Citizen Science Data Quality: Harnessing the Power of Recreational SCUBA Divers for Rockfish (*Sebastes* spp.) Conservation

by

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B.Sc., University of British Columbia, 2011

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Supervisory Committee

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Abstract

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Monitoring rare or elusive species can be especially difficult in marine environments, resulting in poor data density. SCUBA-derived citizen science data has the potential to improve data density for conservation. However, citizen science data quality may be perceived to be of low quality relative to professional data due to a lack of ‘expertise’ and increased observer variability. We evaluated the quality of data collected by citizen science scuba divers for rockfish (*Sebastes* spp.) conservation around Southern Vancouver Island, Canada. An information-theoretic approach was taken in two separate analyses to address the overarching question: ‘what factors are important for SCUBA-derived citizen science data quality?’. The first analysis identified predictors of variability in precision between paired divers. We found that professional scientific divers did not exhibit greater data precision than recreational divers. Instead, precision variation was best explained by study site and divers’ species identification or recreational training. A second analysis identified what observer and environmental factors correlated with higher resolution identifications (i.e. identified to the species level rather than family or genus). We found divers provided higher resolution identifications on surveys when they had high species ID competency and diving experience. Favorable conditions (high visibility and earlier in the day) also increased taxonomic resolution on dive surveys. With our findings, we are closer to realizing the full potential of citizen science to increase our capacity to monitor rare and elusive species.

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Chapter 1. Introduction

1.1 Conservation Context

Rockfish are a congeneric group of midlevel predators found in the North Pacific Ocean. Long life spans (up to 118 years), slow reproductive maturation (11 - 45 years), small home ranges (30 m^2 up to 2.5 km^2), and low recruitment make rockfish particularly vulnerable to overharvest (Haggarty, 2014; Magnuson-Ford, Ingram, Redding, & Mooers, 2009; Marliave & Challenger, 2009; Marliave, Frid, Welch, & Porter, 2013; Williams, Levin, & Palsson, 2010). Several rockfish species are listed as *Threatened* or *Special Concern* through the Committee on the Status of Endangered Wildlife in Canada (Government of Canada, Environment Canada, 2011).

In an effort to protect rockfish species, federally mandated harvest refuges called Rockfish Conservation Areas (RCAs) were established off the coast of British Columbia between 2003 and 2007 (Haggarty, 2014; Yamanaka & Logan, 2010). A decade since the establishment of RCAs, the recovery phase has yet to be observed (Haggarty, Martell, & Shurin, 2016; Lancaster, Dearden, & Ban, 2015). Rockfish are a data depauperate group of species in terms of survival requirements, life history, and current population status; long-term monitoring will be important for RCA management in the future (Iampietro, Young, & Kvitek, 2008; Yamanaka & Logan, 2010). Increased and ongoing monitoring can improve our understanding of rockfish response to protection. However, the difficulties of subsurface monitoring, due to accessibility, equipment, and costs, limit researchers' ability to adequately monitor marine species such as rockfish (Colton & Swearer, 2010).

1.2 Solutions for Monitoring

The plight of Pacific rockfish mirrors broader global biodiversity conservation challenges; threats to natural world are increasing while resources to mitigate threats are diminishing. The current geological period, the Anthropocene, is recognized as the largest extinction event since the notorious 'big five' mass extinctions (e.g. the 'ice age') (Pievani, 2014). Current data densities are insufficient to take conservation action for most species and ecosystems in peril (Bini, Diniz-Filho, Rangel, Bastos, & Pinto, 2006; Brown & Lomolino, 1998; Haggarty, 2014). Simultaneously, resources for ecological monitoring are becoming evermore scarce (Ahrends et al., 2011; Disney, 1989; James, Gaston, & Balmford, 1999).

In the context of Pacific rockfish, the abundance of recreational divers visiting the Salish Sea (a protected coastal waterway bordered by the southwest coast of British Columbia, Canada and the northwest coast of Washington State, USA) represent a potentially powerful, yet untapped resource of citizen scientists to generate subtidal observational data. Further, recreational divers commonly look to add value to their dive experience through citizen science opportunities (Goffredo et al., 2010) and thus are preconditioned to participate. Citizen science has the potential to help ameliorate the issues of data deficiency for rockfish conservation. For example, citizen science has improved data densities for Mediterranean underwater biodiversity monitoring (Goffredo et al., 2010), forest disease outbreaks in Britain (Brown, van den Bosch, Parnell, & Denman, 2017), and powerful owls' (*Ninox strenua*) urban spatial-use in Australia (Bradsworth, White, Isaac, & Cooke, 2017).

Citizen Science is the collection of scientific data by non-scientists usually with guidance from a trained scientist (Bear, 2016; Silvertown, 2009). Citizen science has yet to fully be adopted as a data collection 'best practice' due to criticism of the data quality and therefore scientists and decision makers, wary of bias and error, typically avoid crowdsourcing data collection to the public (Darwall & Dulvy, 1996; Foster-Smith & Evans, 2003). While citizen science increases the number of observers (potentially mitigating data deficiency challenges), citizen scientists invariably include volunteer observers with a broad breadth of expertise relative to professionals (Johnston, Fink, Hochachka, & Kelling, 2018). Increased number of observers and breadth of experience have the potential to introduce more variability to data leading to less precise, less accurate and lower resolution estimates of abundance and diversity.

The obvious opportunities and challenges represented by citizen science have given rise to a field dedicated to the analysis and verification of citizen science data quality (Bird et al., 2014; Lewandowski & Specht, 2015). I define quality as precision (consistency between observations) and resolution (the level of detail to which something is measured). Data quality differences between citizen- and professional-collected data are highlighted by the growing field of citizen science research (Specht & Lewandowski, 2018). Acceptance of citizen science is hindered by an abundance of questions around the quality of citizen science data. Understanding what factors influence citizen science data quality is essential to ensuring proper use of this data collection tool.

Here I set out to address observer effects on data quality, specifically professional versus citizen science data quality. Previous tropical assessments of SCUBA-derived data quality have not dealt with the cold, low visibility conditions of the North East Pacific (e.g. Darwall & Dulvy, 1996; Forrester et al., 2015; Pattengill-Semmens & Semmens, 1998). To address observer effects in SCUBA monitoring of Pacific rockfish, I first asked: (1) What factors (diver attributes, dive site characteristics, and/or dive conditions) best explain data precision? and (2) Does data precision increase with diver certification, peaking at the professional Scientific Diver status? I hypothesized that observer and environmental factors were important for precision. I also hypothesized that SCUBA-derived citizen science data was as precise as professionally collected data. I then asked: (3) Which components of diver expertise most affect taxonomic resolution under the cold-water conditions of the North East Pacific? By addressing these questions, I set out to verify the quality of SCUBA-derived citizen science data and provide recommendations for improving data quality in the future.

1.3 Thesis Structure

The thesis covers the application of citizen science for monitoring Pacific rockfish through surveys of finfish communities where rockfish are present. I have tackled the first step in implementing a long-term monitoring project by assessing the quality of SCUBA-derived citizen science data in the North East Pacific. By looking at precision and taxonomic identification resolution, we can understand where data quality is lacking and where citizen science strengths lie.

The second and third chapters of this thesis are presented as independent manuscripts each focusing on a different measure of data quality (i.e. Chapter 2: precision, Chapter 3: resolution). My assessment of data quality is written for both citizen science and marine monitoring scientific communities, within the context of ecological conservation issues and citizen science practice. The introduction chapter and the conclusion chapter provide regional context for this research relevant to those involved in rockfish conservation in the Salish Sea and anecdotal findings regarding the organization of citizen science projects.

The research presented here was made possible through the creation of a citizen science monitoring program for rockfish conservation called Guardians of the Deep. The Guardians of the Deep program was modeled after the REEF (Reef Environmental Education Foundation) fish survey protocol (REEF, 2012). Additional information about Guardians of the Deep and the finfish diversity and abundance data I collected is available in the appendices of this thesis.

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Chapter 2. Precision in Roving Diver Surveys of Rockfish-Finfish Communities: Recommendations for Citizen Science

2.1 Abstract

Citizen science (the collection of scientific data by non-scientists) has significant capacity to help resolve the issue of data deficiency in species conservation programs. However, a perceived lack of data precision relative to professional data sources hinders its use by decision makers. SCUBA monitoring of marine fishes provides a unique opportunity to test the assumptions of data precision in citizen science monitoring by SCUBA divers, as SCUBA diver certifications organize divers by expertise and putative competency. We hypothesize that precision of estimates of rockfish abundance and diversity from samples obtained by citizen scientists increases uniformly with certification levels of SCUBA diver competency, culminating in professional *Scientific Diver* certification at its peak. We used repeat SCUBA surveys of rockfish (*Sebastes* spp.) communities near Vancouver Island, Canada, to test hypotheses about citizen science data precision. Using an information-theoretic analytical framework we modeled the Bray-Curtis similarity of paired diver data as a function of diver expertise, dive conditions and site attributes. Dive site, diver species ID competency and recreational certification, but not Scientific Diver certification, best explained variability in citizen science SCUBA data precision. Our findings support the use of citizen science only after rigorous testing of the factors influencing data precision variability. We recommend sampling designs that include screening and weighting diver data to ensure precision remains as high as possible.

2.2 Introduction

Many conservation questions are presently unanswerable due to a pervasive lack of data (Bini et al., 2006; Brown & Lomolino, 1998; Haggarty, 2014). Many species may be data deficient because of low densities or elusive behavior, demanding significant time and effort per observation event (Thompson, 2004). Making matters worse, resources available for ecological monitoring are declining (Ahrends et al., 2011; Disney, 1989; James et al., 1999). Marine species are especially difficult to monitor given the ocean's expanse, depth, and our limited access to it – making marine conservation an obvious choice for incorporating citizen scientists.

Citizen science is the collection of scientific data for a research program, usually implemented under the guidance of a professional scientist (Ferran-Ferrer, 2015; Silvertown, 2009). Citizen science may compensate for declining conservation resources by supplementing species distribution, diversity, and abundance data. Involvement of citizen scientists can increase sampling effort and expand temporal and geographic scales of data collection, while also engaging the public (Bear, 2016; Silvertown, 2009).

The quality of parametric estimates derived from samples within a population (i.e. data quality), including those derived using citizen science, is measurable in terms of accuracy and precision (Crall et al., 2011; Lewandowski & Specht, 2015; Williams, Walsh, Tissot, & Hallacher, 2006). We define accuracy as the variability between an observation, and truth; and precision as the variability (or repeatability) between observations (Killourhy, Crane, & Stehman, 2016). To measure data accuracy, we would compare observations against true, known values. In wild natural systems, this is virtually impossible; without a known population parameter against which to compare observations, we must use precision as a proxy measure of data quality.

Widespread use of citizen scientists is hindered by the perceived lack of data quality relative to professionally collected data (Bear, 2016; Cox, Philippoff, Baumgartner, & Smith, 2012; Silvertown, 2009). A common and rational assumption is that involving large numbers of observers of varying qualifications and experience will lead to decreased precision (i.e. *quality*) of species abundance and diversity data (Bird et al., 2014; Johnston et al., 2018). Much research addresses imprecision due to error and bias in visual surveys of organisms, from the aerial survey of large mammals (Jolly, 1969), to underwater visual census of fishes using SCUBA (Thompson & Mapstone, 1997). In addition to method-associated error, resulting in imperfect detection given an organism's presence, observers have also been described as a source of error in visual surveys (Seber, 2002; Thompson & Mapstone, 1997). Individual observer error can be measured as the difference in parameter estimates between observers (i.e. inter-observer precision) (Bernard, Götz, Kerwath, & Wilke, 2013; Fitzpatrick, Preisser, Ellison, & Elkinton, 2009; Thompson & Mapstone, 1997). Deficiencies in inter-observer precision are often attributed to breadth of expertise (skill, training, and experience), and such breadth is prevalent in citizen science (Galloway, Tudor, & Haegen, 2006; Johnston et al., 2018).

Many researchers take observer expertise into account when classifying data derived from citizen science (Lewandowski & Specht, 2015). As one example, Reef Environmental Education Foundation (REEF) is a citizen science program that ranks data by observer expertise (REEF, 2012). REEF participants are recreational divers using SCUBA (Self Contained Underwater Breathing Apparatus) to visually record fish species along a designated transect using a standardized survey protocol. Assessments of SCUBA diver-pair precision from tropical waters have shown that professional divers generate data of higher precision than non-professionals (Darwall & Dulvy, 1996; Forrester et al., 2015; Pattengill-Semmens & Semmens, 1998). However, with practice non-professionals can improve their precision to equal that of professional 'specialist' SCUBA divers (Darwall & Dulvy, 1996). The effect of observer expertise on precision in cold water environments has yet to be evaluated. Cold water environments present challenges not encountered in tropical waters (e.g. lower water clarity and increased gear requirements). Such environmental challenges may augment any observer expertise differences in precision through an interactive effect between environment and expertise.

The hierarchical nature of SCUBA diving certification schemes makes SCUBA an excellent tool to evaluate the effect of observer expertise on inter-observer precision. SCUBA diving certifications follow an established gradient of skill levels, recognized recreationally and professionally. Professional Scientific Divers are considered the top echelon and are certified in Canada and the United States, under the Canadian Association for Underwater Science (CAUS) and American Academy for Underwater Science (AAUS), respectively. Scientific Diver certification is the nominal certification for academic and government divers, and so this benchmark excludes citizen scientists from contributing significantly to marine conservation programs. Simultaneously, recreational diving is a sport that requires proof of training even at the entry level. Therefore, recreational divers are naturally organized by certification level. Further, both recreational and Scientific Divers are required to keep a logbook of dives providing a metric of experience within each certification category. We directly compared precision of SCUBA-observed finfish community data across independent gradients of expertise (e.g. Total diving experience, Scientific Diver certification). The data were collected under temperate diving conditions in the North East Pacific (Vancouver Island, British Columbia) for the purposes of rockfish community monitoring.

We tested several hypotheses. First, previous studies contend that precision increases with training, culminating with professional certifications (Specht & Lewandowski, 2018). However, there is reason to believe the professional Scientific Diver certification is not correlated with superior data precision. The CAUS / AAUS scientific dive programs satisfy dive safety knowledge, underwater skill proficiency, and minimum dive time requirements. Yet, the programs do not explicitly teach species identification skills and the dive time requirement is minimal compared to many recreational divers' lifetime hours logged. Therefore, the presumed superiority of Scientific Diver data over recreational diver data may not always be supported given the breadth of diver expertise in both groups. Diver expertise can more explicitly, for our purposes, be defined as practical skill level in reporting species abundances while diving. We aim to compare data precision between the two groups (i.e. Scientific and non-Scientific Divers) and across the gradient of expertise.

Second, in addition to diver expertise, SCUBA data precision is likely to be affected by environmental conditions (e.g. site percent kelp cover, dive visibility, dive current) that prevent repeatable and precise species identification and abundance estimation (Kosmala, Wiggins, Swanson, & Simmons, 2016). To date, SCUBA-derived citizen science data assessment has been largely restricted to subtropical waters where warmer, high-clarity diving conditions contrast with the cold and low-visibility conditions typical of the North East Pacific (Darwall & Dulvy, 1996; Edgar, Barrett, & Morton, 2004; Forrester et al., 2015; Goffredo, Piccinetti, & Zaccanti, 2004; Holt, Rioja-Nieto, MacNeil, Lupton, & Rahbek, 2013; Pattengill-Semmens & Semmens, 1998; Schmitt, Sluka, & Sullivan-Sealey, 2002). No tropical studies have identified environmental conditions as primary data precision predictors, while research in colder temperate waters has suggested environmental conditions such as kelp cover can bias some species observations (Edgar et al., 2004). The North East Pacific cold temperate waters and low visibility make the gear and skill requirements of cold-water diving substantially different from warm-water diving. These considerations make quantifying precision under variable dive conditions potentially informative.

Numerous methods are used to assess marine fish abundance and diversity, such as catch per unit effort, remotely operated vehicles, and baited cameras (Bassett & Montgomery, 2011; Bicknell, Godley, Sheehan, Votier, & Witt, 2016; Haggarty & King, 2006; Haggarty, Shurin, & Yamanaka, 2016). Unlike some methodologies, SCUBA monitoring is non-destructive, a major advantage when targeting at-risk fauna (Haggarty & King, 2006). Further, some camera-based methods are known to be susceptible to inherent biases such as missing species due to the poor maneuverability and/or restricted survey area due to field of view and resolution limitations (Haggarty & King, 2006; Marliave & Challenger, 2009). Stationary baited underwater video cameras record fewer species and require more personnel hours relative to visual surveys by SCUBA divers (Colton & Swearer, 2010). As such, SCUBA monitoring is a prevalent tool in marine monitoring (Hussey, Stroh, Klaus, Chekchak, & Kessel, 2013; Pattengill-Semmens, Semmens, Holmes, Ward, & Ruttenberg, 2011; Tolimieri, Holmes, Williams, Pacunski, & Lowry, 2017).

We conducted our assessment of SCUBA-derived citizen science data precision on finfish community data collected from locations where rockfish were known to be present (i.e. rockfish-finfish communities). The conservation attention Pacific rockfish (*Sebastes* spp.) receive as an important member of finfish communities motivated us to focus on rockfish-finfish community monitoring. Rockfish are mid-level predators within marine food webs, feeding on invertebrates and small fishes and predated upon by larger finfish (Haggarty, 2014). Therefore, whole finfish community monitoring is important for marine conservation of rockfishes.

Rockfish vulnerability to overfishing motivates their conservation. Rockfish are philopatric, long-lived (up to 118 years), grow to large sizes (18-91 cm), and typically reach sexual maturity at a late age (11- 45 years) (Haggarty, 2014). These demographic parameters make rockfish particularly vulnerable to overfishing (Love, Morris, McCrae, & Collins, 1990; Love, Yoklavich, & Thorsteinson, 2002). Rockfish possess closed swim bladders (physoclistous); when rapidly pulled to the surface in nets or on lines, trapped expanding gasses cause internal injury (barotrauma), making catch and release ineffective and placing a conservation premium on non-capture survey methods.

Federally mandated harvest refuges called Rockfish Conservation Areas (RCAs) have been implemented in the North East Pacific Ocean to reduce fishing pressure on these fishes (Haggarty, 2014; Yamanaka & Logan, 2010). Given the data deficient status of Pacific rockfish, ongoing monitoring has been identified as an important component of future RCA success and management (Iampietro et al., 2008; Yamanaka & Logan, 2010). Inshore rockfish species are commonly found at SCUBA-accessible depths making rockfish-finfish community monitoring a potentially valuable application of SCUBA-derived citizen science (Haggarty & King, 2004; Marliave & Challenger, 2009). Pacific rockfish exhibit data deficiency that can be improved by citizen science SCUBA monitoring of rockfish-finfish communities. However, before the promise of marine citizen science can be realized, important data precision issues must be resolved.

We asked two questions to assess precision of citizen science-derived data for rockfish-finfish community monitoring. (1) What factors (diver attributes, dive site characteristics, and/or dive conditions) best explain variability in diver-pair data precision? (2) Does diver-pair data precision increase with diver-pair certifications similarity, peaking at diver-pairs both with CAUS / AAUS professional *Scientific Diver* status? We tested the hypothesis that diver-pairs with similarly high dive certifications would generate higher precision data, with the peak being Scientific Diver pairs. We also explicitly tested the competing hypothesis that fish species identification ability and/or diving experience (total number of dives or recreational training) explain variability in diver-pair precision. In addition, we expect diving environments with features that obscure fish and provide habitat (e.g. kelp cover) will have reduced diver-pair precision.

2.3 Methods

2.3.1 Study Site Selection

Divers surveyed rockfish-finfish communities in the Salish Sea, an inland sea ecosystem bordered by British Columbia (Canada) and Washington (USA) (Figure 2.1). Between May and October 2017, SCUBA divers conducted finfish abundance and diversity surveys in teams of two at four study sites in the Salish Sea. We used existing well-known dive sites identified using the REEF database: archived global citizen science dive activity available to researchers upon request (REEF, 2012). REEF was used to assess past dive activity at candidate sites, as well as rockfish species presence in the finfish community. We subjectively selected four sites for their accessibility and location within a Rockfish Conservation Area or reputation as a rockfish hotspot: Ogden Point, Henderson Point, Mayne Island, and Trincomali Channel (Table 2.1).

2.3.2 Sampling Design and Diver Recruitment

We established a single permanent 30-m anchored transect following a predetermined isobath to guide diver-surveyors, to standardize sample effort and ensure the same habitat was sampled at each site (Lotterhos, Dick, & Haggarty, 2014). At the end of each transect we affixed stainless steel eyehooks onto rock substrate, a 1.5-m polysteel line, and a hard-plastic net float (diameter 0.15 m) to act as transect-end markers. Further, leaded prawn trap line was laid as a visual guide between the two ends of the transect.

We recruited twenty-nine divers with wide-ranging competencies through local diver organizations into a volunteer pool (Appendices B and E). We required a minimum PADI Advanced Open Water certification (or equivalent), and at least one cold-water dive in the past year. The resultant diver pool experience ranged from novice to professional (Table 2.2).

We sampled divers with replacement (divers were paired with different partners for each dive event) from the diver pool for each two-person team deployed for each finfish-sampling event. During a dive event, each diver in the pair simultaneously sampled a site by recording fish abundance and species, moving in tandem along the 30-m transect. The protocol was modeled after REEF fish survey methodology (REEF, 2012). Diver pairs in this study used a roving transect methodology which allows divers to count all visible fish and allows for divers to move a maximum 1.5-m off the transect line to observe fish in crevasses or other topographical features. Therefore, each dive event yielded two species abundance and diversity datasets, collected simultaneously, one by each diver, at the same site, and under the same diving conditions. Our analysis focusses on the magnitude of difference between the simultaneously generated datasets.

