

Evaluating British Columbia's Artificial Reefs in a Conservation Context

by

Desirée Bulger
B.Sc.H., University of Guelph, 2015

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MASTER OF SCIENCE

in the School of Environmental Studies

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Abstract

Synthetic marine habitats such as artificial reefs (ARs) are deployed to offset marine habitat losses and aid conservation of marine communities, including species at risk. Though environmental benefit is often assumed, AR's ability to support northern temperate marine fish communities has rarely been tested. The structural orientation and location of a reef can strongly influence biodiversity and productivity of faunal communities inhabiting it. For ARs, understanding how reef characteristics affect species and community composition are key in optimizing their use in conservation initiatives. I used ROV and sonar to survey threatened rockfish (*Sebastes* spp.) and other groundfish species associated with 18 ARs and natural reefs (NRs) along the northeast Pacific coastal shelf, along the coast of BC, Canada.

In my second chapter, I investigate how ARs compare to NRs in achieving conservation objectives as measured by fish abundance and species richness. I found that community composition significantly differed between NRs and ARs. ARs had high variability in rockfish abundance, while NRs consistently supported intermediate rockfish abundances. Groundfish diversity was markedly greater on NRs. Depth and relief significantly explained variability in abundance and species richness. Interestingly, rockfish abundance was negatively associated with proximity to nearest rockfish conservation area.

In my third chapter, I assess variation between AR fish communities on six reefs to better understand efficacy of meeting conservation objectives. I quantified structural characteristics of each reef using high-definition sonar data to create three-dimensional models and calculate measurements of reef structure. I also examined the effects of surrounding habitat associated with reef locations. I found that depth, conservation status, rugosity, and reef age significantly explained rockfish abundance. Groundfish species richness was significantly associated with conservation status, relief, reef size, and an interaction between depth and reef age.

This research is a first step in proposing underlying mechanisms for differences between fish communities on ARs in BC, and which reef attributes facilitate successful contributions to conservation. Though ARs show promise in the conservation of some threatened species, the maintenance of diverse fish communities may depend on protection of heterogeneous natural reef communities. Given that a critical component of AR success is structure, using three-dimensional technologies can be used as a tool to understand species-habitat association on existing reefs and help predict the success of future reefs.

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Chapter 1

An introduction to artificial reefs, conservation applications in British Columbia

1.1 Ocean Conservation and the Importance of Habitat

Across natural systems, organisms rely on the presence of suitable habitat for survival.

As human populations grow, anthropogenic disturbance is prolific and accompanied by onset of physical, chemical and biological changes to ecosystems (Steffen et al. 2007, Crain et al. 2008, Doney 2010). These changes raise concerns regarding the loss of valuable habitat and species, often resulting in impaired function of ecosystem services (Lotze et al. 2006, Sala and Knowlton 2006, Worm et al. 2006, Mora et al. 2011).

Conservation issues are especially difficult to manage in marine environments (Leslie and McLeod 2007). Concerns of low map resolution, and limited quantity of species abundance and distribution data impair the assessment of conservation strategy efficacy (Anderson et al. 2005). Despite widespread knowledge of fisheries impacts, physical habitat degradation and overfishing remain among the most concerning destructors of marine ecosystems (Watling and Norse 1998, Turner et al. 1999). Considering most human activities in the ocean impact marine life (Halpern et al. 2008), there is great motivation to offset environmental losses.

Artificial reefs (ARs) are commonly implemented as a fisheries management strategy (Baine 2001). For hundreds of years ARs have been used to improve fishing conditions, but their use remains controversial (Bohnsack and Sutherland 1985). Despite

a large body of literature informing AR development, great disparity exists in the efficacy of ARs (Baine 2001, Becker et al. 2018). Common criticisms of AR planning include lacking assessment plans, objectives, and monitoring (Seaman 2000). Given the variability in environmental influences, structure, age, and conservation objectives between ARs, each context must be researched thoroughly to deliver effective results. There is great value in understanding which structures and conditions are situationally appropriate for maximum conservation benefit.

1.2 Species at Risk, Rockfish

Along the North American western coastal shelf, habitat is widely exposed to human activity (Ban and Alder 2008) and fisheries declines are strikingly evident. Rockfish *Sebastes* spp., are among a group of overexploited groundfish species suffering the consequences of human impact (DFO 2000, Yamanaka and Logan 2010, DFO 2016). Management plans have been implemented, but positive results for fish populations have yet to be detected (Haggarty et al. 2016b, Burke 2018). Rockfish abundance relies heavily on the distribution of physical habitat characteristics (Love et al. 2002, Yamanaka et al. 2012), suggesting the provision of additional high-quality habitat may assist in population recovery. As the abundance and diversity of fish inhabiting an area are a function of the quantity and quality of nearby habitat, fish communities can be used to evaluate the efficacy of ARs as suitable habitat (Anderson et al. 1989, Connell and Jones 1991, Yeager et al. 2011). The assessment of ARs as habitats for groundfish, including rockfish provides an excellent opportunity to understand the conservation role of artificial reefs in British Columbia (BC).

1.3 Thesis Overview

This thesis evaluates the efficacy of ARs on the northeast Pacific coastal shelf. I use ROV surveys, sonar, and mapping software to evaluate the fish communities of Canadian artificial reefs. I aim to understand which variables most influence rockfish abundance and groundfish diversity to inform conservation initiatives.

