A Citizen Science Monitoring Protocol for the Rocky Intertidal Habitat

Bren School of Environmental Science & Management
University of California, Santa Barbara
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MARINe

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Coal Oil Point, Santa Barbara, CA

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As authors of this Group Project report, we are proud to archive this report on the Bren School's website, such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Bren School of Environmental Science & Management.

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The Group Project is required of all students in the Masters of Environmental Science and Management (MESM) Program. It is a three-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific management and policy dimensions of a specific environmental issue. The Final Group Project Report is authored by MESM students and has been reviewed and approved by:

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ABSTRACT

There is a growing trend in the scientific community to incorporate citizen science initiatives into long-term ecological monitoring. Concurrently, the Obama Administration has requested that federal agencies execute ocean stewardship initiatives, address impacts to climate change, and incorporate citizen science and crowdsourcing concepts into future research projects. Since the late 1990s, the Bureau of Ocean Energy Management (BOEM) and their partners in the Multi-Agency Rocky Intertidal Network (MARINe) have monitored the rocky intertidal habitat in California with a prescribed protocol. Their dataset has been integral in providing baseline information about coastal resources damaged by manmade and natural disturbances. In response to executive mandates, BOEM and MARINe are considering citizen science as a way to contribute to their ongoing professional data collection. The objective of this project was to develop a monitoring protocol with a *replicable* methodology for *accurate* volunteer-based data collection in the rocky intertidal habitat. The resulting protocol, developed at an existing MARINe site in Southern California, provides a tool to 1) collect accurate data from volunteers that can flag changes at intertidal sites, and 2) empower environmentally-minded groups to monitor their coastal resources. We show that the protocol is accurate relative to professional data collection, and also efficient through the use of smartphones to directly input and organize monitoring data. Additionally, we demonstrate the utility and accuracy of a crowdsourced data analysis platform. This project contributes directly to BOEM and MARINe's organizational goals, and also provides an applied demonstration of citizen science in a dynamic ecosystem.

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List of Abbreviations and Terms

BOEM: Bureau of Ocean Energy Management

CARP: Carpinteria State Beach

COP: Coal Oil Point

CS: Citizen science

CS Protocol: The Citizen Science Protocol created by the authors of this report for this project.

Low tide cycle: As defined by this project, a low tide cycle is a series of three consecutive field-sampling days that took place when the lowest tide was below 0 ft.

MARINe: Multi-Agency Rocky Intertidal Network

***Mytilus*:** California mussel (*Mytilus californianus*), the target species for the photoplot protocol at Coal Oil Point.

Photoplot: A rocky intertidal monitoring protocol used by both MARINe and the CS Protocol to take photographs of a specified plot marked by permanent bolts to determine changes in percent cover of target species over time. There are five photoplots at Coal Oil Point (M1-M5), and the target species is the California mussel (*Mytilus californianus*). A 50 cm x 75 cm quadrat is laid out on top of permanent bolts, marking each photoplot boundary.

***Phyllospadix*:** Surfgrass (*Phyllospadix scouleri, Phyllospadix torreyi*), the target species for the transect protocol at Coal Oil Point.

Score: To score a transect; to mark which of the 10 CS species categories was present under a determined point on the transect line.

SG3: Surfgrass Transect 3 at Coal Oil Point

Target: Species or species assemblages specifically chosen for long-term monitoring. For a more detailed description, see “Chapter 4: MARINe Infrastructure”.

EXECUTIVE SUMMARY

BACKGROUND

Long-term ecological datasets are valuable to federal and state resource management agencies. Understanding natural processes, species distributions, and species abundances over long time scales is critical to create management plans that can adapt to climate change and other disturbances (Blanchette et al., 2008). In California, this type of baseline information is especially important, as the transport of oil and gas along the coast increases the possibility of a spill or other impacts to coastal resources (Raimondi, 2006).

The Bureau of Ocean Energy Management (BOEM) is the federal agency responsible for managing conventional and renewable energy in federal waters. Since the late 1990s, BOEM has provided the primary funding for the Multi-Agency Rocky Intertidal Network (MARINe), a partnership of over 45 agencies, universities, and private groups that monitor the rocky intertidal habitat with a prescribed protocol. MARINe's dataset has proved to be essential in planning recovery efforts following natural disturbances like ENSO events and population declines in sea stars and abalone, as well as in assessing damages from oil spills (Hewson et al., 2014). A volunteer program to complement MARINe's existing professional monitoring would not only help to bolster data collection, but also help to meet federal obligations for executive agencies, like BOEM.

The rocky intertidal habitat is exposed to severe wave action and temperature gradients on a daily basis, making it challenging for scientific study (Tomanek & Helmuth, 2002). Additionally, rocky intertidal ecosystems are one of the most heavily impacted ecosystems along the California coast. Their ease of access has made them particularly vulnerable to the negative effects of human activities resulting from both extraction (harvesting and collecting) as well as physical disturbance (trampling, overturning, and handling) (Blanchette, Raimondi, Smith, Burnaford, & Bursek, 2015). While its accessibility makes it an ideal ecosystem for volunteer data collection, its environmental variability provides challenges for volunteers and professionals alike.

Volunteer involvement in scientific monitoring is a growing trend, particularly in the fields of ecology and environmental science (Silvertown, 2009). In citizen science, as it is commonly called, volunteers aid in the collection and/or processing of data as part of a scientific endeavor. Crowdsourcing is when the scientific community makes an open call for contributions from a large, undefined network of people, commonly via the Internet, to help solve a problem (Wiggins, Newman, Stevenson, & Crowston, 2011). Data quality is a common concern with volunteer initiatives (Gillette et al., 2012; Aceves-Bueno et al., 2015). However, it has been shown that volunteers can produce data comparable to professionals when there is sufficient guidance and supervision, a rigorous sampling scheme, and a constrained taxonomic scope of the work (Gillett et al., 2012).

PROJECT SUMMARY

This project focused on the accuracy of volunteer-collected data in the intertidal habitat. Adapting the professional protocol to a citizen science context involved iterating the protocol in the field and paring down the species list into tractable monitoring categories. Citizen science species categories were chosen based on three factors: abundance, importance to MARINe, and ease of identification. Protocol iterations arose from multiple field tests and comparisons of volunteer-collected data to professionally collected data.

The resulting Citizen Science Protocol best achieves volunteer-collected data within a 10% accuracy range of the MARINe professionals. Additionally, this protocol was designed to minimize task loading of the volunteers, as well as the Site Leader, in order to achieve efficient use of time and high data quality. A statistical bootstrapping analysis for this 10% accuracy range scenario supports field observations – the number of volunteers needed to complete a survey is a minimum of four and maximum of 10 volunteers. More than 10 volunteers may compromise the Site Leader's ability to manage data quality, while less than four is too small of a number to complete certain tasks. It is likely that this number may narrow as volunteers get experience with the protocol and return for future survey events. Based on the accuracy analysis, it is important to acknowledge environmental variability when evaluating citizen science accuracy in the field.

This project produced a *replicable* citizen science monitoring protocol for the rocky intertidal habitat that yields *accurate* volunteer-collected data. This document outlines methodologies for implementing the protocol at a site, as well as how volunteer accuracy was tested in the field. The goal is to provide users of this protocol with a tool to flag changes at intertidal sites and to empower environmentally minded groups to monitor their local coastal resources.

CHAPTER 1: INTRODUCTION

BOEM & MARINe

Long-term ecological datasets are valuable to federal and state resource management agencies because understanding natural processes, species distributions, and species abundances over long time scales is critical to create management plans that adapt to climate change (Blanchette et al, 2008). The Bureau of Ocean Energy Management (BOEM) is the US federal agency within the Department of the Interior responsible for managing conventional and renewable energy in federal waters on the outer continental shelf. BOEM manages oil and gas energy, renewable energy, and environmental stewardship programs in four regions nationwide. The Pacific Outer Continental Shelf Region's Environmental Studies Program funds and directs environmental, social, and economic research concerning marine, coastal, and human environments offshore in California, Oregon, Washington, and Hawaii (BOEM, nd). The Pacific Rocky Intertidal Survey and Monitoring (PRISM) study has been ongoing since 1991, and addresses the need to collect information to determine the effects of offshore oil and gas operations managed by BOEM. Research conducted by BOEM and PRISM contribute data to the Multi-Agency Rocky Intertidal Network's (MARINe) dataset of intertidal monitoring from over 120 established sites (Figure 1; Gilbane, 2015)

MARINe is a partnership of over 45 agencies, universities, and private groups that monitor the rocky intertidal habitat with a prescribed protocol. BOEM has provided the primary funding for MARINe's database as well as for monitoring mainland sites in five counties since the 1990s. Coastal ecosystem monitoring has proved to be essential in planning recovery efforts following natural disturbances, such as the 1997/98 ENSO event. MARINe's long-term monitoring data have also been used to assess damages caused by manmade disasters such as the 167 barrels (bbl) of crude oil spilled in Santa Barbara County in 1997 (Hewson et al., 2014). As it is not financially possible to study the entire rocky intertidal habitat intensely, long-term monitoring protocols developed by MARINe were created to flag major ecosystem changes. These data were successful in identifying the decline of black abalone populations due to withering foot syndrome, leading to listing the species as endangered and closing the fishery (Miner, et al., 2005; Miner, 2014). The data were also helpful in detecting an outbreak of sea star wasting syndrome in 2013 and tracking its effects along the entire West Coast, which led to isolating a densovirus that may cause the disease (Hewson et al., 2014).

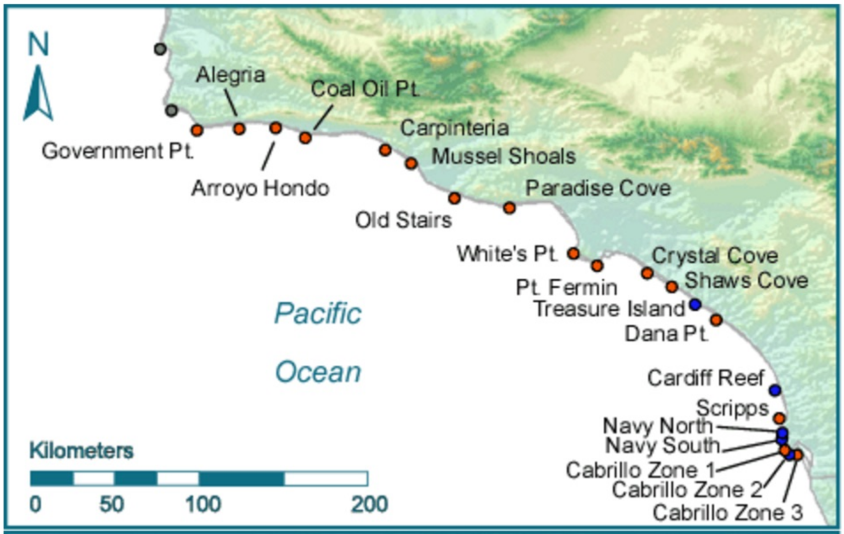


Figure 1. Southern California sites monitored by MARINe. Blue dots represent core survey sites. Red dots represent core *and* biodiversity survey sites. Source: MARINe (http://www.marine.gov/About/StudyArea.html).

MARINe has five key objectives (MARINe, nd):

1) Develop a long-term monitoring program with standardized protocols so data are comparable temporally and spatially.

2) Develop a shared database for the users to analyze data across sites.

3) Promote research projects at MARINe monitoring sites and jointly publish data in peer-reviewed journals, technical conferences, and through workshops.

4) Develop scientifically based, repeatable approaches to biological indices to measure and determine the health of the rocky shore.

5) Make MARINe findings available to the public.

PROJECT SIGNIFICANCE

There has been heightened attention from the Obama Administration to incorporate ocean stewardship initiatives (Executive Order No. 13547, 2010), address impacts to climate change (Secretariat Order 3289A1, 2010), and incorporate citizen science and crowdsourcing concepts into future federal research projects (Holdren, 2015). This project will help BOEM meet these obligations.

BOEM is interested in developing and testing a modified MARINe protocol for citizen science that could provide ongoing data collection at established sites where funding has been lost or where there is a monitoring gap at existing sites. MARINe partners already incorporate volunteers into some rocky intertidal monitoring. Most recently, over a dozen citizen science groups helped gather data on sea stars affected by a wasting syndrome that struck the majority of sea star species along the West Coast of North America (Pacific Rocky Intertidal Monitoring: Trends and Synthesis, 2015).

Expanding data collection opportunities through a strong and accurate citizen science program could allow for additional monitoring opportunities that can strengthen the database in a way that is credible and low-cost. Although citizen science can increase data collection, it is important that a citizen science program designed for MARINe addresses problems typically associated with citizen science, such as misidentification, inaccurate or disorganized data input, and retention of trained volunteers (Cohn, 2008). Emerging technologies, such as smartphone apps, are already used in citizen science programs to establish location records or alerts of abnormal patterns (Liu et al., 2011). Implementing emerging technologies in data collection and database input could also help to solve some of the problems related to citizen science programs. The latest cell phone technologies are rapidly increasing the potential for immediate validation of observations and transmission of data, as well as combining electronic sensor data with human observations (Dickinson et al., 2012). This project focused on accuracy, however, utilizing smartphone technology was also explored. Google Drive was used for data input in the field by volunteers, simulating the use of a citizen science data collection application.

The Citizen Science Monitoring Protocol created from this project can contribute to MARINe's rocky intertidal monitoring efforts. This project can also add to the development of the field of citizen science by incorporating modern technology as a way to streamline data collection and management, as well as to improve the volunteer experience.

This Citizen Science Monitoring Protocol provides a tool to:

1) Collect accurate data from volunteers that can flag changes at intertidal sites

2) Empower environmentally-minded groups to monitor their coastal resources

Chapter 2: The Rocky Intertidal Habitat

The Rocky Intertidal Ecosystem

The Southern California Coast is delimited from Point Conception to Cortez Submarine Banks off the coast of Tijuana, Mexico (Littler, 1980b). The principal basis for this delimitation is oceanographic influences. The cold California Current runs north to south, while the warm Davidson Current runs at a 200-meter depth from Baja California to Point Conception. Because of this delimitation, ecological community structure differs between north and south of Point Conception, with some overlap (Raimondi, 2006). The Southern California Coast is a dynamic ecosystem with a high complexity of physical conditions, where rocky intertidal habitats can be found in irregular patterns around sandy beaches to lagoons and estuaries (Littler, 1980a). Rocky intertidal ecosystems are characterized by distinct zonation patterns on a vertical gradient based on time spent completely immersed in water to completely dry on land (Harley & Helmuth, 2003).

Due to this dynamic variation, species composition in the intertidal habitat is determined by physical parameters (e.g., water and air temperature, wave action, and tides) and biological interactions (Helmuth, Mieszkowska, Moore, & Hawkins, 2006; Hoffmann, 2008; Littler, 1980b; Schoch et al., 2006; Smith, Fong, & Ambrose, 2006a; Tomanek & Helmuth, 2002). Blanchette et al. (2008) found 296 taxa in their study of the biogeographical patterns of intertidal communities of the Pacific West Coast.

Marine organisms of the intertidal zone have a high tolerance to this rapidly changing environment and can endure total submersion as well as complete exposure for long periods (Helmuth et al., 2006). These organisms have adapted so successfully, that some of them spend more time exposed to air than they do underwater (Helmuth & Hofmann, 2001). Physical environmental factors, in addition to predation, competition, and recruitment, are largely responsible for the local population structure, which are based on each species' tolerance (Harley & Helmuth, 2003).

Though these organisms withstand large daily variation, significant changes in water temperature, upwelling regimes, and oxygen levels could cause local extinction of some species (J. Davenport & Davenport, 2005). Upwelling has been reported to be a strong driver of community structure, mainly due to an increase in primary production (Schoch et al., 2006). Changes in environmental parameters will have different effects depending on species' tolerance, and species that have the tolerance level to survive those changes will colonize the space (Helmuth et al., 2006).

Ecological interactions are also central factors of community structure (Harley, 2003; Helmuth et al., 2006; Schoch et al., 2006). For example, if an organism is pushed too close to a zone of a predator or dominant competitor, the prey or lesser species will be eliminated from the zone (Harley, 2003). Thus, the distribution of each species along the intertidal zone is determined by each species' tolerance to environmental factors as well as by its ecological niche (Helmuth et al., 2006).

CHANGES IN SOUTHERN CALIFORNIA'S INTERTIDAL COMMUNITY STRUCTURE

Studies suggest that the general intertidal ecosystems in Central and Northern California are healthier than in the southern part of the state. Invertebrate richness along the entire California intertidal zone, however, has significantly decreased in recent years (Smith, Fong, & Ambrose, 2006b; 2006a). This decrease was present in all sites sampled around the state with special emphasis in Southern California where it changed from 87.7±6.6 to 35.7±3.4. In 2002, biomass in Southern California was found to be less than 50% of what historical data reported (Smith, Fong, & Ambrose, 2006a). Data have also proved that rare species found in historical assessments were not present in recent studies (Smith, Fong, & Ambrose, 2006a). These results suggest a link to regional climate change patterns in the last 30 years (Smith, Fong, & Ambrose, 2006a). The same general decrease is present in mussel bed thickness in Southern California. However, this pattern was only compared in three sites surveyed by MARINe, and two of them (including Carpinteria) did not show decrease (Smith, Fong, & Ambrose, 2006b).