2.3.3 Covariates Explaining Variability in Diver-pair Precision

We divided potential variables explaining variability of diver-pair datasets into three modules: variation due to individual diver expertise, variation due to biophysical site attributes, and variation due to temporally variable dive conditions (Table 2.2).

To quantify *Diver expertise*, all participants completed an online survey evaluating diver experience and fish species identification (ID) ability prior to their first dive for this project (Appendix F). The species ID quiz asked participants to identify local fish species from underwater images. Participants were instructed not to study species ID during the study period to avoid invalidating the initial species ID quiz results which were not shared with participants. Prior to each dive, participants received information only about the research objectives and importance of consistent effort and honesty in data collection. No additional species ID training was provided for participants. From individual diver-expertise metrics (Table 2.2) we quantified within-pair diver expertise dissimilarity (Table 2.3). For example, we used the coefficient of variance for the pair's species quiz scores to measure the dissimilarity in species ID competency within a given survey pair.

For our purposes, biophysical *Site attributes* were assumed to be spatially variable but temporally invariant through the study duration, so biophysical data for each site were collected once in June 2017 by a Scientific Diver team (Table 2.2). We estimated understory kelp cover (e.g. *Saccharina latissima*,) and percent dominant substrate type (e.g. % Boulder) for each 30-m transect (Table 2.2). Site rugosity, measured at the terminus of each transect is a unit-less ratio between A) the straight-line distance between two ends of a chain laid along the contours of the substrate and B) the full length of the chain (McCormick, 1994; Risk, 1972) (Table 2.2). We also recorded dive-specific environmental conditions that varied with each dive: each diver on each dive reported diving conditions (Table 2.2). Diver-pair reports for the same dive event were quantified by aggregating the individually reported dive conditions of both dive partners (Table 2.3). The methods for reporting dive conditions are outlined in detail in Table 2.2 and Appendix B.

2.3.4 Data Analysis

All data analyses were performed using R version 3.4.1 (R Core Team, 2017). Preliminary data exploration identified outliers, collinear covariates, pseudoreplication, temporal or spatial autocorrelation and violations of model assumptions (Zuur, Ieno, & Elphick, 2010). We excluded outlier species (species reported, but not normally found in local waters) and species reported as unknown/unidentifiable from the analysis. Two additional issues arose during data exploration. First, we wanted to reduce potential pseudoreplication (Hurlbert, 1984), which was the result of not all pairs sampling all four sites. Second, we wanted to maximize previous-participation differences (difference in number of in-program dives completed). We solved both issues by considering only the last dive of each pair. Models excluded collinear variables, defined as Pearson correlation coefficients equal to or greater than 0.5 and variance inflation factors equal to or greater than 3.0.

We measured diver-pair precision as the similarity of the reported fish communities' composition within each diver pair. We natural log-transformed the abundance and diversity data due to large differences in counts, and calculated a Bray-Curtis Similarity Index using the R package *vega*n for each diver pair (Oksanen et al., 2017), *sensu* (Clarke & Green, 1988). Bray-Curtis Similarity ranges from zero to one, with one indicating two identical communities in species composition and abundance, whereas zero indicates two communities with no species in common (Faith, Minchin, & Belbin, 1987). The Bray-Curtis Similarity Index is sensitive to large differences in abundances (Clarke & Green, 1988). The largest range in abundance estimates within a pair was 1500, and such large discrepancies between paired divers occurred when observing large schools of fish. The transformation therefore improves the analysis' sensitivity to differences caused by less abundant species (Clarke & Green, 1988).

We ranked generalized linear models corresponding to each hypothesis using an information theoretic approach to weigh evidence for the contribution of different factors in explaining variability in diver-pair precision (Bray-Curtis similarity) given a 'best' model (Burnham & Anderson, 2002). Variability in diver-pair precision was modeled with a beta distribution function (identity link) using R statistical software (R Core Team, 2017) and the *betareg* package (Cribari-Neto & Zeileis, 2010).

2.3.4.1 Initial Single Covariate Model Selection

We grouped single covariate models into three candidate-sets corresponding with the three major sources of variation (diver expertise, biophysical site attributes and dive conditions) (Table 2.4). Support for each candidate model was assessed by ranking models by Akaike Information Criterion adjusted for small sample sizes (AICc) (Burnham & Anderson, 2002). AICc scores balance parsimony and explanatory power and associated AICc weights (probability that the model is the best-supported model in the set) were used to select the 'best' models and associated covariate(s) from each of the three variance-explaining modules.

2.3.4.2 Factors Explaining Precision Variability

We used a hybrid approach to build the global model of covariates that best explained variability in diver-pair precision. The global model included the top covariate subsets from within each variance-explaining module. We included Scientific Diver certification in the global model regardless of performance in the initial single covariate model selection, to explicitly test the hypothesis that this advanced certification level is key to predicting data quality. The global model was not ranked in the candidate set because it included too many covariates. Instead, we limited candidate models, as special cases of the global model, to two covariates per model to not exceed a 1:15 covariate to sample ratio (Harrell, 2001). Thus, we ranked single covariate models and all possible two covariate model combinations derived from the global model (N= 6 covariates, N = 20 models). Model strength was assessed using the ratio of one model weight to that of a lower weighted model, known as an evidence ratio (Burnham & Anderson, 2002). The models chosen for each evidence ratio calculation were selected to only differ by a covariate of interest. The evidence ratio describes how many more times greater the weight of evidence is for the higher ranked model over the lower ranked model (Burnham & Anderson, 2002).

The model selection was repeated for a second time using a 'stepwise' approach where a full model including all possible covariates was iteratively simplified using the 'dredge' function from the *MuMIn* package (Bartoń, 2017). This was done to ensure that we did not overlook any important or unanticipated covariate combinations in the modular approach to model selection.

2.4 Results

Over 16 sampling days between June and October 2017, 30 unique diver-pairs collected species abundance data once at one of four 30-m permanent transect sites (Table 2.1). Diver-pairs varied in their expertise dissimilarity as summarized in Table 2.3. Pairs also reported diving conditions for each dive event. In summary, four sites with different site attributes were sampled by diver-pairs representing a spectrum of expertise combinations all under a variety of diving conditions. Divers identified a total of 30 species (Appendix H). Mean precision (Bray-Curtis Similarity Index) was 0.41 (SD = 0.24), ranging between 0.00 and 0.80.

2.4.1 Initial Single Covariate Model Selection

Diver Expertise Models: Of diver expertise covariates *Quiz Dissimilarity* (species ID quiz score coefficient of variance) and *Recreational Dissimilarity* (within diver-pair difference in certification level) best explained variability in diver-pair precision (AICc = -51.63, AICc weight

= 0.72, AICc = -49.69, AICc weight = 0.27; respectively, Table 2.4, Figure 2.2.). Both *Recreational Dissimilarity*, and *Quiz Dissimilarity* models had similar AICc scores (delta AICc = 1.95) indicating the weight of evidence is similar for both models, given the data, therefore the global model included both *Quiz Dissimilarity* and *Recreational Dissimilarity*. *Scientific Pair* (e.g. the status of a diver-pair as Scientific Divers) was not a well-supported model in the diver expertise module but was included in the global model to directly address our research question (AICc = -37.04, AICc weight = 5e-04, Table 2.4, Figure 2.2.). All other diver expertise covariates performed poorly and were not included in the global model; notably diver-pair difference in previous program participation did not correlate positively with diver-pair precision suggesting in-program experience had little influence on precision (AICc = -37.4, AICc weight = 6e-04, Table 2.4, Figure 2.2.).

Site Attribute Models: Within the *Site Attribute* models, *Site* was the top ranked single covariate model (Table 2.4). The *Kelp* model was the next best model and represented our hypothesis that features such as kelp percent cover may decrease precision by limiting visibility of fish. The *Site* covariate does not provide insight into the reason for site-specific differences in precision, thus the global model included both *Site* and *Kelp*.

Dive Condition Models: Of all the dive conditions measured *Current* (diver-pair average) best explains the variability of precision. The *Current* model was the single best model from the dive conditions module and was included in the global model (AICc = -43.82, AICc weight = 0.85, Table 2.4).

To summarize, the initial model selection identified six covariates to be included in the global model: *Quiz Dissimilarity*, *Recreational Dissimilarity*, *Scientific Diver Pair*, *Site*, *Kelp*, and *Current*.

2.4.2 Factors Explaining Precision Variability

Scientific Diver pairs did not differ from recreational diver-pairs or mixed diver-pairs in their diver-pair precision (Scientific.Pair, AICc= 37.04, AICc weight = 0.00, Parameter estimates: Intercept = -0.21 S.E.= 0.47, Mixed pairing = -0.93, S.E. = 0.57, Scientific-Scientific pairing = -0.72, S.E. = 0.62, Figure 2.3). Further, models including *Scientific Pair* had the lowest AICc weights within the global model set (AICc =-50.9, AICc weight = 1.6e-04, Table 2.5). The weight of evidence suggests that professional and citizen science data were not statistically different in their precision. We conclude that status as a Scientific or non-Scientific Diver does not predict data precision.

Site was the most important determinant of diver-pair precision suggesting data precision is heavily influenced by the geophysical attributes of the environment. Two models within the global candidate set, both of which include *Site*, Model 1: *Site* and *Recreational Dissimilarity* and Model 2: *Site* and *Quiz Dissimilarity*, were equal in explaining variability in precision (Bray-Curtis Similarity) (Table 2.5) although model selection uncertainty was high. Using evidence ratios to further investigate each covariate's importance, we found models including diver expertise covariates (*Quiz* or *Recreational Dissimilarity*) had up to 11.8 times greater weight of evidence than the site only model (ER = 10.57, and ER = 11.8). However, models including *Site* possessed up to 522.9 times greater weight of evidence than models including only diver expertise covariates (ER = 162.6, ER = 522.9, Table 2.6).

Given the above results, it is no surprise that diver-pair precision varied by *Site*, however the cause for differences remains unclear. Mean precision was generally high at Trincomali and Mayne while lower at Henderson Point and Ogden Point (Figure 2.4). Percent kelp cover only partly explains the difference in precision observed among sites (Table 2.4, Figure 2.4). Precision was lowest at sites with higher kelp cover (Table 2.7, Figure 2.4). However, the *Kelp + Quiz Diss.* model was 11.8 times less supported than the *Site + Quiz Diss.* model (Table 2.6) and no combination of these covariates was identified as informative by the 'stepwise' analysis.

Diver-pair precision decreased with increasing dissimilarity in diver expertise, measured by either *Recreational Dissimilarity* or *Quiz Dissimilarity* (Table 2.7, Figure 2.5, Figure 2.6). Divers with higher certifications and higher quiz scores generally reported more species per dive event than those with lower expertise. As previously stated, models including diver expertise covariates (*Quiz Diss*. or *Recreational Diss*.) were 10-12 times better than the site only model (ER = 10 *Site + Quiz Diss.* and ER = 12 *Site + Rec. Diss.*). Therefore, the role of diver expertise in precision should not be ignored.

The 'stepwise' model selection procedure yielded qualitatively similar results to those presented above so we conclude that we did not miss any important covariate relationships.

2.5 Discussion

2.5.1 Diver-Pair Precision did not Peak with Scientific Diver Pairs

Contrary to studies in tropical diving conditions (Darwall & Dulvy, 1996; Forrester et al., 2015; Pattengill-Semmens & Semmens, 1998), we found no evidence that professional Scientific Diver survey data enjoys greater precision relative to non-professional derived data. We suspect our results differed due to the relevant experience of the 'professionals' included in our studies. For example, Darwall and Dulvy (1996) compared non-specialist volunteers to an 'experienced researcher'. Our professionals varied in relevant experience as we only required CAUS certification to qualify as a professional. The CAUS and AAUS Scientific Diver certification programs focus on dive safety through classroom lessons. Divers are only required to conduct 25 dives with scientific task loading to obtain a level 1 certification (American Academy of Underwater Sciences, 2016; Canadian Association for Underwater Science, 2017). Professional Scientific Diver certification does not appear to provide any data precision advantage in a cold-water diving environment, where environmental conditions may create additional challenges, relative to tropical waters, not overcome by CAUS/AAUS training.

Our findings support the growing body of evidence that species ID expertise and dive experience in the local/regional environment is most important for precision and preventing observer error (Bernard et al., 2013; Galloway et al., 2006; Johnston et al., 2018). The importance of *Quiz Dissimilarity* in explaining diver-pair observation precision corroborates previous findings that species familiarity is important for data precision (Fuccillo, Crimmins, Rivera, & Elder, 2015; McDonough MacKenzie, Murray, Primack, & Weihrauch, 2017). Diver-pair precision did not increase with in-program participation in our study, as it has been shown to elsewhere (Darwall & Dulvy, 1996; Kelling et al., 2015). However, diver-pairs with greater differences in their recreational certification level (*Recreational Dissimilarity)* exhibited lower diver-pair precision. We conclude that observers with greater practice and dive skill development prior to the study had greater precision, and our study duration was likely not long enough to show improvements within the study period. Repetitive sampling at the same sites may have also negated any improvement as repetitive sampling programs are known to decrease attentiveness in citizen science SCUBA program participants resulting in decreased data precision (Darwall & Dulvy, 1996).

The most important predictor of precision was the site where surveys occurred. We hypothesize that structurally complex sites have more diverse communities and habitats, which could distract novice or unfamiliar divers resulting in decreased precision (Edgar et al., 2004; Kosmala et al., 2016). Decreased precision at complex sites demonstrates that some divers were more affected by site attributes than others, indicating a potential site-expertise interaction effect, which was not tested here due to an insufficient sample size. We attempted to explain the variability in precision between sites by including kelp cover in our global model as kelp can obscure individual fish (Edgar et al., 2004). Kelp can also provide structurally complex habitat for increased species richness. Detection error is known to increase with species richness (Bernard et al., 2013). However, kelp cover did not perform as well as the general site covariate in model selection. Percent kelp cover alone does not fully account for site differences in precision and so the cause remains partially unresolved.

2.5.2 Recommendations

A. Stratify sampling effort by site

Given precision was variable among sites, we recommend increased sampling at structurally complex sites to account for reduced precision. Such stratified sampling is well researched for aerial mammal surveys and for other species with clustered distributions and heterogeneous probability of detection (Thompson, 2004; Walsh, Campa, Beyer, & Winterstein, 2011). Further assessment of site differences could improve data precision in all monitoring (professional and citizen science) by identifying which factors cause site differences in precision and which sites should have increased monitoring.

B. Increase power by weighting data

The major benefit of crowdsourcing citizen science data is the increased sampling effort, which ideally corresponds with increased statistical power. To take advantage of the power of citizen science we must first account for imprecision due to observer and environmental variability. The large variation in precision we observed shows that SCUBA-derived citizen science data varies in precision depending on the circumstances of data collection. While SCUBA surveys performed under the conditions of the North East Pacific Ocean were generally imprecise, SCUBA surveys remain advantageous for non-lethal detection of cryptic and rare species (e.g. vulnerable species) (Haggarty & King, 2006). Weighting data by observer competency or recreational certification is the first step to improve precision. Increasing sample size through citizen science can then compensate for the remaining imprecision resulting in more powerful data to detect real trends. The use of citizen science is supported by our findings, if observer skill and site complexity are first considered.

C. Training should reflect project aims, not professional standards

Scientific Divers often train to conduct research on a specific study system and may therefore be more familiar with a specific subset of species (e.g. tropical or invertebrate species) other than the target species, in our case, temperate finfish species such as rockfish. We recommend that citizen science programs should tailor participant training to the specific research project rather than mimic professional training programs given the aims may be different (data quality vs. occupational safety).

2.5.3 Caveats

The low precision observed in this study may be explained by failure of divers to swim exactly side by side. Side by side swims ensure both divers have an equal opportunity of observing each fish (Bernard et al., 2013). The steep slope of the dive site may have required divers to swim one above the other or in single file. Often, we observed divers opting for the latter, to remain within 1.5 m of the guideline and to avoid the distraction of exhaled bubbles encountered when swimming above another diver. Swimming in single file likely resulted in lower diversity and abundance reported by the second diver as fish would be scared off by the first diver. Therefore, precision could possibly be improved by strict enforcement of side-by-side finfish surveys.

We note that because each diver-pair rarely sampled more than one dive site we could not analyze replicate samples by each pair at different dive sites. This is analogous to a ‘tank effect’ pseudoreplication (Hurlbert, 1984); the importance of *Site* as a covariate may arise by chance, due to pseudoreplication. However, the analysis included individual divers at multiple sites and represented diver combinations evenly among sites. Our divers were effectively randomized among sites so it is unlikely that all the least precise pairs sampled the most complex sites; pseudoreplication due to a ‘tank effect’ is unlikely. Our observation stands, that site complexity could potentially impact observation precision. Therefore, the site complexity effect on precision warrants consideration and further investigation.

The biophysical covariates at each site assumed invariant over the study period included kelp cover measurements taken at the beginning of the study period. Our assumption is likely false, as perennial kelp species will grow throughout the summer months before dying back or being dislodged by storms through the fall and winter (Dayton, 1985; Germann, 1986). Therefore, we caution that changing probability of species detection, given presence, over the study period could have impacted the results.

2.5.4 Future Directions for Citizen Science SCUBA Data

Our survey protocol replicated the rockfish survey methods of several ongoing Salish Sea marine citizen science initiatives (e.g. REEF, Vancouver Aquarium Rockfish Abundance Survey, SeaDoc). Our results convey an initial validation to these and other allied initiatives. For example, REEF uses fish identification quiz scores and surveying experience to weight data by observer expertise in their database (REEF, 2012). Our data suggest a REEF-like data management protocol is essential to ensuring citizen science data precision is maintained. The next steps for citizen science organizers and researchers include applying similar quality control strategies to data collection protocols and making the data, analyses and quality control metadata available to decision makers.

While our results reflect the first assessment of citizen science diver data precision and general data quality in the North East Pacific, numerous foci for future research remain. We did not test for interactions between diver expertise and environmental conditions due to the small sample size, and these interactions are likely important to consider in future work. Future work to find minimum thresholds for diving certification and species knowledge would aid citizen science program administrators to screen participants, therefore improving data precision. In addition, outliers are regularly encountered in any ecological data set and in citizen science it is common practice to flag these observations and have them corrected or excluded from the data set (Bird et al., 2014). A valuable follow-up analysis to this research would be to look for variables that correlate with outlier species identifications and abundance reports. Our study has been very conservative in calculating precision between divers due to the exclusion of all outlier species observations. Finally, imprecision in this study is due to both differences in abundance estimates and species identifications. Evidence suggests task difficulty can affect data accuracy (Kosmala et al., 2016), and we suggest precision may be similarly affected. Therefore, we recommend testing the hypothesis that collecting only presence data (removing the complex task of abundance estimation) would improve species identification precision between observers.

2.6 Conclusion

Our findings support the growing body of evidence that citizen science generated data for monitoring species is as precise as data generated by Scientific Divers. Further, by interrogating SCUBA-derived citizen science data for important predictors of precision, we have shown that, with optimal environmental conditions and observer attributes, diver-pair data can be more precise than Scientific Diver pair data. Citizen Science is therefore a valid method for supplementing the meager data set currently available for Rockfish in the Salish Sea, North East Pacific. Generally, we conclude that data collected by citizen scientists can be of comparable precision to that collected by professionals (e.g. scientists and field technicians). As such, citizen science, when data is validated, screened for precision, and collected by divers trained for the task, is a valid method for monitoring rare and elusive species in the North East Pacific. The benefits of citizen science (increasing sampling effort and statistical power) are crucial in a time when resources for ecological monitoring are scarce, making citizen science a sound solution to a prevalent problem in conservation.

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2.8 Figures and Tables

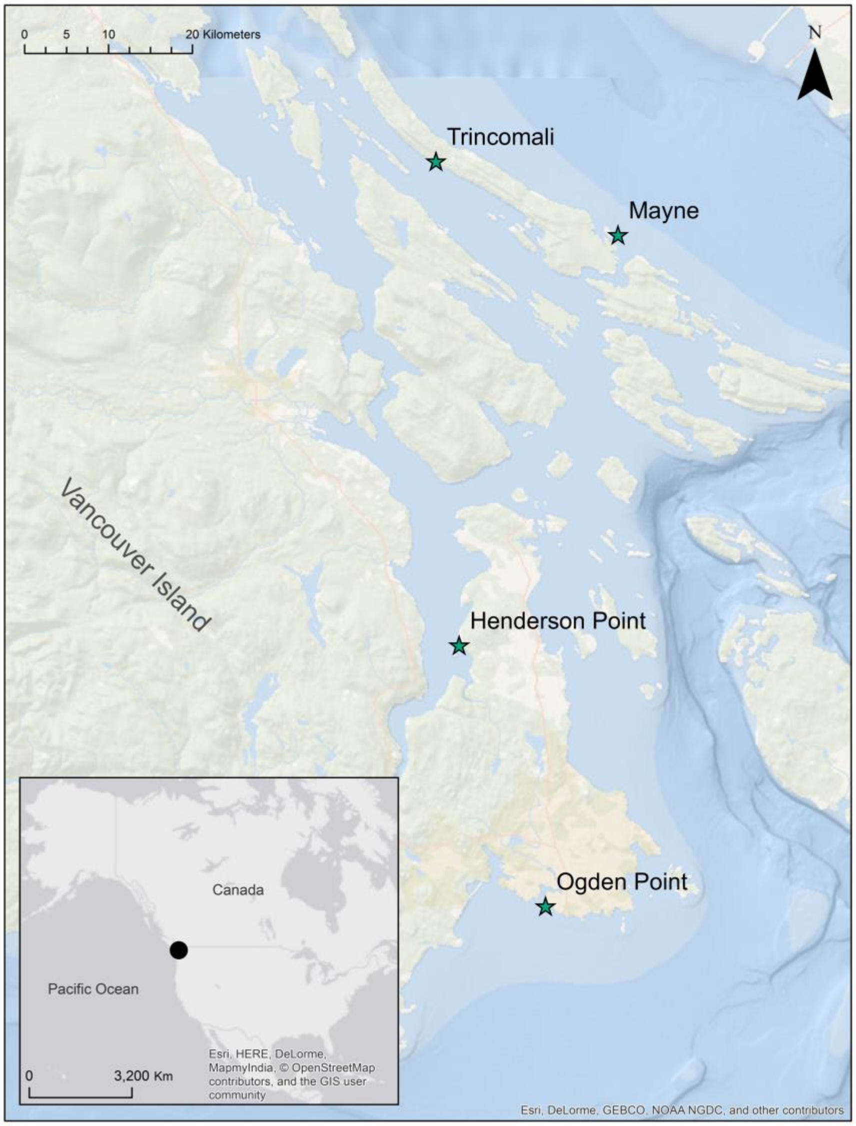

Figure 2.1. Site Map: Diver pairs surveyed rockfish-finfish community diversity and abundance at four study sites in the Salish Sea, North East Pacific Ocean. We selected sites for accessibility and rockfish presence. Map shows the southern end of Vancouver Island and surrounding islands; inset shows the site location relative to the rest of North America.

