society, and the University of Technology Sydney. Thank you to two reviewers who contributed useful comments. This study has been approved by the University of Technology, Sydney Human Research Ethics Committee (UTS HREC REF NO. 2012-052A).

SUPPLEMENTARY TABLE S3.1

Peer-reviewed publications implying use of citizen science for marine data collection, 1993 to 2012. Compiled from SeaWeb Marine Science Review, CitizenScience.org, ReefCheck International, SeagrassWatch, C Sbrocchi, University of Technology Sydney (unpubl data)

Almany, G., Hamilton, R., Williamson, D., Evans, R., Jones, G., Matawai, M., Potuku, T., Rhodes, K., Russ, G. & Sawynok, B. (2010) Research partnerships with local communities: two case studies from Papua New Guinea and Australia, Coral Reefs, 29: 567-76.

Ambrose, R., Hodgson, G., Shuman, C. (2005) Population impacts of collecting sea anemones and anemonefish for the marine aquarium trade in the Philippines, Coral Reefs, 24(4): 564 - 573

Antos, M.J., Weston, M.A. & Priest, B. (2006) Factors Influencing Awareness of Community-Based Shorebird Conservation Projects in Australia, Applied Environmental Education and Communication, 5: 63-72.

Bell, I.P., Paramenter, C. J. (2008) The diving behaviour of inter-nestling hawksbill turtle, eretmochelys imbricata (Linnaeus 1766) on Milman Island Reef, Queensland, Australia. Herpetological Conservation and Biology 3 (2): 254-263

Bell, J. (2006) The use of volunteers for conducting sponge biodiversity assessments and monitoring using a morphological approach on Indo-Pacific coral reefs, Aquatic Conserv: Mar. Freshw. Ecosyst. 16: 1–13"

Biggs, C.R. and Olden, J.D. (2011) Multi-scale habitat occupancy of invasive lionfish (Pterois volitans) in coral reef environments of Roatan, Honduras. Aquatic Invasions 6(3): 347-353

Booth, DJ, Bond, N & Macreadie, P. (2011) Detecting range shifts among Australian fishes in response to climate change Marine and Freshwater Research, 62: 1027–1042.

Bradshaw,C.J.A., Fitzpatrick,B.M., Steinberg,C.C., Brook,B.W., Meekan, M.G. (2008) Decline in whale shark size and abundance at Ningaloo Reef over the past decade: The world's largest fish is getting smaller, Biol.Conserv. 141(7): 1894-1905

Bramanti, L., Vielmini, I., Rossi, S., , Stolfa S., and Santangelo, G. (2011) Involvement of recreational scuba divers in emblematic species monitoring: The case of Mediterranean red coral (Corallium rubrum), Journal for Nature Conservation 19(5): 312-318

Brown, I., Sumpton, W., McLennan, M., Mayer, D., Campbell, M., Kirkwood, J., Butcher, A., Halliday, I., Mapleston, A., Welch, D., Begg, G.A. & Sawynok, B. (2010) An improved technique for estimating short-term survival of released line-caught fish, and an application comparing barotrauma-relief methods in red emperor (Lutjanus sebae Cuvier 1816), Journal of Experimental Marine Biology & Ecology, 385(1/2): 1-7.

Bruno J.F., Selig, E.R. (2007) Regional Decline of Coral Cover in the Indo-Pacific: Timing, Extent, and Subregional Comparisons. PLoS ONE 2(8): e711

Bruno, J.F., Sweatman, H., Precht, W.F., Selig, E.R., Schutte, V.G.W. (2009) Assessing evidence of phase shifts from coral to macroalgal dominance on coral reefs, Ecology, 90(6): 1478-1484.

Campbell, S.J. and McKenzie, L.J. (2004) Flood related loss and recovery of intertidal seagrass meadows in southern Queensland, Australia. Estuarine, Coastal and Shelf Science, 60: 477-490.

Campbell, S.J., McKenzie, L.J. and Kerville, S.P. (2006) Photosynthetic responses of seven tropical seagrasses to elevated seawater temperature, Journal of Experimental Marine Biology and Ecology, 330: 455– 468.

Carpenter, K. (2008) One-Third of Reef-Building Corals Face Elevated Extinction Risk from Climate Change and Local Impacts, Science Express, July 10, 2008.

Chandler, M., Bebber, D.P., Castro, S., Lowman, M.D., Muoria, P., Oguge, N. & Rubenstein, D.I. (2012) International citizen science: making the local global, Front Ecol Environ, 10(6): 328–31.

Chavanich, S., Viyakarn, V., Adams, P., Klammer, J., Cook, N. (2012). Reef communities after the 2010 mass coral bleaching at Racha Yai Island in the Andaman Sea and Koh Tao in the Gulf of Thailand, Phuket mar. biol. Cent. Res. Bull, 71: 103–110.

Clemens, R., Weston, M., Haslem, A., Silcocks, A. & Ferris, J. (2010) Identification of significant shorebird areas: thresholds and criteria, Diversity and Distributions, 16: 229–42.

Clemens, R.S., Kendall, B.E., Guillet, J. & Fuller, R.A. (2012) Review of Australian Shorebird Survey Data, With Notes on their Suitability for Comprehensive Population Trend Analysis, Stilt, 62: 3-17.

Cohen, C.S., McCann, L., Davis, T., Shaw, L., and Ruiz, G. (2011) Discovery and significance of the colonial tunicate Didemnum vexillum in Alaska, Aquatic Invasions 6(3): 263-271

Coles, R.G., Grech, A., Rasheed, M.A., McKenzie, L.J., Unsworth, R.K.F., and Short, F. (2011) Seagrass ecology and threats in the tropical Indo-Pacific bioregion Chapter 9 In: Pirog RS (ed) Seagrass: Ecology, Uses and Threats Editors. 2010 Nova Science Publishers, Inc ISBN: 978-1-61761-987-8

Collier, C.J., Waycott, M.W. and McKenzie, L. (2012). Light thresholds derived from seagrass loss. Ecological Indicators 23: 211–219.

Cornwell, M.L. and Campbell, L.M. (2012) Co-producing conservation and knowledge: Citizen-based sea turtle monitoring in North Carolina, USA. Social Studies of Science 42(1): 101-120

Couturier, L.I.E., Jaine, F.R.A., Townsend, K.A., Weeks, S.J., Richardson, A.J. & Bennett, M.B. (2011) Distribution, site affinity and regional movements of the manta ray, Manta alfredi (Krefft, 1868), along the east coast of Australia, Marine and Freshwater Research, 62: 628–37.

Darwall, W.R. & Dulvy, N.K. (1996) An Evaluation of The Suitability of Non-Specialist Volunteer Researchers for Coral Reef Fish Surveys. Mafia Island, Tanzania - A Case Study, Biological Conservation, 78: 223-31.

Davies, T.K., Stevens, G., Meekan, M.G., Struve, J., and Rowcliffe, J.M. (2012) Can citizen science monitor whale-shark aggregations? Investigating bias in mark–recapture modelling using identification photographs sourced from the public, Wildlife Research 39(8): 696-704

Delaney, D.G., Sperling, C.D., Adams, C.S. & Leung, B. (2008) Marine invasive species: validation of citizen science and implications for national monitoring networks, Biological Invasions, 10: 117-28.

Devictor et al (2010) Beyond scarcity: citizen science programmes as useful tools for conservation biogeography. Diversity and Distributions, 16: 354-362

Eakin CM, Morgan JA, Heron SF, Smith TB, Liu G, et al. (2010) Caribbean Corals in Crisis: Record Thermal Stress, Bleaching, and Mortality in 2005. PLoS ONE 5(11): e13969

Edgar GJ and Stuart-Smith RD (2009). A continental-scale analysis of ecological effects of marine protected areas based on underwater visual surveys. Marine Ecology Progress Series 388:51-62.

Edgar, G.J., Barrett, N.S., Morton, A.J. (2004) Biases associated with the use of underwater visual census techniques to quantify the density and size-structure of fish populations, Journal of Experimental Marine Biology and Ecology 308: 269-290."

Edgar, G.J., Barrett, N.S., Stuart-Smith, R.D. (2009) Exploited reefs protected from fishing transform over decades into conservation features otherwise absent from seascapes, Ecological Applications, 19: 1967-1974.

Ens, E.J., Towler, G.M., Daniels, C., Yugul Mangi Rangers, and Manwurrk Rangers. (2012) Looking back to move forward: Collaborative ecological monitoring in remote Arnhem Land, Ecological Management and Restoration, 13(1): 26-35

Fabricius, K.E. (2006) Effects of irradiance, flow and coral pigmentation on the temperature microenvironments around corals: Implications for coral bleaching? Limnology and Oceanography, 51(1):30-37

Fabricius, K.E., Langdon, C., Uthicke, S et al. (2011) Losers and winners in coral reefs acclimatized to elevated carbon dioxide concentrations, Nature Climate Change, 1(3): 165-169

Feinholz, D.M. (1998) Abundance, distribution, and behavior of the southern sea otter (Enhydra lutris nereis) in a California estuary, Aquatic Mammals 24(2): 105-116

Ferreira, M.A., Soares, L., Andrade, F. (2012). Educating citizens about their coastal environments: beach profiling in the Coastwatch project. J Coast Conserv 16: 567–574

Finn PG, Udy BS, Baltais SJ, Price K and Coles L (2010). Assessing the quality of seagrass data collected by community volunteers in Moreton Bay Marine Park, Australia. Environmental Conservation. 37(1): 83–89.

Finn, P.G., Udy, N.S., Baltais, S.J., Price, K. & Coles, L. (2010) Assessing the quality of seagrass data collected by community volunteers in Moreton Bay Marine Park, Australia, Environmental Conservation, 37(1): 83-9.

Foster-Smith, J. & Evans, S.M. (2003) The value of marine ecological data collected by volunteers, Biological Conservation, 113: 199–213.

Gearheard, S., Aporta, C., Aipellee, G., and O'Keefe, K. (2011) The Igliniit project: Inuit hunters document life on the trail to map and monitor arctic change. Canadian Geographer 55(1): 42-55

Gillett, D.; Pondella, D.; Freiwald, J.; Schiff, K.; Caselle, J.; Shuman, C.; Weisberg, S. (2011). Comparing volunteer and professionally collected monitoring data from the rocky subtidal reefs of Southern California, USA. Environmental Monitoring and Assessment, 184(5):3239-57

Goffredo, S., Piccinetti, C. & Zaccanti, F. (2004) Volunteers in Marine Conservation Monitoring: a Study of the Distribution of the Seahorses Carried Out in Collaboration with Recreational Scuba Divers, Conservation Biology, 18(6): 1492-503.

Gosbell, K. & Clement, R. (2006) Population Monitoring in Australia: Some Insights after 25 years and Future Directions, Stilt, 50: 162-75.

Grech, A., Chartrand-Miller, K., Erftemeijer, P., Fonseca, M., McKenzie, L., Rasheed, M., Taylor, H. and Coles, R. (2012). A comparison of threats, vulnerabilities and management approaches in global seagrass bioregions. Environmental Research Letters 7(2): 024006

Gunn, R., Hardesty, B.D. & Butler, J. (2010) Tackling 'ghost nets': Local solutions to a global issue in northern Australia', Ecological Management & Restoration, 11(2) :88-98.

Hagan, A.B., Foster, R., Perera, N., Gunawan, C.A., Silaban, I., Yaha, Y., Manuputty, Y., Hazam, I., Hodgson, G. (2007). Tsunami Impacts in Aceh Province and North Sumatra, Indonesia. Atoll Research Bulletin, 544: 37-54.

Halusky, J.G., Seaman, J., William & Strawbridge, E. (1994) Effectiveness of Trained Volunteer Divers in Scientific Documentation of Artificial Aquatic Habitats, Bulletin of Marine Science, 55 (2-3): 939-59.

Harding, S.P., J.L. Solandt, R. C. J. Walker, D. Walker, J. Taylor, S. Haycock, M. T. Davis and P. S. Raines. (2003) Reef check data reveals rapid recovery from coral bleaching in the Mamanucas, Fiji. Silliman Journal, 2(44): 80-89.

Harvey, E., Fletcher, D., and Shortis, M. (2001) A comparison of the precision and accuracy of estimates of reef-fish lengths determined visually by divers with estimates produced by a stereo-video system, Fishery Bulletin 99:63-71.

Hodgson, G. (1999) A Global Assessment of Human Effects on Coral Reefs. Marine Pollution Bulletin. 38(5): 345-355.

Hodgson, G. (2000) Coral Reef Monitoring and Management Using Reef Check. Integrated Coastal Zone Management, 1: 169 - 179.

Hodgson, G. (2001) Reef Check: The First Step in Community-Based Management. Bulletin of Marine Science, 69(2): 861-868.

Holmberg, J., Norman, B., Arzoumanian,Z. (2008) Robust, Comparable Population Metrics Through Collaborative Photo-Monitoring of Whale Sharks, Rhincodon Typus, Ecol.Appl., 18(1): 222-233

Humber, F., Godley, B.J., Ramahery, V., and Broderick, A.C. Using community members to assess artisanal fisheries: the marine turtle fishery in Madagascar. Animal Conservation 14(2): 175-185, 2011

Huveneers, C., Luo, K., Otway, N.M. & Harcourt, R.G. (2009) Assessing the distribution and relative abundance of wobbegong sharks (Orectolobidae) in New South Wales, Australia, using recreational scuba-divers, Aquat. Living Resour, 22: 255–64

Inglis, G.J.. & Lincoln Smith, M.P. (1995) An examination of observer bias as a source of error in surveys of seagrass shoots. Australian Journal of Ecology, 20: 273-281.

Jacoby, C., Manning, C., Fritz, S. & Rose, L. (1997), Three recent initiatives for monitoring of Australian coasts by the community, Ocean & Coastal Management, 36(1-3): 205-26.

Johnson, C.R., Banks, S.C., Barrett, N.S., Cazassus, F., Dunstan, P.K., Edgar, G.J., Frusher, S.D., Gardner, C., Haddon, M., Helidoniotis, F., Hill, K.L., Holbrook, N.J., Hosie, G.W., Last, P.R., Ling, S.D., Melbourne-Thomas, J., Miller, K., Pecl, G.T., Richardson, A.J., Ridgway, K.R., Rintoul, S.R., Ritz, D.A., Ross, D.J., Sanderson, J.C., Shepherd, S.A., Slotwinski, A., Swadling, K.M., and Taw, N. (2011). Climate change cascades: shifts in oceanography, species' ranges and subtidal marine community dynamics in eastern Tasmania. Journal of Experimental Marine Biology and Ecology, 400: 17–32.

Jones, A, Barnett, B, William, AJ, Grayson, J, Busilacchi, S, Dusckworth, A, Evans-Illidge, E, Begg, GA, Murchie, CD. (2008) Effective communication tools to engage Torres Strait Islanders in scientific research. Continental Shelf Research. 28: 2350–2356

Jones, A. M., R. Berkelmans, et al. (2011). Species Richness and Community Structure on a High Latitude Reef: Implications for Conservation and Management. Diversity 3(3): 329-355.

Koss, R. and Kingsley, J. (2010). Volunteer health and emotional wellbeing in Marine Protected Area programs, Ocean and Coastal Management, 53:447-453

Koss, R.S., Miller, K., Wescott, G., Boxshall, A., Bellgrove, A., Gilmour, P., Bunce, A., McBurnie, J., and Ierodiaconou, D. (2009). An evaluation of Sea Search as a citizen science programme in Marine Protected Areas. Pacific Conservation Biology, 15:116-127.

Last, P.R., White, W.T., Gledhill, D.C., Hobday, A.J., Brown, R., Edgar, G.J., and Pecl, G (2011) Long-term shifts in abundance and distribution of a temperate fish fauna: a response to climate change and fishing practices. Global Ecology and Biogeography, 20: 58-72.

Le Fur, J., Guilavogui, A., and Teitelbaum, A. (2011) Contribution of local fishermen to improving knowledge of the marine ecosystem and resources in the Republic of Guinea, West Africa. Canadian Journal of Fisheries and Aquatic Sciences 68(8): 1454-1469

Lee Long W J, Coles RG & McKenzie LJ (2000). Issues for seagrass conservation management in Queensland. Pacific Conservation Biology 5: 321-328.

Lee Long, W.j., Mellors, J.E., and Coles, R.G. (1993) Seagrasses between Cape York and Hervey Bay, Queensland, Australia. Australian Journal of Marine and FreshwaterResearch 44: 19-31.

Leiper, Ian A., Siebeck, Ulrike E., Marshall, N. Justin; et al. 2009. Coral health monitoring: linking coral colour and remote sensing techniques. Canadian Journal of Remote Sensing. 35(3): 276-286.

Madin,E.M.P., Ban, N.C., Doubleday, Z.A., Holmes,T.H., Pecl, G.T., Smith, F. (2012) Socio-economic and management implications of range-shifting species in marine systems. Global Environ.Change, 22(1): 137-146

Maguire, G.S., Miller, K.K., Weston, M.A. & Young, K. (2011) Being beside the seaside: Beach use and preferences among coastal residents of south-eastern Australia, Ocean & Coastal Management, 54: 781-8.

Mahoney, A.R., Gearheard, S., Oshima, T., and Qillaq, T. (2011) Sea ice thickness measurements from a community-based observing network. Bulletin of the American Meteorological Society, 90(3): 370-377

Marshall, N.J., Kleine, D.A., Dean, A.J., (2012) CoralWatch: education, monitoring, and sustainability through citizen science. Frontiers in Ecology and the Environment. 10(6): 332--334

Maynou, F., Sbrana, M., Sartor, P., Maravelias, C., Kavadas, S., Damalas, D., Cartes, J.E., and Osio, G. (2011) Estimating trends of population decline in long-lived marine species in the Mediterranean Sea based on fishers' perceptions. PLoS ONE 6(7): e21818

McDougall, A.J., Pearce, M.G. & MacKinnon, M. (2008) 'Use of a fishery model (FAST) to explain declines in the stocked barramundi (Lates calcarifer) (Bloch) fishery in Lake Tinaroo, Australia', Lakes & Reservoirs: Research & Management, 13(2): 125-34.

McKenzie, L.J. (2010). Global monitoring program provides early warning of coastal ecological decline. National Wetlands Update 2010. Wetlands Australia 18: 21.

McKenzie, L.J. and Coles, R.G. (2011). Working together to monitor seagrass in Queensland's Ramsar sites. National Wetlands Update 2011. Wetlands Australia 19: 28-29.

McKenzie, L.J., Lee Long, W.J., Coles, R.G. and Roder, C.A. (2000) Seagrass-Watch: Community based monitoring of seagrass resources. Biol. Mar. Medit. 7(2): 393-396.

Mellors, J.E., McKenzie, L.J. and Coles, R.G. (2008). Seagrass-Watch: Engaging Torres Strait Islanders in marine habitat monitoring. Continental Shelf Research. 28: 2339– 2349.

Micheli, F., Saenz-Arroyo, A., Greenley, A., Vazquez, L., Espinoza, Montes J.A., et al. (2012) Evidence That Marine Reserves Enhance Resilience to Climatic Impacts. PLoS ONE 7(7): e40832

Miller, K.K.M. & Weston, M.A. (2009) Towards a set of priorities for bird conservation and research in Australia: the perceptions of ornithologists, Emu, 109: 67-74.

Minton, C., Dann, P., Ewing, A., Taylor, S., Jessop, R., Anton, P. & Clement, R. (2012) Trends of Shorebirds in Corner Inlet, Victoria, 1982-2011', Stilt, 61: 3-18.

Montano, S., Seveso, D., Galli, P., et al. (2010) Assessing coral bleaching and recovery with a colour reference card in Watamu Marine Park, Kenya. Hydrobiologia 655(1): 99-108

Mora C, Aburto-Oropeza O, Ayala Bocos A, Ayotte PM, Banks S, et al. (2011) Global Human Footprint on the Linkage between Biodiversity and Ecosystem Functioning in Reef Fishes. PLoS Biol 9(4): e1000606

Mumby, P.J., Harborne, A.R., Raines, P.S. & Ridley, J.M. (1995) A Critical Assessment of Data Derived From Coral Cay Conservation Volunteers, Bulletin of Marine Science, 56(3): 737-51.

Nakaoka, M. (2000). Development of local and global networks for reserch and conservation of seagrasses. Aquabiology. 22(6): 566-569.

Nursey-Bray, M., Pecl, G.T., Frusher S., Gardner, C., Haward, M., Hobday A.J., Jennings S., Punt A.E., Revill H., van Putten, I. (2012) Communicating climate change: Climate change risk perceptions and rock lobster fishers, Tasmania. Marine Policy 36, 753–759

Parker P., Bucher D.J. (2000) Seasonal variation in abundance and sex ratio of grey nurse (sand tigers) sharks Carcharias taurus in northern New SouthWales, Australia: a survey based on observations of recreational scuba divers. Pac. Conserv. Biol. 5: 336–346.

Pattengill Semmens, C.V. and Semmens, B.X. (2003) Conservation and management applications of the REEF volunteer fish monitoring program. Environ.Monit.Assess., 81(1-3): 43-50

Prayaga, P., Rolfe, J. & Stoeckl, N. (2010) The value of recreational fishing in the Great Barrier Reef, Australia: A pooled revealed preference and contingent behaviour model, Marine Policy, 34(2): 244-51.

Preen, A., and Marsh, H. (1995) Response of Dugongs to Large-scale loss of Seagrasses from Hervey Bay, Queensland, Australia. Wildlife Research 22: 507-519.

Przeslawski, R., Falkner, I., Ashcroft, M.B., Hutchings, P. (2012) Using rigorous selection criteria to investigate marine range shifts, Estuarine, Coastal and Shelf Science, 113: 205-212

Risk, M.J. (1999) Paradise Lost: How Marine Science failed the world's coral reefs. Mar. Fresh. Res. 50: 831-7.

Roelfsema CM, Phinn SR, Udy N and Maxwell P (2009). An integrated field and remote sensing approach for mapping seagrass cover, Moreton Bay, Australia. Spatial Science. 54(1): 45-62.