Southern California's coastline can be described by three main physical parameters: 1) sand accumulation is greater in the southern part of the state; 2) the mean water and air temperature is 14 ºC; and 3) tides have a mean range of 1.5 m (Schoch et al., 2006). Community structures of intertidal zones are strongly correlated to air and water temperatures.

Few peer-reviewed studies describe the diversity of rocky intertidal zones in Southern California. Littler (1980a) reported 197 macrophytes and 217 macroinvertebrates, for a total of 414 taxa from 12 study sites along the coast (including the Channel Islands). However, a more recent study found 237 taxa in the California intertidal zone and reported taxa overlap within zones (Schoch et al., 2006). This study describes the low tide zone as the most diverse with 176 taxa (Schoch et al., 2006). The dominant species are *Mytilus californianus, Chthamalus* spp., *Anthopleura elegantissima,* and *Anthopleura sola* in many Southern California sites. These taxa are accompanied by large amounts of bare rock and sand (Blanchette et al., 2008).

COAL OIL POINT

Coal Oil Point is a reserve managed by the University of California, Santa Barbara located in Isla Vista, California. The rocky intertidal region exists on sandstone usually covered by sand above the +0.9 m tidal level. Historic monitoring data exist for this location from 1975 to 1978, and BOEM has continuously monitored this site since 1991. 127 taxa were reported in Coal Oil Point: 71 macrophytes and 56 macroinvertebrates (Littler, 1980b). Natural oil seeps are present at Coal Oil Point (Raimondi, 2006). Of the 12 sites surveyed by Littler (1980b), Coal Oil Point had the highest invertebrate density and macroinvertebrate percent cover. A full list of organisms that exist in the intertidal zone of Coal Oil Point can be found on the reserve's website (Organism List at Coal Oil Point, 2004).

According to historical data, biomass and invertebrate density have shown a reduction over time. However, though mussel bed thickness showed a decline, it was not found to be statistically significant (Smith, Fong, & Ambrose, 2006b). In general, invertebrate richness presented a 50% reduction at Coal Oil Point (Smith, Fong, & Ambrose, 2006a).

Coal Oil Point (COP) was the MARINe site used to test the Citizen Science Protocol designed for this project.

CARPINTERIA

MARINe data collected between 2003 and 2014 from Carpinteria State Beach (CARP) were analyzed for this project because CARP is the MARINe site directly south of COP. BOEM has monitored this site, located in Carpinteria, California, since 1991. Natural oil seeps are also present in nearby Ventura (Raimondi, 2006).

As mentioned above, Southern California's intertidal zone has shown decrease in its general community structure, and Carpinteria State Beach is no exception. Data from 2006 suggest a general invertebrate decrease of approximately 20% when compared to historical data (Smith, Fong, & Ambrose, 2006a). The same study found a 50% decrease in invertebrate density. Like COP, mussel cover also declined at CARP. Results from 2002 show a decline from 74% to 26% mussel cover (Smith, Fong & Ambrose, 2006b). Despite being reduced, the thickness of the mussel bed showed no significant difference with historical data (Smith, Fong & Ambrose, 2006b). Surfgrass (*Phyllospadix scouleri* and *Phyllospadix torreyi*) and Gooseneck Barnacle (*Pollicipes polymerus*) cover also decreased in the same time period (Raimondi, 2006).

Carpinteria State Beach (CARP), the MARINe site to the south of COP, was used to analyze historical mean abundance of species in order to choose citizen science categories.

CHAPTER 3: CITIZEN SCIENCE

When volunteers with variable expertise aid in the collection and/or processing of data as part of a scientific endeavor, it can be referred to as public participation in scientific research (PPSR) or citizen science (CS) (Wiggins et al., 2011). Volunteer involvement in scientific monitoring is a growing trend, particularly in the fields of ecology and environmental science (Silvertown, 2009). Partnerships are often initiated by scientists and involve non-scientists to support their research (Jordan, Gray, Howe, Brooks, & Ehrenfeld, 2011). Some citizen science participants, such as fishermen or boat captains, are recruited for their experience and expertise even though they have no formal degree or education on the topic they are helping to research. Other groups are formed through community ties, recreational interests, school groups, or community service requirements (Thiel et al., 2014).

> *Citizen science programs are created for many purposes including long-term monitoring, scientific research, community networking, social empowerment, scientific literacy improvement, and environmental education.*
>
> *Program goals range from contributing quality data to existing data sets, helping scientists answer specific questions, and informing local decision-makers, often all in combination with opportunities to enjoy nature.*
>
> (Newman et al., 2011)

Citizen science programs have been integrated into many different types of scientific research. For example, University of Minnesota and San Francisco State University utilize citizen science programs, the Monarch Larva Monitoring Program and the Great Sunflower Project respectively, to involve undergraduate students in data collection, data analysis, and experimental design (Oberhauser & LeBuhn, 2012). The Billfish Foundation, a non-profit organization dedicated to the conservation of sport fish, enlists volunteer charter boat captains to gain sufficient sample sizes for its research (Prince et al., 2007). Heal the Bay, a Los Angeles-based non-profit organization, trains local beach-goers to monitor the use of marine protected areas (MPAs) in Southern California (Heal the Bay, nd). Citizen science is also a good fit for the new field of urban ecology, which involves the ecological monitoring of ecosystems that have been heavily impacted by humans (Dickinson, Zuckerberg, & Bonter, 2010).

The growth of citizen science can be attributed to many factors, such as: 1) the ease of disseminating information via the Internet; 2) the scientific community's acceptance of volunteers for free labor, computational power, and even financing for research; and 3) the outreach requirements attached to large-scale grant money (Silvertown, 2009). Moreover, citizen scientists can help scientists study areas professionals could not reach because of geographic limitations (Miller-Rushing, Primack, & Bonney, 2012).

Benefits and Concerns

There are several benefits to volunteer participation in science. Reducing the cost of data collection is a draw for some projects because volunteers can provide manpower. Increasing manpower can help to increase the sample size of data collected (Crall et al., 2011). Additionally, citizen science programs encourage science and technology literacy, ensure collected data are relevant to local conservation and management issues, and provide access to lands that may otherwise be off-limits (Crall et al., 2010).

Integration between citizen science groups, professional scientists, and resource managers is becoming increasingly more prevalent in natural resource monitoring. One study compared data collected by volunteer scuba divers trained in Reef Check California's protocol and professional scientists conducting surveys with a similar protocol to monitor kelp forests (Gillett et al., 2012).

> *When there is sufficient guidance and supervision, a rigorous sampling scheme, and a constrained taxonomic scope of the work, trained volunteers could produce data comparable to professional scientists.*
>
> (Gillett et al., 2012)

Data quality is a primary concern for researchers that utilize volunteers (Wiggins et al., 2011). Adequate training is one component that appears to be key in ensuring the quality of data collected from volunteers (Aceves-Bueno et al., 2015). Standardized protocols, adequate resources for equipment, and a well-experienced program participant or paid staff member to accompany novice volunteers also add to the quality and viability of the data (Aceves-Bueno et al., 2015). Many projects that utilize volunteers employ multiple mechanisms to ensure data quality and appropriate levels of validation before, during, and after volunteer participation (Wiggins et al., 2011).

Addressing volunteer retention is important for existing organizations that want to add a volunteer component to their research efforts. The time and financial costs associated with training volunteers can be the deciding factor for the implementation of citizen science programs. In order to retain volunteers, a program must identify the profile of participants that meets its needs, so as not to use resources on training a group that may not have long-term buy-in to the project. Thus, for long-term monitoring, community members are preferable to volunteers that are unconnected to a research site (Aceves-Bueno et al., 2015).

APPLICATION OF TECHNOLOGY IN CITIZEN SCIENCE

TECHNOLOGY

Emerging technologies bridge the gap between scientific research and the public by creating platforms and tools that make science more accessible. There are three reasons for implementing technology into a citizen science program: 1) streamlining the scientific research process; 2) appealing to a diverse set of citizen science partners; and 3) organizing the user community (Newman et al., 2012). The latest cell phone technologies are rapidly increasing the potential for immediate validation of observations and transmission of data as well as combining electronic sensor data with human observations (Dickinson, Zuckerberg, & Bonter, 2010; Liu et al., 2011; Newman et al., 2012).

Incorporating useful technology into citizen science programs may bolster the scientific validity of the data collected by volunteers. Newman et al. (2012) cites many examples of how technology can be applied to citizen science. Moreover, community-wide technology use has already been utilized to report real time situations like flooding and biodiversity monitoring (Liu et al., 2011; Newman et al., 2011; Rio et al., 2013), or in-the-moment traffic updates (Wayze app; Google Maps app). Smartphones are becoming more popular, and can be used as a tool for citizen science (Liu et al., 2011; Newman et al., 2012). The proliferation of smartphones may serve as an advantage to scientists by providing access to low cost data, increasing data quality, improving data collection, engaging broad audiences, motivating volunteers, and corroborating model results (Newman et al., 2010; Liu et al., 2011; Newman et al., 2012: del Rio et al., 2013).

INCREASED DATA QUALITY AND IMPROVED COLLECTION

Applications for mobile devices like Open Data Kit and Open Mobile Consortium have been used to improve both data quality and collection (Liu et al., 2011; Newman et al., 2012). With the use of GPS in smartphones, volunteers can provide geo-references with longitude and latitude (Liu & Kritzer, 2013). Existing projects using smartphone apps, like Project BudBurst, automatically takes the location of the data collected, eliminating error and saving time. Aware-alerts can be used to flag measurements out of a normal range so scientists can identify particular sampling situations (Kim et al., 2009; Newman et al., 2012). Technology can provide citizen science coordinators with an efficient tool to track individuals with experience in different programs, and thus, increase data quality and recruitment (Newman et al., 2012).

ENGAGING PARTICIPANTS

Online social networks are great tools for citizen science programs. They can give volunteers a platform to create teams before going to the field, help program coordinators identify participants, or help scientists locate resources (Newman et al., 2012). Social networks may also be a platform for scientific communication across projects and communities (Hoffmann, 2008; Waldrop, 2008). A study by Newman et al. (2012) found that volunteers are motivated by opportunities to contribute to scientific research and peer-reviewed papers, competition games where participants receive rewards, and general social interactions with like-minded people.

Problems with Technology

With the benefits of technology, problems can also arise when new technologies are applied to citizen science. For example, handling large volumes of data will require improved data management skills (Newman et al., 2012). Geographic coverage will remain a challenge for remote places with limited wireless Internet access or cell phone service (Kelling et al., 2009). The incorporation of social media may create bias or a platform for the dispersal of wrong information. Hence, it is important to ensure that volunteers distinguish between scientifically produced information and personal opinions (Hoffman, 2008; Liu et al., 2011).

Program-specific systems are limited to particular data standards and it is often hard to integrate data from two different systems (Newman et al., 2010). For example, climate change data affecting species distributions are difficult to compare if the species distribution methodology is not the same or similar. This is an issue that has to be addressed by technology in citizen science since different researchers or organizations overseeing the project may have different uses for the data (Newman et al., 2010). Despite these problems, the implementation of technology in the field may increase the speed and accuracy of volunteers' data collection (Newman et al., 2012).

CHAPTER 4: MARINe INFRASTRUCTURE

The Citizen Science Protocol (CS Protocol) was based on MARINe's existing framework for monitoring the rocky intertidal habitat along the Pacific Coast. This chapter explains how MARINe determined current sites, target categories/assemblages, and protocol components.

SITES

MARINe's monitoring effort is one of the largest of its kind (MARINe, n.d.). Monitored sites extend from Alaska to Mexico. In California, site selection is based on available funding and the following main criteria:

- Areas representing the geographic range of the California coastline
- Areas representing major ecological communities along the California shoreline
- Areas previously surveyed or monitored that provide historical data
- Previously un-surveyed areas representing major data gaps
- Areas of special human interest
- Optimum conditions for long-term monitoring including reasonable and safe access, moderate protection from waves to ensure the safety of researchers during low tides, and adequately stable rock surfaces for establishing permanent plots

The CS Protocol examined historical data from two MARINe sites in Southern California: Coal Oil Point and Carpinteria State Beach. MARINe has surveyed both sites since March 1992.

TARGET CATEGORIES

Target categories are species or species assemblages specifically chosen for long-term monitoring. There are 18 target species, 60 additional scored species depending on site and protocol components, and three non-biological characteristics, including bare rock, tar, and sand (Engle, 2008).

Target species were selected based on the following main criteria (Engle, 2008);

- Species that are ecologically important in structuring intertidal communities
- Species that have wide or interesting distributions (e.g., rare or unique to a particular intertidal habitat, approaches biogeographic limits, characteristic of discrete intertidal heights)
- Species that have been well studied, with extensive literature available
- Species of human interest (e.g., vulnerable to human impacts, special legal status, harvest for sport or commercial activities)
- Practical species for long-term monitoring (e.g., readily identifiable, sessile or sedentary of reasonable size, non-cryptic species, and located in an area of the intertidal that permits sufficient time to sample)

PROTOCOL COMPONENTS

MARINe uses fixed plot sampling. In fixed plot sampling, permanent bolts designate where a sampling component must occur. This sampling design, as opposed to randomly located plots, was chosen as the best way to detect changes in the rocky intertidal habitat for several reasons. First, intertidal species assemblages are heterogeneous, so an impractically high number of replicates would be necessary to detect temporal change in species abundance. Second, fixed plots reduce the high variability of the intertidal habitat (Engle, 2008).

MARINe's core fixed plot sampling includes the following protocol components: photoplots, point-intercept transects, circular plots, band transects, and irregular plots. There is a compromise between more detailed sampling and a wider range of sampling resources (Engle, 2008). The CS Protocol modified the photoplot and point-intercept transects to suit citizen science volunteers as a user group. A site survey (general site information, 360° photograph, and elevated photo) and a search for species of concern were also included. The following chapter provides details on each of these components.

Chapter 5: The Citizen Science Protocol

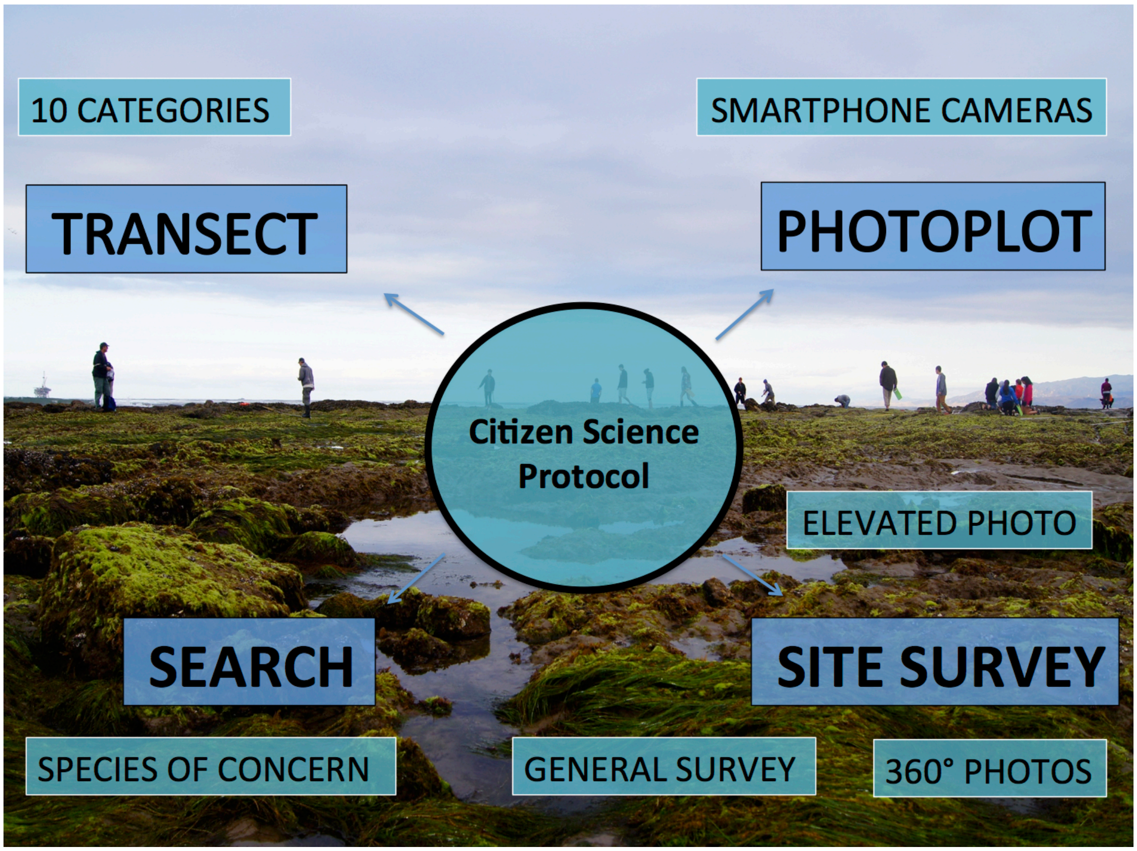


Figure 2. The final CS Protocol components. All components were modified from MARINe's Core Survey.

