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Citizen science monitoring of marine protected areas: case studies and recommendations for integration into monitoring programs

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Abstract

Ecosystem-based management and conservation approaches such as marine protected areas (MPAs) require large amounts of ecological data to be implemented and adaptively managed. Recently, many citizen science programs have endeavored to help provide these much needed data. Implementation of MPAs under the Marine Life Protection Act (MLPA) Initiative in southern California was followed by a monitoring program to establish a comprehensive baseline of the ecological conditions of several marine ecosystems at the time of MPA implementation. This baseline monitoring consortium involved several citizen science monitoring programs alongside more traditional academic monitoring programs, creating an opportunity to evaluate the potential for citizen scientists to become more involved in future long-term monitoring efforts. We investigated different citizen science models, their program goals, and contributions to MPA baseline monitoring, including their respective monitoring protocols and data quality assurance measures, in the context of the goals of the MLPA baseline monitoring program. We focused on three very different case studies: (1) commercial

fishermen and other volunteers collaborating with researchers to study the California spiny lobster, (2) volunteer divers monitoring rocky reefs with the Reef Check California (RCCA) program and (3) middle and high school students monitoring the intertidal life of rocky shore and sandy beach ecosystems with the National Marine Sanctuaries' LiMPETS program (Long-term Monitoring Program and Experiential Training for Students). We elucidate capacities and potential of citizen science approaches for MPA baseline monitoring and for building capacity towards sustainable long-term monitoring of MPAs. Results from this study will be relevant and timely as the monitoring of California's MPAs transitions from baseline to long-term monitoring, and as citizen science continues to become more prevalent in California and elsewhere.

Introduction

Natural resource management requires the support of sound and rigorous science. However, bringing science to bear on natural resource management decisions is an ongoing challenge, made all the more crucial by the increased data and information needs required by Ecosystem Based Management approaches and adaptive management policies. One aspect of this challenge is that there is often a mismatch between the needs of managers and outputs of science. Academic scientists, and the broader science system, are not incentivized to organize research around the needs of managers (McNie 2007). Successfully delivering useful information to resource managers requires capacity and careful attention, but many agencies and scientific institutions struggle to support this function (Clark et al. 2011, Lemos et al. 2012, Matso 2012). Beginning in the 1990s, volunteer-based citizen science monitoring of marine environments began addressing the need for dataset based on long-term studies (Thiel et al. 2014). Citizen science, as we refer to it here, engages non-scientists in authentic scientific research and monitoring (Dickinson et al. 2012). Marine citizen science programs now range from online projects, to observation along beaches and shores to underwater observations. These efforts cover a wide variety of taxa and ecosystems, notably coral reefs and other shallow reefs—key habitats that can be studied in the intertidal zone or by using SCUBA

(Pattengill-Semmens and Semmens 2003, Selig and Bruno 2010, Thiel et al. 2014). Beyond contributing to basic or applied research, citizen science projects provide opportunities to involve stakeholders in management of marine resources while enhancing scientific literacy, environmental awareness, and resource stewardship, and the very activity of conducting research educates participants about the scientific process, creating trust between stakeholders and resource managers (Bonney et al. 2009b, Dickinson et al. 2012, Jordan et al. 2012, Shirk et al. 2012, McKinley et al. 2015, McKinley et al. 2016).

An increasing number of citizen science projects have an explicit goal of supporting management in some way (Aceves-Bueno et al. 2015, McKinley et al. 2015, McKinley et al. 2016). However, the challenge of effectively linking citizen science programs with natural resource management remains. There is a diversity of approaches to citizen science, each with different potential outcomes related to factors such as participant experience and learning, data quality and credibility, and data use. Furthermore, data production is not the only way in which citizen science can contribute to management. There are other ways in which outcomes of citizen science (e.g., scientific literacy, environmental awareness, stewardship, trust building) may intersect with resource management (Cigliano et al. 2015, McKinley et al. 2015, McKinley et al. 2016). In striving to understand the opportunity that it might present for natural resource management, we must avoid treating ‘citizen science’ as a monolith, and recognize that different kinds of programs have different goals, strengths, weaknesses, and needs when it comes to collaboration with academic scientists, and with resource managers (e.g., Freitag et al. 2016).

Citizen science programs have been categorized in a variety of ways. For example, Bonney et al. (2009) put forward a framework for understanding the types of participation by volunteers, ranging from contributions of data to co-creation of projects. McKinley et al. (2016) point to stages of a decision-making process such as policy formulation, management implementation, and evaluation, as offering different opportunities for citizen science data to play a role. Freitag et al. (2016) document a variety of approaches used by citizen science projects to demonstrate the credibility of their results. Scientists and managers must carefully consider these factors in structuring a collaboration involving citizen science.

Citizen science and MPA monitoring in Southern California

In 1999, the California State Legislature passed the Marine Life Protection Act (MLPA), which sought to protect and preserve the state's underwater ecosystems and heritage by establishing a coherent network of protected sites and —crucially — to ensure that they were managed adaptively and "based on sound scientific guidelines" (Fish and Game Code) as a network. Motivations to evaluate the effectiveness of MPAs in meeting their management objectives are numerous (Syms and Carr 2001, Willis et al. 2003, Gaines et al. 2010) and the MLPA mandates that the MPA network be monitored to inform its adaptive management (Botsford et al. 2014). Further, the MPA monitoring framework explicitly mentions the potential role of citizen science programs in MPA monitoring (California Department of Fish and Game 2008). As such several citizen science programs were included in the baseline monitoring program of the MPAs in California's south Coast Study region (SCSR) after MPAs were established in 2011.