Scarpaci, C., Nugegoda, D. and Corkeron, P.J. (2005). Tourists swimming with Australian fur seals (Arctocephalus pusillus) in Port Phillip Bay, Victoria, Australia: Are tourists at risk? Journal of Tourism in Marine Environments 1(2): 89-95

Schuyler, Q., Hardesty, B.D., Wilcox, C., Townsend, K. (2012) To Eat or Not to Eat? Debris Selectivity by Marine Turtles. PLoS ONE 7(7): e40884

Selig, E.R., Bruno, J.F. (2010) A Global Analysis of the Effectiveness of Marine Protected Areas in Preventing Coral Loss. PLoS ONE 5(2): e9278

Shuler, A.J. et al. (2012) Spatial and temporal trends of the toxic diatom Pseudo-nitzschia in the Southeastern Atlantic United States. Harmful Algae 17: 6-13

Sumpton, W., Mayer, D., Brown, I., Sawynok, B., McLennan, M., Butcher, A. & Kirkwood, J. (2008) Investigation of movement and factors influencing post-release survival of line-caught coral reef fish using recreational tag-recapture data, Fisheries Research, 92(2/3): 189-95.

Sumpton, W.D., Brown, I.W., Mayer, D.G., McLennan, M.F., Mapleston, A., Butcher, A.R., Welch, D.J., Kirkwood, J.M., Sawynok, B. & Begg, G.A. (2010) Assessing the effects of line capture and barotrauma relief procedures on post-release survival of key tropical reef fish species in Australia using recreational tagging clubs, Fisheries Management & Ecology, 17(1): 77-88.

Teymour, A. and Sanjani, M.S. (2010) Status of Coral Reef Species at Chabahar Bay, Sistan and Baluchistan, Iran. Pakistan Journal of Biological Sciences, 13(8): 369-374

Theberge, M.M., Dearden, P. (2006) Detecting a decline in whale shark Rhincodon typus sightings in the Andaman Sea, Thailand, using ecotourist operator-llected data. Oryx 40: 337-342

Unsworth, R.K.F., Collier, C.J., Henderson, G.M. and McKenzie, L.J. (2012). Tropical seagrass meadows modify seawater carbon chemistry: implications for coral reefs impacted by ocean acidification. Environmental Research Letters. 7(2): 024026

Uychiaoco, A.J., Arceo, H.O., Green, S.J.,De la Cruz, M.T., Gaite, P.A. and Aliño, P.M. (2005) Monitoring and evaluation of reef protected areas by local fishers in the

Philippines:tightening the adaptive management cycle. Biodiversity and Conservation 14(11): 2775-2794.

Ward-Paige, C.A., Myers, R.A., Lotze, H.K., Pattengill-Semmens C. (2011) Spatial and temporal trends in yellow stingray abundance: Evidence from diver surveys Environmental Biology of Fishes. 90(3): 263-276

Ward-Paige, C.A., Lotze, H.K. (2011) Assessing the Value of Recreational Divers for Censusing Elasmobranchs. PLoS ONE 6(10): e25609

Ward-Paige, C.A., Mora, C, Lotze, HK, Pattengill-Semmens, C., McClenachan, L., Arias-Castro, E., Myers, R.A. (2010) Large-scale absence of sharks on reefs in the greater-Caribbean: a footprint of human pressures. PloS one, 5(8): e11968

Weichselgartner, J. and Marandino, C.A. (2012) Priority knowledge for marine environments: challenges at the science–society nexus. Current Opinion in Environmental Sustainability 4(3): 323-330

Weston, M.A. & Paton, S. (2002) A Survey of Victorian Hooded Plover Counters, The Stilt, 42: 30-31.

Weston, M.A., Fendley, M., Jewell, R., Satchell, M. & Tzaros, C. (2003) Volunteers in bird conservation: Insights from the Australian Threatened Bird Network, Ecological Management and Restoration 4(3): 205-11.

Weston, M.A., Silcocks, A., Tzaros, C. & Ingwersen, D. (2006) A survey of contributors to an Australian bird atlassing project: Demography, skills and motivation, Australian Journal on Volunteering, 11(2): 51–58.

Weston, M.A., Tzaros, C.L. & Antos, M.J. (2006) Awareness of wetlands and their conservation value among students at a primary school in Victoria, Australia, Ecological Management & Restoration, 7(3): 223-6.

Wilcox, C., Hardesty, B., Sharples, R., Griffin, D., Lawson, T. & Gunn, R. (2012) Ghostnet impacts on globally threatened turtles, a spatial risk analysis for northern Australia, Conservation Letters, 1: 1-8.

Wilcox, C., Hardesty, B.D., Sharples, R., Griffin, D.A., Lawson, T.J. & Gunn, R. (2012) Ghostnet impacts on globally threatened turtles, a spatial risk analysis for northern Australia, Conservation Letters, 1: 1-8.

Wilde, G.R. & Sawynok, W. (2005) Growth rate and mortality of Australian bass,Macquaria novemaculeata, in four freshwater impoundments in south-eastern Queensland, Australia, Fisheries Management & Ecology, 12(1): 1-7.

Wilde, G.R. & Sawynok, W. (2009) Effect of Hook Removal on Recapture Rates of 27 Species of Angler-Caught Fish in Australia, Transactions of the American Fisheries Society, 138(3): 692-7.

Wilkinson, C. and G. Hodgson. (1999) Coral Reefs and the 1997-1998 Mass Bleaching and Mortality. Nature & Resources. 35(2): 16-25.

Wilkinson, C., Linden, O., Cesar, H., Hodgson, G., Rubens, J. and Strong, A.E. (1999) Ecological and Socioeconomic Impacts of 1998 Coral Mortality in the Indian Ocean: An ENSO Impact and a Warning of Future Change? Ambio. 28(2): 188-196.

Wilson, H.B., Kendall, B.E., Fuller, R.A., Milton, D.A. & Possingham, H.P. (2011) Analyzing Variability and the Rate of Decline of Migratory Shorebirds in Moreton Bay, Australia, Conservation Biology, 25(4):758-66

Wolcott, I., Ingwersen, D., Weston, M.A. & Tzaros, C. (2008) Sustainability of a long-term volunteer-based bird monitoring program: Recruitment, retention and attrition, Volunteering Australia, 13(1): 48-53

.

SUPPLEMENTARY TABLE S3.2

Presence of parallel tests and data validation in a sample of peer-reviewed literature of marine monitoring studies involving citizen scientists, 1993-2012 (randomly selected from Supplementary Table S3.1)

Study; Study subject	**Subtidal/ Intertidal**	**Parallel test performed (comparing volunteer and expert data)**	**Data Validation performed on citizen data (accuracy)**	**Data Validation performed on expert data**	**Result of parallel test and/or data validation**
Halusky et al. (1994); Phys/Chem measures, reef profiling, invertebrates, Fish	Subtidal (SCUBA)	None	Yes	None	Volunteers performed seven tasks with adequate accuracy. Five other variables were performed satisfactorily after modification of the methods. Three tasks could not be executed successfully due to inadequate equipment or technique/knowledge.
Mumby et al. (1995); Coral, macroalgae, substrate composition, biological cover	Subtidal (SCUBA)	Yes	Yes	None	Substrate composition and biological cover estimated with >90% accuracy in seagrass habitats and 70-90% in reef sites. No clear trend of improved accuracy and consistency for coral or macroinvertebrate identification was found with survey experience.
Darwall & Dulvy (1996); Fish lengths, abundance and diversity	Subtidal (SCUBA)	Yes	Yes	None	Consistency of volunteer data on abundance and diversity estimates of fish species improved between two census dates. Fish length estimates by divers exhibited a high degree of accuracy by the third trial.
Foster-Smith & Evans (2003); Snails and limpets	Intertidal	Yes	Yes	Yes	Volunteers were capable of identifying species, counting and measuring some gastropods. Recording errors made during the fieldwork were similar to those made by professional scientists. Volunteers' abundance assessments for some species were inconsistent due to (1) a lack of field experience (2) inadequate guidelines on the use of the abundance scale; and (3) insufficient training before field surveys commenced.

Pattengil-Semmons and Semmons (2003); Fish	Subtital (SCUBA)	Yes	Yes (implied)	Unsure	Implied that volunteer results are adequately accurate.
Bell (2006); Sponges	Subtital (SCUBA)	Yes	Yes	None	General agreement between data collected by volunteers and author (expert).
Delaney et al. (2008); Crabs	Intertidal	Yes	Yes	No	Primary school students were at least 80% accurate (third-grade students) and up to 95% accurate (seventh-grade students) when discerning the differences between native and invasive crab species. Determination of crab gender required at least a seventh grade education to obtain 80% accuracy, and 2 years of university education to exceed 95% accuracy.
Koss et al. (2009); Rocky Reefs, seagrasses	Subtidal (SCUBA) ; Intertidal	Yes	Yes	No	Intertidal assessments were found to be typically comparable with scientists. Subtidal (SCUBA) assessments found species richness measures were not significantly different, but species identification and abundance measures particularly in algae are significantly different.
Edgar & Stuart-Smith (2009); Fish, Reef, Invertebrates	Subtidal (SCUBA)	Yes - during training	Yes	Yes	Volunteer-generated data were comparable to professionals' for all metrics investigated. Variation between individual divers within volunteer and professional groups also contributed little to total estimated variance between transects compared to residual variation between replicate transects, variation between sites, and variation between regions studied.
Finn et al. (2010); seagrass	Intertidal	Yes	None	Precision test only	Volunteers' visual estimates of percent seagrass cover highly correlated with that of scientists.
Huveneers et al. (2009); Sharks	Subtidal (SCUBA)	Yes - 20% of participants	None	None	Identification skills of volunteers were adequately accurate.

Gillett et al. (2012); Reefs, Fish	Subtidal (SCUBA)	Yes	None	None	Reasonable agreement between data collected by the citizen science and professional monitoring programs. Observed differences were likely a product of biases and error inherent to the sampling programs (methodological differences) and the analyses (post-hoc, non-synoptic nature of the study).

REFERENCES

Anderson, M.J. 2001, 'A new method for non-parametric multivariate analysis of variance', Austral Ecology, vol. 26, pp. 32-46.

Andrew, N. & Mapstone, B. 1987, 'Sampling and the description of spatial pattern in marine ecology', Oceanography and Marine Biology: an Annual Review, no. 25, pp. 39-90.

Bell, S., Marzano, M., Cent, J., Kobierska, H., Podjed, D., Vandzinskaite, D., Reinert, H., Armaitiene, A., Grodzinska-Jurczak, M. & Mursic, R. 2008, 'What counts? Volunteers and their organisations in the recording and monitoring of biodiversity', Biodivers Conserv no. 17, pp. 3443–54.

Benz, S., Miller-Rushing, A., Domroese, M., Ballard, H., Bonney, R., DeFalco, T., Newman, S., Shirk, J. & Young, A. 2013, Workshop 1: Conference on Public Participation in Scientific Research 2012: An International, Interdisciplinary Conference, vol. Meeting Reports, Bulletin of the Ecological Society of America, pp. 112-7, <http://www.esajournals.org/doi/pdf/10.1890/0012-9623-94.1.112>.

Bird, T.J., Bates, A.E., Lefchek, J.S., Hill, N.A., Thomson, R.J., Edgar, G.J., Stuart-Smith, R.D., Wotherspoon, S., Krkosek, M., Stuart-Smith, J.F., Pecl, G.T., Barrett, N. & Frusher, S. 2013, 'Statistical solutions for error and bias in global citizen science datasets', Biological Conservation, vol. in press.

Bonney, R., Cooper, C.B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K.V. & Shirk, J. 2009b, 'Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy', BioScience, vol. 59, no. 11, pp. 977-84.

Carr, A.J. 2004, 'Why Do We All Need Community Science?', Society & Natural Resources, vol. 17, pp. 841–9.

Clarke, R., Aslin, H., Kruger, H. & Bury, A. 2012, Volunteer monitoring in biosecurity: An issues paper, vol. research report 12.9, Agricultural and Resource Economics and Sciences, Canberra.

Conrad, C.C. & Hilchey, K.G. 2011, 'A review of citizen science and community-based environmental monitoring: issues and opportunities', Environ Monit Assess, no. 176, pp. 273-91.

CSIRO 2009, 'Nationally Relevant Environmental Monitoring: Existing Approaches and Future Opportunities Workshop Booklet', Nationally Relevant Environmental Monitoring: Existing Approaches and Future Opportunities CSIRO, CSIRO Discovery Centre, Canberra

Dalton, S.J. & Smith, S.D.A. 2009, A Review of Underwater Volunteer Groups in NSW, National Marine Science Centre for the Hunter Central Rivers Catchment Management Authority, Coffs Harbour, NSW, Australia.

Danielsen, F., Burgess, N.D. & Balmford, A. 2005, 'Monitoring matters: examining the potential of locally-based approaches', Biodiversity and Conservation, vol. 14, pp. 2507–42.

Danielsen, F., Burgess, N.D., Balmford, A., Donald, P.F., Funder, M., Jones, J.P., Alviola, P., Balete, D.S., Blomley, T., Brashares, J., Child, B., Enghoff, M., Fjelds, J., Holt, S., Hubertz, H., Jensen, A.E., Jensen, P.M., Massao, J., Mendoza, M.M., Ngaga, Y., Poulsen, M.K., Rueda, R., Sam, M., Skielboe, T., Stuart-Hill, G., Topp-Jorgensen, E. & Yonten, D. 2009, 'Local Participation in

Natural Resource Monitoring: a Characterization of Approaches', Conservation Biology, vol. 23, no. 1, pp. 31-42.

Darwall, W.R. & Dulvy, N.K. 1996, 'An Evaluation of The Suitability of Non-Specialist Volunteer Researchers for Coral Reef Fish Surveys. Mafia Island, Tanzania - A Case Study.', Biological Conservation, vol. 78, pp. 223-31.

Delaney, D.G., Sperling, C.D., Adams, C.S. & Leung, B. 2008, 'Marine invasive species: validation of citizen science and implications for national monitoring networks', Biological Invasions, vol. 10, pp. 117-28.

Demers, M., Davis, A. & Knott, N. 2013, 'A comparison of the impact of 'seagrass-friendly' boat mooring systems on Posidonia australis', Marine Environmental Research, no. 83, pp. 54-62.

Dickinson, J.L., Zuckerberg, N. & Bonter, D.N. 2010, 'Citizen Science as an Ecological Research Tool: Challenges and Benefit', Annual Reivew of Ecology, Evolution and Systematics, no. 41, pp. 149-72.

Duarte, C. & Kirkman, H. 2001, 'Methods for the measurement of seagrass abundance and depth distribution', in F. Short (ed.), Global seagrass research methods, Elsevier Science B.V, Amsterdam, pp. 141-53.

Edgar, G.J. & Stuart-Smith, R.D. 2009, 'Ecological effects of marine protected areas on rocky reef communities - a continental-scale analysis', Marine Ecology Progress Series, vol. 388, pp. 51-62.

Ely, E. 2008b, 'Volunteer monitoring and the democratization of science', The Volunteer Monitor, vol. 19, no. 1, Summer 2008, pp. 1-5.

Finn, P.G., Udy, N.S., Baltais, S.J., Price, K. & Coles, L. 2010, 'Assessing the quality of seagrass data collected by community volunteers in Moreton Bay Marine Park, Australia', Environmental Conservation, vol. 37, no. 1, pp. 83-9.

Fore, L.S., Paulsen, K. & O'Laughlin, K. 2001, 'Assessing the performance of volunteers in monitoring streams', Freshwater Biology, no. 46, pp. 109-23.

Foster-Smith, J. & Evans, S.M. 2003, 'The value of marine ecological data collected by volunteers', Biological Conservation, vol. 113, pp. 199–213.

Gladstone, W. 2010, Seagrass Friendly Moorings in Manly Cove - Report of 2010 Monitoring, University of Technology Sydney, Sydney.

Gladstone, W. 2011, Seagrass Friendly Moorings in Manly Cove - Report of 2011 Monitoring, University of Technology Sydney.

Gladstone, W. 2012, Seagrass Friendly Moorings in Manly Cove: Final Report of 2012 Monitoring, University of Technology Sydney.

Goffredo, S., Neri, P., Orlandi, A., Pensa, F., Scola Gagliardi, M., Velardi, A., Piccinetti, C. & Zaccanti, F. 2008, 'Citizen Education by Involvement in Marine Biodiversity Monitoring', International Technology, Education and Development Conference, Valencia.

Goffredo, S., Piccinetti, C. & Zaccanti, F. 2004, 'Volunteers in Marine Conservation Monitoring: a Study of the Distribution of the Seahorses Carried Out in Collaboration with Recreational Scuba Divers', Conservation Biology, vol. 18, no. 6, pp. 1492-503.

Halusky, J.G., Seaman, J., William & Strawbridge, E. 1994, 'Effectiveness of Trained Volunteer Divers in Scientific Documentation of Artificial Aquatic Habitats', Bulletin of Marine Science, vol. 55, no. 2-3, pp. 939-59.

Katsanevakis, S., Weber, A., Pipitone, C., Leopold, M., Cronin, M., Scheidat, M., Doyle, T., Buhl-Mortensen, L., Buhl-Mortensen, P., D'Anna, G., de Boois, I., Dalpadado, P., Damalas, D., Fiorentino, F., Garofalo, G., Giacalone, V., Hawley, K., Issaris, Y., Jansen, J., Knight, C., Knittweis, L., Kröncke, I., Mirto, S., Muxika, I., Reiss, H., Skjoldal, H. & Vöge, S. 2012, 'Monitoring marine populations and communities: methods dealing with imperfect detectability', Aquatic Biology, vol. 16, pp. 31-52.

Kercher, S.M., Frieswyk, C.B. & Zedler, J.B. 2003, 'Effects of sampling teams and estimation methods on the assessment of plant cover', Journal of Vegetation Science vol. 14, pp. 899-906.

Koss, R.S. & Kingsley, J.Y. 2010, 'Volunteer health and emotioinal wellbeing in marine protected areas', Ocean & Coastal Management, vol. 53, pp. 447-53.

Lanyon, J. & Marsh, H. 1995, 'Temporal changes in the abundance of some tropical intertidal seagrasses in North Queensland', Aquatic Botany, vol. 49, pp. 217-37.

Mackney, P. & Spring, N. 2001, 'The Earthwatch perspective on volunteers and data validity', Developing and sharing best practice in marine-related fieldwork, Occasional Publication, no. 8, pp. 37-41.

McArdle, B.H. & Anderson, M.J. 2001, 'Fitting multivariate models to community data: a comment on distance-based redundancy analysis', Ecology, vol. 82, pp. 290-7.

McDonald, J., Coupland, G. & Kendrick, G. 2006, 'Underwater video as a monitoring tool to detect change in seagrass cover. ', Journal of Environmental Management, vol. 80, pp. 148-55.

McIntyre, E. 2008, 'Volunteer Management in Environmental Organizations: Best Practices, Benefits and Barriers ', Brock University (Canada).

McKenzie, L.J., Lee Long, W.J., Coles, R.G. & Roder, C.A. 2000, 'Seagrass-Watch: Community Based Monitoring of Seagrass Resources', Biol. Mar. Medit. , vol. 7, no. 2, pp. 393-6.

Miller-Rushing, A., Primack, R. & Bonney, R. 2012, 'The history of public participation in ecological research', Frontiers in Ecology and the Environment, vol. 10, no. 6, pp. 285-90.

Mumby, P.J., Harborne, A.R., Raines, P.S. & Ridley, J.M. 1995, 'A Critical Assessment of Data Derived From Coral Cay Conservation Volunteers ', Bulletin of Marine Science, vol. 56, no. 3, pp. 737-51.

Newman, C., Buesching, C.D. & Macdonald, D.W. 2003, 'Validating mammal monitoring methods and assessing the performance of volunteers in wildlife conservation - "Sed quis cutodiet ipsos custodies?"', Biological Conservation, vol. 113, pp. 189-97.

NSW Department of Primary Industries Fisheries 2009, Bringing Back the Fish, viewed 31/03/13, <http://www.dpi.nsw.gov.au/fisheries/habitat/publications/passage/bringing-back-the-fish-project-reports>.

Pattengil-Semmens, C.V. & Semmens, B.X. 2003, 'Conservation and Management Applications of the REEF Volunteer Fish Monitoring Program', Environmental Monitoring and Assessment, vol. 81, pp. 43-50.

Roy, H., Pocock, M., Preston, C., Roy, D., Savage, J., Tweddle, J. & Robinson, L. 2012, Understanding Citizen Science and Environmental Monitoring. Final Report on behalf of UK-EOF., NERC Centre for Ecology & Hydrology and Natural History Museum.

Shirk, J.L., Ballard, H.L., Wilderman, C.C., Phillips, T., Wiggins, A., Jordan, R., McCallie, E., Minarchek, M., Lewenstein, B.V., Krasny, M.E. & Bonney, R. 2012, 'Public Participation in Scientific Research: a Framework for Deliberate Design', Ecology and Society, vol. 17, no. 2, p. 29.

Smith, S.D. & Edgar, R.J. 1999, Description and comparison of benthic community structure within the Solitary Islands Marine Park, Solitary Islands Underwater Research Group Inc., Coffs Harbour.

Stenekes, N. & Sahlqvist, P. 2011, Community involvement in recreational fisheries data collection: Opportunities and challenges, ABARES, Canberra, ABARES technical report 11.5.

Thomsen, D. 2003, 'Community-Based Research: An Opportunity for Collaboration and Social Change', Griffith University.

Thomsen, D. 2008, 'Community-based research: facilitation of sustainability learning', Australasian Journal of Environmental Management, vol. 15, pp. 222-30.

Underwood, A. 1997, Experiments in ecology: their logical design and interpretation using analysis of variance, Cambridge University Press, Melbourne.

Walker, G.B. & Daniels, S.E. 2001, 'Natural Resource Policy and the Paradox of Public Involvement: Bringing Scientists and Citizens Together', Journal of Sustainable Forestry, vol. 13, no. 1/2, pp. 253-69.

Ward-Paige, C.A. & Lotze, H.K. 2011, 'Assessing the value of recreational divers for censusing elasmobranchs', PLoS One, vol. 6, no. 10, p. e25609.

West, R. 2011, 'Impacts of recreational boating activities on the seagrass Posidonia in SE Australia', Wetlands Australia, no. 26, pp. 3-13.

CHAPTER 4[ii]

WHO CARES ABOUT CITIZEN SCIENCE? A SURVEY ON THE UTILITY OF MARINE CITIZEN SCIENCE IN AUSTRALIA

CARLA SBROCCHI[1], TIM GLASBY[2] , WILLIAM GLADSTONE[1]

Submitted *xx/xx/13*

[1] School of the Environment, University of Technology Sydney, Sydney NSW

[2] Department of Primary Industries, Port Stephens Fisheries Institute, Taylors Beach, NSW

Corresponding author: Carla Sbrocchi, Carla.d.sbrocchi@student.uts.edu.au

Word Count (including references and legends) = xxxx

[ii] This chapter has been formatted for submission to the journal Environmental Conservation. Material from Chapter 2 may be repeated here as this chapter is intended to stand alone.