The final CS Protocol was modified from MARINe's core survey (Engle, 2008). This protocol recommendation assumes that volunteers use smartphones and conduct surveys at predetermined sites with permanent or fixed structures for repeated monitoring. See "Chapter 10: Recommendations" for recommendations on how to implement the CS Protocol at a new site or at an existing MARINe site. See "Appendix A: Field Guide" for in-depth details of each protocol component.

Fixed Plot Sampling Design

The CS Protocol was modified from MARINe's intertidal survey design. MARINe conducts monitoring at fixed permanent plots within a site. Since the objective of both protocols is to monitor changes in targeted species abundance (percent cover) over time, fixed plots, rather than random plots, are advised due to the inherent variability of the intertidal habitat (Engle 2008).

TRANSECT

The transect methodology is a point-intercept transect design. The purpose of a transect is to track the percent cover of a target species that covers a large area (e.g., Surfgrass at Coal Oil Point). Three 10 m transects are laid out between permanent bolts in the intertidal site, and 100 evenly spaced points are scored to account for the taxa or substrate present at each point along the transect.

PHOTOPLOT

The purpose of the photoplot is to monitor the surface cover of densely spaced, sessile organisms (e.g., Mussels, Anemones, and Barnacles). Five 50 cm x 75 cm quadrats are laid out on top of permanent bolts marking each photoplot boundary. A large umbrella is used to shade the entire photoplot in order to standardize the light in each photograph. The areas inside the quadrats are photographed in the field, and then scored later, to minimize survey time and to create a photographed record of the site. Citizen scientists are asked to use their smartphones to take pictures.

SITE SURVEY

Three components make up the site survey protocol: elevated photo, 360° photo, and general survey.

ELEVATED PHOTO

The elevated photo provides a visual overview of the site from a higher vantage point, such as from the top of a bluff, and is taken with a smartphone. This may not be possible at every site, but does work well for Coal Oil Point. The primary purpose of this photo is to provide a qualitative sense of the changes in the site over time, such as sand cover, movement of large rocks, or large-scale changes in species assemblages. Photographic records of MARINe sites have proved helpful in mapping and orienting new users to sites. Ideally, elevated photos are taken when quadrats, transect tapes, and marker cones are already in place to give reference points in the photo.

360° PHOTO

This photo element provides another qualitative photographic record of the site. From a marker bolt, a series of photos are taken to the north, northwest, west, southwest, south, southeast, east, and northeast directions. Smartphones should be tilted 45° from the horizon to show the intertidal habitat and minimize skyline.

General Survey

Information to be recorded includes site name, volunteer names, date, and low tide time. Additional observations include weather (sunny, partially cloudy, cloudy, rainy), wind (high, medium, low), swell (high, medium, low), debris (seaweed wrack, dead animals, oil/tar, trash), and biological activity (humans, mammals, birds).

Species of Concern Search

The purpose of the species of concern search is to flag the presence or absence of a species of concern. A "charismatic" intertidal species, such as a sea star, limpet, or chiton, is an ideal species to search for, as this component provides volunteers with a fun and exploratory task. Volunteers search for 30 minutes within designated boundaries of the site. If an organism is found, volunteers record the size of the organism using calipers.

Site Leader

The Site Leader does not have to be a professionally trained intertidal ecologist. He or she can be a citizen scientist with the skills necessary to appropriately orient to the site (identify permanent bolts and structures), understand all protocol components, and help other volunteers appropriately collect and input data.

Field Guide

The field guide created for this project can be found in "Appendix A". Having a site-specific field guide accessible to participants is imperative to the success of accurate volunteer-collected data.

Materials Required

- 1 smartphone for every 2 volunteers
- Transect tape(s)
- 50 cm x 75 cm PVC quadrats (ideally as many quadrats as there are photoplots)
- Large umbrella
- Calipers (to measure species of concern, if found)
- Orange cones (to mark reference points)

Google Sheets

To expedite data flow into a spreadsheet, volunteers input data into a Google Sheet shared through the Google Drive.

CHAPTER 6: METHODOLOGY

This chapter outlines the methods that were used to modify the MARINe protocol to create the CS Protocol outlined in Chapter 5. The methodology can be separated into two major components:

1) **Citizen science species category selection**

2) **Protocol iterations through field tests**

Category selection was conducted prior to field tests. However, modifications to the selected categories were made as a result of observations in the field during protocol tests. Therefore, these methodologies should not be considered mutually exclusive processes. The category selection process should be conducted when applying this CS Protocol to a new site. Field tests, however, may not be necessary when applying this protocol to a new site. See "Chapter 10: Recommendations".

PART 1: SELECTION OF SPECIES CATEGORIES

The citizen science (CS) species categories are as follows: Target (*Phyllospadix*, or Surfgrass), Sand, Rock, Feather Boa, Sea Lettuce, Seaweed, Barnacles, Sea Anemones, Gooseneck Barnacles, Mussels and Unknown. See "Appendix A: Field Guide" for descriptions of these species categories. CS species categories were chosen based on three parameters: abundance, importance to MARINe, and ease of correct identification.

Citizen science species categories selection parameters:

- Historical mean abundance
- Importance to MARINe
- Ease of correct identification

SITE SPECIFIC INFORMATION:
COAL OIL POINT

Choosing the species, assemblages, and non-biological categories that citizen scientists would be required to identify was a critical component of this project. This step should be done at each new site in which this protocol will be implemented. To begin the selection process, historical mean data from scored photoplots and transects at Coal Oil Point (COP) and Carpinteria State Beach (CARP) from 2003 to 2014 were analyzed. COP is the MARINe site where the CS Protocol was tested and CARP was the adjacent MARINe site to the south of the test site. This analysis generated the most abundant species and assemblages scored by MARINe.

All 10 CS categories (not including "Unknown") are the most abundant at both sites, except Acorn Barnacles (*Chthamalus/Balanus*) and Gooseneck Barnacles (*Pollicipes*), which are not highly abundant in photoplot or transect plots at COP. Once the most abundant categories were determined, CS species categories were checked to ensure importance to MARINe. Anemones, Surfgrass, Mussels, and Barnacles are MARINe target species, and are scored specifically to track changes in percent cover. Lastly, through field observations and recommendations from advisors, categories were altered to ensure that volunteers could easily and correctly identify them. Ten categories proved to be an appropriate starting point for a CS program. Volunteers were not required to know as many species as MARINe professionals, but 10 categories were enough to make in-field scoring fun and challenging for the volunteers, while still contributing useful data to MARINe. The following descriptions better define each parameter and the analyses used within the scope of this project.

ABUNDANCE

Conceptually, it was deduced that a higher abundance would mean that a category or species was also easy to correctly identify and was ecologically important. Consistent scoring through time means that the category is consistently present at the site. Therefore, in the first step of choosing CS species categories, the species with a historical mean percent cover of less than 1% were eliminated. Next, the historical mean percent covers from 2003 to 2014 for target species (*Phyllospadix*, *Mytilus*, *Anthopleura*, *Balanus*, and *Pollicipes*) were calculated (Figure 3). For this second step, percent cover was calculated with photoplot and transect data at each site. The three most abundant categories at each photoplot per site, and three most abundant categories at each transect per site were then chosen. Due to the range of intertidal species between COP and CARP and the nature of the implementation of the MARINe protocol, there were overlapping categories. Eight biological categories were chosen for the first iteration of the CS Protocol to be tested in the field. Sand and Rock were also included as non-biological categories due to their high abundance and importance to the MARINe protocol. However, in evaluating the most abundant categories, Sand and Rock were removed (even though they were some of the most abundant) so as to not underrepresent biological categories.

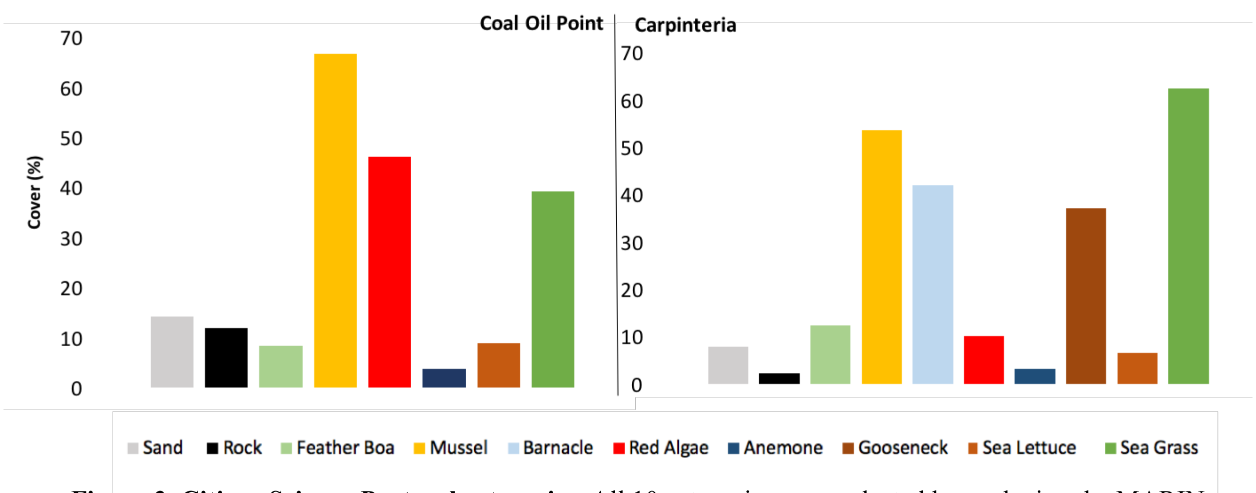


Figure 3. Citizen Science Protocol categories. All 10 categories were selected by analyzing the MARINe data for Coal Oil Point and Carpinteria from 2003 to 2014. The "Unknown" category is not represented here, but it is included in the field guide**.** Barnacles and Goosenecks are not highly abundant at Coal Oil Point.

IMPORTANCE TO MARINe

The objective of the CS Protocol is to yield accurate data. Therefore, all steps of this methodology lead toward creating a CS Protocol that would add value and/or bolster MARINe's existing long-term study. The final protocol recommendation is based on modifying MARINe's existing protocol to fit a volunteer audience, rather than one of professional scientists. The bulk of the final results are heavily slanted toward determining accurate percent cover of Surfgrass (*Phyllospadix)* transects and Mussel (*Mytilus*) photoplots. Based on resources and time available for this project, these results were prioritized because they appeared to add the most tangible and helpful results for MARINe in Southern California.

EASE OF CORRECT IDENTIFICATION

Misidentification is a common problem in citizen science data collection (Wiggins et al., 2011). This parameter addresses ease of identification of the most abundant categories. This parameter was confirmed through a literature review, discussions with intertidal experts, and field tests of the protocol. Some organisms, such as Barnacles (*Balanus glandula; Chthamalus dalli/fissus*; *Semibalanus cariosus*) and Anemones (*Anthopleura elegantissima/sola*) are grouped assemblages for the CS Protocol. The most major change of the CS species categories based on this parameter was to lump Red Turf Algae into a general Seaweed category. This change was made to prevent misidentification, which can readily occur at different life stages of the algae. Even though Sea Lettuce (*Ulva*) and Feather Boa (*Egregia*) are also types of seaweed, both were maintained separately from the "Seaweed" category because they are easy to correctly identify and because *Ulva* can correlate with disturbance at a site. The addition of the Unknown category is also an important factor in preventing misidentification. By including this category, citizen scientists are less likely to fill in a category incorrectly.

USE OF SPECIES CATEGORIES IN THE CS PROTOCOL

The 10 chosen species categories, plus the Unknown category, were determined prior to the structuring of the CS Protocol components (transect, photoplot, site survey, search). In this project, citizen scientists only used these categories to score Surfgrass transects (SG3) at COP. However, categories were chosen using data from photoplots and transects at both COP and CARP.

This was done so the CS Protocol could be flexible within MARINe in the future for the following reasons:

1) ***Possibility for photoplot field scoring by CS.*** Even though professionals do not score photoplots in the field, the category selection allows for the possibility for citizen scientists to do so in the future. For example, rather than gather photos of photoplots to be scored later by professionals or a crowdsourced community (discussed in "Chapter 8: Crowdsourcing"), the CS Protocol could be modified to score for percent cover or presence or absence of a MARINe target species in photoplot (such as Mussels). Other materials, such as a 100-point grid, would have to be placed on the photoplot quadrat for this to be possible.

2) ***Possibility for CS Protocol to be applied at other Southern California sites***. The intention of the CS Protocol is to allow for its framework to be applied to existing MARINe sites or new sites created specifically for CS monitoring. By including the most abundant categories from COP (the field test site) and CARP (the next closest site) there is a higher potential that this analysis includes a broader range of other abundant categories at sites in Southern California. However, it is highly recommended to analyze abundant categories on site-specific levels, even within Southern California. This would be an imperative step for sites north of Point Conception as intertidal assemblages greatly differ from those south of the Point (Raimondi et al., 2006).

PART 2: PROTOCOL ITERATIONS THROUGH FIELD TESTS

The goal of field-testing the CS Protocol was to test the efficiency of data collection by volunteers at a MARINe intertidal site. Ultimately, the protocol is aimed to yield results with accuracy akin to that of a MARINe survey, but with less precision due to modifications necessary for citizen science. Protocol iterations tested and emphasized different protocol components. All volunteer-collected data were compared to data collected by professionals.

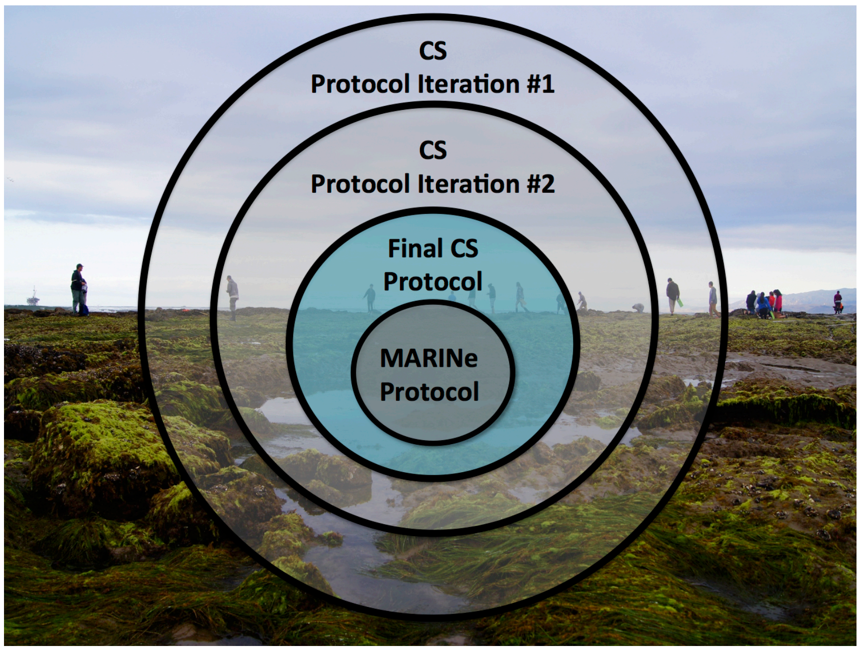


Figure 4. Protocol iteration diagram. Each iteration tested different characteristics of the protocol components. Volunteer-collected data were compared to data collected by professionals.

The final version of the CS Protocol was achieved by first examining the current MARINe protocol, both in writing and in practice in the field. Next, the CS species categories selection provided initial insights into which components of the MARINe protocol could be included, and the extent to which those components should be simplified for citizen scientists.

Once the initial design of the CS Protocol was created, it was first tested by the Bren student researchers at COP, and then by CS volunteers over multiple low tide field days. Over the course of three months of field tests, the protocol was adjusted based on its effectiveness in achieving accuracy, clarity of instructions, and time efficiency (Figure 4). Three major edits were made to the protocol, and are referred to as Iteration 1, Iteration 2 and Iteration 3. See Table 1 (page 23) for the differences between each protocol iteration.

A major component that was maintained throughout all protocol iterations was the input of collected data through Google Sheets. Citizen scientists recorded transect data directly into Google Sheets while in the field. This served as a means to maximize the efficiency of data flow both in the field and for data analysis. Google Sheets allows for the data to be recorded, saved, and accessed instantly upon entry. Prior to the field day, the volunteers were asked to download the Google Sheets app on their smartphone so they could access the spreadsheets for data entry in the field. Copies of the spreadsheets were made in tabs with each volunteer's name to prevent people from accidentally overwriting another volunteer's data. Paper copies of the data sheets were available in the field, however only two participants opted for this data entry method. Use of Google Sheets through Google Drive could be maintained in future applications of this protocol. Google Sheets also served as a way to explore the idea of using a smartphone app for citizen science data collection in the future.

