Examining the Influence of Depth and Tidal Current on Nearshore Fish Communities Using Scientific and Citizen Science Data

By

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B.Sc., Vancouver Island University, 2019
B.A., University of Calgary, 2008

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We acknowledge with respect the Lekwungen peoples on whose traditional territory the university stands and the Songhees, Esquimalt, and W̲SÁNEĆ peoples whose historical relationships with the land continue to this day.

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Abstract

Learning about marine ecosystems is challenging; organisms move, abiotic conditions change, underwater environments are difficult to sample, and in BC, the coastline is lengthy and largely remote. This thesis explores two ways to address these challenges, first through developing surrogates and second through using citizen science data. Physical aspects of the environment are relatively easy to sample and can be used to explain observed changes or differences in biodiversity, which are often difficult to sample. Characteristics of marine biodiversity can then be inferred based on the intensity or extent of the abiotic surrogate and habitats critical for commercially important or endangered species, or habitats that support increased biodiversity or ecosystem services can be identified. Still, information about taxa distribution and abundance are required to determine the success of these abiotic surrogates in explaining biodiversity. Gathering abundance data on wide temporal and spatial scales is expensive and difficult to achieve with small scientific diving crews. However, the recreational SCUBA diving community is well-positioned to aid in filling biological data gaps. In this study, depth and current speed are evaluated for their effectiveness at explaining fish community biodiversity using a scientifically collected data set. We found depth to be a suitable abiotic surrogate for fish species richness and abundance, but tidal current speed was ineffective at determining trends in fish biodiversity. Citizen science data were examined to demonstrate how robust these data are for use in scientific studies through the exploration of two case studies. The first case study explored how lingcod (*Ophiodon elongatus*) abundances changed over time due to fishery management efforts, and the second case study examined how current speed, as identified by citizen science surveyors, could be used as an abiotic surrogate for fish biodiversity.

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Chapter 1: Introduction

I would like to begin by acknowledging with respect the Lekwungen Peoples on whose traditional territory the University of Victoria stands and the Songhees, Esquimalt and WSÁNEĆ Peoples whose historical relationships with the land continue to this day. I also acknowledge that this research was conducted on the traditional territories of Snuneymuxw, Stz'uminus, Hul'qumi'num Treaty Group, W̱SÁNEĆ, and scəẃaθən məsteyəxʷ. Throughout my life I benefit daily from being an uninvited guest on First Nation territory. I am deeply grateful to the countless generations of People who have come before me and stewarded these lands. I hope that through my actions in this life that I can also be a good steward of these lands. I offer my gratitude to the 3,272 fish that unknowingly contributed directly to this research.

This is not a typical biology thesis introduction chapter. I begin by briefly introducing my thesis chapter and my work, highlighting the research questions asked and the data sets used. However, most of my introduction focuses on how my experiences throughout my masters have shaped me as a researcher and have changed the way I will choose to conduct science in my future. I am learning what it means to combine Western and Indigenous science and the moral, ethical, and spiritual aspects of both, to better understand my relationships to marine organisms and environments. Having space to communicate what I have learned on these topics is as important to me as communicating what I have learned from the Western ecological science I have conducted.

Learning about marine ecosystems is challenging; organisms move, abiotic conditions cycle and are changing, underwater environments are difficult or dangerous to sample, and in BC, the coastline is lengthy and largely remote. This thesis explores two ways to address these challenges; first through exploring how abiotic conditions, that are relatively easy to sample, can be used to describe changes in fish biodiversity, and second, through collaborating with recreational scuba divers to collect fish species taxa and abundance data. Physical aspects of the marine environment, such as temperature, salinity, depth, substrate type, compaction of soft substrates, rugosity, slope, or current speeds (McArthur et al. 2010), are relatively easy to sample. These aspects have been used to explain observed changes or differences in marine fish, invertebrate, or algae biodiversity, which are often difficult to sample. Characteristics of marine biodiversity of interest can then be inferred based on the magnitude or extent of these physical conditions or surrogates. Thus, it is possible to identify habitats critical for commercially important or endangered species, or habitats that support increased biodiversity or ecosystem services. Still, information about taxa distribution and abundance and the surrogates are required to determine the success of surrogates in explaining biodiversity. Gathering abundance data on fish, invertebrates, and algae is expensive and difficult to achieve. However, the recreational SCUBA diving community is well-positioned to aid in filling biological data gaps, as recreational divers are more abundant, dive more frequently, and in more areas, than small, seasonal scientific dive operations. In this study, two abiotic surrogates, depth and current speed, are evaluated for their effectiveness at explaining fish biodiversity using a scientifically collected data set from the Salish Sea, BC. Fish biodiversity was measured by evaluating differences in fish species richness, abundance, biomass, and community composition between two current regimes ('high' and 'low') and two depths (3 meters and 15 meters below chart datum). We found depth to be a suitable abiotic surrogate for fish species richness and abundance, but no statistically significant differences in fish biodiversity were detected between the two current regimes tested. Citizen science data from Reef Environmental Education

Foundation (REEF, reef.org) were examined to demonstrate how robust these data are for use in scientific studies. Data from REEF spans 22 years and 572 locations along the BC coast, and over 150,000 species abundance records have been collected during this time. Basic abiotic and biotic data analyses are shown to demonstrate the characteristics of the data, followed by an analysis of the two surveyor experience levels on fish species richness and abundance data collection. These data were then explored using two case studies. The first case study examines how lingcod (*Ophiodon elongatus*) abundances changed over time due to fishery management efforts in Howe Sound, and the second case study examines how current speed, as identified by citizen science surveyors, could be used as an abiotic surrogate for fish biodiversity.

Having a space to communicate how my master's program has influenced and changed me as a person and researcher is important to me. Not only are we as master's students contributing to our collective understanding of the world, but we are also influencing how science will be done in future generations. The knowledge that we gain and how we are changed by our experiences throughout our degrees reflects the values of the post-secondary institutions we choose to attend. Recognizing who we are as researchers, acknowledging our background, biases, beliefs, and assumptions of the world, and understanding why we care about our research topic is important to properly understand the context behind why and how our science was conducted in the first place (Wilson-Hokowhitu, 2019).

I would like to acknowledge that my research comes from a place of great privilege. I am a white settler of mixed European ancestry with over ten years of training in the Western university worldview. With this background comes certain biases, beliefs, and assumptions about the world. I have two bachelor's degrees, one in political science and economics and another in biology. I began my academic journey in marine biology after spending years SCUBA diving in the Salish Sea, witnessing many phenomena I could not understand. I decided to go back to school to broaden my understanding of this ecosystem and my connection to it. However, through the course of both these degrees I struggled with ideological challenges of how to do the work in ethical and sustainable ways amidst a toxic culture focused almost solely on progress for the sake of progress.

During my master's degree, I had the incredible opportunity to take a course called "Indigenous and Decolonizing Methodologies" with Dr. Sarah Hunt. In this course we learned how Western science entrenches the white, patriarchal status quo which often silences other ways of knowing. This narrow view limits how those of us who are scientists coming from a Western, positivist tradition can come to understand our world (Kuokkanen, 2007). We also learned how to conduct research with, by, and for Indigenous Peoples in ways that are ethical, respectful, and supportive of Indigenous rights (Tuhiwai Smith, 2013). Our work as ecologists is always conducted on Indigenous territory, thus acting in ways that are respectful of and uphold the values of First Nation communities should be the most valuable work we can hope to accomplish.

Western science typically assumes an objective, positivist stance which does not offer much space to consider how researcher or institutional biases influence their science (Kuokkanen, 2007; Tuhiwai Smith, 2013). It is important to always look critically at the lens through which we view the world. By not acknowledging that we conduct ourselves and our science from a set of assumptions, we risk overlooking or discounting other ways of knowing and understanding the world, thus limiting us in many aspects of our lives, including the solutions we produce to collective problems such as climate change (Kuokkanen, 2007). It is important for all of us to learn how to see the world from multiple points of view rather than only the dominant Western science point of view (Reid et al., 2020). A few examples of other lenses through which to view the world are Indigenous perspectives, racialized perspectives, spiritual perspectives, or animal or plant-centered perspectives.

Western science knowledge generation is often done in an extractive way with the goal of generating facts to support theories of how we think the world works. However, Indigenous methodologies tell us that knowledge generation can be done in ways that allows us to learn how to be in relationship with our environment (Wilson-Hokowhitu, 2019). Post-secondary degrees through western science-based institutions are often conducted on time scales not conducive to meaningful connection to the places or entities we are researching. My inability to spend time in place at my research sites or treat my research as a ceremony negatively impacted my ability to connect to my work, and I feel like I stole knowledge from those places I have no connection to or relationship with. At a time when humans are destructively out of sync with our surroundings, finding better ways of connecting to our planet and learning to heal ourselves through those better connections, I think, is the most important thing we should be doing. I have come to learn how Western ecology is deeply entrenched in imperialistic human-centered values, yet routinely writes humans out of ecological processes, or only includes them in a human-centric way. I am understanding more and more how humans have coevolved with non-human entities over millennia and how the removal of people from the ecosystem has played a role in the current poor health of the planet and of humanity (Jackley et al. 2016; Toniello et al. 2019).

Unfortunately, due to the timing of my research and when the Indigenous and Decolonizing Methodologies course was offered, I was unable to incorporate much of what I learned into my two research chapters as data collection had occurred and the chapters were nearly complete. As a result, this research was conducted primarily through the lens of Western science and much more could be said on my research topic that is outside of the Western science scope. However, my research does, in a small way, incorporate ways of knowing generated by people not necessarily trained through Western science institutions to better understand how tidal current influences fish communities. While my second chapter centers around scientifically collected data from ten locations in the Southern Gulf Islands during the winter of 2019-2020, my third chapter centers on citizen collected data collected all along the BC coast over the past 22 years. By looking at the same topic using multiple data sets and goals for those data, we gain broader understandings of how our world operates (Reid et al., 2020).

Citizen science data are not typically seen by the Western scientific community as rigorous or robust enough for inclusion in scientific research (Dickinson et al. 2010; Tulloch et al. 2013; Theobald et al. 2015). This stance can be seen as elitist and exclusionary, reserving science for only those privileged enough to participate in it. By encouraging and training everyone to collect publicly available data, better understandings of the world can result, and more minds can contribute to creating positive solutions for our collective problems. The use of digital platforms such as iNaturalist are starting to change these views, especially since citizen generated data are spatially widespread, focus on a wide variety of taxa, and are publicly available. Science therefore becomes less of a black box, more accessible, and more engaging. In my citizen science chapter, I explore how data collected by non-scientists can provide valuable insights into data limited areas that could inform policy changes at the federal level. People sometimes forget that everyone does science almost every day, we learn from our experiences and, through what we have learned, we make assumptions about the world and refine how we interact with those around us. The world can be interacted with and interpreted through many lenses including Western science, Indigenous ways of knowing, or citizen science. Incorporating multiple ways of doing science and of understanding our world makes our research more inclusive and collaborative (Kimmerer, 2013; Reid et al., 2020).

If I could go back and incorporate what I have now learned into this degree, I would first contact local First Nations, preferably Nations on whose territory I already have a connection to (e.g. territories on which I live, work, and/or play), to inquire if they would be interested in me working with them to answer an ecological question that is important to them. If I were to do these same projects again, I would like to include traditional and additional local ecological knowledge regarding productive fishing spots for benthic associated fish species, oral histories of the region, and locations where marine mammals and/or birds have been observed feeding. It would be interesting to see how the locations identified via these other ways of knowing overlap, or do not overlap, with the locations a priori selected for this research and to learn what these other ways of knowing understand about how tidal current influences fish communities. I would also like to provide time for ceremony and for asking for proper consent from non-human entities. Taking a moment before jumping in the water to introduce ourselves to the ocean and animals, asking for permission to enter and collect data, and waiting for an answer can foster so much connection to place and is a practice I have adopted into my personal SCUBA diving. It fills me with much more gratitude, I am more observant, and have a more positive experience when I take a moment to acknowledge nature as a fellow being and this is a practice I wish I knew to conduct prior to collecting the data for this research. Additionally, it would have been helpful to take the time to dive the sites prior to collecting data and get to know them better, perhaps using the time to develop some basic maps which would have helped in determining optimal locations for the surveys and tilt current meter placement. Any of these alternative routes to completing my degree would likely increase its duration. It takes time to develop trust and relationships with people whose stories I would be gathering and to adequately include and represent Indigenous knowledges in my research, but it is a much more ethical way to conduct ourselves as scientists.

Indigenous and Decolonizing Methodologies taught me ways of conducting science that align with my values and provided me with space to view my research practices more critically. This course had a huge impact on who I am and how I interact with my work and surroundings. Through taking this course, I am learning to view my thoughts and actions critically to uncover how my background impacts how I interact with the world. While I still struggle with how to conduct ecological research in ways that provide space for ceremony and proper consent from non-human entities, this course has provided me with the tools to ensure my future work is conducted in a good way, a way that honours and respects all of Creation.

I am just beginning to understand how I contribute to the perpetuation of colonialism through my actions and ecological research. Going forward I will choose actions that reflect my desire to act as a respectful guest on First Nation territories that I now live, work, and play on. My future career goal is to work with Fisheries and Oceans Canada, where meaningful collaboration with Indigenous Peoples is of growing importance. My future work will undoubtedly be conducted alongside members of First Nations and learning how to conduct my scientific work in a manner that is supportive of Indigenous rights and decolonization is essential. I choose to conduct my future research with, by, and for Indigenous Peoples in ways that align with the values and needs of specific Nations, and in ways that increases our connections to each other, the other than human entities, and this planet.

My time spent at the University of Victoria has altered how I see the world and how I choose to interact with it. I have been able to witness how the University is changing how it conducts itself to include more ways of knowing and understanding the world. These values were reflected in the teachings I was a part of and will be reflected in how I will represent the institution going forward in my career. I am deeply grateful for the experiences I have had.

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Chapter 2: Depth is an important driver of nearshore benthic fish communities in the Salish Sea

Abstract

In this study, deeper, rocky habitats were found to support increased fish species richness and abundance in the Southern Gulf Islands of BC Canada; however, tidal current speed did not have a significant effect on fish biodiversity. High and low current sites were surveyed at two depths (3 and 15 meters below chart datum) by SCUBA divers from October 2019 to March 2020 in the Southern Gulf Islands. Fish biodiversity was characterized by fish species richness, abundance, biomass, and community composition. Current, temperature, salinity, and primary substrate type were collected to investigate relationships between these metrics and fish biodiversity. Non-parametric statistics, nMDS plots, analysis of similarity tests, and linear mixed effect models were used to determine differences in fish biodiversity between high and low current sites and survey depths. Results from these analyses indicate that univariate measures such as fish species richness and abundance differ significantly between survey depths but not by current speed. Additionally, multivariate analyses of fish biodiversity indicated a significant effect of depth, but not current speed, on fish abundance. The most abundant species observed were *Artedius harringtoni, Hexagrammos decagrammus, Jordania zonope*, *Rhinogobiops nicolsii*, and *Sebastes caurinus*, and there were significant differences in abundances /or lengths of four of these five species across current categories and/or survey depths. This is the first study to explore how depth and tidal current influence fish communities in the Salish Sea.

Introduction

Protecting marine biodiversity is key to ensuring the stability and resilience of our oceans and in maintaining the ecosystem services humans depend on (Holmlund and Hammer 1999; Covich et al. 2004; Sala and Knowlton 2006; Worm et al. 2006; Palumbi et al. 2008). However, collecting widespread marine biodiversity data necessary to support effective management or conservation efforts is not always feasible due to the challenging and time-intensive methods of collecting subtidal species richness and abundance data. These data are often collected via scuba surveys which are depth and time limited, via hydroacoustic data collection or ROV surveys which require extensive post-survey annotation, or via destructive or damaging seining, trawling, or fishing surveys. Since biotic data are often difficult to obtain, abiotic variables that appear to influence specific species or communities can be used to inform species distributions. Information on species distributions can be helpful in determining areas of habitat suitable for commercially valuable or endangered species or areas that support increased biodiversity or ecosystem services. These abiotic variables, or surrogates, are especially useful in remote areas, or in identifying potential areas for protection (Ward et al, 1999; Rodrigues and Brooks 2007, Mellin et al. 2011; Rees et al. 2014; McHenry et al. 2017). Here, surrogates are defined as “an attribute of an ecosystem that is used as a proxy for another aspect of biodiversity of interest” (Sato et al. 2015). Abiotic surrogates have been identified as physical characteristics such as habitat, depth, temperature, salinity (McHenry et al. 2017), or current (Baynes and Szmant 1989; McHenry et al. 2017, Haak et al.

2019, Rubidge et al. 2020). Here, we explore the use of tidal current and depth as abiotic surrogates for fish species diversity and abundance in the Salish Sea.

Tidal currents often result in areas of higher productivity and invertebrate and fish biodiversity (Baynes and Szmant 1989; Palardy and Witman 2011; Embling et al. 2012; Pitcher et al. 2012; Fenberg et al. 2015; Kregting et al. 2016; Rubidge et al. 2020; Nephin et al. 2020). Previous studies show currents promote water mixing that brings nutrient-rich water to the surface (Thomson 1981; Leonard et al. 1998) and has been linked to increased abundances of phytoplankton and zooplankton (Batten and Crawford 2009; Ueno et al. 2010; Moser et al, 2017; Blauw et al. 2012). Bottom-up processes have been shown to drive trends in biodiversity (Leonard et al. 1998; Ware and Thomson 2005; Watson et al. 2011; Fenberg et al. 2015) and this increase in abundance of low trophic level species results in increased fish biomass. In addition to influencing food webs, currents have also been shown to connect communities by circulating reproductive propagules (Siegel et al. 2008; Palardy and Witman 2011; Watson et al. 2011).

Depth has also been shown to influence fish communities, but several other physical factors are correlated with depth, such as light, temperature, or pressure. Light availability results in increased seaweed abundance at shallow depths, providing habitat structure and food for lower trophic level fish prey species. These shallower waters also experience more variability in temperature, salinity, and surface wave motion (Stefansdottir et al. 2010) which may be difficult for some species to tolerate. Depth preferences may also vary with life-stage, with recently settled juveniles preferring shallower habitats for some species (Love et al. 2009; Sobocinski et al. 2018).

This project has three objectives. First, we will determine if temperature and salinity vary with tidal current speed. Second, we will determine how fish species richness, abundance, biomass, and community composition vary with high and low tidal current speeds and 3 meter and 15 meter depths (below chart datum). The 3 meter depth allowed for the fish community residing in the kelp/seaweed habitat to be surveyed. The 15 meter depth is typically deeper than most kelps and seaweed grow and experiences less variability in temperature, salinity, and water motion from waves and boat traffic. This depth was also the deepest depth that could be surveyed while following Canadian Association of Underwater Scientist Level 1 standards. Third, we will explore how the five most abundant species observed differ in terms of lengths and abundances between the current regimes and transect depths.

Based on previous studies we expect to see increased fish species richness, abundance, and biomass (Baynes and Szmant 1989; Gibson et al. 1996; Pitcher et al. 2012;) and fewer recently settled juvenile fish in high current areas and at 15 meter depths (Love et al. 2009; Sobocinski et al. 2018; Haak et al. 2019). Fish species flourish at different optimal current speeds. Higher tidal current velocities (> 120 cm/sec) were found to support higher abundances of *Sebastes melanops* young-of-year (Markel et al. 2017) and *Sardinops sagax* (Robinson et al. 2007), and lower tidal current velocities (< 63 cm/sec) supported higher abundances of *S. caurinus, S. maliger*, and *S. auriculatus* young-of-year (Markel et al. 2017), *Ammodytes hexapterus* (Robinson et al. 2013), and juvenile *Albula vulpes* (Haak et al. 2019). These species-specific differences in current speed preference may dominate community-level trends (Gibson et al. 1996; Tolimieri et al. 2009; Díaz-Astudillo et al. 2017; Viehman and Zydlewski 2017). Only two studies could be found exploring how benthic fish biodiversity differs with tidal current speed. Haak et al. (2019) looked at only one species (*Albula vulpes*) in its juvenile life stage in the Bahamas and found increasing abundances at current speeds of less than 3.2 cm/sec. A study by Eggertsen et al. 2016 in

Mozambique analysed benthic fish communities in current speeds up to 144 cm/sec and found no significant differences in abundances or trophic levels with increasing current speeds. Studies examining fish community compositions between areas of high or low current or by depth have not been tested in the Southern Gulf Islands of BC.

This study contributes data to a relatively data-poor region of the BC coast where no studies have explored how tidal current influences nearshore fish diversity, and few or no studies exist on some of the species we observed. Human demands for space and resources within the Salish Sea are increasing and the information provided here can help inform marine spatial planning efforts by providing more information on fish species in the region and more broadly by evaluating the use of tidal current and depth as abiotic surrogates for fish biodiversity.

Methods

Site selection

Ten sites were selected for this study in the Southern Gulf Islands, BC. This group of islands is located within the Strait of Georgia, a relatively shallow, near estuarine basin, greatly affected by seasonally driven, freshwater run-off from the Fraser River (Thomson, 1981). Water circulation pattens are driven by oceanic in and outflows through the Juan de Fuca Strait and from Fraser River outflows (especially in the southern region of the Strait of Georgia) (Thomson, 1981). The subtidal habitat in the Strait is dominated by soft substrates, with rock substrate contributing to only 25.7% of the area from the intertidal down to 20 meters subtidal (Thomson, 1981). Sites with either high or low current speeds were identified for this study based on local knowledge, site scouting, and tidal current modeling from Fisheries and Oceans Canada, and were refined by current speed data collected during the study. Sites were selected to include locations over rocky substrate (bedrock, boulder, or cobble) to a depth of 15 meters below chart datum.

The sites chosen are within Snuneymuxw, Stz'uminus, Hul’qumi’num Treaty Group, W̱SÁNEĆ, and scəw̓aθən məsteyəxʷ territories; we used Hul’q’umin’um’ site names when they could be found in the literature alongside the English names in the figures (Rozen, 1985; Abramczyk, 2017).