Table 2.1. Summary of site characteristics and sampling effort, including number of sampling days.

Site	Access	Habitat	RCA	Kelp (% cover)	Rugosity	# of Obs	# Obs days
Mayne	Boat	Smooth bedrock reef	Yes	0	1.39	4	2
Trincomali	Boat	Bedrock and boulder wall	Yes	1.5	1.61	13	5
Ogden Pt.	Shore or Boat	Manmade rocky reef	No	5.2	2.5	9	5
Henderson Pt.	Shore or Boat	Crevassed bedrock reef	Yes	12.7	1.11	4	4

Table 2.2. Raw single-diver variables collected for diver-pair precision models.

Module	Single-Diver Variable	Description	Range	Units
Diver expertise	Total Dives	Total dives of a diver, ln transformed	12 - 5000	# dives
	Program participation	Individual number of in-program dives at the time of the dive event	1 - 20	# dives
	Recreational certification	Recreational certifications corresponded to four levels: 1-Open water, 2-Advanced, 3-Advanced plus, 4-Instructor	N = 8 Open water, N = 3 Advanced, N = 7 Advanced plus, N = 11 Instructor	Ranking between 1 and 4
	Scientific Diver (yes or no)	Certification as a Scientific Diver, Yes/No	N = 18 Non-Sci divers, N = 11 Sci divers	Sci or Non
	Species ID Quiz Score	Divers asked identify fish species from images	2.5 - 25 pts	Score out of 25
Site attributes	Dive site	Site name	Henderson, Mayne, Ogden Point, Trincomali	Site
	Rugosity	Chain and tape method: the ratio of the length of a chain to the shorter distance between ends of the chain when following the contours of the substrate (McCormick, 1994; Risk, 1972), was measured at the terminus of each transect.	1.11 to 2.5	None
	% Boulder	The dominant substrate type was recorded every three meters along each transect (10 estimations per transect)	0 to 5	of 10 estimations
	% Bedrock crevassed	’’	0 to 6	of 10 estimations
	% Bedrock smooth	’’	0 to 8	of 10 estimations

	% Shell	’’	0 to 2	of 10 estimations
	% Kelp	Percent of a 30-m measuring tape intersecting with chlorophytes, ochrophytes, and rhodophytes combined, when viewed from above	0 to 12.7	% cover at depth
Dive Conditions	Difficulty	Divers scored Difficulty between 1 (easy) and 5 (difficult) to capture factors beyond current and visibility that may have affected a diver’s ability to observe fish	1 to 4	rating out of 5
	Horizontal Visibility	Visibility was estimated as the horizontal distance at which a diver’s bubbles were no longer visible	1 to 20	Meters
	Current at depth	Divers rated Current strength on a 3-point scale, 0= none, 1 = weak, 2 = Strong, and was rated as with (+) or against (-) direction of swimming	-2 to 2	Rating between -2 and +2

Table 2.3. Single-diver variables were transformed for use in diver-pair precision models. Diver-pair variables combine the individual diver attributes of the two-diver pair using the coefficient of variance (Variance:Mean), the difference, the average, or an assigned category.

Module	Raw Single Diver Variable	Transformation	Diver-Pair Variable	Range	Units
Diver expertise	Total Dives	Coefficient of Variance of ln transformed # of dives	Total Dives Dissimilarity	0.01 to 1.83	None
	Program participation	Difference	Previous participation difference	0 to 12	# dives
	Recreational certification	Difference in levels	Recreational Dissimilarity	0 to 3	# levels
	Scientific Diver (yes or no)	Categorized by pair type: Non-Non, Sci-Non, Sci-Sci	Scientific Pair	Non-Non N = 7, Sci-Non N = 14, Sci-Sci N = 9)	3 types of pairings
	Species ID Quiz Score	Coefficient of variance	Quiz Dissimilarity	2.5 to 25	None
Site attributes	Dive site	None	Dive site	Henderson, Mayne, Ogden Point, Trincomali	Site
	Rugosity	None	Rugosity	1.11 to 2.5	None
	% Boulder	None	% Boulder	0 to 5	of 10 estimations
	% Bedrock crevassed	None	% Bedrock crevassed	0 to 6	of 10 estimations
	% Bedrock smooth	None	% Bedrock smooth	0 to 8	of 10 estimations
	% Shell	None	% Shell	0 to 2	of 10 estimations

	% Kelp	None	% Kelp	0 to 12.7	% cover at depth
Dive Conditions	Difficulty	Coefficient of variance	Difficulty dissimilarity	0 to 1.8	None
	Horizontal Visibility	Coefficient of variance	Visibility dissimilarity	0 to 4.39	None
	Current at depth	Average	Avg. Current	-1.5 to 2	Average rating

Table 2.4 Single-covariate models split into candidate sets according to module.

Module	Model	df	loglik	AICc	Delta AICc	Weight
Diver	Quiz Diss.	3	29.28	-51.63	0	0.72
Diver	Recreational Diss.	3	28.31	-49.69	1.95	0.27
Diver	Total Dives Diss.	3	22.66	-38.4	13.23	0
Diver	Participation Diff.	3	22.16	-37.4	14.23	0
Diver	Scientific Pair	4	23.32	-37.04	14.6	0
Site	Site	5	34.8	-57.1	0	0.99
Site	Kelp	3	27.23	-47.54	9.56	0.01
Site	Bedrock Crevassed	3	24.09	-41.25	15.85	0
Site	Rugosity	3	23.65	-40.38	16.72	0
Site	Shell	3	23.21	-39.5	17.6	0
Site	Bedrock Smooth	3	22.39	-37.87	19.23	0
Site	Boulder	3	22.09	-37.26	19.84	0
Dive	Current	3	25.37	-43.82	0	0.85
Dive	Difficulty Diss.	3	23.19	-39.47	4.36	0.1
Dive	Visibility Diss.	3	22.65	-38.37	5.45	0.06

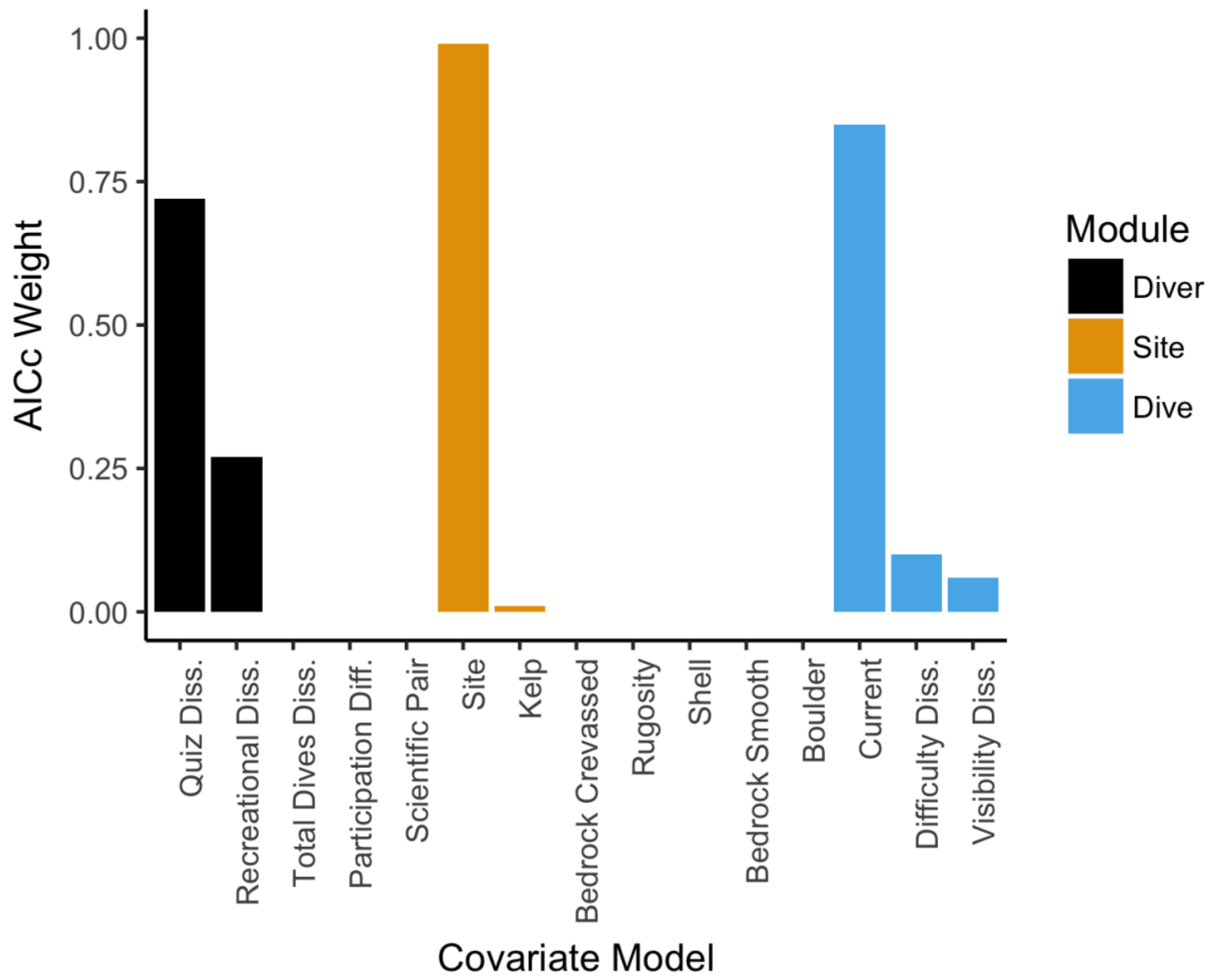

Figure 2.2. Single-covariate model weights within each subset of models. We selected the covariates from the model with the most support (highest weight) to be included in the global model. We also included Scientific Pair and Kelp in the global model because those covariates were necessary to test our hypotheses.

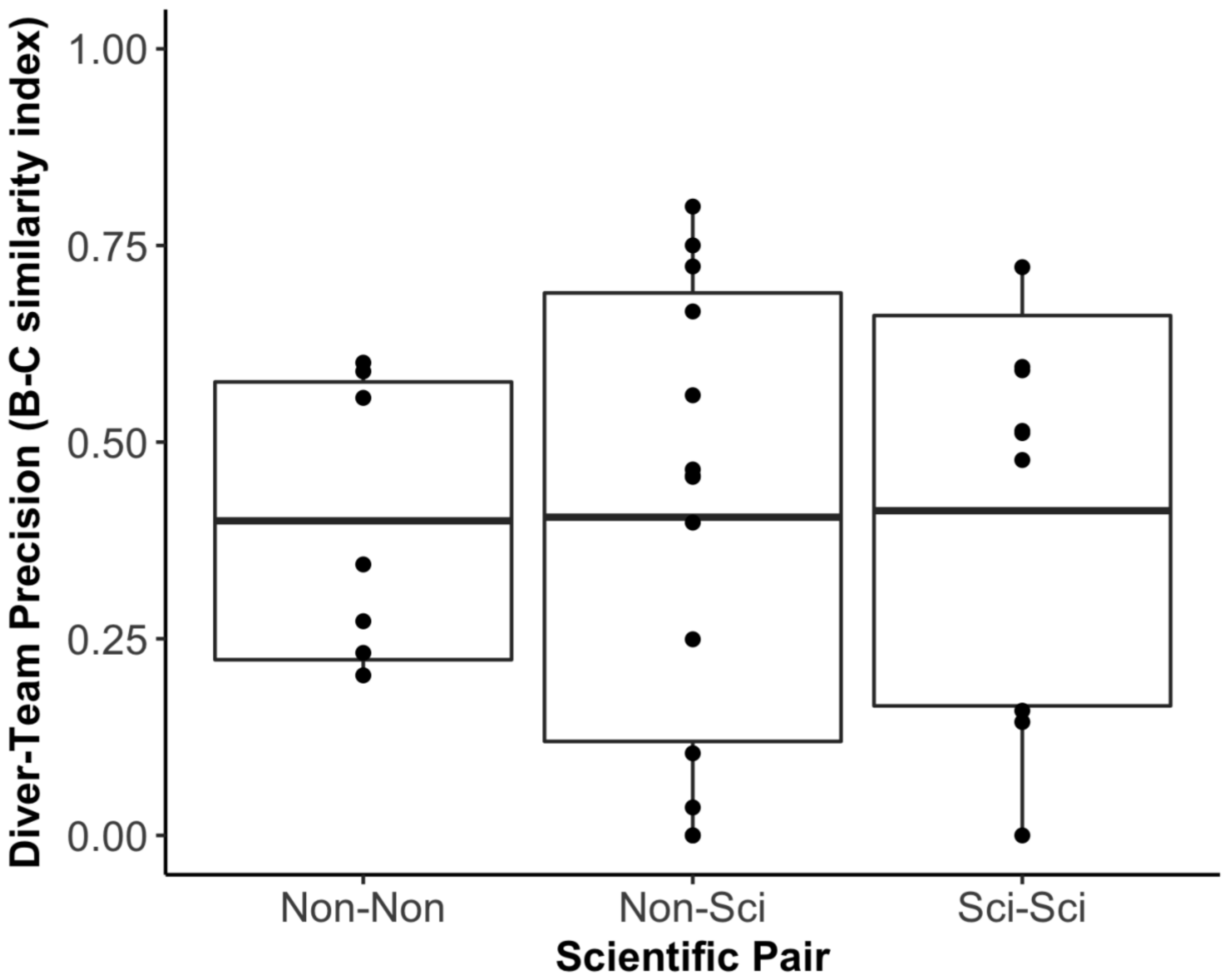

Figure 2.3. Mean diver-pair precision of three 'Scientific Pair' categories. Boxes and whiskers represent the standard deviation and min/max values respectively. Diver-pairs fit into one of three 'Scientific Pair' categories: Non-Non = Two non-scientific divers (N = 7), Sci-Non = A scientific diver paired with a non-scientific diver (N = 14), Sci-Sci = Two scientific divers (N = 9). There is no significant difference in precision (Bray-Curtis similarity) among diver-pair categories: The mean precision and standard deviation for each diver-pair 'Scientific Pair' category was 0.400 +/- 0.177, 0.405 +/- 0.285 and 0.413 +/- 0.248 respectively.

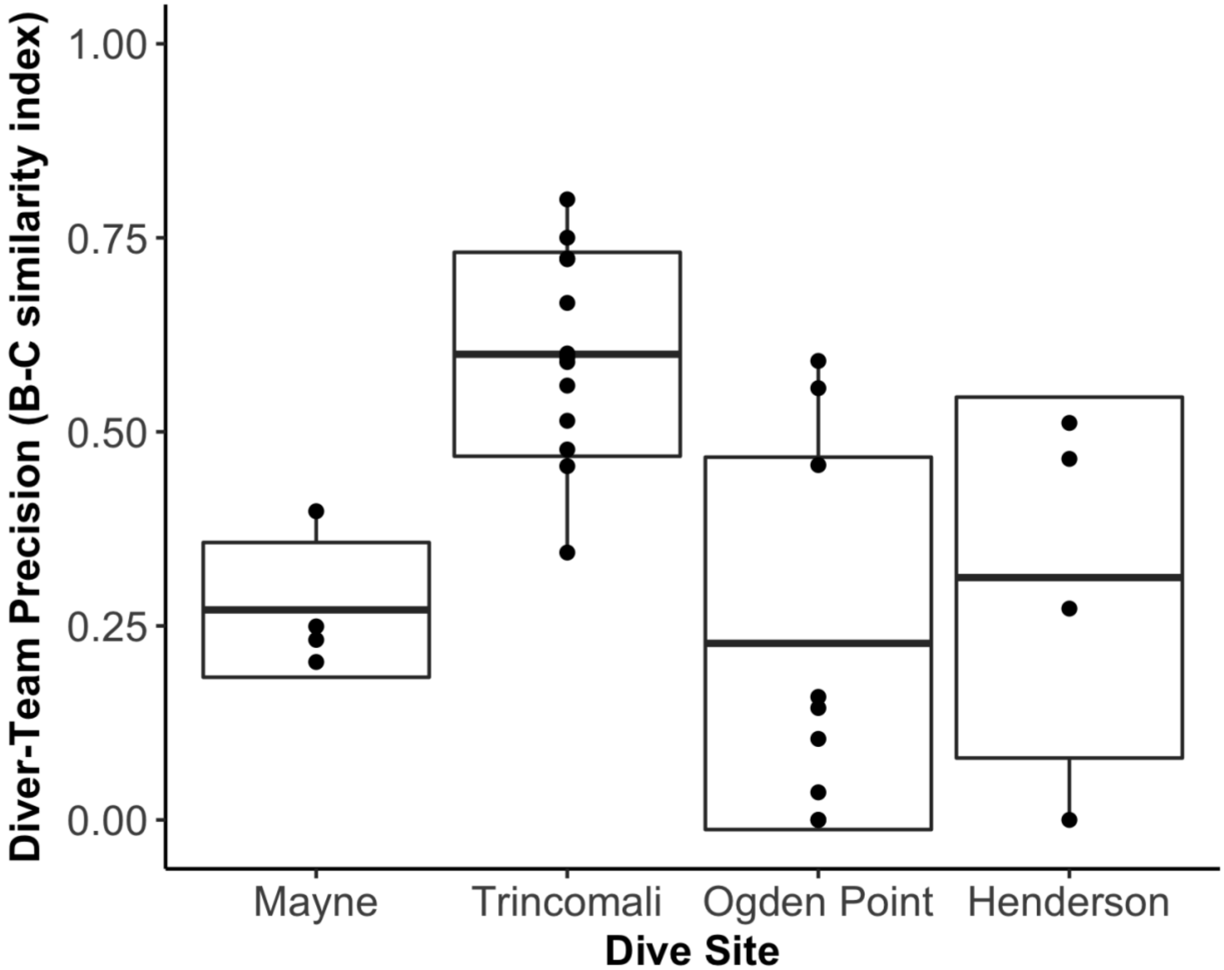

Figure 2.4. Mean diver-pair precision at each site (in order of appearance, N = 4, 13, 9 and 4). Boxes and whiskers represent the standard deviation and min/max values respectively. Sites are arranged from lowest to highest kelpcover (%). Mayne (0%), Trincomali (1.5%), Odgen Point (5.2%), Henderson Point (12.7%). Mean and variance of precision differ between sites.

Table 2.5. Diver-pair precision model selection for SCUBA-derived finfish community data. Models are special cases of the global model (not shown) where a maximum of two covariates are included in each model. The two best models (Site + Recreational Diss. and Site + Quiz) are highlighted in bold and together account for 83% of model weight.

Model Name	df	logLik	AICc	Delta AICc	Weight
Site + Recreational.Diss	**6**	**38.93**	**-62.21**	**0**	**0.46**
Site + Quiz Diss.	**6**	**38.73**	**-61.82**	**0.39**	**0.37**
Site	5	34.8	-57.1	5.11	0.04
Kelp + Quiz Diss.	4	33.24	-56.88	5.33	0.03
Current + Quiz Diss.	4	33.11	-56.61	5.6	0.03
Kelp + Recreational.Diss	4	33.1	-56.61	5.6	0.03
Current + Site	6	35.78	-55.91	6.3	0.02
Recreational.Diss + Quiz Diss.	4	32.53	-55.47	6.74	0.02
Current + Kelp	4	31.45	-53.29	8.92	0.01
Quiz Diss.	3	29.28	-51.63	10.57	0
Scientific.Pair + Site	7	35.01	-50.92	11.29	0
Current + Recreational.Diss	4	29.66	-49.72	12.49	0
Recreational.Diss	3	28.31	-49.69	12.52	0
Scientific.Pair + Quiz Diss.	5	30.59	-48.69	13.52	0
Kelp	3	27.23	-47.54	14.67	0
Scientific.Pair + Recreational.Diss	5	28.96	-45.42	16.78	0
Current	3	25.37	-43.82	18.39	0
Scientific.Pair + Kelp	5	27.71	-42.92	19.29	0
Scientific.Pair + Current	5	26.72	-40.94	21.26	0
Scientific.Pair	4	23.32	-37.04	25.17	0

Table 2.6. Lists evidence ratios (ER) as evidence for the inclusion of covariates in model A relative to model B. ERs represent how many times more weight of evidence model A has relative to model B.