In my second chapter, I focus on understanding the degree to which artificial habitat mimics natural habitat. I use diversity indices to compare groundfish communities in artificial and natural reefs on BC's south coast. Utilizing an information theoretic approach, I identify habitat characteristics that influence rockfish abundance and groundfish diversity.

My third chapter aims to understand which ARs are most effective and why. I evaluate which features of ARs best explain variation in fish communities and suggest how this may be incorporated into species of concern conservation initiatives. I use advances in sonar technology to compare three-dimensional structures of temperate ARs and their fish communities under different temporal and spatial conditions.

The fourth and final chapter summarizes findings from each data chapter, contextualizes the results with implications for future research, discusses how ARs can be used in Canadian conservation initiatives and how these principles may be extended globally.

With this thesis, I provide a first step in evaluating ARs as a tool in meeting Canadian groundfish conservation objectives. Results may be used to inform and optimize the future design and establishment of conservation-focused ARs in BC, while explaining variation in conservation efficacy between reefs.

Chapter 2

Differences in fish communities on natural versus artificial temperate reefs: groundfish conservation applications in British Columbia

This chapter is in preparation for publication with co-authors John P. Volpe and Jason T. Fisher

2.1 Introduction

Human-mediated disturbance leading to habitat loss and degradation is a widely recognized driver of fisheries declines (Turner et al. 1999). Artificial reefs (ARs) are synthetic structures, employed worldwide for recreation, fisheries enhancement, research, and conservation (Seaman 2000). In a conservation context, ARs are intended to restore marine populations through the provision of additional habitat and / or offset human disturbance of natural habitats (Seaman 2000, Dafforn et al. 2015). However, restoration of marine communities with ARs remains controversial, as initiatives often lack robust assessment plans, objectives, and monitoring (Seaman 2000). AR literature is mixed and suggests that ARs can contribute to positive outcomes in the right circumstances, with 50 - 60% of fisheries and conservation-focused ARs meeting their objectives (Baine 2001, Becker et al. 2018). However, improperly designed ARs may displace valuable natural habitat, or facilitate pollution or establishment of invasive species (George et al. 2005, Sherman and Spieler 2006, Glasby et al. 2007). Assumed ecological benefits without proper assessment are especially of concern when ARs may lead to a false sense of security in fisheries conservation. ARs must have clearly defined and bounded objectives supported by empirical evidence demonstrating goals are being met (Bortone 2011).

Since 1991, nine ARs (eight ships, and one Boeing 737 airplane) have been purposely established in southern BC marine waters by the Artificial Reef Society of BC (ARSBC). ARSBC states its goal as, "... to create environmentally and economically sustainable artificial reefs, for the protection and enhancement of sensitive marine habitats, while also providing interesting destinations for the enjoyment of SCUBA divers." (ARSBC 2017). Formal AR research in Canadian waters is limited, with few to no contributions in the past three decades (Lee et al. 2018). Because there are no legislated monitoring regulations in British Columbia (BC), most AR information consists of anecdotal observations by recreational divers (Jones et al. 1997, Smiley et al. 2006, OWCA 2018). These observations suggest that ARs may provide physical refuge from fishers, deterring fishing due to a high likelihood of gear entanglement (REEF, 2017). If ARs are to be considered as future conservation tools, there is obvious need for statistically rigorous analyses, testing assumed conservation benefits.

On the Pacific coastal shelf, several species of rockfish (*Sebastes* spp.), are listed as *Threatened* or *Special Concern* by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Rockfish are typically associated with rocky reefs and are and philopatric, maintaining small home-ranges throughout their lives (Love et al. 2002). These traits make them good candidate species to benefit from ARs, and thus foci for testing hypotheses about AR efficacy. Rockfish are highly susceptible to overfishing due to late reproductive maturity, susceptibility to barotrauma, and inconsistent reproductive years (Love et al. 2002). Concerns of overexploitation prompted Fisheries and Oceans Canada to implement 164 Rockfish conservation areas (RCAs) (DFO 2000, Yamanaka and Logan 2010, DFO 2016) defined as areas in which rockfish harvest is

limited or prevented through the control of conventional angling gear (Yamanaka and Logan 2010). However, lack of fisher compliance and flawed RCA placement and planning have resulted in limited, if any detectable benefit of RCAs to rockfish (Haggarty et al. 2016a, Haggarty et al. 2016b, Lancaster et al. 2017). Several species of rockfish including Quillback Rockfish, (*S. maliger*), Copper Rockfish (*S. caurinus*), Black Rockfish (*S. melanops*), Brown Rockfish (*S. auriculatus*), Tiger Rockfish (*S. nigrocinctus*), China Rockfish (*S. nebulosus*), Yellowtail Rockfish (*S. flavidus*), and Yelloweye Rockfish (*S. ruberrimus*) inhabit shallow inshore rocky reefs (Kramer et al. 1986, Love et al. 2002). Other economically significant species of groundfish such as lingcod (*Ophiodon elongatus*), are sympatric. If BC's ARs are meeting their putative conservation objectives, providing shelter habitat and refuge from fishing, we contend a measure for this success is rockfish abundance and groundfish diversity comparable to natural inshore rocky reefs (NRs). ARs with comparable fish communities to NRs may provide a direct contribution to conservation, accompanying current RCAs and groundfish conservation practices.