Current data collection

Tilt Current Meters (Lowell Instruments, LLC., Figure 1) were configured to record the current speed for a 15 second duration each minute at a burst rate of 8 Hz. The burst rate determines the rate at which observations are recorded in order to account for small oscillations of the current meter due to water movement, and the rate used here was recommended by Lowell Instruments, LLC. Recording current speeds using a 15 second duration with 8 Hz burst rate allows increased battery life as compared to continuous current speed recording. The recorded speeds were averaged over the 15 second duration to produce one current speed value per minute. The maximum recording speed of the Tilt Current Meters is 120 cm/sec.

Figure 1: Tilt Current Meters (Lowell Instruments LLC) were deployed in 10 meter depths (below chart datum). These loggers require a large, flat area free of obstructions to move freely.

Tilt Current Meters were placed at 10 meters depth below chart datum in areas close to where the fish and substrate surveys were conducted. The main challenge with placing the Tilt Current Meters is the large, flat area free of any rock or kelp necessary for them to move in 360° to accurately record current observations. At many sites, it was challenging to find such locations, therefore the location of the current meter was not always directly between where the 3 and 15 meter fish and substrate transects were conducted. Current speeds were recorded at all sites for 41 days, from 16 December 2019 to 26 January 2020.

Site categorization

Sites were categorized as either high or low current sites based on the average daily maximum current speeds recorded at each site via the Tilt Current Meters. Other studies have also used maximum current speeds in their studies (Haak et al. 2019; Rubidge et al. 2020). Maximum current speeds were used as these extreme conditions may represent abiotic thresholds for certain species (Liao 2007). Once a threshold is reached or exceeded it may become difficult for individuals of certain species to thrive under those conditions and the risk increases of being outcompeted by species who have higher thresholds, which may result in community level change.

Daily maximum current speeds were extracted for each site by determining the maximum recorded current speed over each 24-hour period. All daily maximum current speeds were plotted from the fastest speed to the slowest speed, and the inflection point in the curve was determined using the inflection package in R (Christopoulos, 2019). Any site with a mean daily maximum current speed faster than the inflection point current speed was categorized as a high current site, and this categorization was consistent with site conditions experienced by divers (e.g., short slack windows, current experienced underwater). This resulted in four high and six low current sites (Figure 2, generated using the PBSmapping package in R (Schnute et al, 2019; R Core Team, 2020)).

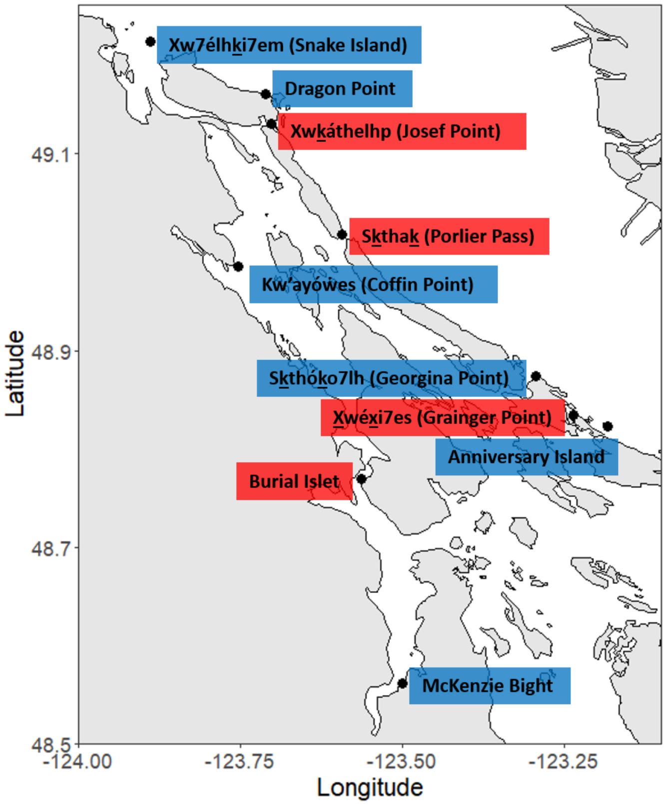

Figure 2: Map of survey sites within the Southern Gulf Islands BC Canada. High current sites are coloured red, low current sites are coloured blue. Current speed categories were defined by using the inflection point of all daily maximum current speeds at all sites. Hul’q’umin’um’ site names are used when they could be found in the literature.

Temperature and salinity data collection and analysis

Temperature and salinity data were recorded at 10 meters depth (below chart datum) from 16 December 2019 to 26 January 2020. Temperature was measured every minute using Tilt Current Meters and salinity was measured every 30 minutes using CT loggers from Star Oddi. The Star Oddi CT loggers were placed approximately 2 meters away from the Tilt Current Meters and were attached to a line weighed down by a 15-20lb weight with a small float on the top of the line to ensure the logger remained approximately 1 meter off the substrate. Salinity data at Xwk̲áthelhp (Josef Point) are not available as the CT logger was lost. Daily mean temperature and salinity values were calculated by averaging the temperature or salinity values recorded at each site over each 24-hour period.

Differences in site daily mean temperature and salinity values between high and low current sites were analysed using Mann-Whitney U test as the data were not normally distributed.

Fish and substrate data collection

All fish in the study were surveyed using non-destructive, observational techniques with animal ethics approval from the University of Victoria Animal Care Committee (2019-020 (1)). The fish and substrate data collection protocols were adapted from Partnership for Interdisciplinary Studies of Coastal Oceans (http://www.piscoweb.org/kelp-forest-sampling-protocols), Reef Life (https://reeflifesurvey.com/methods/), and Reef Check (https://reefcheck.org/PDFs/RCCAmanual9thedition.pdf). Transect lengths, depths, and observational windows were altered to account for the typically reduced visibility in the northeastern Pacific as compared to the tropics or California where these protocols were created.

Fish and substrate surveys were conducted from 17 October 2019 to 7 March 2020. Each site was visited as often as currents, weather, and personnel availability allowed over the survey period resulting in three or four replicate surveys at each site. High current sites were surveyed during slack current to ensure diver safety. Transects were 20-meters long and were conducted along 3 and 15 meter depth contours (below chart datum) at each site using SCUBA (Figure 3). At each visit, transects were conducted at similar GPS coordinates, but the starting point of these replicate transects varied. The intention was to observe variation at the site level, while capturing representative conditions at each site within the confines of logistical limitations.

Two passes were conducted over each transect. On the first pass at each depth the transect tape was deployed while swimming at least 1 m above the substrate to avoid disturbing benthic fishes. During this first pass, all larger fish situated within a 1 m swath along the length of the transect path and up to 1 m above the substrate were recorded, along with their lengths (to the nearest cm) to avoid losing that information if the fish moved away prior to being recorded on the second pass. On the second pass back along the transect tape, all fish species, their abundances, and estimated lengths (to the nearest cm) were recorded within a 1 m width along the entire length of the transect path, which included fish located in all cracks and crevices and up to 1 m above the substrate. The fish recorded on the first pass were not counted again if they were encountered on the second pass. These two passes were treated as one single transect unit in all analyses. The same diver collected all the fish data to reduce variability. They determined the lengths of the fish by measuring the fish against known lengths along their hand, arm, or dive slate. When fish could not be approached closely enough to determine lengths directly, the diver noted the position of the fish's snout and tail relative to the surrounding rock, then measured that distance after the fish had moved. The second diver recorded primary and secondary substrate type over the same area where the fish were observed in 1 m^2 quadrats along the transect tape every 2 m (10 quadrats along each 20 m transect). Primary and secondary substrate types were based on the Wentworth Class (Wentworth 1922) and were limited to bedrock (> 1 m), boulders (1 – 0.25 m), cobble (0.25 – 0.06 m), gravel/sand/silt/mud (< 0.06 m), and shell hash.

Species from the family Embiotocidae were not included in the statistical analyses, although they were recorded. These included four Surf perch species (*Brachyistius frenatus, Cymatogaster aggregate, Embiotoca lateralis, and Rhacochilus vacca*) which are highly mobile, less territorial than other species, and may move into and out of sites based on current speeds or directions (Simard et al. 2002), or only move into high current sites when the current is slow enough for them to maneuver. Since these species may be more transient at the site level, the analyses were conducted without them to better capture the effect of current on the resident fish community.

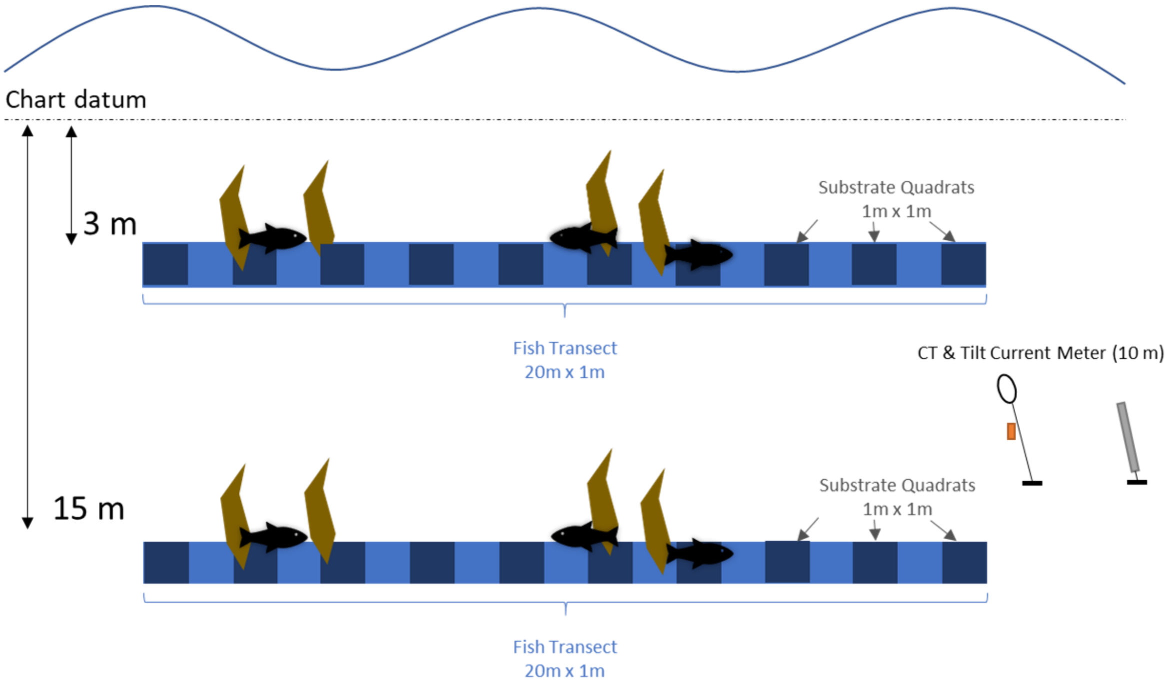

Figure 3: Schematic of fish and benthic data collection protocol. Fish and benthic characteristics were measured at 3 meter and 15 meter depth contours (below chart datum) at each of the 10 sites. Fish were counted and measured in a 1 meter width along the 20 meter long transect (light blue rectangle). Substrate characteristics were recorded in 1 m^2 quadrats every 2 meters (10 quadrats per 20 meter long transect, dark blue squares). Sites were surveyed multiple times from October 2019 to March 2020 resulting in replicate transects at each depth. Current, temperature, and salinity data were continuously recorded at 10 meter depth from 16 December 2019 to 26 January 2020 using Tilt Current Meters from Lowell Instruments, LLC and conductivity and temperature loggers from Star Oddi.

Fish lengths were converted into biomass estimates using the power formula,

$$Weight = a \text{ x } Length^b \tag{Equation 1}$$

with *a* and *b* coefficient values coming from multiple sources (Washington et al. 1978; Lea et al. 1999; Haggarty and King 2004; Froese et al. 2014). The same person conducted all fish surveys to reduce sampling variability, however substrate data were collected by nine individuals over the survey period with each given consistent top-side training.

Fish and substrate data analysis

To ensure surveys were conducted over similar habitats, the primary substrate observation in each quadrat were summed over each transect. These transect level values were then plotted and compared between current categories and transect depths. While secondary substrate type data were collected, only 49% of the quadrats had a secondary substrate type, therefore these data were not explored.

Fish metrics - fish species richness, abundance, and biomass - were pooled across the replicate transects conducted on different dates. To compare the fish metrics between high and low current sites, the transect values were pooled at the site level, regardless of depth, generating four high current site fish metric values and six low current site fish metric values. To compare the fish metrics between 3 and 15 meter depths, the pooled transect values were compared across site, regardless of current regime, generating 10 fish metric values for each depth. Since the sample sizes were small (< 20 observations), the data were not normally distributed, and/or did not exhibit equal variance between groups, non-parametric Mann-Whitney U tests (coin package in R; Hothorn et al, 2008) were conducted to compare the fish metrics between the two current categories (high vs low) and the two depth communities (3 meter vs 15 meter depths).

Fish community composition was compared among the current and depth categories using non-metric multi-dimensional scaling of Gower distance measures (nMDS; reshape2 package in R, Wickham, 2007; vegan package in R, Oksanen et al, 2019) to visualize the relative dissimilarities of the transects between current category or transect depth communities. Data included abundance values for each species at each site and depth. This resulted in a zero-inflated data set with 72% of the abundance observations being zeros. To account for this in the nMDS analysis, data were Wisconsin double standardized and square root transformed. In a Wisconsin double standardization, each abundance value is divided by its column maximum and then divided by the row total. The Gower dissimilarity index was calculated to provide the best fit to the data and was used in the nMDS analysis. The dissimilarities between current and depth categories were tested statistically using an analysis of similarity test (vegan package in R). To determine how species contributed to community differences, the five most abundant species were selected, and the abundance and length differences of these species were analyzed. Non-parametric Mann-Whitney U tests were used as the sample sizes were small (< 20 observations), not normally distributed, and/or did not exhibit equal variance between groups.

We also modeled fish abundance using linear mixed effect models for two reasons. First, while sites were categorized as either high or low current, we observed a continuum of current among sites that could not be captured in the non-parametric analyses using the categorical current data. Second, the random effect in the mixed effect models can better account for site variation, rather than averaging the replicate transects at each site as was done in the non-parametric analyses to avoid pseudoreplication. We considered four candidate models: a null model (~ (1|Site)), a mean daily maximum current speed model, referred to hereafter as max current (~ Max Current + (1|Site)), a transect depth model (~ Transect Depth + (1|Site)), and a max current + transect depth model (~ Max Current + Transect Depth + (1|Site)). All models included survey site as a random effect to account for the replicate transects at each site over the study period. Linear mixed effect models were fit using the lme function in the nlme package in R (nlme package in R, Pinheiro et al, 202). We used Akaike's information criterion (*AIC*), (bblme package in R, Bolker and R Development Core Team, 2020) to identify the best model to test for differences in fish abundance between the selected explanatory variables. We determined the best-supported model as that with the lowest AIC value (Burnham and Anderson 2002).

Statistical analyses were conducted in R version 3.6.2 (R Core Team, 2020).

Results

Current data analysis

Daily maximum tidal current speeds measured at 10 meter depth over the 41-day collection period (16 December 2019 to 26 January 2020) ranged from 1.81 cm/sec to 118.50 cm/sec over the 10 sites (Figure 4). The Tilt Current Meters can only record speeds up to 120 cm/sec but for them to reach this maximum speed they need to become completely horizontal, which is unlikely to occur since they are positively buoyant. We believe that current speeds at S<u>k</u>tha<u>k</u> (Porlier Pass), <u>X</u>wé<u>x</u>i7es (Grainger Point), and Burial Islet repeatedly exceeded this speed and therefore, the true values are actually higher. Sites were categorized as being either high current or low current based on the inflection point, 72.94 cm/s, when all daily maximum current speeds were plotted (Figure 4).

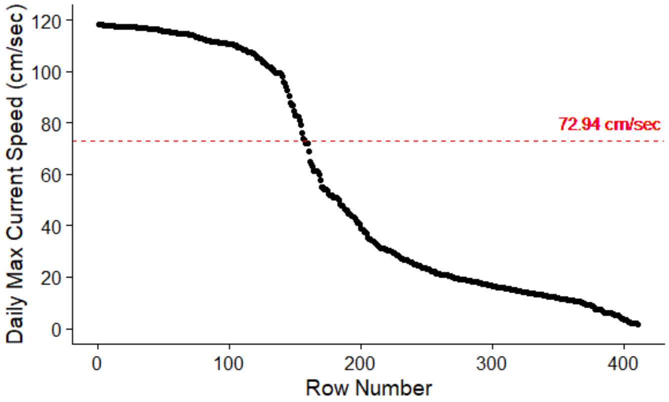

Figure 4: Daily maximum current speeds from all sites (black dots) ranked fastest to slowest, were plotted to determine the inflection point of the curve, as indicated by the dashed red line.

Sites with average daily maximum current speeds faster than the inflection point current speed were categorized as high current sites (n = 4) and sites with average daily maximum current speeds slower than the inflection point current speed were categorized as low current sites (n = 6) (Figure 5). Daily maximum current speeds at high current sites ranged from 43.98 cm/sec to 118.50 cm/sec with an average daily maximum speed of 107.06 cm/sec. Daily maximum current speeds at low current sites ranged from 1.81 cm/sec to 86.91 cm/sec with an average daily maximum speed of 22.12 cm/sec. High current sites were on average 4.8x faster than the low current sites.

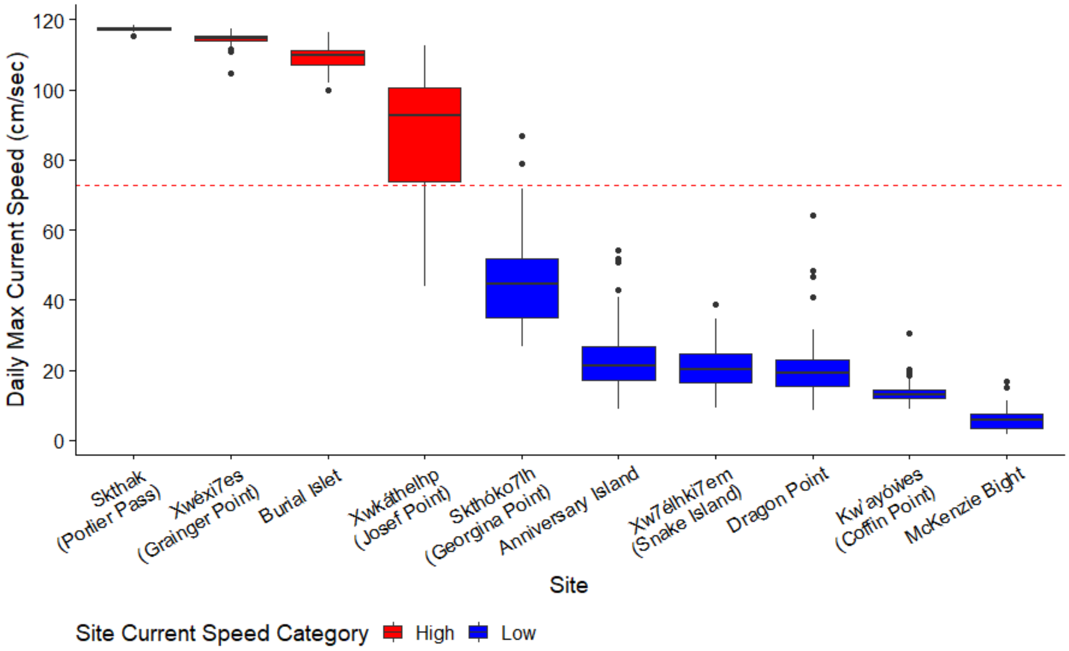

Figure 5: Daily maximum current speeds at each site presented as boxplots, indicating the median and quartiles with whiskers extending to 1.5 times the interquartile range. Sites were categorized as either high current (red) or low current (blue) based on the inflection point of a curve of all daily maximum current speeds (72.94 cm/sec; red dashed line).

Temperature and salinity data analysis

The daily median temperature and salinity values, as measured at 10 meters depth, were significantly cooler by 0.12 °C and less saline by 2.25 psu at the high current sites as compared to the low current sites (*Temperature*: $p < 0.001$, $U = 4.004$, High: n = 164, 8.84°C, Low: n = 246, 8.96°C; *Salinity*: $p < 0.001$, $U = -8.503$, High: n = 123, 24.84 psu, Low: n = 246, 27.09 psu; Figure 6). Non-parametric statistics were used as the data between high and low current categories were neither normally distributed nor had equal variances. The salinity logger at Xwk̲áthelhp (Josef Point) was lost, therefore the number of data points for the high current sites varies between temperature and salinity analyses.