Table 1. Protocol iterations. Over the course of three months of field tests, the CS Protocol was adjusted based on its effectiveness in achieving accuracy, clarity of instructions, and time efficiency. Specific objectives for each iteration of the protocol are outlined, followed by the professional data collected during each iteration. Finally, specific changes made to each protocol component over time are outlined.

	Protocol Iteration 1	Protocol Iteration 2	Protocol Iteration 3
Objectives	▪ Conceptualized CS Protocol in the field ▪ Tested field materials ▪ Gathered first set of data for Surfgrass transect (SG3) ▪ Tested data input in smartphone ▪ Measured time and difficulty of finding bolts ▪ Measured time to complete entire survey of the site	▪ Prioritized data collection for SG3 to make results more robust ▪ Tested field guide ▪ Tested data input on smartphones in the rain ▪ Measured time for transect completion ▪ Explored role and responsibility of Site Leader	▪ Continued prioritization of data collection for SG3 ▪ Standardized Site Leader role ▪ Field guide was made accessible to CS ▪ Standardized information to CS ▪ No further changes were made
Expert Data	▪ No professionals available ▪ Data were compared to MARINe's 2015 data	▪ Two field technicians working with the PISCO biodiversity study at UCSB's Marine Science Institute scored SG3 using the CS field guide	▪ MARINe professionals over the course of 5 weeks
Components Tested	▪ Located bolts ▪ Photoplot (M1 – M5) ▪ Transect (SG3) ▪ Sea star search ▪ Site survey (360° photos of site) ▪ Google Sheets data input	▪ No bolt search ▪ Photoplot (M1 – M5) ▪ Transect (SG3) ▪ Sea star search ▪ General briefing for all components ▪ Site Leader used discretion during field collection	▪ All components tested ▪ Designated role for Site Leader

	Protocol Iteration 1	Protocol Iteration 2	Protocol Iteration 3
Transect	▪ Verbal instructions were given ▪ Photos of 10 CS species categories were provided ▪ Red Algae was still included as its own category	▪ Verbal and written instructions were given ▪ Red Algae was lumped into a general Seaweed category ▪ Site Leader role was created	▪ Practice on SG1 before scoring SG3 ▪ Site Leader role was defined ▪ Google Sheets orientation before beginning protocol
Photoplot	▪ Tested photographs with and without umbrella shading ▪ Smartphone cameras were used ▪ Written instructions were provided	▪ Use of umbrella was maintained to standardize lighting within quadrat ▪ Site Leader gave verbal instructions in addition to written instructions	▪ Photographs of protocol actions accompanied written instructions ▪ Analogy to "depositing a check with a mobile phone" helped volunteers
Species of Concern Search	▪ At least one pair of volunteers was assigned ▪ Volunteers set timer for 30 minutes ▪ Site boundaries were not well defined	▪ Verbal and written instructions ▪ Site boundaries were defined	▪ Written instructions ▪ Site boundaries maintained
Site Survey	▪ Not tested by volunteers ▪ 360° and elevated photo ▪ Compass was not used ▪ Labels were included in photos	▪ Not tested due to prioritization of photoplot and transect data	▪ Well defined written instructions ▪ Compass was used ▪ General survey information collected
Field Guide	▪ Photos of 10 CS species categories ▪ Field map ▪ Google Sheets tested ▪ First draft of written instructions for all protocols	▪ Photos of updated CS species categories ▪ Field map ▪ Re-formatted Google Sheets to fit to smartphone design ▪ Maintained first draft of written instructions ▪ Post-field survey administered	▪ Maintained photos of CS species categories ▪ Field map ▪ Maintained Google Sheets format ▪ Updated written instructions for all protocols based on questions received from volunteers ▪ Final field guide design addressed anticipated questions

Chapter 7: Citizen Science Accuracy Results & Discussion

This chapter reports and discusses the quantitative and qualitative results from measuring the accuracy of each of the four CS Protocol components: transect, photoplot, site survey, and species of concern search.

From November 25, 2015 to February 21, 2016, different protocol iterations were tested at Coal Oil Point in Isla Vista, California. Protocol iterations tested and emphasized different aspects of the four protocol components. Table 1 in "Chapter 6: Methodology" (pages 23-24) summarizes the changes that were made for each protocol. It is important to note that Iteration 3 was adopted as the final CS Protocol because it yielded acceptable accuracy results. Iteration 3 was then tested over the course of three low tide cycles.

Measuring Transect Accuracy

Data were collected by citizen scientists and professionals, using the transect methodology from the CS Protocol (citizen science) or the MARINe protocol (professionals) for accuracy comparison. All data were collected at MARINe's Surfgrass Transect #3 (SG3) at Coal Oil Point.

FIELD TESTING THE CS PROTOCOL ITERATIONS

The Iteration 1 field test was conducted on November 25, 2015. The low tide of -1.1 ft occurred at 3:25 PM. Iteration 1 had a small sample size (n=4 citizen scientists), however, there was low variation between citizen scientists (Figure 5). Additionally, similar results were observed between citizen science and professional scoring.

Iteration 1 was the preliminary field trial with volunteers. Despite being a preliminary version of the protocol, this iteration was valuable to establish a baseline for future testing. It demonstrated CS capabilities in scoring species categories with comparable accuracy to professionals. The priority of Iteration 1's experimental design was to see if all protocol components could be completed during a low tide cycle. Thus, SG3 results were not as robust for this iteration as they were for subsequent iterations. Of the eight participants in the field, only four tested the transect component of the protocol. In subsequent field tests, SG3 scoring was prioritized to provide a more robust data set for volunteer accuracy comparisons.

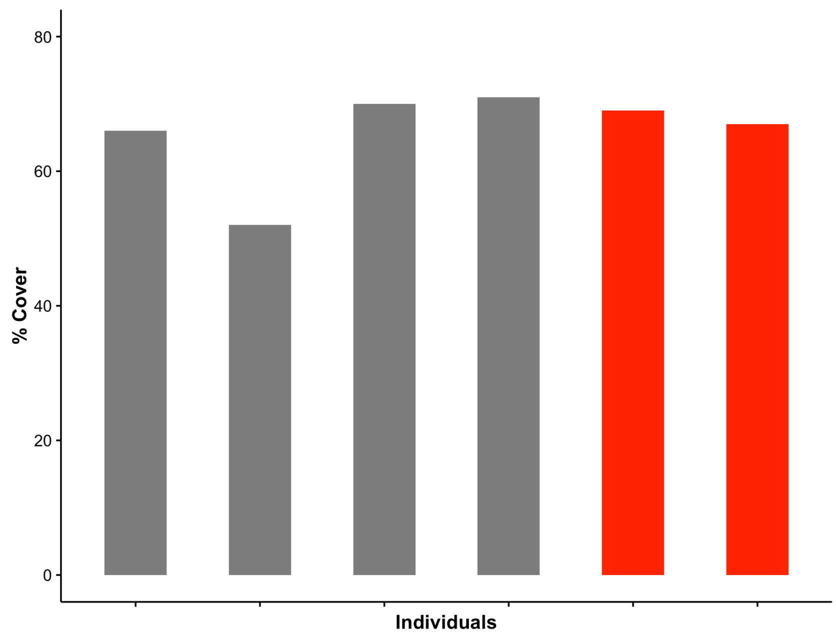


Figure 5. Iteration 1 results for Surfgrass percent cover of SG3. Grey bars represent citizen scientists (n=4). Red bars represent professionals (n=2).

The Iteration 2 field test was conducted on January 9 and 10, 2016. The low tides were -1.04 ft at 3:39 PM and -1.12 ft at 4:15 PM, respectively. Data from this iteration, shown in Figure 6, were aggregated between the two days to increase the sample of volunteers (n= 13). Iteration 2 proved to have more variation between citizen scientists when they were compared to each other, as well as when citizen scientists were compared to the professional. It is speculated that the high variation was due to a lack of standardization of instructions before participants conducted the transect protocol. For example, one individual scored less than 20% cover because it was unclear to her how to score Surfgrass in the water of a tide pool, as opposed to laying on dry rock. Based on field notes, this was due to a miscommunication between the volunteer and the Site Leader of the day. See "Chapter 5: The Citizen Science Protocol" for a discussion on the role of the Site Leader. Additionally, this factor proved even more significant when analyzing all data collected from this iteration. Four CS volunteers scored under 40% cover. A comparison of points along the transect revealed that a tide pool with water consistently covering approximately 30 points each field day contributed to this exceptional variability. Additional qualitative results showed that volunteers had more difficulty, and thus more variability, when scoring over water than on hard substrate. Moreover, water increases Surfgrass movement, and thus changes the composition of the transect.

There are several qualitative results that can be gleaned from Iteration 2. First, the weather for both field days proved to be challenging. Windblown sand and rain made it difficult for volunteers to input data into the Google Sheets app on their smartphones. This added some adversity to CS data collection, and possibly contributed to increased variation. It is important, however, to keep in mind that some variation is a reality of working in the intertidal. Second, the role of Site Leader was not standardized, resulting in volunteers receiving mixed messages. Lastly, volunteers did not receive standardized briefings for each protocol component. Overall, Iteration 2 provided important lessons that helped design Iteration 3, particularly in standardizing protocols in the field guide and designating responsibilities for the Site Leader.

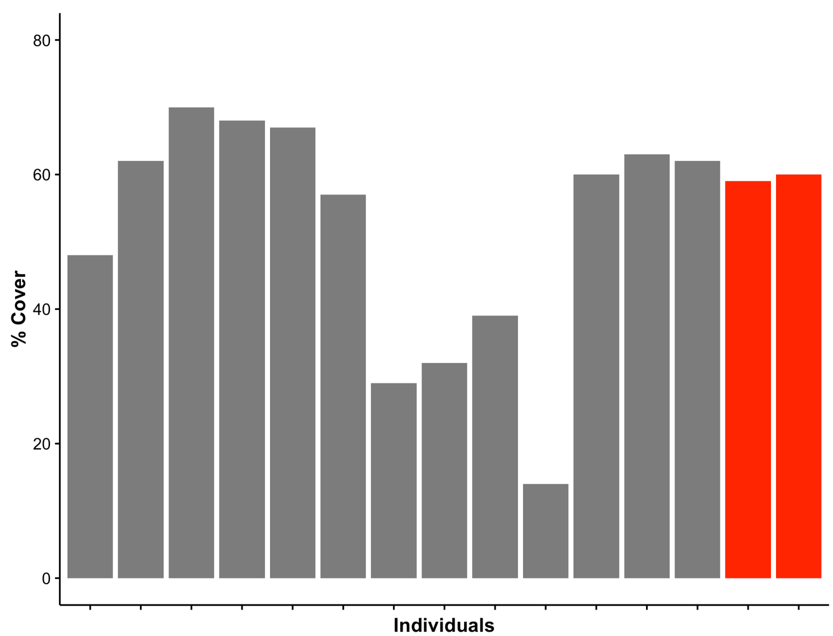


Figure 6. Iteration 2 results for Surfgrass percent cover of SG3. Grey bars represent citizen scientists (n=13). Red bars represent professionals (n=2).

The first field tests of Iteration 3, shown in Figure 7, were conducted on January 21, 23, and 24, 2016, with low tides of -1.08 ft at 2:25 PM, -1.13 ft at 3:41 PM, and -0.95 ft at 4:15 PM, respectively. Data were aggregated between these three days (n=19). Less variation was observed between citizen scientists as well as between citizen scientists and professionals. Several changes to the protocol may have contributed to this decrease in variation. First, the standardization of the transect briefing and clarification of confusing factors in the actual scoring of categories mostly contributed to this decrease. Additionally, volunteers practiced the transect protocol by scoring along a different transect line (SG1) before collecting data on the SG3 transect. Again, the three values under 40% were caused by the same tide pool referred to in Iteration 2, reinforcing the difficulty of scoring in the dynamic intertidal zone.

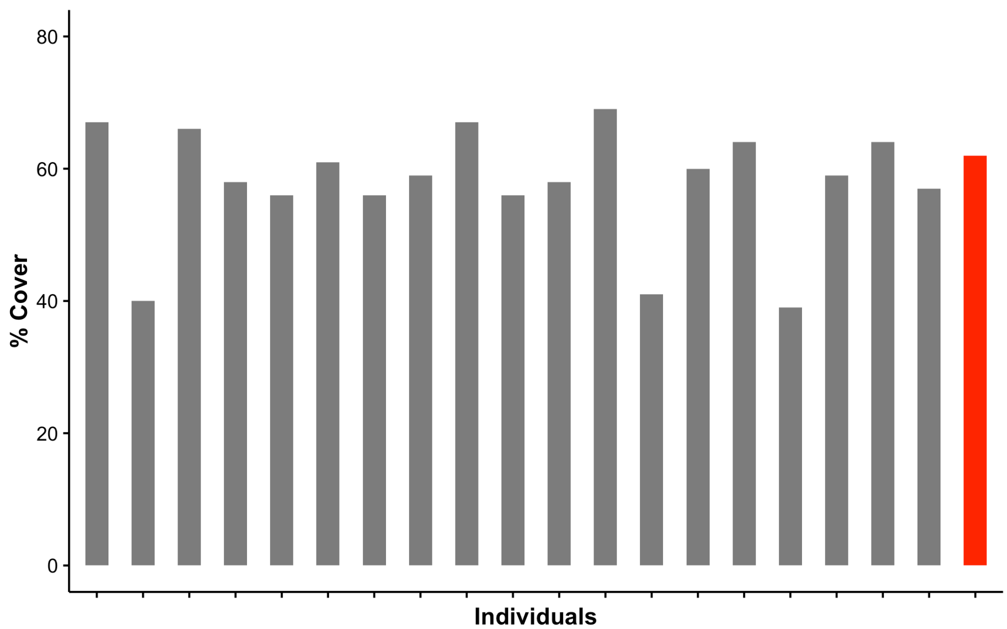


Figure 7. Iteration 3 results for Surfgrass percent cover of SG3. Grey bars represent citizen scientists (n=19). Red bar represents professionals (n=1).

FINAL CS PROTOCOL

The results of the accuracy of citizen scientists from Iteration 3 were satisfactory, and thus, this protocol version was adopted as the final CS Protocol and then further tested in the field. Field tests were conducted on February 6, 7, and 21, 2016, with low tides at -0.95 ft at 2:40 PM, -1.15 ft at 3:14 PM, and -0.71 ft at 3:17 PM, respectively. The results are the aggregation of data collected from multiple tests of Iteration 3.

While checking for normality, data from each field test did not meet the assumptions required for a Student's t-test. Therefore, a nonparametric, one-sample t-test for unpaired data, the One-Sample Wilcoxon Single Rank Test (UNM, n.d), was conducted to test for differences in scoring between citizen scientists and professionals. The results of this test at a 95% confidence interval showed no significant difference ($p > 0.05$) between the median percent cover scored by CS and the professionals (see Table 2 below). This result suggests that even though data from Tests #1 and #2 of Iteration 3 were collected on different days, the dynamics of the intertidal did not influence the results. Due to this last conclusion, all tests were aggregated to provide a more statistically robust set of data.

Table 2. Summary result of non-parametric t-test (Wilcoxon).

	Test 1	Test 2	Test 3
P-value	0.09	0.08	0.08
Test Statistic	52	114	42
n	19	17	15

Results from all field tests of Iteration 3 were aggregated (n=51) and compared to the mean score of professionals who went to the field in the same period (n=3) (Figure 8). This aggregation was based on three assumptions: 1) the protocol was identical in each field test; 2) the professional score was considered to be the true value of the Surfgrass percent cover; and 3) the environmental dynamics of the intertidal did not affect the test results.

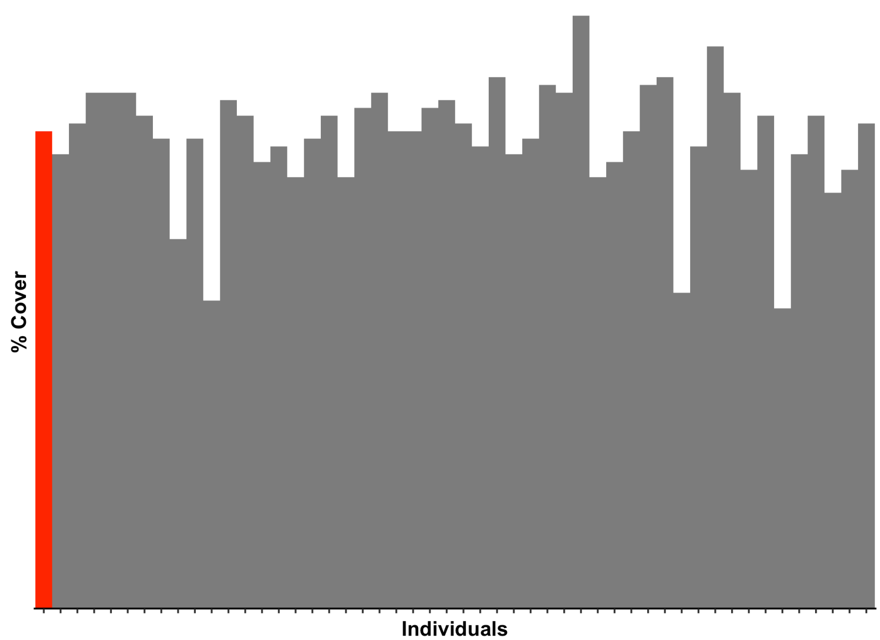


Figure 8. Final Protocol results for Surfgrass percentage cover of SG3. Grey bars represent citizen scientists (n=51). CS data from 3 test cycles were aggregated. Red bar represents professionals (n=1). Professional score was averaged from 3 professionals.