In this paper we focus on the opportunity for citizen science to play a role in natural resource management by examining three very different citizen science programs in the context of baseline phase of MPA monitoring in Southern California (2011-2016). Taken together, the three cases illuminate the different considerations discussed above, and also show that even within a single natural resource management program, there may be room for multiple kinds of participation by many different kinds of stakeholders. We focus on three case studies: (1) commercial fishermen, agency scientists, and other volunteers collaborating with academic researchers to study the California spiny lobster (*Panulirus interruptus*) in the Southern California Lobster Research Group (SCLRG), (2) volunteer SCUBA divers monitoring rocky reefs with the Reef Check California (RCCA) program, and (3) middle and high school students monitoring rocky intertidal and sandy beach ecosystems with the Long-term Monitoring Program and Experiential Training for Students (LiMPETS) program. All three programs contributed data to the MPA baseline monitoring in the SCSR. We examine their respective motivations, program goals and contributions to the baseline monitoring in light of the goals of the MLPA baseline monitoring program.

Case studies

Southern California Lobster Research Group

The Southern California Lobster Research Group was created in 2011 to perform baseline monitoring for California spiny lobsters in South Coast MPAs (Figure 1). Scientists from San Diego State University, Scripps Institution of Oceanography, and the California Department of Fish and Wildlife teamed with commercial lobster fishermen from the San Diego, Laguna Beach, and Palos Verdes, California areas to form a tag-recapture program using commercial fishing vessels as research platforms. It also teamed with the San Diego Oceans Foundation (SDOF), a 501(c)3 nonprofit organization dedicated to educating community members about local marine organisms and the habitats upon which they depend.

Over the course of three years, working primarily in the spring and summer months, members of the SCLRG conducted a mark-recapture study on California spiny lobsters. Fishermen, scientists, and volunteers took day trips on commercial fishing vessels or research vessels to collect data on spiny lobster abundance, size distribution, sex, reproductive status, and movement. Growth and movement were assessed by marking lobsters with individually numbered plastic “t-bar” tags that were color coded based on whether lobsters were trapped inside or outside of MPAs. Trapping was conducted by one commercial fisherman accompanied by at least two project participants (usually, one project scientist and one or two volunteers). Approximately 19,000 lobsters were captured, tagged and released over the course of the three-year study.

Volunteers were recruited by the SDOF, which received hundreds of volunteer applications. Each volunteer was interviewed individually and then was required to read a volunteer manual, upon which they were tested before being allowed to go to sea. Their training covered what to expect at sea, what their responsibilities would be, the importance of accurate data collection, and basic safety protocols for being on a vessel. Collectively the process required hundreds of hours of time by SDOF staff to vet the potential volunteers and to train them. Interestingly, many of the staff members of SDOF are themselves volunteers who devote several months of time to the organization with no compensation.

Volunteers needed no particular set of skills but were required to be comfortable being on a small boat for several hours, and needed to be able to neatly record data at a relatively fast pace in field conditions. Volunteers were specifically tasked with data recording and more experienced volunteers sometimes assisted with lobster tagging. Volunteers were asked to commit to a minimum of one day per month of being at sea for the project, though as the project progressed we wound up with a “core” set of reliable volunteers who participated at least several times per month.

The project involved the efforts of several lobster fishermen over the course of the study. One primary fisherman was recruited in each of three geographic areas in which the team conducted research: San Diego (3 MPAs), Laguna Beach (1 MPA), and Palos Verdes (1 MPA). Other fishermen acquainted with the primary fishermen assisted with the research out of interest or necessity (e.g., when a primary fishing vessel developed mechanical problems, a back-up vessel was used). Ninety percent of daily trapping and tagging trips were performed aboard vessels owned by these fishermen who were compensated for the cost of fuel, insurance and wear-and-tear to their vessels. Fishermen were not provided salary, but instead donated their time to the project.

The lobster trapping and tagging typically yielded over a dozen completed data sheets at the end of each day, which required hundreds of lines of data to be entered. To quality control the data, data sheets were checked for irregularities daily or weekly, and any questionable data entries were shown to the data recorder or scientists that had been at sea when the data were recorded for clarification. Data points that could not be clarified were discarded. Data entry was done by project staff who were trained in entering data using the correct format, and analyses were conducted by project staff (principal investigators and students).

The goal of the project was to form a collegial group of researchers and volunteers representing different perspectives and walks-of-life to successfully evaluate the status of lobsters in and around South Coast MPAs. The team specifically wanted to involve members of the fishing community to take advantage of their tremendous local ecological knowledge and to get their buy-in for lobster monitoring. In turn, the fishermen wanted a hand in monitoring to see that it was being done to their satisfaction and standards. They also expressed sense of responsibility and stewardship to the lobster population and the fisheries it supports. The team wanted to go beyond a collaboration between fishers and scientists and involve the public in this research, in order to better educate citizens about lobster ecology, the lobster fishery, and the nature of marine research.

There were two key reasons to structuring the research in this collaborative framework: first, it allowed implementation of a variety of monitoring tools. Building a strong team of researchers from academia, management, and industry, with different expertise, enabled a focus on several different components of monitoring (e.g., boat-based tagging, SCUBA-based surveys, and analysis of fishery records) which contributed different but complementary information. Second, the collaboration promoted buy-in from the fishing community that monitoring is being done correctly and that the data accurately reflect population trends of fishery species. The contributions of the fishing community, in terms of local ecological knowledge, were invaluable to the research and can contribute substantially to future monitoring efforts. For example, not only did fishermen contribute expertise for trapping lobsters (including methodology and key locations to target for lobster capture), but they also collaborated with project scientists to discuss the reasons behind trends in lobster abundance and distribution that became apparent after data collection was initiated.