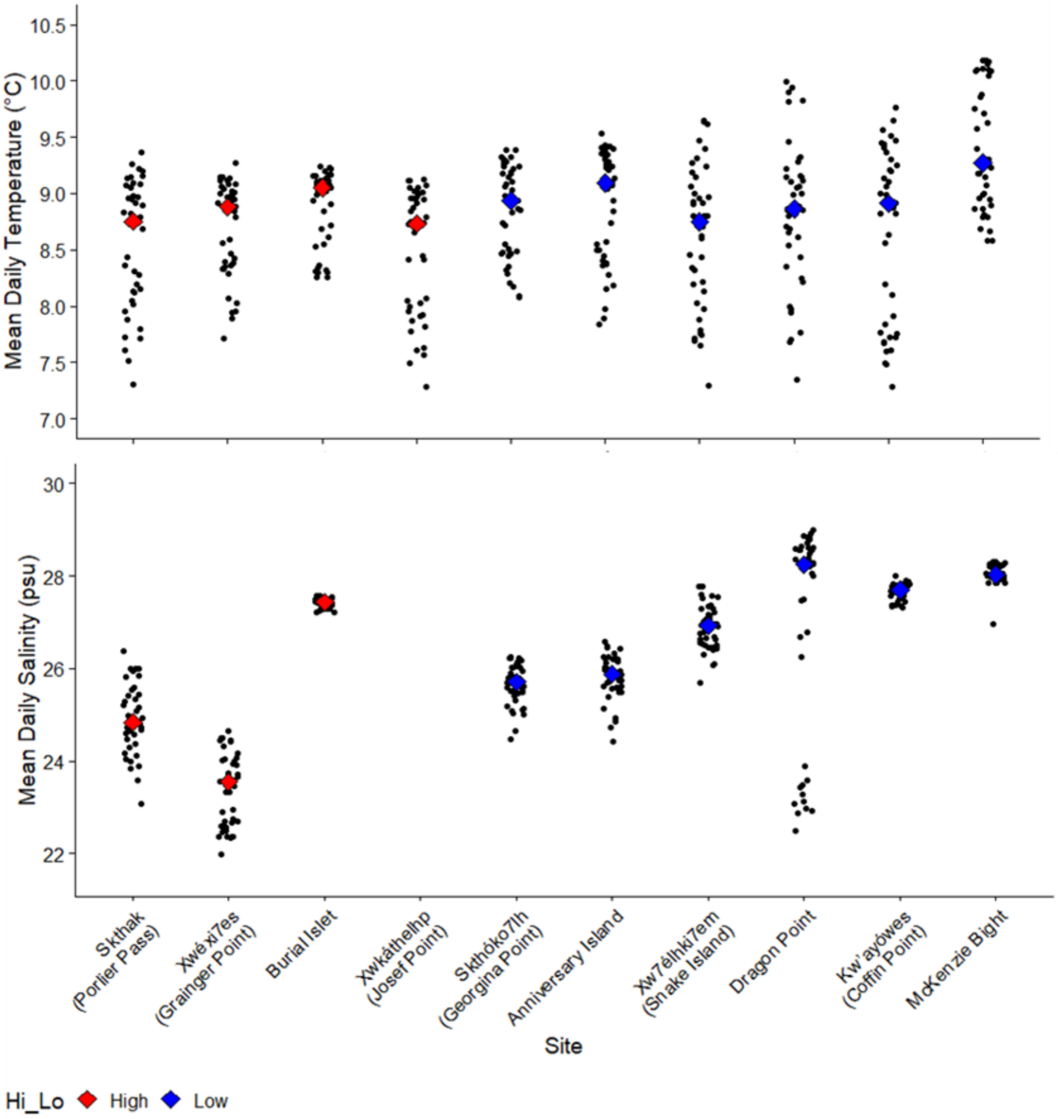

Figure 6: Daily mean temperature (°C) and salinity (psu) values at each site. Black dots indicate daily mean values and coloured diamonds indicate the site median value. Colours indicate site current category, red for high current sites, blue for low current sites. Readings were taken from 10 meters depth (below chart datum) from 15 December 2019 to 26 January 2020 by Tilt Current Meters (Lowell Instruments LLC) for temperature every minute and by CT loggers (Star Oddi) for salinity every thirty minutes. The CT logger at Xwkáthelhp (Josef Point) was lost.

Substrate analysis

The primary substrate observation in each quadrat were summed by transect. Substrate type was similar over both current categories and transect depths (Figure 7). Bedrock was the dominant primary substrate type identified at each current category (72.7% of high current quadrats and 62.2% of low current quadrats) and over each transect depth (74.5% of the 3 meter depth quadrats and 66.3% of the 15 meter depth quadrats). Soft substrates were rarely encountered on the transects. The sand/silt/mud substrate type was only observed at low current sites in 4.4% of the quadrats and was encountered almost nine times more often on the 15 meter depth transects (5.3% of quadrats) than the 3 meter depth transects (0.6% of quadrats). Shell hash was encountered twice of often at low current sites (5.2% of 3 meter depth quadrats vs 2.5% of 15 meter depth quadrats) and was encountered almost twice as often on the 15 meter depth transects (5.3% of 15 meter depth quadrats vs 3.0% of 3 meter depth quadrats). Substrate type was also grouped and analysed as 'rock' (bedrock, boulder, and cobble) or 'not rock' (sand/silt/mud and shell hash). Rock substrates were the primary substrate in 89 - 97% of the quadrats in both current regimes and transect depths.

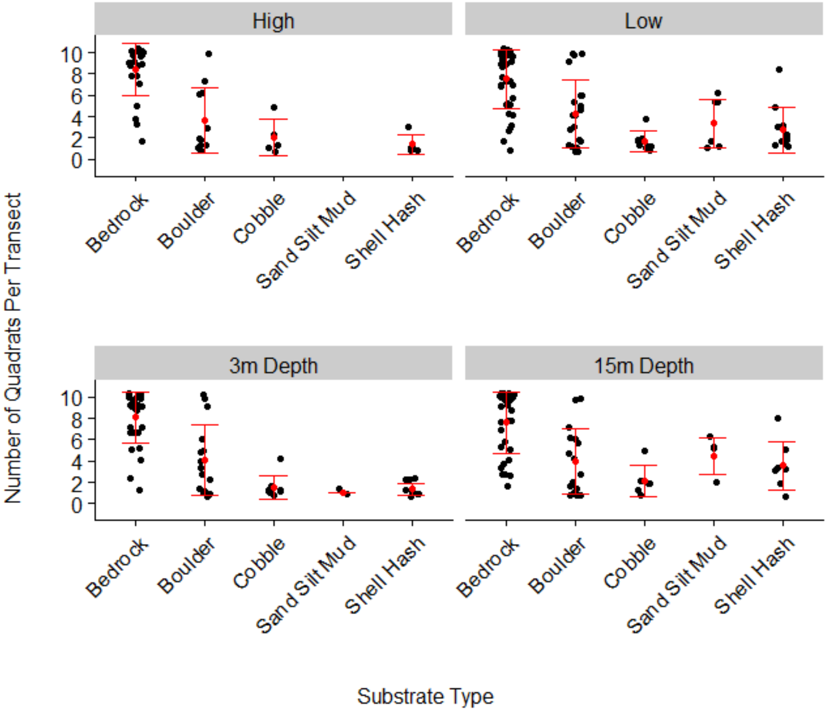

Figure 7: Comparisons of primary substrate type observed in each 1 m^2 quadrat along each 20-meter transect for current categories (top row, pooled across transect depths) and transect depths (bottom row, pooled across current regimes). Black dots represent the number of quadrats with each substrate type along each transect. Red dots indicate the mean number of quadrats of each substrate type along each transect and red horizontal lines indicate one standard deviation.

Fish species richness, abundance, and biomass analyses

Across all sites and depths a total of 1,653 fish from 25 species were observed, resulting in a biomass of 210.7 kg. Sixteen species were observed at both high and low current sites with seven species observed only at low current site and two species only observed at high current sites (Table 1). Six species were only observed on 3 meter depth transects and seven species were only observed on 15 meter depth transects.

Table 1: Species observed and their total recorded abundances. Species are grouped based on which current regimes and transect depths they were observed on.

Species Name	Total Abundance
Species observed at both current regimes and at both depths	
Rhinogobiops nicholsii	776
Artedius harringtoni	459
Jordania zonope	153
Sebastes caurinus	86
Hexagrammos decagrammus	68
Oxylebius pictus	37
Chirolophis nugator	7
Pholis laeta	7
Hemilepidotus hemilepidotus	7
Anoplarchus sp.	6
Nautichthys oculofasciatus	6
Sebastes auriculatus	3
High current	
3 meter depths	
Enophrys bison	1
15 meter depths	
Chirolophis decoratus	2
Low current	
3 meter depths	
Gobiesox maeandricus	5
Rimicola muscarum	1
Syngnathus leptorhynchus	1
15 meter depths	
Sebastes maliger	12
Citharichthys stigmaeus	3
Sebastes flavidus	3
Pholis clemensi	1
Only at 3 meter depths	
Artedius lateralis	8
Hexagrammos stelleri	6
Only at 15 meter depths	
Ophiodon elongatus	9
Rhamphocottus richardsonii	4

A total of 69 transects were completed and the number of replicate transects at each site and depth are not consistent, due to logistical limitations (e.g., poor weather, currents, and/or visibility, or personnel and/or boat availability). Individual transect species richness, abundance, and biomass are displayed in Figure 8.

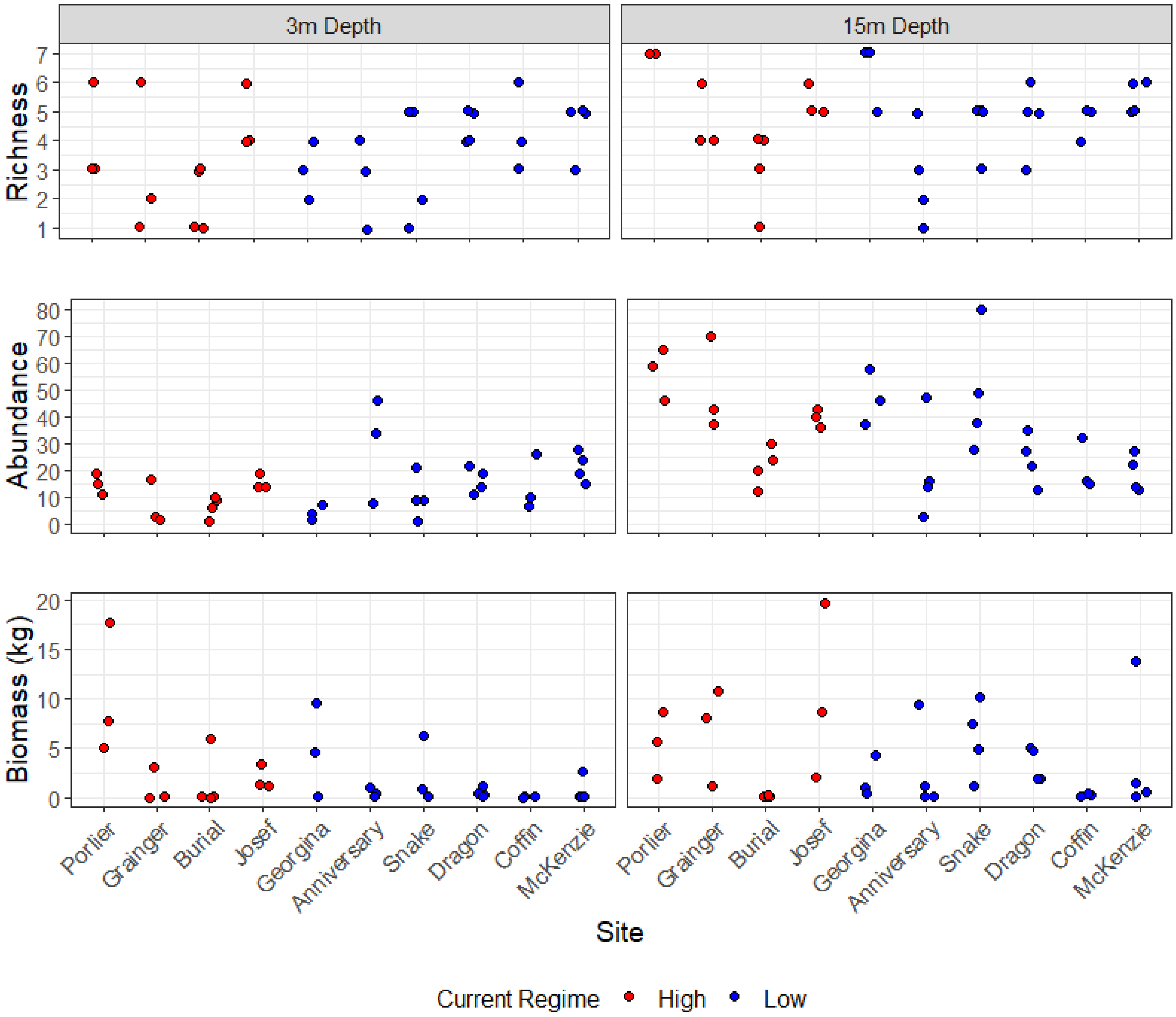

Figure 8: Individual transect fish species richness, abundance, and biomass (coloured circles). The number of replicate transects at each site and depth were inconsistent due to site sampling logistic limitations. Red circles represent transects conducted at high current sites, blue circles represent transects conducted at low current sites. To reduce overplotting, the circles within each site have a small amount of horizontal jitter added.

Median fish species richness at high current sites was 4.4 species and 4.6 species at low current sites (Figure 9A). Median fish abundance at high current sites was 28.2 fish and 22.2 fish at low current sites (Figure 9C). Median fish biomass at high current sites was 4.5 kg and 2.2 kg at low current sites (Figure 9E). There were no statistically significant differences in the median fish species richness, abundance, or biomass as indicated by Mann-Whitney U Tests (*Richness*: *p*-value = 0.915, *U* = -0.107; *Abundance*: *p*-value = 0.394, *U* = -0.853; *Biomass*: *p*-value = 0.201, *U* = -1.279).

Median fish species richness at 3 meter depths was 3.6 species and 4.7 species at 15 meter depths (Figure 9B). Median fish abundance at 3 meter depths was 14.7 fish and 32.0 fish at 15 meter depths (Figure 9D). Median fish biomass at 3 meter depths was 1.3 kg and 3.7 kg at 15 meter depths (Figure 9F). There were significantly more fish species and higher fish abundances (1.1 times more species and 17.3 more fish) on 15 meter depth transects, but no statistically significant differences in median biomass (*Richness*: *p*-value = 0.015, *U* = -2.430; *Abundance*: *p*-value = 0.002, *U* = -3.138; *Biomass*: *p*-value = 0.151, *U* = -1.436).

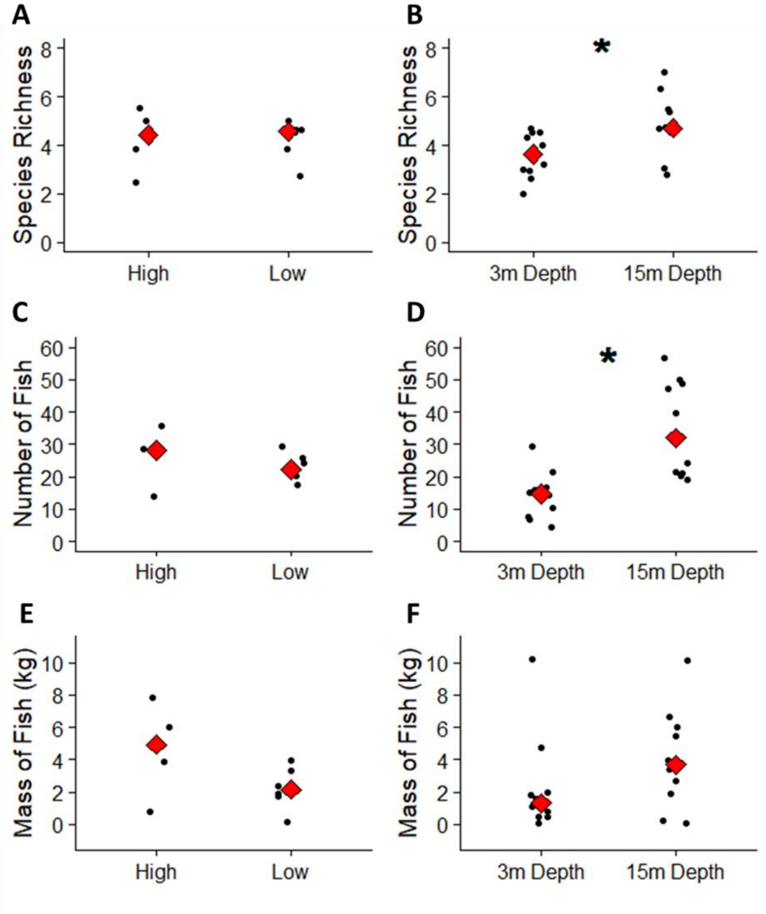

Figure 9: Comparisons of fish species richness (A, B), abundance (C, D), and biomass (E, F) between high and low current sites (A, C, E) and transect depths (B, D, F). Black dots on the high and low current plots indicate site averages of each fish metric and black dots on the 3 and 15 meter depth plots indicate

transect averages of each fish metric. Red diamonds indicate the median values and asterisks indicate significant differences in medians at the α = 0.05 level.

Fish abundance and biomass values for each transect do not necessarily exhibit a positive relationship since the species driving the abundance differences have a maximum length of 15 cm or less (*Rhinogobiops nicholsii, Artedius harringtoni* and *Jordania zonope),* whereas the species driving the biomass differences can reach lengths up to 61 cm for *Hexagrammos decagrammus* or 152 cm for *Ophiodon elongatus* (Figure 10).

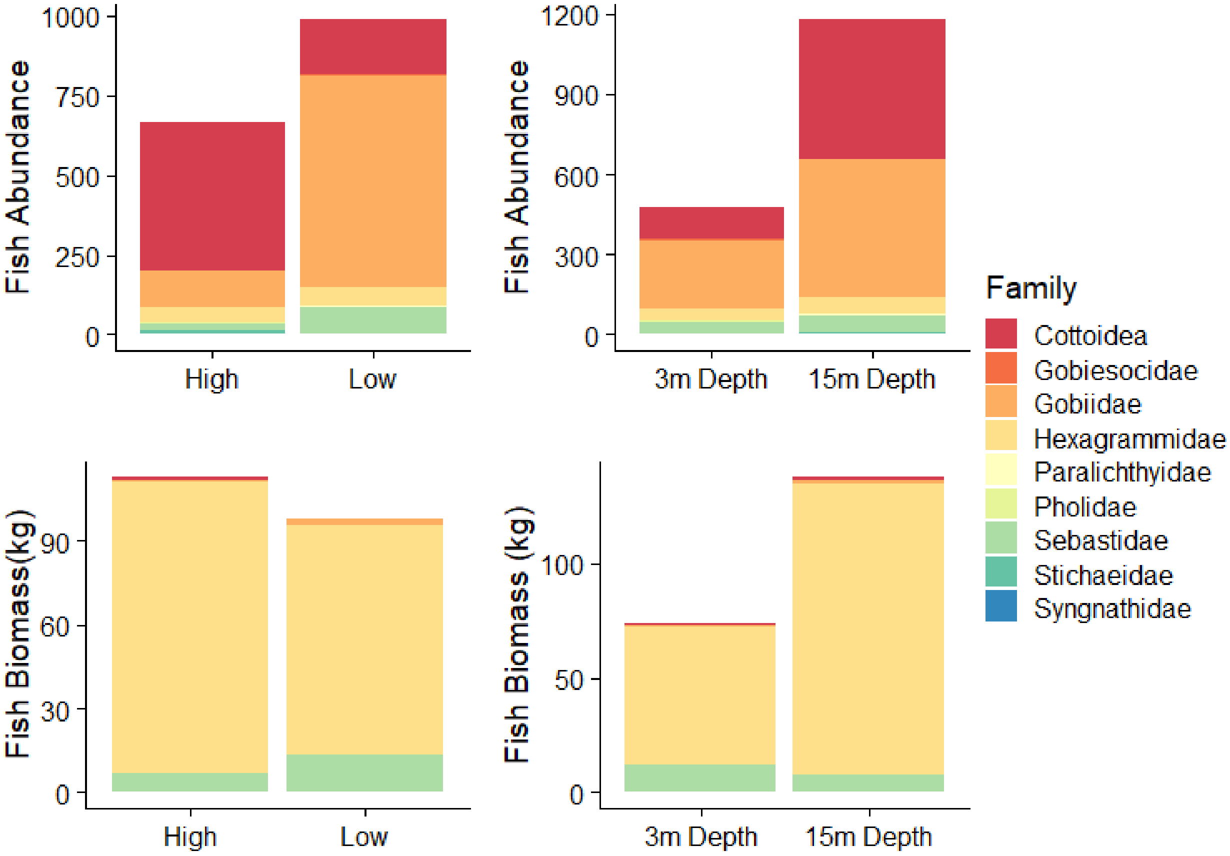

Figure 10: Total fish abundances (top row) and biomass (bottom row) grouped by Family. Results are displayed comparing high and low current sites (left column) and 3 and 15 meter depths (right column).

Fish community results

The fish community composition at different current speeds and depths were compared using non-metric multi-dimensional scaling (nMDS) plots (Figure 11). The current category and transect depth communities overlap, but the high stress value (0.243) of the nMDS plot indicates the dissimilarities between replicate transects are not well represented by the 2-dimensional plot. The analysis of similarity (ANOSIM) test results indicate there is no differences between current (*p*-value = 0.051, *R* statistic = 0.142) or depth (*p*-value = 0.046, *R* statistic = 0.097) communities; an *R* statistic close to 0 indicates community similarity and a value close to 1 indicates community dissimilarity, with the *p*-value measuring how likely that result is over 999 permutations.