SUMMARY

Citizen science describes the involvement of members of the public in scientific research projects and its benefits include provision of data, increasing public knowledge, and influencing policy development. One method for gauging the utility of citizen science is to review the uptake and use of data provided by citizen scientists. Globally, there are many examples of citizen science providing accurate and valid data, but it is also important to ascertain whether such data are being used to develop policies or contribute to decision-making, and if not, to determine why. We investigated these questions using an online questionnaire, distributed to citizen scientist groups, resource use groups such as dive clubs and recreational fishers, researchers in universities and environmental managers in local, state and federal government agencies. The questionnaire quantified: a) the characteristics of citizen science groups (number of groups, scale of monitoring, protocols, group operations, factors for provision of data); b) characteristics of data users (those who use citizen science data), including operational arrangements, use of validation protocols, levels of engagement and factors influencing use of citizen science data; and c) uses of data from citizen science. The focus of the questionnaire was limited to marine environments in Australia. Respondents (n=185) primarily represented state government agencies (25%) and community groups (20%). The design of the monitoring program and the calibre of the quality assurance/quality control measures were the factors which most influenced usage of data. The capacity of volunteer groups to provide data was primarily affected by the number of skilled members and the security of funding and partnerships. More than 70% of respondents reported having used citizen science-collected data for natural resource management decisions or research. Within Australia alone, 53 marine citizen science programs have produced 72 peer-reviewed publications and 110 technical reports. Involvement in citizen science produced additional benefits for data users, including the development and maintenance of relationships, increased funding opportunities and increased community skills and knowledge. These output measures indicate engaging in citizen science is a valid method for achieving natural resource management outcomes.

4.1 INTRODUCTION

Natural resource management (NRM) is the intersection of science and policy – the nexus between societal values and scientific evidence. If decisions are to achieve benefits for both the environment and society, a series of requirements should be met: an informed citizenry is engaged in defining values for the area that support conservation and development, good quality research is made available which can help to prioritise management actions and inform decisions for improved ecosystem function, and an opportunity is provided for communities to become more informed about issues of the area and discuss potential solutions (Carr 2004; Pohl & Hadorn 2008). These are the underlying principles of adaptive management, where a continuous cycle of monitoring and evaluation is conducted to assess progress against achieving a desired societal outcome, usually of improving or maintaining the quality of the environmental asset (Curtis & Lockwood 2000; Duncan & Wintle 2008).

NRM is undertaken at a variety of scales – from local, which may address point-source issues, and up to bioregional scale, such as the Great Barrier Reef. National scale monitoring schemes occur in parts of the world (Rebele 1997; Certain & Skarpaas 2010). However, a government-run, national monitoring program does not occur in Australia, (Gibbons et al. 2008; Lindenmayer & Likens 2009) partially due to the size of the continent and practical constraints in funding and implementing a monitoring program at this scale.

There is momentum in demonstrating the utility of citizen science for advancing science. Citizen science research can take the form of observations, physical sample collection, data collection for environmental studies and monitoring. Several studies have addressed the capacity for citizen science to contribute specifically to marine monitoring in Australia (Koss et al. 2005a; Koss et al. 2005b; Turner 2006; Dalton & Smith 2009), and the large number of volunteers currently involved in marine monitoring activities throughout Australia in particular is staggering. More than 700 shorebird observers participate in surveys each year and up to 7000 observers participated in the Atlas of Australian birds 1998–2002 (Barrett in Weston et al. 2006b; Clemens et al. 2010). Over the past 25 years, nearly 27,000 people have contributed to Infofish, a recreational fishing program, with an estimated 2,000 people contributing each year (Bill Sawynok, Infofish program manager, pers comm). Internationally, Goffredo et al. (2004) estimated recreational divers saved a professional biologist 18 yr and nearly $1.4 million USD. Much of the current discussion on citizen science focusses on its contribution to research (Foster-Smith & Evans 2003; Newman et al. 2003; Dickinson et al. 2010; Roy et al. 2012). Volunteer data have been validated in studies on invasive species (Delaney et al. 2008), species abundance and distributions (Goffredo et al. 2004; Lovell et al. 2009; Schmeller et al. 2009; Szabo et al. 2012), vegetation assessments (Gollan et al. 2012), mammalian field ecology (Newman et al. 2003), marine habitat assessments (McKenzie et al. 2000; Edgar & Stuart-Smith 2009; Finn et al. 2010) and water quality (Fore et al. 2001). In each of these, non-experts have demonstrated their capacity to provide high-quality data.

Although a worthy consideration, science is only one of three described outcomes of citizen science programs, the others being outcomes for individuals and society (Shirk et al. 2012). Given that there has been some discussion of the benefits to individuals (sustainability learning; Thomsen 2008; well-being; Koss & Kingsley 2010), the lack of information on societal outcomes (how citizen science can or has been used) is concerning (Walker & Daniels 2001; Danielsen et al. 2005). Other than in a very specific context (localised in developing countries, see Danielsen et al. (2009)) the question of whether monitoring data collected by non-experts has had a management or policy application has not been explicitly addressed. Therefore, it would be useful to understand the current uptake of citizen science by decision-makers and the factors that most influence their decision to use citizen science in their decision-making processes. Citizen science is purported to improve decision making processes as it directly involves the public in the research process, thereby educating the citizens who then are more likely to make more informed and environmentally responsible decisions (Carr 2004; Thomsen 2008).

The aim of this study was to investigate the societal outcomes of citizen science, specifically in the marine environment. Jacoby (1997) proposed that the critical components that link environmental research with natural resource management include observation, data management, links to management actions, evaluation of management actions, feedback mechanisms and feed-out mechanisms (communication). The current study provides a test of whether such critical links occur in Australia. We used an online questionnaire to ask citizen science groups, resource user groups (e.g. recreational fishing, recreational SCUBA divers), researchers and natural resource managers a series of questions about their involvement in and use of data from citizen science programs.

4.2 METHODS

A web-based questionnaire (Survey Monkey ®) was used to deliver 43 questions covering the following themes: a) characteristics of citizen science groups, b) characteristics of data user organisations (those who use citizen science data), and c) uses of data provided by citizen science (Table 4.1).

Table 4.1. Questionnaire Themes

Theme	Question topics
a) characteristics of citizen science groups	Operations (length of time operating, source of funding)
	Topic of study and location, scale of monitoring
	Protocols
	Factors affecting provision of data
b) characteristics of data user organisations	Operational arrangements (capacity to support citizen science)
	Level of engagement with citizen science, benefits of engagement
	Factors affecting use of data
	Quality assurance and data validation
c) uses of data provided by citizen science data	Reported/perceived uses and documentation of actual results
	Impact of citizen science

Skip-logic functions directed respondents through the questionnaire based on the answers they provided (i.e. if 'no' was selected for one question, the questionnaire skipped to the next set of questions) (Survey Monkey). All questions offered non-response options (e.g. "don't know") and participants were permitted to skip questions they did not wish to answer. The questionnaire was developed with input from a range of researchers and managers in both academic and management agencies and staff in volunteer-based organisations and resource-use groups.

A database of potential respondents and their associated organisations was compiled from a literature review, suggestions from researchers, searches of Australian funding programs and a web-based search (Google) limited to Australian websites with the terms "community-based monitoring" and "citizen science". A search of funding programs [the federal Natural Heritage Trust, Envirofund, Coastcare and Caring for our Country; the New South Wales Environmental Trust; and Western Australia Coastcare grants] yielded more than 200 organisations or networks which manage citizen science programs. This included community groups, nongovernment organisations (NGOs), natural resource management (NRM) agencies at local, regional, state and federal level (e.g. Fisheries, Marine Parks, regional NRM bodies) and universities.

Using a purposive non-random sampling approach (Neyman 1934), potential respondents within organisations identified through the search described above were contacted via email, provided with an outline of the aims of the project, and asked to complete the online questionnaire. Personal contacts, other scientific networks (Australian Marine Sciences Association, Australian Coastal Society, science communicators, marine educators) and Facebook were also used to promote the questionnaire. In many cases, the initial contact person passed the survey on to the most appropriate people within the organization (e.g. the research unit and the management unit of the same organization). The online questionnaire was open for 47 days (Aug–Sept 2012). Closed-ended questions were analysed using a descriptive summary of findings in the form of frequencies and percentages or rankings. A complete list of questions is provided in Supplementary Material, Appendix S4.1.

4.3 Results

4.3.1 General respondent information

Participating organisations have not been identified in the results; aggregated data only are reported to maintain privacy. The number of people who received the questionnaire is unknown, but 207 individuals submitted responses. Of these, 11% responded that the questionnaire was not relevant to them and did not continue, 34% partially completed the questionnaire and 55% completed the questionnaire in full. Responses from those who completed both partial and full questionnaires were used in this analysis (n=185). Respondents represented seven types of organisations (Table 4.2), with the greatest representation from state government agencies (25%) or community groups (20%). Responses in the ‘other’ category tended to be associated with commercial enterprises such as ecotourism operations or private consulting firms.

Table 4.2. Characteristics of respondents by organisation type, based on n=185 partially/fully completed surveys (percentages rounded to nearest whole number).

Organisation Type	% respondents	% citizen scientists	% data user	% both
Federal (Australian) Government	5%	1%	2%	2%
State Government	25%	1%	21%	3%
Local Government	5%	1%	3%	1%
Regional Natural Resource Management Body	10%	1%	6%	3%
University/Research Institution	17%	3%	11%	4%
Non Government Organisation	15%	6%	2%	6%
Community Group	20%	17%	1%	3%
No Organisation	1%	1%	1%	1%
Other	5%	1%	3%	1%
TOTAL		**30%**	**48%**	**22%**

Citizen science entities tended to fall into two types: a 'group' or a 'program'. A 'group' was defined by the authors as a self-organised collective of people (e.g. a community group, Indigenous rangers) who may collect a variety of environmental data in a variety of ways depending on their interests, whereas a 'program' was defined as having a design with a specific focus and generally having a specific approach to community involvement and data collection (e.g. CoralWatch, SeagrassWatch, Reef Life Survey). This survey recognized that public involvement could arise from either perspective and did not differentiate results between groups and programs. Thirty percent of respondents identified themselves as belonging to community groups or programs consisting of volunteers who collected data. Examples of these respondents included members of community organisations who collect water quality information, and participants in local-government based community engagement programs. Forty-eight percent of respondents identified themselves as 'associated' with these types of groups, in that they assisted, funded, analysed and/or otherwise used data collected by volunteer groups. The greatest number of responses from those associated with volunteers came from universities and state government NRM agencies. Hereafter, those that identified themselves as collectors of data through citizen science are called 'citizen scientists' and those that used, assisted, funded or analysed data from volunteers are called 'data users'. Some respondents identified themselves with both of these categories (22%), i.e., they both provided and used data. Examples of this included a university-based researcher who established a non-government organization which undertook citizen-science based monitoring programs. Responses from those who both provided and used data were incorporated into the analysis of citizen scientists and data users and not differentiated. We assumed that only one person per section within an organization (eg. research unit, management unit) provided responses: respondents could elect to answer anonymously and therefore we were unable to track all individuals or organisations.

4.3.2 Characteristics of Citizen Scientists

The length of time citizen science organisations had been operating in the Australian marine environment varied from less than 1 yr to more than 50 yr (mean±SD=9.5±10.5 yr, n=73). All groups and programs were based in and operated from Australia, with 8% also having overseas affiliates (e.g. ReefCheck, Coral Watch and Reef Life Survey). The majority of groups and programs undertook monitoring primarily to increase their knowledge on an area or species of interest (35%), but also in response to a potential environmental threat (28%), a request from a natural resource management agency or other expert (14%), out of general interest (5%), or for self-education and capacity building (1%).

Programs operated over a range of spatial scales, with most at the local (32%) or regional (25%) scales (3% operated across regions, 19% at state level, 11% at a national level and 11% at international). 'Local' was undefined in the questionnaire, but represented a scale smaller than 'regional' and 'state' and was likely understood to mean within the boundaries of a local government area. 'Regional' was defined to mean the jurisdictional boundary of the natural resource management agency. The majority of groups (64%) collected data from multiple monitoring sites across areas (e.g. multiple sites in more than one estuary, or multiple study sites within an area such as a Marine Park), 25% oversaw multiple monitoring sites in one area (e.g. multiple study sites in an estuary), 6% monitored one monitoring site in one area (e.g. one study site in an estuary), and 6% responded that the spatial scale of their monitoring varid depending on the program in which they were most recently involved.

Of the citizen scientist respondents, 57% reported that their monitoring occurred in "marine" environments, while 22% targeted estuarine environments, 11% studied beaches/dunes, 3% focused on air/climate, 3% on social (behavioural) issues and 5% were undefined. The subjects of monitoring ranged from physical and chemical measures to biological observations, with biotic measures most highly reported (68%) (Table 4.3). Of the biotic measures, 'integrated measures' that encompassed multiple species and types of parameters relating to reef condition, for example, was the most highly reported (16%).

Table 4.3. Monitoring activities according to biotic, physical and social categories. Data are percentages of 73 'citizen scientist' respondents. Percentages are rounded to nearest whole number.

	% Respondents
Biotic - Aquatic Vegetation	8%
Biotic - Bacteria	1%
Biotic - Birds	9%
Biotic - Fish	11%
Biotic - Integrated (habitats - reefs, seagrass beds, etc)	16%
Biotic - Invasive Species	6%
Biotic - Invertebrates	11%
Biotic - Marine Mammals	5%
Biotic - Plankton	1%
Physical/Chemical - Clarity/Turbidity	5%
Physical/Chemical - Flow/Water levels/Tides	4%
Physical/Chemical - Meteorological	2%
Physical/Chemical - Nutrients, Temperature, Salinity, pH, etc.	7%
Physical/Chemical - Toxicity/Pesticides	0%
Social - Attitudes, behaviours	4%
Social - Debris	7%
Social - Resource Use	2%
Climate Change	1%
Other	3%

Citizen scientists primarily funded their operations through government or natural resource management agency grants (75%). Other sources of funds included self-funding through membership fees and fund-raising activities (29%), corporate grants (20%), private grants (16%), or donations (6%). In-kind support (such as advice, facilities, administration, technical support) was accessed by a large proportion of respondents (57%) to sustain their operations and 20% of respondents were internally funded through another organisation's operational budget. Responses were filtered to reflect the funding source of greatest influence on operational support of citizen science groups (Figure 4.1), demonstrating a substantial reliance on government grants with some in-kind support from other organisations. Interestingly, 7% of all respondent groups indicate they are primarily (>90% of total operational budget) self-funded.

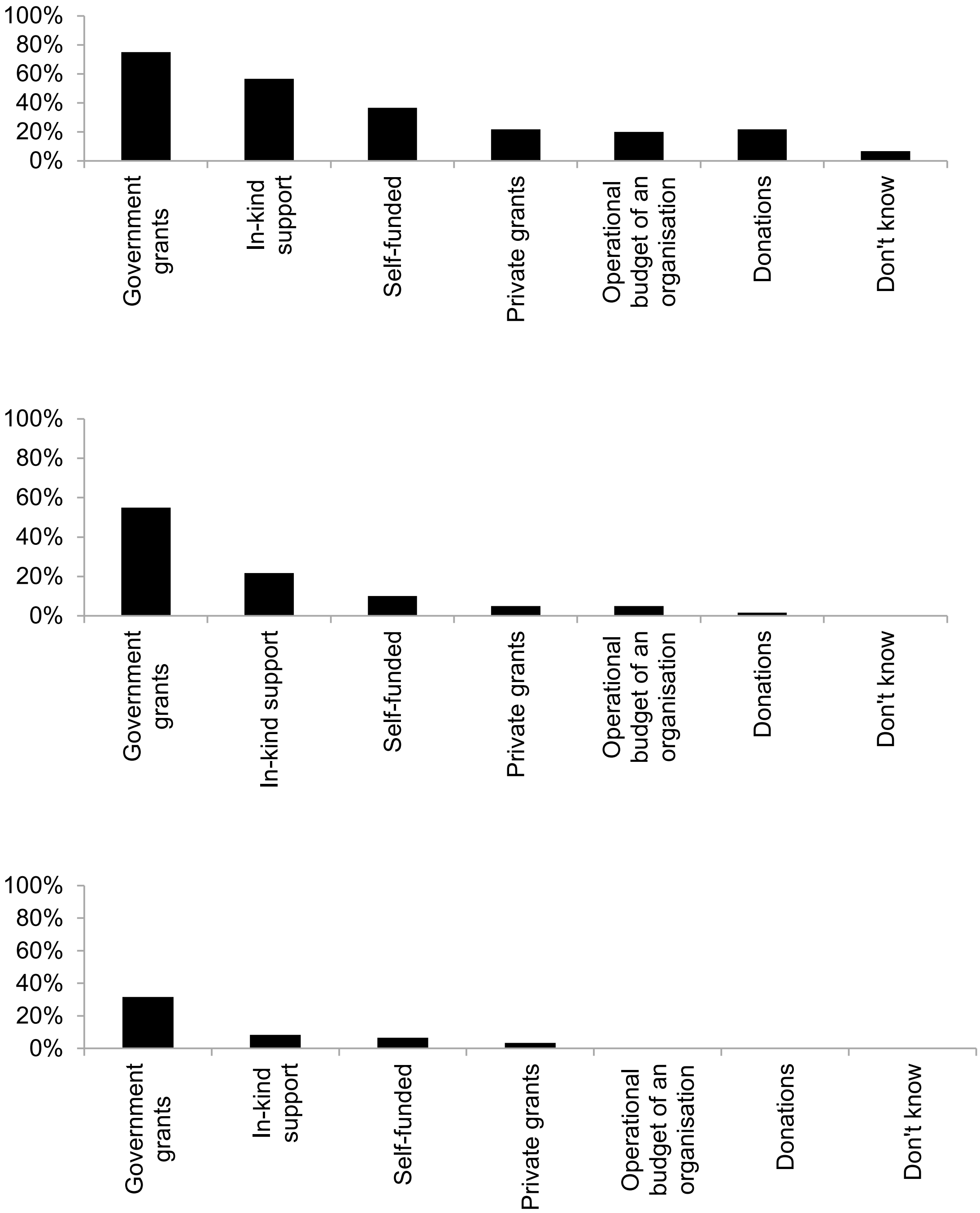


Figure 4.1. Comparison of funding sources for citizen scientist respondents, showing (upper panel) proportion of respondents reporting all sources of funding (respondents could select more than one response so percentages may total >100); (middle panel) proportion of respondents reporting a funding source that made up more than 50% of their total operational budget; and (lower panel) proportion of respondents reporting a funding source that made up more than 90% of their total operational budget. N=60.

Citizen science organisations used international, national or other recognized scientific protocols (53%) or a protocol that had been developed by the group itself (41%). Quality assurance methods employed by citizen science groups included: participation in training programs (79%), use of field guides (69%), periodic review of data and protocols (67%), using accepted scientific protocols and methods (64%), calibration of instruments (23%) and a written quality assurance plan (21%), validation of data (11%), and other responses (5%), which included team meetings and using simple methods. Four percent did not know what quality assurance methods they employed. Citizen scientists used multiple methods to store their data, with 56% keeping hard copies, 46% storing data in electronic formats on personal computers, 41% using electronic formats on institutional computers and 40% storing data on internet-accessible databases. Other formats include mapping software, such as Google Earth or ESRI products (27%), and smartphone apps (6%). 'Other' responses (7%) comprised passing the data onto another organisation for custodianship, and reviwing current data management options. Only 9% percent of respondents used metadata statements for data sharing purposes. Thirty-two respondents provided URLs for an online database where citizen science data were stored (available upon request).

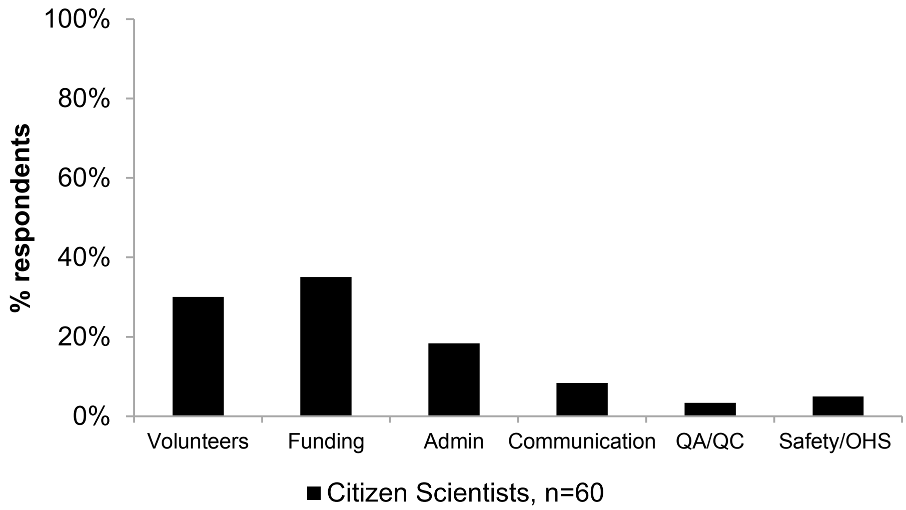


Figure 4.2: Key factors that affect citizen scientists' ability to provide data to organisations. Responses displayed for % respondents selecting top answer ('1'). 'Volunteers' describes the number of volunteers in the group and their technical skills, 'funding' refers to the financial support and partnerships the group maintains, 'admin' includes the capacity of the group to enter and store data, 'communication' is the amount of feedback the group receives from researchers or other project proponents, 'QA/QC' describes data quality and assurance protocols, and 'safety/OHS' relates to insurances and protocols for group monitoring activities.

More than 87% of citizen scientists have made their data available to at least one university or research institution, a government body or a natural resource management organization at some point in time. Respondents were asked to rank the key factors that affect their ability to provide data. Citizen scientists' highest concerns are maintaining a skilled volunteer base and securing ongoing funding and partnerships (Figure 4.2).

4.3.3 Characteristics of Data User Organisations

Data users, who were primarily those in universities and government agencies, (n=101) had engaged in various aspects of citizen science programs including: establishment or administration of groups (including providing funding) (13%); supervision and training (9%); design of methods or study aims (3%); or data storage and analysis (5%). Some respondents (47%) engaged in multiple aspects of a citizen science program, which involved more than one of these activities. Nineteen percent of data users limited their engagement in citizen science to using the provided data only. The length of time data users had been engaged in citizen science programs was relatively evenly distributed across the given time periods ranging from 1 to 10+ years, with the greatest percentage of respondents engaged for 3 yrs (Figure 4.3). Seventeen percent of respondents were intermittently or opportunistically engaged in citizen science, meaning they did not have an ongoing relationship with a particular program or group and occasionally used citizen science data if the data were suitable for a particular purpose.