A widely-adopted measure of AR efficacy is biological and structural similarity to proximate natural habitat (Carr and Hixon 1997, Seaman 2000, Perkol-Finkel et al. 2006, Walker and Schlacher 2014, Granneman and Steele 2015, Mills et al. 2017). In rocky reefs, structural habitat characteristics are known to affect community species composition (Hayden-Spear and Gunderson 2007, Gunderson et al. 2008). For instance, structural complexity is a significant predictor of community diversity and species abundance in tropical rocky reefs, however its role is more poorly understood in northern temperate environments (Willis and Anderson 2003, Gregor and Anderson 2016, Parsons

et al. 2016). Further, community structure, species richness and density all vary with depth on rocky reefs (Arreola-Robles and Elorduy-Garay 2002, Garrabou et al. 2002, Tolimieri 2007, Zintzen et al. 2012). ARs provide hard, complex structures for fish habitat, and fish community composition is expected to fluctuate with structural characteristics as observed on NRs.

Remotely operated underwater vehicle (ROV) surveys are a useful method in assessing underwater habitat conditions and sampling groundfish populations (Johnson et al. 2003, Haggarty et al. 2016b, Laidig and Yoklavich 2016). As ROV cost and size continue to decline, they are becoming popular tools deployed to survey data-poor AR habitats. Concomitant performance improvements mean longer deployment times, larger survey areas, and improved visual resolution leading to greater species identification confidence relative to conventional SCUBA-based surveys (Rosen et al. 2016).

We used ROV surveys to compare groundfish communities in artificial and natural habitats on BC's south coast. We test the hypothesis that ARs and NRs support similar abundances of rockfish targeted for conservation, as well as groundfish diversity. Utilizing an information theoretic approach, we identify habitat characters that most influence rockfish abundance and groundfish diversity. This is the first study to evaluate ARs as a potential tool in meeting Canadian groundfish conservation objectives. Results aim to inform and optimize the future design and deployment of conservation-focused ARs in BC waters.

2.2 Methods

2.2.1 Study Location

Surveys were conducted along the South Coast of BC, Canada, between Vancouver Island and mainland BC (Figure 2.2.1). Sample sites were selected within the inshore waters within Discovery Passage (Johnstone Strait) and the Strait of Georgia. These areas are characterized by variable benthic habitats, currents and nutrient inputs creating a gradient of environmental conditions across survey sites (Crawford and Thomson 1991).

2.2.2 Study Design

Nine artificial reefs and nine proximate reference natural nearshore rocky reefs were surveyed. A spatially paired design allowed for 13 independent comparisons between proximate natural and artificial sites under similar environmental conditions (Figure 2.2.2). Putatively relevant reef characteristics including local habitat variables (Reef Type, Depth, Relief), surrounding habitat variables (dominant current, proportion of nearby natural habitat), and conservation status (distance to nearest RCA,

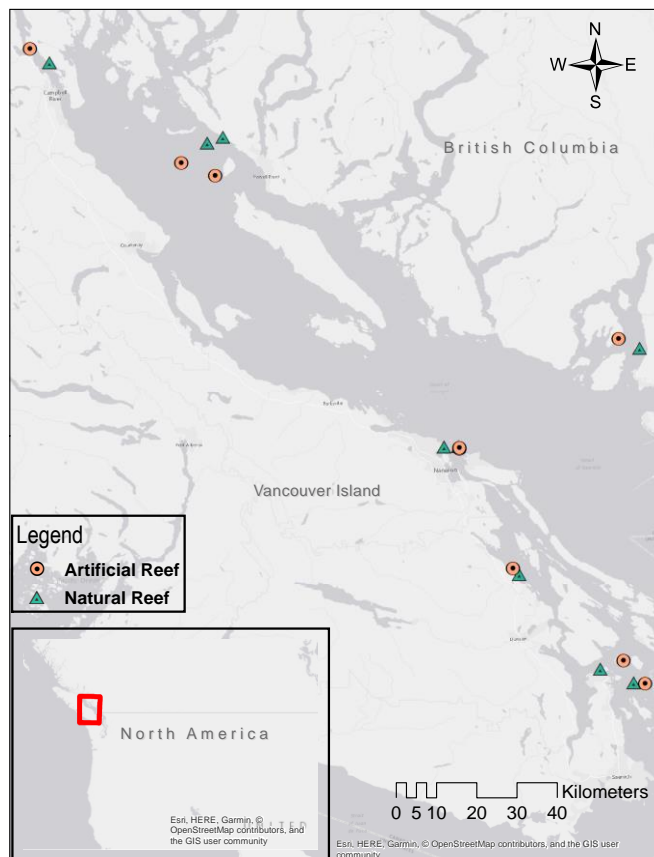


Figure 2.2.1 Natural and artificial reef survey locations along the South Coast of BC, Canada. 18 sites were surveyed across a variety of benthic habitats, currents and nutrient inputs in September and early October 2017.

inside/outside RCA) (Appendix A, Table A.3.) were used to form competing hypotheses regarding the effect of physical and contextual features of natural and artificial reefs on rockfish abundance and groundfish diversity. We ranked support for these hypotheses using multiple regression analyses in a model selection framework based on Akaike Information Criterion (AIC) scores (Burnham and Anderson 2002).