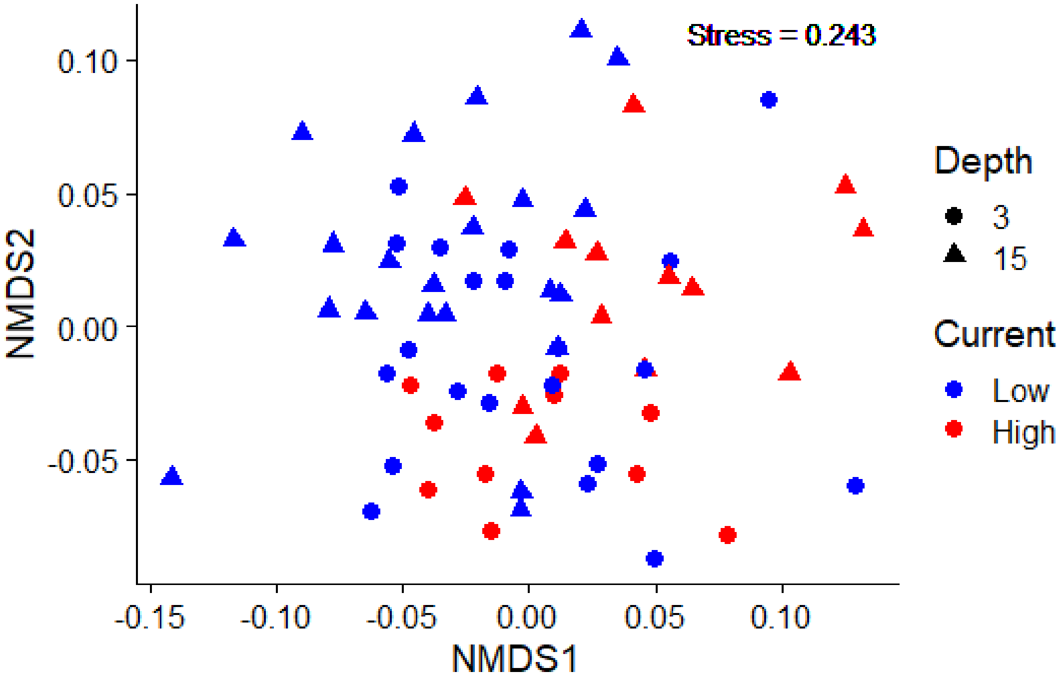

Figure 11: Non-metric multi-dimensional scaling (nMDS) plot of the Gower dissimilarity measure of fish community dissimilarities for current category or depth transects. Each symbol represents a replicate transect. The shape represents the transect depth (circle for 3 meter depth and triangle for 15 meter depth) and colour represents current category (blue for low current and red for high current).

Artedius harringtoni, Hexagrammos decagrammus, Jordania zonope, Rhinogobiops nicholsii, and *Sebastes caurinus* were the five most abundant species observed during this study and were selected to examine community differences between current or depth categories. Non-parametric Mann Whitney U Tests were conducted since sample sizes were < 20 between categories, data were not normally distributed, and/or there was unequal variance between categories.

Two of the five species, *A. harringtoni* and *S. caurinus*, had significant differences in median abundances or lengths between current categories (Figure 12). *A. harringtoni* median abundance was higher at the high current sites with high current sites median abundance of 16.3 fish and 0.5 fish at low current sites (*p*-value = 0.010, *U* = 2.566, Appendix Table A1). Additionally, *A. harringtoni* median lengths were smaller at high current sites, with high current site median lengths (n = 405) of 4.0 cm and 5.5 cm at low current sites (n = 58) (*p*-value < 0.001, *U* = -3.564, Appendix Table A2). *S. caurinus* median lengths were larger at high current sites, with high current site median lengths (n = 22) of 24.0 cm and 14.5 cm at low current sites (n = 64) (*p*-value < 0.001, *U* = 4.196, Appendix Table A2).

Two of the five species, *J. zonope* and *H. decagrammus*, had significant differences in median abundances or lengths between depth categories (Figure 13). *J. zonope* median abundance was lower at 3 meter depths, with 3 meter depth median abundance of 0.3 fish and 2.0 fish at 15 meter depths (*p*-value = 0.011, *U* = 2.548 Appendix Table A1). *H. decagrammus* median lengths were smaller at 3 meter depths, with 3 meter depth median lengths (n = 31) of 14.0 cm and 24.0 cm at 15 meter depths (n = 37) (p-value = 0.001, U = -3.334, Appendix Table A2).

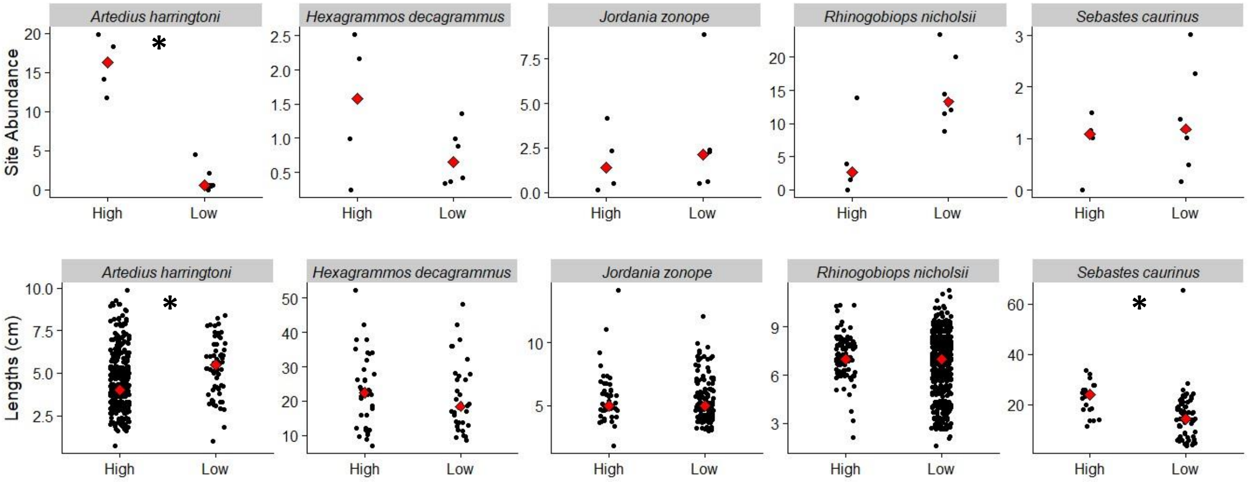

Figure 12: Abundance (top) and length (bottom) differences between current regimes for the five most abundant species. Black dots on the abundance plots represent site averages, black dots on the length plots represent individual fish lengths. Red diamonds indicate median values and asterisks indicate significant differences in medians at the α = 0.05 level.

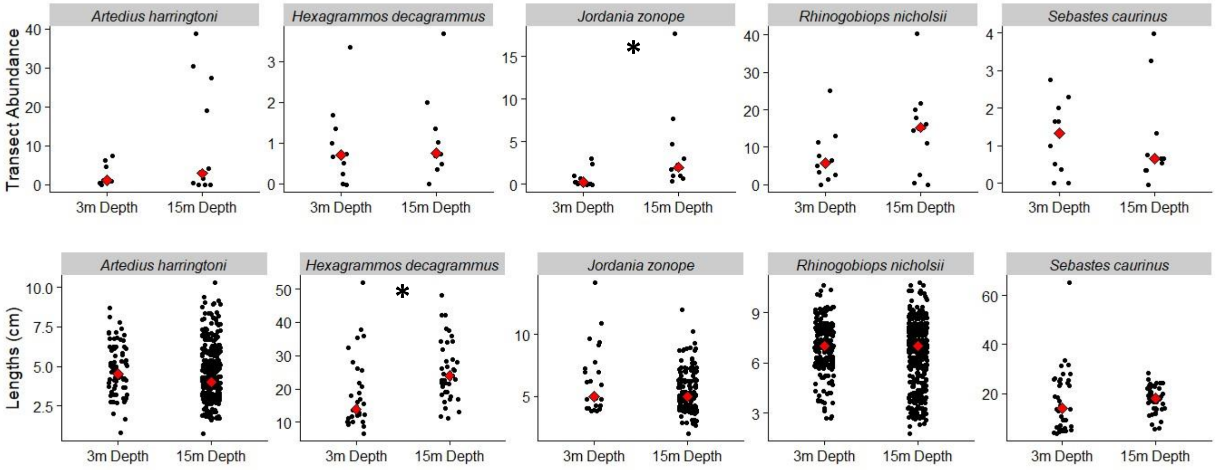

Figure 13: Abundance (top) and length (bottom) differences between transect depths for the five most abundant species. Black dots on the abundance plots represent transect averages, black dots on the length plots represent individual fish lengths. Red diamonds indicate median values and asterisks indicate significant differences in medians at the α = 0.05 level.

Fish abundance models

The two explanatory variables tested in the linear mixed effect models to estimate fish abundance were Max Current (mean daily maximum current speed) and Transect Depth. The raw abundance data were plotted against these two variables to observe how fish abundance varied with these explanatory variables (Figure 14).

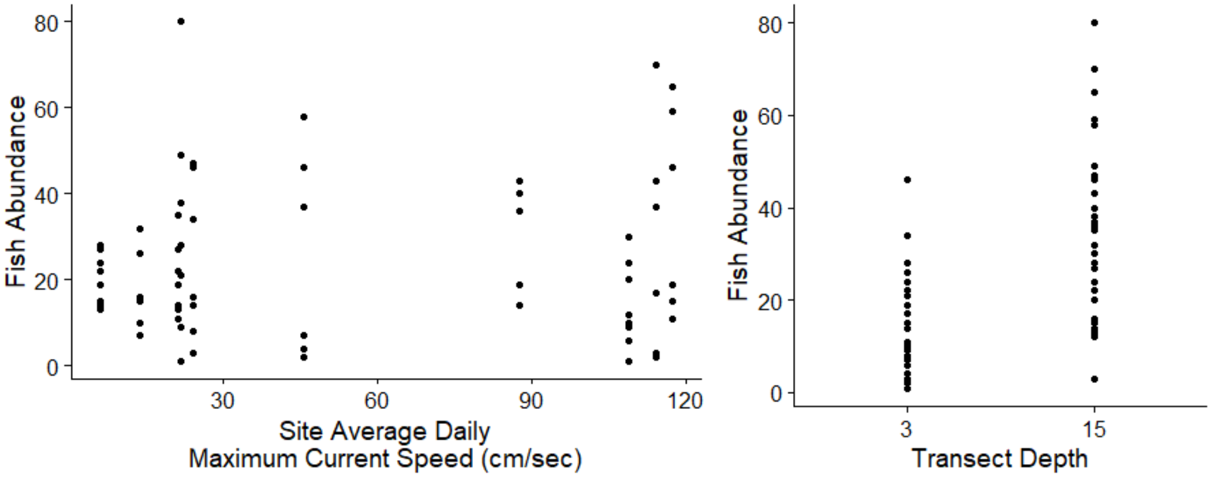

Figure 14: Fish abundance on each transect as compared to site average daily maximum current speed (left panel) and transect depth (right panel).

The top linear mixed effect model for estimating fish abundance was the Transect Depth model (Equation 2; Table 2) as indicated by the low AIC score. The three other models tested had AIC scores of between 5.4 to 33.8 points higher. The model residuals showed some positive skew as demonstrated by a Pearson residuals vs fitted plot and a Q-Q plot (Figure 15), indicating that the model may be overpredicting fish abundance on the 15 meter depth transects. Mean fish abundance was more than twice as high (19.64 fish on average) at 15 meter depth transects than the 3 meter depth transects (3 meter mean fish abundance: 14.10 ± 5.4 fish; 15 meter mean fish abundance: 33.74 ± 6.9 fish, Figure 16).

$$\text{Abundance} = 14.105 + (19.636 * TransectDepth) + (1|Site)$$

(Equation 2)

Table 2: Results of model selection for four candidate models of fish abundance.

	Model Parameters	logLikelihood	*AIC*	Δ*AIC*	Weight
Transect Depth	4	-278.8	565.6	0.0	0.936
Transect Depth + Max Current	5	-280.5	571.0	5.4	0.064
Null Model	3	-293.9	593.9	28.3	<0.001
Max Current	4	-295.7	599.5	33.8	<0.001

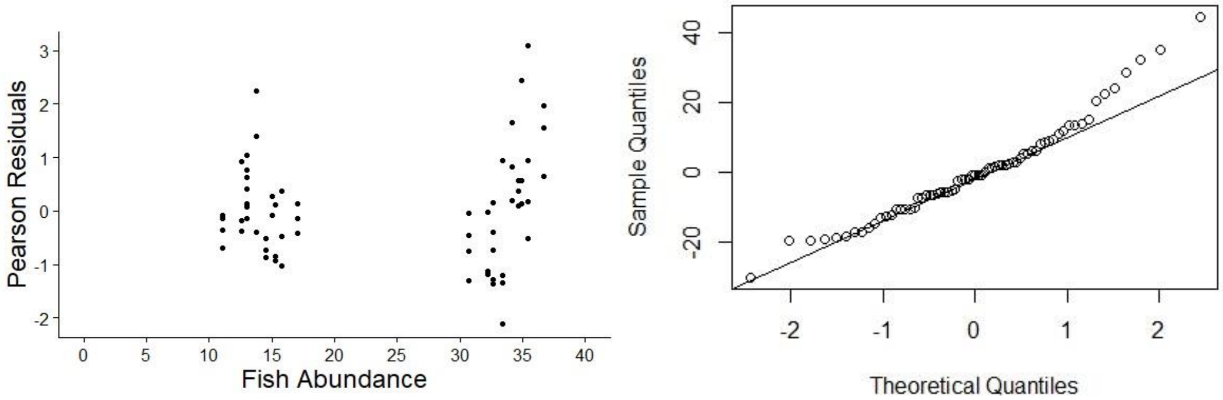

Figure 15: Plots showing model fit. Pearson residuals versus fitted abundance data plot (left) showing fish abundance estimates at 3 meter (cluster of black dots on left of plot) and 15 meter (cluster on right of plot) depths. Quantile-quantile plot (right) showing right skew.

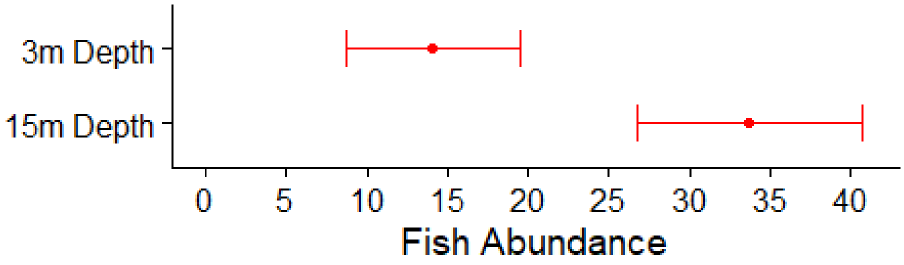

Figure 16: Predicted mean fish abundance at 3 meter and 15 meter depths from a linear mixed effects model with transect depth as the fixed effect and site as the random effect. Red dots indicate predicted mean abundance, horizontal lines represent 95% confidence intervals.

Fish abundances at 3 meter and 15 meter depths were similar under the linear mixed effect model estimates and non-parametric median values. The 3 meter depth median value was 14.7 fish and the linear mixed effect model abundance estimate was 14.10 ± 5.4 fish. The 15 meter depth median value was 32.0 fish and the linear mixed effect model abundance estimate was 33.74 ± 6.9 fish. The similarities of these two methods in determining fish abundances provides added confidence in the model results.

Discussion

Transect depth was determined to be an important driver of fish abundance in our study in both the non-parametric analyses and the linear mixed effect models, demonstrating the importance of depth for the nearshore fish species observed. Both statistical methods predicted similar fish abundances for both depths. However, tidal current did not have a significant effect on fish species richness, abundance, or biomass in either the non-parametric analyses or the linear mixed effect models. Tidal current also did not have a statistically significant effect on fish communities as determined by the nMDS plot and analysis of similarity test. However, current speed and depth did result in species specific differences. The five most abundant species observed during this study were

Artedius harringtoni, Hexagrammos decagrammus, Jordania zonope, Rhinogobiops nicholsii, and *Sebastes caurinus*. At high current sites, *A. harringtoni* were significantly more abundant and smaller and *S. caurinus* were significantly longer than at low current sites. At 15 meter depths *J. zonope* were significantly more abundant and *H. decagrammus* were significantly longer than at 3 meter depths. The results of this study suggest that depth may be a useful abiotic surrogate for fish species richness and abundance in the Southern Gulf Islands of BC, however, tidal current was not shown to be a suitable surrogate for fish biodiversity but may be useful for species-specific studies.

There were significant differences between high and low current sites in daily average temperature and salinity values. High current sites were on average 0.22 °C cooler and 1.61 psu fresher than the low current sites. Thomson (1981) indicates that temperatures and salinities are often lower in areas with tidal mixing. However, the temperature and salinity differences observed here are not likely to be biologically meaningful as temperature and salinity values vary more annually than over the period recorded here (Thomson, 1981; Burd et al. 2008). Additionally, most of the species encountered here range from California to Alaska and therefore can tolerate a broader range of temperature and salinity values than those recorded in this study. Rock substrate (comprised of bedrock, boulder, and cobble substrates) was the primary substrate identified in 89-97% or more of the transect quadrats at each current regime or transect depth, confirming that surveys were conducted over similar substrates and therefore substrate type may not be confounding fish community results.

The current categorization that resulted from using the Tilt Current Meter readings and inflection point speed differed from our a priori assumptions of the sites. We had initially thought S<u>k</u>thó<u>k</u>o7lh (Georgina Point) would be a high current site, yet through the analysis conducted here, was categorized as a low current site. Current speeds are dampened along shorelines as the friction between the water and substrate reduces the speed of the water. At S<u>k</u>thó<u>k</u>o7lh (Georgina Point), the substrate has a very shallow slope, resulting in a wide area between the shoreline and where the Tilt Current Meter was placed over which the water may be slowed. This may be why the current speeds observed here were much slower than what we had initially assumed. Additionally, the Tilt Current Meters require an area approximately 1.5 m^2 to be able to move freely, which, at many locations, was a challenge to find since the substrate is quite complex. This was especially evident at Xw<u>k</u>áthelhp (Josef Point) where the only area large enough to place the Tilt Current Meter at 10 meters below chart datum was also surrounded by tall boulders, which may have created a back eddy, thus limiting the ability of the Tilt Current Meter to detect the true current speed at the site. Therefore, the current speeds at both S<u>k</u>thó<u>k</u>o7lh (Georgina Point) and Xw<u>k</u>áthelhp (Josef Point) may be higher than those observed in this study.

Transect depth was a strong indicator of increased fish species richness and abundance, similar to results found by others (Gibson et al. 1996; Love et al. 2009; Sobocinski et al. 2018). These studies examined fish biodiversity over much shallower depth ranges (0.5-5 m, Gibson et al. 1996) or much deeper depth ranges (19-365 m, Love et al. 2009; 30-100 m, Sobocinski et al. 2018) and this study fills in the knowledge gap between these depth ranges. While Gibson et al. generally found increased species richness, abundance, and weight at 5 meter depths versus 0.5 meters, both Love et al. and Sobocinski et al. found increased species richness and abundance at the shallower depths in their range. Those results, coupled with the results from this study may indicate that species richness and abundance are highest between 5 and 19 meter depths. All three studies also found higher abundances of juvenile fish in the shallower depth ranges, which may also be the case here for *H. decagrammus.* Here, the lower fish species richness and abundance in the 3 meter depth communities may be a result of exposure to variability in temperature or salinity or from unpredictable wave and surge motion from wind and boat traffic, particularly at sites along high traffic boat and ferry routes or near marinas (all survey sites with the possible exception of X̲wéx̲i7es (Grainger Point) and Anniversary Island). This stress may result in fish occupying calmer, more stable conditions at depth (Liao 2007; Young and Carr 2015). As well, increased kelp cover and reduced visibility along many 3 meter depth transects may have reduced our ability to detect all fish present, or since the 3 meter transects were conducted after the 15 meter depth transects, surveyors were sometimes constrained by the increasing current speeds at sites with narrow slack current windows or by limited air reserves. Here, two species were found to have significant differences in either abundance or length between transect depths. *J. zonope* had 1.7 more fish and *H. decagrammus* were 10.0 cm longer on the 15m depth transects, suggesting perhaps distinct depth preference for *J. zonope*, and life stage movements for *H. decagrammus*.

Vieham and Zydlewski (2017) also did not find any correlation between fish abundance and current speed, but other studies have linked tidal phase to fish abundance (Kingsford and Suthers 1996; Embling et al. 2012; Haak et al. 2019; Robinson et al. 2007; Vieham and Zydlewski 2017). Unfortunately, this research was not able to take tidal phase into account as the high current sites could not safely be dove during maximum flood or ebb.

While we did not detect any community level differences between the current regimes, it does appear that certain species abundances and lengths are influences by current speed. There were significant differences in *A. harringtoni* abundance and length differences between current or depth communities. *A. harringtoni* were more abundant in high current communities at both depths but were larger in low current communities. *A. harringtoni* prefers rock habitat free from shell hash or silt (Norton 1991) and prefers giant acorn barnacles (*Balanus nubilus*) which provide cover for ambush attacks on their prey and protection from predators (Demetropoulos et al. 1990). The high current sites had 7% fewer quadrats with sand, silt, or mud or shell hash substrate types and had dense aggregations of giant acorn barnacles, providing optimum habitat compared to low current sites. *S. caurinus* were 1.7 time smaller at low current sites than high current sites. Multiple young-of-year (recently settled juveniles) *S. caurinus* were routinely observed at the low current site McKenzie Bight, which may have influenced the results. Just over half (52.5%) of the quadrats on the 3 meter depth transects had understory kelp as the dominant algae type which is optimal habitat for this life stage (Hayden-Spear 2006).

If there are differences in fish biodiversity between current categories, and we did not detect them, it could be due to a number of factors such as: the range of current speeds observed here was too narrow, the dives were conducted during slack current and may be misrepresenting the high current communities, the six-month sampling period introduced seasonal effects which obscure the trends, or the within site variation obscured the between current category variation. The sites included in this study represent the strongest tidal currents in the area and were observed over some of the largest tidal exchanges of the year. However, to address these concerns, future studies should sample over a much shorter time frame and sample more sites, rather than a few sites multiple times. Additionally, factors outside of the study design, such as the presence of sea lions and harbour seals, anthropogenic stressors such as boat traffic or fishing, or pollution from nearby towns or the Fraser River plume may have influenced our ability to determine the effectiveness of tidal current as a suitable abiotic surrogate. Sea lions and harbour seals were observed on the surface at each site at almost every visit and sea lions were also observed during some of the transect surveys, which may have altered fish behaviour. As well, boat traffic is a very common occurrence at many of the sites.