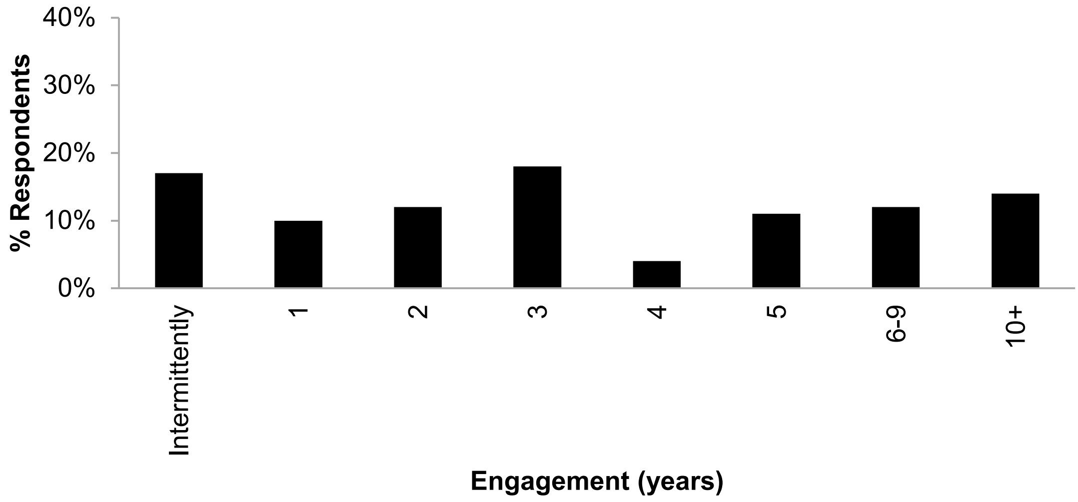


Figure 4.3. Frequency distribution of time data users had engaged with citizen science (based on n=101 responses).

A total of 85% of respondents affiliated with data user organisations reported that they had an operational model which allowed for the use of volunteer-collected data in research and management activities. A substantial proportion (71%) also reported their organization had a stated aim of increasing skills and knowledge of environmental issues and management in the broader community. Many organisations (69%) had someone within the organization available to handle data arising from citizen science activities (receiving, storing, retrieving), either as part of their overall data collection activities (47%) or exclusively for citizen science groups and their data (22%). Dedicated community liaison officers were employed in 58% of data user organizations, while 6% contracted out that role.

Data validation had been performed in some capacity by 52% of respondent data user organisations. Details of the validation procedure were not requested. Of those who undertook a data validation process, the results were: accuracy adequate (74%), data was corrected (30%) and could not use the data (10%). A validation of the volunteers' skills and protocols had been performed in some capacity by 48% data users, however, 43% had not and 10% did not know. Of those who undertook some form of validation, the results were: accuracy adequate (67%), skills and/or protocols required correction (40%) and data could not be used (11%). As a result of the validation processes, organisations reported they were most likely to provide feedback to group members on the results of the validation process (43%), change some protocols or procedures (34%), change or initiate additional training (34%), change some aspects of the monitoring program's design (32%), and/or confirm the record with the observer (27%). Twelve percent did not know what action was taken following validation processes, 3% did not give any explicit feedback or make any changes, and 3% responded with other processes, such as notifying an affiliate organization of results of validation and using different techniques depending on the program and the volunteers involved. Key factors which affected the ability to use data centred around the monitoring program design and the calibre of quality assurance/quality control measures employed (Figure 4.4).

Data is stored by users in multiple formats: electronic formats on institutional or personal computers (43% and 36% respectively), with some use of hard copy (26%), internet-based databases (26%) and/or mapping software (23%). Twenty percent of respondents either did not store the citizen science data they used, or do not know how it was stored.

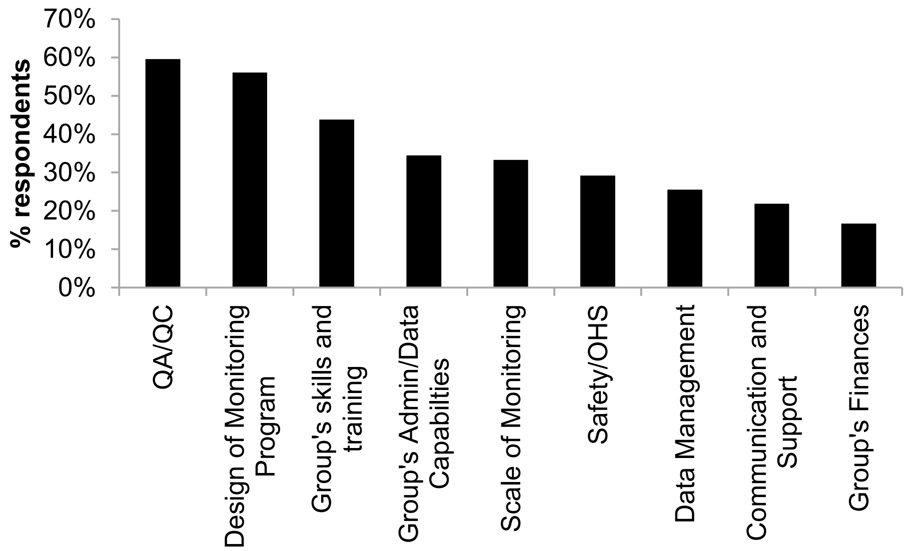


Figure 4.4. Factors which contribute to a data user's decision to use citizen science data. Responses displayed are proportion of respondents selecting factor as top answer ('1' rank), n=90. 'QA/QC' describes data quality and assurance protocols employed by the group, 'Group's admin' includes the capacity of the group to enter and store data, 'Safety/OHS' relates to insurances and protocols for group monitoring activities, and 'Communication' is the amount of feedback the user provides to the citizen science groups.

4.3.4 USES OF CITIZEN SCIENCE DATA

Table 4.4 outlines the various uses of citizen science data, reported and ranked for both citizen scientists and data users. These responses compare how citizen scientists perceived or knew their data to be used, and the actual uses of citizen science data, reported by data user groups.

Table 4.4. Perceived and known uses of citizen science data reported by citizen scientists and data users. Responses displayed are ranked, where 1 = top answer. (94 citizen science respondents, 97 data user respondents; 1=highest/most used rank, 9=lowest/least used)

Rank	Citizen Scientist Reponses	Data User Responses
1	Education and communication	No present use for the data
2	Research	Advocacy
3	Management decision or policy	Management decision or policy
4	Storage in database	Education programs
5	Advocacy	Storage in database
6	Spatial products	Communications products: websites, newsletters, social media
7	Compliance	Spatial products (maps)
8	Other	Compliance
9	Don't know	Research

The ranks given by citizen scientists and data users regarding uses of citizen science data were markedly different. Citizen scientists either used or thought their data were used primarily for education, communication, and research. A high rank given by citizen scientists indicates they used or thought their data were used for decision-making purposes. Data users, on the other hand, may have received data from citizen scientists, but did not have a present use for the data. Others felt it could be used for advocacy and management decisions. The lowest rank given by data users indicated research was the least frequently reported use for citizen science data.

Both citizen scientists and data users were asked to supply evidence of uses of their programs. More than 130 respondents reported a management, policy, research or advocacy use of citizen science data (Table 4.5). Of the 130 responses, 53 provided documentation demonstrating various uses of citizen science data, including: decision-making uses (management and policy such as strategic planning processes, regulations to exclude dogs from wildlife reserves, and fisheries assessments, 30/130, 23%); peer-reviewed scientific papers (14/130, 10%); and advocacy through written submissions (10/130, 7%). Additionally, 110 technical reports have been produced using citizen science data. Although making up only 10% of the responses, 72 published peer-reviewed journal articles were based on data collected by citizen scientists in Australian marine environments (Supplementary Material, Appendix S4.2).

Table 4.5. Outputs of citizen science programs, compiled from all respondents ((n=185)) as a measure of usefulness of citizen science data.

Output	N	% all respondents	% data users
Programs reporting a use of decision-making, research or advocacy	130	70%	
Programs demonstrating uses of decision-making, research or advocacy	53	29%	73%
Programs demonstrating decision-making uses	30	16%	41%
Programs demonstrating peer reviewed research	14	8%	19%
Number of peer reviewed papers utilising Australian marine citizen science	72		
Number of reports/books/submissions using Australian marine citizen science	110		

Data users were asked to record whether there were any real or perceived additional benefits from interacting with citizen science groups, apart from the ‘use’ of data. The benefits listed (n=97 respondents) included building relationships (94%), increasing community skills and knowledge (91%) and community stewardship of the marine environment (90%). Other benefits included increasing funding opportunities (62%) and contributing to management targets (58%).

4.4 Discussion

We believe this is the first survey to examine current citizen science practices specifically in the marine environment, and also in Australia. Citizen science programs aim to achieve outcomes for science, for the benefit of individuals, and for the benefit of society more broadly through decision-making processes and community-building. This survey provides a point of reference for evaluating the status of marine-based citizen science in Australia and the contributions of citizen science to natural resource management decision making. Citizen scientists monitor a great range of subjects from water quality to biological assemblages. With an average of 10 yr in operation, citizen science groups currently in existence in Australia are well established. The main challenges to ongoing provision of data were reported as maintaining funding and the skill levels of volunteers. These challenges have been reported elsewhere (Weston et al. 2003; Bell et al. 2008; Wolcott et al. 2008) and are addressed primarily through assessments of and addressing group aims and volunteer motivations. Articulating group aims may also assist in diminishing the competition that arises between citizen science groups and programs for funding, as grants schemes can thus be targeted to specific locales, issues and relevant groups.

Few respondents (14%) had established their monitoring activities as a result of a direct request from an NRM professional or other expert, but rather the subject of the citizen scientists' monitoring, and the environment in which they worked, reflected their interests or the location of a perceived environmental threat. However, the result that 87% provided data to universities or agencies suggests these groups were looking for stronger relationships to assist in analysing data and facilitating its application in potential policy options. Monitoring programs arose as a result of specific interests of the citizen science group. Many utilised scientifically-recognised protocols (53%) in their monitoring program, however 41% developed their own protocols. Tailoring a protocol for a specific location or objective may be necessary or may contribute to feelings of group-ownership of the process (Halusky et al. 1994; Koss & Kingsley 2010), but if the monitoring program is designed to provide scientifically valid data, it is equally important to ensure that the protocols are scientifically robust. Some programs reported there were no established methods available for use by citizen scientists and therefore these programs, in developing their own protocols, provide the first record of methods for these purposes. In some cases, like Coral Watch, these methods are now published and used in national and international monitoring contexts, even by researchers not engaged with citizen scientists (Fabricius 2006; Montano et al. 2010; Teymour & Sanjani 2010; Fabricius et al. 2011).

The concerns data users had with citizen science data related to the design of the monitoring program and the calibre of quality assurance measures employed by the groups. However, it appears data users are not taking the opportunity to review data, to test their perception that it is not valid. Approximately half of data users did not or do not know whether their organization validated any of the methods or data provided to them by citizen scientists. Two possible scenarios arise from this; either the data are used, and their reliability questioned, or the data are not used due to a lack of faith in their reliability. Either outcome would seem to be wasteful of resources. The cause of not validating the data most likely relates to logistical constraints. One respondent reported that managers had many demands on their time, and if the data had not been collected in response to a specific request from him, he found it difficult to find the time to further assess it. As validation of citizen science is not seen as core business of many NRM operations, the capacity required to assess and provide feedback may be seen as too limited.

In the majority of cases, it seems, citizen scientists and data users are not interacting early enough in the development phase of the sampling program for scientists and managers to have confidence in the quality of data produced from the program. The low degree of participation of data users in citizen science, particularly in development of sampling design and supervision (ranges of: 3-50% and 9-56% respectively) cannot be attributed to an institutional problem: data users reported their organisations had the capacity to engage with, train and assist citizen science groups. It is possible that the problem lay in the perception of managers and scientists of the value of the data compared to the effort expended by them in assisting the volunteers (Underwood & Chapman 2002; Newman et al. 2003), which is reflected in the result that users did not have a current use for citizen science data. Although their organization does not exclude the possibility of using citizen science data, managers and scientists may not have the capacity, authority, willingness or flexibility to accommodate it.

Measuring the publication output from citizen science programs is one way of determining the utility of citizen science for research. In coast and marine environments within Australia, 72 peer-reviewed publications and over 110 reports using citizen science data have been produced by 53 programs over 13 years. In reality, this value may even be higher as not all respondents provided evidence of these uses in time to be included in this paper. Evaluating uses against documented cases only, 30 groups or programs (23% of all respondents) could support claims of management and policy uses, 14 (10%) provided peer-reviewed research and 10 (7%) demonstrated advocacy through submissions. Many of these programs which produce high-quality, peer-reviewed articles are based entirely on citizen science-derived data. Such programs include Bird Life Australia (>25 papers), Infofish Australia (10), Earthwatch (7), Seagrass-Watch (13), Coralwatch (6), RedMap (5) and Reef Life Survey (5 papers).

4.5 Conclusions

Data arising from citizen science programs has been criticized for being of poor quality and not collected with particular management questions in mind (Lunney & Matthews 2002; Underwood & Chapman 2002). This survey of nearly 200 individuals involved in marine-based citizen science activities across Australia indicated that some citizen science is being used for management and policy decisions, as well as high-quality research (as evidenced by the numbers of peer-reviewed papers).

It is important to note that not all citizen science projects are the same – there is not a single model of citizen science – and outcomes for research (e.g. scientific findings), for individual participants (e.g. acquiring new skills or knowledge, well-being) and/or for social-ecological systems (eg. influencing policies, taking conservation action) may be achieved in varying degrees. Theoretical models of public-scientist interactions highlight strong outcomes for decision-making and research when citizens and scientists/managers are mutually benefitting from the citizen science process, in either a Contributory, Collaborative or Co-created framework (Shirk et al. 2012). Clearly, in cases where scientists and the public are working together, citizen science can result in high-quality research outputs: in this case, 14 programs (19% of data users) produced 72 peer-reviewed articles over 13 years. Cohn (2008) surmised that volunteers generally do not analyse data or write scientific papers and scientists are often required to make sense of the data collected by citizens. The questionnaire results may support this statement. While 53 programs prepared ‘reports’ on their data, only 14 have published in peer-reviewed journals. Given that the majority of groups surveyed were self-initiated, engaging managers and scientists in the early stages of the development of monitoring programs may achieve enhanced research outcomes, including outputs such as journal articles.

Many have written about the consistent and widespread problem facing citizen science: the need for managers and scientists to work with the participants to drive appropriate monitoring programs so that good scientific and decision-making outcomes can be achieved from the expended effort (Bell et al. 2008; Dalton & Smith 2009; Koss & Kingsley 2010; Shirk et al. 2012). Less than 56% and as few as 3% of data users we surveyed were directly engaged in the design or oversight of citizen science groups, indicating there is opportunity for local and regional managers to be more involved in citizen science programs, to more strongly link citizen science activities with decision-making processes at appropriate scales. This may be achieved by inviting scientists and managers to sit as members of advisory committees, assisting in setting questions and objectives for monitoring and experimental design, or by directly engaging scientists to periodically review methods and data to ensure they align with group monitoring objectives. If natural resource managers and scientists with to make use of data arising from citizen science programs, supporting local and regional citizen science programs, perhaps by way of providing or facilitating training or offering administration or data management solutions, may be beneficial. Scientists may also wish to enhance the learning environment, where citizens become more active in the scientific process, and find more meaning and value in the experience (Luther et al. 2009; C Sbrocchi, University of Technology Sydney, unpubl data). As these citizens become more engaged, they are also more likely to contribute higher quality data with fewer biases (Luther et al. 2009). Volunteers tend to choose monitoring sites based on access issues (Clarke et al. 2012) presence of charismatic species or habitats (Baker et al. 2012; Hammerton et al. 2012), or proximity to home (Koss & Kingsley 2010). These biases could be overcome by targeting under-represented areas by either employing professionals or encouraging volunteers to monitor elsewhere (Tulloch et al. 2012).

With a strong focus on monitoring at the local and regional level (58% of respondents), there is a great opportunity to influence local and bio-geographic scale NRM decisions. In fact, 46% citizen scientists indicated their data were used for decision-making purposes, and data users (those who assist/fund/support/use citizen science data) rank decision-making within their top three uses of citizen science data. The applications of citizen science are certainly not insignificant, and more could be done to maximize on the opportunities present within this emerging field to harness a willing and capable workforce who are equally capable of integrating more fully with scientific and management processes (Thomsen 2003; Carr 2004; Luther et al. 2009;

Shirk et al. 2012). Citizen science research has addressed this by providing frameworks for maximizing the available workforce that volunteers provide to environmental research no matter whether the approach is localized and community-driven or a top-down, broad scale monitoring program (Bell et al. 2008; Dickinson et al. 2010; Conrad & Hilchey 2011; Shirk et al. 2012).

If we accept Jacoby's model (1997) that the critical components that link environmental monitoring with natural resource management include observation, data management, links to management actions, evaluation of management actions, feedback mechanisms and feed-out mechanisms (communication), we can conclude from the responses given by more than 200 professionals across Australia that citizen science has more than just a place in natural resource management in Australia, it is essential.

ACKNOWLEDGEMENTS

Our thanks to the survey respondents who so willingly shared their thoughts and time. The questionnaire received Human Ethics approval (University of Technology, Sydney Human Research Ethics Committee UTS HREC REF NO. 2012-052A). Thanks to two reviewers who provided useful comments on an earlier manuscript.

APPENDIX S4.1 QUESTIONNAIRE

Community based monitoring, or citizen science, is on the rise in Australia, particularly in the coastal and marine domain. The premise of many community based monitoring programs (also known as citizen science, or public participation in scientific research) is that they contribute useful data; however, to date, no comprehensive analysis has been undertaken within Australia to review such programs, to determine the extent to which data provided by citizen scientists has been used in published research or has influenced management decisions or policy. Your input through this survey will seek to provide a clearer picture on the past, current and future provision of data by coastal/marine community monitoring groups, which will help to understand;

- the types of data that are collected by community volunteers
- uses of the data
- the degree to which decision-making or policies have already benefited from this data
- the factors that may affect the quality of data provided
- data capture and management options, and
- other issues that may influence the provision and use of volunteer collected data in Australia.

The results of this survey will be compiled into an MSc thesis and shared with those who have participated in this study, with the aim to publish the results in a peer-reviewed journal. Initial findings will be presented at the 2012 Coast to Coast Conference in Brisbane, Australia. This survey consists of a maximum of 41 questions, but most people will only need to answer about 22 questions, and should take about 10-15 minutes. If you have any questions or concerns regarding the distribution of this survey please contact:

Carla Sbrocchi
carla.d.sbrocchi@student.uts.edu.au
MSc candidate at University of Technology, Sydney

This study has been approved by the University of Technology, Sydney Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research which you cannot resolve with the researcher, you may contact the Ethics Committee through the Research Ethics Officer (ph: 02 9514 9772, Research.Ethics@uts.edu.au) and quote the UTS HREC reference number 2012052A. Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

1. Which of the following best describes you?
Manager what is this? Professional what is this? Technician what is this?
Federal Government
State Government
Local Government
Regional NRM body (CMA, NRM board)
University/Research Institution
Incorporated Non
Government Organisation
Community Group
Not applicable (no organisation)
Other (please specify below)

2. Please tell me about the organisation to which you belong, with respect to your engagement with coastal/marine citizen science.
A. Community Group or Program consisting of volunteers who collect data
B. Associated with community groups/programs that use volunteers to collect data (we assist, fund, analyse and/or use data)
C. Both A and B
D. Neither A nor B. Survey is not relevant to me.

In this section you will be asked questions relating to your organisation's community-based monitoring activities. If this does not pertain to you, go back and choose another option, or exit this survey. If you also fund or support community monitoring programs or use (analyse, manipulate, report, etc) data collected by volunteers, complete this section and continue on to Section 2.

3. What is the name of your community group or marine monitoring program that undertakes data collection in the coastal and/or marine environment?

4. How many years has your group/program been involved in marine monitoring?

5. Does the operation of your citizen science group/program have an Australian base?
Group/program AND sites are both Australia-based.
Group/program IS Australia-based but sites are NOT in Australia.
Group/program does NOT have an Australian base but sites ARE in Australia.
Group/program and sites are NOT Australia-based.
Other (please specify)

6. What was the main driver in initiating your data collection activities? (choose one only)
General interest
Response to a potential environmental threat
Increase knowledge on local area or local species
Request from Natural Resource Management agency or experts
Other (please specify)

7. What types of data are collected?
Environments Study Subjects Type of Measurements
Other (please specify)

8. What scale does your monitoring program relate to?
International (your group monitors sites across nations or is one of several in an international program)
National (your group monitors sites across a country or is one of several in a national program)
State (your group monitors sites across the state or is one of several in a statewide monitoring program)
Regional (your group monitors sites across a region or is one of several in a region-wide monitoring program)
Local
Other (please specify)

9. Specify the size and type of monitoring your group undertakes.
One monitoring site in one area (eg. One study site in an estuary)
Multiple monitoring sites in one area (eg. Multiple study sites in an estuary)
Multiple monitoring sites in multiple areas (eg. Multiple sites in more than 1 estuary or multiple study sites at different places in a Marine Park)
Other (please specify)

10. Are your methods....
A. Based on an international, national, or other recognized scientific protocol/method?
B. Based on a protocol/method developed by your group/program?
C. Neither A nor B
D. Don't know

11. Name the protocol/method you use OR name the person/organisation who developed it.

12. What methods do you use to guarantee the reliability of your data? Choose all that apply.
Calibration of instruments

Written quality assurance plan
Metadata statements for data sharing
Use of accepted scientific protocols and methods
Use of field guides
Training programs
Periodic review of data and/or protocols
Don't know
Other (please specify)

13. How do you store your data?
Hard copy (paper)
Spreadsheet or database on personal computer
Spreadsheet or database on institutional computer
Internet-based database (please provide web address below)
Mapping software (eg. GIS, Google Earth)
Smart Phone app
Other (please specify below)
Other Storage Option or Web address of database

14. Is your data provided to a university/researcher, local/state/federal government or natural resource management organisation?
Yes
No
Don't know
Other

15. To whom is the data provided? This may be the name of an organisation, a contact person and their details (phone/email) or an internet-based database web address.
Data provider 1
Data provider 2
Data provider 3

16. Has your data been used for any of the following? (tick all that apply)
Stored in an institutional/online database
Advocacy
Spatial products (maps)
Education programs or communications products (websites, newsletters, social media)
Compliance
Research
Management decision or policy (decision on land use, restoration of habitat, etc., planning process, evaluation of management practice, or development of policy/legislation)
Don't know
Other (please specify)

17. Could you provide references that illustrate uses of your data? (eg. reports, communications products, media articles, journal articles)
Yes. I can document some below.
Yes, I can provide by email. (contact details are provided at the end of the survey)
Yes, but could you please follow up with me later? I will leave my details at the end of the survey.
No.
Place reference(s) here

18. How are your group's monitoring activities funded? (Estimate answers as percentages of your total budget. Entries should sum to a total of 100%)

Membership fees/fund raising activities/selffunded
Donations
Government grants (federal, state, CMA/NRM region, local)
Corporate grants
Private grants
Operational budget of an organisation
Inkind support
Don't know

19. If funded by government grants, who was the funding body? Name of Funding Body (e.g. Sydney Metro CMA) OR Name of Funding Round (e.g. Envirofund 2006)
Funding Provider 1
Funding Provider 2
Funding Provider 3
Funding Provider 4
Funding Provider 5

20. What are the key factors that impact on your ability to provide data to organisations? Please rank your answers from 1 = most important factor to 6 = least important factor.
Our administrative capabilities (data management, group coordination)
Quality assurance/Quality control measures
Communication with researcher/organisations
Number of volunteers or their technical skills
Safety/OHS considerations
Securing ongoing funding or partnerships

21. In addition to collecting data, does your organisation also use or analyse volunteer collected data?
Yes. You will now continue on to Section 2 of the survey.
No. You will be forwarded on to Section 3 of the survey.
Other

This section is for those who assist or fund volunteers/community groups or are provided with, manipulate, store, analyse or otherwise use volunteer data from coastal/marine environments. If this does not pertain to you, you may go back and choose another option or exit this survey. Realising that your organisation may engage with citizen science in varying ways and degrees, please select the options that illustrate the complete range in which you utilise citizen science.