One challenge was the different levels of preparedness and competency of volunteers. Though all of them went through training, some still had a difficult time remaining organized when asked to record data. Some were very concerned about making sure numbers were recorded correctly, whereas a few volunteers did not seem to care about making mistakes on data recording (or they perhaps were embarrassed about admitting not being able to keep up).

Luckily, this was rare and most volunteers were engaged and accurate. The small number of volunteers that had problems recording data were not invited back to participate in the research.

Though collaborating with fishermen greatly aided the research, fishermen and scientists sometimes are at odds regarding how sampling should be performed. There were occasional discussions regarding the placement of traps for catching lobsters. For a fisherman interested in maximizing the number of lobsters per trap, it would not make sense to deploy traps in unsuitable habitats that sometimes were within or adjacent to MPAs. In contrast scientists may favor randomly deploying or spatially dispersing traps among different habitat types, even if low catches are expected in some areas. The group had numerous meetings before, during and after each research season to work out the optimal placement of traps to maximize catch (which was important for maximizing recaptures and analyzing growth and movement) and to effectively make unbiased comparisons of lobster abundance inside and outside of MPAs.

Reef Check California

The Reef Check California (RCCA) program was established in 2005 by the Reef Check Foundation, a California based 501(c)3 non-profit organization (Figure 2). The program was developed with the goal of involving the public in the scientific monitoring of California's rocky reefs and kelp forests to improve marine management by providing scientific data to the management and decision making entities. Further, the program aims to educate the public about the marine environment, its management and conservation by involving people in the scientific monitoring of key habitats. Specifically, RCCA uses trained volunteer scuba divers to collected data on the ecological communities of shallow subtidal rocky reefs along the California coast. RCCA's monitoring protocol was developed with the oversight of a scientific advisory committee and modeled after a successful large-scale academic rocky reef monitoring program conducted by the Partnership for Interdisciplinary Study of Coastal Oceans (PISCO). The PISCO protocol was modified by reducing the number of species monitored, modifying some sampling procedures and changing the replication of transects to enable volunteers to complete the monitoring with a reasonable amount of training. Importantly, protocol modifications were made in a way that would allow for data to be compatible. For example, RCCA's taxonomic groupings were designed to directly correlate to PISCO's taxonomic categories so that data of both programs can be combined at higher taxonomic levels. The resulting monitoring protocol for RCCA surveys consist of 18 transects along which 35 fish species are counted and sized, and 6 transects along which 28 invertebrate and 5 algae taxa are counted (and in some cases sized) and the physical habitat is characterized (Freiwald et al. 2015).

To participate in RCCA monitoring, volunteers have to be experienced scuba divers (30 cold-water dives minimum) and are trained during a four-day training course and then annually retrained and tested in their skills. The initial training involves lectures on marine ecology, MPAs, species identification and the scientific methods for counting and sizing organisms along standardized transects. Next, species identification and monitoring skills are practiced during two days of diving (6 dives). At the end of the training volunteers are tested in their species identification skills and the monitoring methods during written and field exams. This testing leads to a tiered approach to data collection in which volunteers are allowed to collect certain types of data (i.e. certain taxonomic groups) based on their skill level and only the most skilled volunteers are able to collect all data types. Annual recertification ensures that the skills of volunteers are tested before each field season and provide participants with an opportunity to demonstrate increased skills so that they can collect other types of data. The required prior scuba diving experience, the high level of training as well as the substantial time (typical survey days are 6-8 hours plus travel) and financial investment (> $1000 in dive equipment) results in recruitment that is highly selective for dedicated and invested volunteers.

The RCCA program was developed at the time when the Marine Life Protection Act (MLPA) initiative began to design and implement MPAs along California's central coast. Therefore, MPA monitoring was at the forefront of the development of the monitoring program and the program goals correspond closely to the MPA monitoring goals of the MLPA baseline monitoring. The usefulness of the data collected by RCCA for marine management and specifically for the use with respect to the goals of the MLPA was recognized early on during program development through a Memorandum of Understanding between the Reef Check Foundation and the California Department of Fish and Wildlife (CDFW). Through this cooperation with the potential end user of the data a direct avenue for scientific information collected by RCCA volunteers to the relevant management agency was created. RCCA began monitoring in 2006 and was involved in the baseline monitoring of California's MPAs in every MLPA study region as MPAs were implemented sequentially. During the baseline monitoring programs as well as in a separate study, RCCA data were compared to data collected by academic monitoring projects (Gillett et al. 2012, Carr et al. 2013, Ocean Science Trust and California Department of Fish and Wildlife 2013). These comparisons were used to improve RCCA's monitoring protocol and to evaluate the compatibility of data among programs.

In the south coast study region (SCSR) baseline monitoring project RCCA closely collaborated with the two academic programs that monitor rocky reefs in the region (PISCO/Vantuna Research Group (VRG)) on survey design. Over the two years of the SCSR baseline monitoring, RCCA trained approximately 100 new citizen scientists that completed 91 surveys. Many of the participants in the SCSR monitoring have been with Reef Check for many years and a 2013 survey of active and past volunteers showed that volunteers are on average 38.5 years old (range 17-69) and have a high level of education.