Since these surveys were conducted during slack current to ensure the safety of the dive team, the fish communities that are active during the high flow times were not observed, which might alter the inferred effect of current on fish communities. Further studies using cameras secured to the substrate (Bond et al. 2018) or hydroacoustic data (Viehman and Zydlewski 2017) that capture the communities present during the highest current flow periods may yield more complete results. Additionally, we did not take temporal (seasonal or interannual) effects into consideration as surveys were only conducted during the winter months of 2019-2020. Fish species diversity may vary during the spring when many species breed and nest and when plankton abundances are highest (Vieham and Zydlewski 2017). As well, many rockfish species are thought to hide more over the winter months (Carlson and Barr 1977), which may have biased the abundances and biomass estimates observed here. However, this study provides much needed data on many of these locations and species and provides valuable baseline data.

The depths surveyed here are quite shallow for both the sites studied and the region in general; the average depth of the Strait of Georgia is 155 m (Thomson, 1981). Fish communities deeper than those surveyed here may yield different results. However, within the study area, hard substrate habitat is rare deeper than 10 meters and was a limiting factor in site selection. Supplementary studies could be conducted in additional areas to determine if the trends observed here are widespread or a phenomenon localized to the Southern Gulf Islands of BC. Other studies on benthic fish have found additional drivers of biodiversity, including: substrate type (Dean et al. 2000; Laidig et al. 2009; Mcarthur et al. 2010; Easton et al. 2015; Kregting et al. 2016; Bond et al. 2018; Le Bris and Wroblewski 2018; Carrasquilla-Henao et al. 2019), habitat rugosity (Andrews and Anderson 2004; Love and York 2006; Mcarthur et al. 2010; Young and Carr 2015; McHenry et al. 2017; Frid et al. 2018), biogenic habitat (Dean et al. 2000; Zalmon et al. 2011; Young and Carr 2015; Le Bris and Wroblewski 2018; Paes Gomes et al. 2018), slope (Dean et al. 2000; Easton et al. 2015; Carrasquilla-Henao et al. 2019), and wave velocity (Young and Carr 2015). Only one of these studies was conducted in the Strait of Georgia (Carrasquilla-Henao et al. 2019) and more work is needed to determine if the previously mentioned biodiversity drivers are important for nearshore benthic fish in this area.

In conclusion, the results presented here indicate that depth may be a useful abiotic surrogate for fish species richness and abundance over rocky habitat in the Southern Gulf Islands of BC. These results were determined via two statistical methods, non-parametric Mann-Whitney U tests and linear mixed effect models. While tidal current speed did not influence the fish community, it was an important driver of *A. harringtoni* abundance and length differences and *S. caurinus* length differences. As well, transect depth was an important driver of *J. zonope* abundance and *H. decagrammus* length differences. Additionally, some fish species appear to prefer certain depth or tidal current habitats and may require additional consideration to ensure they are adequately protected. These results can be of use for marine spatial planning, nearshore fish conservation efforts, and species distribution modeling, as areas with a range of depths should be considered to protect fish biodiversity and species-specific preferences for current may need to be taken into account.

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Appendix

Table A1: Results of Mann-Whitney U tests for abundance differences between current categories and transect depths for the five species that contributed most to current-depth category fish community dissimilarities as determined from a Similarity Percentages analysis.

	Current Category Abundance						Transect Depth Abundance					
	p-Value	Test Score (*U*)	High		Low		*p*-Value	Test Score (*U*)	3m Depth		15m Depth	
			n	Median	*n*	Median			*n*	Median	*n*	Median
Artedius harringtoni	0.010	2.566	4	16.3 fish	6	0.5 fish	0.621	0.494	10	1.0 fish	10	2.8 fish
Hexagrammos decagrammus	0.336	0.962	4	1.6 fish	6	0.7 fish	0.649	0.456	10	0.7 fish	10	0.8 fish
Jordania zonope	0.593	-0.535	4	1.4 fish	6	2.1 fish	0.011	2.548	10	0.3 fish	10	2.0 fish
Rhinogobiops nicholsii	0.055	-1.92	4	2.7 fish	6	13.3 fish	0.226	1.210	10	5.8 fish	10	15.3 fish
Sebastes caurinus	0.593	-0.535	4	1.1 fish	6	1.2 fish	0.791	-0.266	10	1.3 fish	10	0.7 fish

Table A2: Results of Mann-Whitney U tests for length differences between current categories and transect depths for the five species that contributed most to current-depth category fish community dissimilarities as determined from a Similarity Percentages analysis.

	Current Category Length						Transect Depth Length					
	p-Value	Test Score (*U*)	High		Low		*p*-Value	Test Score (*U*)	3m Depth		15m Depth	
			n	Median	*n*	Median			*n*	Median	*n*	Median
Artedius harringtoni	< 0.001	-3.564	408	4.0 cm	58	5.5 cm	0.363	0.910	76	4.5 cm	390	4.0 cm
Hexagrammos decagrammus	0.457	0.744	36	22.5 cm	32	18.5 cm	0.001	-3.334	31	14.0 cm	37	24.0 cm
Jordania zonope	0.218	1.231	44	5.0 cm	135	5.0 cm	0.271	1.101	26	5.0 cm	153	5.0 cm
Rhinogobiops nicholsii	0.060	1.881	115	7.0 cm	675	7.0 cm	0.105	1.622	258	7.0 cm	532	7.0 cm
Sebastes caurinus	< 0.001	4.196	22	24.0 cm	64	14.5 cm	0.272	-1.100	42	14.0 cm	44	18.0 cm

Chapter 3: Exploring the value of citizen science-gathered nearshore data

Abstract

Baseline data are key to understanding how species, communities, and habitats change over time. Citizen science data collection programs can support the collection of data at a greater spatial scale and over longer time periods than other types of scientifically collected data that tend to be project-specific and often tied to short periods of funding. This is particularly true for difficult to sample environments such as subtidal ecosystems. Citizen scientist surveyors have been collecting fish, invertebrate, and algae data for REEF since 1998 in British Columbia, generating over 7,000 surveys and over 150,000 species abundance observations as of August 2020. These data can tell us a great deal about marine life in the northeastern Pacific and how species are responding to environmental changes. The purpose of this study is to demonstrate how citizen science data from the Reef Environmental Education Foundation (REEF) can be used to answer scientific questions via two case studies. The first case study explores how lingcod (*Ophiodon elongatus*) populations have responded to fishery management efforts in the Howe Sound area. In the second case study, oceanographic current observations by surveyors are explored to determine the influence of current on fish community compositions. The results of these case studies suggest that REEF data, despite its limitations, can be used to improve our understanding of nearshore marine ecosystems.

Introduction

Understanding coastal ecosystems and the species that inhabit them is crucial to ensure their protection, especially as our ecosystems face anthropogenic impacts from regional (e.g., habitat destruction) to global scales (e.g., climate change). As marine environments are increasingly impacted, the need for long term data sets to assess species or ecosystem level changes is growing in importance. Yet subtidal data collection is expensive and challenging, therefore limited baseline data exist making it difficult to detect any long-term changes in species abundances or community compositions.

Scientific subtidal nearshore data collection tends to be seasonally focused towards commercially valuable species or species or habitats of conservation concern, limiting the temporal and spatial scope of the resulting data (Duprey 2011; DFO 2016; DFO 2018). It also may be challenging for organizations to physically gather the data at the temporal and spatial resolutions necessary to properly manage and conserve our marine ecosystems. However, recreational SCUBA divers are keen observers of nearshore subtidal ecosystems and are often experienced naturalists willing to contribute data on the species they encounter. Recreational divers typically dive year-round, enjoy exploring new areas, provide their own gear and SCUBA training, and are not limited by the strict dive safety protocols scientific organizations are required to follow. The Southern coast of British Columbia offers countless interesting dive sites and a large recreational diver population, resulting in spatially and temporally widespread data. Citizen science organizations, such as Reef Environmental Education Foundation (REEF), Reef Life, or Reef Check, provide a reputable place to submit their observations to and numerous opportunities for surveyors to increase their knowledge and skills. These data are then often made publicly available, resulting in very inexpensive data at scales of interest for scientists (Pattengill-Semmens and Semmens 2003; Heery et al. 2018) or resource managers (Tolimieri et al. 2017; Grüss et al. 2018; Safiq et al. 2018).

Baseline data are key in understanding how climate change is impacting species, communities, and habitats. However, it is difficult to anticipate what baseline data will be needed in the future. Citizen science organizations typically carefully curate species lists or ask their surveyors to collect data on all the species they encounter, resulting in baseline data on a broad range of species that are critical to support our understanding of how these ecosystems function. For example, in the case of the ongoing sea star wasting disease epidemic in the eastern Pacific, citizen science data curated by REEF (www.reef.org) provided valuable baseline and up-to-date population information to support multiple studies on the species most impacted by the disease, *Pycnopodia helianthoides*. Little scientific data on sea star species existed at the spatial and temporal resolution necessary to understand the quick spread and Alaska to Mexico impact of this disease on nearshore ecosystems. Citizen science data proved instrumental in determining the impact of the disease on *P. helianthoides* populations (Montecino-Latorre et al. 2016), the subsequent ecosystem-level impacts of this population decline (Schultz et al. 2016), and in placing this species on the International Union for Conservation of Nature's Red List of Threatened Species (Harvell et al 2019; Gravem et al. 2021).

The quality of citizen science data is often a concern, yet studies have found that citizen scientists can have as good, or better, data quality and taxonomic resolution as scientists (Gorgopa et al. 2011; Cox et al. 2012). With some training, citizen scientists can improve their diving and species identification skills both of which improve data resolution (Gorgopa et al. 2011). REEF recognizes this and has established a series of five levels that surveyors advance through by completing specific numbers of surveys and by completing species identification tests. These experience levels are recorded in the data set and it is possible to use only data collected by more experienced surveyors as a means of quality control, if desired, as explored in this chapter. However, an important challenge of citizen science is encouraging the volunteer recreational divers to continuously collect data. By keeping the survey methodology simple for citizen science divers, organizations such as REEF have ensured that surveys are easy to accomplish, do not require additional equipment other than a slate, and do not alter the flow of a normal dive. This simplicity enables surveyors to dive with non-surveyors, which allows for more flexibility in when divers can complete surveys.

In this study, citizen science collected data from REEF was used to demonstrate how these data can be used in a variety of ways to inform resource management. Citizen scientist surveyors have been collecting fish, invertebrate, and algae data for REEF for over 22 years, since 1998 in British Columbia, generating over 7,000 surveys and over 150,000 species abundance observations as of August 2020. The vast majority of these observations are from the Southern coast of BC (e.g., Vancouver Island and the lower mainland area), however a few surveys have been conducted along the Central and Northern coasts. This plethora of data can tell us a great deal about marine life in the northeastern Pacific and how species are responding to environmental change. This chapter is organized as a guide to demonstrate how these data could be incorporated into scientific studies. The methodology used by REEF surveyors is explained, followed by how the data were prepared for use in this study. Next, preliminary analyses of abiotic and biotic data are conducted, and the data are compared based on surveyor experience level. Two case studies follow that demonstrate some of the methods and statistics that can be used with these data. The first case study examines changes in lingcod (*Ophiodon elongatus*) populations before and after a fishery closure in 2006 in the Howe Sound area. The second case study explores the potential relationships between oceanographic (e.g., temperature and tidal current) and fish biodiversity data (e.g. species richness, abundance, and community composition).

REEF Survey Methodology

Under REEF's protocol, surveyors employ a 'roving diver strategy'; they have no set transects, depths, or methods for navigating the sites. They simply go out and dive, recording the species and abundances they encounter and are encouraged to look in cracks and crevices and observe species in the water column. For surveys conducted in the northeastern Pacific, REEF provides data sheets with a set list of 33 fish species, 59 invertebrate species (including three invasive tunicates), and four algae species. Surveyors are encouraged to record all fish species they can positively identify and their relative abundances, not just those on the list, but are limited to the set list of invertebrate and algae species. Surveyors can survey fish only, invertebrates and algae only, or all species during a single survey. Species abundances are recorded as a category based on a log scale of abundance: Single (1 individual), Few (2-10 individuals), Many (11-100 individuals), or Abundant (101+ individuals). These categories are then represented by the numbers 1 through 4 in the data file. Some invertebrate and algae species are recorded at presence/absence only due to their high abundance, aggregating nature (e.g., Strawberry anemones, Sargassum). A summary of the data for fish, invertebrates, and algae is provided in Table 1. A list of the invertebrate and algae species surveyed by REEF can be accessed at: https://www.reef.org/pacific-northwest-invertebrates-and-algae.

Table 1: Summary table of the REEF species observations for fish, invertebrate, and algae taxa. Surveyors can survey fish only, invertebrates and algae only, or all species, therefore the number of surveys, sites, and survey hours are not exclusive to each taxa. Additionally, the Total Mean Species Observed does not correct for the taxa that were collected on each survey.

Taxa	# of Species	# of Surveys	# of Sites Taxa Has Been Observed At	# of Survey Hours	Mean Species Observed Per Survey (± SD)
Fish	177 (39 Families)	6,960	568	5,639	10.1 ± 4.42
Invertebrates	62 (8 Phyla)	6,213	518	5,025	14.1 ± 5.43
Algae	4 (2 Phyla)	1,136	183	1,070	1.4 ± 0.51
Total	244	7,040	572	5,698	22.6 ± 9.97

Surveyors also provide information about survey site location, date, surface and bottom temperatures (as recorded on surveyors' dive computers), starting time, survey duration, maximum survey depth, average survey depth, visibility (as a qualitative categorical variable: < 10 feet, 10 ft to 24 ft, 25 ft to 49 ft, or > 49 feet), current (as a qualitative categorical variable: none, weak, or strong), and dominant habitat type (from a set list of 12 types: artificial reef, bull kelp forest, cobble/boulder field, eel grass bed, kelp forest, mud/silt bottom, open ocean, pinnacle, rock/shale reef, sandy bottom, surf grass bed, and wall). Survey site location and associated latitude and longitude coordinates are highly controlled by REEF, and surveyors must select the dive site they visited from a set list provided by REEF. If surveyors conduct a survey at a site not included in the REEF database, they can request its addition by contacting REEF directly, but cannot add it themselves.

REEF Data Preparation

The data analyzed here were obtained from REEF's global database, limited to BC, and included the date range from the first survey REEF received on 10 May 1998 to 17 August 2020 when the data were requested (REEF 2020). There were 572 site locations, 7,040 surveys and 159,139 recorded fish, invertebrate, and algae species abundance observations in that period. The data are contained in four text files:

1. Survey information: survey form number (a unique record identifier for the database), date, site, duration, maximum depth, average depth, current speed, bottom water temperature, visibility, habitat type, and surveyor experience level.
2. Species abundance observations: survey form number, site, date, duration, species number code (unique to REEF), and the abundance of each species observed by the surveyor.
3. Species taxonomy: species number code, species common name, scientific name, family, and an indicator if the species is an invertebrate or vertebrate.
4. GPS coordinates for each site.

The text files were imported into R and all analyses were conducted in this program (R Core Team, 2020). Since generating maps was a key part of the data exploration, any surveys that did not have associated GPS coordinates were dropped from the analysis, resulting in 356 surveys being dropped (5% of the total surveys) with an associated 7,225 species abundance observations dropped (4.5% of the total observations).

The species abundance observations are recorded on a categorical log scale which makes interpreting the raw data challenging. To better understand trends in abundances, the data can be interpreted by three metrics as recommended by REEF (Wolfe and Pattengill-Semmens 2013):

Percent sighting frequency: determines how often a particular species was observed at a site over time.

$$\text{Percent sighting frequency} = \frac{\text{Number of surveys a species is present at a site}}{\text{Total number of surveys at that site}} * 100$$

(Equation 1)

Density score: a weighted average of the recorded observed abundance categories of a particular species at a site over time.

$$\text{Density score} = \frac{(\text{nSx1})+(\text{nFx2})+(\text{nMx3})+(\text{nAx4})}{\text{nS} + \text{nF} + \text{nM} + \text{nA}},$$

(Equation 2)

where nS, nF, nM, and nA represent the number of times each abundance category (Single, Few, Many, Abundant) was assigned to a given species at a site.

Abundance score: corrects the density score for surveys were a species was absent, using the percent sighting frequency.

$$\text{Abundance score} = \frac{\text{Density Score} * \text{Percent Sighting Frequency}}{100}$$

(Equation 3)

As an example of how these equations have been used to analyse REEF data, see Serafy et al. 2015 where they found that over then entire Caribbean region mangrove habitat provides vital, highly utilized nursery space for certain species. Schultz et al. (2016) and Harvell et al. (2019) both tracked population changes over time and calculated 60-day or annual abundance score averages by site, respectively. Schultz et al (2016) was able to detect trophic cascades following *P. helianthoides* decline, and Harvell et al (2019) linked the decline in *P. helianthoides* to rising sea surface temperatures. Other studies have interpreted the categorical abundance data in different ways. Tolimieri et al. (2017) used the minimum fish numbers for each abundance category (Single = 1, Few = 2, Many = 11, Abundant = 101) as species counts before conducting their analyses to determine rockfish species abundance declines. Rather than using the minimum category values, Montecino-Latorre et al. (2016) used count data from supplementary surveys to determine median values for surveys with *P. helianthoides* in the Few and Many categories, then substituted those median values into the data to detect species decline. Other authors, such as Grüss et al. (2018), Heery et al. (2018), and Safiq et al. (2018) converted the data to presence/absence and then either used only REEF data or combined REEF data with other data sets to address various research questions.

Abiotic Data Visualizations

Using the nepacLLhigh base map in the PBSmapping package in R (Schnute et al, 2019) a bubble map was created showing the survey sites with bubble size indicating the number of surveys conducted at each site (Figure). Since there was a gap along the Central and Northern Coasts of BC, the area with no conducted surveys was omitted, and an inset was created to show the 14 surveys conducted at nine sites along the North Coast near Prince Rupert.

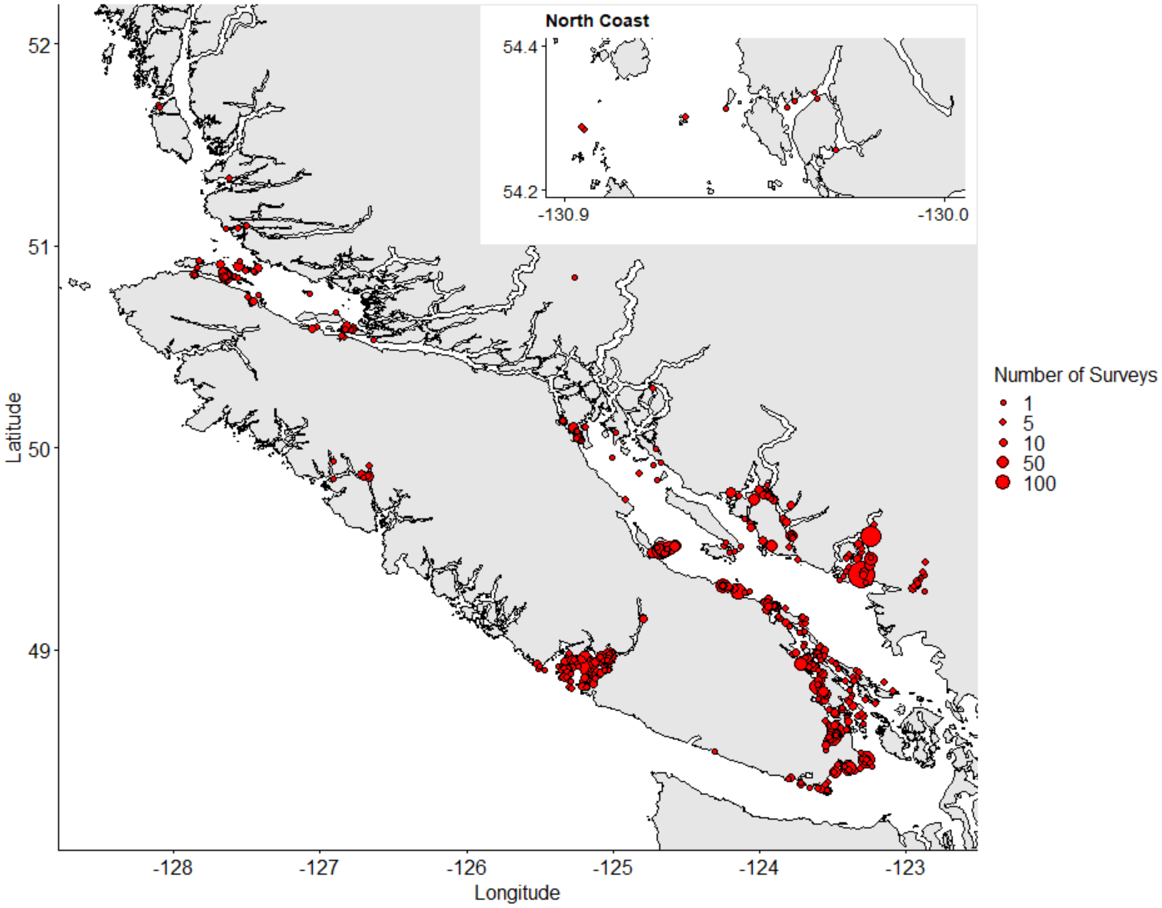

Figure 1: Map of the REEF survey sites from 10 May 1998 to 17 August 2020 as indicated by red bubbles. Bubble size indicates the number of surveys conducted at each site. There is a gap with no surveys conducted along the Central and Northern coast, so this area was omitted and the 14 surveys from 9 sites along the North Coast near Prince Rupert are shown in the inset.

Habitat maps were generated in QGIS (QGIS.org, 2020) using the Biological Records Tool in the Field Studies Council (FSC) plugin (Field Studies Council, 2020). Maps were generated for surveys conducted in Barkley Sound as a means to demonstrate the data resolution. A 0.5 km^2 grid was overlaid on the Esri ocean base map available in QGIS. Any grid resolution can be defined in the program and grid size should reflect the scale of each individual project. The spatial area covered on each dive varies and this information is not recorded by surveyors, but many sites can be surveyed at this scale (author personal observation). To generate habitat maps, if any survey within each grid square indicated it was conducted over the selected habitat type, that square was coloured red. See Figure for an example of where artificial reefs, cobble/boulder field habitats, mud/silt habitats, and wall habitats are located in Barkley Sound. Some REEF site locations in Figure 2 are not coloured in as those sites were conducted over habitats other than the 4 shown. Multiple habitat types were observed at 54% of the sites, therefore some REEF site locations may be coloured on multiple panels.