Model A	Model B	ER
Site + Quiz Diss.	Site	10.57
Site + Recreational Diss.	Site	12.85
Site + Quiz Diss.	Quiz Diss.	162.6
Site + Recreational Diss.	Recreational Diss.	522.9
Site + Quiz Diss.	Kelp + Quiz Diss.	11.8

Table 2.7. Parameter estimates for four models selected from the global model candidate set (Table 2.5).

Model	Parameter	Estimate	Std. Error	Pr>|z|
Site + Recreational.Diss	(Intercept)	0.16	0.58	0.78
	SiteTrincomali	0.75	0.57	0.19
	SiteOgden Point	-1.56	0.61	0.01
	SiteHenderson	-1.37	0.74	0.06
	Recreational.Diss	-0.48	0.17	0
Site + Quiz Diss.	(Intercept)	0.76	0.67	0.26
	SiteTrincomali	0.14	0.63	0.83
	SiteOgden Point	-1.93	0.64	0
	SiteHenderson	-1.64	0.73	0.02
	Quiz Diss.	-0.24	0.07	0
Kelp + Quiz Diss.	(Intercept)	0.86	0.37	0.02
	Kelp	-0.17	0.05	0
	Quiz Diss.	-0.28	0.07	0
Scientific pair	(Intercept)	-0.21	0.47	0.65
	Scientific.PairNon-Sci	-0.93	0.57	0.1
	Scientific.PairSci-Sci	-0.73	0.62	0.24

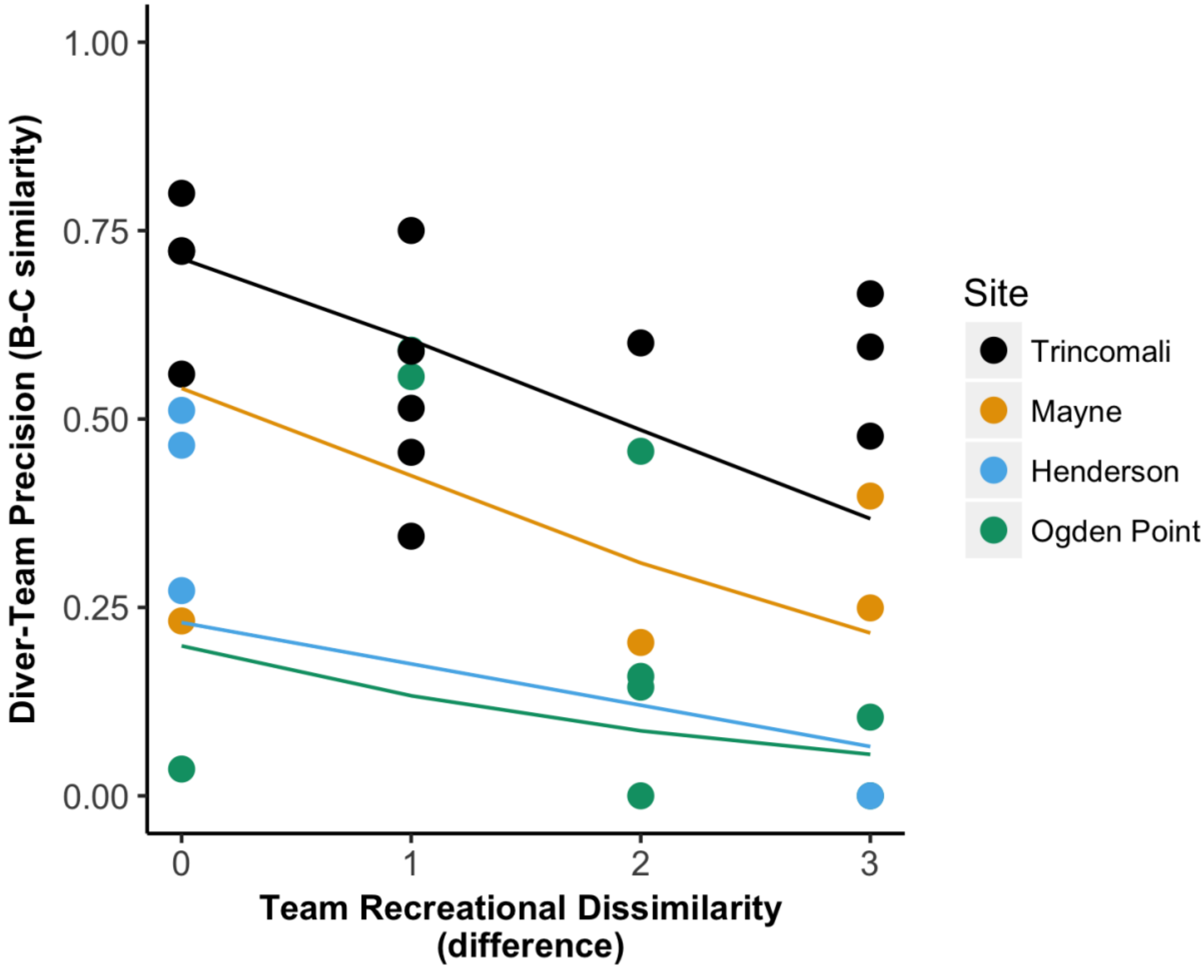

Figure 2.5. Diver-pair precision varies with Recreational Dissimilarity and at four different sites. Precision decreases as the Recreational Dissimilarity increases. Precision is higher at Mayne and Trincomali sites compared to Ogden Point and Henderson Point sites. Trend lines are the fitted values of the 'site + recreational diss.' model.

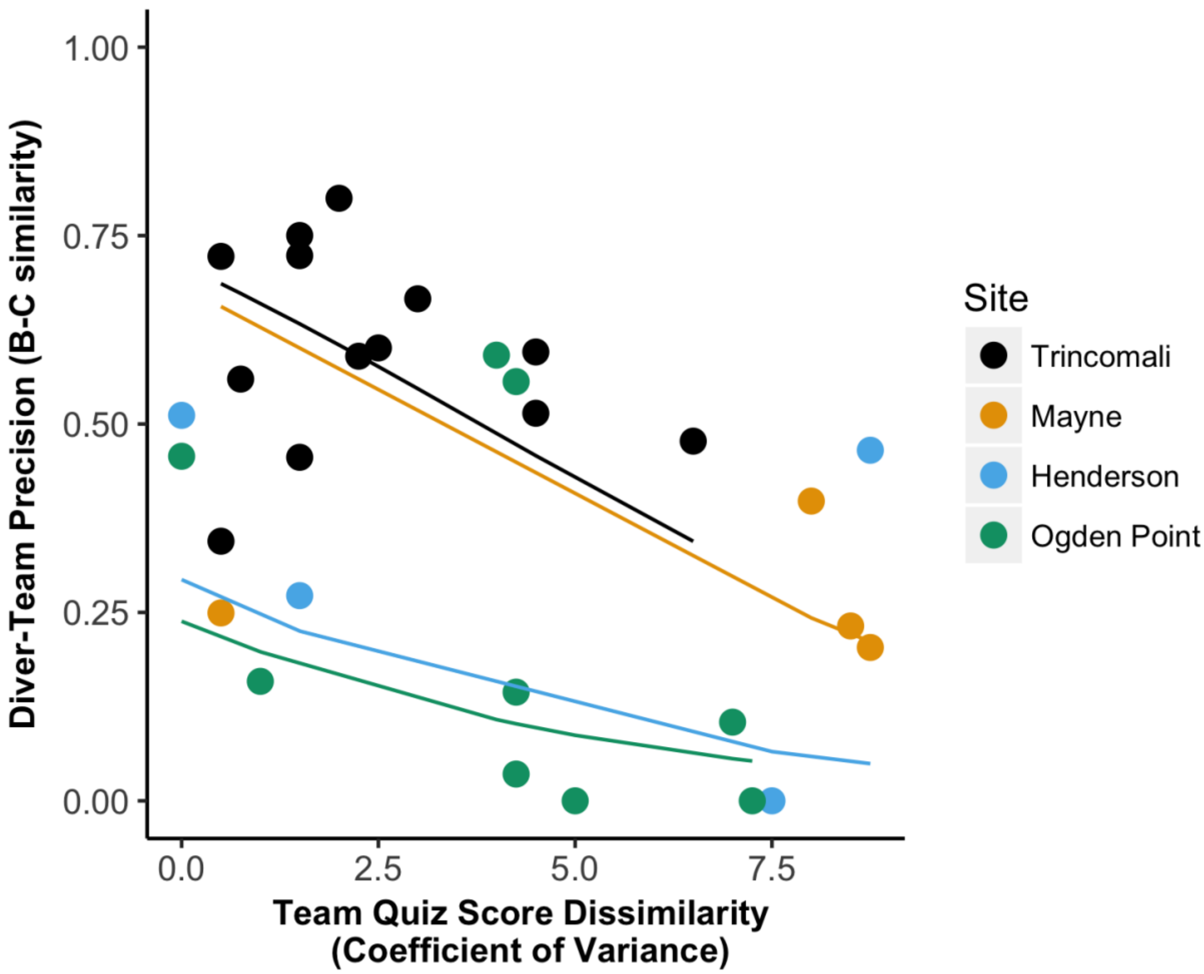

Figure 2.6. Diver-pair precision varies with Quiz Score Dissimilarity and at four different dive sites in the North East Pacific. Precision decreases as the Quiz Score Dissimilarity increases. Precision is higher at Mayne and Trincomali sites compared to Ogden Point and Henderson Point. Trend lines are the fitted values of the 'Site + Quiz Diss.' model. The diver-pair Quiz Score Dissimilarity (score coefficient of variance) ranged from 0 to 8.75 (mean = 3.73, SD = +-2.89).

Chapter 3. Citizen Science SCUBA Divers Require Species Identification Expertise for High Taxonomic Resolution

3.1 Abstract

The quality of citizen science-derived data is an ongoing area of concern in the citizen science ecological literature. In addition to accuracy and precision of population parameter estimates, data quality may also be measured as the level of detail in which observations are made (i.e. resolution); organisms identified to the species level are higher resolution data than identifications to the genus level. High resolution data are essential for detecting fine scale patterns. Variation in resolution in fish species identification by SCUBA-equipped divers may be attributable to observer expertise and/or environmental conditions. Discriminating among high- and low-resolution observers is essential if data are to be of highest quality possible, and most useful; organisms not identified to a species level cannot be integrated into species-level inventories. Therefore, we ask: which components of diver expertise most affect taxonomic resolution, measured by proportion of high resolution identifications, under cold-water SCUBA-diving conditions of the North East Pacific? We used the proportion high resolution identifications (PHRI) from diver-reported finfish species presence data as a measure of diver taxonomic resolution. An information-theoretic analysis suggests multiple elements of observer expertise (species ID competency and total diving experience), in addition to environmental conditions (visibility and time of day), contribute to taxonomic resolution. By identifying high-expertise observers and optimal environmental conditions, we can improve the proportion-high-resolution-identifications through selection or weighting, thus improving taxonomic resolution and database quality. The observer effect on taxonomic resolution is just one of many data-quality metrics we must address within citizen science. Improving resolution by accounting for observer differences can improve the utility of citizen science-derived data.

3.2 Introduction

Citizen science has significant potential to improve data densities for data-deficient species conservation management through biodiversity and abundance surveys. Citizen science is the creation of scientific data by non-scientists where a trained scientist has contributed to the methodology design (Bear, 2016; Silvertown, 2009). Crowdsourcing data collection in remote and challenging environments can reduce costs for researchers by harnessing the power of users that are already accessing such environments (Bergmann, Lutz, Tekman, & Gutow, 2017).

Unfortunately, the increased data density citizen science affords is problematic if those data are of low quality; fewer higher quality data are preferable to a greater volume of erroneous or unusable data (Foster-Smith & Evans, 2003; Hunter, Alabri, & Ingen, 2013; Saunders, 2002). An emerging area of citizen science research focuses on identifying how volunteer pools with varying degrees of experience and skill may compromise data quality (Bird et al., 2014; Crall et al., 2011; Johnston et al., 2018; Specht & Lewandowski, 2018). Challenging monitoring conditions may act to distract observers from the identification task thus increasing observer error resulting in variation in taxonomic identification resolution (Ninio, Delean, Osborne, & Sweatman, 2003; Overdyk, Holm, Crawford, & Hanner, 2016).

Data quality can be assessed in many ways (Pipino, Lee, & Wang, 2002). Similar to accuracy and precision, one can describe the quality of a parameter estimate or species identification in terms of its resolution (Chapman, 2005). Resolution is defined as the level of detail to which something is measured (Chapman, 2005). When resolution is applied to organismal identification, a species level identification has higher resolution than a genus or family level identification (Chapman, 2005; McCune et al., 1997). Low resolution identifications decrease the compatibility and usability of a dataset by limiting the ability to detect fine scale changes, the specificity of questions that may be answered by that data set, and the ability to combine related data sets in an analysis (Chapman, 2005; Jones, 2008). We can always artificially decrease data resolution but we cannot artificially increase it beyond the level at which it was collected. Resolution is not independent of accuracy and precision, and as such inaccuracy and imprecision may be symptoms of variable data resolution (McCune et al., 1997; Ninio et al., 2003).

Variable resolution in taxonomic identification of fishes using SCUBA may be attributable to observer expertise and/or environmental factors. Discriminating among high- and low-resolution observers is essential if data is to be of highest resolution possible. In addition, identifying environmental factors that facilitate or hinder high resolution data collection can be used to optimize experimental designs.

SCUBA monitoring of marine fish populations is among the longest-standing applications of citizen science (Bear, 2016; Goffredo et al., 2004; Pattengill-Semmens & Semmens, 2003). Marine environments are challenging and costly (in effort, time etc.) to access, resulting in limited sampling effort by researchers. The application of citizen science is beneficial when costs per datum are high and scientific tasks are simple (Hesley, Burdeno, Drury, Schopmeyer, & Lirman, 2017; Hyder, Townhill, Anderson, Delany, & Pinnegar, 2015); underwater biota surveys satisfy both conditions.

Rockfish (*Sebastes* spp.) monitoring by SCUBA is a valuable application of citizen science given numerous inshore rockfish species are of conservation concern, data deficient, and occur at SCUBA-accessible depths. Philopatry and the late age of sexual maturity makes these species vulnerable to over-fishing (Love et al., 1990, 2002; Parker & Tunnicliffe, 1994). Further, the closed swim bladder (physoclistous) of rockfish will trap expanding gasses when individuals are brought to the surface in fishing gear, resulting in internal injury (barotrauma). Such injuries make survival after catch and release unlikely, putting a premium on non-capture survey methods.

Observer expertise is especially important to consider for finfish surveying by SCUBA. Identifying species in marine finfish surveys can be particularly difficult due to the challenging environment (Colton & Swearer, 2010) and may be particularly difficult for cryptic species like some rockfish. Water clarity, kelp cover, and highly rugose substrates can obscure species (Edgar et al., 2004; Goffredo et al., 2004; Lowry, Folpp, Gregson, & Suthers, 2012; Marliave & Challenger, 2009). Currents and tides create dynamic three-dimensional spaces that are challenging to navigate requiring technical skills to successfully operate in. Accounting for these skills becomes even more important when multiple observers of different skill levels are employed. The potential for increased experimental error resulting in decreased resolution in SCUBA-derived citizen science due to multiple observers must be addressed.

SCUBA-diver observer expertise can be divided into three subcategories: *diving experience*, *species identification competency*, and *scientific survey skills* (Darwall & Dulvy, 1996; Pattengill-Semmens & Semmens, 1998). Explicit metrics of diving experience are contained in a diver's log book. As required by all recognized international certification organizations, a diver must record summary statistics of every dive in their personal log book, yielding information to be used as an accurate metric of experience. Assessments of citizen-science species surveys suggest practice (i.e. survey skills and species ID experience) is an important predictor of participant's capacity to provide 'complete' species lists (Kelling et al., 2015). However, few studies have interrogated the relative contributions of the three components of diver expertise (diving experience, species ID competency, and scientific survey skills) to data quality, including resolution (e.g. Goffredo et al., 2010). Further, most examinations to date have been limited to tropical warm-water diving. Water conditions, and associated greater gear requirements for cold-water diving are likely to increase distraction in less experienced divers. SCUBA-derived data therefore provides the opportunity to examine observer attributes in addition to environmental factors affecting diver taxonomic resolution under challenging conditions.

We ask: which components of diver expertise most affect taxonomic resolution under the cold-water conditions of the North East Pacific? We hypothesize that under all environmental conditions, species ID competency positively correlates with resolution, as would any environmental change that increases observer visual acuity. We also hypothesize that species ID competency may be acquired through dive experience, and visibility may change with time of day in addition to water clarity. Therefore, we test the assumptions that species ID competency and dive experience are collinear, and that visibility and time of day are collinear. By addressing these questions, we hope to provide means for researchers to satisfy prerequisite data resolution verification for citizen science initiatives using SCUBA.

3.3 Methods

The proportion high resolution identifications (PHRI) is a measure of taxonomic resolution, an observer's self-assessed resolution in taxa ID on dive surveys. We calculated the PHRI on a survey by dividing the number of 'high resolution' taxa identified (to the species level) by a single diver, by the total number of taxa the same diver discerned on that same survey (including 'low resolution' identifications), yielding a ratio of high resolution identifications to total identifications reported by one diver during one survey event.

Equation 1

For each dive survey *i:*

$$PHRI_i = \frac{High\ Res_i}{High\ Res_i + \ Low\ Res_i}$$

The variability in PHRI ratios across all diver surveys represents the variability in divers' taxonomic resolution. For example, a diver observes many individual fishes on a survey, which they categorize into 20 distinct taxa. The diver reports 18 taxa to the species level (*High Res$_i$*). Two taxa are reported as species unknown, and given a higher taxonomic classification (*Low Res$_i$*) (e.g. one is reported as an unknown rockfish (genus) and the other as an unknown sculpin (family)). In this example, the resulting PHRI is 18 / 20 = 0.9.

3.3.1 Data Collection

From May to October 2017, 29 SCUBA divers surveyed four sites in the Salish Sea, North East Pacific Ocean for finfish species abundances (Figure 2.1). The study sites, Ogden Point, Henderson Point, Mayne and Trincomali, were selected for their accessibility and known presence of rockfish (Table 3.1).

Surveys were conducted by diver pairs along a single permanent 30-m transect anchored at each site. Leaded prawn trap line was laid along a predetermined isobath to visually guide diver-surveyors (Lotterhos et al., 2014). The start and finish of each transect was marked by hard plastic net floats secured with 1.5 m of polysteel line.

The 29 diver participants were recruited from local sport and academic/professional dive organizations (Appendix E). Diver participants were certified to a minimum of PADI Advanced Open Water, and had at least one cold water dive experience within the past year. An experience gradient from novice (12 dives) to professional (5000 dives) was represented in the resultant diver pool (Table 3.3).

Diver pairs individually recorded all observed species as they swam along the 30-m transect. Divers were instructed to remain within 1.5 m of the transect line but were permitted to count any fish within view. Divers were provided a list of potential species (Table 3.2) and were instructed to record species they could not identify to the species level as 'unknown'. Divers were instructed to include identifying information with each unknown species reported (e.g. 'unknown rockfish', 'unknown perch with stripes'), therefore unknown species are classified at different levels of taxonomic resolution.

Environmental conditions were divided into two categories: site attributes and dive conditions. Site attributes were assumed temporally invariant over the study period and were quantified once in June 2017. Dive conditions varied with each dive event (Table 3.3).

Diver attributes were recorded prior to a diver's first dive for the project via an online survey covering i) diver experience and ii) a test of fish species ID competency (Appendix F). The quiz assessing species ID competency asked participants to identify local fish species from underwater images. No species ID training was provided prior to or during the project, and participants were instructed not to study species ID for the project duration. We would expect some learning to occur with project participation, therefore practice (project participation to date, number of dives) was included as a diver attribute (Table 3.3).

3.3.2 Analysis

We calculated a PHRI for each diver from their taxa presence data. When calculating the PHRI from high resolution and low resolution identifications, all identifications were assumed accurate (i.e. no misidentifications) (Equation 1, Table 3.2). High resolution identifications were any finfish identified to the species level by an unambiguous common name (e.g. copper rockfish) (Table 3.2). A fish identification field guide provided a list of accepted common names for the fish species reported by divers (Lamb & Edgell, 2010). Reported species names that were not on the field guide list were considered ambiguous. Finfish identifications that were ambiguous were classified as 'low resolution' identifications (e.g. unknown rockfish, Table 3.2). Data were assessed for outliers, collinearity between explanatory variables, pseudoreplication, and violation of model assumptions (Zuur et al., 2010). Two individual surveys resulted in zero high resolution identifications and were omitted from the analysis as outliers, as were collinear variables (Pearson correlation ≥ 0.50). To avoid considering models with multicollinearity between covariates, multicollinearity was assessed by variance inflation factors equaling 3.0 or greater. Pseudoreplication can occur when several supposed replicates are not independent because they are derived from the same source (Hurlbert, 1984). In our study, we had repeat samples (surveys) from each diver. We were unable to account for the pseudoreplication using a mixed-effects model with 'diver ID' as the random effect due the limitations of our sample size. Instead we have included several diver attributes as variables that account for much of the individual diver variation.