RCCA's data are entered into a database by interns, volunteers or staff and are publicly available through Reef Check's Global Reef Tracker (data.reefcheck.org). Data are examined by a rigorous quality assurance and quality control process that ranges from the training and certification of volunteers, to data checks in the field, to automated data evaluation during data entry ("smart filter" sensu: Bonter and Cooper 2012), and a final data check by RCCA staff before data are released. For the MPA baseline monitoring, data are analyzed by RCCA staff, often in collaboration with academic researchers, and analyses and data are made available for peer review.

Overall, RCCA reached its goal of contributing scientific information to the management process of California's marine resources by involving the pubic in MPA monitoring and making its data available to decision makers. Reef Check's MPA baseline data and analyses have been included in technical reports, summary reports, presentations and documentation provided to decision makers (i.e. Fish and Game Commission) in the respective MLPA regions. Three aspects of the program have strongly contributed to RCCA's success in using citizen science for MPA baseline monitoring and informing marine management: (1) modeling the RCCA's citizen science monitoring protocol on an existing monitoring program, (2) involving the end user of the data early on in the program development, and (3) the rigorous training and testing of volunteers and the comparison of volunteer collected data to data from other monitoring programs. Reporting highly technical results back to the public continues to be a challenge. RCCA is addressing this by implementing a user-friendly interface for online data display. This allows volunteers and the interested public to search and graph RCCA data but further steps to report results in engaging ways would be beneficial.

LiMPETS Case Studies for Rocky Intertidal and Sandy Beach Ecosystems

LiMPETS is an environmental monitoring and education program primarily focused on 7th-12th grade students (Figure 3). This hands-on program was launched in 2004 in and around California's National Marine Sanctuaries as a way to increase awareness and stewardship of these important areas, with now approximately 5,000 students participating annually at 68 sites state-wide. Participants engage in monitoring activities, gain experience using the tools and methods employed by field scientists, and can enter their data online. The program focuses on two intertidal habitat types: rocky shore (27 sites) and sandy beach (41 sites). The rocky intertidal program collects count and presence/absence data on a list of 34 categories scored in $0.25m^2$ quadrats (either random or fixed along a permanent transect). Information on total counts of sea stars and sea anemones, and size frequency data for owl limpets (*Lottia gigantea*) are collected at some sites. At sandy beach sites, data on the numbers and size frequency distributions of Pacific mole crabs *Emerita analoga* captured in core samples taken along a fixed sampling grid are collected. Complete protocols, archived data and additional information are available at http://limpetsmonitoring.org. Although the two intertidal habitats are monitored separately, the audience, level of training and participant involvement are comparable. Teachers must attend a prerequisite 1-day training workshop and a LiMPETS Coordinator gives a classroom presentation on program background, protocols and species identification. This program is accompanied by a 4-unit curriculum that meets California state science standards and provides teacher-led classroom exercises and learning tools, that teachers are expected to implement before field trips. Typically, a classroom only participates in one field trip, although some teachers repeatedly involve their classrooms each year. For many students, the LiMPETS field trip may be their first exposure to the coast and ocean environment. The program model maximizes the number of distinct class trips rather than focusing on more intensive study and experience for fewer students. After the field trip, teachers and students are encouraged to enter their data via the on-line entry portal into the public LiMPETS database. The data entry portal was not built with formal error checking capacity or any way to flag questionable data once they are entered.

In 2011, academic scientists leading the SCSR MPA baseline evaluation program of rocky intertidal and sandy beach ecosystems collaborated with the coordinators of the LiMPETS program at Channel Island National Marine Sanctuary (CINMS) on studies to evaluate the potential for LiMPETS to contribute to monitoring of southern California MPAs. The goals of this partnership were: 1) to compare data collected by LiMPETS participants with those collected by professional scientists (UCSB and the Multi-Agency Rocky Intertidal Network –MARINe), 2) to refine existing protocols and test new protocols for more efficient and accurate data collection, and 3) to work with teachers to field test new protocols, and refine training methods based on teacher feedback. Participants in our protocol testing and development studies in the field and classroom included scientists, LiMPETS coordinators and K-12 teachers.

LiMPETS uses protocols to estimate species abundance that differ from that used by most marine scientists, owing to the multiple program goals including education and experiential training. Some factors initially implemented to make sampling easier for students may reduce the efficacy of data collection. For example, in the rocky intertidal, quadrats are scored by the ratio out of 25 sub-grids that an organism occurs in (number of squares), rather than for percent cover based upon 60 to 100 points. Students must spend time searching through the quadrat, which is an educational benefit, but the units of measure are not equivalent to those used by academic scientists and thus the data loses relevance outside of the LiMPETS arena. Sand crabs are individually measured and counted per core along a fixed grid that is not adaptable to the dynamic zone of occurrence of sand crabs or changing beach conditions (Nielsen et al. 2011, Dugan et al. 2013), which means that sampling often misses these highly mobile animals, leading to a dataset erroneously populated with zeros. Additionally, the existing program databases contain obvious errors due to species misidentification (taxa entered for sites where they are not known to occur). Because of these and other issues, collaborating scientists were unable to conduct a formal comparative analysis using existing LiMPETS datasets for either intertidal habitat, but informal data exploration confirmed these observations.

The next phase of the comparative analysis focused on experimentally evaluating correlations between abundance estimates generated side-by-side by CINMS staff and interns, LiMPETS coordinators and professional scientists and their graduate students. On multiple days at both rocky intertidal and sandy beach sites, samplers worked transects side by side, or scored the same plots, using the two distinct protocols plus one protocol modification (LiMPETS vs. academic scientist or vs. a modified LiMPETS for sandy beaches). This modified approach shared similarities with LiMPETS but was sensitive to changing beach conditions and mole crab habitat. Results of these field comparisons found that abundance estimates differed significantly between protocols.