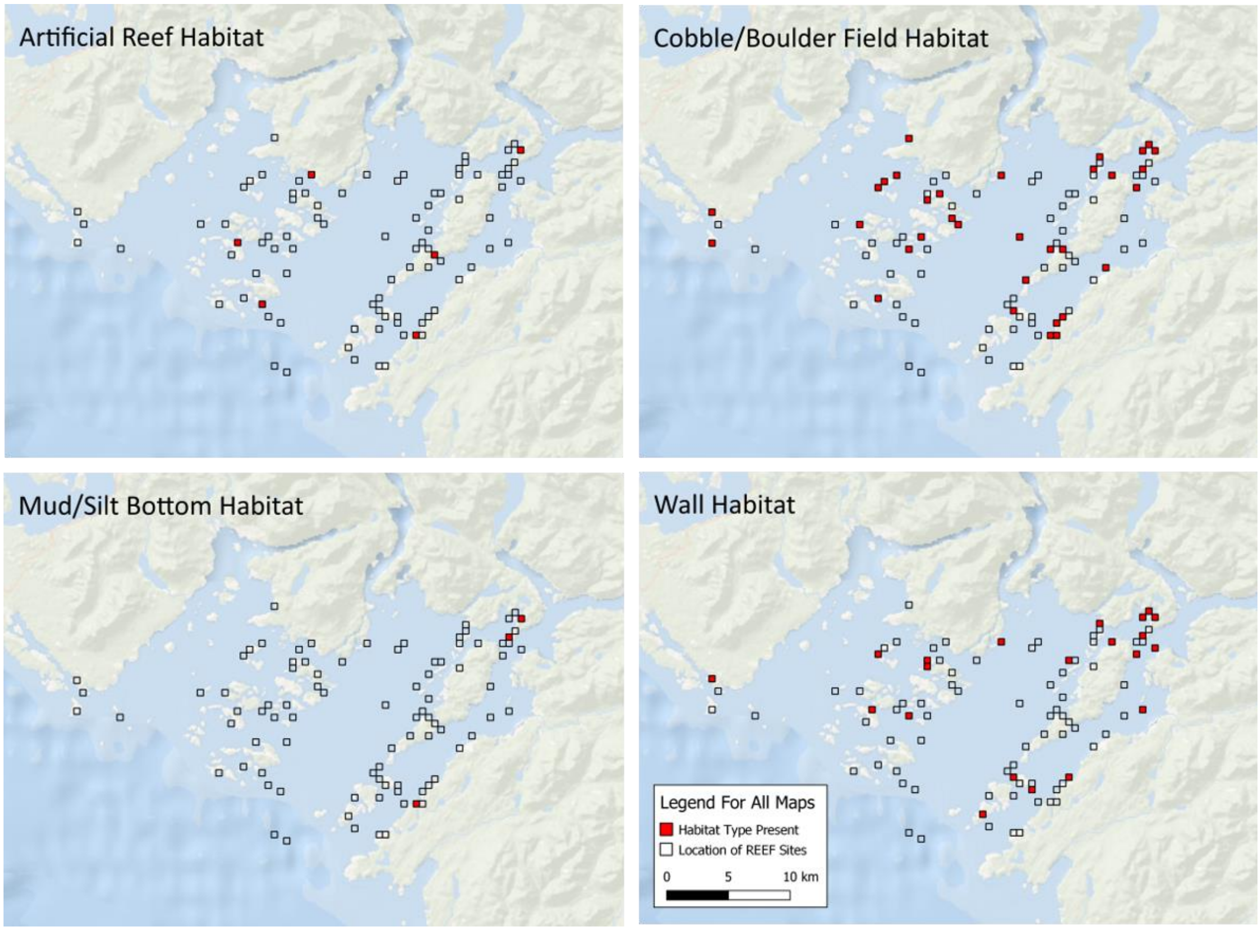

Figure 2: Locations of REEF survey sites in Barkley Sound conducted over artificial reefs, cobble/boulder field, mud/silt bottom, and wall habitats. Squares (0.5 km^2) were coloured red if at least one survey within each square was conducted over the specified habitat as indicated by the surveyor. Maps were created in QGIS using the Biological Records Tool in the FSC plugin.

Bottom temperature data were plotted by site to determine if there were any trends over the past 22 years of observations. These data were recorded on surveyors' dive computers, of which there are many brands and sensor types, and this technology has improved during the past two decades, all contributing to noise in data precision. There is no feasible way to calibrate these data based on the technology used as this information is not collected. Temperature data were first cleaned to remove observations of 0°F and one value of 95°F which were assumed to be missing data or data entry errors. Values were then converted into Celsius. There were 4 survey sites with more than 150 temperature observations, which were used to plot temperature readings over time (Figure). Site headings in Figure 3 include the colloquial site name, water body or island where the site is located, and the number of data points. The effect of dive computer inaccuracy and/or depth can be observed at Ford Cove Reef especially (Figure , top right panel) where multiple various temperature readings were observed on the same day. The average maximum survey depth and range of depths varies between the four sites and are summarized in Table 2. The effect of depth on water temperature is especially relevant for surveys conducted during the summer when strong thermoclines can develop sometimes resulting in near 10°C abrupt changes (Thomson 1981).

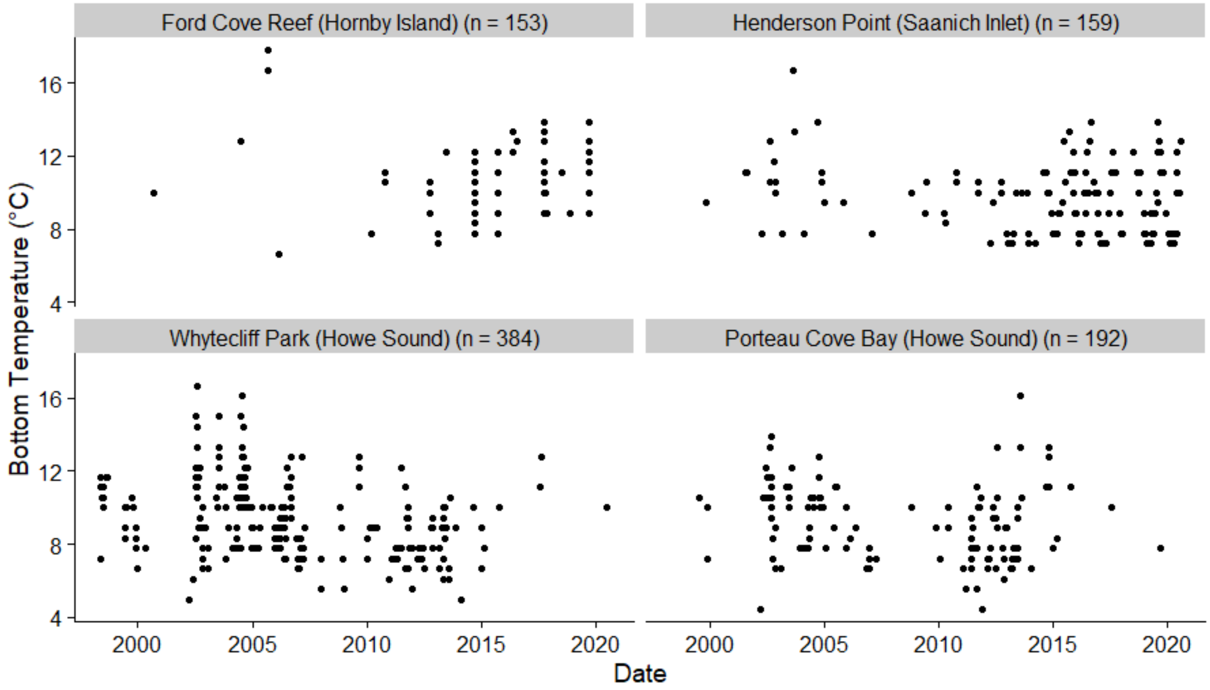

Figure 3: Bottom temperature values as recorded by surveyors' dive computers for survey sites with 150 or more temperature observations. Each black dot indicates an individual temperature reading.

Table 2: Summary of survey depths for the four survey locations with more than 150 temperature observations from May 1998 to August 2020.

Site	Average Maximum Survey Depth	Range of Survey Depths
Ford Cove Reef	26 feet	snorkel - 59 feet
Henderson Point	72 feet	30 feet - 120+ feet
Whytecliff Park	64 feet	10 feet - 120+ feet
Porteau Cove Bay	42 feet	snorkel - 109 feet

Biotic Data Visualizations

Species tables can be created to show the number of sites and surveys for which each species was observed. These can be generated for fish, invertebrate, and algae data separately, and Table 3 shows a small example of the information these tables could contain, with the ten most commonly observed fish species shown.

Table 3: Species table of fish species observations from 10 May 1998 to 17 August 2020 from British Columbia. The top 10 most observed species across all surveys are listed.

Common Name	Family Name	Scientific Name	# of Sites	# of Surveys
Kelp Greenling	Greenling	*Hexagrammos decagrammus*	444	5316
Copper Rockfish	Scorpionfish	*Sebastes caurinus*	436	5314
Blackeye Goby	Goby	*Rhinogobiops nicholsii*	424	4904
Lingcod	Greenling	*Ophiodon elongatus*	388	4309
Quillback Rockfish	Scorpionfish	*Sebastes maliger*	374	3626
Striped Seaperch	Surfperch	*Embiotoca lateralis*	321	3164
Longfin Sculpin	Sculpin	*Jordania zonope*	349	2806
Scalyhead Sculpin	Sculpin	*Artedius harringtoni*	345	2550
Painted Greenling	Greenling	*Oxylebius pictus*	293	2379
Pile Perch	Surfperch	*Rhacochilus vacca*	252	2309

Expert vs Novice Surveyor Data Comparison

REEF provides ample learning opportunities for its surveyors and encourages them to increase their species identification skills by advancing through a series of five levels. Surveyor species identification is a large part of REEF training and species identification resources and “fish-inars” (webinars) are provided to encourage surveyors to increase their skills in an entertaining, group environment. Surveyors progress through the five levels by successfully completing species identification tests and conducting surveys. Level one, two, and three surveyors are classified as Novice surveyors, and level four and five surveyors are classified as Expert surveyors. To achieve level four or five Expert status, surveyors need to conduct 35 or 50 surveys and to achieve 90% or 95% accuracy, respectively, on a 100-question fish, invertebrate, and algae species identification test, in which pictures of species are displayed and the surveyor correctly identifies the species common and family (for fish) or phyla (for invertebrates and algae) names. Expert data comprises 49% of the surveys conducted between 10 May 1998 and 17 August 2020.

We compared survey duration, fish species richness, and fish abundance observations collected by Expert and Novice surveyors using non-parametric Mann-Whitney U tests since data were not normally distributed or did not display equal variance between groups. Fish observations were used, rather than invertebrate or algae which have set species lists, to enable more accurate tests of the species identification skills between the two experience levels. Expert surveyors recorded 161 unique fish species, and Novice surveyors recorded 130 unique fish species. Expert surveyors recorded 45 species not recorded by Novice surveyors with observations ranging from 72 to 1 observation (Appendix A Table 1). Novice surveyors recorded 14 species not recorded by Expert surveyors with observations ranging from 3 to 1 observation with the exception of ‘Unidentified Surfperch’ which had 28 observations (Appendix A Table 2). Species richness was tested using only sites both Experts and Novices had conducted surveys at to reduce any variability between surveyor levels due to survey location. Site species abundance scores were also compared between Expert and Novice surveyors. To accurately compare species abundances at the site level, again, only the sites where both Experts and Novice surveyors had conducted surveys at were used and only species that were observed by both Expert and Novice surveyors were included in the analysis. This resulted in data from 237 sites and 116 fish species.

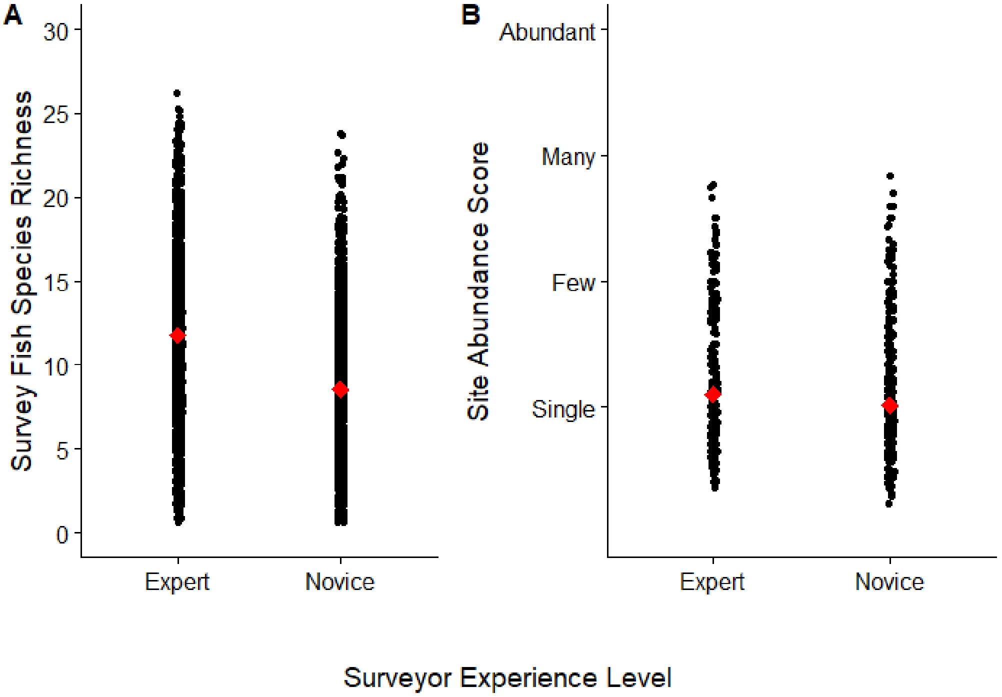

Figure 4: Survey fish species richness (panel A) and site abundance scores (panel B) by Expert and Novice surveyors. Black dots represent survey (panel A) or site (panel B) values. Red diamonds indicate the median value for each experience level.

Expert surveyors spend, as a median value, 52 minutes surveying (n = 3489 surveys) while Novice surveyors spend only 46 minutes surveying (n = 3118 surveys) which represents a statistically significant difference in survey effort (*p*-value < 0.001, *U* = 21.2). Expert surveyors also observed significantly more median fish species than Novice surveyors, 12 fish species compared to 8 species, (*p*-value < 0.001, *U* = 28.111, Figure 4A). However, there were no significant differences in survey median site species abundances between Expert surveyors (1.10 median fish abundance score) or Novice surveyor (1.01 median fish abundance score) experience levels (*p*-value = 0.138, *U* = 1.484, Figure 4B). To put the abundance scores into perspective, based on this categorical abundance metric, the median site abundance scores ranged between Single (1 fish = 1.0) to Few (2-10 fish = 2.0). These results indicate that while expert surveyors observe more species, perhaps due to their extended survey time and increased fish identification training, Expert and Novice surveyors observe similar species abundances at the same site and over the same species.

Case Study One: Lingcod (*Ophiodon elongatus*) in Pacific Fishery Management Area 28

Species abundance data can be used to observe trends in populations over time at specific sites or regions. In this case study, lingcod (*Ophiodon elongatus*) survey abundances were analyzed for all sites within Pacific Fishery Management Area (PFMA) 28 (Howe Sound and Indian Arm) from May 1998 to August 2020. Lingcod abundances reached historic lows within the Strait of Georgia in the late 1980s due to pressure from targeted commercial and recreational fishing. As a result, commercial fishing was prohibited in 1990 and recreational fishing was subsequently prohibited in 2002. Recreational fishing for lingcod resumed in certain areas in the Strait of Georgia in 2006 but was still prohibited within PFMA 28 due to a slow recovery in the region (DFO, 2015). The recovery measures for lingcod introduced by Fisheries and Oceans Canada provide an opportunity to demonstrate how data from REEF can be used to analyse lingcod population abundance trends in response to recovery efforts in PFMA 28 since 1998 when data were first collected by REEF surveyors. Data were analysed using a variety of methods. First, the raw abundance observations from each dive were plotted to visualize when surveys were conducted (Figure 5). Next, the data were pooled by year and percent sighting frequency (Equation 1, Figure 6) and weighted averages of abundance (Equation 2, Figure 7) were calculated. These two metrics were then multiplied together (Equation 3, Figure 8) to generate an abundance score that was corrected for surveys where lingcod were not observed. Indications of fishery management efforts are included on the figures as vertical red dashed lines, indicating periods when the recreational fishery was either open or closed. Abundance scores were also calculated for each REEF survey location with the data pooled temporally based on fishery management effort implementation. These data were then visualized in a series of maps to observe how lingcod populations were affected by the conservation measures (Figure 9).

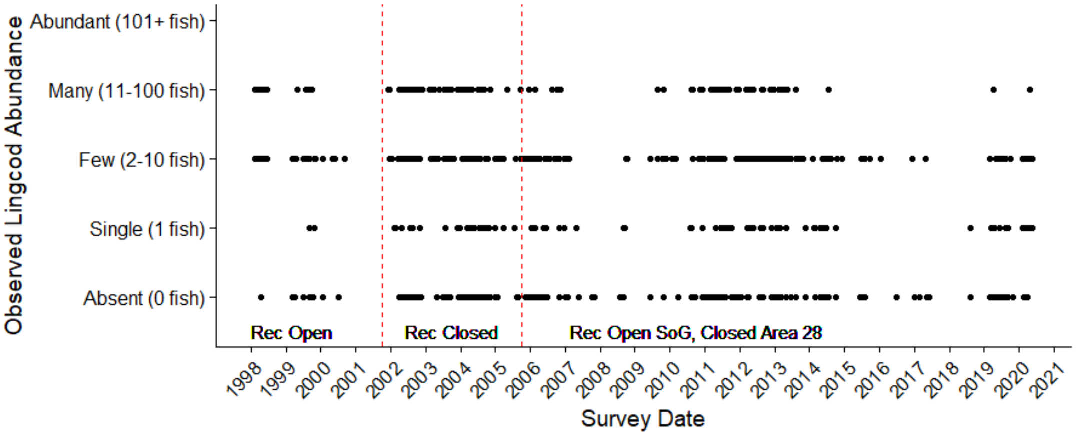

Figure 5: Lingcod (*Ophiodon elongatus*) abundances over time at all REEF survey locations in Pacific Fishery Management Area 28. Each black dot represents the recorded lingcod abundance on each survey.

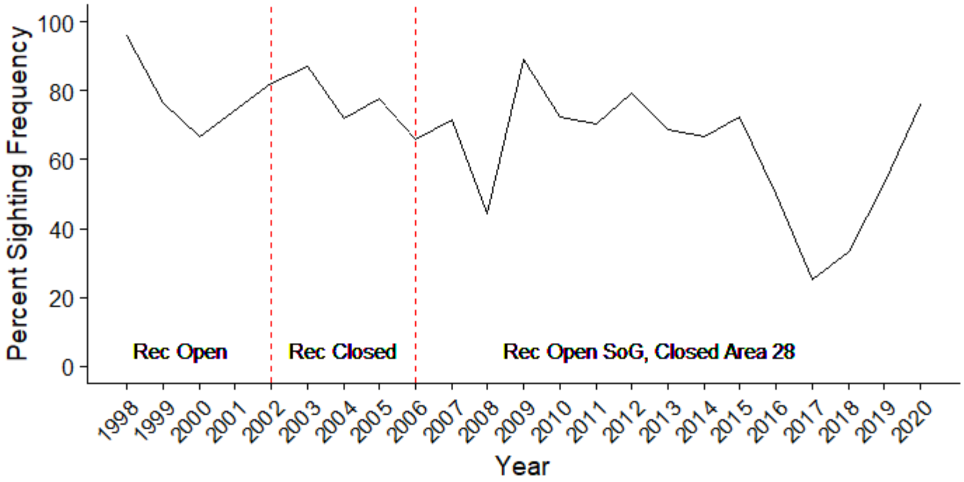

Figure 6: Percent sighting frequency of lingcod (*Ophiodon elongatus*) in Pacific Fishery Management Area 28 by year. See Equation 1 for details on how values were calculated. Red dashed lines indicate fishery management efforts by Fisheries and Oceans Canada to limit the impact of the recreational fleet on lingcod abundances; recreational fishing for lingcod was permitted until 2002 after which it was prohibited until 2006. In 2006, recreational fishing for lingcod was permitted in certain areas of the Strait of Georgia (SoG) but was still prohibited in Pacific Fishery Management Area 28.