2.2.3 Site Selection – Artificial Reefs

The nine ARs are located on the South Coast of BC. AR positions were derived from DFO (2006), REEF (2017) and ARSBC (2017) databases. Seven of the ARs were created through the intentional scuttling of ships by the ARSBC. In each of these cases, Environment and Climate Change Canada’s “disposal at sea” permit was obtained before sinking (DFO 2017). Two additional sites consist of older “accidental” wrecks that permit investigation of effects of reef age. ARs composed of metal vessels were chosen to control for substrate, composition and decomposition rates. The maximum survey depth at a site was between 15 and 40 metres. Reefs ranged from 15 – 135m in length and were established between 1915 and 2015 (Table 1).

2.2.4 Site Selection – Natural Reefs

To ensure AR sites were being compared to analogous natural rockfish habitat, bathymetric ArcGIS (ArcMap 10.5) data were used to identify matching geophysical profiles by combining seafloor features (substrate and rugosity) generated on a 70m grid (BC Marine Conservation Analysis 2017). Our criteria for rockfish habitat were rocky

substrates with high rugosity (defined as rugosity values in the top 20% of the dataset by BC Marine Conservation Analysis 2017), though other biotic and abiotic features may also define habitat (Love et al. 1991, Love et al. 2002, Yamanaka et al. 2012, Haggarty et al. 2016b). Specific survey sites were identified within these habitats using coordinates of documented SCUBA surveys that consistently identified rockfish occurrence (REEF, 2017). Final selection included preference for: sites with minimum distance to focal AR sites, similar depth range to focal ARs (15 to 40 m) and maximum fish survey data available at each citizen science-documented scuba site.

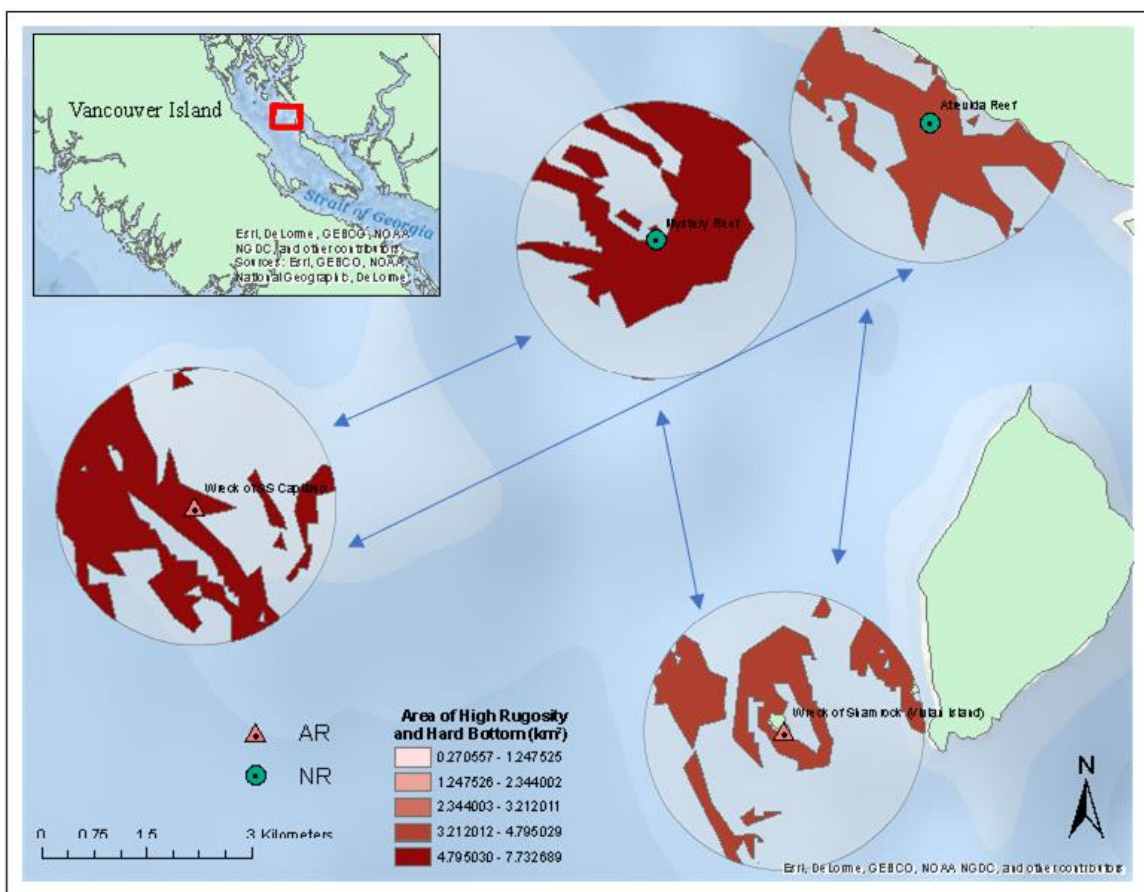


Figure 2.2.2 Study Design - Example of comparisons between four neighbouring reef sites. Locations between Vancouver Island and mainland British Columbia. Spatial design allowed for some sites to be used in 2 comparisons. Blue arrows indicate pairwise AR – NR comparisons within a study area subject to similar environmental conditions. Rings indicate 2 km buffers of adjacent suitable groundfish habitat at each site. NRs consisted of hard-bottomed, rugose rocky reefs, while ARs consisted of repurposed human structures.