22. List the marine monitoring program or community group with which your organisation/project has associated. If you don't engage with groups/programs specifically (eg you devolve funds to other organisations who work with citizen scientists) you may enter 'don't engage directly' in box below.
Group or Program 1
Group or Program 2
Group or Program 3
Group or Program 4
Group or Program 5
Group or Program 6

23. Of these groups/programs with whom you have associated, in which aspects of their monitoring program has your organisation/project been involved? **Primary Aspect AND Number of Years involved**
Group or Program 1 (from question above)
Group or Program 2 (From question above)
Group or Program 3 (from question above)
Group or Program 4 (from question above)
Group or Program 5 (from question above)

Group or Program 6 (from question above)
Other aspect

24. Does your organisation/project have a person dedicated to liaising with and coordinating community groups?
Yes within our organisation.
Yes provided by contracted organisation.
No.
Don't know.

25. Does your organisation/project have a training and community capacity role? (Community capacity is an organisational objective to increase community skills and knowledge)
Yes.
No.

26. Does your organisation/project have anyone dedicated to handling data arising from citizen science activities (e.g. receiving it, storing it, retrieving it)?
Yes, specifically for Community Monitoring groups and their data.
Yes, as part of our organisation's overall data collection and monitoring activities.
No.

27. Does your organisation's operational model allow for the use of volunteer-collected data to contribute towards your research, management decisions or planning activities?
Not applicable
Yes
No
Don't know

28. Would any of the following be considered by your organisation/project to be 'fringe benefits' of using community data? Choose all that apply.
Contributes to our management targets
Increases our knowledge base for decision-making or policy development
Increases our funding opportunities
Increases community stewardship of marine environment
Increases community skills and knowledge
Builds relationships

29. What factors influence the willingness of your organisation/project to use
community data? Choose all that apply and assign a factor rank (1 is major factor, 5 is not a factor)
Data management/storage capacity
Group having a dedicated coordinator for liaison, data entry, retrieval, analysis, etc.
Calibre of quality assurance/quality control measures
Extent/type of training group has received
Design of monitoring program
Level of support we can provide group
Safety/OHS considerations
Scale of group's monitoring activities (temporal or spatial)
Level of financial support group maintains
Group's data analysis capabilities

30. How do you store data collected from marine community monitoring groups?
Hard copy (paper)
Internet-based database
Don't know

We don't store the data ourselves
Mapping software (eg. GIS, Google Earth)
Spreadsheet or database (personal)
Spreadsheet or database (institutional)
Other (please specify)

31. How have you used data from community-based monitoring programs and how
valuable was the community data to this use? Choose all that apply and assign a value rank (1 is Essential, 5 is Trivial)
Evidence towards management decision, planning process, evaluation of management practice, or policy development/legislation
Research
Communications products: websites, newsletters, social media
Storage of monitoring data on database
Spatial products (maps)
Education programs
Regulation/compliance
Advocacy
Filed only (no plan at present to use data)
Other (please specify)

32. Could you provide references that illustrate the uses of citizen science data by your organisation/project?
Yes, I can document some below.
Yes, I can provide by email (Contact details provided at the end of the survey).
Yes, but could you please follow up with me later? I will leave my details at the end of the survey.
No.
I have provided an answer in Section 1.
Place reference(s) here.

33. Has your organisation/project performed a validation ('QA/QC') test on volunteer data? (ie. to screen for clerical errors or inconsistencies)
Yes on data we receive from some projects/groups.
Yes on data we receive from all projects/groups.
No
Don't know

34. What was the result of the validation? (choose all that apply)
Accuracy adequate
Could not use the data
Data was corrected

35. Has your organisation/project performed a validation ('QA/QC') test on the skills and protocols the volunteers employ? (ie. to check whether the procedures and application of techniques are correct)
Yes on some of the projects/groups.
Yes on all of the projects/groups.
No
Don't know

36. What was the result of this validation? (choose all that apply)
Accuracy adequate
Could not use the data

37. As a result of the validation process(es), did your organisation do any of the following: (Choose all that apply)
Skills and/or protocols required correction
Provide feedback to group members on results of validation
Change some aspects of the monitoring program's design
Change some protocols or procedures
Change or initiate additional training
Confirm record with observer
No explicit feedback given or changes made
Not applicable
Don't know
Other (please specify)

Please complete this section if volunteers use SCUBA in their marine monitoring activities.

38. Is SCUBA used by volunteers to collect the data provided to you?
Yes
No
Don't know

39. What qualifications are the SCUBA divers required to have to participate in monitoring activities? (Tick all that apply)
Open Water
Advanced
Rescue Diver
Dive Master
Dive Instructor
Commercial or Scientific Diver (ADAS)
Other accredited Scientific Diver
Commercial level medical certificate (compliant with AS2299)
Minimum number of dive hours or logged dives (please specify below)
Project-specific training (please specify below)
PADI specialty (please specify below)
First Aid Certificate
Oxygen provider certificate
Other (please specify)

40. Are you aware of the new Dive Standard in Australia? Click here: Part 4.8 Diving Work on page 177 of the document To summarise, a volunteer who participates in monitoring for the purposes of providing data to a natural resource manager or research body ('limited scientific diving work') must now have 60 hours of logged dives, an annual commercial-level medical certificate, a current First Aid and CPR ticket, a current Oxygen Provider ticket and a VET accredited dive qualification.
Yes
I was not previously aware.

41. How do you think this will affect your ability to acquire and use data from volunteer groups and programs?

42. Please take the opportunity to mention any other issues or comments relating to volunteer monitoring programs or your involvement with them.

43. I may like to follow up on some of the answers you have provided, and I certainly would like to share the results of the survey with you. Are you happy to leave your details with me? Rest assured that your personal information is completely confidential.

Yes I'm happy for you to contact me and I'd like to hear about the results of the survey.
No thanks. Good luck with your project.

If you would like to receive updates on this research, provide additional answers or you just want to let me know who you are, please enter your name, phone number and email address here. Your personal information is completely confidential and will not be shared with anyone.

44. Leave your details here.
Name:
Company:
Address 1:
Address 2:
City/Town:
State/Province:
ZIP/Postal Code:
Country:
Email Address:
Phone Number:

Thanks for sharing your thoughts on coastal and marine community-based monitoring programs in Australia. If you would like to forward additional information or if you have any queries you can find me at:

carla.d.sbrocchi@student.uts.edu.au

And in case you needed to see this one more time:

This study has been approved by the University of Technology, Sydney Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research which you cannot resolve with the researcher, you may contact the Ethics Committee through the Research Ethics Officer (ph: 02 9514 9772, Research.Ethics@uts.edu.au) and quote the UTS HREC reference number: 2012052A. Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

APPENDIX S4.2: CITIZEN SCIENCE PUBLICATIONS BASED ON AUSTRALIAN CITIZEN SCIENCE ACTIVITIES

Almany, G., Hamilton, R., Williamson, D., Evans, R., Jones, G., Matawai, M., Potuku, T., Rhodes, K., Russ, G. & Sawynok, B. (2010) Research partnerships with local communities: two case studies from Papua New Guinea and Australia, Coral Reefs, 29: 567-76.

Ambrose, R., Hodgson, G., Shuman, C. (2005) Population impacts of collecting sea anemones and anemonefish for the marine aquarium trade in the Philippines, Coral Reefs, 24(4): 564 - 573

Antos, M.J., Weston, M.A. & Priest, B. (2006) Factors Influencing Awareness of Community-Based Shorebird Conservation Projects in Australia, Applied Environmental Education and Communication, 5: 63-72.

Bell, I.P. and, Paramenter, C.J. (2008). The diving behaviour of inter-nestling hawksbill turtle, eretmochelys imbricata (Linnaeus 1766) on Milman Island Reef, Queensland, Australia. Herpetological Conservation and Biology 3 (2): 254-263

Booth, DJ, Bond, N & Macreadie, P. (2011). Detecting range shifts among Australian fishes in response to climate change Marine and Freshwater Research. 62: 1027–1042.

Bradshaw,C.J.A., Fitzpatrick,B.M., Steinberg,C.C., Brook,B.W., Meekan, M.G. (2008) Decline in whale shark size and abundance at Ningaloo Reef over the past decade: The world's largest fish is getting smaller, Biol.Conserv. 141(7): 1894-1905

Brown, I., Sumpton, W., McLennan, M., Mayer, D., Campbell, M., Kirkwood, J., Butcher, A., Halliday, I., Mapleston, A., Welch, D., Begg, G.A. & Sawynok, B. (2010) An improved technique for estimating short-term survival of released line-caught fish, and an application comparing barotrauma-relief methods in red emperor (Lutjanus sebae Cuvier 1816), Journal of Experimental Marine Biology & Ecology, 385(1/2): 1-7.

Butler, J.R.A., Gunn, R., Berry, H., Wagey, G., Hardesty, B. & Wilcox, C. 2013, 'A Value Chain Analysis of ghost nets in the Arafura Sea: Identifying trans-boundary stakeholders, intervention points and livelihood trade-offs', Journal of Environmental Management, vol. 123.

Campbell SJ and McKenzie LJ (2004) Flood related loss and recovery of intertidal seagrass meadows in southern Queensland, Australia. Estuarine, Coastal and Shelf Science 60: 477-490.

Campbell SJ, McKenzie LJ and Kerville SP (2006) Photosynthetic responses of seven tropical seagrasses to elevated seawater temperature. Journal of Experimental Marine Biology and Ecology 330: 455– 468.

Carpenter, K. (2008). One-Third of Reef-Building Corals Face Elevated Extinction Risk from Climate Change and Local Impacts. Science Express: July 10, 2008.

Chandler, M., Bebber, D.P., Castro, S., Lowman, M.D., Muoria, P., Oguge, N. & Rubenstein, D.I. (2012) International citizen science: making the local global, Front Ecol Environ, 10(6): 328–31.

Clemens, R., Weston, M., Haslem, A., Silcocks, A. & Ferris, J. (2010) Identification of significant shorebird areas: thresholds and criteria, Diversity and Distributions, 16: 229–42.

Clemens, R.S., Kendall, B.E., Guillet, J. & Fuller, R.A. (2012) Review of Australian Shorebird Survey Data, With Notes on their Suitability for Comprehensive Population Trend Analysis, Stilt, 62: 3-17.

Coles RG, Grech A, Rasheed, MA, McKenzie LJ, Unsworth RKF, and Short F (2011) Seagrass ecology and threats in the tropical Indo-Pacific bioregion Chapter 9 In: Pirog RS (ed) Seagrass: Ecology, Uses and Threats Editors. 2010 Nova Science Publishers, Inc ISBN: 978-1-61761-987-8

Collier, C.J., Waycott, M.W. and McKenzie, L. (2012). Light thresholds derived from seagrass loss. Ecological Indicators 23: 211–219.

Couturier, L.I.E., Jaine, F.R.A., Townsend, K.A., Weeks, S.J., Richardson, A.J. & Bennett, M.B. (2011) Distribution, site affinity and regional movements of the manta ray, Manta alfredi (Krefft, 1868), along the east coast of Australia, Marine and Freshwater Research, 62: 628–37.

Edgar GJ and Stuart-Smith RD (2009). A continental-scale analysis of ecological effects of marine protected areas based on underwater visual surveys. Marine Ecology Progress Series 388:51-62.

Edgar GJ, Barrett NS, Morton AJ (2004) Biases associated with the use of underwater visual census techniques to quantify the density and size-structure of fish populations. Journal ofExperimental Marine Biology and Ecology 308, 269-290.

Edgar GJ, Barrett NS, Stuart-Smith RD (2009). Exploited reefs protected from fishing transform over decades into conservation features otherwise absent from seascapes. Ecological Applications 19: 1967-1974.

Ens, E.J., Towler, G.M., Daniels, C., Yugul Mangi Rangers, and Manwurrk Rangers. Looking back to move forward: Collaborative ecological monitoring in remote Arnhem Land. Ecological Management and Restoration 13(1): 26-35, 2012.

Fabricius, K.E. (2006) Effects of irradiance, flow and coral pigmentation on the temperature microenvironments around corals: Implications for coral bleaching? Limnology and Oceanography. 51(1):30-37

Finn, P.G., Udy, N.S., Baltais, S.J., Price, K. & Coles, L. (2010) Assessing the quality of seagrass data collected by community volunteers in Moreton Bay Marine Park, Australia, Environmental Conservation, 37(1): 83-9.

Gosbell, K. & Clement, R. (2006) Population Monitoring in Australia: Some Insights after 25 years and Future Directions, Stilt, 50: 162-75.

Grech, A., Chartrand-Miller, K., Erftemeijer, P., Fonseca, M., McKenzie, L., Rasheed, M., Taylor, H. and Coles, R. (2012). A comparison of threats, vulnerabilities and management approaches in global seagrass bioregions. Environmental Research Letters 7(2): 024006 (8pp) doi:10.1088/1748-9326/7/2/024006

Gunn, R., Hardesty, B.D. & Butler, J. (2010) Tackling ‘ghost nets’: Local solutions to a global issue in northern Australia', Ecological Management & Restoration, 11(2) :88-98.

Holmberg, J., Norman, B., Arzoumanian,Z. (2008) Robust, Comparable Population Metrics Through Collaborative Photo-Monitoring of Whale Sharks, Rhincodon Typus, Ecol.Appl., 18(1): 222-233

Huveneers, C., Luo, K., Otway, N.M. & Harcourt, R.G. (2009) Assessing the distribution and relative abundance of wobbegong sharks (Orectolobidae) in New South Wales, Australia, using recreational scuba-divers, Aquat. Living Resour, 22: 255–64

Inglis, GJ & Lincoln Smith, MP (1995) An examination of observer bias as a source of error in surveys of seagrass shoots. Australian Journal of Ecology, 20: 273-281.

Iwamura, T., Possingham, H.P., Chadès, I., Minton, C., Murray, N., J. , Rogers, D.I., Treml, E.A. & Fuller, R.A. 2013, 'Migratory connectivity magnifies the consequences of habitat loss from sea-level rise for shorebird populations', Proc. R. Soc. B, vol. 280.

Jacoby, C., Manning, C., Fritz, S. & Rose, L. 1997, 'Three recent initiatives for monitoring of Australian coasts by the community', Ocean & Coastal Management, vol. 36, no. Nos 1-3, pp. 205-26.

Johnson, C.R., Banks, S.C., Barrett, N.S., Cazassus, F., Dunstan, P.K., Edgar, G.J., Frusher, S.D., Gardner, C., Haddon, M., Helidoniotis, F., Hill, K.L., Holbrook, N.J., Hosie, G.W., Last, P.R., Ling, S.D., Melbourne-Thomas, J., Miller, K., Pecl, G.T., Richardson, A.J., Ridgway, K.R., Rintoul, S.R., Ritz, D.A., Ross, D.J., Sanderson, J.C., Shepherd, S.A., Slotwinski, A., Swadling, K.M., and Taw, N. (2011). Climate change cascades: shifts in oceanography, species' ranges and subtidal marine community dynamics in eastern Tasmania. Journal of Experimental Marine Biology and Ecology, 400: 17–32.

Jones, A, Barnett, B, William, AJ, Grayson, J, Busilacchi, S, Dusckworth, A, Evans-Illidge, E, Begg, GA, Murchie, CD. 2008. Effective communication tools to engage Torres Strait Islanders in scientific research. Continental Shelf Research. 28: 2350–2356

Jones, A. M., R. Berkelmans, et al. (2011). Species Richness and Community Structure on a High Latitude Reef: Implications for Conservation and Management. Diversity 3(3): 329-355.

Koss, R. and Kingsley, J. 2010. Volunteer health and emotional wellbeing in Marine Protected Area programs. Ocean and Coastal Management, 53:447-453

Koss, R.S., Miller, K., Wescott, G., Boxshall, A., Bellgrove, A., Gilmour, P., Bunce, A., McBurnie, J., and Ierodiaconou, D. 2009. An evaluation of Sea Search as a citizen science programme in Marine Protected Areas. Pacific Conservation Biology, 15:116-127.

Last, P.R., White, W.T., Gledhill, D.C., Hobday, A.J., Brown, R., Edgar, G.J., and Pecl, G (2011). Long-term shifts in abundance and distribution of a temperate fish fauna: a response to climate change and fishing practices. Global Ecology and Biogeography, 20: 58-72.

Lee Long W J, Coles RG & McKenzie LJ (2000). Issues for seagrass conservation management in Queensland. Pacific Conservation Biology 5: 321-328.

Lee Long, W.j., Mellors, J.E., and Coles, R.G. (1993) Seagrasses between Cape York and Hervey Bay, Queensland, Australia. Australian Journal of Marine and FreshwaterResearch 44: 19-31.

Madin,E.M.P., Ban, N.C., Doubleday, Z.A., Holmes,T.H., Pecl, G.T., Smith, F. (2012) Socio-economic and management implications of range-shifting species in marine systems. Global Environ.Change, 22(1): 137-146

Maguire, G.S., Miller, K.K., Weston, M.A. & Young, K. (2011) Being beside the seaside: Beach use and preferences among coastal residents of south-eastern Australia, Ocean & Coastal Management, 54: 781-8.

Marshall, N.J., Kleine, D.A., Dean, A.J., (2012) CoralWatch: education, monitoring, and sustainability through citizen science. Frontiers in Ecology and the Environment. 10(6): 332--334

McDougall, A.J., Pearce, M.G. & MacKinnon, M. (2008) 'Use of a fishery model (FAST) to explain declines in the stocked barramundi (Lates calcarifer) (Bloch) fishery in Lake Tinaroo, Australia', Lakes & Reservoirs: Research & Management, 13(2): 125-34.

McKenzie LJ (2010). Global monitoring program provides early warming of coastal ecological decline. National Wetlands Update 2010. Wetlands Australia 18: 21.

McKenzie LJ and Coles RG (2011). Working together to monitor seagrass in Queensland's Ramsar sites. National Wetlands Update 2011. Wetlands Australia 19: 28-29.

McKenzie LJ, Lee Long WJ, Coles RG and Roder CA (2000) Seagrass-Watch: Community based monitoring of seagrass resources. Biol. Mar. Medit. 7(2): 393-396.

Mellors JE, McKenzie LJ and Coles RG (2008). Seagrass-Watch: Engaging Torres Strait Islanders in marine habitat monitoring. Continental Shelf Research. 28: 2339–2349.

Miller, K.K.M. & Weston, M.A. (2009) Towards a set of priorities for bird conservation and research in Australia: the perceptions of ornithologists, Emu, 109: 67-74.

Minton, C., Dann, P., Ewing, A., Taylor, S., Jessop, R., Anton, P. & Clement, R. (2012) Trends of Shorebirds in Corner Inlet, Victoria, 1982-2011', Stilt, 61: 3-18.

Nakaoka M (2000). Development of local and global networks for reserch and conservation of seagrasses. Aquabiology. 22(6): 566-569.

Nursey-Bray, M., Pecl, G.T., Frusher S., Gardner, C., Haward, M., Hobday A.J., Jennings S., Punt A.E., Revill H., van Putten, I. (2012) Communicating climate change: Climate change risk perceptions and rock lobster fishers, Tasmania. Marine Policy 36: 753–759

Parker P., Bucher D.J. (2000) Seasonal variation in abundance and sex ratio of grey nurse (sand tigers) sharks Carcharias taurus in northern New SouthWales, Australia: a survey based on observations of recreational scuba divers. Pac. Conserv. Biol. 5: 336–346.

Prayaga, P., Rolfe, J. & Stoeckl, N. (2010) The value of recreational fishing in the Great Barrier Reef, Australia: A pooled revealed preference and contingent behaviour model, Marine Policy, 34(2): 244-51.

Preen, A., and Marsh, H. (1995) Response of Dugongs to Large-scale loss of Seagrasses from Hervey Bay, Queensland, Australia. Wildlife Research 22: 507-519.

Przeslawski, R., Falkner, I., Ashcroft, M.B., Hutchings, P. (2012) Using rigorous selection criteria to investigate marine range shifts, Estuarine, Coastal and Shelf Science, 113: 205-212

Roelfsema CM, Phinn SR, Udy N and Maxwell P (2009). An integrated field and remote sensing approach for mapping seagrass cover, Moreton Bay, Australia. Spatial Science. 54(1): 45-62.