We used an information-theoretic model framework (Burnham & Anderson, 2002) to weigh evidence for multiple hypotheses by competing a series of generalized linear models (beta distribution, identity link) in two stages. Model fitting was conducted using ‘R’ statistical software (R Core Team, 2017), and the *betareg* package (Cribari-Neto & Zeileis, 2010). The first stage identified a core model that accounted for the variation in the PHRI due to environmental conditions. A full seven-variable environmental model was chosen *a priori* to include all potentially important environmental covariates. The core model was created from the full environmental model by iteratively dropping all non-significant ($p > 0.05$) variables from the environmental model (Table 3.4) (Crawley, 2005). The model with the lowest AICc (corrected Akaike Information Criterion) score proceeded to the next iteration as the core model.

In the second analysis stage, we combined the core model with three diver expertise covariates to form a global model (Table 3.5). The global model represents the hypothesis that three measures of diver expertise and environmental conditions are important for high resolution species identification. To test the hypothesis that diver expertise is not important for high resolution species identification, we included the core model in the candidate set. To test the hypothesis that diver expertise covariates only are important for high resolution species identification, a third model including the three diver-expertise covariates only was included in the set. The remaining models, numbered four through nine, comprise all possible combinations of the three diver-expertise covariates. Candidate set models were ranked by AICc scores and AICc weights (estimated likelihood of a model given the data (Burnham & Anderson, 2002)) were also calculated (Table 3.5). Model pairs were then selected to differ only in the inclusion of one covariate or a set of related covariates; evidence ratios (the relative likelihood of model pairs) were calculated for each model pair (Burnham & Anderson, 2002) (Table 3.5). The evidence ratios therefore describe the improved model likelihood, given the data, due to the inclusion or exclusion of a (set of) covariate(s) (Table 3.6).

3.4 Results

From 111 unique dive surveys, high resolution and low resolution identifications were enumerated (Table 3.2). The dive surveys were conducted at four sites between May and October 2017. Across all surveys at all sites, the maximum proportion-high-resolution-identifications was 100% (PHRI = 1), however on some surveys only 25% of taxa were identified to the species level (PHRI minimum = 0.25, mean = 0.87, SD = 0.19).

Divers with greater species ID competency and dive experience were significantly superior in identifying taxa on surveys, resulting in higher resolution data (Figure 3.1, Figure 2.1); these diver attributes were much more important than the environmental conditions at the time of the survey. There was 284.6 times the weight of evidence for including expertise covariates in the top model (Model A: species ID competency + total dives + visibility + time of day) than for excluding expertise covariates (Model B: visibility + time of day) (ER = 284.6,Table 3.6; AICc = -473.9, Weight = 0.46, Table 3.5).

Divers did not necessarily have high species ID competency if they were experienced divers. Species ID competency and total dives were not collinear (Pearson = 0.36). The different skills represented by species ID competency and dive experience are both important for high resolution taxa identification on surveys. The inclusion of total dives in the top model in addition to species ID competency was supported (ER = 2.17, Table 3.6; AICc = -473.9, Weight = 0.46, Table 3.5).

Diver ability to provide high resolution data did not change by participating in more surveys. Previous program participation was not found to be important for explaining PHRI variability; the removal of the practice covariate from the global model was supported (ER = 2.85, Table 3.6).

Visibility (m) and time of day combined with species ID competency and total dives (lifetime experience) best explained divers' resolution in identifying taxa on surveys: (AICc = -473.9, weight = 0.46, Table 3.5). Divers identified to the species level more readily on surveys with higher visibility (Table 3.7, Figure 3.3). Conversely high resolution species ID was reduced in the afternoon relative to morning surveys (Table 3.7, Figure 3.4). Visibility did not change with time of day (Pearson = -0.16).

3.5 Discussion

A citizen scientist's species ID competency and dive experience were far more important than environmental dive conditions for increasing data resolution during SCUBA surveys. Participation in our dive program did not increase taxonomic resolution. For citizen science to benefit ecological research, a formal training program with a minimum threshold species ID competency, is strongly recommended.

Diver data resolution was highest for those with high species ID competency (quiz scores) combined with extensive diving experience. Studies that have considered the correlation between observer expertise and taxonomic resolution, generally found differences in data resolution between novice and expert observers (McCune et al., 1997; Overdyk et al., 2016; Tsehaye, 2007). We corroborate many studies that have shown observer expertise is correlated with data accuracy (as accuracy is related to resolution) (Cox et al., 2012; Crall et al., 2011; Kosmala et al., 2016). Our findings also support the division of expertise into categories (i.e. species ID competency and dive experience) (Darwall & Dulvy, 1996; Pattengill-Semmens & Semmens, 1998). Diving experience was not correlated with species ID competency, demonstrating experienced divers are not always better fish naturalists. By increasing observers' species ID competency and diving experience, we can improve observer ability to identify taxa with high resolution.

Our study design may have prevented us from detecting survey practice as a third aspect of observer expertise important for data resolution. We expected data resolution might increase with program participation as species richness estimates and accuracy can increase with survey experience (Kelling et al., 2015; McCune et al., 1997; Pattengill-Semmens & Semmens, 1998; Williams et al., 2006). Our study duration was possibly too short or did not provide appropriate conditions for improvement. Only two divers in our study surpassed the ten-dive benchmark required to show improvement in tropical citizen science diver expertise studies (Darwall & Dulvy, 1996; Williams et al., 2006). Further, diver-surveyors in cold-water may require more practice for detectable improvement. We also suspect the survey protocol may have introduced variability reducing the power of our analysis to detect a 'practice effect' for two reasons. Our survey protocol i) called for identification of any fish within view, resulting in a variable transect width, and ii) did not prevent divers from accidentally swimming ahead of their buddy during the transect swim, likely causing the second diver to report diver-averse species at lower resolutions if reported at all. Finally, our study resulted in many observers repeating dives at the same four sites; repetitive diving tasks can decrease observer-diligence in recording accurate data (Darwall & Dulvy, 1996), which could counteract any improvements associated with practice. It is understandable why we did not find a practice effect however the exact reason remains unclear.

The improved taxonomic resolution in high visibility conditions substantiates previous research showing visual obstructions, like water clarity and kelp cover, limit sampling effectiveness (e.g. species identification, abundance estimation) for marine species (Edgar et al., 2004; Goffredo et al., 2004; Lowry et al., 2012). In our study, diver estimates of visibility were highly variable within diver pairs. The visibility metric was not standardized so it may indicate a diver's confidence in their data rather than true visibility distance. Still, participant self-assessed comfort with a task has been found to be an indicator of species ID accuracy (Crall et al., 2011). (Crall et al., 2011). Regardless, visibility can account for variation in taxonomic resolution.

Afternoons were unexpectedly correlated with decreased resolution in identifications relative to morning surveys. Visibility was not correlated with time of day, so it is likely that time of day represents variability additional to diel changes in lighting regime. Time of day may account for circadian dips in human task performance (Johnson, 2008; Pink, 2018) or fatigue due to prolonged or repeated SCUBA diving (Goffredo et al., 2010).

3.5.1 Caveats

We have only partially accounted for variable identifiability among species and its effect on variability in taxonomic resolution. Not all species are equally identifiable; rarer species or more cryptic species are more difficult to identify (Goffredo et al., 2010). Therefore, taxonomic resolution may vary with the fish community present on a survey. In our study rockfish-finfish communities were variable among sites and among surveys at the same site. We accounted for diel patterns in species behavior, such as migrations that change the fish community present on a survey (Bas, Devictor, Moussus, & Jiguet, 2008; Parker, Olson, Rankin, & Malvitch, 2008), by including time of day as a covariate. Some rockfish species associate closely with certain substrate types (Marliave & Challenger, 2009), and we approximated site differences in community composition by including substrate rugosity in the analysis. Beyond community differences due to habitat type or time of day, we assumed all divers had the same opportunities to identify the same species on every survey.

We assumed there were no species misidentifications in our study, however it is likely some occurred. We emphasize that PHRI is a measure of resolution and not accuracy; a lower PHRI could represent a more conservative species survey while a high PHRI may correspond with an inaccurate yet 'complete' high resolution survey. We do not suggest that greater resolution in taxa identification always results in greater accuracy (i.e. closeness to truth), however low resolution limits our ability to detect fine scale patterns and assess accuracy.

3.5.2 Future Work and Recommendations

Future analysis using a ‘diver’ random-effect could improve our conclusions. At the time of writing, the *glmmTMB* software package had recently become available, making beta-distributed mixed-effects models accessible to scientists without advanced knowledge of statistics (Bolker, 2018; Brooks et al., 2017; Magnusson et al., 2018). Use of such software to run mixed-effects models would improve the generalizability of our conclusions to other groups of divers observing finfish, and could improve the confidence intervals of our parameter estimates.

In the future, we would also like to see thresholds for observer expertise and environmental conditions identified through rigorous analysis. We inspected our data for the minimum expertise level where the proportion high resolution identifications (PHRI) was maximized. To balance sufficient data density while also maximizing resolution, a cutoff of 0.6 PHRI was identified. Meeting this 60% benchmark required at least 10 out of 25 on our species ID quiz and over 55 dives experience. The quiz score and dive experience thresholds we recommend can be used to filter or weight existing citizen science data or can be used as objectives for citizen science diver training. In Appendix A we present our fish diversity and abundance data in two formats, filtered by observer expertise thresholds (Table A.1) and unfiltered (Table A.2).

For ongoing monitoring of finfish by citizen science divers, we also recommend a stratified sampling effort to account for environmental conditions that could contribute to experimental error; in our study, taxonomic resolution (PHRI) was best when visibility was 8 m or more while dives in the late afternoon (after 2 pm) had a lower PHRI. While we have stated thresholds here as starting points, verification of these thresholds by change point analysis is warranted.

REEF is a global organization maintaining a database of citizen science SCUBA data on marine life. Our findings support the REEF protocol of weighting data by participant’s species ID competency and previous program participation. Program participation was not identified as important in our study; however, the possibility remains for program participation to improve data resolution over the longer timeframes. In addition, we would recommend REEF consider collecting participant metadata equivocal to total dives and incorporating it into their weighting system. REEF is an example of a citizen science program using appropriate observer expertise information to account for observer-derived variation in data quality, including taxonomic resolution, within their database.

3.6 Conclusion

Taxonomic identification resolution by citizen science SCUBA divers requires sufficient species ID competency skills and diving experience in addition to favorable environmental dive conditions (good visibility and earlier in the day). We have shown that participation in our program alone was insufficient for improved taxonomic resolution. The aspects of diver expertise contributing to observer-derived variation in taxonomic resolution in SCUBA-derived citizen science data from the North East Pacific were previously undescribed. We are now closer to realizing the tremendous potential of citizen science to improve data density while accounting for observer effects on data quality.

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3.8 Figures and Tables

Table 3.1. Summary of site attributes and sampling effort, including number of sampling days and status as a Rockfish Conservation Area (RCA).

Site	Access	Habitat	RCA	Kelp (% cover)	Rugosity	# of Obs	# Obs days
Mayne	Boat	Smooth bedrock reef	Yes	0	1.39	4	2
Trincomali	Boat	Bedrock and boulder wall	Yes	1.5	1.61	13	5
Ogden Pt.	Shore or Boat	Manmade rocky reef	No	5.2	2.5	9	5
Henderson Pt.	Shore or Boat	Crevassed bedrock reef	Yes	12.7	1.11	4	4

Table 3.2. List of taxa reported, whether they were preprinted on the datasheet and whether they were considered high resolution identifications, low resolution, or excluded from the analysis. Three observations of taxa considered non-native to the study region (i.e. "frog fish", "sea bass", and "wrasse") were excluded from the analysis.

Common Name	Latin Name	Printed on Datasheet	High/Low Res
Copper Rockfish	*Sebastes caurinus*	Yes	High
Quillback Rockfish	*Sebastes maliger*	Yes	High
Puget Sound Rockfish	*Sebastes emphaeus*	Yes	High
Yellowtail Rockfish	*Sebastes flavidus*	Yes	High
Black Rockfish	*Sebastes melanops*	Yes	High
Brown Rockfish	*Sebastes auriculatus*	Yes	High
Black Eye Goby	*Rhinogobiops nicholsii*	Yes	High
Lingcod	*Ophiodon elongatus*	Yes	High
Shiner Perch	*Cymatogaster aggregata*	Yes	High
Kelp Perch	*Brachyistius frenatus*	Yes	High
Pile Perch	*Damalichthys vacca*	Yes	High
Striped Perch	*Embiotoca lateralis*	Yes	High
Kelp Greenling	*Hexagrammos decagrammus*	Yes	High
Painted Greenling	*Oxylebius pictus*	Yes	High
Unknown Rockfish	*Sebastes* spp.	Yes	Low
Unknown Sculpin	Family Cottidae	Yes	Low
Scalyhead sculpin	*Artedius harringtoni*	No	High
Tiger Rockfish	*Sebastes nigrocinctus*	No	High
Herring	*Clupea clupea*	No	High
Crescent Gunnel	*Pholis laeta*	No	High
Longfin Sculpin	*Jordania zonopes*	No	High
Tubesnouts	*Aulorhynchus flavidus*	No	High
Pipefish	*Syngnathus leptorhynchus*	No	High
Pacific Salmon	*Onchorhynchus* spp.	No	High
Decorated Warbonnet	*Chirolophis decoratus*	No	High
Cabezon	*Scorpaenichthys marmoratus*	No	High

Table 3.2 *continued*

Common Name	Latin Name	Printed on Datasheet	High/Low Res
Whitespotted Greenling	*Hexagrammos stelleri*	No	High
Grunt Sculpin	*Ramphocottus richarsonii*	No	High
Northern Ronquil	*Ronquilus jordani*	No	High
Sailfin Sculpin	*Nautichthys oculofasciatus*	No	High
Padded Sculpin	*Artedius fenestralis*	No	High
Unknown Perch	Family Embiotocidae	No	Low
Unknown Flatfish, righthanded speckled	Family Pleuronectidae	No	Low
Unknown Flatfish	Order Pleuronectiformes	No	Low
Unknown Sculpin, genus *Artedius*	*Artedius* sp.	No	Low
Unknown Fish	Class Actinopterygii *	No	Low
Unknown Juvenile Rockfish	*Sebastes* spp.	No	Low
Unknown Greenling	Family Hexagrammidae	No	Low
Unknown Perch, copper tail, black fins	Family Embiotocidae	No	Low
Unknown Perch, beige, white spots	Family Embiotocidae	No	Low
Frogfish	Family Antennariidae	No	Excluded
Seabass	Ambiguous	No	Excluded
Wrasse	Family Labridae	No	Excluded

* *Unknown fish was most likely a bonyfish (Actinopterygii), however potentially could have been a cartilagenous fish species (Chondrichthyes).*

Table 3.3. Independent variables used in proportion-high-resolution-identifications models.

Module	**Single-Diver Variable**	**Description**	**Range**	**Units**
Diver expertise	Total Dives	Diver lifetime total dives, ln transformed	12 - 5000	# dives
	Practice	Diver in-program experience at the time of the dive event	1 - 20	# dives
	Species ID Competency	Online quiz asked divers to identify fish species from images	2.5 - 25 pts	Score out of 25
Site Attributes	Rugosity	Chain and tape method: the ratio between the length of a chain to the straight line distance between chain-ends when laid along the substrate contours (McCormick, 1994; Risk, 1972), was measured at the terminus of each transect	1.11 to 2.5	None
	Kelp cover	Percent of a 30-m measuring tape intersecting with chlorophytes, ochrophytes, and rhodophytes combined, when viewed from above	0 to 12.7	% cover at depth
Dive Conditions	Difficulty	Divers scored Difficulty between 1 (easy) and 5 (difficult) to capture factors beyond current and visibility that may have affected a diver's ability to observe fish	1 to 4	rating out of 5
	Horizontal Visibility	Visibility was estimated as the horizontal distance at which a diver's bubbles were no longer visible	1 to 20	Meters
	Current at depth	Divers rated strength on a 3-point scale, 0 = none, 1 = weak, 2 = Strong, and direction relative to swimming direction as with or against (positive or negative)	-2 to 2	Rating between -2 and +2
	Survey Duration	Time spent surveying the 30 m transect, end to end	1 to 14	minutes
	Time of Day	Hour when the dive survey began, in 24-hour clock format	9 to 18	hour

Table 3.4. Parameter estimates of the environmental-only model. Non-significant parameters (p > 0.05) were dropped to generate a core model.

Parameter	Estimate	Std. Error	Z value	p value	Incl. in core model?
(Intercept)	2.29	0.86	2.67	0.01	NA
Rugosity	0.25	0.24	1.01	0.31	Dropped
Kelp cover	0.01	0.02	0.58	0.56	Dropped
Difficulty	0.22	0.14	1.63	0.1	Dropped
Survey Duration	-0.06	0.05	-1.18	0.24	Dropped
Current	0.03	0.12	0.24	0.81	Dropped
Time of day	-0.09	0.04	-1.99	0.05	Incl. in Core
Visibility	0.07	0.03	2.35	0.02	Incl. in Core

Table 3.5. Proportion-high-resolution-identifications model selection for SCUBA-derived finfish presence data. Models are special cases of the cumulative model. The best model (Model 4) is bolded and has a weight of 0.46.

Model No.	Description	Model	df	logLik	AICc	Delta AICc	Weight
1	Core	Visibility + Time of Day	4	235.5	-462.6	11.3	0
2	Global Model	Core + Species ID + Total Dives + Practice	7	243.5	-471.8	2.1	0.16
3	Diver Exp. only	Species ID + Total Dives + Practice	5	239.7	-468.9	5.02	0.04
4	**2 Diver covariates**	**Core + Species ID + Total Dives**	**6**	**243.4**	**-473.9**	**0**	**0.46**
5	2 Diver covariates	Core + Practice + Species ID	6	241.7	-470.5	3.44	0.08
6	2 Diver covariates	Core + Practice + Total Dives	6	239.8	-466.9	7.05	0.01
7	Single Diver covariate	Core + Species ID	5	241.5	-472.4	1.55	0.21
8	Single Diver covariate	Core + Total Dives	5	239.8	-468.9	4.97	0.04
9	Single Diver covariate	Core + Practice	5	235.6	-460.6	13.36	0

Table 3.6. Lists evidence ratios (ER) as evidence for the inclusion of covariates in model A relative to model B. ERs represent how many times model A is more parsimonious than model B.

Model A	Model B	Evidence for	ER
Core + Species ID + Total Dives	Core	Inclusion of Observer Expertise	284.6
Core + Species ID + Total Dives	Core + Total Dives	Inclusion of Species ID	12.03
Core + Species ID + Total Dives	Vis + Species ID + Total Dives	Inclusion of time of day	4.56
Core + Species ID + Total Dives + Practice	Species ID + Total Dives + Practice	Inclusion of Core	4.3
Core + Species ID + Total Dives	Core + Species ID + Total Dives + Practice	Removal of Practice	2.85
Core + Species ID + Total Dives	Core + Species ID	Inclusion of Total Dives	2.17

Table 3.7. Parameter estimates for the best model from the candidate model set (Model 4, Table 3.6).

Parameter	Estimate	Std. Error	Z value	p value
(Intercept)	1.6	0.73	2.2	0.03
Visibility	0.04	0.03	1.29	0.2
Time of Day	-0.1	0.04	-2.27	0.02
Species ID	0.04	0.02	2.62	0.01
Total Dives	0.14	0.07	1.83	0.07

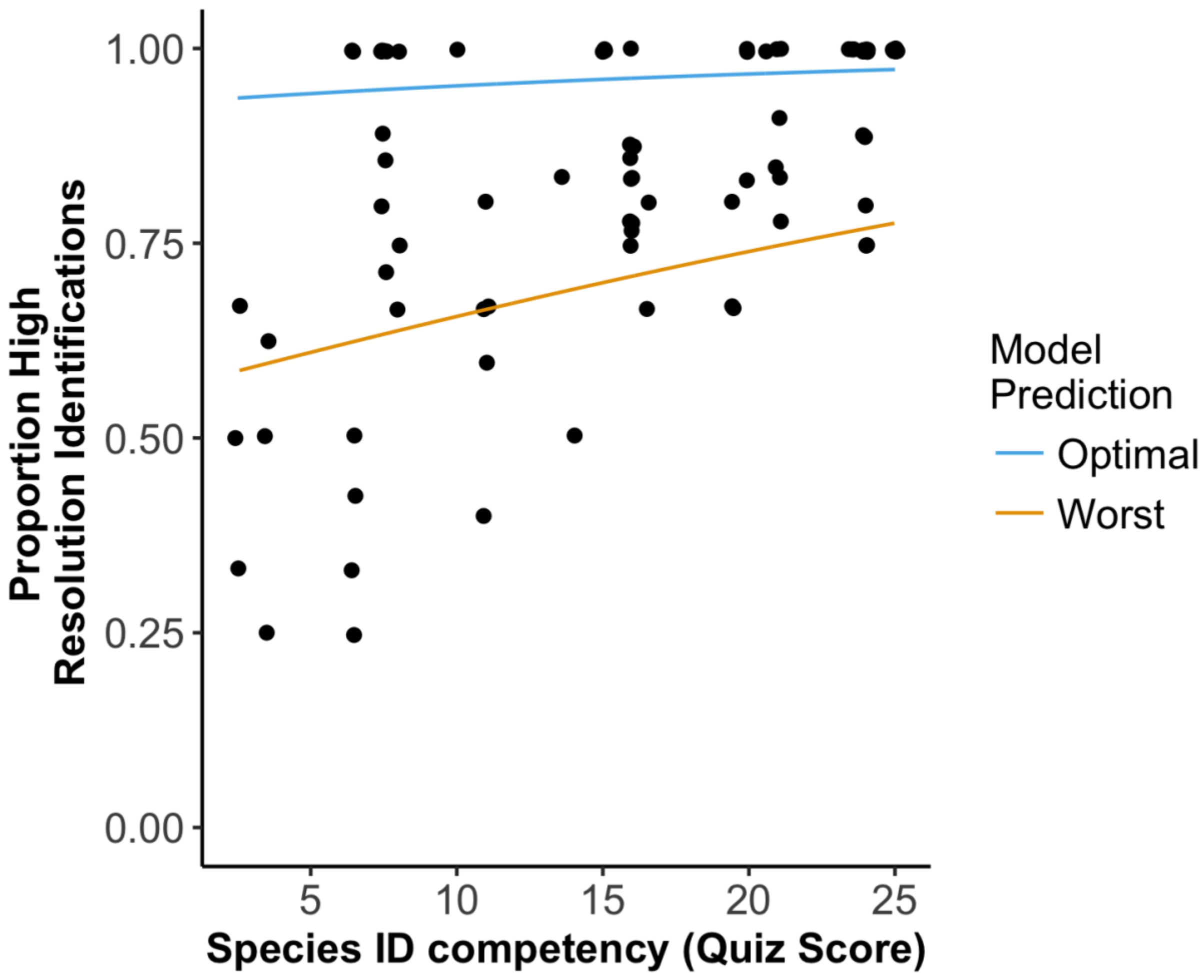

Figure 3.1. The proportion-high-resolution-identifications increases with species ID competency. Trend lines show the predicted PSID given the top model (Parameters given in Table 3.8). The optimal prediction assumes maximum Visibility (20 m), maximum Total dives (ln) (8.52) and earliest Time of day (9 h). The worst prediction assumes minimum Visibility (1 m), minimum Total dives (ln) (2.77), and latest Time of day (18 h). For both optimal and worst predictions Species ID competency increases from 2.5 to 25 pts.