2.2.5 Data Collection

ROV surveys were conducted aboard the University of Victoria research vessel *Jolly Seber* (10m) in September and October 2017. A *Saab Seaeye Falcon* ROV, equipped with a 400m fibre optic umbilical was used to carry out 100-300m roving transects at all sites (Ajemian et al. 2015). All data were collected during daylight hours. For NR sites, the ROV ran transects along depth contour lines, predetermined from nautical charts and GIS, while transects at AR sites followed wreck landmarks to maintain consistent depth (eg. Top deck, port side). A stratified sampling design was used to ensure a balanced sample of depths on ARs and NRs, and that NR transects were conducted on high rugosity, hard substrate. Video footage was spatially referenced by estimating ROV position relative to the boat, by following floats affixed to the ROV tether; and underwater using an onboard compass as well as visual landmarks. The ROV was manually operated topside, accounting for the effects of current and to maintain a position of ~2-3m away from substrate. Streaming video was constantly monitored during piloting to look for navigation cues and to ensure the ROV stayed on transect. Transect speed was estimated *post hoc* using sonar data and video timestamps (mean speed 0.25 ms^{-1}). The ROV was equipped with two forward facing 75-watt Tungsten Halogen flood lights. Onboard lights were used during all transects. Video was captured

using a standard 480 TVL *Seaeye* camera with a 91° field of view. Data were recorded onto external hard drives topside using a *Dazzle* analog to digital converter and open source video recording software (*AmarecTV*; Appendix A, Figure A.2). An *Imagenex* 881L sonar system was positioned behind the camera and used in conjunction with camera angle to estimate field of view. Sonar data were recorded in real-time with 881L software on a separate laptop. To account for differences in sampling difficulty due to ROV maneuverability, current speed and direction was recorded from the Fisheries and Oceans Canada website preceding each survey (<http://www.waterlevels.gc.ca/eng>; [FAO, 2017](#)). Visibility was measured with sonar and defined as the distance (m) from the camera at which the anchor line was no longer discernable.

Upon completion of surveys, video was annotated using Video Miner (Version 3.0.8), a Fisheries and Oceans Canada (DFO)-proprietary marine video annotation program. All demersal fishes were counted and identified to the lowest taxonomic level possible. Portions of unusable video, due to technical difficulties (eg. temporary loss of resolution, tether entanglement, loss of maneuverability) were removed (~9% of total footage). Transects were annotated in a random order to avoid bias due to observer learning. Each transect was annotated in 30 second blocks to quantify within-transect variance, then aggregated for final analysis. A pilot study evaluating fish turnover rate within the field of view determined that 30 second blocks ensured independence in samples. A subset of video clips (~ 10% total footage) was re-annotated by marine fish identification professionals to confirm accuracy of identification. For each transect a single *relief* value (high (> 2 m) or low (< 2 m)) and mean depth (m) were recorded (Pacunski and Palsson 2001). Linear field of view was calculated using a combination of

camera and sonar data; trigonometry functions were applied to the distance of the camera from substrate, and the 91° angle of view (typical linear field of view was ~2.2 m; Figure 2.2.3.). Because the ROV lacked GPS capability, field of view measurements were combined with transect length to estimate the total survey area (m²).

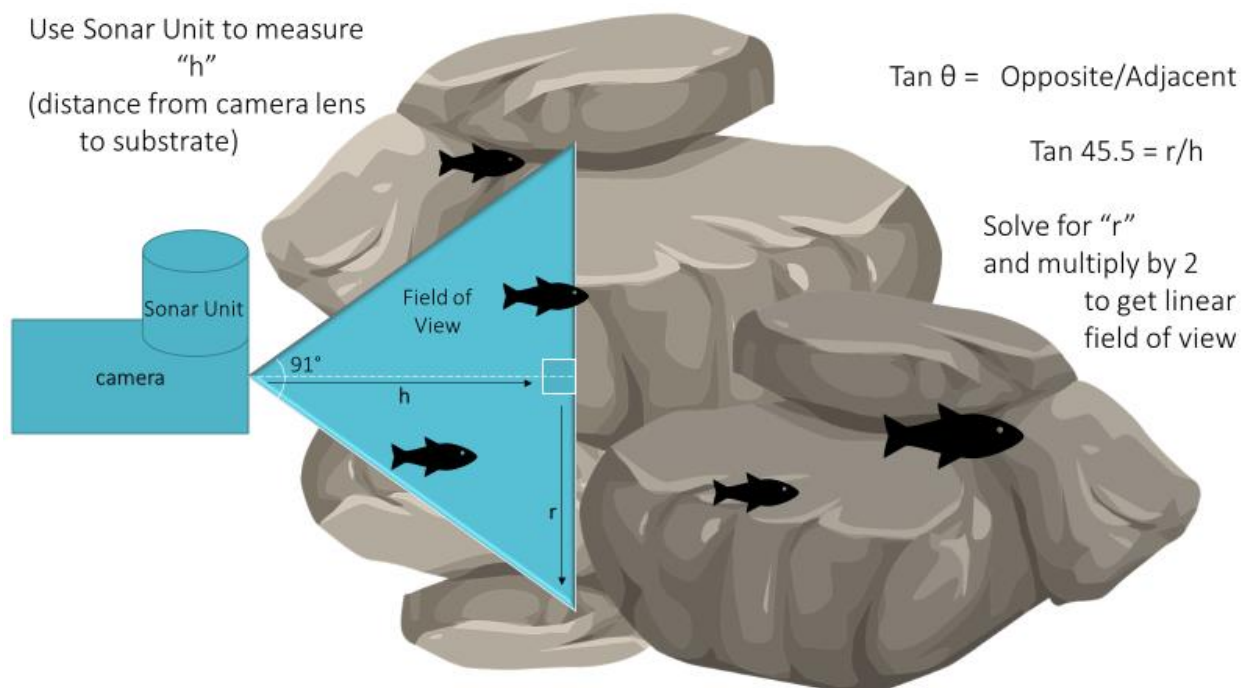


Figure 2.2.3 Field of View Calculations

We used a combination of camera and sonar data to estimate field of view and total sample area. Using simple trigonometry functions and the 90° angle of view, we calculated the linear field of view. Field of view was calculated every 10 seconds throughout each transect.