Scarpaci, C., Nugegoda, D. and Corkeron, P.J. (2005). Tourists swimming with Australian fur seals (Arctocephalus pusillus) in Port Phillip Bay, Victoria, Australia: Are tourists at risk? Journal of Tourism in Marine Environments 1(2): 89-95

Schuyler, Q., Hardesty, B.D., Wilcox, C., Townsend, K. (2012) To Eat or Not to Eat? Debris Selectivity by Marine Turtles. PLoS ONE 7(7): e40884

Sumpton, W., Mayer, D., Brown, I., Sawynok, B., McLennan, M., Butcher, A. & Kirkwood, J. (2008) Investigation of movement and factors influencing post-release survival of line-caught coral reef fish using recreational tag-recapture data, Fisheries Research, 92(2/3): 189-95.

Sumpton, W.D., Brown, I.W., Mayer, D.G., McLennan, M.F., Mapleston, A., Butcher, A.R., Welch, D.J., Kirkwood, J.M., Sawynok, B. & Begg, G.A. (2010) Assessing the effects of line capture and barotrauma relief procedures on post-release survival of key tropical reef fish species in Australia using recreational tagging clubs, Fisheries Management & Ecology, 17(1): 77-88.

Unsworth, R.K.F., Collier, C.J., Henderson, G.M. and McKenzie, L.J. (2012). Tropical seagrass meadows modify seawater carbon chemistry: implications for coral reefs impacted by ocean acidification. Environmental Research Letters. 7(2): 024026

Uychiaoco, A.J., H.O. Arceo, S.J. Green, M.T. De la Cruz, P.A. Gaite and P.M. Aliño.(2005). Monitoring and evaluation of reef protected areas by local fishers in the Philippines:tightening the adaptive management cycle. Biodiversity and Conservation 14: 2775-2794.

Weston, M.A. & Paton, S. (2002) A Survey of Victorian Hooded Plover Counters, The Stilt, 42: 30-31.

Weston, M.A., Fendley, M., Jewell, R., Satchell, M. & Tzaros, C. (2003) Volunteers in bird conservation: Insights from the Australian Threatened Bird Network, Ecological Management and Restoration, 4(3): 205-11.

Weston, M.A., Silcocks, A., Tzaros, C. & Ingwersen, D. (2006) A survey of contributors to an Australian bird atlassing project: Demography, skills and motivation, Australian Journal on Volunteering, 11(2): 51–58.

Weston, M.A., Tzaros, C.L. & Antos, M.J. (2006) Awareness of wetlands and their conservation value among students at a primary school in Victoria, Australia, Ecological Management & Restoration, 7(3): 223-6.

Wilcox, C., Hardesty, B., Sharples, R., Griffin, D., Lawson, T. & Gunn, R. (2012) Ghostnet impacts on globally threatened turtles, a spatial risk analysis for northern Australia, Conservation Letters, 1: 1-8.

Wilcox, C., Hardesty, B.D., Sharples, R., Griffin, D.A., Lawson, T.J. & Gunn, R. (2012) Ghostnet impacts on globally threatened turtles, a spatial risk analysis for northern Australia, Conservation Letters, 1: 1-8.

Wilde, G.R. & Sawynok, W. (2005) Growth rate and mortality of Australian bass,Macquaria novemaculeata, in four freshwater impoundments in south-eastern Queensland, Australia, Fisheries Management & Ecology, 12(1): 1-7.

Wilde, G.R. & Sawynok, W. (2009) Effect of Hook Removal on Recapture Rates of 27 Species of Angler-Caught Fish in Australia, Transactions of the American Fisheries Society, 138(3): 692-7.

Wilson, H.B., Kendall, B.E., Fuller, R.A., Milton, D.A. & Possingham, H.P. (2011) Analyzing Variability and the Rate of Decline of Migratory Shorebirds in Moreton Bay, Australia, Conservation Biology, 25(4):758-66

Wolcott, I., Ingwersen, D., Weston, M.A. & Tzaros, C. (2008) Sustainability of a long-term volunteer-based bird monitoring program: Recruitment, retention and attrition, Volunteering Australia, 13(1): 48-53

References

Baker, G., Parr, J. & Sewell, J. 2012, *Citizen Science: Engaging with change in the marine environment*, The Marine Biological Association, Plymouth.

Bell, S., Marzano, M., Cent, J., Kobierska, H., Podjed, D., Vandzinskaite, D., Reinert, H., Armaitiene, A., Grodzinska-Jurczak, M. & Mursic, R. 2008, 'What counts? Volunteers and their organisations in the recording and monitoring of biodiversity', *Biodivers Conserv* no. 17, pp. 3443–54.

Carr, A.J. 2004, 'Why Do We All Need Community Science?', *Society & Natural Resources*, vol. 17, pp. 841–9.

Certain, G. & Skarpaas, O. 2010, *Nature Index. General framework, statistical method and data collection for Norway*, vol. 542, Norwegian Institute for Nature Research, Oslo.

Clarke, R., Aslin, H., Kruger, H. & Bury, A. 2012, *Volunteer monitoring in biosecurity: An issues paper*, vol. research report 12.9, Agricultural and Resource Economics and Sciences, Canberra.

Clemens, R., Weston, M., Haslem, A., Silcocks, A. & Ferris, J. 2010, 'Identification of significant shorebird areas: thresholds and criteria', *Diversity and Distributions*, vol. 16, pp. 229–42.

Cohn, J.P. 2008, 'Citizen Science: Can Volunteers Do Real Research?', *BioScience*, vol. 58, no. 3, pp. 192-7.

Conrad, C.C. & Hilchey, K.G. 2011, 'A review of citizen science and community-based environmental monitoring: issues and opportunities', *Environ Monit Assess*, no. 176, pp. 273-91.

Curtis, A. & Lockwood, M. 2000, 'Landcare and Catchment Management in Australia: Lessons for State-Sponsored Community Participation', *Society and Natural Resources*, vol. 13, pp. 61-73.

Dalton, S.J. & Smith, S.D.A. 2009, *A Review of Underwater Volunteer Groups in NSW*, National Marine Science Centre for the Hunter Central Rivers Catchment Management Authority, Coffs Harbour, NSW, Australia.

Danielsen, F., Burgess, N.D. & Balmford, A. 2005, 'Monitoring matters: examining the potential of locally-based approaches', *Biodiversity and Conservation*, vol. 14, pp. 2507–42.

Danielsen, F., Burgess, N.D., Balmford, A., Donald, P.F., Funder, M., Jones, J.P., Alviola, P., Balete, D.S., Blomley, T., Brashares, J., Child, B., Enghoff, M., Fjelds, J., Holt, S., Hubertz, H., Jensen, A.E., Jensen, P.M., Massao, J., Mendoza, M.M., Ngaga, Y., Poulsen, M.K., Rueda, R., Sam, M., Skielboe, T., Stuart-Hill, G., Topp-Jorgensen, E. & Yonten, D. 2009, 'Local Participation in Natural Resource Monitoring: a Characterization of Approaches', *Conservation Biology*, vol. 23, no. 1, pp. 31-42.

Delaney, D.G., Sperling, C.D., Adams, C.S. & Leung, B. 2008, 'Marine invasive species: validation of citizen science and implications for national monitoring networks', *Biological Invasions*, vol. 10, pp. 117-28.

Dickinson, J.L., Zuckerberg, N. & Bonter, D.N. 2010, 'Citizen Science as an Ecological Research Tool: Challenges and Benefit', *Annual Reivew of Ecology, Evolution and Systematics*, no. 41, pp. 149-72.

Duncan, D.H. & Wintle, B.A. 2008, 'Towards Adaptive Management of Native Vegetation in Regional Landscapes', in Christopher Pettit, William Cartwright, Ian Bishop, Kim Lowell, David Pullar & D. Duncan (eds), *Landscape Analysis and Visualisation*, Springer Berlin Heidelberg.

Edgar, G.J. & Stuart-Smith, R.D. 2009, 'Ecological effects of marine protected areas on rocky reef communities - a continental-scale analysis', *Marine Ecology Progress Series*, vol. 388, pp. 51-62.

Fabricius, K.E. 2006, 'Effects of irradiance, flow and coral pigmentation on the temperature microenvironments around corals: Implications for coral bleaching?', *Limnology and Oceanography*, vol. 51, no. 1, pp. 30-7.

Fabricius, K.E., Langdon, C. & Uthicke, S. 2011, 'Losers and winners in coral reefs acclimatized to elevated carbon dioxide concentrations ', *NATURE CLIMATE CHANGE*, vol. 1, no. 3, pp. 165-9.

Finn, P.G., Udy, N.S., Baltais, S.J., Price, K. & Coles, L. 2010, 'Assessing the quality of seagrass data collected by community volunteers in Moreton Bay Marine Park, Australia', *Environmental Conservation*, vol. 37, no. 1, pp. 83-9.

Fore, L.S., Paulsen, K. & O'Laughlin, K. 2001, 'Assessing the performance of volunteers in monitoring streams', *Freshwater Biology*, no. 46, pp. 109-23.

Foster-Smith, J. & Evans, S.M. 2003, 'The value of marine ecological data collected by volunteers', *Biological Conservation*, vol. 113, pp. 199–213.

Gibbons, P., Zammit, C., Youngentob, K., Possingham, H.P., Lindenmayer, D.B., Bekessy, S., Burgman, M., Colyvan, M., Considine, M., Felton, A., Hobbs, R.J., Hurley, K., McAlpine, C., McCarthy, M.A., Moore, J., Robinson, D., Salt, D. & Wintle, B. 2008, 'Some practical suggestions for improving engagement between researchers and policy-makers in natural resource management', *Ecological Management and Restoration* vol. 9, no. 3.

Goffredo, S., Piccinetti, C. & Zaccanti, F. 2004, 'Volunteers in Marine Conservation Monitoring: a Study of the Distribution of the Seahorses Carried Out in Collaboration with Recreational Scuba Divers', *Conservation Biology*, vol. 18, no. 6, pp. 1492-503.

Gollan, J., Bruyn, L., Reid, N. & Wilkie, L. 2012, 'Can Volunteers Collect Data that are Comparable to Professional Scientists? A Study of Variables Used in Monitoring the Outcomes of Ecosystem Rehabilitation', *Environmental Management*, vol. 50, no. 5, pp. 969-78.

Halusky, J.G., Seaman, J., William & Strawbridge, E. 1994, 'Effectiveness of Trained Volunteer Divers in Scientific Documentation of Artificial Aquatic Habitats', *Bulletin of Marine Science*, vol. 55, no. 2-3, pp. 939-59.

Hammerton, Z., Dimmock, K., Hahn, C., Dalton, S.J. & Smith, S.D. 2012, 'SCUBA diving and marine conservation: collaboration at two Aus tralian sub tropical destinations', *Tourism in Marine Environments*, vol. 8, no. 1/2, pp. 77-90.

Jacoby, C., Manning, C., Fritz, S. & Rose, L. 1997, 'Three recent initiatives for monitoring of Australian coasts by the community', *Ocean & Coastal Management*, vol. 36, no. Nos 1-3, pp. 205-26.

Koss, R., Bunce, A., Gilmour, P. & McBurnie, J. 2005a, *Sea Search: Community-Based Monitoring of Victoria's Marine National Parks and Marine Sanctuaries*, 16, Parks Victoria.

Koss, R., Gilmour, P., Miller, K., Bellgrove, A., McBurnie, J., Wescott, G. & Bunce, A. 2005b, *Community-Based Monitoring of Victoria's Marine National Parks and Marine Sanctuaries*, 19, Melbourne, Victoria.

Koss, R.S. & Kingsley, J.Y. 2010, 'Volunteer health and emotioinal wellbeing in marine protected areas', *Ocean & Coastal Management*, vol. 53, pp. 447-53.

Lindenmayer, D.B. & Likens, G.E. 2009, 'Adaptive monitoring: a new paradigm for long-term research and monitoring', *Trends in Ecology and Evolution*, vol. 24, no. 9, pp. 482-6.

Lovell, S., Hamer, M., Slotow, R. & Herbert, D. 2009, 'An assessment of of the use of volunteers for terrestrial invertebrate biodiversity surveys', *Biodiversity Conservation*, vol. 18, pp. 3295-307.

Lunney, D. & Matthews, A. 2002, 'Community-based research: where are the rewards?', in D. Lunney, C. Dickman & S. Burgin (eds), *A clash of paradigms: Community and research-based conservation*, Royal Zoological Society of New South Wales, Mosman, pp. 8-19.

Luther, K., Counts, S., Stecher, K.B., Hoff, A. & Johns, P. 2009, 'Pathfinder: An Online Collaboration Environment for Citizen Scientists', paper presented to the *CHI 2009*, Boston, Massachusetts, USA, April 4–9, 2009.

McKenzie, L.J., Lee Long, W.J., Coles, R.G. & Roder, C.A. 2000, 'Seagrass-Watch: Community Based Monitoring of Seagrass Resources', *Biol. Mar. Medit.* , vol. 7, no. 2, pp. 393-6.

Montano, S., Seveso, D. & Galli, P. 2010, 'Assessing coral bleaching and recovery with a colour reference card in Watamu Marine Park, Kenya ', *HYDROBIOLOGIA*, vol. 655, no. 1, pp. 99-108.

Newman, C., Buesching, C.D. & Macdonald, D.W. 2003, 'Validating mammal monitoring methods and assessing the performance of volunteers in wildlife conservation - *"Sed quis cutodiet ipsos custodies?"*', *Biological Conservation*, vol. 113, pp. 189-97.

Neyman, J. 1934, 'On the Two Different Aspects of the Representative Method: The Method of Stratified Sampling and the Method of Purposive Selection', *Journal of the Royal Statistical Society*, vol. Vol. 97, no. 4, pp. 558-625.

Pohl, C. & Hadorn, G. 2008, 'Methodological challenges of transdisciplinary research', *Natures Sciences Societes*, vol. 16, pp. 111-21.

Rebele, L.M. 1997, 'An Evaluation of Citizen Volunteer Monitoring Initiatives in the National Estuary Program (NEP)', Oregon State University, Portland, Oregon.

Roy, H., Pocock, M., Preston, C., Roy, D., Savage, J., Tweddle, J. & Robinson, L. 2012, *Understanding Citizen Science and Environmental Monitoring. Final Report on behalf of UK-EOF.*, NERC Centre for Ecology & Hydrology and Natural History Museum.

Schmeller, D.S., Henry, P.-Y., Julliard, R., Gruber, B., Clober, J., Dziock, F., Lengyel, S., Nowicki, P., D'Eri, E., Budrys, E., Kull, T., Talk, K., Bauch, B., Settele, J., Van Swaay, C., Kobler, A., Babij, V., Papastergiadou, E. & Henle, K. 2009, 'Advantages of Volunteer-Based Biodiversity Monitoring in Europe', *Conservation Biology*, vol. 23, no. 2, pp. 307-16.

Shirk, J.L., Ballard, H.L., Wilderman, C.C., Phillips, T., Wiggins, A., Jordan, R., McCallie, E., Minarchek, M., Lewenstein, B.V., Krasny, M.E. & Bonney, R. 2012, 'Public Participation in Scientific Research: a Framework for Deliberate Design', *Ecology and Society*, vol. 17, no. 2, p. 29.

Survey Monkey 2012, *Survey Monkey,*, <http://www.surveymonkey.com/>.

Szabo, J.K., Fuller, R.A. & Possingham, H.P. 2012, 'A comparison of estimates of relative abundance from a weakly structured mass-participation bird atlas survey and a robustly designed monitoring scheme', *Ibis*, vol. 154, no. 3, pp. 468-79.

Teymour, A.R. & Sanjani, M. 2010, 'Status of Coral Reef Species at Chabahar Bay, Sistan and Baluchistan, Iran. ', *Pakistan Journal of Biological Sciences.*

Thomsen, D. 2003, 'Community-Based Research: An Opportunity for Collaboration and Social Change', Griffith University.

Thomsen, D. 2008, 'Community-based research: facilitation of sustainability learning', *Australasian Journal of Environmental Management*, vol. 15, pp. 222-30.

Tulloch, A.I.T., Mustin, K., Possingham, H.P., Szabo, J.K. & Wilson, K.A. 2012, 'To boldly go where no volunteer has gone before: predicting volunteer activity to prioritize surveys at the landscape scale', *Diversity and Distributions*, pp. n/a-n/a.

Turner, D.J., Brook, J. and Murray-Jones, S. 2006, *Examining the health of subtidal reef environments in South Australia Part 3: An evaluation of the potential for the community to undertake environmental monitoring of temperate reef habitats: A review of the South Australian Reef Watch Program*, 151, South Australian Research and Development Institute (Aquatic Sciences), Adelaide, p. 32.

Underwood, A. & Chapman, M. 2002, 'Conservation of coastal organisms depend on scientific realism, not community 'monitoring'', in D. Lunney, C. Dickman & S. Burgin (eds), *A clash of paradigms: Community and research-based conservation*, Royal Zoological Society of New South Wales, Mosman, pp. 20-37.

Walker, G.B. & Daniels, S.E. 2001, 'Natural Resource Policy and the Paradox of Public Involvement: Bringing Scientists and Citizens Together', *Journal of Sustainable Forestry*, vol. 13, no. 1/2, pp. 253-69.

Weston, M.A., Fendley, M., Jewell, R., Satchell, M. & Tzaros, C. 2003, 'Volunteers in bird conservation: Insights from the Australian Threatened Bird Network', *Ecological Management and Restoration* vol. 4, no. 3, pp. 205-11.

Weston, M.A., Tzaros, C.L. & Antos, M.J. 2006b, 'Awareness of wetlands and their conservation value among students at a primary school in Victoria, Australia.', *Ecological Management & Restoration*, vol. 7, no. 3, pp. 223-6.

Wolcott, I., Ingwersen, D., Weston, M.A. & Tzaros, C. 2008, 'Sustainability of a long-term volunteer-based bird monitoring program: Recruitment, retention and attrition', *Volunteering Australia*.

CHAPTER 5: GENERAL DISCUSSION AND CONCLUSION

5.1 INTRODUCTION

Citizen science is not new (Miller-Rushing et al. 2012) however the growth in this field in recent years requires researchers, policymakers and natural resource managers to determine what role it might play in contemporary natural resource management. Governments have been encouraged to include community participation in monitoring activities to progress sustainability goals (Ecologically Sustainable Development Steering Committee 1992; UN Department of Economic and Social Affairs - Division for Sustainable Development 1992) and, as a result, have primarily directed monitoring funds to community groups over the past 20 years. Researchers have capitalized on a willing volunteer workforce and have used it to progress understanding on environmental conditions and other environmental research (Newman et al. 2003; Goffredo et al. 2004; Lovell et al. 2009; Crall et al. 2010; Szabo et al. 2012; Tulloch et al. 2012; Benz et al. 2013; Iwamura et al. 2013). Potential benefits to employing a citizen science approach to research and monitoring range from increasing opportunities for funding to increasing opportunities for knowledge gathering (see Chapter 1).

The discussion in this chapter will use the findings from Chapters 2 to 4 to demonstrate the actual benefits and uses of citizen science and discuss the application of citizen science to marine natural resource management in Australia. It will conclude with the presentation of pathways for better integration of citizens into research and management leading to meaningful decision-making.

5.2 BENEFITS OF CITIZEN SCIENCE

As discussed in Chapter 1, citizen science can benefit research and monitoring programs by supplementing condition and trend information collected by natural resource management agencies (McKenzie et al. 2000; Zeller et al. 2001), covering areas rarely or not visited by management agencies and surveying numerous sites simultaneously (Edgar & Stuart-Smith 2009; Finn et al. 2010), providing access to greater amounts of data (eg. data sets collected over long periods), often at a lower cost than if the data had been collected by professional scientists (Darwall & Dulvy 1996; Newman et al. 2003; Goffredo et al. 2008). Results of a national questionnaire found that benefits observed and experienced by over 90% of data users (those who assist/fund/store/analyse data from citizen scientists) include building relationships, increasing community skills and knowledge and community stewardship of the marine environment. Other benefits included increasing funding opportunities and contributing to management targets. These aspects could be collectively seen as critical components of natural resource management by feeding into adaptive management processes (monitoring and other research) and building capacity in the wider community for ongoing sustainable management outcomes.

5.3 Challenges to the Field of Citizen Science

5.3.1 Data Issues

The role of the public in environmental monitoring and research has certain perceived limitations that must be addressed to be more widely adopted for use in natural resource management. Challenges focus on (1) issues with data (its quality, accessibility and integration into other research and into decision-making processes) and (2) funding and support for citizen science activities.

Data quality has been identified as a key factor in the use of citizen science by multiple researchers (see Chapter 3) and respondents of a national questionnaire (see Chapter 4). Data validation is a process within the field of science that ensures the quality of data. Results of various data validation studies indicate citizen scientists, provided they have adequate training and support, can provide results comparable to experts in a variety of environmental science fields and research contexts, including fish length estimates, species identification, water quality parameters, and percentage cover estimates (Halusky et al. 1994; Pattengil-Semmens & Semmens 2003; Delaney et al. 2008; Edgar & Stuart-Smith 2009; Finn et al. 2010 and see also Chapter 3). Citizen scientists, at least in marine environments, have been validated most often in the use of field techniques. The growing use of technology in environmental science and thus the potential involvement of citizens in it will require validation to be extended into data-entry and other computer-based tasks. The evidence of this research indicated these tasks can be more difficult for the volunteers to perform accurately, and the tasks may only appeal to a small number of potential volunteers. However, the engagement of the volunteers in these tasks provided opportunities which extended beyond the immediate provision of data. Involvement in these non-traditional types of tasks provided the volunteers with an increased understanding of scientific method and research and improved their understanding of the need for quality assurance processes. This also had flow-on effects into improved field monitoring techniques.

The purpose of research (and by association, gathering data) is to share insights (Wilson 2002) with other regions that can be applied elsewhere (Lunney & Matthews 2002; Wilson 2002; Sharpe and Conrad in Finn et al. 2010). It is possible that the lack of broader uptake of citizen science data (the sharing of insights and application elsewhere) could either be due to the inaccessibility of the data or lack of awareness of the data's existence. Many citizen scientist projects keep their data either in hard copy or on a personal computer. Many established programs are taking steps to increase the accessibility of citizen science data for the purpose of data sharing, including Redmap (www.redmap.org.au), the Atlas of Living Australia (www.ala.org.au), Atlas of Life in the Coastal Wilderness (www.alcw.org.au) and ClimateWatch (www.climatewatch.org.au) domestically, OPAL/i-spot (www.opalexplorenature.org/surveys) in the United Kingdom, and ProjectNoah (www.projectnoah.org) and eBird (www.ebird.org), internationallly.[iii]

Increasing the visibility of groups and programs may be another way of improving usage of data. In Australia, the Listening to the Land directory (1996) provided a baseline of volunteer environmental monitoring. It surveyed groups across the country regarding their monitoring activities, both terrestrial and marine. Since the "Listening to the Land" survey, the numbers of marine monitoring programs have increased exponentially over 15 yr, from 14 in 1996 to greater than 200 in 2013 (see Chapter 4). It also provided a directory of citizen science groups, outlining their monitoring objectives, monitoring subjects, location of activities and points of contact. An ongoing updated version of such a directory would assist in increasing visibility of groups, but would also provide a centralized location for data users to easily find

[iii] There are also a number of terrestrial-based citizen science programs in Australia and abroad making their data available online: Bowerbird (www.bowerbird.org.au), RabbitScan (http://www.feralscan.org.au/rabbitscan/), and Project Budburst (www.budburst.org) are a few examples.

monitoring programs. Such an approach is used in the United States (http://www.birds.cornell.edu/citscitoolkit) and would be useful for ongoing citizen science promotion in Australia.