The result of the One-Sample Wilcoxon Signed Rank Test showed no significant difference between volunteers and professionals at SG3 (W=581.5, n=51, p=0.95). Though this proves to be a promising result for CS accuracy, the assumptions required further testing, specifically the third assumption concerning environmental variability.

To check whether the dynamics of the intertidal affected accuracy results, a One-Way Analysis of Variance (Stats The Way I Like It, n.d) was performed. This test compared the mean value of each of the three CS Protocol tests to determine if the values were significantly different from each other. The results were reinforced by a nonparametric version of the same test, a Kruskal-Wallis Rank Test (Stats The Way I Like It, n.d). These results showed significant difference between sample means (ANOVA=$F(2,48)=5.53$, $p=0.006$, $\alpha=0.05$; Kruskal-Wallis=$\chi^2= 9.17$, df=2, p-value=0.01). The post-hoc test (Tukey's HSD for ANOVA, and multiple comparisons for Kruskal-Wallis) only showed significant differences between Test #1 and #3, for both types of tests (Table 3), but no significant differences between Test #1 and Test #2, or between Test #2 and Test #3. The results suggest environmental dynamics of the intertidal strongly influence nonparametric t-test results and may have biased previous results. This does not discredit the findings, but perhaps instead points out the importance of considering environmental dynamics of the intertidal habitat when evaluating CS accuracy in the intertidal.

Table 3. Post-hoc test summary for ANOVA (top) and Kruskal-Wallis (bottom). Data from Surfgrass percent cover in SG3 suggest significant difference between Field Test #1 and Field Test #3 ($p < 0.05$), but not between #1 and #2 or #2 and #3. * Statistically significant

	Dif.	Lower	Upper	p-adjusted
Test #2-Test #1	3.5	-1.98	8.97	0.300
Test #3-Test #1	7.8	2.13	13.46	0.004*
Test #3-Test#2	4.3	-1.51	10.10	0.180

	Obs. Dif.	Critical Dif.	Difference
Test #2-Test#1	5.49	11.88	FALSE
Test #3-Test#1	15.43	12.29	TRUE*
Test #3-Test #2	9.95	12.60	FALSE

CITIZEN SCIENCE ACCURACY RANGE SCENARIOS: A NON-STATISTICAL COMPARISON

Another way to account for data quality in a comparison between CS and professionals was to create accuracy range scenarios. The scoring scenarios were established based on 5%, 10%, and 15% ranges above and below the mean professional score of Surfgrass percent cover of SG3 (Figure 9).

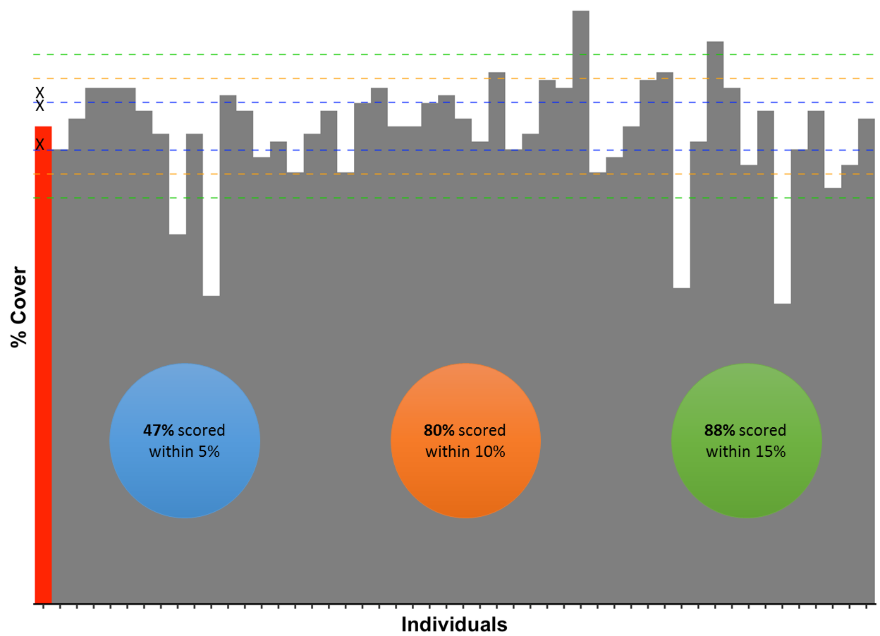


Figure 9. Final Protocol results for Surfgrass percentage cover of SG3 under three different scenarios. Grey bars represent citizen scientists (n=51). Red bar represents the mean professional value (n=1). Black X's represent individual professional values that were averaged together (n=3). 47% of CS scored within 5% range from the professional mean. 80% of CS scored within 10% range from the professional mean. 88% of CS scored within 15% range from the professional mean.

The most conservative scenario includes those individuals who scored within a 5% range of the professionals' mean score. The analysis shows that 47% of CS scored within 5% of the professional mean. While this is not the majority of the volunteers, this number is important for several reasons. First, it demonstrates that citizen scientists are capable of scoring within a close range of accuracy to professionals. It is possible that with more field training, a higher percentage of participants could reach this high standard of accuracy. However, it is more likely that the dynamics of the intertidal habitat played a critical role in this disparity, and thus perhaps the 5% range is too precise of an accuracy scenario for the ever-changing intertidal habitat. See Figure 13 and the accompanying text for more detail on the environmental variability of the intertidal habitat. This hypothesis is supported by the fact that the score of one of the three professionals also does not fall within the 5% range of the professionals' mean.

The next most conservative scenario includes CS participants who scored within a 10% range of the professionals' mean score. The analysis shows that 80% of CS participants scored within this range. This is consistent with the first test of the final protocol (Figure 7). This is important because it shows that the protocol design can achieve a 10% accuracy range regardless of the sample size.

Finally, little change occurs between the 10% and 15% accuracy range scenarios. The analysis shows that 88% percent of CS participants scored within a 15% range of the professionals' mean. Ultimately, MARINe or other organizations using the protocol will have to determine the acceptable range of accuracy. Based on these results, the 10% accuracy range is the most plausible and conservative scenario achievable for the CS Protocol.

It is important to note that only a few discrepancies in percent cover can yield major variation in scores. For example, 10% cover of Surfgrass in SG3 represents 6 out of 100 points, which is a narrow margin of error. Numerous confounding factors can lead to this, such as water movement, previous scoring disturbances, and general environmental variability.

In both the MARINe professional survey and the CS Protocol, the percent cover of the target species is used to track changes at the site over time. The target species is Surfgrass at Coal Oil Point. Professionals track 50-60 species that occur with the Surfgrass habitat, whereas citizen scientists score 11 CS species categories.

Figure 10 shows the median percent cover of the categories that were scored in addition to Surfgrass on Transect SG3. Only 6 of the 11 CS species categories were present on the transect during sampling events conducted by CS and professionals.

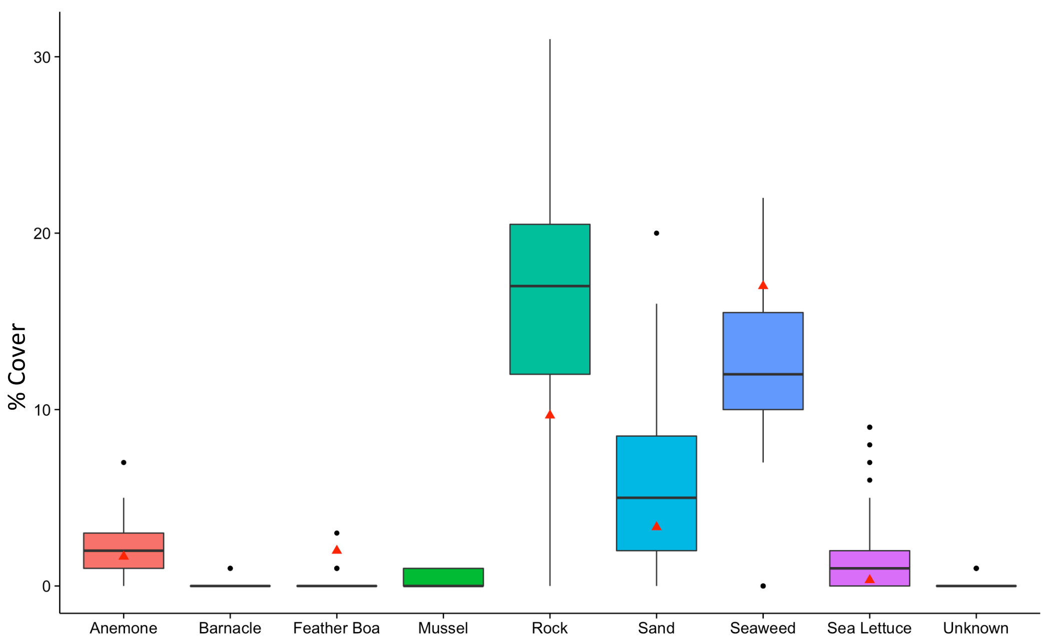


Figure 10. Percent cover of CS species categories for SG3. Surfgrass is not represented. Black dots represent outliers. Colored boxes represent the majority of the scores. Vertical lines represent the entirety of the range. Thick horizontal lines represent the median. Red triangles represent the professional score for that low tide cycle.

Citizen scientists and professionals scored similarly for Anemone, Feather Boa, and Sea Lettuce. However, the professional score was on the upper 25% quartile for Seaweed and the lower 25% quartile for Rock. Additionally, Rock and Sand had the most variability. As previously mentioned, the tide pool in the SG3 contributed to this variation. As the Surfgrass moved naturally with the tidal currents or when participants put their hands or feet in the pool, the volunteers most often scored Rock or Sand, providing a plausible explanation for the variation. A comparison of individual datasheets further supported this fact.

Citizen scientists scored all of the same categories that the professionals also scored. There were few identifications of categories that were not likely to be present on the transect, like Mussel and Barnacle. The inclusion of an Unknown category helped to prevent misidentifications. Citizen scientists appeared to be comfortable scoring what was present on the transect with the information provided in the field guide and knowing they could choose Unknown if they were unsure about the species.

Bootstrapping

In order to determine how many citizen scientists would be needed to accomplish a satisfactory sampling of an intertidal site, the data were bootstrapped to develop a Monte Carlo-type model. For each scenario, a number of volunteers (from 2 to 10) were randomly selected. One thousand simulations for each combination of citizen scientists were completed and the results were plotted (e.g., 1000 means of two citizen scientists, 1000 means of three citizen scientists, etc.). The scores were then compared to the accuracy range scenarios (5%, 10%, and 15%) that were previously described.

Figure 11 shows the results of the simulations and marks the limits of the professionals within a 5% range. In this case, even using 10 citizen scientists to score a site would not result in confident accuracy results. With this scenario, there is no proof to support a CS Protocol with enough accuracy to reach a 5% range of the professionals. However, future field tests and increased volunteer training could potentially achieve this range scenario.

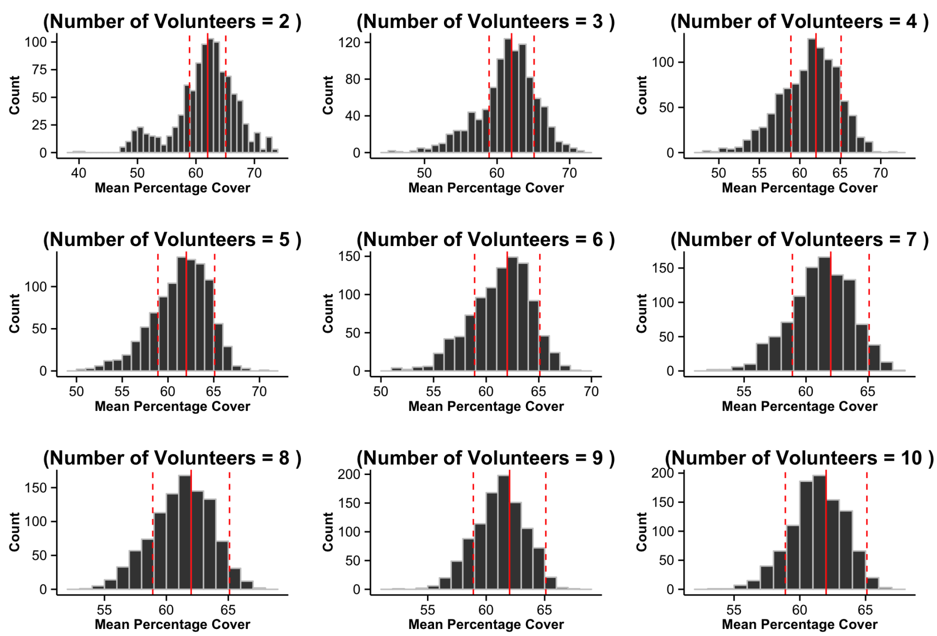


Figure 11. Simulation results plotted against a 5% range from professionals. Dotted red lines represent ±5% limits from the mean. Solid red line represents the professional mean. Number of volunteers represents the amount of scores randomly selected with replacement from the total number of volunteers (n=51).

Based on previous results, it is believed that the 10% accuracy range scenario is most achievable for the CS Protocol (Figure 12). The bootstrapping results for this scenario further support these results. This scenario could be achieved with a minimum of four citizen scientists. This result is based on the fact that 95% of results were within the scenario limits. It should be mentioned that using only four citizen scientists could result in some chance of having unsatisfactory scores. However, this chance is very small (less than 50 tryouts out of 1000 simulations). If the CS Protocol user desires less uncertainty from volunteer data, then nine volunteers would be required to achieve the highest accuracy rate.

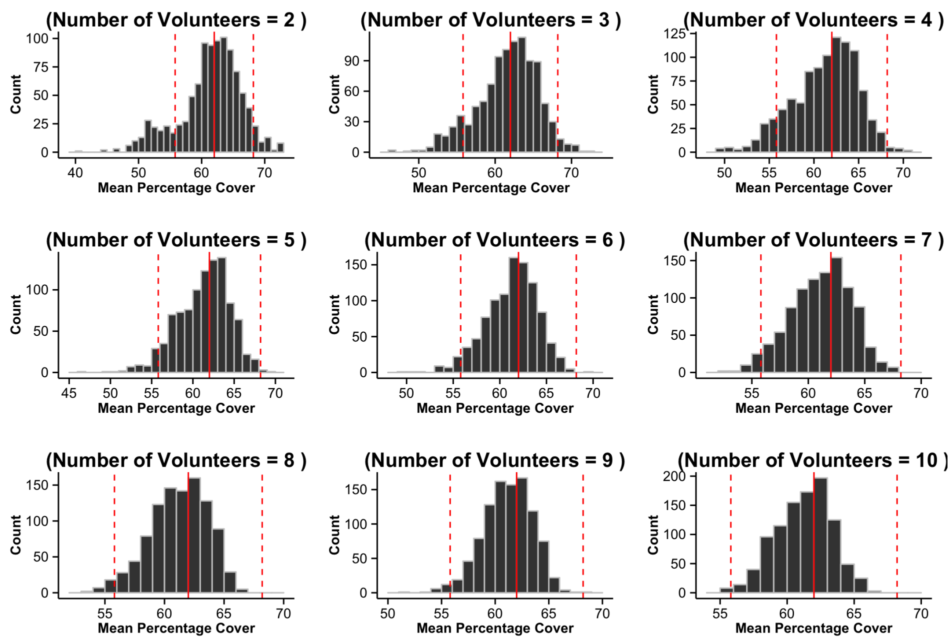


Figure 12. Simulation results plotted against a 10% range from professionals. Dotted red lines represent ±10% limits from the mean. Solid red line represents the professional mean. Number of volunteers represents the amount of scores randomly selected with replacement from the total number of volunteers (n=51).

Finally, the least conservative scenario uses an accuracy range of 15% from the professionals' mean (Figure 13). Simulations suggest that using five volunteers would yield 100% of results within that range. It is worth mentioning that for this case, using two volunteers would result in less than 50 failed tryouts (out of 1000).