To account for habitat features that may affect variability in fish communities, we recorded site characteristics with potential to influence rockfish abundance or groundfish diversity through fish movement and fish harvest (Appendix A, Table A.3). Groundfish movement is influenced by a combination of currents, bottom topography, and habitat preferences dependent on life-stage (Carlson and Straty 1981, Matthews 1990, West et al. 1994, Love et al. 2002, Johansson et al. 2008). To account for variability between sites, maps of current speed and direction were created using a combination of ArcGIS

software and the Webtide Tidal Prediction Model (version 0.7.1) (Bedford Institute of Oceanography 2015; BC Marine Conservation Analysis 2017; Appendix A, Figure A.3).

To address potential source-sink relationships with adjacent habitat, proximity of the focal reef to adjacent reefs was calculated via maps of suitable habitat (defined as proportion of high rugosity-hard bottomed habitat within a two km buffer of the study area) created in ArcGIS (ArcMap 10.2; (Pulliam 1988)). Buffer sizes were selected based on recommended distances for potential fish attraction from neighbouring habitats in a DFO report on BC's ARs (Smiley et al. 2006). To account for possible effects of conservation status on fish mortality, sites were overlaid with an RCA map to determine whether they were ostensibly protected from the use of traditional angling gear. Each of the recorded habitat features were included as explanatory variables in GLM modelling (Table 2.1).

Table 2.1 Explanatory variables grouped by model sets hypothesized to influence total rockfish abundance and groundfish species diversity.

Mechanism influencing fish community	Model Variables	Hypothesis: Total Rockfish Abundance(Δ) is influenced by:	Variable description
Local Habitat	ReefType	Natural or Artificial Reef	Categorical - classification of substrate. Human-made or natural rocky features (site level)
	Depth	Transect Depth	Continuous - mean depth for transect (transect level)
	Relief	Slope of substrate	Categorical – High relief = steep slope, low relief = shallow slope (transect level)
Surrounding Habitat	MaxCurrent	Current Speed	Continuous - Maximum current speed in m/s derived from mean current ebb/flow data collected in the spring months by BC Marine Conservation Analysis (site level)
	SuitableHabitat	Area of suitable habitat surrounding the site	Continuous - % Hard Bottom High rugosity substrate - 2km buffer. Radius derived from DFO artificial reef spacing recommendations based on movement of adult fishes (Smiley et al. 2006).
Relationship to conservation Areas	RCA	Rockfish Conservation Area Status	Categorical - Protected status. 1 = within RCA boundaries, 0 = outside RCA boundaries
	RCADist	Distance to nearest Rockfish Conservation Area	Continuous - Distance in meters from sampling area to edge of nearest RCA. Calculated by creating a near table in ArcGIS
Other Terms Present in all models	Offset (number)	Offset number of samples per transect (account for differences in transect area)	

2.2.6 Statistical Analysis

We calculated diversity metrics to compare fish communities between proximate AR and NR sites using the R package *vegan* (Oksanen et al. 2017). Pairs of reefs were compared using Bray-Curtis dissimilarity, species richness, Shannon-Weaver diversity index, and Pielou evenness index (Bray and Curtis 1957; Shannon and Weaver 1949; Pielou 1975). Summary statistics were calculated for aggregated data and within each reef type.

We used regression analyses and diversity metrics to test whether artificial and natural reefs have distinguishably different groundfish communities and if so, which habitat characteristics most influenced observed patterns. Following an exploratory analysis of data (Zuur et al. 2010), generalized linear models were created using R statistical software (ver 3.3.3; *lme4* and *MuMIn* packages; (Bates et al. 2015, Barton 2018, R Core Development Team 2018)). Response variables were rockfish abundance and groundfish species richness with site and habitat characteristics as explanatory variables (Table 2). Models of rockfish abundance used a negative binomial distribution with a log link, as a Poisson distribution yielded variance in fish counts that exceeded the mean, causing overdispersion; data were positive and non-normally distributed. An offset function was included to account for differences in sampling effort due to varying transect lengths. Though there were repeated samples within each “site”, limitations of sample size prevented the inclusion of a random effect, as each level in a random effect must have >15 data points (Bolker, 2009). To assess whether spatial pseudoreplication potentially affected results, models were plotted individually by “site” to uncover clustering of data points or trends within each site.

Support for each competing hypothesis was assessed by ranking corresponding models using an information theoretic approach (Burnham and Anderson 2002). Continuous variables were standardized (mean = 0, s.d. = 1) to allow comparison of effect sizes. Variables treated as fixed effects were combined into model candidate set “blocks” of habitat and community covariates (Appendix A, Table A.5 – A.6). Empirical support for each hypothesis was evaluated using Akaike Information Criterion scores corrected for small sample sizes (AICc). When competing models differed by $<2 \Delta AICc$, we selected the most parsimonious model. Visual inspection of quantile-quantile plots, residuals versus the fitted values plots, and correlation coefficients between variables, were used to verify assumptions of normality and homoscedasticity of the residuals, and independence of variables.