Data integration tools are in development to assist collection, analysis and dissemination of citizen science data (Mayfield et al. 2001; Gouveia et al. 2004; Hochachka et al. 2009; Luther et al. 2009; Crall et al. 2010; Bird et al. 2013). In the US, leaders in public participation in scientific research have sought to address issues of accessibility and visibility and interpersonal relationships to improve communication, innovation, and best practices across the field of citizen science. This has led to a toolkit for citizen science project development (www.citizenscience.org/toolkit), the creation of the web site citizenscience.org, which supports a community of ~2000 subscribers, and the development of best practices for citizen science data management (McEver in Benz et al. 2013). In addition to this, a conference was born to further progress these ideas and partnerships in citizen science. Considering the progress of these concepts in Australia, a similar set of tools may be useful to the citizen science community here. In fact, some tools have already been developed (see Citizen Science Toolbox, https://app.secure.griffith.edu.au/03/toolbox, and Conservation Council of Western Australia, http://ccwa.org.au/programs/citizen-science) and collaboration on increasing awareness on the presence of these and other tools should be a priority for those in this field.

5.3.2 Funding and support for Citizen Science

The current federal funding model, initiated nearly two decades ago (the Natural Heritage Trust through to the current Caring for our Country) devolved funds to communities at regional and local scales for conservation, restoration and management (Centre for International Economics 2005; Commonwealth of Australia 2012). Responses of a questionnaire indicate citizen scientists have taken advantage of this funding and rely heavily upon it: 75% of all groups rely at least in part, and 32% of all groups rely almost exclusively on government funding. Natural resource management in Australia, in general, occurs at bioregional scales, as this is the scale that ecosystems and landscapes function. Therefore, the model of funding being devolved to smaller scale operators is conceptually aligned with natural resource management processes (see Chapter 1 and following section). A difficult challenge, however, is the inevitable competition that arises between citizen science groups and programs for the same pool of funds. By identifying and articulating primary goals and conducting honest evaluations of strengths and weaknesses within a citizen science group, much of the competition between groups could be alleviated: grants could be much more targeted to specific issues, relevant scales of monitoring and appropriate skillsets.

Despite the positive results reported by questionnaire respondents, only 14% of groups undertook monitoring at the request of an expert and a maximum of 50% of data users have engaged with citizen science groups to develop project aims. The division between researchers and communities may in part be due to the current funding model where each must compete for funds to achieve, arguably, a common goal of maintaining or improving the condition of environmental assets across the country. This creates silos, not collaboration. Parks Victoria (n.d.) research suggests there is little cross-over in communication between agencies, scientific communities, and the wider public. As a result, individuals go to other individuals within their own 'niche' for information - agency staff go to other agency staff, researchers go to the literature and people in the community go to other individuals in the community.

A large proportion of citizen scientists responding to the questionnaire (87%) have provided their data to research organisations and NRM bodies. Less than 52% of questionnaire respondents identifying themselves as data users participated directly in citizen science – in the development of the monitoring program, the absorption of data, or making meaning of the data. Given that the data users who responded to the questionnaire are only a fraction of the total population of NRM professionals and experts across the country, there are gaps in the interactions between citizen scientists and experts that may affect the ongoing progress of citizen science in Australia. Citizen science groups identified support mechanisms (the level of support - both financial and partnership – they could expect to receive) and maintaining a skilled volunteer base as the main factors in continuing to provide data. It could be argued that maintaining volunteers and skills (eg training) in part relies on involvement from other organisations (eg. provision of funding or technical support), raising the importance of 'support' even more.

5.4 CITIZEN SCIENCE AND NATURAL RESOURCE MANAGEMENT

The predominant model of natural resource management in Australia is adaptive management. Adaptive management is 'learning by doing', a structured and iterative process of decision making and improving management (Jacoby et al. 1997; Duncan & Wintle 2008). For monitoring to be meaningful and play its part in an adaptive management process at the bioregional scale, the monitoring (funded by governments but undertaken by communities as part of the current funding model) must feed back into this cycle. In order for this to occur, managers, scientists, policy-makers and members of the public must be more intimately engaged.

Managing the condition of environmental assets (ecosystems and natural resources) requires knowledge on the condition of the asset as well as input from social processes to gauge the capacity and willigness to enact change. These processes are a constant push and pull between various drivers and solutions. Transdisciplinary approaches respond to the complexity of environmental issues: as the issue itself transgresses disciplinary boundaries, research should have the capacity to adapt to respond accordingly. Transdisciplinary research is issues-based, dynamic and socially relevant and draws upon experts from multiple disciplines, including environmental science and those representing society (Nowotny et al. 2003; Pohl & Hadorn 2008; Robinson 2008; Cordell 2010; Lang et al. 2012)

Bonney et al. (2009b) recommended a consortium approach to team and project development: (1) a researcher to maintain the scientific rigour and develop protocols that will lead to the collection of quality data and who will analyse and publish the data; (2) an educator to work with citizen scientists in explaining and field-testing methods, develop clear and comprehensive supporting material and to share feedback between citizen scientists and researchers; (3) a computational statistician or information scientist to develop the technology required to receive, store, visualise and disseminate data; and (4) an evaluator to ensure the project begins with measurable objectives and assesses the project against those objectives. Arguably, a (5) social scientist should also be involved in the consortium to gain a better understanding of the human element involved in the process of doing citizen science (e.g. where the motivations for doing science is to bring about change). These people may all exist within certain organisations (our findings – Chapter 4) and may be a matter of developing relationships across the organization to access people with these skills. Moving the field of citizen science forward requires better integration between these groups of people.

5.5 Practical solutions for integrated citizen science

The engagement of public in the transdisciplinary approach can be implemented in a variety of ways, and frameworks for public-scientist interactions are emerging (Bell et al. 2008; Dickinson et al. 2010; Shirk et al. 2012). The five models of public-scientist interactions (Chapter 2, but also Danielsen et al. 2009; Dickinson et al. 2010; Conrad & Hilchey 2011; Shirk et al. 2012) represent modes of interaction amongst scientists, community members and natural resource managers, ranging from a contractual relationship where the public hires scientists to investigate an issue to a collegial model where amateurs have developed and tested their own hypotheses. The majority of citizen science operates in the middle of these extremes, where public and scientists are both involved in the research processes, however, in varying degrees. These models are: Contributory, where the scientist develops the questions of interest and methods and engages the public to assist with data collection; Collaborative, where the study is designed by the scientist, but the public are involved in data collection, project (re)design and dissemination of findings; and Co-create, where the study is designed by scientists and members of the public working together and for which at least some of the public participants are actively involved in most or all steps of the scientific process (Bonney et al. 2009a). The models presented above will have strengths and weaknesses with respect to the outcomes each can produce. Therefore it is essential that each project develop a framework (project plan) that clearly articulates the project's desired outcomes (for research, individuals and/or society), which in turn will influence the model of public-scientist interaction selected for the project (Dickinson et al. 2010).

A variety of resources are available to assist NRM managers and scientists to better understand how members of the public can be integrated into research activities, potentially leading to better outcomes for research, individuals and society. Frameworks are available to provide assistance to managers and scientists in working with members of the public for specific outcomes (Bell et al. 2008; Conrad & Daoust 2008; Bonney et al. 2009b; Dickinson et al. 2010; Shirk et al. 2012). Currently the uptake of this information by natural resource managers and scientists in Australia is limited (only 14% of citizen scientists monitor at the request of an NRM manager or other expert – Chapter 4) and presents a barrier to the development of the field of citizen science.

Consortium approaches at Cornell Lab of Ornithology, and the OPAL program in UK demonstrate that partnerships between disciplines and formal and informal science are leading to positive social and scientific outcomes, with the aim of yielding better ecological outcomes into the future. Information specialists ('data scientists') are needed to integrate data from Bioblitzes, traditional knowledge, recreational diver surveys, hypothesis-driven monitoring, physical samples, and technology-enabled observations (such as project Noah, iSpot, bluecloud spatial, epicollect) and a rich set of information technologies are required to decode and decipher the patterns in the data. Experiences in Australia demonstrate there are opportunities in local and regional natural resource management to more strongly link citizen science activities with decision-making processes at appropriate scales. This may be achieved by citizen scientists inviting scientists and managers to sit as members of advisory committees, assisting in setting questions and objectives for monitoring and experimental design, or by directly engaging scientists to periodically review methods and data to ensure they align with group monitoring objectives. If natural resource managers and scientists wish to make use of data arising from citizen science programs, they must make a commitment to supporting local and regional citizen science programs, perhaps by providing or facilitating training, or offering administration or data management solutions. Scientists may also wish to enhance the learning environment so that citizens become more active in the scientific process, and find more meaning and value in the experience (Luther et al. 2009, our findings, Chapter 4). As these citizens become more engaged, they are also more likely to contribute higher quality data with fewer biases (Luther et al. 2009).

The growth in the field of citizen science demonstrates a desire from the public to be more actively involved in the processes of research for the advancement of scientific understanding, their own personal development or well-being, and ultimately, for improved environmental outcomes. Results from this study and from many other global examples can demonstrate that where scientists and the public are working together, citizen science is a powerful research tool that has an added benefit of expanding the individual well-being of the participants involved. This study has also been able to demonstrate that citizen science is achieving its purported use of data for decision-making, and additional documented cases are likely to arise as the field gains trust. However, for the field to truly advance, a paradigm shift must occur in the way that managers and scientists view and interact with citizen science, as only then will its potential be realized for natural resource management in Australia.

APPENDIX 1: GLOSSARY

Citizen science – has been used in a variety of scientific disciplines and social contexts and has also been used as an analogous term to civic science, community-based management, community-based monitoring, community research, community science, community participation in natural resource management, public participation in scientific research, and volunteer biological monitoring. Although there are similarities amongst the various terms, there are important differences that differentiate them (see other glossary entries). The term 'citizen science' has produced confusion amongst scholars due to its varied use and meanings which has resulted in more descriptive terminologies more recently, however, amongst practitioners citizen science is understood to mean the involvement of members of the public in scientific research. Citizen science can be seen as a way professional scientists leverage the labour of large numbers of people across a wide geographic area, or a way to leverage the knowledge, experience, and insights of the world's people to advance understanding (Cornell Lab of Ornithology 2007).

Civic science – is a scientist-centric approach where scientists engage non-scientists in policy issues which have technical or scientific components, but focusses on the planning and consultation components rather than the collection of data or design of studies. Civic science also comprises the engagement of research scientists in the democratic and policy process (Irwin 1995).

Community-based management – is a bottom up (public-led) approach which aims for local stakeholder participation in natural resources, including the planning, research, development, management and policy making, often while generating a revenue to benefit the community. Is generally used in the context of natural resources/industry (fisheries, marine parks, forestry) (Danielsen et al. 2005).

Community-based monitoring (*also* community-based research *and* public-interest research) – the engagement of members of the community to initiate and undertake monitoring activities. Can be used in a wide variety of disciplines, including health, social welfare, education, toxins research and natural sciences.

Community participation in conservation/natural resources – General participation in natural resource management includes activities such as volunteering to work on environmental projects, investing in ethical investments, adopting environmentally responsible habits, and choosing to purchase goods and services with smaller ecological footprints (ACT Natural Resource Management Council) . It has a broad field, but generally is used in the context of restoration and maintenance activities (revegetation, best-practice farm and industry practices, and consultation) (Harrington et al. 2008).

Community science - the interaction between conventional (university/agency/industry) and community-based scientific knowledge systems used in a particular place to discover, map, monitor, model, or measure changes in species number and/or behaviour, or changes in the state of the environment (Carr 2004); relates to a collective (communities). It does not imply an application of fieldwork, however, the research centres around issues that are in the public interest where no established data exist at a local level or for which institutional science funding is absent. Community science is typically issues- and concerns-driven rather than policy and funding driven, usually related to issues of environmental restoration and management.

Public participation in scientific research – a more recent term, coined to provide a more descriptive term specifically for citizen science in ecological fields, meaning, lay people interacting with scientists to participate in a scientific research effort (Shirk et al. 2012). Generally used in the context of conservation, ecology, and environmental management.

Volunteer biological monitoring – more often used in European countries, this term is understood to mean environmental monitoring undertaken by volunteers (generally naturalist group members) for research towards conservation outcomes (Schmeller et al. 2009).

References

ACT Natural Resource Management Council 2013, viewed 30/06/13, <www.actnrmcouncil.org.au/nrmplan/part3/community/participation>.

Alexandra, J., Haffenden, S. & White, T. 1996, Listening to the Land: A Directory of Community Environmental Monitoring groups in Australia, Australian Conservation Foundation.

Anderson, M.J. 2001, 'A new method for non-parametric multivariate analysis of variance', Austral Ecology, vol. 26, pp. 32-46.

Andrew, N. & Mapstone, B. 1987, 'Sampling and the description of spatial pattern in marine ecology', Oceanography and Marine Biology: an Annual Review, no. 25, pp. 39-90.

Antos, M.J., Weston, M.A. & Priest, B. 2006, 'Factors Influencing Awareness of Community-Based Shorebird Conservation Projects in Australia', Applied Environmental Education and Communication, no. 5, pp. 63-72.

Baker, G., Parr, J. & Sewell, J. 2012, Citizen Science: Engaging with change in the marine environment, The Marine Biological Association, Plymouth.

Bell, J.J. 2006, 'The use of volunteers for conducting sponge biodiversity assessments and monitoring using a morphological approach on Indo-Pacific coral reefs', Aquatic Conserv: Mar. Freshw. Ecosyst, vol. 16, pp. 1-13.

Bell, S., Marzano, M., Cent, J., Kobierska, H., Podjed, D., Vandzinskaite, D., Reinert, H., Armaitiene, A., Grodzinska-Jurczak, M. & Mursic, R. 2008, 'What counts? Volunteers and their organisations in the recording and monitoring of biodiversity', Biodivers Conserv no. 17, pp. 3443–54.

Benz, S., Miller-Rushing, A., Domroese, M., Ballard, H., Bonney, R., DeFalco, T., Newman, S., Shirk, J. & Young, A. 2013, Workshop 1: Conference on Public Participation in Scientific Research 2012: An International, Interdisciplinary Conference, vol. Meeting Reports, Bulletin of the Ecological Society of America, pp. 112-7, <http://www.esajournals.org/doi/pdf/10.1890/0012-9623-94.1.112>.

Bird, T.J., Bates, A.E., Lefchek, J.S., Hill, N.A., Thomson, R.J., Edgar, G.J., Stuart-Smith, R.D., Wotherspoon, S., Krkosek, M., Stuart-Smith, J.F., Pecl, G.T., Barrett, N. & Frusher, S. 2013, 'Statistical solutions for error and bias in global citizen science datasets', Biological Conservation, vol. in press.

Bonney, R., Ballard, H., Jordan, R., McCallie, E., Phillips, T., Shirk, J. & Wilderman, C. 2009a, Public Participation in Scientific Research: Defining the Field and Assessing Its Potential for Informal Science Education, Center for Advancement of Informal Science Education (CAISE). Washington DC.

Bonney, R., Cooper, C.B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K.V. & Shirk, J. 2009b, 'Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy', BioScience, vol. 59, no. 11, pp. 977-84.

Burgin, S. 2002, 'Tragic consequences for conservation of mis-defining the term 'community'', in D. Lunney, C. Dickman & S. Burgin (eds), A Clash of Paradigms: Community and research-based conservation, Royal Zoological Society of New South Wales, Mosman, pp. 1-7.

Carr, A.J. 2004, 'Why Do We All Need Community Science?', Society & Natural Resources, vol. 17, pp. 841–9.

Centre for International Economics 2005, Evaluation of the Natural Heritage Trust Envirofund, Canberra and Sydney.

Certain, G. & Skarpaas, O. 2010, Nature Index. General framework, statistical method and data collection for Norway, vol. 542, Norwegian Institute for Nature Research, Oslo.

Clarke, R., Aslin, H., Kruger, H. & Bury, A. 2012, Volunteer monitoring in biosecurity: An issues paper, vol. research report 12.9, Agricultural and Resource Economics and Sciences, Canberra.

Clemens, R., Weston, M., Haslem, A., Silcocks, A. & Ferris, J. 2010, 'Identification of significant shorebird areas: thresholds and criteria', Diversity and Distributions, vol. 16, pp. 229–42.

Cohn, J.P. 2008, 'Citizen Science: Can Volunteers Do Real Research?', BioScience, vol. 58, no. 3, pp. 192-7.

Commonwealth of Australia 2012, Caring for Our Country: An Outline for the Future 2013-2018, Commonwealth of Australia,, Canberra.

Commonwealth Of Australia Constitution Act 1900.

'Conference on Public Participation in Scientific Research,' 2012, Conference on Public Participation in Scientific Research, Portland, Oregion.

Conrad, C.C. & Hilchey, K.G. 2011, 'A review of citizen science and community-based environmental monitoring: issues and opportunities', Environ Monit Assess, no. 176, pp. 273-91.

Conrad, C.T. & Daoust, T. 2008, 'Community-Based Monitoring Frameworks: Increasing the Effectiveness of Environmental Stewardship', Environmental Management, vol. 41, pp. 358–66.

Cordell, D. 2010, The Story of Phosphorus. Sustainability implications of global phosphorus scarcity for food security., Linkoping University, Linkoping.

Cornell Lab of Ornithology 2007, 'WHAT IS THIS, "CITIZEN SCIENCE"?', paper presented to the Citizen Science Toolkit Conference

Ithaca, NY, June 20th-23rd, 2007, <www.citizenscience.org/conference>.

Crall, A.W., Newman, G.J., Jarnevich, C.S., Stohlgren, T.J., Waller, D.M. & Graham, J. 2010, 'Improving and integrating data on invasive species collected by citizen scientists', Biol Invasions, vol. 12, pp. 3419–28.

CSIRO 2009, 'Nationally Relevant Environmental Monitoring: Existing Approaches and Future Opportunities Workshop Booklet', Nationally Relevant Environmental Monitoring: Existing Approaches and Future Opportunities CSIRO, CSIRO Discovery Centre, Canberra

Curtis, A. & Lockwood, M. 2000, 'Landcare and Catchment Management in Australia: Lessons for State-Sponsored Community Participation', Society and Natural Resources, vol. 13, pp. 61-73.

DAFF, D.o.A.F.a.F. 2013, RFAs: How?, Description of how Regional Forest Agreements are developed, viewed 12/7/13, <http://www.daff.gov.au/forestry/policies/rfa/about/how>.

Dalton, S.J. & Smith, S.D.A. 2009, A Review of Underwater Volunteer Groups in NSW, National Marine Science Centre for the Hunter Central Rivers Catchment Management Authority, Coffs Harbour, NSW, Australia.

Danielsen, F., Burgess, N.D. & Balmford, A. 2005, 'Monitoring matters: examining the potential of locally-based approaches', Biodiversity and Conservation, vol. 14, pp. 2507–42.

Danielsen, F., Burgess, N.D., Balmford, A., Donald, P.F., Funder, M., Jones, J.P., Alviola, P., Balete, D.S., Blomley, T., Brashares, J., Child, B., Enghoff, M., Fjelds, J., Holt, S., Hubertz, H., Jensen, A.E., Jensen, P.M., Massao, J., Mendoza, M.M., Ngaga, Y., Poulsen, M.K., Rueda, R., Sam, M., Skielboe, T., Stuart-Hill, G., Topp-Jorgensen, E. & Yonten, D. 2009, 'Local Participation in Natural Resource Monitoring: a Characterization of Approaches', Conservation Biology, vol. 23, no. 1, pp. 31-42.

Darwall, W.R. & Dulvy, N.K. 1996, 'An Evaluation of The Suitability of Non-Specialist Volunteer Researchers for Coral Reef Fish Surveys. Mafia Island, Tanzania - A Case Study.', Biological Conservation, vol. 78, pp. 223-31.

Delaney, D.G., Sperling, C.D., Adams, C.S. & Leung, B. 2008, 'Marine invasive species: validation of citizen science and implications for national monitoring networks', Biological Invasions, vol. 10, pp. 117-28.

Demers, M., Davis, A. & Knott, N. 2013, 'A comparison of the impact of ‘seagrass-friendly’ boat mooring systems on Posidonia australis', Marine Environmental Research, no. 83, pp. 54-62.

Department of Environment and Climate Change NSW 2008, A new Biodiversity Strategy for New South Wales, Department of Environment and Climate Change NSW, Sydney.

Department of Environment Water Heritage and the Arts 2009, Caring for our Country Business Plan 09-10, Canberra.

Department of Sustainability, E., Water, Population and Communities 2012, Caring for Our Country Business Plan 2012-2013, Canberra.

Dickinson, J.L., Zuckerberg, N. & Bonter, D.N. 2010, 'Citizen Science as an Ecological Research Tool: Challenges and Benefit', Annual Reivew of Ecology, Evolution and Systematics, no. 41, pp. 149-72.

Duarte, C. & Kirkman, H. 2001, 'Methods for the measurement of seagrass abundance and depth distribution', in F. Short (ed.), Global seagrass research methods, Elsevier Science B.V, Amsterdam, pp. 141-53.

Duncan, D.H. & Wintle, B.A. 2008, 'Towards Adaptive Management of Native Vegetation in Regional Landscapes', in Christopher Pettit, William Cartwright, Ian Bishop, Kim Lowell, David Pullar & D. Duncan (eds), Landscape Analysis and Visualisation, Springer Berlin Heidelberg.

Ecologically Sustainable Development Steering Committee 1992, National Strategy for Ecologically Sustainable Development, Department of Sustainability, Environment, Water, Population and Communities, Canberra, <http://www.environment.gov.au/about/esd/publications/strategy/communit.html>.