In the rocky intertidal, comparing number of squares to percent cover, the best agreements were for taxa that occur uniformly in high density (e.g., mussel beds), and the worst were for taxa that occur infrequently but are evenly distributed (e.g., scattered barnacles) (Blanchette et al. 2014). The LiMPETS protocol consistently underestimated the number of sand crabs on the beach, by an order of magnitude or more compared to the modified LiMPETS protocol (Dugan et al. 2015). The time-intensive set up and sampling of the fixed grid used by LiMPETS did not account for the highly mobile behavior and active predator avoidance responses of sand crabs, which means that the sampling grid can miss the species zone entirely and crabs have often left the sampling area before the sampling can commence.

These results were consistent with those obtained in a similar comparative study done on sandy beaches in the North Central Coast MPA region (Nielsen et al. 2011).

Clearly, protocol modifications are needed to enhance the accuracy for both of the LiMPETS programs. Many errors stem from participant misidentification of rocky intertidal species. This is not surprising given both taxonomic complexity and the level of introductory training available to participants. Reducing species list complexity and incorporating bioregional differences into expanded field guides and survey protocols could help mitigate training limitations. Also, Total Count and Size Frequency methods focusing on larger species, such as owl limpets and sea stars, may be more teachable and easier to validate. Modifications of the protocol and the adoption of an adaptive sampling approach for sand crab surveys could help to increase the accuracy and utility of the data. In order to increase the usability of LiMPETS data, both programs would greatly benefit from restructuring to a tiered system and adoption of a quality assurance plan for training and certifying participants to each tier level.

Investigators considered the feasibility of using the modified LiMPETS sampling protocols during a Teacher Professional Development Workshop. Teachers liked the tiered approach in which students of all abilities could participate and feel successful, the tiers offered challenges/something to strive for, and they allowed for differential learning within classrooms. After a field session implementing the modified sand crab protocol that featured adaptive sampling, teachers indicated that it was highly feasible and would carry additional important educational benefits by fostering scientific observation and quantitative reasoning skills in their students (Dugan et al. 2015). Most of the teachers thought that participation in LiMPETS was a valuable experience even if the data collected were not made available as part of a scientific monitoring program, and was a great way to train and expose students to different methodologies and levels of taxonomic complexity, preparing them to assist or work with more experienced scientists.

The educational value of LiMPETS is undeniable and the program excels at introducing students to coastal environments and MPAs. However, there are many challenges with its usefulness as a citizen science program aiming to contribute data suitable for use in guiding management decisions. LiMPETS should explore practical considerations to build more effective monitoring outcomes including modified protocols, a strong and detailed training program with tests that document expertise, consistent mentorship and direct oversight by program staff and/or professional scientists, data sheet and database input review, quality assurance and quality control testing, use of standard methodologies in the field, and reliance on a science advisory team for guidance, oversight, and endorsement. As a result of the south coast MPA baseline monitoring program, LiMPETS has embraced addressing these considerations and program modifications are underway.

Discussion

The case studies highlight three very different citizen science projects. They differ in their temporal scope, their target audiences (i.e. citizen scientist demographics) and their program goals. Together they exemplify a broad range of citizen science programs and demonstrate the breadth of goals of citizen science (Dickinson and Bonney 2012). Through these three projects a wide range of non-scientists were involved in the SCSR MPA baseline monitoring. They ranged from K-12 students and teachers, to recreational scuba divers to professional fishermen and their participation varied from single day excursions (for students in the LiMPETS program and some spiny lobster volunteers) to long-term involvement lasting far beyond the baseline monitoring for Reef Check volunteers. Commitment to training also varied, from short training sessions in the classroom (LiMPETS) to extensive training and testing (RCCA). All three programs were successful in engaging stakeholders in MPA monitoring and especially the SCLRG highlights how this can lead to fruitful discussions among scientists and resource users that lead to better understanding of research methods and monitoring outcomes by stakeholders. Along the continuum of participant involvement put forward by Bonney et al. (2009a), the three projects can be defined as contributory, with participants collecting data according to a protocol put forward by scientists. The SCLRG project exhibits elements of a collaborative citizen science program in which volunteers began to contribute to the design of the study taking the involvement of stakeholder a step further than the two other programs in this respect.