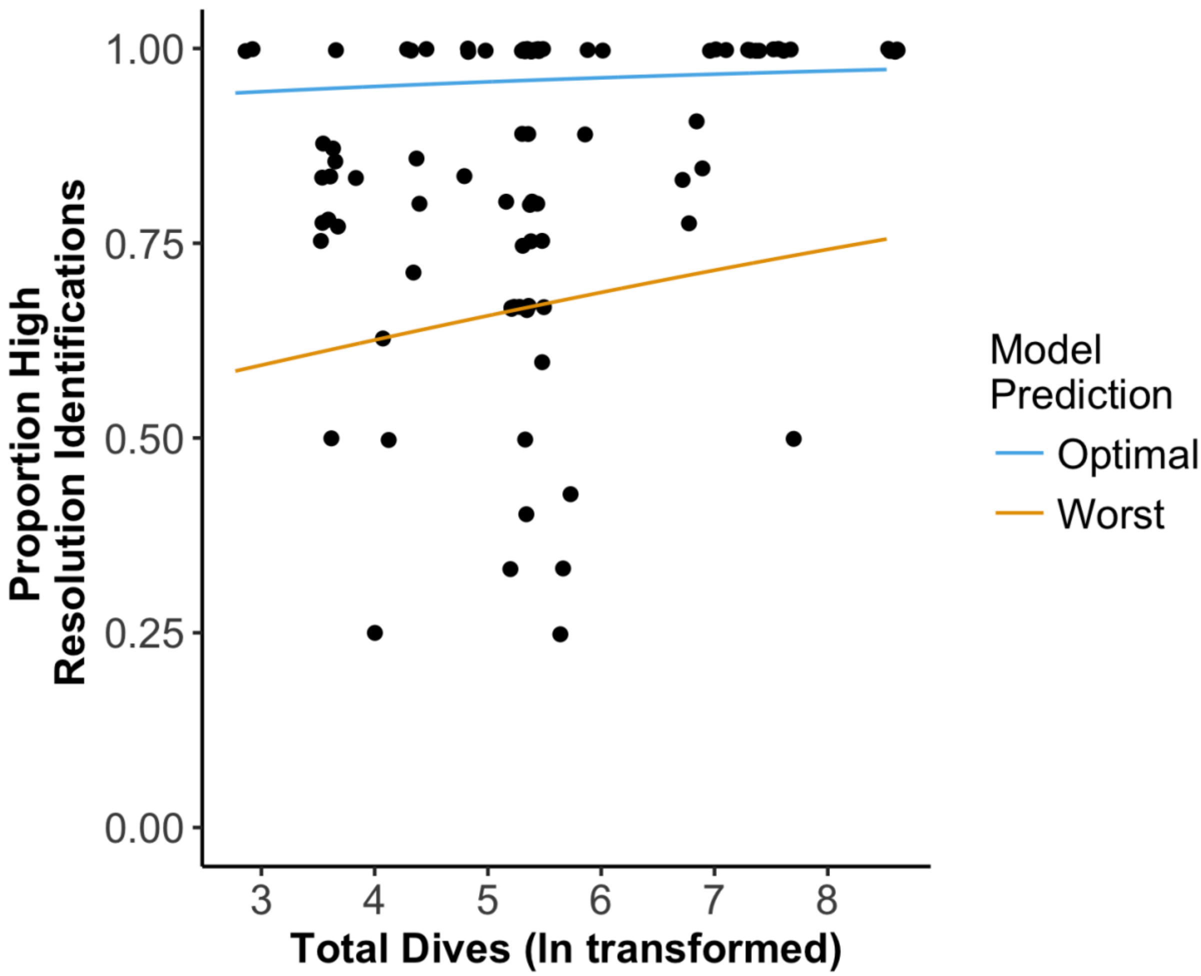

Figure 3.2. The proportion-high-resolution-identifications increases with total dives (ln transformed). Trend lines show the predicted PSID given the top model (Parameters given in Table 3.8). The optimal prediction assumes maximum Visibility (20 m), maximum Species ID competency (25 pts) and earliest Time of day (9 h). The worst prediction assumes minimum Visibility (1 m), minimum Species ID competency (2.5 pts), and latest Time of day (18 h). For both optimal and worst predictions, Total dives (ln) increases from 2.77 to 8.52. Points are jittered to reduce over-plotting.

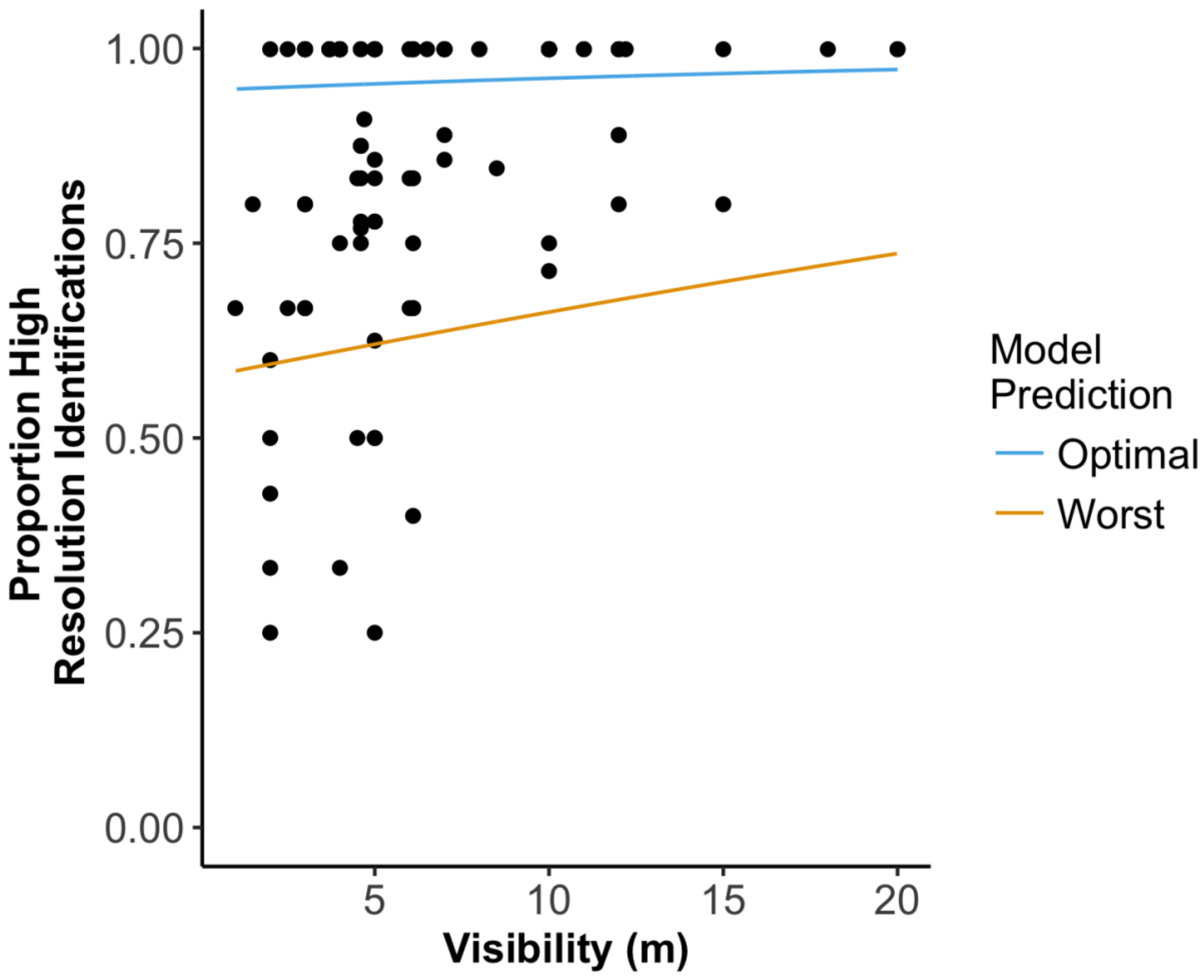

Figure 3.3. *The proportion-high-resolution-identifications increases with visibility. Trend lines show the predicted PSID given the top model (Parameters given in Table 3.8). The optimal prediction assumes maximum Total dives (ln) (8.52), maximum Species ID competency (25 pts) and earliest Time of day (9 h). The worst prediction assumes minimum Total dives (ln) (2.77), minimum Species ID competency (2.5 pts), and latest Time of day (18 h). For both optimal and worst predictions Visibility increases from 1 m to 20 m.*

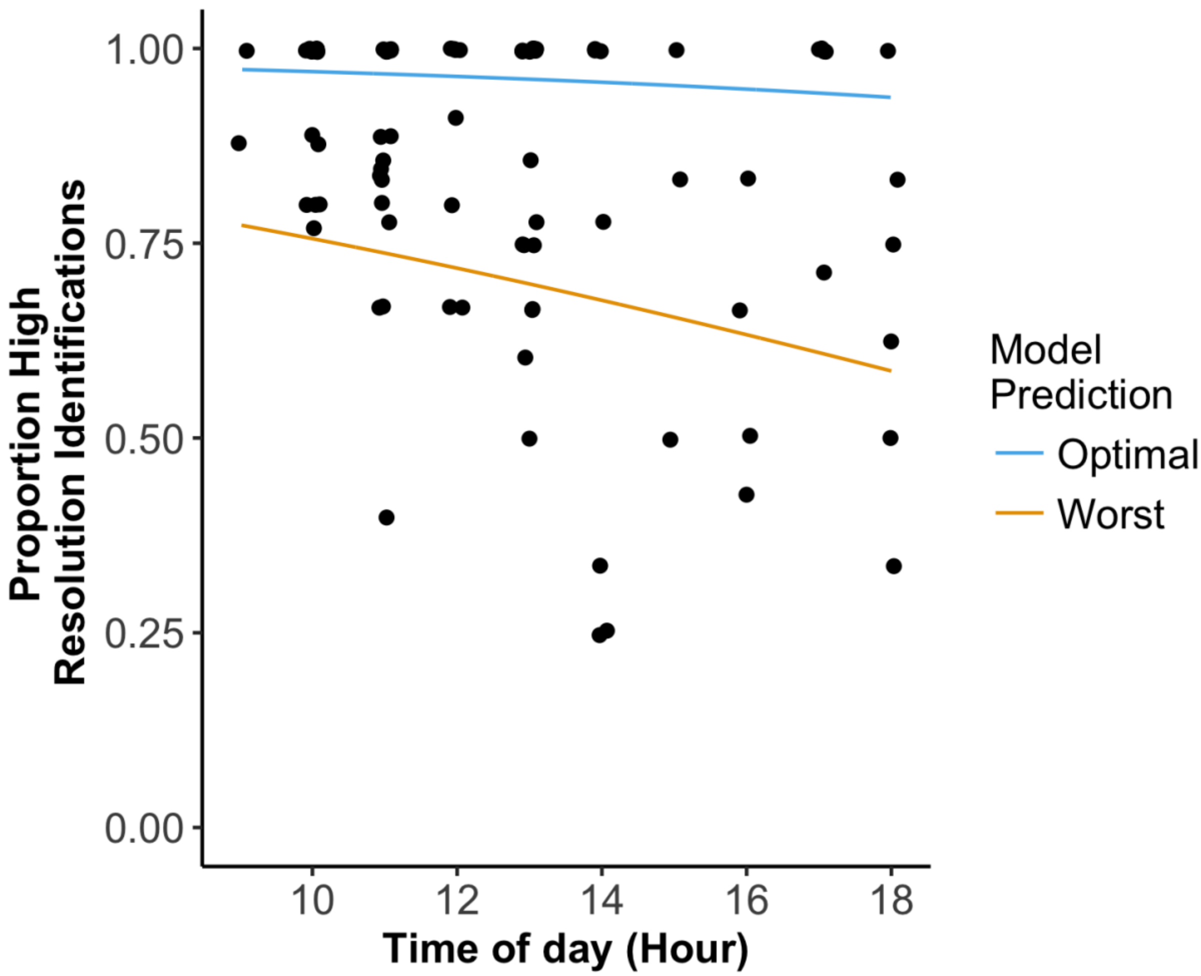

Figure 3.4. *The proportion-high-resolution-identifications decreases with time of day (hour). Trend lines show the predicted PSID given the top model (Parameters given in Table 3.8). The optimal prediction assumes maximum Total dives (ln) (8.52), maximum Species ID competency (25 pts) and maximum Visibility (20 m). The worst prediction assumes minimum Total dives (ln) (2.77), minimum Species ID competency (2.5 pts), and minimum Visibility (1 m). For both optimal and worst predictions Time of day progresses from 9 hr to 18 hr (24-hour time). Jitter has been added to points to alleviate over-plotting.*

Chapter 4. Conclusion

4.1 Summary of Findings

Through this thesis, I have explored the different observer expertise and environmental factors that affect data quality (precision and taxonomic resolution) of SCUBA-derived citizen science data. I have answered my questions about citizen science data quality: (1) What factors (diver attributes, dive site characteristics, and/or dive conditions) best explain data precision? (2) Does data precision increase with diver certification, peaking at the professional Scientific Diver status? (3) Which components of diver expertise most affect taxonomic resolution under the cold-water conditions of the North East Pacific? The analyses presented in Chapter 2 and Chapter 3 show that data quality improves with diver expertise and favorable environmental conditions.

Data precision and taxonomic resolution was greatest for divers with high species ID competency and diving expertise or higher certifications. Chapter 2 shows that professional scientific divers do not generate more precise data than recreational divers. The variation in precision among professionals is the same among recreational volunteer participants. Instead, similar species ID competency and similar recreational training correlated with increased precision. Chapter 3 shows that similar factors (species ID competency and diving experience) are important for high taxonomic resolution. I conclude that the perceived lack of citizen science data quality relative to professional data is only warranted where participants are insufficiently trained and inexperienced. I corroborate the growing evidence that the common assumption that professionally derived data are the pinnacle of data quality in citizen science needs to be challenged (Specht & Lewandowski, 2018).

In addition to observer expertise, environmental factors were important for data quality. In Chapter 2 site differences were particularly strong factors explaining variation in precision. In Chapter 3, variability in taxonomic resolution was explained by environmental factors in addition to observer expertise. I conclude that environmental conditions cannot be ignored when assessing data quality in citizen science.

4.2 Implementing Long Term Citizen Science Monitoring

The aim of this research, in addition to answering questions about factors affecting data quality, was to create a long-term monitoring program for monitoring rockfish in the Salish Sea.

By adapting the REEF (Reef Environmental Education Foundation) methodology (REEF, 2012), and by incorporating the permanent transect marker infrastructure, I have demonstrated that such methods can generate data of known quality. I have shared the data with organizations working on rockfish monitoring in the Salish Sea; those data are made available in Appendix A as both a full data set and a higher quality data set where low observer-expertise derived data have been removed. Data removal was based on the species ID competency and dive experience thresholds discussed in Chapter 3; a minimum fish ID quiz score of 10 out of 25 and 55 total dives experience was used to generate the higher quality data set presented in Appendix A. I hope my data will serve as a baseline for future monitoring at my sites, three of which are inside Rockfish Conservation Area boundaries.

While my pilot project was a success with over 100 dives completed in the summer season, it was not without issues. I recognize a lot of work went into creating a citizen science program from scratch. Challenges included recruiting enough divers and getting them out to the sites. Some divers had a particularly hard time finding the transects, or were easily discouraged if the transect was not marked clearly enough. This was particularly evident at Ogden Point where divers gave up on data collection when the transect guideline had broken, even though end marker buoys remained intact. Divers at Ogden Point were often there for a fun dive and not for sole purposes of data collection. Conversely, Trincomali was the most sampled site even though it required ferry travel to Galiano Island. Overnight Galiano Island trips were ‘data collection’ focused trips that required divers to make a commitment to travel to Galiano Island. The self-selection of divers and the data collection mentality on Galiano trips likely increased diver tenacity and diligence in data collection as evident by the volume of surveys completed on Galiano trips.

Campaigning to recruit divers was labor intensive and most data were collected with researchers present at the dive site. Future citizen science initiatives would benefit from automation of campaigning (e.g. Facebook ads) and focusing recruitment on highly motivated individuals rather than motivating the masses. I agree with many other citizen science studies which report the majority of participants tend to submit very little data relative to the large amounts submitted by a core group of volunteers (‘Pareto principle’) (Cooper et al., 2017; Newman, 2013). Regardless of the challenges, the amount of data collected was much greater than if the field work had been conducted by a traditional research team. In that way, I have demonstrated the power of crowdsourcing data.

For others attempting similar initiatives, I would advise designing a simple protocol that requires very little participant supervision (Goffredo et al., 2010). Participant recruitment and training can be achieved through information meetings. Mentorship of novice participants by experienced ones may improve participant retention and engagement. I found that participants wanted to learn more about species identification. Moving forward, I recommend species ID be incorporated into the training program to both satisfy participants and improve data quality.

Efforts to recognize participants with certificates, gift cards and t-shirts were well received. I hypothesize that divers were not motivated to participate by the incentives alone as it was at times difficult to get the rewards to participants after the fact; they were not highly motivated to collect their free t-shirt. A few inexperienced divers inquired about participation but were not qualified to participate for safety reasons. I hypothesize the opportunity to join a diving community and improve diving skills could be a motivator for participating in citizen science.

The potential contributions of citizen science to improve data density are too great to ignore. Relative to professionally collected data, SCUBA-derived citizen science data is just as precise. However, data precision and taxonomic resolution vary with observer expertise and environmental conditions. We must account for observer variability, and environmental factors, by filtering or weighting citizen science data for optimal quality. By addressing these factors for data quality, we can validate and improve the application of citizen science. Once validated, citizen science can find widespread support in the scientific community, and only then can we achieve the full potential of citizen science to reduce data deficiencies in conservation ecology.

4.3 Literature cited

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Appendix A. Summary of Finfish Data

Table A.1. High quality finfish abundance data by species observed at each site and during each month of the project (2017). Data is filtered for quality: compiled from only top scoring divers in fish identification skill (≥10 out of 25 species ID quiz score) and diving experience (Total dives ≥55). Not all sites were sampled each month. Many divers counted fish simultaneously, an adjustment for survey effort is necessary (divide the abundance (given) by No. Surveys to give # of fish per survey) before abundance data can be analyzed to compare sites or months. E.g. Copper RF abundance/survey at Henderson in July: 38 fish / 7 surveys = 5.4 fish / survey.