2.3 Results

We analyzed 81 transects: 40 in ARs and 41 in NRs. AR ages ranged from 2.5 to 102 years old (Appendix A, Table A.2). Artificial reef length ranged between 15 and 137.4 metres. All natural reef sites were hard bottomed, high rugosity habitats. Transects at all sites occurred at depths between 10 and 40 metres. In total, we observed 14 species of groundfish, with quillback rockfish the most abundant species at both ARs and NRs (Appendix A, Table A2).

Table 2.2 - Summary statistics for transects within artificial reefs, natural reefs and all reef groupings

	Rockfish Density			Groundfish Species Richness		
	<i>Artificial</i>	<i>Natural</i>	<i>All Reefs</i>	<i>Artificial</i>	<i>Natural</i>	<i>All Reefs</i>
Mean (Standard Error)	10.45(3.23)	5.29(1.18)	7.84(1.71)	2.30(0.24)	3.14(0.26)	2.73(0.18)
Variance	417.99	57.13	239.08	2.32	2.83	2.73
# of transects	N = 40	N = 41	N = 81	N = 40	N = 41	N = 81

Mean rockfish density was greater on ARs than on NRs, however ARs had greater within-group variance (Table 2.2). Mean groundfish species richness was greater on NRs than ARs (Table 2.2). Bray-Curtis dissimilarity tests found all comparisons of AR-NR sites to have less than 50% community similarity (Figure 2.3). In nine of 13 reef pairs, the NR site had greater Shannon-Weaver diversity. In seven of 13 pairs, the AR site had greater rockfish abundance, however Bray-Curtis differences were often extreme in these cases.

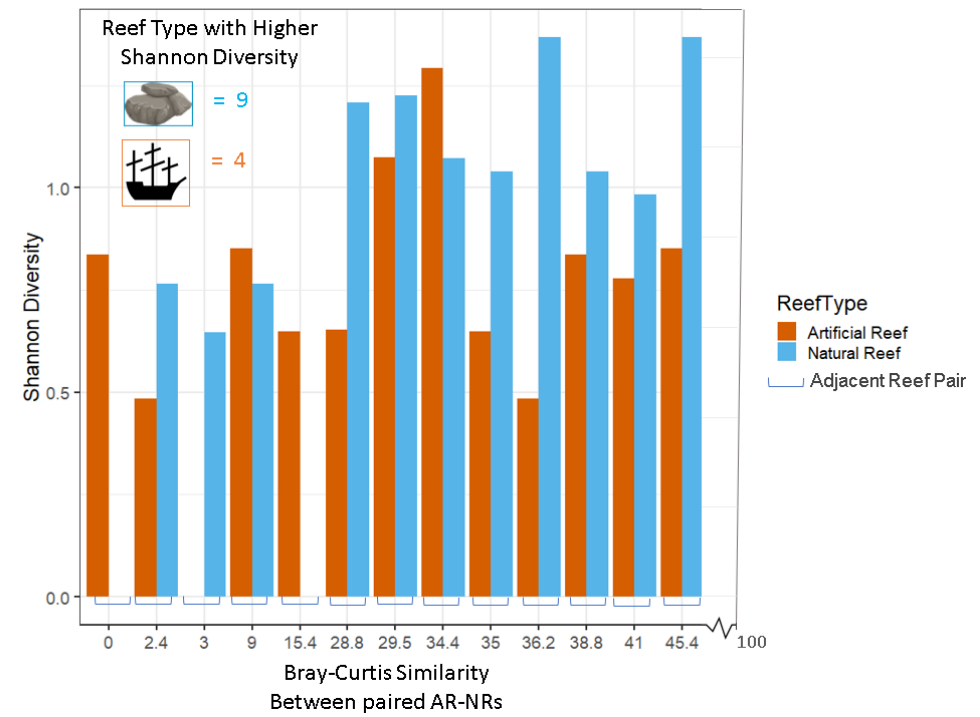
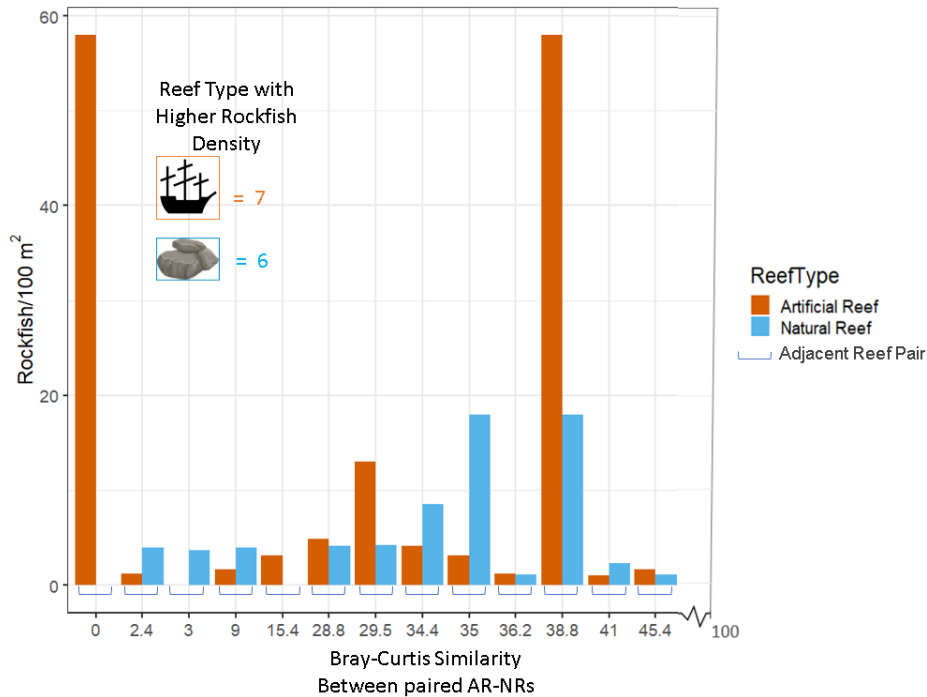