An essential goal of all citizen science projects should be the generation of scientific data or, more broadly, a contribution to new scientific understanding while involving the public in the process (Dickinson and Bonney 2012, Shirk et al. 2012). This definition of citizen science sets citizen science apart from projects purely focused on science education and clearly aligns with the goals of generating a scientific baseline of the MPAs in the SCSR. While RCCA and SCLRG were developed to collect scientific data for MPA monitoring, the LiMPETS program was developed foremost around educational goals prior to its involvement in the MPA baseline monitoring. Therefore, the programmatic goals of the three citizen science projects aligned to different degrees with the MPA baseline monitoring goals. In this respect the LiMPETS program was different from the other two, as its participation in the baseline monitoring focused on exploring and evaluating whether a school-based program could collect high quality scientific data for MPA monitoring and expand its educational focus to the generation of scientific knowledge (Shirk et al. 2012). As a result of the evaluation of the data produced by the LiMPETS program they were ultimately not used for the characterization of the south coast MPAs. This does not suggest that education-based citizen science programs cannot adapt protocols to collect management relevant data; in fact, protocol revisions were suggested following the direct comparison of methodologies in the LiMPETS case study. On the other hand, RCCA and SCLRG data were used for the baseline characterization of the SCSR MPAs (Freiwald and Wisniewski 2015, Hovel et al. 2015). Therefore, both programs met their goal of providing information to the MPA baseline while involving the stakeholder community in the MPA monitoring. Further, RCCA built capacity for continued MPA monitoring and the program has successfully monitored sites in the SCSR every year following the baseline period. While SCLRG was not designed to continue after the baseline period, it reached its goal of engagement and "buy-in" from an important group of stakeholders – commercial fisherman. The close working relationship that the SCLRG formed between scientists and volunteers is likely to lead to future collaborations and increased stakeholder stewardship and involvement in MPA management, an important outcome of public participation in scientific research (Shirk et al. 2012). The LiMPETS program achieved its goal of evaluating its monitoring program with respect to the accuracy of data collection and it remains to be seen if the modifications can be implemented to produce quality monitoring data while not compromising its educational goals (Nielsen et al. 2011, Blanchette et al. 2015, Dugan et al. 2015). Additionally, strengthening the scientific rigor of programmatic aspects such as in-field training and data collection hold promise for enhancing science, technology, engineering and math (STEM) learning.

For all three citizen science programs the participation in the MPA baseline monitoring was considered a success and has let to programmatic improvement for the two programs that continue their monitoring (i.e. RCCA, LiMPETS). For example, RCCA has modified its protocol as it became apparent that its method of sizing fish was not sufficient to detect changes in fish population's size distribution. The program implemented a protocol to collected higher resolution size data for fish (standard length to nearest cm). The LiMPETS program identified the need for modified monitoring protocols for beaches and rocky shores, new quality assurance procedures, and training tools. Each of the three programs identified the need for a tiered approach to data collection based on the participant's abilities. In the RCCA protocol this is realized through the training and testing procedures that were established prior to the SCSR baseline monitoring. The LiMPETS program identified the need for a tiered approach through its comparative study and the teacher workshop. The SCLRG project was designed for participants of different skill levels (i.e. data recorders, commercial fishermen) but even within these groups there were different skill levels and participants that could not perform the tasks with the required accuracy were given simpler tasks. In the case of SCLRG, this tiered approach was implemented ad hoc as it had not been anticipated given the relatively small amount of training required for volunteers. The need for strategies to account for volunteer capabilities while maintaining high credibility of the data they collect has been identified in other citizen science programs especially if many volunteers are involved in a program as was the case as in each of these three programs (Freitag et al. 2016).

The experiences from all three programs demonstrated that if scientific data collection is the goal, there need to be appropriate entry requirements for participants. Entry requirements can take the form of prerequisites (i.e. technical skills required for participation, RCCA) and/or rigorous initial training (e.g., SCLRG) of participants followed by testing prior to data collection. The three programs had different approaches for selecting participants with the required skills. LiMPETS participants were part of a class rather than chosen by personal skill or interest, and there are no prerequisites for participation in data collection. In the SCLRG program volunteers were chosen based on interviews and for RCCA, volunteers must have substantial prerequisite diving experience in order to participate in the program. Often this need for highly trained participants in order to collect scientific data conflicts with the educational outreach or science engagement goals of a program (Freitag and Pfeffer 2013). Educational outreach and science engagement are aimed at participants of all skill levels, whereas accurate data collection to be used in scientific studies must be done by volunteers with verified skills. This tradeoff is important to consider when citizen science programs participate in ecosystem monitoring because the need for high quality data might compromise other important program goals. In the case of SCLRG, entry requirement or initial tests would have helped identify able volunteers and probably not impacted the educational outreach and science engagement goals of the program, as the required skills of data recording are not very complex. In the case of LiMPETS, there is a clear tradeoff between educational and data collection goals, therefore entry requirements might not be feasible unless education goals are given less priority. In this case, a tiered approach to data collection might be able to achieve both education and data quality goals. RCCA's prerequisite requirements are high due to the scuba skills required for monitoring the rocky reefs. This limits the number of volunteers that can participate and therefore confines the educational benefits of the monitoring program.

Data quality control was identified as a critical component by all three citizen science programs. In contrast to many other citizen science programs, all three programs conducted data collection during organized events rather than letting volunteers collect data independently and for RCCA and SCLRG all data were collected when scientists were present. In general, only about 30% of marine citizen science programs use organized approaches (Thiel et al. 2014) and these programs have been shown to employ more measures to ensure the credibility of their data than programs that rely on individuals working independently (Freitag et al. 2016). Large-scale citizen science projects, especially if the goals are biodiversity surveys, detection of invasive species, or description of qualitative population trends might benefit from the large numbers of observations that can be made if volunteers are collecting data independently and on “their own time”, for example, during recreational activates (Goffredo et al. 2010, Wolf and Pattengill-Semmens 2013). In this study, all programs indicated that professional scientific oversight is an important part of their quality control. Oversight and the presence of peers (i.e. other trained volunteers), provide opportunity for early detection of mistakes and errors in the data when they are easy to correct. Therefore, direct engagement of staff in the data collection is an important step in data quality control protocols for citizen science programs as it allows for correction rather than just the dismissal of erroneous data. Other studies have shown that data collected in groups and in the presence of scientifically trained staff might be perceived as more reliable than data collected by individuals on their own (Freitag et al. 2016).