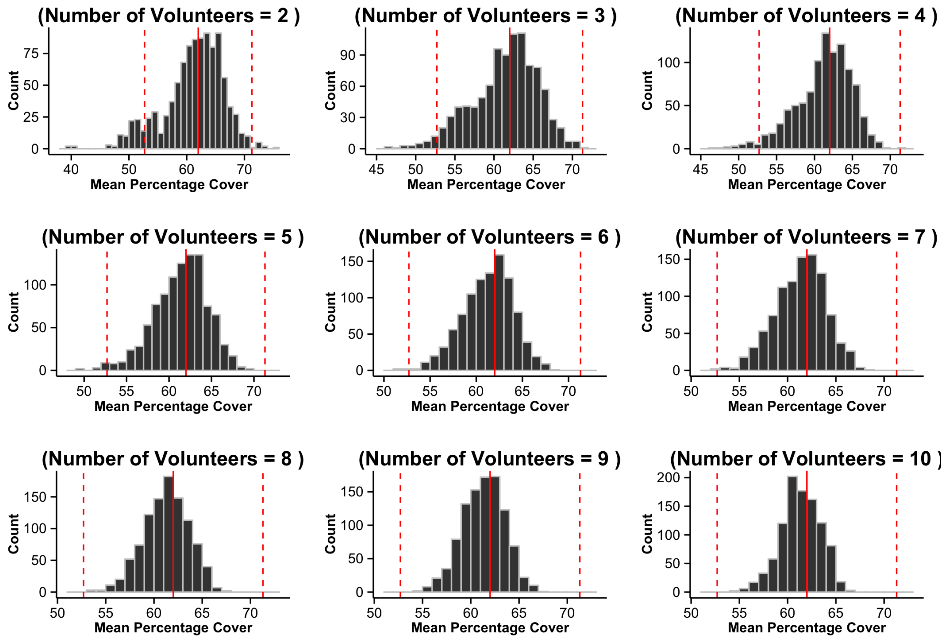


Figure 13. Simulation results plotted against a 15% range from professionals. Dotted red lines represent ±15% limits from the mean. Solid red line represents the professional mean. Number of volunteers represents the amount of scores randomly selected with replacement from the total number of volunteers (n=51).

To summarize these results of the transect accuracy analysis:

The protocol is best fit to work under the 10% accuracy range scenario.

This protocol was designed to minimize task loading of volunteers and Site Leader to achieve efficiency and data quality. The bootstrapping results for this scenario suggest that four volunteers should be enough to complete the CS Protocol to an acceptable accuracy. Field observations suggest that the implementation of a field survey with more than 10 volunteers will compromise the ability of the Site Leader to manage data quality. Hence, it is strongly recommended that protocol users employ a **minimum of four and maximum of 10 citizen scientists** to conduct field surveys. It is most likely that this number could narrow as volunteers gain experience with the protocol.

The 10% accuracy range scenario was also evaluated in regards to MARINe's historical data (2003-2011) for Transect SG3 at Coal Oil Point (Figure 14). It was determined that if citizen scientists used the CS Protocol during this time period, major changes in Surfgrass percent cover could have been detected.

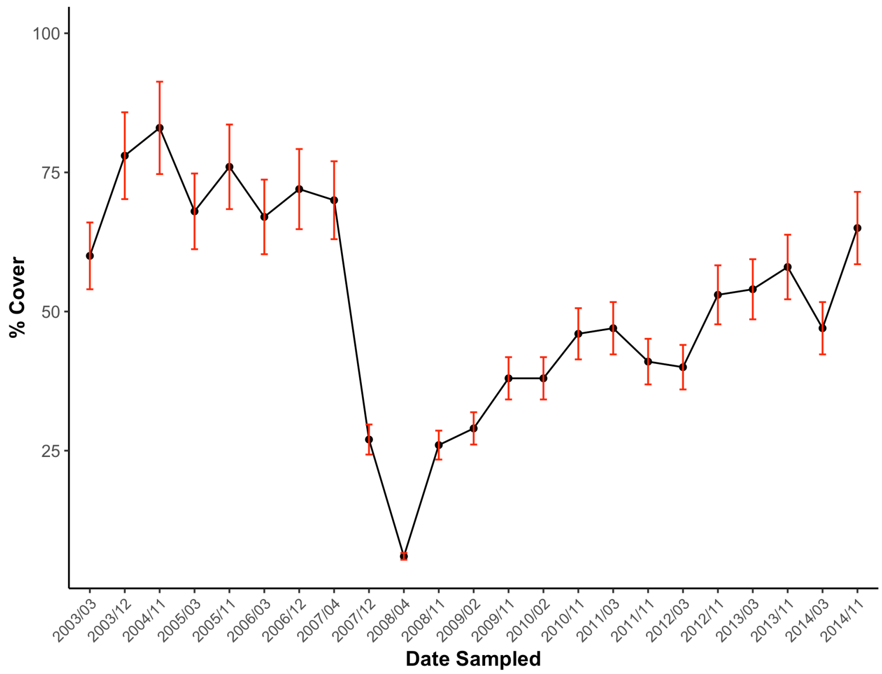


Figure 14. Surfgrass percent cover in SG3 scored by MARINe professionals between 2003 and 2014. Red bars represent the (hypothetical) CS 10% range scenario. X-axis represents the date (year/month) of sampling (two per year, except for 2004).

When looked at on an annual scale, volunteers could have identified changes in percent cover for 7 of the 11 years examined. Though they would not have been able to provide as exact of a result for the other four years, their scores would have correctly suggested that COP was not experiencing major change during those years. Professionals surveyed COP twice per year from 2003-2011 (except for 2004). When overlaying the 10% accuracy range scenario over these biannual surveys, it was found that CS could have helped identify 10 seasonal changes. Like the annual assessment, the other 13 periods would show no major change. Therefore, this analysis supports the conclusion that CS could identify *major* changes in the intertidal zone, defined as *any percent cover change larger than 10% from one sampling period to the next.*

Even though the CS Protocol has shown to achieve a 10% accuracy range in field tests and historical analysis, there are some limitations in using this range when making comparisons between the data collected by the volunteers and the professionals. As the percent cover of a species increases, there is a wider margin of error for comparison between citizen scientists and professionals. However, if the percent cover is small, there is a narrow margin of error.

For example, had the 10% accuracy range been applied in November 2005, citizen scientists could have misidentified 10 points along the transect and could have still been included in the 10% accuracy range because there was a high percent cover of Surfgrass (76%). However, in 2008, Surfgrass cover was drastically lower (less than 20%). Therefore, citizen scientists would have had to score nearly perfectly when compared to the professionals. Due to the small margin of error with such a low percent cover, a small discrepancy between the citizen scientists and the professionals could flag a major change. Because of this, it is strongly recommended that the CS species categories are initially chosen based on a high historical abundance at the site. By choosing categories with higher percent cover, the chances of this discrepancy can be minimized.

PHOTOPLOT ACCURACY: METHODS, RESULTS, & DISCUSSION

METHODS

The Site Leader set up the California mussel (*Mytilus californianus)* photoplot prior to volunteers arriving to the field. A field guide with written instructions and photographs was provided for volunteers (see "Appendix A: Field Guide").

A large umbrella was provided for volunteers to shade the photoplot quadrat so the lighting would be standardized for the photos. Volunteers were asked to take photos of each quadrat located between orange marker cones. One volunteer shaded the plot with the umbrella while another took a photo with the quadrat label oriented in the upper left corner of the photo frame. The volunteers were asked to make sure the photo met a specific set of criteria (see below).

RESULTS & DISCUSSION

The quality of photographs of the Mussel photoplots, quadrats M1-M5, was assessed using a scoring system that ranged from 0 to 5 (Figure 15). Photographs were scored based on the following five criteria:

1) Entire quadrat is shaded by the umbrella

2) Entire quadrat is visible

3) Minimal space outside the perimeter of the quadrat

4) Photograph taken from a "bird's eye view"

5) Photograph is focused

A

B

C

Figure 15. Citizen science photoplot ranking, shown in photos. (A) Umbrella used to create consistent lighting in the photograph. (B) The photograph is focused, the entire quadrat is visible, and there is minimal space outside the perimeter of the quadrat. (C) Photograph of the quadrat taken from a "bird's eye view".

One point was awarded to the photograph each time one of the criteria was met, so that a perfect photo received a score of 5. Only photos with a score of 5 were considered accurate enough to determine Mussel percent cover. The mean of the photo scores was calculated for each iteration of the CS Protocol to determine if the iteration changes were facilitating the improvement of photo quality.

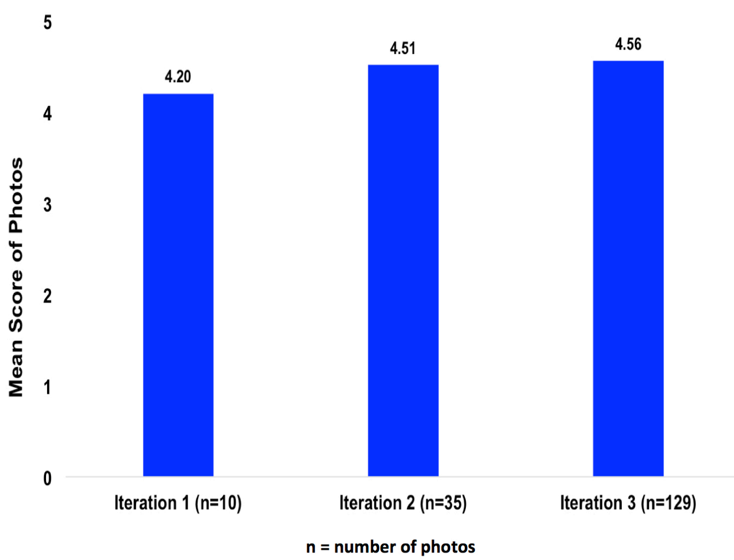


Figure 16. Mean scores of CS photos for Mussel photoplots. Blue bars represent the calculated means of the photo scores for each of the three iterations of the CS Protocol. Numbers above the bars are the calculated means. Photo scores range from 0 to 5.

The mean scores of photos provide a numerical quantification of the quality of photographs taken by citizen scientists. Results show that the overall quality of photographs was high from the beginning, and only increased during the protocol evolution. The mean ranking increased for each iteration from a mean score of 4.2 for Iteration #1 to a score of 4.56 for Iteration #3 (Figure 16). Thus, the quality of CS photographs of the photoplots is sufficient for researchers and the online community to score percent cover of California mussels (*Mytilus californianus*), as several photos received a perfect score of 5.

SITE SURVEY ACCURACY: METHODS, RESULTS, & DISCUSSION

SITE SURVEY – 360° PHOTOS

METHODS

The Site Leader placed an orange marker cone on the R4 marker rock to designate the location for the 360° photos to be taken (see map in "Appendix A: Field Guide"). A field guide with written instructions and photographs was provided for volunteers. Volunteers used the camera and compass app on their smartphones to orient to the N, NW, W, SW, S, SE E, and NE directions, and take photos in that order. Volunteers were instructed to angle the smartphone camera at a 45° angle from the ground.

RESULTS & DISCUSSION

The 360° photos were evaluated to determine whether or not the citizen scientists' photos are sufficient at revealing the intertidal habitat surrounding the R4 marker rock. The photos were assessed based on the following criteria:

1) Photos are in focus

2) Photos reveal the intertidal habitat within a 10 m radius around the marker rock

3) Photos were oriented in all eight of the specified directions (N, NW, W, SW, S, SE, E, NE)

The 360° photos were successful at exposing the intertidal habitat surrounding the R4 marker rock. Volunteers were able to orient to the appropriate directions and take photos at an acceptable angle (approximately 45°; Figure 17).

Figure 17. The 360° protocol component documents the site from a marker bolt. Eight photographs orienting north, northwest, west, southwest, south, southeast, east and northeast taken at 45° angle from the ground.

SITE SURVEY – ELEVATED PHOTO

METHODS

Volunteers were instructed to take a single photo of the site with their smartphone camera from the top of the bluff overlooking the site (referred to as an "elevated photo"; Figure 18). The Site Leader assisted the volunteers to the bluff, where the volunteers captured the entire site in the photo.

RESULTS & DISCUSSION

The elevated photos were evaluated to determine whether the citizen scientists' photos are sufficient at revealing an overview of the site. The elevated photos were assessed based on the following criteria:

1) Photo is in focus

2) The entire intertidal site is visible in the photo

3) Orange marker cones are sufficiently visible in the photo

Figure 18. Example of elevated photo at Coal Oil Point. Four orange marker cones are labeled by white numbers.

Site Survey – General Survey

Methods

Volunteers used their smartphones to record information such as the site name, survey date, and low tide time in a shared Google Sheet. Volunteers used specified codes to describe the observations recorded such as weather, wind, swell, debris, and biological activity. Descriptions of these conditions and characteristics for these terms were provided on the Google Sheet for volunteers to reference when recording.

Results & Discussion

The site details were evaluated to determine whether citizen scientists could complete data entry about the site on a digital field log. The site details were assessed based on the following criteria:

1) Data entry sections are complete

2) Logistical information is correct

3) Data entry terms used are correct

The volunteers were able to successfully access the shared Google Sheet and enter the observational data. The Site Leader often input the low tide time prior to the survey because the volunteers did not have that information readily available. Volunteers had no difficulty entering data and were confident with their observations based on the given descriptions.

Species of Concern Search Accuracy: Methods, Results, & Discussion

Methods

The species of concern search is an important component of the MARINe protocol. It was developed to account for species that were of particular importance to MARINe, but that were not covered by the photoplot or transect protocols. The selection of the species of concern could depend on ecological, economic, or human importance. Invasive species, species with diseases, or species that show extreme biomass changes are some examples of species that could be surveyed with this protocol. In some cases, the species of concern search protocol can address particular species that are covered by other protocols but need special attention.

The Ochre Sea Star (*Pisaster ochraceus*) was chosen as the species of concern for the CS Protocol. Finding individuals in the intertidal is relatively difficult, especially when they are in low abundance. Hence, the main objective of the CS species of concern search protocol is to flag an anomaly, rather than to report an exact number or density of individuals present.

The species of concern search protocol did not change much over the three CS Protocol iterations. Two citizen scientists spent 30 minutes looking for Ochre Sea Stars within a designated search zone. If an individual was found, volunteers measured it with calipers from its center to the end of its longest arm, and recorded its size in the Google Sheet.

RESULTS & DISCUSSION

Results from the species of concern search protocol are mainly qualitative. Throughout the three months of field-testing, there were six incidents where citizen scientists found Ochre Sea Stars at Coal Oil Point. It is important to note that the protocol is not designed to tag individual sea stars, and thus, it is possible that these six incidents are repeat measurements of the same individual(s). It is certain that two of these incidents are two different individuals, as they were found on the same day. However, it is possible that the remaining four incidents were the same sea stars already accounted for, but found on a different day. Though few sea stars were actually found, the species of concern search was one of the most popular components of the CS Protocol. Volunteers enjoyed looking for individuals around the tide pools, and it was a good time to engage volunteers in discussions about the rocky intertidal zone.

Chapter 8: Crowdsourcing

Definition

Crowdsourcing is when an open call is made for contributions from a large, undefined network of people, typically by means of online engagement (Wiggins et al., 2011). This type of outreach can be an important tool used in citizen science programs. Various platforms are used depending on the intended result, including crowdvoting to gather opinions, crowdsearching to locate specific items or services, and crowdfunding to raise funds. Crowdsourcing is commonly used in the research field to obtain data based on observations from the general public.

Methods

An initial study using crowdsourcing was done to test the accuracy of citizen science in identifying the percent cover of Mussels in a photograph. A photo of a Mussel photoplot from Coal Oil Point that was taken by a citizen scientist on a smartphone and received a perfect score of "5" was cropped to show only the inner area of the rectangular quadrat (for photo scoring information, see page 38-39). A red 10 x 10 grid was superimposed over the photo to create 100 points at the intersections of the gridlines.

A survey was created on Google Forms which asked volunteers to identify whether a mussel was present or absent under the point where the gridlines intersected (see "Appendix B: Crowdsourcing Survey"). If a mussel was present under the intersection point, the volunteer recorded "1". If a mussel was absent under the intersection point, the volunteer recorded "0". To minimize recording errors, the picture was shaded so that only one row was clearly visible. This was intended to keep volunteers focused on a single row while scoring. After the volunteer submitted data for that row, the photo on the next page revealed the next row for the volunteer to score, and so on, until all 100 points were scored. All 100 points were then summed to reveal the percent cover of the Mussel photoplot.

Demographic information about the volunteers was collected as well. The survey was distributed primarily via email and social media.

Results

In the two weeks that the survey was posted, 123 responses were received. Of the 123 respondents, 24% were male and 76% were female. The highest age range represented was between 23 to 26 years (39%). Responses were received from people all over the United States and around the world, including California, Hawaii, New York, Washington D.C., Uruguay, Brazil, Mexico, Germany, and Israel. Most respondents said they go to the ocean at least weekly, though 48% said they go to the ocean monthly or less.

The participants identified an average of 53% mussel cover in the photo with a standard deviation of 10. MARINe professionals also scored the same photo, and identified an average of 49% mussel cover with a standard deviation of 1. This demonstrates that crowdsourced data results can reliably approximate professional results, and thus, could help flag changes in percent cover so that professionals can look more closely into what might be happening in the field. The crowdsourcing technique used for this CS Protocol was in a pilot stage. If a crowdsourcing component is to be used with this CS Protocol in the future, the citizen scientists' accuracy could be improved even further with a few minor changes to the survey design based on feedback received from the respondents (elaborated below).

RECOMMENDATIONS

Crowdsourcing has the potential to provide data that are accurate enough to be considered scientifically rigorous (well within a 10% range of the professionals). The key component to achieve this level of accuracy lies in the survey design.