Site_Month	No. Surveys	Copper RF	Quillback RF	Puget Sound RF	Yellowtail Rockfish	Black Rockfish	Brown Rockfish
Henderson_7	7	38	0	0	1	0	8
Henderson_8	5	28	2	3	2	0	5
Henderson_total	**12**	**66**	**2**	**3**	**3**	**0**	**13**
Mayne_7	13	61	27	1	0	0	0
Mayne_total	**13**	**61**	**27**	**1**	**0**	**0**	**0**
Ogden Point_5	1	0	0	40	41	0	0
Ogden Point_7	3	1	1	598	389	1	0
Ogden Point_8	4	2	0	576	409	1	0
Ogden Point_9	2	0	0	2000	1100	0	0
Ogden Point_total	**10**	**3**	**1**	**3214**	**1939**	**2**	**0**
Trincomali_10	16	90	240	0	163	0	1
Trincomali_7	12	101	69	12	26	0	23
Trincomali_8	4	60	23	0	27	2	0
Trincomali_total	**32**	**251**	**332**	**12**	**216**	**2**	**24**

Table A.1 Continued:

Site_Month	No. Surveys	Tiger Rockfish	Unk Rockfish	unk juv rockfish	Unk fish
Henderson_7	7	0	0	0	0
Henderson_8	5	0	0	0	8
Henderson_total	**12**	**0**	**0**	**0**	**8**
Mayne_7	13	0	0	1	0
Mayne_total	**13**	**0**	**0**	**1**	**0**
Ogden Point_5	1	0	0	0	0
Ogden Point_7	3	0	3	0	0
Ogden Point_8	4	0	0	0	0
Ogden Point_9	2	3	0	0	0
Ogden Point_total	**10**	**3**	**3**	**0**	**0**
Trincomali_10	16	0	2	0	0
Trincomali_7	12	0	7	0	1
Trincomali_8	4	0	0	0	0
Trincomali_total	**32**	**0**	**9**	**0**	**1**

Table A.1 Continued:

Site_Month	No. Surveys	Black Eye Goby	Lingcod	Shiner Perch	Kelp Perch	Pile Perch	Striped Perch	Kelp Greenling	Paint Greenling
Henderson_7	7	2	0	80	19	1	4	0	1
Henderson_8	5	10	1	30	5	1	6	0	1
Henderson_total	**12**	**12**	**1**	**110**	**24**	**2**	**10**	**0**	**2**
Mayne_7	13	812	0	115	24	17	46	9	9
Mayne_total	**13**	**812**	**0**	**115**	**24**	**17**	**46**	**9**	**9**
Ogden Point_5	1	0	0	0	0	0	0	0	0
Ogden Point_7	3	1	2	2	0	0	0	0	0
Ogden Point_8	4	1	6	0	0	0	0	0	3
Ogden Point_9	2	0	5	0	0	0	0	0	6
Ogden Point_total	**10**	**2**	**13**	**2**	**0**	**0**	**0**	**0**	**9**
Trincomali_10	16	622	0	1746	57	46	60	7	8
Trincomali_7	12	305	0	0	17	17	30	11	10
Trincomali_8	4	83	0	64	16	6	19	5	5
Trincomali_total	**32**	**1010**	**0**	**1810**	**90**	**69**	**109**	**23**	**23**

Table A.1 Continued:

Site_Month	**No. Surveys**	**Unk Sculpin**	**Unk Perch**	**Scalyhead sculpin**	**Tiger Rockfish**	**Herring**	**RH flounder speckled**	**Unknown flatfish**	**crescent gunnel**
Henderson_7	7	3	0	0	0	0	0	0	0
Henderson_8	5	0	4	0	0	0	0	0	0
Henderson_total	**12**	**3**	**4**	**0**	**0**	**0**	**0**	**0**	**0**
Mayne_7	13	32	13	4	0	100	0	3	0
Mayne_total	**13**	**32**	**13**	**4**	**0**	**100**	**0**	**3**	**0**
Ogden Point_5	1	0	0	0	0	0	0	0	0
Ogden Point_7	3	0	0	0	0	0	0	0	0
Ogden Point_8	4	0	0	0	0	0	0	0	0
Ogden Point_9	2	0	0	0	3	0	0	0	0
Ogden Point_total	**10**	**0**	**0**	**0**	**3**	**0**	**0**	**0**	**0**
Trincomali_10	16	0	0	7	0	0	0	0	0
Trincomali_7	12	9	5	1	0	0	0	1	0
Trincomali_8	4	3	0	6	0	0	0	0	0
Trincomali_total	**32**	**12**	**5**	**14**	**0**	**0**	**0**	**1**	**0**

Table A.1 Continued:

Site_Month	No. Surveys	Longfin Sculpin	Tubesnouts	Pipefish	Artedius Sculpin	Unk Greenling	Salmon	Decorated Warbonnet	Cabezon
Henderson_7	7	1	16	0	0	0	0	0	0
Henderson_8	5	0	0	0	0	0	0	1	0
Henderson_total	**12**	**1**	**16**	**0**	**0**	**0**	**0**	**1**	**0**
Mayne_7	13	1	26	91	0	0	1000	0	0
Mayne_total	**13**	**1**	**26**	**91**	**0**	**0**	**1000**	**0**	**0**
Ogden Point_5	1	0	0	0	0	0	0	0	0
Ogden Point_7	3	3	0	0	0	0	0	0	0
Ogden Point_8	4	2	0	0	0	0	0	0	0
Ogden Point_9	2	0	0	0	0	0	0	0	0
Ogden Point_total	**10**	**5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Trincomali_10	16	20	0	0	0	0	0	0	0
Trincomali_7	12	8	0	0	1	0	0	0	0
Trincomali_8	4	6	0	0	0	0	0	0	0
Trincomali_total	**32**	**34**	**0**	**0**	**1**	**0**	**0**	**0**	**0**

Table A.1 Continued:

Site_Month	**No. Surveys**	**Whitespotted greenling**	**Unk Perch (copper tail, black fins)**	**Perch beige small with white spots**	**Grunt Sculpin**	**Northern Ronquil**	**Sailfin Sculpin**	**Padded Sculpin**
Henderson_7	7	0	0	0	0	0	0	0
Henderson_8	5	1	1	2	0	0	0	0
Henderson_total	**12**	**1**	**1**	**2**	**0**	**0**	**0**	**0**
Mayne_7	13	0	0	0	0	0	0	0
Mayne_total	**13**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Ogden Point_5	1	0	0	0	0	0	0	0
Ogden Point_7	3	0	0	0	0	0	0	0
Ogden Point_8	4	0	0	0	0	0	0	0
Ogden Point_9	2	0	0	0	0	0	0	0
Ogden Point_total	**10**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Trincomali_10	16	1	0	0	4	0	2	1
Trincomali_7	12	0	0	0	0	0	0	0
Trincomali_8	4	0	0	0	1	1	0	0
Trincomali_total	**32**	**1**	**0**	**0**	**5**	**1**	**2**	**1**

Table A.2. All finfish abundance data, by taxa observed at each site and during each month of the project (2017). Data is not filtered for data quality, it is compiled from multiple divers of varying expertise under varying conditions. Not all sites were sampled each month. Many divers counted fish simultaneously, an adjustment for survey effort is necessary (divide the abundance (given) by No. Surveys to give # of fish per survey) before abundance data can be analyzed to compare sites or months. E.g. Copper RF abundance/survey at Henderson in July: 38 fish / 7 surveys = 5.4 fish / survey.

Site_Month	**No. Surveys**	**Copper RF**	**Quillback RF**	**Puget Sound RF**	**Yellowtail Rockfish**	**Black Rockfish**	**Brown Rockfish**
Henderson_7	7	38	0	0	1	0	8
Henderson_8	5	28	2	3	2	0	5
Henderson_total	**12**	**66**	**2**	**3**	**3**	**0**	**13**
Mayne_7	13	61	27	1	0	0	0
Mayne_total	**13**	**61**	**27**	**1**	**0**	**0**	**0**
Ogden Point_5	1	0	0	40	41	0	0
Ogden Point_7	3	1	1	598	389	1	0
Ogden Point_8	4	2	0	576	409	1	0
Ogden Point_9	2	0	0	2000	1100	0	0
Ogden Point_total	**10**	**3**	**1**	**3214**	**1939**	**2**	**0**
Trincomali_10	16	90	240	0	163	0	1
Trincomali_7	12	101	69	12	26	0	23
Trincomali_8	4	60	23	0	27	2	0
Trincomali_total	**32**	**251**	**332**	**12**	**216**	**2**	**24**

Table A.2 Continued:

Site_Month	No. Surveys	Tiger Rockfish	Unk Rockfish	unk juv rockfish	Unk fish
Henderson_7	7	0	0	0	0
Henderson_8	5	0	0	0	8
Henderson_total	**12**	**0**	**0**	**0**	**8**
Mayne_7	13	0	0	1	0
Mayne_total	**13**	**0**	**0**	**1**	**0**
Ogden Point_5	1	0	0	0	0
Ogden Point_7	3	0	3	0	0
Ogden Point_8	4	0	0	0	0
Ogden Point_9	2	3	0	0	0
Ogden Point_total	**10**	**3**	**3**	**0**	**0**
Trincomali_10	16	0	2	0	0
Trincomali_7	12	0	7	0	1
Trincomali_8	4	0	0	0	0
Trincomali_total	**32**	**0**	**9**	**0**	**1**

Table A.2 Continued:

Site_Month	No. Surveys	Black Eye Goby	Lingcod	Shiner Perch	Kelp Perch	Pile Perch	Striped Perch	Kelp Greenling	Paint Greenling
Henderson_7	7	2	0	80	19	1	4	0	1
Henderson_8	5	10	1	30	5	1	6	0	1
Henderson_total	**12**	**12**	**1**	**110**	**24**	**2**	**10**	**0**	**2**
Mayne_7	13	812	0	115	24	17	46	9	9
Mayne_total	**13**	**812**	**0**	**115**	**24**	**17**	**46**	**9**	**9**
Ogden Point_5	1	0	0	0	0	0	0	0	0
Ogden Point_7	3	1	2	2	0	0	0	0	0
Ogden Point_8	4	1	6	0	0	0	0	0	3
Ogden Point_9	2	0	5	0	0	0	0	0	6
Ogden Point_total	**10**	**2**	**13**	**2**	**0**	**0**	**0**	**0**	**9**
Trincomali_10	16	622	0	1746	57	46	60	7	8
Trincomali_7	12	305	0	0	17	17	30	11	10
Trincomali_8	4	83	0	64	16	6	19	5	5
Trincomali_total	**32**	**1010**	**0**	**1810**	**90**	**69**	**109**	**23**	**23**

Table A.2 Continued:

Site_Month	No. Surveys	Unk Sculpin	Unk Perch	Scalyhead sculpin	Tiger Rockfish	Herring	RH flounder speckled	Unknown flatfish	crescent gunnel
Henderson_7	7	3	0	0	0	0	0	0	0
Henderson_8	5	0	4	0	0	0	0	0	0
Henderson_total	**12**	**3**	**4**	**0**	**0**	**0**	**0**	**0**	**0**
Mayne_7	13	32	13	4	0	100	0	3	0
Mayne_total	**13**	**32**	**13**	**4**	**0**	**100**	**0**	**3**	**0**
Ogden Point_5	1	0	0	0	0	0	0	0	0
Ogden Point_7	3	0	0	0	0	0	0	0	0
Ogden Point_8	4	0	0	0	0	0	0	0	0
Ogden Point_9	2	0	0	0	3	0	0	0	0
Ogden Point_total	**10**	**0**	**0**	**0**	**3**	**0**	**0**	**0**	**0**
Trincomali_10	16	0	0	7	0	0	0	0	0
Trincomali_7	12	9	5	1	0	0	0	1	0
Trincomali_8	4	3	0	6	0	0	0	0	0
Trincomali_total	**32**	**12**	**5**	**14**	**0**	**0**	**0**	**1**	**0**

Table A.2 Continued:

Site_Month	No. Surveys	Longfin Sculpin	Tubesnouts	Pipefish	Artedius Sculpin	Unk Greenling	Pacific Salmon	Decorated Warbonnet	Cabezon
Henderson_7	7	1	16	0	0	0	0	0	0
Henderson_8	5	0	0	0	0	0	0	1	0
Henderson_total	**12**	**1**	**16**	**0**	**0**	**0**	**0**	**1**	**0**
Mayne_7	13	1	26	91	0	0	1000	0	0
Mayne_total	**13**	**1**	**26**	**91**	**0**	**0**	**1000**	**0**	**0**
Ogden Point_5	1	0	0	0	0	0	0	0	0
Ogden Point_7	3	3	0	0	0	0	0	0	0
Ogden Point_8	4	2	0	0	0	0	0	0	0
Ogden Point_9	2	0	0	0	0	0	0	0	0
Ogden Point_total	**10**	**5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Trincomali_10	16	20	0	0	0	0	0	0	0
Trincomali_7	12	8	0	0	1	0	0	0	0
Trincomali_8	4	6	0	0	0	0	0	0	0
Trincomali_total	**32**	**34**	**0**	**0**	**1**	**0**	**0**	**0**	**0**

Table A.2 Continued:

Site_Month	**No. Surveys**	**Whitespotted greenling**	**Unk Perch (copper tail, black fins)**	**Perch beige small with white spots**	**Grunt Sculpin**	**Northern Ronquil**	**Sailfin Sculpin**	**Padded Sculpin**
Henderson_7	7	0	0	0	0	0	0	0
Henderson_8	5	1	1	2	0	0	0	0
Henderson_total	**12**	**1**	**1**	**2**	**0**	**0**	**0**	**0**
Mayne_7	13	0	0	0	0	0	0	0
Mayne_total	**13**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Ogden Point_5	1	0	0	0	0	0	0	0
Ogden Point_7	3	0	0	0	0	0	0	0
Ogden Point_8	4	0	0	0	0	0	0	0
Ogden Point_9	2	0	0	0	0	0	0	0
Ogden Point_total	**10**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Trincomali_10	16	1	0	0	4	0	2	1
Trincomali_7	12	0	0	0	0	0	0	0
Trincomali_8	4	0	0	0	1	1	0	0
Trincomali_total	**32**	**1**	**0**	**0**	**5**	**1**	**2**	**1**

Appendix B. Instructions for Diver participants

Guardians of the Deep – Salish Sea Citizen Science Project

Instructions to Divers

Submit copies of completed data sheets to guardiansofthedeep at gmail dot com.

The point of this project is to document how fish counts vary across a variety of fish identification skill levels, don't worry if you don't know how to ID fish, we still need your data!

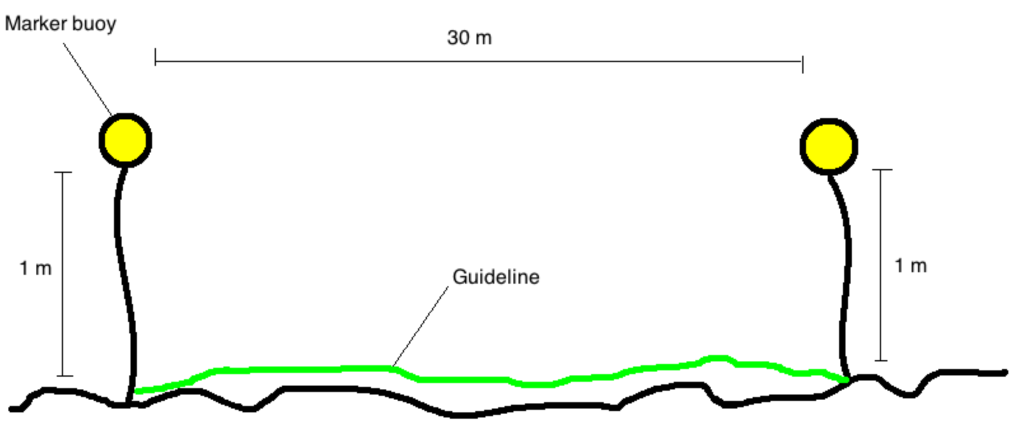
Gear required:

- Slate/clipboard and pencil
- Data sheet, waterproof copies available, contact guardiansofthedeep at gmail dot com
- Coldwater dive gear

Dive within the limits of your training and comfort. Go over your dive plan and emergency procedures before every dive. *Dives are to be completed during daylight hours.*

Index site markers:

Each index site is marked by two yellow submerged buoys 1 m off the ocean floor. The buoys are anchored 30 m apart. Buoys are connected by a guideline indicating the direction of the other end marker. Swim in that direction.



Site Setup

Objective: Swim from one marker buoy to the other while identifying and counting as many fish as possible. Do not to approach the index site until you AND your buddy are ready to go, this could disturb fish before you are ready to record data.

<u>General instructions:</u>

Navigate to the index site marker (GPS coordinates and landmarks described below). **Note the start time of the dive.**

You will find a floating start marker (index sites may be swam in either direction, each pass is considered a separate survey). From the start marker, begin counting fish and swimming in the direction of the other marker. **Note the time (minutes into the dive) when the fish count begins**.

Swim along the guideline. As you swim, **count and identify as many fish you can find**. You may wander away from the guideline up to +/- 1.5 m to look closer at any fish and check out any interesting crevasses etc. When you reach the end marker buoy, stop counting fish and **note the number of minutes into the dive**. Continue the dive and **note the end time and max depth for your whole dive**.

Large schools of fish may be approximated. Unknown species should be described (e.g. Unknown perch). Any distinguishing features can be noted in the comments section on the data sheet (e.g. perch with vertical black stripe).

Rate the current encountered <u>during the survey</u> as follows:

Current direction:	Swam against current		or	Swam with current
Current strength:	0 = None	1 = Weak	2 = Strong	

Note the visibility: Distance (in metres) at which a diver's bubbles are no longer visible.

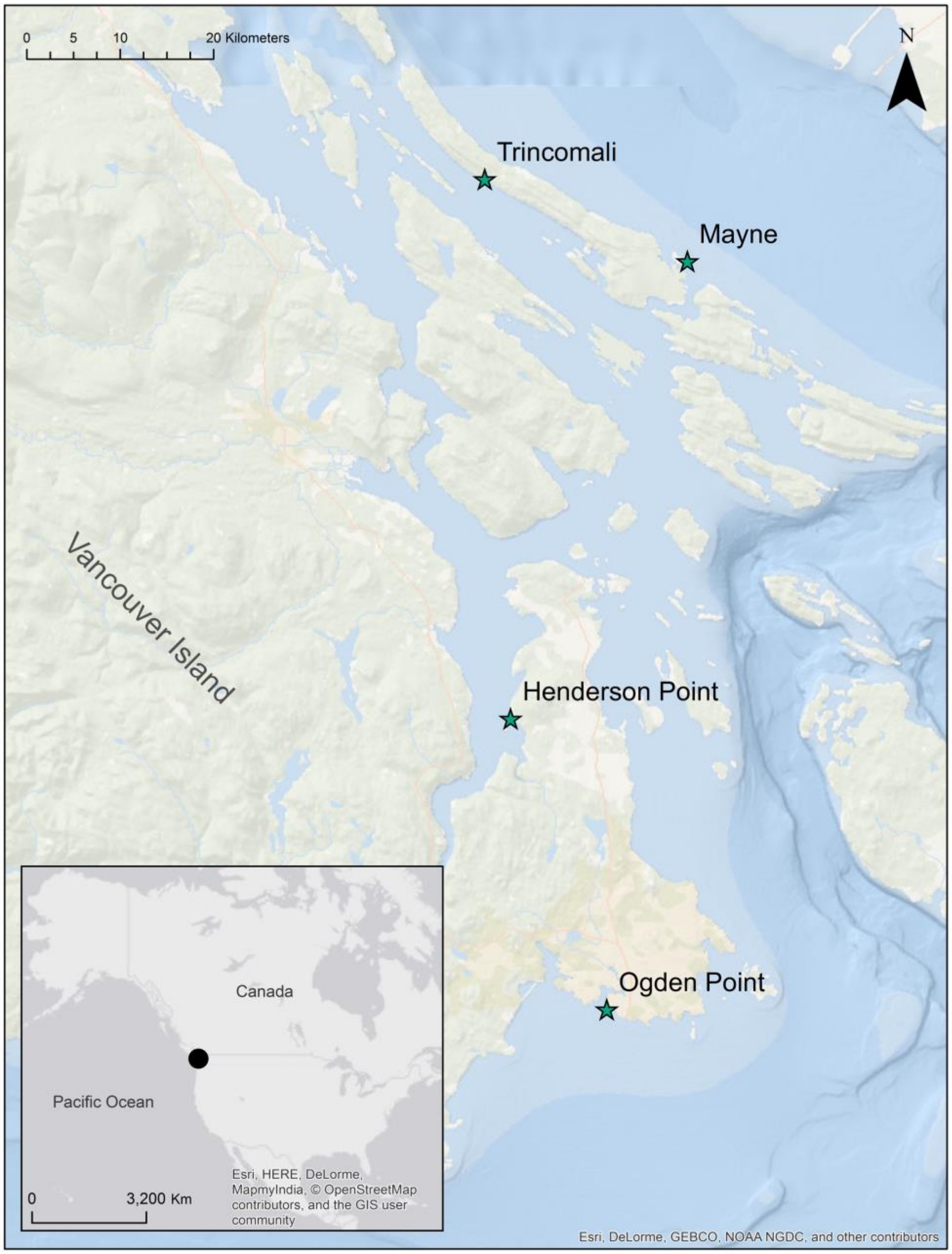
Rate the dive difficulty: Rate between 1 = easy and 5 = difficult. Factors to consider – coldness, buoyancy, gear malfunctions and other distractions.
Do not consider current or visibility in this rating.

Please ensure data sheets are legible. Submit your data sheets in person to Stefania Gorgopa or by sending a photo of the data sheet to guardiansofthedeep@gmail.com. Both dive buddies will submit fish data for the same dive. Both divers count separately, without collaborating, and therefore may be counting the same individual fish**.** ~~Buddies may only be paired once for the study, if diving in a group make sure to switch buddies each dive.~~ **This is no longer a requirement. Dive with the same buddy as much as you like.*

Do not study fish identification during the project duration (ends Oct 2017) as this could invalidate the knowledge assessment results. No adjustments to dive sheets shall be made if an unknown species is identified through post-dive discussion. Remember, this is a scientific monitoring project and data integrity is important. Please follow the methods outlined above.

Please complete the <u>online knowledge assessment</u> before your first dive.
Connect with other divers on the Facebook group facebook.com/GuardiansofthedeepBC.

Index Sites



Potential Hazards:
Boats, low visibility, current, kelp, wind and waves, fishing line (Ogden especially), possible to exceed max depth on wall dives

Ogden Point

Shore entry. Walk along the breakwater being careful on the granite blocks. Underwater sloped rocky wall.
Facilities – café, Note: Ogden Point Dive shop was permanently closed as of April 2017.

Near the 3rd red dive marker on the breakwater and the metal staircase, the underwater markers line up with the hummingbird and orca murals on the wall. Enter the water between the stair case and the orca mural. Descend to 12.8 m (add tidal height for actual depth) and turn seaward (right). The start marker is neon pink rope wrapped around a rock at 12.8 m depth. Swim towards the end marker maintaining a reference depth of 12.8 m keeping the rock breakwater to the right.