Quantitative evaluation of data quality was identified as important when the goal is to contribute to the scientific understanding of an ecosystem by these programs and by others (e.g., Burgess et al. 2017). Comparisons of citizen science data to data collected by academic researchers have been done for two of the programs (LiMPETS, RCCA) (Gillett et al. 2012, Blanchette et al. 2015). Other citizen science projects have used quantitative analyses of the accuracy of citizen science data to establish participation-criteria based on the volunteers’ education levels (i.e. primary school to post graduate education) (Delaney et al. 2007). Such analyses can not only be used to establish entry requirements, they could also help to assign levels of confidence to citizen science data based on participants’ backgrounds (e.g., grade level). This would be useful in programs for which education, and therefore participation of volunteers with a board range of backgrounds, is an important program goal. Automated data checks that flag unusual data based on quantitative measures such as maximum allowable counts or regional species presences/absence information have been identified by these programs and others as increasing data quality and data use by researchers (Bonter and Cooper 2012, Burgess et al. 2017). RCCA has implemented quantitative data checks in its database and the LiMPETS program has suggested that automated data checks would greatly improve the data quantity if implemented.

All three cases pointed to modifications of the programs that would improve their ability to contribute to adaptive management of California's MPAs. It is worth noting that a long-term monitoring program can provide an opportunity for iteration and adjustment on the part of citizen science programs, professional scientists, and natural resource managers, as they work toward a productive relationship.

Conclusions and Recommendations

Overall, these three case studies demonstrate how citizen science projects can contribute scientific data to MPA monitoring while engaging important stakeholders in the monitoring and management process and also achieve some of their educational goals. The degree to which data can be integrated into the management process depends in large part on the other programmatic goals of the citizen science programs. If programs are developed first and foremost with an educational goal in mind it will likely require extra steps to make the data useful in a research and management context. On the other hand, if data collection is the main goal of the program, other beneficial aspects such as education might be limited. Key steps in making data collected by citizen scientists useful in a management context that were identified in all three case studies are: (1) The goal of collecting data and contributing to the understanding of the ecosystems under management requires carefully balancing other program goals lest data quality and reliability or the other program goals can be compromised. (2) Strict and explicit entry requirements for volunteers into the program are necessary to insure data quality and build credibility of the program. To achieve this, volunteers can be pre-selected based on a set of skills that is required (e.g., RCCA divers, SCLRG commercial fishermen) and/or they can be trained and tested in the data collection protocols (RCCA divers, LiMPETS students). (3) A tiered approach that qualifies volunteers for different levels of data collection was identified in all three case studies as important for insuring data quality. This allows volunteers to collect data according to their abilities and allows programs to include participants with different skill levels. It also provides an opportunity to reach educational and science engagement goals while still collecting high quality data by broadening the scope of volunteers that are able to participate in a program. (4) Direct oversight of volunteer groups by trained marine scientists in the field was identified as an important aspect of data quality assurance/quality control in all programs. Collecting data in a peer group as well as the presence of scientists during the field surveys make it much easier to correct errors and identify mistakes before it is too late to make simple corrections. Together these steps contribute to the quality and reliability of monitoring data collected by citizen science programs and can help to ensure that these programs contribute valuable data to marine management while involving stakeholders in the process.

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Figures

Figure 1. Volunteer recording data on California spiny lobster for the Southern California Lobster Research Group.

Figure 2. Reef Check California volunteer counting organisms along a transect.

Figure 3. Students working in the rocky intertidal with the LiMPETS program

Figure 1

Figure 2.