The following are recommendations based on volunteer feedback to improve the survey design:

- Design the webpage so that the photo "floats" down the page as the volunteer scrolls down. That way, the volunteer does not have to continue scrolling up the page to look at the photo and then back down to fill out the score for a particular point. Having the photo right next to the score could minimize recording errors. While this feature is not possible with Google Forms, it could be easily achieved through HTML coding of a website dedicated to data collection for this program.

- Design the webpage so that volunteers can click on the photo to zoom in to get a closer look at what is lying underneath the point. Many volunteers were unsure how to zoom in using their browser settings.

- Use highly visible dots, rather than a grid, to eliminate confusion over whether the volunteer should score what is at the intersection of the gridlines or what is inside the box created by the gridlines.

- To avoid confusion, ask the volunteers to score "ABSENT" and "PRESENT" rather than "0" or "1". This was originally designed so that the responses could be summed and a percent cover could be calculated easily. However, the "IF/THEN" function in Excel could easily turn "ABSENT" into "0" and "PRESENT" into "1", and then a percent cover could be calculated.

Though a survey may be an acceptable platform for this type of data collection, an interactive design could promote even more accurate responses. We have identified Zooniverse (https://www.zooniverse.org/) as a potential platform with an interactive design for MARINe to use to identify mussel cover using the photographs of Mussel photoplots. Zooniverse claims to be the "largest online platform for collaborative volunteer research".

Photos of Mussel photoplots with 100 points superimposed on them can be uploaded to Zooniverse for volunteers from all over the world to score. Rather than marking “ABSENT” or “PRESENT”, a feature in Zooniverse would allow volunteers to click the specific points on the picture that indicate a “present” mussel. Alternatively, volunteers could also trace the outline of the mussels present in the whole photo, which could also provide the percent coverage.

While Zooniverse could be a great interactive platform, BOEM and MARINe should consider if the website’s user agreement is conducive to the agencies’ needs:

> “The major goal for this project is for the analyzed data to be available to the researchers for use, modification, and redistribution in order to further scientific research. Therefore, if you contribute to Zooniverse, you grant the CSA and its collaborators permission to use your contributions however we like to further this goal, trusting us to do the right thing with your data. However, you give us this permission non-exclusively, meaning that you yourself still own your contribution.”

CHAPTER 9: POST-SURVEY

This chapter provides a description of the 77 citizen scientists that participated in this project, and discusses their feedback about their experiences using the CS Protocol to monitor the rocky intertidal zone.

Because this project was created as a group master's thesis project for students at the Bren School of Environmental Science & Management at UC Santa Barbara, most of the volunteers were also master's students from the Bren School. However, 40% of the volunteers were UCSB undergraduates or community members unaffiliated with UCSB.

A post-field survey was administered to all volunteers to find out demographic information and to receive feedback on the protocol design. There was a 51% response rate. From these responses, the following information was gathered:

- Volunteers ranged in age from 18-33 years
- 78% used iPhone models in the field to collect data
- 84% agreed that the photoplot protocol was easy to perform
- 87% agreed that the transect protocol was easy to perform
- 85% said they would consider participating in citizen science programs in the future
- 100% agreed that the experience was enjoyable

When asked what would be the main factors that would motivate them to join a citizen science program, the volunteers responded with these top five answers:

1) Works with schedule
2) Good weather
3) Community building/social activity
4) Knowledge gained/contribution to science
5) Fun!

The following are comments volunteers provided that helped shape protocol iterations:

> *"I think the actual protocol is very easy and straightforward. However, I think the hardest part for people will be finding the bolts. If the cones weren't already set up, it would have been difficult to find the area to start in. Once we found the bolts, taking the pictures and uploading the data is very simple, but finding the bolts was complicated and took too long."*

This comment inspired the creation of the Site Leader role for Iteration #3.

> *"Data entry in Google Sheets might be difficult for some volunteers with less experience or comfort with electronics. Although I understand the need to input data immediately, it might be good to have actual hard copy data sheets available in case some people are more comfortable with that."*

This suggestion was instated in Iteration #2. Though only two people opted to use the paper data sheets, it has been adopted as a recommendation for the CS Protocol.

> *"I felt unsure if some of my Sand and Rock identifications were accurate."*

This was a particularly confusing aspect of the protocol for many volunteers because often, the rock substrate did have a little bit of sand covering it. Therefore, how to identify Rock and Sand was explained more clearly in the field guide in Iteration #3. It was explained that a point should be scored as Sand if the participant's finger could be covered in sand up to his or her first knuckle. If not, then the point should be scored as Rock.

> *"The search for species of concern was probably the easiest protocol for people to understand. I loved this part! It gave us a chance to look around and experience the intertidal zone while we were working. It was like a sea star treasure hunt!"*

Very few changes were made to the species of concern search protocol because volunteers seemed to understand and enjoy it.

The following are comments volunteers provided about their experience using the CS Protocol:

> *"To make this protocol even more effective, the project could use a dedicated monitoring app. Entering data into Google Sheets works, but an app would allow volunteers to upload pictures and fill out data forms without needing to go through Google Drive. However, this is a great application of technology in citizen science!"*

> *"Even though it was extremely windy and cold, it was still a great experience!"*

> *"This could be a great program for community organizations to adopt, or even for reoccurring school field trips."*

> *"It was fun to get outside and enjoy nature! I love citizen science!"*

CHAPTER 10: RECOMMENDATIONS

REQUIREMENTS FOR IMPLEMENTATION

There are three main recommendations for implementation of the CS Protocol at an intertidal site, whether the site is already an established MARINe site or is a new site being considered:

1) Use the prescribed methodology for citizen science species category selection.
   See “Chapter 6: Methodology”.

2) Use permanent survey structures (e.g., bolts, epoxy, other permanent structures).
   See “Chapter 5: The Citizen Science Protocol”.

3) A minimum of 4 and maximum of 10 volunteers are required to survey a site.
   See “Chapter 7: Citizen Science Accuracy”.

The following recommendations are aimed at improving the accuracy of data collected by citizen scientists:

SITE LEADER

The CS Protocol is not designed to be an unsupervised program that allows volunteers to collect data on their own. Analysis shows that having a Site Leader present, as described in “Chapter 5: The Citizen Science Protocol”, improves the accuracy of data collected by citizen scientists. The Site Leader is particularly helpful in finding the permanent bolts, as this task can be difficult for citizen scientists unfamiliar with the site. The bolts are often covered by algae or blend in well with the rock or other intertidal organisms. A metal detector is sometimes needed to find the bolts.

Additionally, a Site Leader can help provide guidance about the CS Protocol should there be any questions from volunteers. Because the intertidal is such a dynamic environment, a well-trained Site Leader would be experienced enough to make decisions regarding protocol execution or species scoring that may confuse a new volunteer. Finally, the Site Leader can also manage the logistics of the sampling event (establishing dates and times, e-mailing and coordinating volunteers, establishing Google Sheets in advance, etc.).

Minimize Task Loading

Analysis shows that the accuracy of the data collected by the citizen scientists improves when volunteers are taught the protocol for each survey component immediately before they are about to perform it, as opposed to all at once. While volunteers' accuracy will increase after repeated sampling events, the CS Protocol is designed so that a one-time in-field training is sufficient enough to promote accurate data collection. The field guide is designed so that volunteers can read through the protocol instructions and see examples of photos right before they are to do a task. This helps increase accuracy of data because the information is fresh in the volunteers' minds, and they can refer back to the field guide if necessary.

Standardize Briefings

In addition to minimizing task loading, the field guide also standardizes the information provided to the volunteers. Analysis shows that having standardized briefings increases the accuracy of the data collected by the citizen scientists. This can especially be seen in the increase of data accuracy collected between Protocol Iteration #2, where standardized briefings were not used, and Protocol Iteration #3, where standardized briefings were used. Standardized briefings ensure that all volunteers are receiving the same protocol instructions regardless of the time or date that they are in the field. This also allows for flexibility of Site Leader assignments, as Site Leaders can rotate duties with confidence that the data collected will not be skewed.

Repeat Volunteers

Even though only a few volunteers came to the field more than once during the duration of this project, the data show that their accuracy did increase each time they repeated the protocol. Therefore, Iteration #3 was adjusted so that volunteers first performed the transect protocol on a test transect before actually collecting data on SG3. Analysis shows that this did help first-time volunteers achieve higher accuracy rates than previous iterations. While it is highly recommended that efforts are made to foster volunteer dedication and prioritize repeat volunteers, the CS Protocol is designed so that even first-time volunteers can achieve an acceptable level of accuracy.

The following recommendations are aimed at simplifying data flow:

Smartphone Technology (Google Sheets or a Citizen Science App)

While there are benefits to using paper data sheets in the field, the CS Protocol was designed to utilize smartphone apps in order to simplify data flow. This CS Protocol used Google Sheets for in-field data input, which eliminated the need for the Site Leader to collect paper data sheets and then input handwritten data onto a computer spreadsheet later. The Google Sheets were organized in tabs labeled with each volunteer's name to prevent volunteers from overwriting previously inputted data. Though Google Sheets was an effective tool for this CS Protocol, the Protocol could also be linked with a citizen science app (such as iNaturalist) in the future.

CROWDSOURCING

Crowdsourcing can provide an effective avenue for analyzing photoplot photos taken in the field. See "Chapter 8: Crowdsourcing" for details on how crowdsourcing was used in this project. The Federal Crowdsourcing and Citizen Science Toolkit (https://crowdsourcing-toolkit.sites.usa.gov) is also a great resource to help establish a crowdsourcing component for the CS Protocol.

CITIZEN SCIENCE SPECIES CATEGORIES SELECTION

Citizen science species categories selection is discussed in depth in "Chapter 6: Methodology". Selection was based on abundance, importance to MARINe, and ease of correct identification. Category selection is a critical aspect in the CS Protocol so that volunteer-collected data appropriately reflect the habitat structure and species assemblages of a site.

This project analyzed the most abundant species between two pre-existing, adjacent MARINe sites. However, analyzing data from more than two MARINe sites, for example, one to the north and one to the south, could also be done. Ultimately, it is most important to take a holistic approach to species categories selection once the abundance data are available. For example, if 20 categories across two or three sites are most abundant, CS Protocol users may need to use the "Importance to MARINe" and "Ease of Correct Identification" specifications to concentrate the categories scored by citizen scientists. The number of categories used in this project should not dictate how many categories other protocol users employ at a site, as each site may be different. **It is recommended to include an "Unknown" category to minimize misidentification.**

ENVIRONMENTAL CONSIDERATIONS

Environmental variability is intrinsic to intertidal monitoring. As described in "Chapter 6: Methodology", volunteer-collected data yielded from this CS Protocol are within a 10% accuracy range of professionals surveying the same site, even with environmental variation. However, to further minimize environmental variation, there are several things to consider:

- **Water in the tide pools:** Qualitative results showed that citizen scientists had more difficulty, and thus more variability, when scoring points on the transect over water than those over hard substrate. While pools of water on a transect can contribute to higher error, they could also help to appropriately discard outliers. It is therefore highly recommended that data collection method over pools of water is standardized and explained to volunteers. See "Appendix A: Field Guide" for the example used in this project.

- **Minimizing subjectivity of scoring:** In tests of this protocol, deciphering between a thin layer and a thick accretion of sand was deemed important to the overall survey of the site. It is therefore highly recommended that very specific variables, such as the scoring of Sand, are clarified in a standardized way. See "Appendix A: Field Guide" for an example of how Sand was scored in this project.

- **Rain and wind:** Data input into smartphones was compromised during rainy and windy weather. Though the CS Protocol is designed to be used with smartphone technology, it is recommended to always have paper copies of the data sheet available in case of poor weather (or poor cell phone reception/limited Internet connection).

FUTURE CONSIDERATIONS

Implementing the CS Protocol at additional intertidal sites is the recommended next step for testing the effectiveness of this protocol. It is recommended to follow the citizen science species categories selection methodology, however, conducting repetitive fields tests to validate volunteer accuracy does not need to be prioritized. Rather, a designated Site Leader (a MARINe professional or highly-trained citizen scientist) should run-through the protocol at the new site prior to volunteer collection. The accuracy results compiled in this document should provide validation that citizen science can achieve accuracy comparable to professionals using the outlined protocol components.

It is particularly important to follow the recommendations of the CS Protocol to determine the CS species categories, as this is a major contributing factor to the volunteers' accuracy rates. It is possible one of the more abundant species at a new site may also be difficult to identify, especially at different life stages. If species that are difficult to identify are included in the CS species categories, further accuracy validation methods (such as additional training) are recommended to maintain the 10% accuracy range this protocol offers.

Additionally, an in-depth analysis of ideal intertidal citizen scientists was not within the scope of this project. Thus, identifying candidates for ideal site-specific citizen science groups would be an important component to consider for future use of this protocol. Ideally, volunteer groups that are already organized and mobilized would be the best users of this protocol.

APPENDIX A: FIELD GUIDE

Site Leader Briefing

Background

- We are from the Bren School and we are working on our master project….
- We are working with the **Bureau of Ocean Energy Management (BOEM)**
    - Manages off-shore energy in federal waters (point to Platform Holly - but that is in state waters).
    - BOEM funds scientific research, including a long-term study to monitor the intertidal habitat.
- BOEM partners with the Multi-Agency Rocky Intertidal Network (MARINe)
    - They have monitored this site (COP) since the late 1990's.
    - We will be using their permanent bolts.

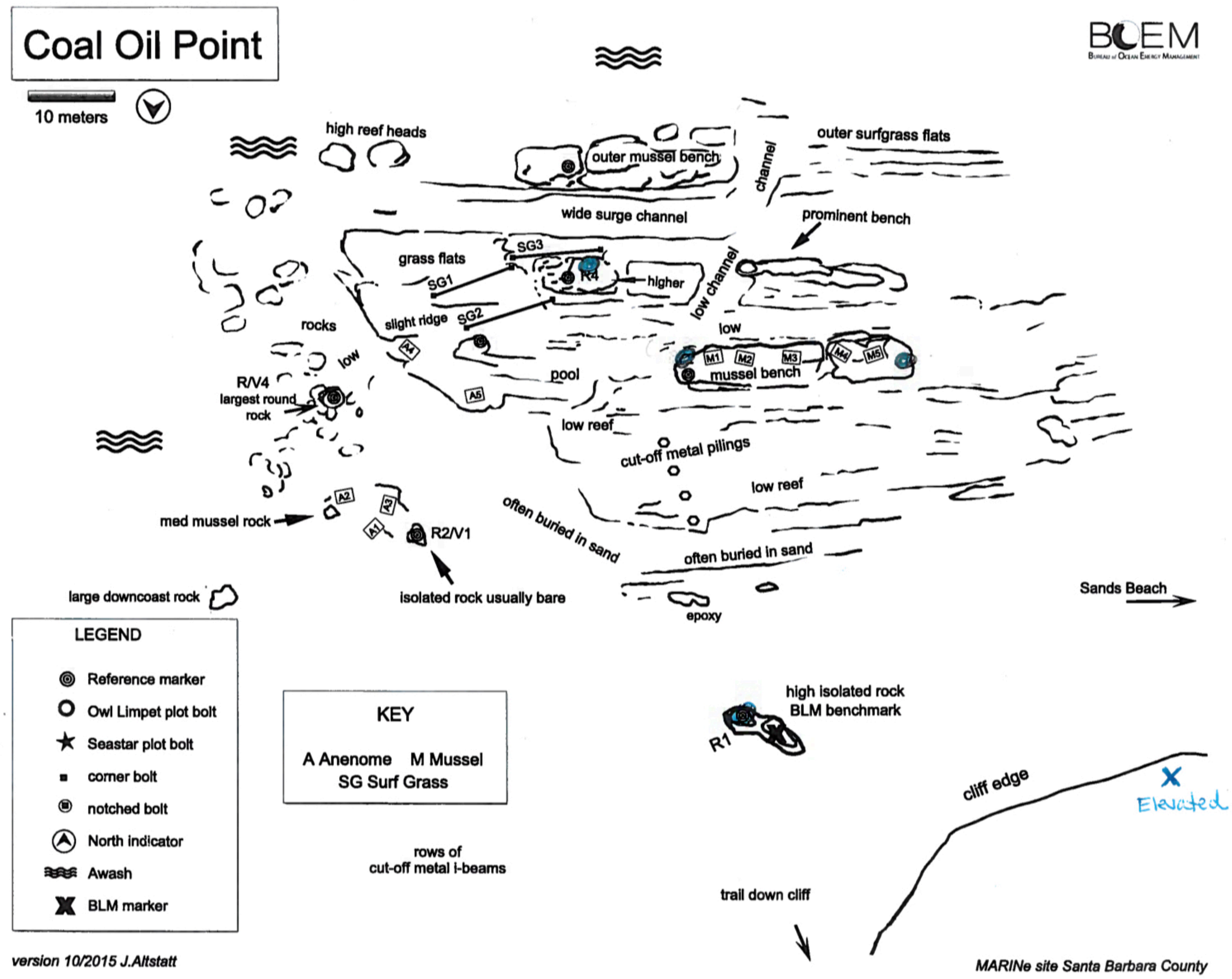
Coal Oil Point

- UC Reserve System
- Campus Point State Marine Conservation Area - No Take Zone
    - That means we can study this area, but we cannot take anything with use, besides pictures.
    - Please be respectful of all marine life that we interact with, including octopus, anemones, and crabs.
    - ***Operation and maintenance of artificial structures inside the conservation base on the appropriate Fish and Wildlife Permits - we are covered under our client's permit.***

Google Sheets and Data Entry

- We have paper if you don't want to use your smartphone.
- Does everyone have Google Sheets? Google Drive, at least at home?
    - TROUBLESHOOT
        - Easier to open spreadsheets from SHEETS rather than DRIVE?
        - Some participants had to go through their email to retrieve the link.
- Ideally, everyone has his or her own phone, but at least every buddy pair.
- Open up the SG3 Transect Sheet (most important)
    - Explain that their names should be on a spreadsheet tab.
        - If it is not, create one now.
    - Data that they score should be recorded under their names.
    - Explain how to type at the (*Fx)* prompt at the bottom.
    - Show how to make the sheet accessible offline.
        - Remember to upload data when you have WiFi again later.