GPS coordinates of Humming bird and Orca murals:

Orca: 48.413350, -123.388617

Hummingbird: 48.413317, -123.389017

Marker depth: 12.8 m (42 ft) relative to chart datum (add tidal height for actual depth)

<u>Henderson Point</u>

Reefs/ridges/walls with shore entry point at the end of a trail from the parking area. Be careful getting down to the rocky beach from the trail.

Facilities – none, please be respectful of neighbours

Land marks:

From the flag pole swim out from shore at a heading of 245°. Swim down the slope and over a shallow reef at 10 m depth, and over a second reef at 12 m. The start marker buoy will be anchored at 12.4 m relative to chart datum (add tidal height for actual depth) just over the second reef. The guideline and the far end marker will be to your right.

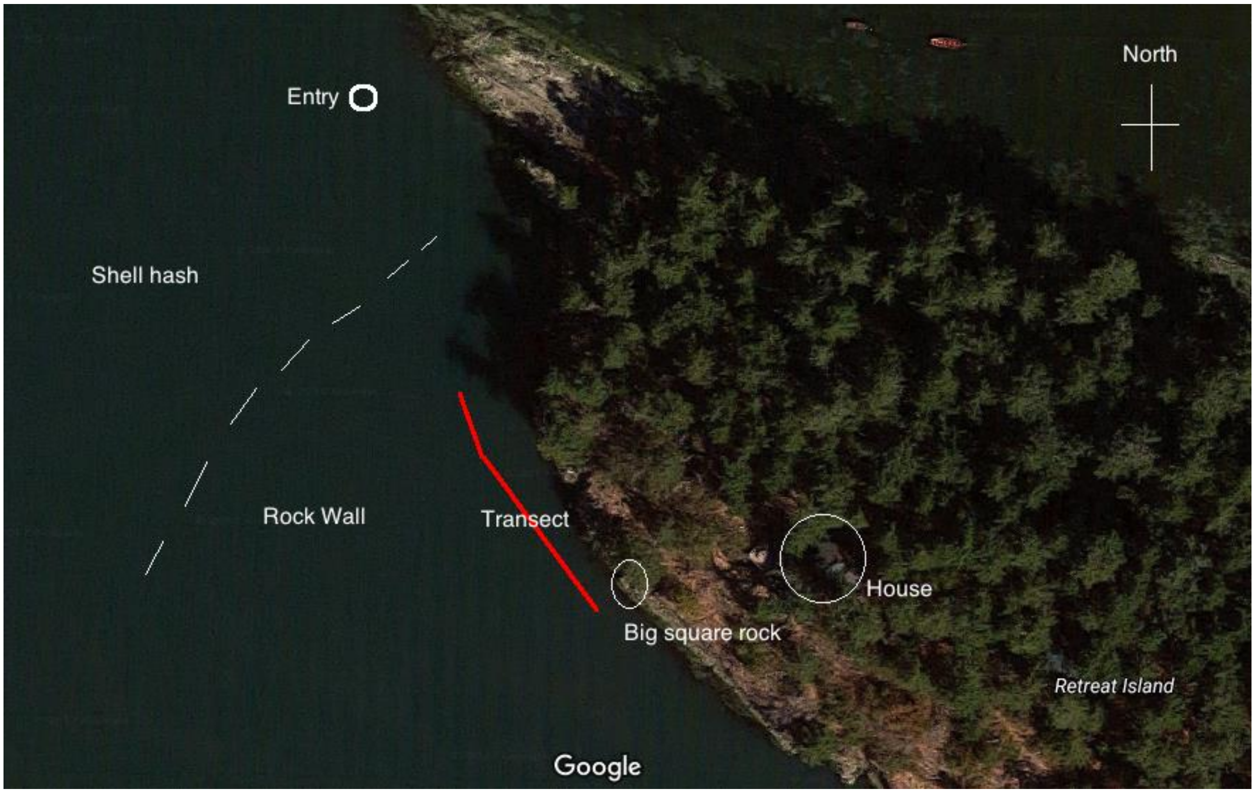
GPS coordinates: Flag pole: 48.597860, -123.480930

Marker depth: 12.4 m (41ft) relative to chart datum (add tidal height for actual depth)

Galiano Mayne
Boat accessible only. Dive this site at slack tide only. On shoals at the South-East side of Gossip Island at the northern entrance to Active pass. The transect is on the land ward side of the rock exposed at low tide.

GPS coordinates: 48*53.313’ N 123*18.661’ W

Marker depth: 7.9 m relative to chart datum (add tidal height for actual depth) (26 ft)



Galiano Trincomali

Boat accessible only. Start at the shallows on the west end of Retreat Island. Drop down to (~20ft) over the shell hash bottom. Swim East towards the rock wall along Retreat Island. The transect is at 11.3 m depth relative to chart datum, it begins near where the rocky boulders and shell hash slope meet and continues to the right hand side (if facing the wall).

GPS coordinates: 48*56.418' N 123*30.359' W

Marker depth: 11.3 m relative to chart datum (add tidal height for actual depth) (37 ft)

Depth conversions:

___ m X 3.28 = ___ ft ___ ft X 0.3048 = ___ m

Appendix C. Data Collection Sheet

Date:	Diver:	Buddy:
Location:	Difficulty: /5	Current: 0 1 2 with/against
Dive start time:	Survey start:	Visibility: m
Dive end time:	Survey end:	Max depth: m

Fish Species	**Tally**	**Total**	**Notes**
Copper Rockfish			
Quillback Rockfish			
Puget Sound Rockfish			
Yellowtail Rockfish			
Black Rockfish			
Brown Rockfish			
Black Eye Goby			
Lingcod			
Shiner Perch			
Kelp Perch			
Pile Perch			
Striped perch			
Kelp Greenling			
Painted Greenling			
Unknown Rockfish			
Unknown Sculpin			

Current : 0 = none, 1 = weak, 2 = strong   Dive difficulty: 1 = easy, 5 = hard

Visibility: distance at which you can no longer see buddies' bubbles

Appendix D. Certificate of Approval

Board of Record
University of Victoria

Certificate of Ethical Approval for Harmonized Harmonized Minimal Risk Study

Human Research Ethics Board (HREB)
Administrative Services Building
Room B202
PO Box 1700 STN CSC
Victoria, BC V8V 2Y2

Also reviewed and approved by:

UBC
SFU

Principal Investigators:	Primary Appointment:	Board of Record Approval Reference #:
Stefania Gorgopa	**University of Victoria**	**BC17-134**

Study Title: **Evaluating the reliability of citizen science SCUBA surveys for long term monitoring of Pacific Rockfish (Sebastes spp.)**

Study Approved: **09-May-2017** Expiry Date: **08-May-2018**

Research Team Members: **John P. Volpe, Supervisor (UVic)**

Sponsoring Agencies: 1. NSERC (pending); 2. Mitacs (pending)

Documents included in this approval:

Document Name	Approved version date
Human Research Ethics Application, Version 2	May 9, 2017
APPENDICES	
University of Victoria, Diving Safety manual for Open Water Diving, May 2015	May 9, 2017
Participant Consent Form	May 9, 2017
Diver Information Survey	May 9, 2017
Diver Site Briefing	May 9, 2017

This ethics approval applies to research ethics issues only and does not include provision for any administrative approvals required from individual institutions before research activities can commence.

The Board of Record (as noted above) has reviewed and approved this study in accordance with the requirements of the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS2, 2014).

The "Board of Record" is the Research Ethics board designated on behalf of the participating REBs involved in a harmonized study to facilitate the ethics review and approval process. In the event that there are any changes or amendments to this approved protocol, please notify the Board of Record.

Board of Record Research Ethics Board Representative
Name: Dr. Rachael Scarth
Signature: Rachael Scarth

Title: Associate VP Research Operations
Date: 09-May-2017

Appendix E. Annual Renewal Approval

Board of Record
University of Victoria

Certificate of Ethical Approval for Annual Renewal of Harmonized Minimal Risk Study

Human Research Ethics Board (HREB)
Administrative Services Building
Room B202
PO Box 1700 STN CSC
Victoria, BC V8V 2Y2

Also reviewed and approved by:

University of British Columbia
Simon Fraser University

Principal Investigators:	Primary Appointment:	Board of Record Approval Reference #:
Stefania Gorgopa	**University of Victoria**	**BC17-134**

Study Title: **Evaluating the reliability of citizen science SCUBA surveys for long term monitoring of Pacific Rockfish (Sebastes spp.)**

Renewal Approved: **10-MAY-2018** Expiry Date: **08-MAY-2019**

Research Team Members: **John P. Volpe, Supervisor (UVic)**

Sponsoring Agencies: **1. NSERC; 2. Mitacs**

Documents included in this approval:

Document Name	**Approved date**
Request for Annual Renewal – V1 – April 23, 2018	May 10, 2018

This ethics approval applies to research ethics issues only and does not include provision for any administrative approvals required from individual institutions before research activities can commence.

The Board of Record (as noted above) has reviewed and approved this study in accordance with the requirements of the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS2, 2014).

The "Board of Record" is the Research Ethics board designated on behalf of the participating REBs involved in a harmonized study to facilitate the ethics review and approval process. In the event that there are any changes or amendments to this approved protocol, please notify the Board of Record.

Board of Record Research Ethics Board Representative
Name: Dr. Rachael Scarth
Signature: Rachael Scarth

Title: Associate VP Research Operations
Date: 10-MAY-2018

Appendix F. Participant Consent

University of Victoria

Participant Consent Form

'Guardians of the Deep'

Evaluating the reliability of citizen science SCUBA surveys for long term monitoring of Pacific Rockfish (*Sebastes* spp.)

You are invited to participate in a study entitled "Evaluating the reliability of citizen science SCUBA surveys for long term monitoring of Pacific Rockfish (*Sebastes* spp.)" that is being conducted by Stefania Gorgopa.

Stefania is a graduate student in the Faculty of Social Sciences at the University of Victoria and you may contact her if you have further questions by emailing sgorgopa@uvic.ca.

As a graduate student, Stefania is required to conduct research as part of the requirements for a master's degree in Environmental Studies. It is being conducted under the supervision of Dr. John P. Volpe. You may contact Dr. Volpe at 250-472-4298.

This study is also being conducted in partnership with the Galiano Conservancy Association and REEF (Reef Environmental Education Foundation).

This work is supported by Mitacs through the Mitacs Accelerate program.

Purpose and Objectives
The purpose of this research project is to evaluate what aspects of diver expertise (training and experience) as well as environmental factors may affect dive survey results.

Importance of this Research
Research of this type is important because the marine ecosystem is at risk due to several factors including overfishing and habitat loss. Monitoring is important for ensuring conservation efforts are appropriate and effective. Subtidal monitoring is complicated and difficult given safety constraints and equipment requirements. By enlisting recreational divers to aid in data collection previously performed only by scientific divers the amount of data temporally and spatially available will be increased. This will also provide benefits to recreational divers by adding value to their dive experience and involving them in the local dive community.

Participants Selection
You are being asked to participate in this study because you are at minimum a certified open water diver (PADI Open water or equivalent) and 19 years or older.

What is involved

If you consent to voluntarily participate in this research, your participation will include writing an online knowledge assessment covering fish species identification, providing information about your dive certification level, diving experience and history (number of dives and geographic region of those dives). The diver survey and knowledge assessment should take about 30 mins to complete and will be administered online. You will also be asked to dive at selected sites around Victoria B.C. and Galiano Island between April 2017 and September 2017. The dive conditions and fish observation counts that you collect on each dive will be collected and analyzed along with the diver attributes and test score that you provide initially. To maintain the validity of the initial knowledge test and learning curve associated with diving we ask that you refrain from studying up on fish identification during the course of the study. Dive buddies will be assigned by the researcher and no two dives shall be completed by the same buddy pair. Logistics of coordinating dive buddies will be facilitated by the researcher. Divers will follow the directions to find the permanent transect at the dive site, these directions will be provided prior to the dive. Once at the permanent transect divers will note the time and then begin identifying fish and counting individual fish while swimming within visual contact of the permanent transect and their dive buddy. Once the divers reach the end of the transect they will note the end time or the amount of time they spent counting fish. The data will be recorded by divers on a dive slate and then transferred to a paper or electronic version to be sent to the researcher. Dive activities are expected to take between 3-5 hours per dive day including setup and take down at the site. Travel time from Victoria (or other) to the dive site will be in addition to that. Divers will be expected to do 1-15 days of diving over the study period (3-75 hrs over 6 months). Divers will be instructed on the scientific method and importance of adhering to the instructions to maintain the integrity of the study.

Inconvenience

Participation in this study may cause some inconvenience to you, including cost of dive gear (rental or purchase, and maintenance), and travel to dive sites.

Risks

There are some potential risks to you by participating in this research and they include the usual risks of injury associated with SCUBA diving. To prevent or to deal with these risks the following steps will be taken: dive safety takes a priority over data collection and research activities. Divers must only dive within their own limitations as set by their training and personal limits. Divers shall assess diving conditions and follow dive safety protocols consistent with their dive training. Divers shall communicate with their dive buddy prior to and during diving activities. Divers are able to abort diving activities for any reason at any time. All dives will be done in dive buddy pairs as is industry standard. Some information about each dive site will be provided prior to your dive in the form of a written or verbal dive site briefing. If an incident or near miss occurs during dive activities related to this project please notify Stefania Gorgopa once the situation is under control and the appropriate authorities have been contacted (ie. EMS).

Benefits

The potential benefits of your participation in this research include improving your knowledge of local species and dive sites. Contributing to our knowledge of vulnerable fish species. Contribute to our knowledge of how to treat citizen science data in a monitoring program and what aspects are most related to survey accuracy.

Voluntary Participation

Your participation in this research is completely voluntary. If you do decide to participate, you may withdraw at any time without any consequences or any explanation. If you do withdraw from the study your data will be used unless you request otherwise at which point it will not be used and removed from the data base. By submitting data to the database you consent to future use of the data in projects related to biological monitoring of subtidal fish species.

On-going Consent

Subsequent dive data submitted to implies that you continue to consent to participate in this research.

Anonymity

In terms of protecting your anonymity individuals will be identified in the data base using a unique numerical id code. Details about diver expertise, fish identification knowledge test score and diver survey data will be associated with your numerical id code. It may be possible for someone to identify you based on the dives you submit data for or the information provided in the online survey. This low level of anonymity is necessary to allow for individual effects on survey results to be quantified.

Confidentiality
Your confidentiality and the confidentiality of the data will be protected by not including the numerical id code from any published data. Data connecting your name with your numerical id code will be kept on password protected computers and drives. Hard copy data sheets will be kept in a secure cabinet.

Dissemination of Results
It is anticipated that the results of this study will be shared with others in the following ways: published in peer reviewed journal articles, thesis, dissertation as well as class and conference/scholarly presentations. Results will also be shared through partner organization newsletters and websites and partner meetings (Galiano Conservancy Association, and REEF).

Disposal of Data
Data from this study will not be disposed of and may be useful for future analysis. This data will be stored electronically on hard drives. Documentation associating diver names with diver identification codes will be destroyed (electronic data erased), hard copy data sheets shredded.

Contacts
Individuals that may be contacted regarding this study include Stefania Gorgopa (information at the beginning of the consent form.

In addition, you may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Human Research Ethics Office at the University of Victoria (250-472-4545 or ethics@uvic.ca).

Your signature below indicates that you understand the above conditions of participation in this study, that you have had the opportunity to have your questions answered by the researchers, and that you consent to participate in this research project.

_______________________ _______________________ _______________

Name of Participant Signature Date

Photography and Video release
Over the course of this study photos and videos may be taken of participants to be used while sharing the results of the research and to promote the citizen science program to others.

Do you consent to the use of images and videos of yourself participating in the project to be used in this way?

[ ] Yes [ ] No

A copy of this consent will be left with you, and a copy will be taken by the researcher.

Appendix G. Species ID Quiz Sample Questions

Page 7

Question 5

top of image species: Type here

bottom of image species: Type here

Page 17

Question 15

Top Species	Type here
Bottom Species	Type here

Appendix H. Diver Pair Precision

Table H.1. Diver-pair precision of SCUBA-derived citizen science data collected by 30 unique diver-pairs across four dive sites. We sampled diver-pairs from a pool of 29 divers with replacement. The diver pool included a range of experience levels (e.g. recreational and Scientific Diver certifications). Diver-pair precision is the Bray-Curtis similarity between the divers' reported rockfish-finfish communities (abundance by species). Data is organized by day of year (DOY).

Diver-Pair Precision	DOY	Recreational Diss.	Scientific Pair	Quiz Diss.	Nth dive Diff.	Total Dives Diss.	Site	Kelp	Current	Difficulty	Visibility
0.16	148	2	Sci-Sci	1	0	0.01	H	5.2	1.5	0	0.03
0	148	3	Sci-Sci	5	0	0.92	H	5.2	1.5	0.2	0.19
0.59	148	1	Sci-Sci	4	0	0.91	H	5.2	2	0.2	0.08
0.14	176	2	Sci-Sci	4.25	1	0.4	H	5.2	1	0.67	1.6
0.04	176	0	Non-Sci	4.25	2	1.11	H	5.2	-1	0.33	0
0.46	176	2	Non-Sci	0	0	0.71	H	5.2	1	1.8	0.82
0.67	187	3	Non-Sci	3	0	1.81	M	1.5	-1	0.33	0.09
0.72	187	0	Non-Sci	1.5	1	0.7	M	1.5	-1	0	0.4
0.6	187	3	Sci-Sci	4.5	1	1.11	M	1.5	-1	0.33	0.11
0.1	189	3	Non-Sci	7	2	1.31	H	5.2	-0.5	0.33	1
0	197	3	Non-Sci	7.5	5	1.45	O	12.7	0	0	0.4
0.51	193	0	Sci-Sci	0	3	0.16	O	12.7	0	0.33	0
0.47	194	0	Non-Sci	8.75	4	1.1	O	12.7	-1	0.33	2.09
0.4	203	3	Non-Sci	8	2	1.48	T	0	0.5	0.33	0.18
0.23	203	0	Non-Non	8.5	1	0.13	T	0	0.5	0	3.33

Table G.1 Continued:

Diver-Pair Precision	**DOY**	**Recreational Diss.**	**Scientific Pair**	**Quiz Diss.**	**Previous Participation Diff.**	**Total Dives Diss.**	**Site**	**Kelp**	**Current**	**Difficulty**	**Visibility**
0.25	203	3	Non-Sci	0.5	1	1.61	T	0	0	0.33	2
0.48	203	3	Sci-Sci	6.5	7	0.06	M	1.5	1	1	0.67
0.56	207	1	Non-Non	4.25	5	0.71	H	5.2	1	1	0.11
0.56	210	0	Non-Sci	0.75	1	0.82	M	1.5	0.5	0	0.38
0.75	210	1	Non-Sci	1.5	0	0.07	M	1.5	0.5	0	1
0.59	210	1	Non-Non	2.25	1	0.75	M	1.5	0	0	2.4
0.8	210	0	Non-Sci	2	0	0.23	M	1.5	0	0.33	0
0.46	210	1	Non-Sci	1.5	0	0.8	M	1.5	0	0	1.29
0.34	210	1	Non-Non	0.5	0	0.58	M	1.5	0	0.33	1.29
0.2	210	2	Non-Non	8.75	3	1.35	T	0	-1.5	0	0.09
0	218	2	Non-Sci	7.25	0	0.73	H	5.2	1.5	0	3.77
0.27	229	0	Non-Non	1.5	0	0.02	O	12.7	-1	0	0
0.6	239	2	Non-Non	2.5	2	1.83	M	1.5	1	0	0.11
0.51	287	1	Sci-Sci	4.5	3	1.71	M	1.5	-1	0	0.19
0.72	287	0	Sci-Sci	0.5	12	0.8	M	1.5	-1	0	4.39

Appendix I. Species List

List of 30 species analyzed in Chapter 2, including seven rockfish species.

Copper Rockfish, *Sebastes caurinus*
Quillback Rockfish, *Sebastes maliger*
Puget Sound Rockfish, *Sebastes emphaeus*
Yellowtail Rockfish, *Sebastes flavidus*
Black Rockfish, *Sebastes melanops*
Brown Rockfish, *Sebastes auriculatus*
Black Eye Goby, *Rhinogobiops nicholsii*
Lingcod, *Ophiodon elongatus*
Shiner Perch, *Cymatogaster aggregata*
Kelp Perch, *Brachyistius frenatus*
Pile Perch, *Damalichthys vacca*
Striped Perch, *Embiotoca lateralis*
Kelp Greenling, *Hexagrammos decagrammus*
Painted Greenling, *Oxylebius pictus*
Scalyhead Sculpin, *Artedius harringtoni*
Tiger Rockfish, *Sebastes nigrocinctus*
Herring, *Clupea clupea*
Crescent Gunnel, *Pholis laeta*
Longfin Sculpin, *Jordania zonopes*
Tubesnouts, *Aulorhynchus flavidus*
Pipefish, *Syngnathus leptorhynchus*
Pacific Salmon, *Onchorhynchus spp.*
Decorated Warbonnet, *Chirolophis decoratus*
Cabezon, *Scorpaenichthys marmoratus*
Whitespotted Greenling, *Hexagrammos stelleri*
Grunt Sculpin, *Ramphocottus richarsonii*
Northern Ronquil, *Ronquilus jordani*
Sailfin Sculpin, *Nautichthys oculofasciatus*
Padded Sculpin, *Artedius fenestralis*