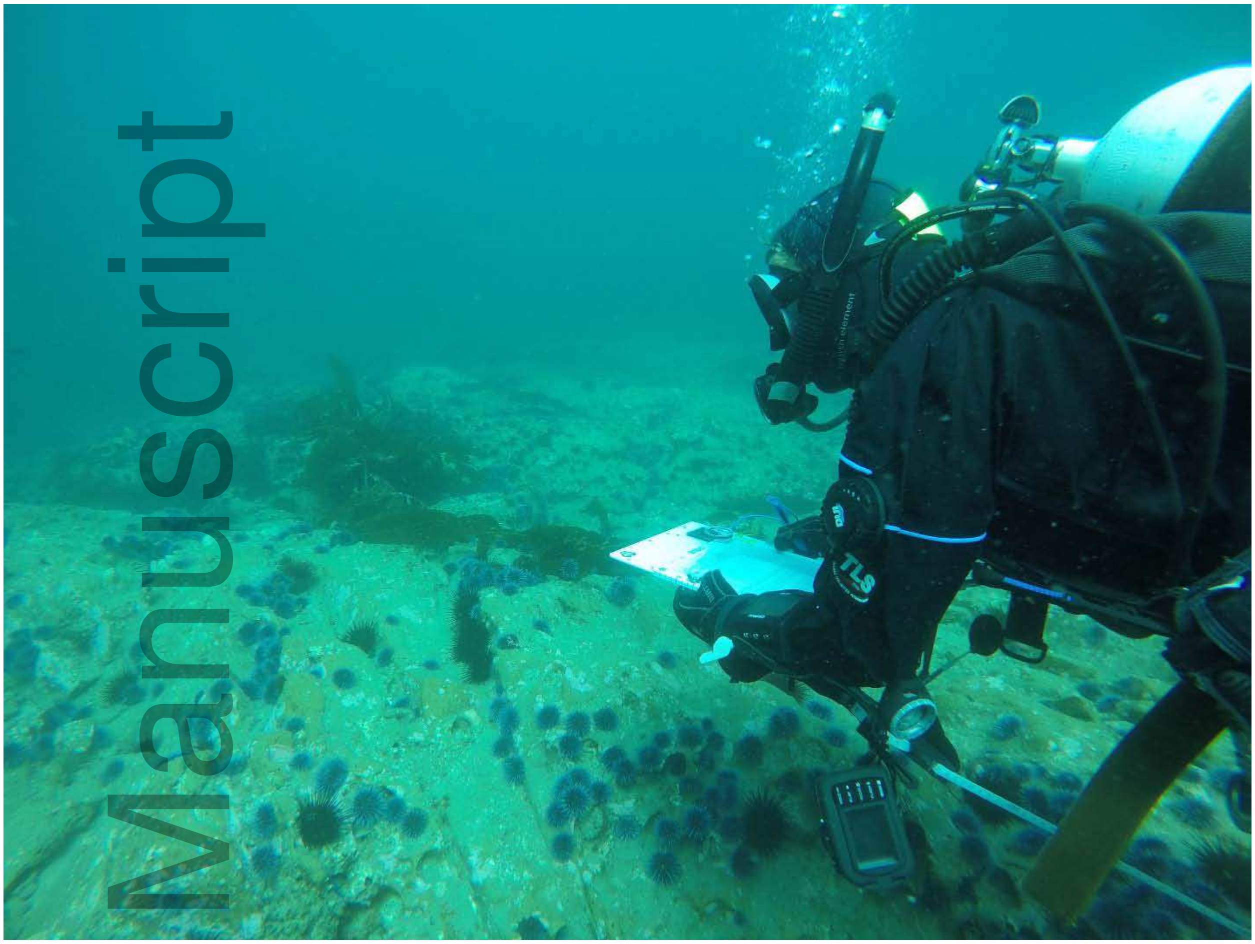

Figure 3

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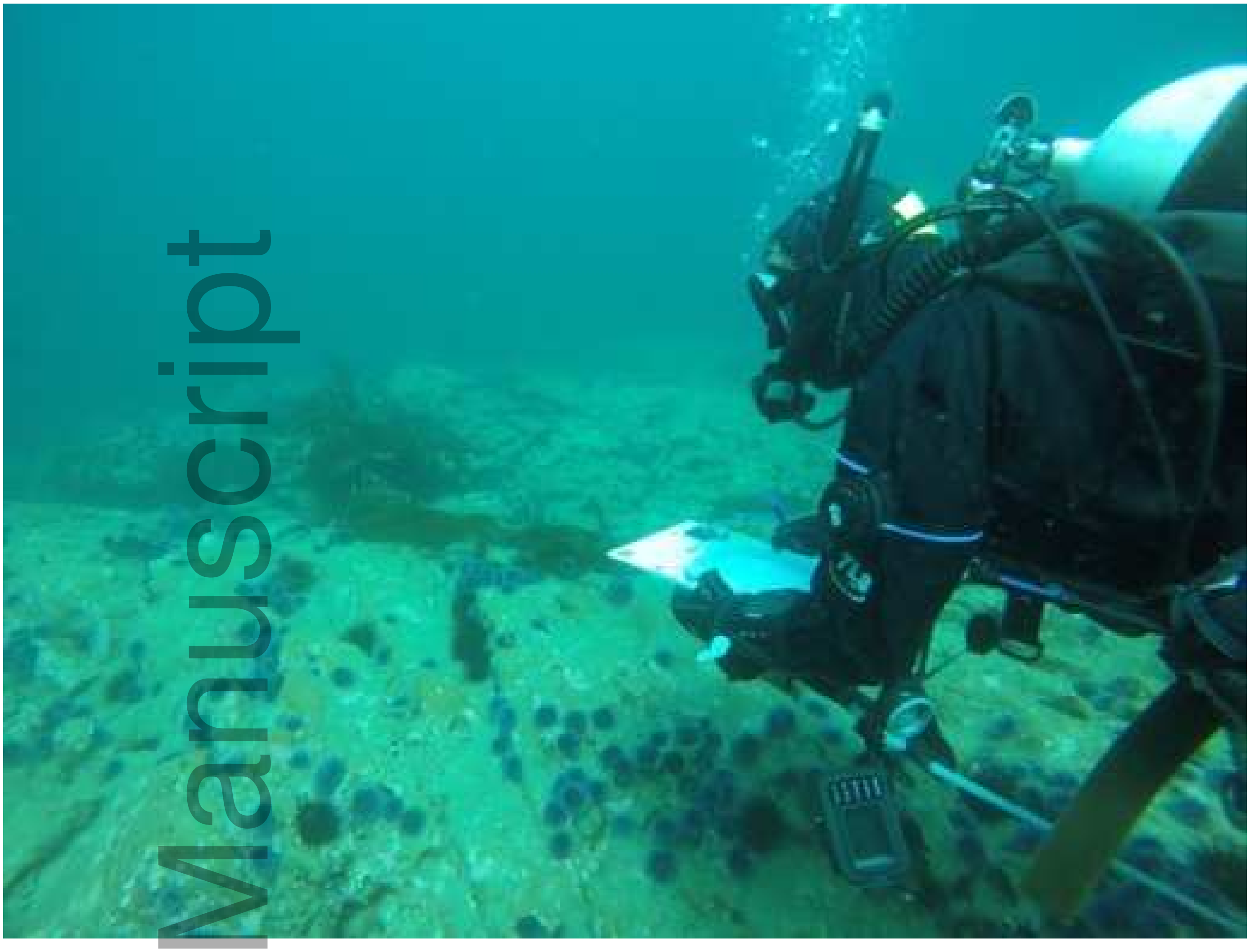

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