MARINe's Coal Oil Point Site Map



Intertidal Citizen Science:
Coal Oil Point Field Guide

Site Overview

Transect

1. Target (T)

2. Sand (S)

3. Rock (R)

4. Feather Boa (FB)

5. Mussel (M)

6. Barnacle (B)

Intertidal Citizen Science:
Coal Oil Point Field Guide

7. Seaweed (SW)

8. Anemone (A)

9. Gooseneck (GN)

10. Sea Lettuce (SL)

11. Unknown (U)

<u>Species of Concern Search</u>

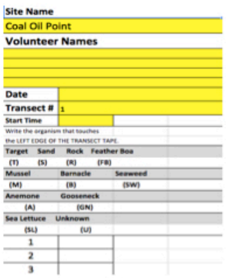
Ochre sea star

<u>Bolts</u>

YES

NO

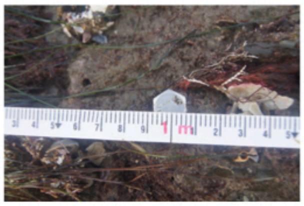
TRANSECT SURVEY

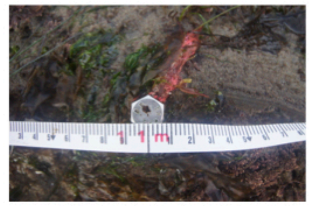

Site Name
Coal Oil Point
Volunteer Names
Date
Transect # 1
Start Time
Write the organism that touches
the LEFT EDGE OF THE TRANSECT TAPE.
Target (T) Sand (S) Rock (R) Feather Boa (FB)
Mussel (M) Barnacle (B) Seaweed (SW)
Anemone (A) Gooseneck (GN)
Sea Lettuce (SL) Unknown (U)
1
2
3

1. Open the transect survey data sheet on the Google Sheets smartphone app and fill out the yellow highlighted fields.

2. Locate the permanent bolts of the Sea Grass transect in between orange cones.

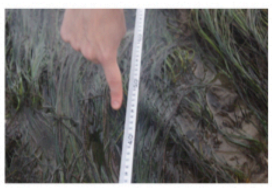
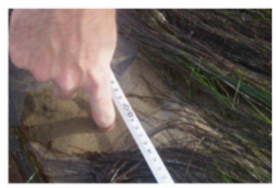
3. Roll out the transect tape so the 1m mark is touching the up-coast bolt and the 11m mark is touching the down coast bolt.





4. **Tape Holders:** Two people will hold the transect tape down at each bolt on the 1m mark and the 11m mark. The tape must be taut to minimize movement while the survey is happening.

5. **Scorer:** One person will identify each organism or category along the transect (up-coast to down-coast) at every 10cm to total 100 points.

Important

a. Identify the category directly below the **left side of the tape at each point.** See Field Guide.

b. **If the tape touches sand,** wiggle your finger down. If sand touches your **first knuckle,** then mark sand (S). Otherwise, mark the category the sand is covering.

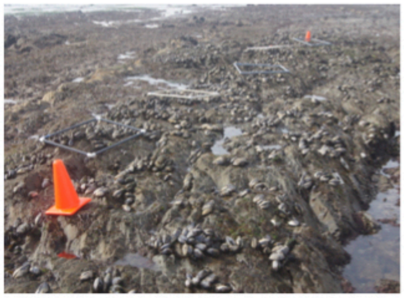
c. **If there is a pool of water covering a section of the transect**, imagine how the categories would sit without the water. Mark the category directly below the tape.

6. **Recorder:** One person will fill-out the data sheet and record all 100 data points on the Google Sheet. See the Field Guide for category codes for data entry as well as on the top of the Google Sheet.

7. Switch roles and repeat scoring at the same transect until all people have had a chance to be the scorer.

8. Repeat these steps to perform this protocol on all transects (SG1, SG2, and SG3).

PHOTOPLOT SURVEY



1. Locate **Quadrat 1** in between orange cones.

2. **Umbrella Holder**: Hold the umbrella to standardize the light in the quadrat.

3. **Photographer:** Orient to the quadrat so the label is in the upper left corner. Make sure the camera is fully zoomed out, directly over the quadrat. Hold phone as if you were taking a picture of a check to deposit it through your bank's mobile app- "a bird's eye view."

4. Before taking the photo, make sure:
   - Entire quadrat is shaded by umbrella.
   - Entire quadrat is visible in photo.
   - Minimize excess space in photo surrounding quadrat.
   - Camera is oriented to "birds eye view."
   - Focus camera (tap the center).

5. Repeat these steps for the remaining four quadrats.

SITE SURVEY					
Site Details					
Site Name					
Survey Date					
Start Time					
End Time					
Low Tide Height					
Low Tide Time					
Recorder Name(s)					
Participant Name(s)					
Physical Observations					
Weather		**Sunny**	**Partically cloudy**	**Cloudy**	**Rain**
Wind		**High** (whitecapped sea surface)	**Medium** (rippled sea surface)	**Low** (smooth sea surface)	
Swell		**High** (high wave activity and high surge)	**Medium** (noticable wave activity and some surge)	**Low** (negligible wave acvtivity and no surge)	
Debris		**Plant wrack**	**Dead animals**	**Oil/tar**	**Trash**
Biological Activity		**Humans**	**Mammals**	**Birds**	
Elevated Photo					
Confirmation					
360° Photos					
Confirmation (N)					
Confirmation (NW)					
Confirmation (W)					
Confirmation (SW)					
Confirmation (S)					
Confirmation(SE)					
Confirmation (E)					
Confirmation (NE)					
Othe Notes		lost equipment, other observations, challenges, etc			

360° PHOTOS

1. Locate the orange cone on the marker rock for the 360° photo survey.

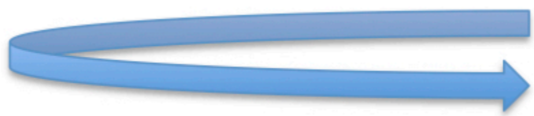
2. Open the Camera app on your smartphone.

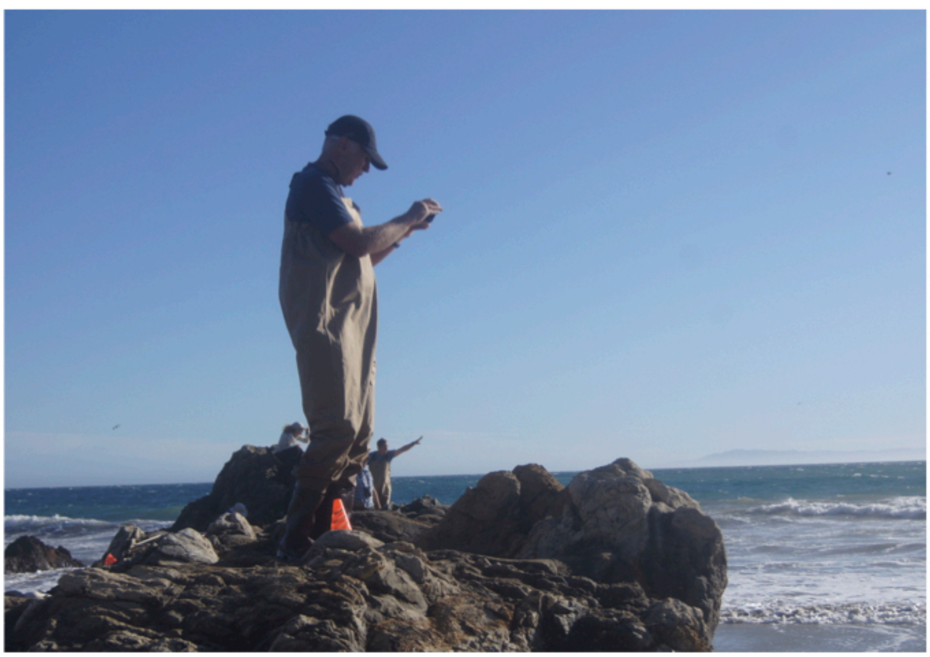
3. Open the Compass app on your smartphone. Orient to NORTH.

4. Facing NORTH, switch back to your camera app. Tilt the smartphone downward approximately 45° toward the ground (90° would be birds eye view). Focus the camera and take a photo.

5. Repeat these steps 3 & 4 for the NW, W, SW S, SE, E, and NE direction (8 photos total). You will be moving in a counter clockwise direction.

6. Repeat these steps for each participant.





SEA STAR SEARCH

1. You will do a 30-minute search for sea stars in the intertidal zone within the site boundary. Set your timer on your phone to 30 minutes. Open the sea star search data sheet on Google Sheets and fill out information in the highlighted section.

2. The search will take place within the site boundaries: between the furthest up-coast and furthest down-coast orange cone (parallel to the shore) and between the cones and the ocean's edge (perpendicular to the shore).

3. Sea stars are likely to be found closer to the ocean edge (caution is advised for incoming waves, rogue waves, whitewash surge, incoming tide, and slippery surfaces). Make sure you look underneath and in between rock crevices! You may move algae around to peek underneath, but do not remove or detach any organisms.

4. When a sea star is found, **measure the sea star from its center to the end of its longest arm** with the calipers. Round to the nearest centimeter. For example, if the organism measures 17.2cm, write "17cm" in a box between 15cm and 20cm.

5. If the sea star's arm is bent or covered, try your best to estimate where the end of it would be if it were straight.



Appendix B: Crowdsourcing Survey

Photoplot Crowdsourcing: Mussel Presence

The purpose of this survey is to understand how crowdsourcing can help collect data about the presence or absence of mussels. You will be looking at a photo of a mussel bed (Mytilus californianus) and identifying whether a mussel is present or absent at certain points throughout the picture.

Mussels have a shell that is a bluish-black color, often with eroded white valves and darker lines at the margins. The photo below is meant to help you understand how to properly identify mussels. Please note: arrows are not pointing to all the mussels present in the photo.

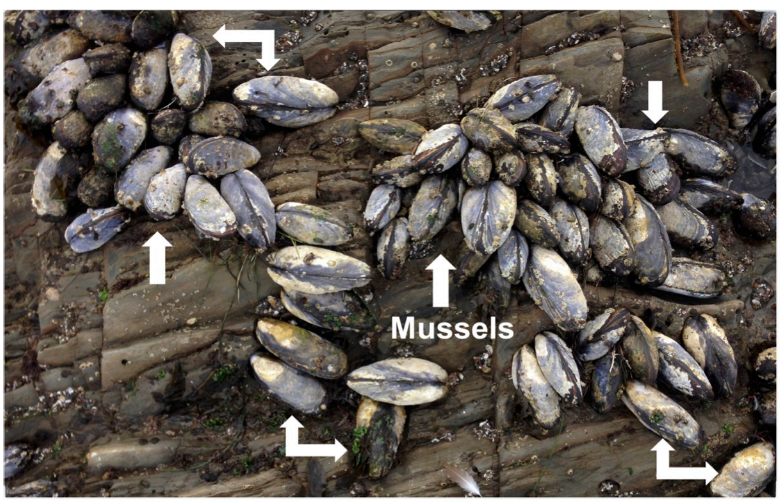
You do not need any experience or prior knowledge of marine organisms to complete this survey.

This survey will take approximately 10 minutes to complete. Your answers will not be recorded until you press "submit" at the end. Thank you for taking a few moments to help us collect data for our master's thesis!

For more information about our thesis group, check out http://www2.bren.ucsb.edu/~intertidal/

Thank you,
The Intertidal Team

Bren School of Environmental Science & Management
UC Santa Barbara

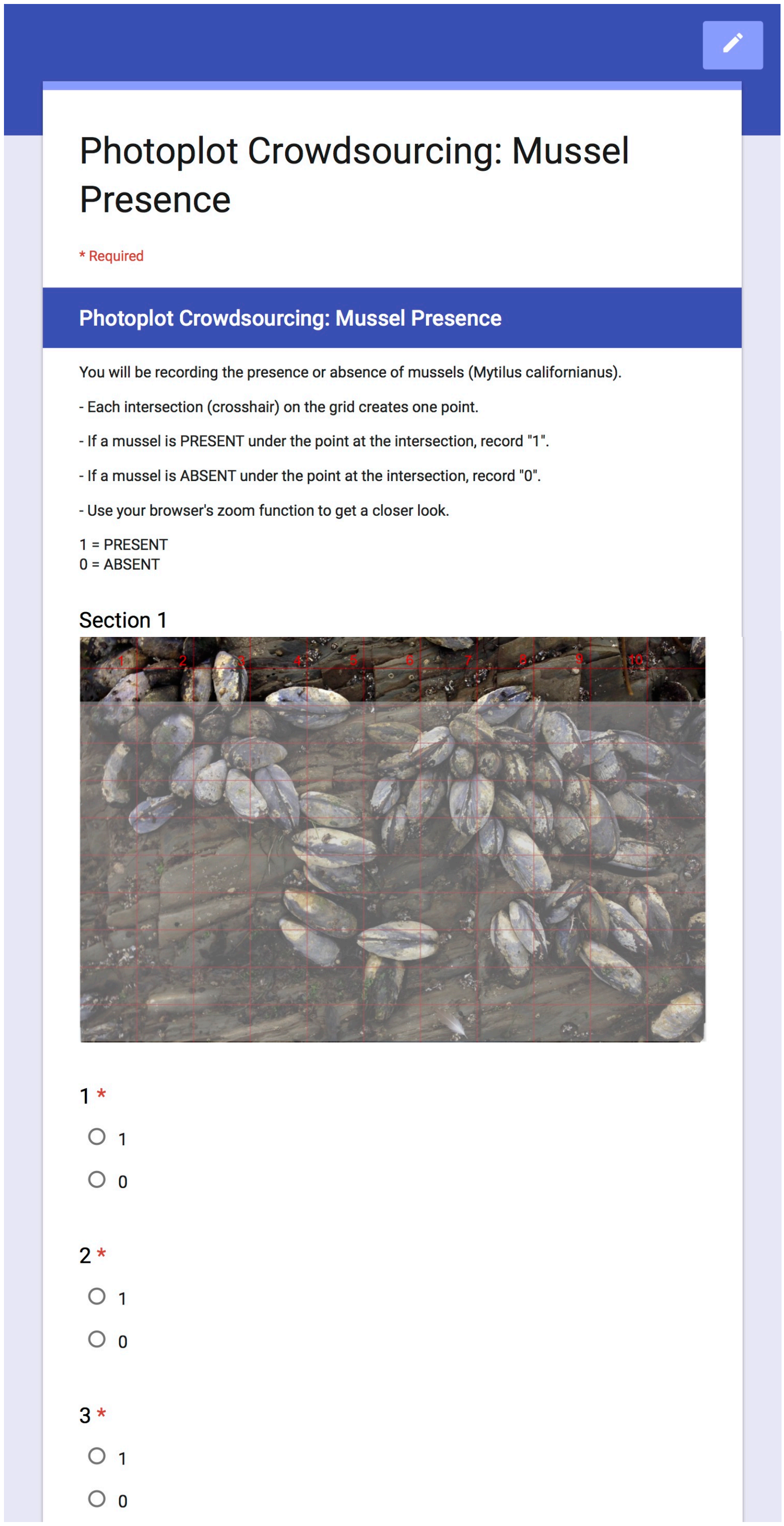


Ready? Let's go!

7% complete

NEXT

Never submit passwords through Google Forms.



Photoplot Crowdsourcing: Mussel Presence

* Required

Photoplot Crowdsourcing: Mussel Presence

You will be recording the presence or absence of mussels (Mytilus californianus).

- Each intersection (crosshair) on the grid creates one point.

- If a mussel is PRESENT under the point at the intersection, record "1".

- If a mussel is ABSENT under the point at the intersection, record "0".

- Use your browser's zoom function to get a closer look.

1 = PRESENT
0 = ABSENT

Section 1

1 *

○ 1

○ 0

2 *

○ 1

○ 0

3 *

○ 1

○ 0

The survey continued on with 10 points per page. The subsequent pages showed the same photograph, but with the next line of points to score in clear view while the rest of the photo was slightly shaded to keep volunteers focused on one row at a time.

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