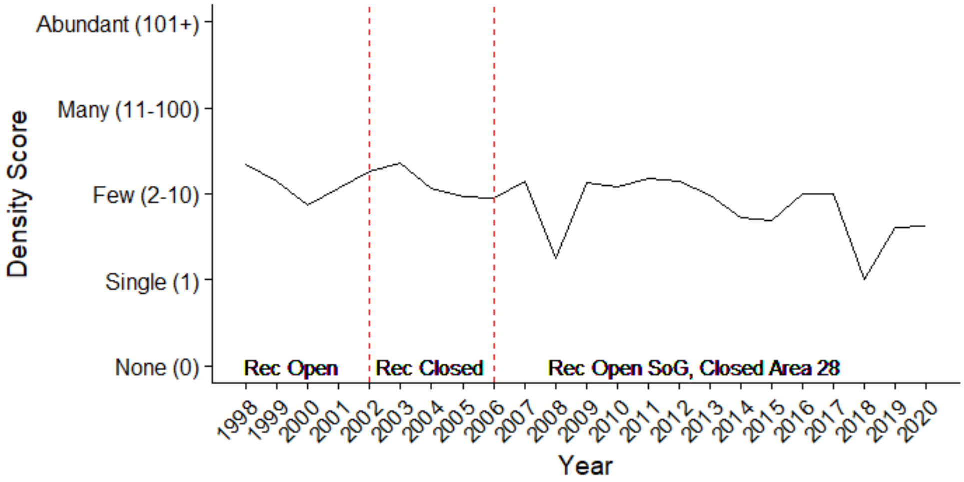

Figure 7: Density score of lingcod (*Ophiodon elongatus*) in Pacific Fishery Management Area 28 by year. See Equation 2 for details on how values were calculated. Red dashed lines indicate fishery management efforts by Fisheries and Oceans Canada to limit the impact of the recreational fleet on lingcod abundances; recreational fishing for lingcod was permitted until 2002 after which it was prohibited until 2006. In 2006, recreational fishing for lingcod was permitted in certain areas of the Strait of Georgia (SoG) but was still prohibited in Pacific Fishery Management Area 28.

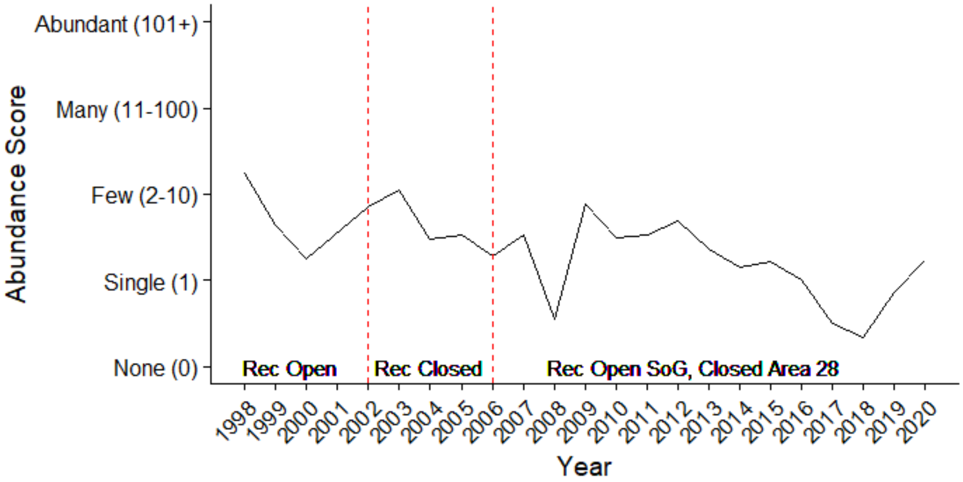

Figure 8: Abundance score of lingcod (*Ophiodon elongatus*) in Pacific Fishery Management Area 28 by year. See Equation 3 for details on how values were calculated. Red dashed lines indicate fishery management efforts by Fisheries and Oceans Canada to limit the impact of the recreational fleet on lingcod abundances; recreational fishing for lingcod was permitted until 2002 after which it was prohibited until 2006. In 2006, recreational fishing for lingcod was permitted in certain areas of the Strait of Georgia (SoG) but was still prohibited in Pacific Fishery Management Area 28.

Lingcod sightings have varied considerably over the past 22 years (Figure 5, Figure 6). The observed abundances of lingcod appear to be declining over this period (Figure 7), which results in an overall declining abundance score (Figure 8). While the last three years of data (2017-2020) indicate lingcod are being sighted more often, they do not appear to be observed at abundances higher than normal in this time series. This is also reflected in the abundance score which, while on a positive trend, is still lower than in many earlier years. This visual trend was also supported by a statistical analysis. Since the sample sizes were normally distributed as indicated by a Shapiro-Wilk test and the before and after groups had equal variance as determined by an F test, we were able to conduct a Student's t-test. These results indicated that there was on average an abundance score of 1.72 in the years before the closure (1998-2001) and an abundance score of 1.29 after the closure (2002-2020), which did not represent a statistically significant difference (t = -1.3617, df = 2.595, p-value = 0.2794). These data suggest that lingcod populations in PFMA 28 have not increased after fishery closures were put in place. To put the abundance scores into perspective, based on this categorical abundance metric, lingcod abundances remained between Single (1 fish = 1.0 abundance score) and Few (2-10 fish = 2.0 abundance score) between the two fishery closure eras.

However, surveyors are constrained by their training to depths shallower than 40 meters and lingcod that may inhabit deeper portions of this area or locations further off-shore are not captured in these data. Recreational and commercial fishers typically target depths ranging from 80 – 140 meters (Cass et al. 1990), so REEF data can provide a useful complement to fishery dependent data. A 2016 stock assessment from DFO (Holt et al. 2016) indicate slightly different results. They found that lingcod biomass within the Strait of Georgia has increased approximately 8% from 1998 to 2014. However, the authors indicate that when the lingcod populations in PFMA 28 & 29 (Lower Mainland, Sunshine Coast, Fraser River) are excluded from the entire Strait of Georgia population, the Strait of Georgia population shows a more rapid recovery than when the lingcod populations in PFMA 28 & 29 are included in their analyses. While this 2014 stock assessment does not directly address the populations in PFMA 28 & 29, it does appear from their results that these populations are not recovering as quickly as other populations in the Strait of Georgia, which is similar to the results obtained here using the REEF data collected in PFMA 28 which indicate no change in abundance after the fishery closure. However, changes in biomass are not directly related to changes in abundance and the REEF data do not include information on fish lengths or age, so some caution is required when comparing these two studies. These analyses demonstrate how citizen science data can be useful baseline data to observe the potential effects of fishing closures or other conservation measures.

Species abundance scores can also be useful in generating species distribution maps (Figure 9) using the Biological Records Tool in the FSC plugin (Field Studies Council, 2020) in QGIS (QGIS.org, 2020). Here, we averaged abundance scores by site over the years of implemented fishery management efforts: 1998 – 2001 (beginning of REEF survey data to 2001, recreational fishery open), 2002 – 2005 (duration of recreational fishery closure throughout the Strait of Georgia), 2006 – 2010 (five- year period following the opening of recreational fishing within the Strait of Georgia but still prohibited within PFMA 28). Grid square size can be user defined, and here 0.5 km^2 grids were used to visualize the data. Square colour indicates the average abundance score of lingcod during each period within each square. These stylized maps can be generated quickly and easily within the Biological Records Tool. This tool also allows for batch map generation to make maps of multiple species at once. Instructions for generating these maps are provided as supplemental material. These maps can also incorporate other closures of interest such as Rockfish Conversation Areas or marine protected areas.

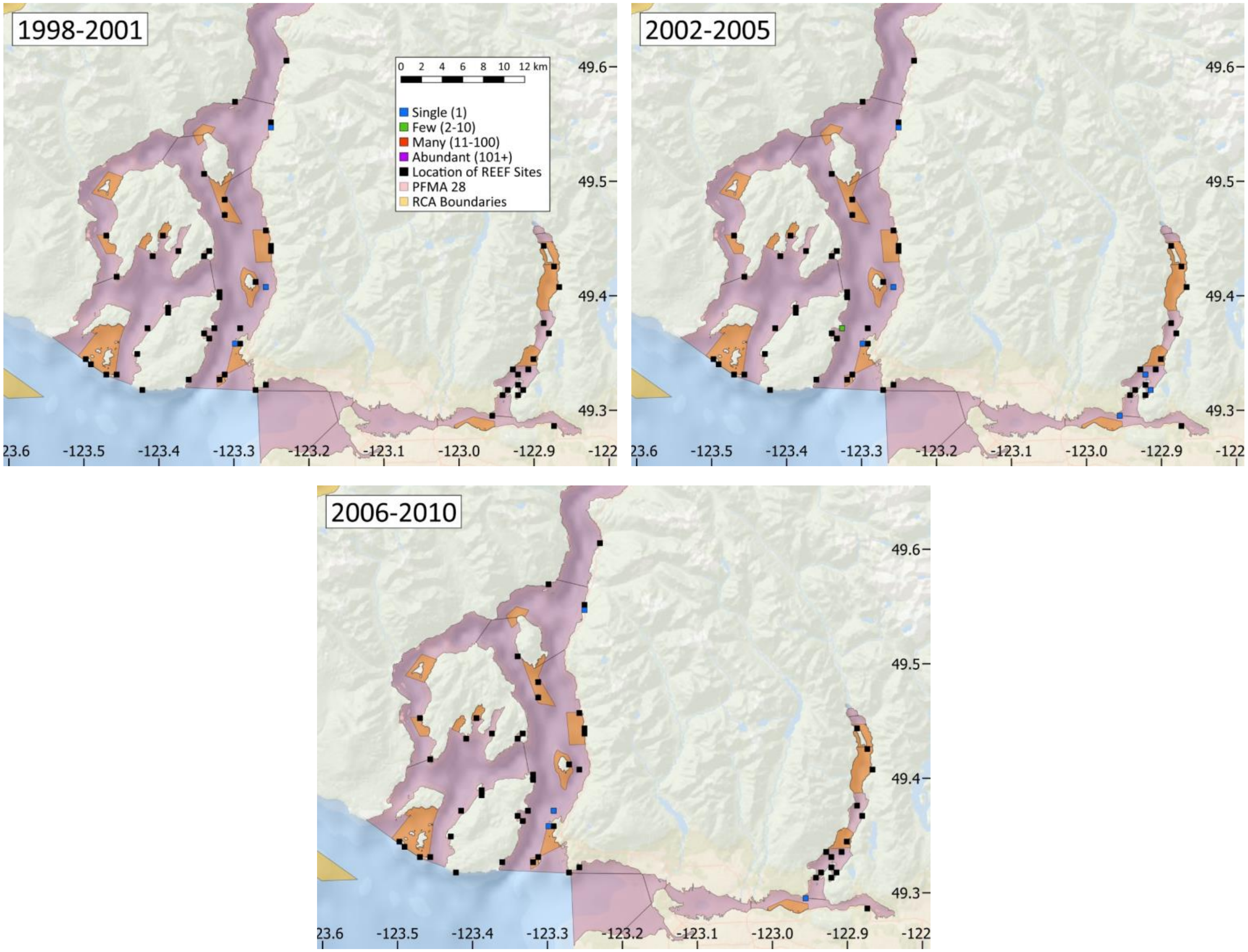

Figure 9: Species distribution maps for lingcod (*Ophiodon elongatus*) in Pacific Fishery Management Area (PFMA) 28. Black squares represent 0.5 km^2 areas where a REEF survey site exists. Squares are coloured based on the average abundance score of lingcod at all REEF survey sites within each grid square during each survey period. Survey periods are based on Fisheries and Oceans Canada recreational fishery closures: 1998-2001 (beginning of REEF survey data to 2001, recreational fishery open), 2002-2005 (duration of recreational fishery closure), 2006-2010 (five-year period following the opening of recreational fishing within the Strait of Georgia but still prohibited within PFMA 28). The number of surveys conducted in each grid square varies. Pink shading indicates PFMA 28 boundaries; orange shading indicates Rockfish Conservation Area boundaries (provided for interest only).

Case Study Two: Influence of current on fish species richness, abundance, and community composition

A case study was conducted to explore if tidal current could be used as an abiotic surrogate for fish biodiversity as a comparison to the experimental work described in Chapter 2. Tidal current has been linked to increased biodiversity as it increases water mixing (Thomson 1981), promotes phyto- and zooplankton abundance (Batten and Crawford 2005), which provides food for many animals including fish (Leonard et al. 1998; see Chapter 1). We compared temperature, habitat type, fish species richness and abundance by site, and rockfish (*Sebastes spp.*) community composition between two levels of current.

REEF surveyors indicate the strength of current they experienced during their survey based on a qualitative categorical scale: strong, weak, or none. These observations are influenced by surveyor experience level and comfort in the water, and noise in precision and accuracy of these data are expected. In this case study, sites were designated as 'No Current' sites if all surveys at that site were only ever categorized as having an observed current strength of 'none' (sites = 114, surveys = 243). These No Current sites had between 1 and 12 conducted surveys. Sites were designated as 'Some Current' sites if all surveys at that site were only ever categorized as having observed current strengths of 'weak' or 'strong' (sites = 163, surveys = 533). These Some Current sites had between 1 and 24 conducted surveys. This method for grouping the sites reduces some of the between surveyor variability in current speed categorization, however some sites may be misclassified, especially with low numbers of surveys, however sample sizes were too low to compare strong current only sites versus no current sites, or to require a minimum of 5 surveys at each site. There appears to be a relatively even distribution of No Current and Some Current sites around the South Coast and Vancouver Island (Figure 10).

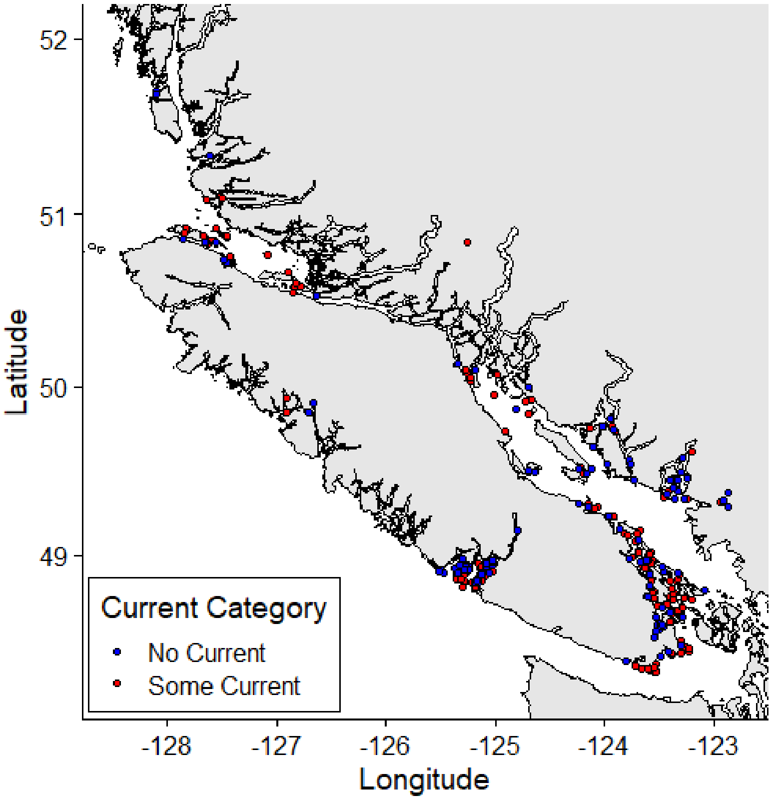

Figure 10: Map of No Current and Some Current survey sites. No Current sites are any survey sites where current observations were always recorded as 'none'. Some Current sites are any survey sites where current observations were always recorded as either ‘weak’ or ‘strong’.

Temperature values, as recorded by surveyors’ dive computers were compared between No Current and Some Current sites using a Mann Whitney U test since data were not normally distributed and there was not equal variance between the two current categories. There were significant differences between the median temperatures with Some Current sites being significantly cooler than No Current sites by 1.11 °C ($p < 0.001$, $U = 3.481$, No Current: 10.00 °C, Some Current: 8.89 °C, Figure 1).

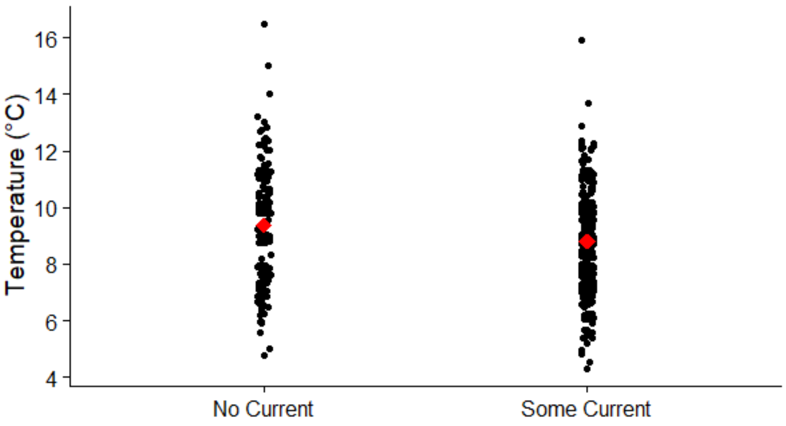

Figure 11: Water temperature observations recorded by surveyors' dive computers between No Current and Some Current Sites. Black dots represent recorded temperature observations for each survey and red diamonds indicate the median value for each current category.

No Current sites had a more even spread of habitat types than Some Current sites. Habitat types for both current categories were dominated by hard substrate habitats (No Current: 64.5%, Some Current: 87.6%, Figure 126, red stacked bars) more so for Some Current sites, followed by seaweed/seagrass habitats (No Current: 22.3%, Some Current: 8.5%, Figure 126, green stacked bars), with soft substrate habitats being the least observed habitat types (No Current: 13.2%, Some Current: 4.0%, Figure 126, yellow stacked bars), markedly so for Some Current sites.

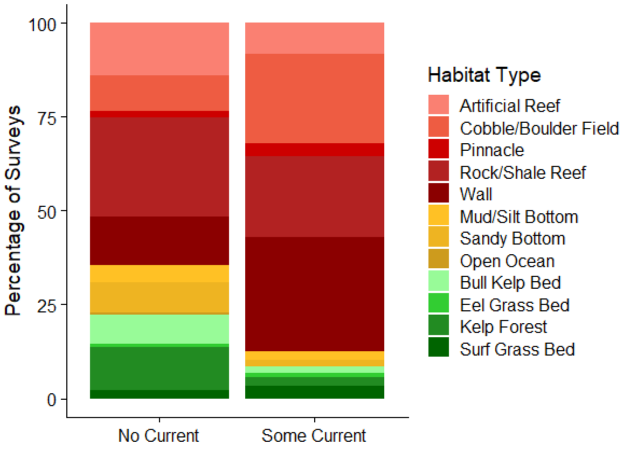

Figure 126: Habitat types at No Current and Some Current sites presented as percentages of total surveys for each current category. The habitat types are coloured based on if they are hard substrate habitats (red), soft substrate habitats (yellow), or seaweed/seagrass habitats (green).

A total of 123 species were observed between No Current and Some Current sites. No Current sites had a combined species richness of 100 fish species, and Some Current sites had a combined species richness of 104 fish species. No Current sites had observations of 18 species not observed at

Some Current sites with observations ranging from 1 to 3 observations (Appendix C, Table 1). Some Current sites had observations of 22 species not observed at No Current sites with observations ranging from 1 to 6 (Appendix C, Table 1). Fish species richness was calculated for each survey and then compared between No Current and Some Current sites using a Mann Whitney U test since data were not normally distributed and there was not equal variance between the current categories. Median fish species richness on No Current surveys (n = 243) was 8.0 species. Median fish species richness on Some Current surveys (n = 533) was 9.0 species. There were no significant differences in median fish species richness between No Current and Some Current sites (*U* = 64,354, p-value = 0.888, Figure 13).

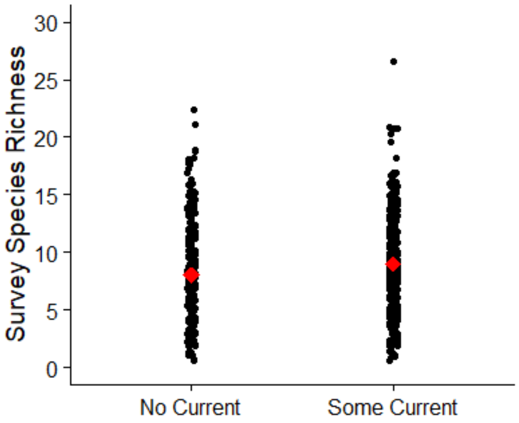

Figure 13: Survey species richness at No Current and Some Current sites. Black dots represent the total number of fish species observed on each survey and red diamonds indicate the median value for each current category.

Fish abundance was also compared between the two current categories. While the proportion of Single observations between the two current categories is similar, there is a higher proportion of Few sightings at No Current sites and a higher proportion of Many and Abundant sightings at Some Current sites (Figure 14). The abundance scores (see Equation 3) of all fish species are calculated at the site level over time. These abundance scores were compared between No Current and Some Current sites using the non-parametric Mann Whitney U test since the data were not normally distributed, however there was equal variance between the two current categories. The median abundance score at No Current sites was 1.79 and was 1.75 at Some Current sites, which did not represent a statistically significant differences in median fish abundances (*p* = 0.998, *U* = 0.002, Figure 15). To put these numbers into perspective, based on the categorical abundance metric that surveyors use, most species have between one and ten observed individuals (Single (1 fish) = 1.0, Few (2-10 fish) = 2.0).

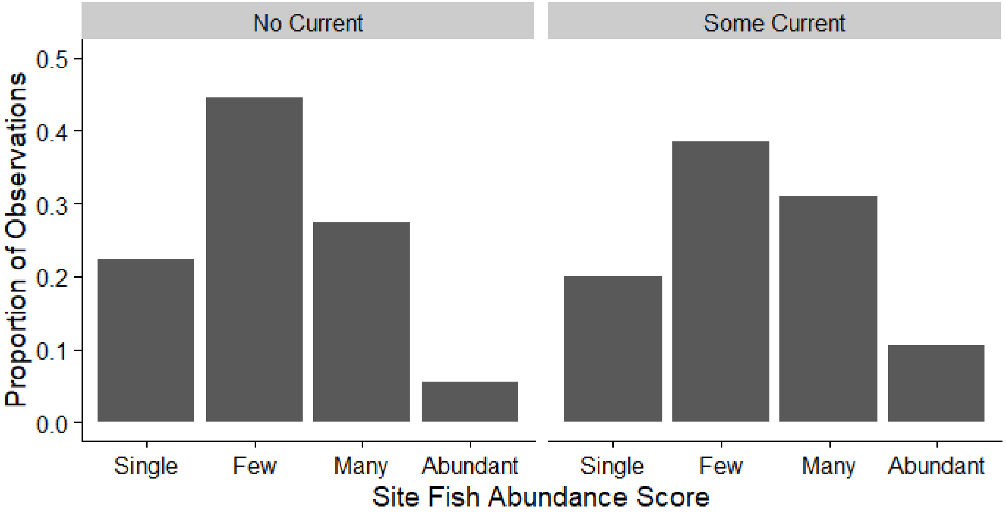

Figure 14: Categorical abundance data between No Current and Some Current sites displayed as a proportion of the total surveys conducted in each current category.