Edgar, G.J., Barrett, N.S. & Morton, A.J. 2004, 'Biases associated with the use of underwater visual census techniques to quantify the density and size-structure *of fish populations', Journal of Experimental Marine Biology and Ecology, vol. 308, pp. 269– 90.*

Edgar, G.J. & Stuart-Smith, R.D. 2009, 'Ecological effects of marine protected areas on rocky reef communities - a continental-scale analysis', Marine Ecology Progress Series, vol. 388, pp. 51-62.

Ely, E. 2008a, 'Getting volunteer data into science journals.', The Volunteer Monitor, vol. 19, no. 1, pp. 8-11.

Ely, E. 2008b, 'Volunteer monitoring and the democratization of science', The Volunteer Monitor, vol. 19, no. 1, Summer 2008, pp. 1-5.

Engel, S.R. & Voshell, J.R., Jr. 2002, 'Volunteer Biological Monitoring: Can It Accurately Assess the Ecological Condition of Streams?', American Entomologist vol. 48, no. 3, pp. 164-77.

European Commission n.d., Science Shops: Knowledge for the community, EUR 20877, European Commission.

Fabricius, K.E. 2006, 'Effects of irradiance, flow and coral pigmentation on the temperature microenvironments around corals: Implications for coral bleaching?', Limnology and Oceanography, vol. 51, no. 1, pp. 30-7.

Fabricius, K.E., Langdon, C. & Uthicke, S. 2011, 'Losers and winners in coral reefs acclimatized to elevated carbon dioxide concentrations ', NATURE CLIMATE CHANGE, vol. 1, no. 3, pp. 165-9.

Finn, P.G., Udy, N.S., Baltais, S.J., Price, K. & Coles, L. 2010, 'Assessing the quality of seagrass data collected by community volunteers in Moreton Bay Marine Park, Australia', Environmental Conservation, vol. 37, no. 1, pp. 83-9.

Fore, L.S., Paulsen, K. & O'Laughlin, K. 2001, 'Assessing the performance of volunteers in monitoring streams', Freshwater Biology, no. 46, pp. 109-23.

Foster-Smith, J. & Evans, S.M. 2003, 'The value of marine ecological data collected by volunteers', Biological Conservation, vol. 113, pp. 199–213.

Gibbons, P., Zammit, C., Youngentob, K., Possingham, H.P., Lindenmayer, D.B., Bekessy, S., Burgman, M., Colyvan, M., Considine, M., Felton, A., Hobbs, R.J., Hurley, K., McAlpine, C., McCarthy, M.A., Moore, J., Robinson, D., Salt, D. & Wintle, B. 2008, 'Some practical suggestions for improving engagement between researchers and policy-makers in natural resource management', Ecological Management and Restoration vol. 9, no. 3.

Gillett, D., Pondella, D., II, Freiwald, J., Schiff, K., Caselle, J., Shuman, C. & Weisberg, S. 2012, 'Comparing volunteer and professionally collected monitoring data from the rocky subtidal reefs of Southern California, USA', Environmental Monitoring and Assessment, vol. 184, no. 5, pp. 3239-57.

Gladstone, W. 2010, Seagrass Friendly Moorings in Manly Cove - Report of 2010 Monitoring, University of Technology Sydney, Sydney.

Gladstone, W. 2011, Seagrass Friendly Moorings in Manly Cove - Report of 2011 Monitoring, University of Technology Sydney.

Gladstone, W. 2012, Seagrass Friendly Moorings in Manly Cove: Final Report of 2012 Monitoring, University of Technology Sydney.

Gladstone, W., Stanger, R. & Phelps, L. 2006, 'A participatory approach to university teaching about partnerships for biodiversity conservation', Australian Journal of Environmental Education, vol. 22, pp. 21-32.

Goffredo, S., Neri, P., Orlandi, A., Pensa, F., Scola Gagliardi, M., Velardi, A., Piccinetti, C. & Zaccanti, F. 2008, 'Citizen Education by Involvement in Marine Biodiversity Monitoring', International Technology, Education and Development Conference, Valencia.

Goffredo, S., Piccinetti, C. & Zaccanti, F. 2004, 'Volunteers in Marine Conservation Monitoring: a Study of the Distribution of the Seahorses Carried Out in Collaboration with Recreational Scuba Divers', Conservation Biology, vol. 18, no. 6, pp. 1492-503.

Gollan, J., Bruyn, L., Reid, N. & Wilkie, L. 2012, 'Can Volunteers Collect Data that are Comparable to Professional Scientists? A Study of Variables Used in Monitoring the Outcomes of Ecosystem Rehabilitation', Environmental Management, vol. 50, no. 5, pp. 969-78.

Gouveia, C., Fonseca, A., Camara, A. & Ferreira, F. 2004, 'Promoting the use of environmental data collected by concerned citizens through information and communication technologies', Journal of Environmental Management, vol. 71, pp. 135-54.

Halusky, J.G., Seaman, J., William & Strawbridge, E. 1994, 'Effectiveness of Trained Volunteer Divers in Scientific Documentation of Artificial Aquatic Habitats', Bulletin of Marine Science, vol. 55, no. 2-3, pp. 939-59.

Hammerton, Z., Dimmock, K., Hahn, C., Dalton, S.J. & Smith, S.D. 2012, 'SCUBA diving and marine conservation: collaboration at two Aus tralian sub tropical destinations', Tourism in Marine Environments, vol. 8, no. 1/2, pp. 77-90.

Harrington, C., Curtis, A. & Black, R. 2008, 'Locating Communities in Natural Resource Management', Journal of Environmental Policy & Planning, vol. 10, no. 2, pp. 199–215.

Hochachka, W.M., Fink, D., Hooker, G., Kelling, S., Riedewald, M., Caruana, R. & Ballard, G. 2009, 'Data-intensive Science: A New Paradigm for Biodiversity Studies', BioScience, vol. 59, no. 7, pp. 613-20.

Holt, B.G., Rioja-Nieto, R., Aaron MacNeil, M., Lupton, J. & Rahbek, C. 2013, 'Comparing diversity data collected using a protocol designed for volunteers with results from a professional alternative', Methods in Ecology and Evolution, vol. 4, no. 4, pp. 383-92.

Huveneers, C., Luo, K., Otway, N.M. & Harcourt, R.G. 2009, 'Assessing the distribution and relative abundance of wobbegong sharks (Orectolobidae) in New South Wales, Australia, using recreational scuba-divers', Aquat. Living Resour, no. 22, pp. 255–64

Irwin, A. 1995, Citizen science: a study of people, expertise, and sustainable development, Routledge, New York.

Iwamura, T., Possingham, H.P., Chadès, I., Minton, C., Murray, N., J. , Rogers, D.I., Treml, E.A. & Fuller, R.A. 2013, 'Migratory connectivity magnifies the consequences of habitat loss from sea-level rise for shorebird populations', Proc. R. Soc. B, vol. 280.

Jacoby, C., Manning, C., Fritz, S. & Rose, L. 1997, 'Three recent initiatives for monitoring of Australian coasts by the community', Ocean & Coastal Management, vol. 36, no. Nos 1-3, pp. 205-26.

Katsanevakis, S., Weber, A., Pipitone, C., Leopold, M., Cronin, M., Scheidat, M., Doyle, T., Buhl-Mortensen, L., Buhl-Mortensen, P., D'Anna, G., de Boois, I., Dalpadado, P., Damalas, D., Fiorentino, F., Garofalo, G., Giacalone, V., Hawley, K., Issaris, Y., Jansen, J., Knight, C., Knittweis, L., Kröncke, I., Mirto, S., Muxika, I., Reiss, H., Skjoldal, H. & Vöge, S. 2012, 'Monitoring marine populations and communities: methods dealing with imperfect detectability', Aquatic Biology, vol. 16, pp. 31-52.

Kercher, S.M., Frieswyk, C.B. & Zedler, J.B. 2003, 'Effects of sampling teams and estimation methods on the assessment of plant cover', Journal of Vegetation Science vol. 14, pp. 899-906.

Koss, R., Bunce, A., Gilmour, P. & McBurnie, J. 2005a, Sea Search: Community-Based Monitoring of Victoria's Marine National Parks and Marine Sanctuaries, 16, Parks Victoria.

Koss, R., Gilmour, P., Miller, K., Bellgrove, A., McBurnie, J., Wescott, G. & Bunce, A. 2005b, Community-Based Monitoring of Victoria's Marine National Parks and Marine Sanctuaries, 19, Melbourne, Victoria.

Koss, R.S. & Kingsley, J.Y. 2010, 'Volunteer health and emotioinal wellbeing in marine protected areas', Ocean & Coastal Management, vol. 53, pp. 447-53.

Koss, R.S., Miller, K., Wescott, G., Bellgrove, A., Boxshall, A., McBurnie, J., Bunce, A., Gilmour, P. & Ierodiaconou, D. 2009, 'An evaluation of Sea Search as a citizen science programme in Marine Protected Areas', Pacific Conservation Biology, vol. 15, pp. 116-27.

Lang, D.J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M. & Thomas, C.J. 2012, 'Transdisciplinary research in sustainability science: practice, principles, and challenges', Sustainability science, vol. 7 no. Supplement 1, pp. 25–43.

Lanyon, J. & Marsh, H. 1995, 'Temporal changes in the abundance of some tropical intertidal seagrasses in North Queensland', Aquatic Botany, vol. 49, pp. 217-37.

Lindenmayer, D.B. & Likens, G.E. 2009, 'Adaptive monitoring: a new paradigm for long-term research and monitoring', Trends in Ecology and Evolution, vol. 24, no. 9, pp. 482-6.

Lovell, S., Hamer, M., Slotow, R. & Herbert, D. 2009, 'An assessment of of the use of volunteers for terrestrial invertebrate biodiversity surveys', Biodiversity Conservation, vol. 18, pp. 3295-307.

Lunney, D. & Matthews, A. 2002, 'Community-based research: where are the rewards?', in D. Lunney, C. Dickman & S. Burgin (eds), A clash of paradigms: Community and research-based conservation, Royal Zoological Society of New South Wales, Mosman, pp. 8-19.

Luther, K., Counts, S., Stecher, K.B., Hoff, A. & Johns, P. 2009, 'Pathfinder: An Online Collaboration Environment for Citizen Scientists', paper presented to the CHI 2009, Boston, Massachusetts, USA, April 4–9, 2009.

Mackney, P. & Spring, N. 2001, 'The Earthwatch perspective on volunteers and data validity', Developing and sharing best practice in marine-related fieldwork, Occasional Publication, no. 8, pp. 37-41.

Mayfield, C., Joliat, M. & Cowan, D. 2001, 'The roles of community networks in environmental monitoring and environmental informatics', Advances in Environmental Research, vol. 5, pp. 385-93.

McArdle, B.H. & Anderson, M.J. 2001, 'Fitting multivariate models to community data: a comment on distance-based redundancy analysis', Ecology, vol. 82, pp. 290-7.

McDonald, J., Coupland, G. & Kendrick, G. 2006, 'Underwater video as a monitoring tool to detect change in seagrass cover. ', Journal of Environmental Management, vol. 80, pp. 148-55.

McIntyre, E. 2008, 'Volunteer Management in Environmental Organizations: Best Practices, Benefits and Barriers ', Brock University (Canada).

McKenzie, L.J., Lee Long, W.J., Coles, R.G. & Roder, C.A. 2000, 'Seagrass-Watch: Community Based Monitoring of Seagrass Resources', Biol. Mar. Medit. , vol. 7, no. 2, pp. 393-6.

Miller-Rushing, A., Primack, R. & Bonney, R. 2012, 'The history of public participation in ecological research', Frontiers in Ecology and the Environment, vol. 10, no. 6, pp. 285-90.

Mims III, F.M. 1999, 'Amateur Science-Strong Tradition, Bright Future', Science, vol. 284, no. 5411, pp. 55-6.

Monk, J., Ierodiaconou, D., Bellgrove, A. & Laurenson, L. 2008, 'Using community-based monitoring with GIS to create habitat maps for a marine protected area in Australia', Journal of the Marine Biological Association of the United Kingdom, vol. 88, no. 5, pp. 865-71.

Montano, S., Seveso, D. & Galli, P. 2010, 'Assessing coral bleaching and recovery with a colour reference card in Watamu Marine Park, Kenya ', HYDROBIOLOGIA, vol. 655, no. 1, pp. 99-108.

Mumby, P.J., Harborne, A.R., Raines, P.S. & Ridley, J.M. 1995, 'A Critical Assessment of Data Derived From Coral Cay Conservation Volunteers ', Bulletin of Marine Science, vol. 56, no. 3, pp. 737-51.

Newman, C., Buesching, C.D. & Macdonald, D.W. 2003, 'Validating mammal monitoring methods and assessing the performance of volunteers in wildlife conservation - "Sed quis cutodiet ipsos custodies?"', Biological Conservation, vol. 113, pp. 189-97.

Neyman, J. 1934, 'On the Two Different Aspects of the Representative Method: The Method of Stratified Sampling and the Method of Purposive Selection', Journal of the Royal Statistical Society, vol. Vol. 97, no. 4, pp. 558-625.

Nowotny, H., Scott, P. & Gibbons, M. 2003, ''Mode 2' Revisited: The New Production of Knowledge', Minerva, vol. 41, pp. 179-94.

NSW Department of Premier and Cabinet 2011, NSW 2021: A plan to make NSW number one, pp. 42-54, <http://www.2021.nsw.gov.au/sites/default/files/NSW2021_WEB%20VERSION.pdf>.

NSW Department of Primary Industries Fisheries 2009, Bringing Back the Fish, viewed 31/03/13, <http://www.dpi.nsw.gov.au/fisheries/habitat/publications/passage/bringing-back-the-fish-project-reports>.

Overdevest, C., Orr, C.H. & Stepenuck, K. 2004, 'Volunteer Stream Monitoring and Local Participation in Natural Resource Issues', Human Ecology Review, vol. 11, no. 2, pp. 177-85.

Oxford English Dictionary 2013, Oxford University Press.

Parks Victoria n.d., Agencies under the Lens: Parks Victoria Museum Victoria Partnership Pilot Project.

Pattengil-Semmens, C.V. & Semmens, B.X. 2003, 'Conservation and Management Applications of the REEF Volunteer Fish Monitoring Program', Environmental Monitoring and Assessment, vol. 81, pp. 43-50.

Pfeffer, M.J. & Wagenet, L.P. 2007, 'Volunteer Environmental Monitoring, Knowledge Creation and Citizen–Scientist Interaction', in J. Pretty, A. Ball, T. Benton, J. Guivant, D.R. Lee, D. Orr, M. Pfeffer & P. Ward, Hugh (eds), The Sage Handbook of Environment and Society SAGE Publications, pp. 235-49.

Pohl, C. & Hadorn, G. 2008, 'Methodological challenges of transdisciplinary research', Natures Sciences Societes, vol. 16, pp. 111-21.

Rebele, L.M. 1997, 'An Evaluation of Citizen Volunteer Monitoring Initiatives in the National Estuary Program (NEP)', Oregon State University, Portland, Oregon.

Robinson, J. 2008, 'Being undisciplined: Transgressions and intersections in academia and beyond.', Futures, vol. 40, pp. 70-86.

Roy, H., Pocock, M., Preston, C., Roy, D., Savage, J., Tweddle, J. & Robinson, L. 2012, Understanding Citizen Science and Environmental Monitoring. Final Report on behalf of UK-EOF., NERC Centre for Ecology & Hydrology and Natural History Museum.

Saunders, D.A. 2002, 'Conservation research leads to a paradigm shift in farming practice: a case study from the Australian wheatbelt', in D. Lunney, C. Dickman & S. Burgin (eds), A Clash of Paradigms: community and research-based conservation, Royal Zoological Society of New South Wales, Mosman, pp. 54-63.

Schmeller, D.S., Henry, P.-Y., Julliard, R., Gruber, B., Clober, J., Dziock, F., Lengyel, S., Nowicki, P., D'Eri, E., Budrys, E., Kull, T., Talk, K., Bauch, B., Settele, J., Van Swaay, C., Kobler, A., Babij, V., Papastergiadou, E. & Henle, K. 2009, 'Advantages of Volunteer-Based Biodiversity Monitoring in Europe', Conservation Biology, vol. 23, no. 2, pp. 307-16.

Seak, S., Schmidt-Vogt, D. & Thapa, G.B. 2011, 'A comparison between biodiversity monitoring systems to improve natural resource management in Tonle Sap Biopshere Reserve, Cambodia', International Journal of Biodiversity Science, Ecosystem Services & Management, vol. 7, no. 4, pp. 258-72.

Shirk, J.L., Ballard, H.L., Wilderman, C.C., Phillips, T., Wiggins, A., Jordan, R., McCallie, E., Minarchek, M., Lewenstein, B.V., Krasny, M.E. & Bonney, R. 2012, 'Public Participation in Scientific Research: a Framework for Deliberate Design', Ecology and Society, vol. 17, no. 2, p. 29.

Silvertown, J. 2009, 'A new dawn for citizen science', Trends in Ecology and Evolution vol. 24, no. 9, pp. 467-71.

Smith, S.D. & Edgar, R.J. 1999, Description and comparison of benthic community structure within the Solitary Islands Marine Park, Solitary Islands Underwater Research Group Inc., Coffs Harbour.

Stenekes, N. & Sahlqvist, P. 2011, Community involvement in recreational fisheries data collection: Opportunities and challenges, ABARES, Canberra, ABARES technical report 11.5.

Stepath, C.M. 2000, 'Awareness and community-based monitoring', 9th International Coral Reef Symposium, vol. 2, Bali, Indonesia.

Stuart-Smith, R.D., Bates, A.E., Lefcheck, J.S., Duffy, J.E., Baker, S.C., Thomson, R.J., Stuart-Smith, J.F., Hill, N.A., Kininmonth, S.J., Airoldi, L., Becerro, M.A., Campbell, S.J., Dawson, T.P., Navarrete, S.A., Soler, G.A., Strain, E.M.A., Willis, T.J. & Edgar, G.J. 2013, 'Integrating abundance and functional traits reveals new global hotspots of fish diversity', Nature, vol. 501, no. 7468, pp. 539-42.

Survey Monkey 2012, Survey Monkey,, <http://www.surveymonkey.com/>.

Szabo, J.K., Fuller, R.A. & Possingham, H.P. 2012, 'A comparison of estimates of relative abundance from a weakly structured mass-participation bird atlas survey and a robustly designed monitoring scheme', Ibis, vol. 154, no. 3, pp. 468-79.

Teymour, A.R. & Sanjani, M. 2010, 'Status of Coral Reef Species at Chabahar Bay, Sistan and Baluchistan, Iran. ', Pakistan Journal of Biological Sciences.

Thomsen, D. 2003, 'Community-Based Research: An Opportunity for Collaboration and Social Change', Griffith University.

Thomsen, D. 2008, 'Community-based research: facilitation of sustainability learning', Australasian Journal of Environmental Management, vol. 15, pp. 222-30.

Tulloch, A.I.T., Mustin, K., Possingham, H.P., Szabo, J.K. & Wilson, K.A. 2012, 'To boldly go where no volunteer has gone before: predicting volunteer activity to prioritize surveys at the landscape scale', Diversity and Distributions, pp. n/a-n/a.

Turner, D.J., Brook, J. and Murray-Jones, S. 2006, Examining the health of subtidal reef environments in South Australia Part 3: An evaluation of the potential for the community to undertake environmental monitoring of temperate reef habitats: A review of the South Australian Reef Watch Program, 151, South Australian Research and Development Institute (Aquatic Sciences), Adelaide, p. 32.

UN Department of Economic and Social Affairs - Division for Sustainable Development 1992, Agenda 21: The United Nations Programme of Action from Rio, viewed 1 October 2010, <http://www.un.org/esa/dsd/agenda21/res_agenda21_00.shtml>.

Underwood, A. 1997, Experiments in ecology: their logical design and interpretation using analysis of variance, Cambridge University Press, Melbourne.

Underwood, A. & Chapman, M. 2002, 'Conservation of coastal organisms depend on scientific realism, not community 'monitoring'', in D. Lunney, C. Dickman & S. Burgin (eds), A clash of paradigms: Community and research-based *conservation, Royal Zoological Society of New South Wales, Mosman, pp. 20-37.*

Convention on Wetlands of International Importance especially as Waterfowl Habitat. As amended by the Paris Protocol, 3 December 1982, and Regina Amendments, 28 May 1987 1971.

Walker, G.B. & Daniels, S.E. 2001, 'Natural Resource Policy and the Paradox of Public Involvement: Bringing Scientists and Citizens Together', Journal of Sustainable Forestry, vol. 13, no. 1/2, pp. 253-69.

Ward-Paige, C.A. & Lotze, H.K. 2011, 'Assessing the value of recreational divers for censusing elasmobranchs', PLoS One, vol. 6, no. 10, p. e25609.

West, R. 2006, Wonboyn Lake Seagrasses, School of Biological Sciences, University of Wollongong.

West, R. 2011, 'Impacts of recreational boating activities on the seagrass Posidonia in SE Australia', Wetlands Australia, no. 26, pp. 3-13.

Weston, M.A., Fendley, M., Jewell, R., Satchell, M. & Tzaros, C. 2003, 'Volunteers in bird conservation: Insights from the Australian Threatened Bird Network', Ecological Management and Restoration vol. 4, no. 3, pp. 205-11.

Weston, M.A., Silcocks, A., Tzaros, C. & Ingwersen, D. 2006a, 'A survey of contributors to an Australian bird atlassing project: Demography, skills and motivation', Australian Journal on Volunteering, vol. 11, no. 2.

Weston, M.A., Tzaros, C.L. & Antos, M.J. 2006b, 'Awareness of wetlands and their conservation value among students at a primary school in Victoria, Australia.', Ecological Management & Restoration, vol. 7, no. 3, pp. 223-6.

Wilson, P.D. 2002, 'Community-based research: science conducted as if people really matter', in D. Lunney, C. Dickman & S. Burgin (eds), A clash of paradigms: Community and research-based conservation, Royal Zoological Society of New South Wales, Mosman, pp. 74-87.

Wolcott, I., Ingwersen, D., Weston, M.A. & Tzaros, C. 2008, 'Sustainability of a long-term volunteer-based bird monitoring program: Recruitment, retention and attrition', Volunteering Australia.

Zeller, B., Petroeschevsky, A. & Dwyer, C. 2001, 'Monitoring coastal marine habitats and waterways: Government and community partnerships in action', Australasia Pacific Extension Network, The Regional Institute, Ltd.