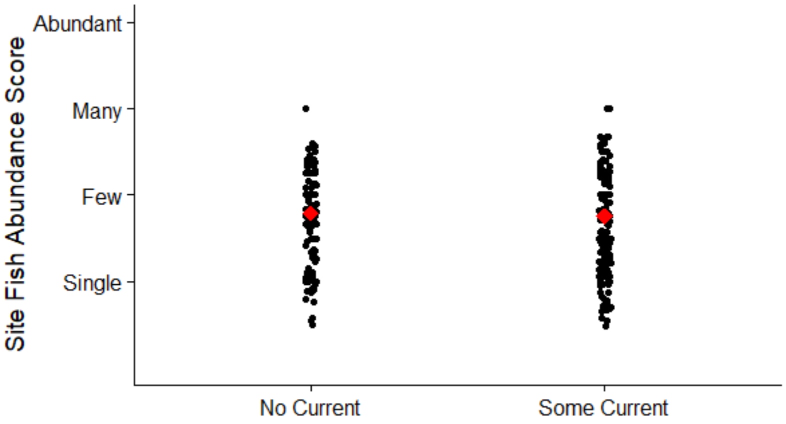

Figure 15: Fish abundance at No Current and Some Current sites. Black dots represent the site average abundance score for all fish species observed at each site and red diamonds indicate the median value for each current category.

Fish communities were compared between No Current and Some Current sites using a non-metric multidimensional scaling (nMDS) plot and analysis of similarity test (ANOSIM) using functions from the vegan package in R (Oksanen et al., 2019). Only rockfish species (*Sebastes spp.*) were used in this analysis, totaling 30 species (see Table 4 for a list of the species included). When all 123 fish species and all 776 fish surveys were included, the data frame was too large for R to run the nMDS analysis using my laptop hardware.

Table 4: Names of the fish species included in the fish community analysis comparing No Current and Some Current sites. Species are listed alphabetically.

Common Name	**Common Name**
Black Rockfish	Puget Sound Rockfish
Black Rockfish YOY	Quillback Rockfish
Blue / Deacon Rockfish YOY	Quillback Rockfish YOY
Blue Rockfish - generic ID	Redstripe Rockfish
Brown Rockfish	Silvergray Rockfish
Canary Rockfish	Tiger Rockfish
Canary Rockfish YOY	Unidentified Black / Yellowtail YOY
China Rockfish	Unidentified Rockfish
China Rockfish YOY	Vermilion Rockfish
Copper Rockfish	Vermilion Rockfish YOY
Copper Rockfish YOY	Widow Rockfish
Deacon Rockfish (was Blue Sided species)	Yelloweye Rockfish
Dusky Rockfish	Yelloweye Rockfish YOY
Greenstriped Rockfish	Yellowtail Rockfish
Juvenile (YOY) Rockfish - Unidentified	Yellowtail Rockfish YOY

The fish communities were neither visually nor statistically significantly different between the No Current and Some Current sites (ANOSIM: $p = 0.807$, $R = -0.020$, Figure 16). The 95% confidence intervals of the community centroids overlap indicating that rockfish species abundance scores are not significantly different between current categories. The community center confidence intervals are shown here rather than each survey, as in Chapter 2, because there were 696 surveys on with rockfish were observed, which made the plot difficult to interpret. These results indicate that current, as defined here, may not a good surrogate for assessing rockfish community differences.

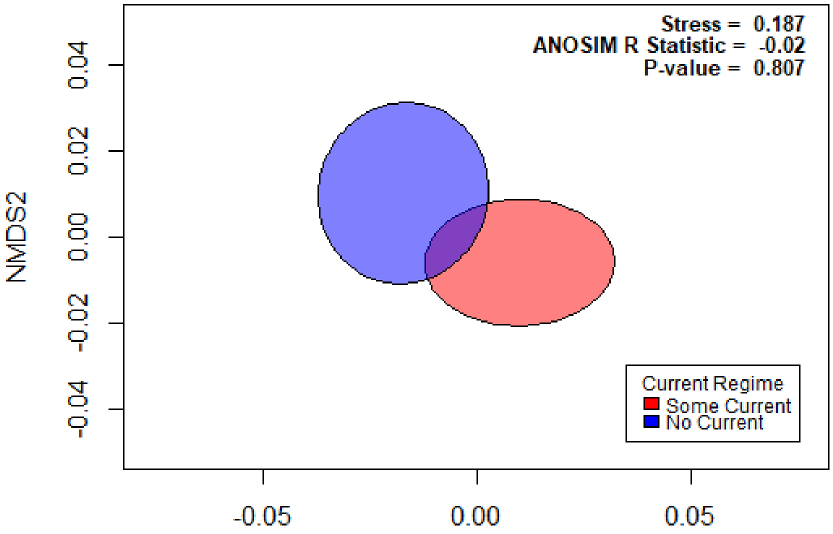

Figure 16: Comparison of rockfish community compositions between No Current and Some Current sites presented in a non-metric multi-dimensional scaling (nMDS) plot using the Gower dissimilarity index. The ellipsoids represent the 95% confidence regions for the location of the community centroids.

In conclusion, while Some Current sites were significantly colder than No Current sites, this small difference in median values (1.11°C) is not likely to be biologically meaningful as temperature values vary more annually at the site level (Thomson, 1981). The results from this chapter and the previous chapter both found cooler temperatures in higher current areas, which Thomson (1981) indicates is due to upwelling caused by tidal currents which circulates deep, cooler water to the surface water. No Current sites had more habitat diversity, but both No Current and Some Current sites were dominated by hard substrate habitats. There were no significant differences in median fish species richness, abundance scores, or rockfish community composition between current regimes. This lack of statistical significance may be due to how the data were pooled. Since we did not use extreme strong current and extreme calm/no current sites, any differences that may exist between these two current habitats could not be detected due to the pooling methodology used here. Using only sites that had all 'Strong' current observations resulted in a very low site sample size (n = 22), therefore the 'Strong' and 'Weak' sites had to be combined. It is likely that some sites may have been misclassified, especially for sites that only have one or two surveys, as a strong current site could have been surveyed during slack current, resulting in a no current observation. However, requiring a minimum of 5 surveys at each site for inclusion in the analysis also resulted in very low site sample sizes (No Current n = 9, Some Current n = 22). The qualitative scale employed by REEF to define current speed is unlikely to be at a resolution that would be of similar importance to fish, and it is likely that many fish species can maneuver in faster current speeds than divers can safely tolerate. The abiotic data collected by REEF surveyors has been demonstrated here to perhaps be too coarse for scientific studies. Rather than relying on surveyor qualitative observations of abiotic variables, higher resolution data layers or models should be used instead.

Discussion

These results demonstrate a few of the analyses and visualizations possible with citizen science data from Reef Environmental Education Foundation. The decades of available data from BC and worldwide provide a source of invaluable baseline data that are useful for tracking species population changes over time or community composition differences. Additionally, these citizen science data offer an inexpensive way for organizations to gather quality marine population data at a broader scale that might not be possible through small scientific dive teams. REEF data can be used alongside scientifically collected biological data or oceanographic models to support species distribution models, identifying potential research sites, support monitoring efforts, or assist in other targeted scientific analyses.

As with all data sets, there are limitations. The main limitation for these data is the low-resolution abundance data. The categorical abundance metric can make it appear as though species populations sizes are not increasing or decreasing as they fluctuate within the abundance categories. This can make it difficult to observe population trends for certain species. Large-bodied territorial species such as some rockfish species (*Sebastes spp.*) may experience substantial population changes over time while still remaining in the Many (11-100 fish) category, therefore, these data many not be suitable for detecting abundance changes for those species. As well, these categories may not be of high enough resolution for schooling species, such as Pacific herring (*Clupea pallasii*) or shiner perch (*Cymatogaster aggregat*a) which can often be observed in the hundreds, although accurately counting that many moving objects is a significant challenge. However, any statistically significant results using the abundance data would be reliable as they indicate order of magnitude differences due to the log scale nature of the observations. Calculating the abundance scores (Equation 3) can eliminate some of these challenges, however they do require averaging the data over time which requires enough data to render the result meaningful. Another limitation to these data is that absences of a species cannot be a considered a true absence, only that the species was not observed. REEF encourages divers to only record species they can positively identify. Therefore, some species may be present and observed, but not recorded by surveyors if they are uncertain of their identity. Similarly, species may be present at the site but not observed as they may be very cryptic or live within the cracks and crevices of the substrate. Unfortunately, there is no way to account for species identification variability between surveyors but using the expert data only could reduce some of the identification uncertainty issues, but many biotic data collection methods have difficulty in determining true species absences. Related to this, the survey effort is not equal between surveyors or between sites, which poses challenges in standardizing the data. For instance, the lack of standardized area or searching effort coupled with the categorical abundance data makes it difficult to determine any reliable count per unit effort metrics. Surveyor movement in the water or light from flashlights can cause fish to move away or seek shelter. However, many of the sites used by REEF surveyors are visited frequently by divers and fish do seem to acclimatize to diver presence, resulting in less fleeing behaviour (author personal observation). Additionally, recreational divers are only certified to 40-meter depths, unless they obtain technical dive training, and this is the maximum depth recorded in the REEF data used here. This maximum diving depth is shallow compared to the average depth of the Salish Sea, at 155m (Thomson, 1981), and only represents a portion of the habitat most of these species inhabit. For instance, among the top five most observed species, kelp greenlings have been observed to 45 m, copper rockfish to 183 m, blackeye gobies to 640 m, lingcod to 2,000 m, and quillback rockfish to 275 m (Lamb and Hanby, 2005). Additionally, the sites are not randomly chosen over the entire BC coast, which could be an issue for some study designs.

Marine spatial planning efforts could benefit from incorporating REEF data into their work. Marine spatial planning and oil spill response planning require knowledge of species distributions, which REEF data are well suited for (Grüss et al. 2018). These data are also well suited for informing the placement of marine conservation areas and their subsequent monitoring. For example, future research with these data includes evaluating Rockfish Conservation Area (RCA) effectiveness by assessing species richness, abundance, and community composition between REEF survey sites inside and outside of RCAs. Such an assessment could also help determine which habitats or areas could be considered for future conservation efforts by highlighting where increased biodiversity is observed, or through determining areas of suitable habitat within existing RCAs. Another potential application of these data in marine conservation is to evaluate young-of-year rockfish observations to determine areas of strong recruitment and the abiotic conditions most likely to result in strong recruitment years when used alongside abiotic models.

Overall, citizen science data are a valuable source of information that is often overlooked. Here we have demonstrated numerous ways these data can be used and how they could inform marine spatial planning, oil spill response, and conservation efforts. The breadth of species observation data is a strength of the citizen science data which has been collected along most of the Southern BC coast year-round since 1998. While the plethora of data is an advantage, there are some limitations with using these data such as the categorical abundance records, the inability to determine true species absences, the inability to standardize the survey effort across surveys and sites, and the non-random site selection. Few studies have employed these types of data, but as we have shown, the information provided can be an invaluable source of baseline data and data generated by citizen science divers are more cost effective and temporally and spatially abundant than data generated by small, often seasonal, scientific dive teams.

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Appendix A

Table A1: Summary table of fish observations made only by Novice Surveyors organized from most to least sightings.

Common Name	Expert Observations	Novice Observations
Barred Surfperch	0	3
Black Perch	0	3
Threadfin Sculpin	0	3
Arrow Goby	0	2
Rainbow Seaperch	0	2
California Halibut	0	1
Giant Kelpfish	0	1
Green Sturgeon	0	1
Lavender Sculpin	0	1
Prickly Sculpin	0	1
Reef Perch	0	1
Starry Skate	0	1
Unidentified Greenling	0	1
Yellowtail	0	1

Table A2: Summary table of fish observations made only by Expert Surveyors organized from most to least sightings.

Common Name	Expert Observations	Novice Observations
Yellowtail Rockfish YOY	72	0
Canary Rockfish YOY	54	0
Blue / Deacon Rockfish YOY	16	0
Black Rockfish YOY	14	0
Unidentified Black / Yellowtail YOY Rockfish	13	0
Puget Sound Rockfish YOY	8	0
Dusky Rockfish	7	0
Thornback Sculpin	6	0
China Rockfish YOY	5	0
Rosylip Sculpin	5	0
Slim Sculpin	5	0
Unidentified Snailfish	5	0
Sharpnose Sculpin	4	0
Snubnose Sculpin	4	0
Widow Rockfish YOY	4	0
Coho Salmon	3	0
Pacific Sardine	3	0
Sand Sole	3	0
Vermilion Rockfish YOY	3	0
Dover Sole	2	0

Flathead Sole	2	0
Marbled Snailfish	2	0
Ocean Sunfish	2	0
Pacific Tomcod	2	0
Ribbed sculpin	2	0
Slender Sole	2	0
Tiger Rockfish YOY	2	0
Black Prickleback	1	0
Butter Sole	1	0
Chum Salmon	1	0
Longnose Skate	1	0
Pacific Lamprey	1	0
Pink Salmon	1	0
Puget Sound Sculpin	1	0
Red Gunnel	1	0
Redstripe Rockfish	1	0
Ribbon Prickleback	1	0
Rock Prickleback	1	0
Saddleback Sculpin	1	0
Spotted Snailfish	1	0
Stripefin Ronquil (R. alleni)	1	0
Stripetail Rockfish YOY	1	0
Surf Smelt	1	0
Unidentified Copper / Quillback YOY Rockfish	1	0
Unidentified Salmon	1	0

Appendix B

QGIS Field Studies Council Tool Instructions

The csv data file must include latitude and longitude as decimal degrees, species name, and abundance scores for each species at each site. If multiple species are contained in the file, a 'Grouping' column containing family name for instance, is helpful.

-Load Project in QGIS
-Open Biological Reference Tool
-Under the 'Data Specification' tab:

- Make sure the correct 'Source layer' is used.
- Under 'Column definitions':
  - X column = Longitude
  - Y column = Latitude
  - Abundance column = Abundance Score
  - Grouping column = Family
  - Taxon column = Latin name or common name
  - Check 'Scientific names' and 'Load taxa on source selection'
- Input CRS = Default CRS: EPSG:4326 - WGS 84 (this may vary based on your data)
- Output CRS = Project CRS: EPSG:3005 - NAD83 / BC Albers (this may vary based on your data)
- Select 'Atlas Squares', 'User-defined atlas size', '1000.000' (in meters, is equivalent to 1 km^2 grid)

-Under the 'Taxa' tab:

- Select the taxa you want to map, multiple species can be selected and a separate map will be created for each

-Under the 'Options' tab:

- Select 'Batch map mode', if multiple species are selected
- Load the style you would like applied to the squares
- Select 'Apply style'
- Under 'Output options', select Format 'Composer image', load the composer template you would like used for map creation. The composer manager needs to be loaded for the template to be applied

-The values for each square the plugin generates are sums of the Abundance Scores in each square instead of averages.

- Right-click the TEMP layer. Select 'Open Attribute Table'. Select 'Open Field Calculator' (the abacus symbol).
  - 'Create a new field'
  - Output field name = Pick an appropriate name for the field
  - Output field type = Decimal number
  - Output field length = 5, Precision = 3
  - In the Expression box type 'Abundance/Records'
- The style might need to be reapplied. Ensure the style is determining the colour of the square bases on the newly created field.

-To create stylized maps:

- Rename the layer to remove 'TEMP' as the legend text is generated from the layer name
- Open the composer tool: Project -> Layers -> ‘Name of your Composer Template’
- Hit the 'Save' button at the bottom of the Biological Records Tool window
- Sometimes the Abundance legend does not save properly. This is usually fixed by resaving the image.

Appendix C

Table C1: Summary table of fish observations made only at No Current Sites organized from most to least sightings.

Common	No Current Observations	Some Current Observations
Greenstriped Rockfish	3	0
Sand Sole	3	0
Bay Goby	2	0
Blackbelly Eelpout	2	0
Flathead Sole	2	0
Rosylip Sculpin	2	0
Chinook Salmon	1	0
High Cockscomb	1	0
Lavender Sculpin	1	0
Puget Sound Sculpin	1	0
Quillfish	1	0
Red Gunnel	1	0
Redstripe Rockfish	1	0
Ribbed sculpin	1	0
Spotted Snailfish	1	0
Tadpole Sculpin	1	0
Unidentified Snailfish	1	0
Vermilion Rockfish YOY	1	0

Table C2: Summary table of fish observations made only at Some Current Sites organized from most to least sightings.

Common	No Current Observations	Some Current Observations
Deacon Rockfish (was Blue Sided species)	0	6
Rock Greenling	0	6
Pacific Cod	0	5
Canary Rockfish YOY	0	3
Dusky Rockfish	0	3
Unidentified Kelpfish	0	3
Widow Rockfish	0	3
Tidepool Snailfish	0	2
Barred Surfperch	0	1
Blue / Deacon Rockfish YOY	0	1
Brown Irish Lord	0	1
China Rockfish YOY	0	1
Chum Salmon	0	1
Pink Salmon	0	1
Ribbon Prickleback	0	1

Rockweed Gunnel	0	1
Saddleback Sculpin	0	1
Silvergray Rockfish	0	1
Silversides spp.	0	1
Unidentified Gunnel	0	1
Unidentified Salmon	0	1
Yelloweye Rockfish YOY	0	1

Chapter 4: General Conclusion

This research explored how scientific and citizen science data can be used to analyse nearshore marine fish species and communities in BC. The data collected using scientific methods were on small temporal and spatial scales but contained detailed observations of individual fish. This approach was useful for determining accurate abundance and biomass estimates, although the small sample sizes made meeting the assumptions of parametric statistics a challenge which limited analyses to be either less sensitive, non-parametric methods or complex linear mixed effects models. The citizen science data from REEF were collected over a span of 22 years and along much of the Southern BC coast. This broad temporal and spatial dataset allowed for population and community changes over time to be explored, which is important in determining the impacts of climate change or fishery management efforts on marine species along our coast. While the abundance data are categorical, useful analyses and interpretations are still possible. Additionally, the REEF data can act as baseline data for many species and ecosystems not typically targeted by long-term scientific studies or for which data limitations are a challenge in detecting spatial or temporal change. These data can also be used alongside scientifically collected abiotic or biotic data. The data set best suited for researchers may change depending on the intention or question being asked.

In Chapter 2, depth was found to be an important driver of fish species richness and abundance and may be an useful abiotic surrogate for fish biodiversity in the Southern Gulf Islands of BC. However, there were no statistically significant differences in fish biodiversity with tidal current. Few studies have been conducted on how tidal current influences fish communities, and no studies on this topic have been conducted along the BC coast. Chapter 3 explored how citizen science data from REEF may be of use in scientific studies. While there are considerable challenges with these data, having information on many species and their distributions over large areas of the Southern BC coast is of considerable benefit to researchers. Using these data, we were able to demonstrate that lingcod do not appear to have responded positively to fishery management efforts and that the abiotic data are possibly too coarse to determine if current, as defined by surveyors, can be a suitable abiotic surrogate for fish biodiversity.

By using multiple data sets, some of the limitations of each can be accounted for, resulting in more robust, definitive results, assuming the data sets used are capable of addressing the research question proposed. The scientifically collected data were limited by the temporal and spatial scales that were logistically feasible and by scientific diving safety protocols, which resulted in low sample sizes and a limited depth range, yet these data were able to include individual fish lengths and accurate abundance counts with consistent survey effort. The citizen science data were limited by the categorical abundance data and qualitative categorical abiotic variables, potential discrepancies between surveyors, inability to determine the amount of area covered by the survey, among others, yet these data cover a temporal and spatial scale that is much more broad than many scientific data sets and are free and publicly available for use in research.

Future work using the data set from REEF includes exploring how these data can provide insight into the performance of RCAs on species conservation. Previous studies looking into the effectiveness of RCAs have used smaller data sets that are constrained temporally and spatially. Preliminary analyses indicate there are 49 RCAs with available REEF data. Another future study could identify surrogates, proxies, or indicators (definitions of these terms appear to vary by paper and are occasionally used interchangeably) other studies have used in subtidal marine ecosystems and determine what impact they may have on fish communities along the BC coast.

This work provides evidence that depth can be a valuable abiotic surrogate for fish species richness and abundance and that tidal current is not an appropriate abiotic surrogate. These findings may also be meaningful in other regions in the world as we work to understand how fish biodiversity is altered by the surrounding abiotic conditions. Little research has been conducted globally on nearshore benthic fish communities and the results presented here help to fill some of those data gaps. Additionally, publicly available, citizen science data from organizations such as REEF are useful tools for increasing our understanding of nearshore marine ecosystems. They can provide valuable information for data limited species or ecosystem and span decades and large portions of the BC coast as well as other regions of the world. Nearshore ecosystems are difficult and expensive to sample and little data exists on them despite them being so heavily impacted by humans through overfishing, pollution, or habitat destruction. As we work to mitigate our impacts on our marine neighbours, data that can contribute to species distribution models, conservation area planning, and ecosystem monitoring are required. The work I have presented here can help contribute to those efforts by indicating depth should be included in conservation area planning and habitat suitability models and demonstrating the utility of citizen science to aid in conservation area planning and ecosystem monitoring.

I am excited to use the skills and knowledge I have gained from my time at the University of Victoria in my future career. During this degree I have only scratched the surface of information and methodologies available in marine ecological conservation. However, I feel I have acquired a solid base from which to grow and hope to contribute to the advancement of the field in ways that are supportive of decolonization and promote inclusionary science.