Figure 2.3 a-b: Percentage compositional similarity between paired adjacent natural and artificial sites (Bray-Curtis value along the x-axis). Pairs are indicated by grey brackets. 0% indicates no species in common, while 100% indicates identical composition. All pairs had less than 50% similarity. In 9/13 cases, the natural site had greater groundfish species diversity (Shannon-Weaver Index). In 7/13 cases, the artificial site had greater rockfish relative abundance (displayed as density).

2.3.1 Effects of specific habitat characteristics on rockfish abundance

GLM models revealed that rockfish were more abundant with increasing depth ($p < 0.001$). Variation in rockfish abundance was also explained by low relief and reef type, although effect sizes were smaller. Unexpectedly, rockfish were more abundant farthest from RCAs ($p < 0.05$). The best-fit model carried 60% of the AICc weight of evidence (AICcw) and included reef type, depth, relief, and distance to nearest RCA (AICcw = 0.595, Null deviance = 143.649 on 80 df, Residual deviance = 94.011 on 76 df, theta = 0.735). The second ranked model, including only depth and relief, was the most parsimonious model being within two AICc points of the top model, explaining variance with the least degrees of freedom (Table 2.3). There were no trends observed between rockfish abundance and adjacent suitable habitat or current speed. Inspection of quantile-quantile plots, residuals versus fitted values plots, and correlation coefficients between variables confirmed assumptions of normality, homoscedasticity of the residuals, and independence of variables were met.

Table 2.2 Rockfish relative abundance top models in order within top 5 delta AICc including model estimates of fixed effects. Model 1 (AICcw 59.5%) included Reef Type, Depth, Relief, and distance from nearest conservation area as variables. Model 2 (AICcw 23.5%) shared variables of depth and relief, as did model 3 (7.9%) with the addition of Reef Type. (Reef Type not significant). Model 2 was the most parsimonious model. Reef type, depth and relief were consistently included in the highest ranked models. Standard error displayed in brackets. Significance: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$. models ranked by AICc(x).

<i>Model Rank</i>	<i>(Intercept)</i>	<i>ReefTypeNR</i>	<i>Depth</i>	<i>ReliefLow</i>	<i>RCADist</i>	<i>N</i>	<i>AICc</i>	<i>Delta</i>	<i>Weight</i>	<i>df</i>
1	2.28 *** (0.23)	0.16 (0.29)	0.60 ***(0.14)	0.51 (0.28)	0.33 * (0.14)	81	606.8	0	0.595	6
2	2.37 *** (0.20)		0.76 ***(0.14)	0.62 * (0.29)		81	608.6	1.85	0.235	4
3	2.38 *** (0.24)	0.02 (0.29)	0.75 ***(0.15)	0.62 * (0.29)		81	610.8	4.04	0.079	5

2.3.2 *Effects of habitat on species richness*

Groundfish species richness was higher at natural reefs ($p < 0.05$), deeper depths ($p < 0.05$), and low relief areas ($p < 0.05$). The best-fit model carried 34% of the AICc weight of evidence (AICcw = 0.335, Null deviance = 95.924 on 80 df, Residual deviance = 80.460 on 76 df). Reef type, depth and relief were consistent variables within the highest ranked models (top 5 AICc; Table 2.4). Depth had the greatest effect size, explaining the most variance in each of the top models. Surprisingly, conservation status did not have a significant effect on species richness, nor did area of adjacent suitable habitat or current speed. Quantile-quantile plots, residuals versus fitted values plots, and correlation coefficients between variables confirmed assumptions of normality, homoscedasticity of the residuals, and independence of variables were met.

Table 2.3 Comparison of top models for groundfish species richness within top 5 delta AICc including model estimates of fixed effects. Model 1 (AICcw = 303.9) included Reef Type, Depth, Relief as explanatory variables. Model 2 (AICcw = 305.1) shared variables of depth and relief with the addition of distance from nearest RCA, as did Model 3 (AICcw = 305.7) with the addition of RCA. Standard error displayed in brackets. Significance: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

<i>Model Rank</i>	<i>(Intercept)</i>	<i>ReefTypeNR</i>	<i>Depth</i>	<i>ReliefLow</i>	<i>RCADist</i>	<i>RCA</i>	<i>Current</i>	<i>Habitat</i>
1	-2.30 ***(0.12)	0.34*(0.14)	0.15*(0.07)	0.29*(0.14)				
2	-2.31 ***(0.13)	0.39*(0.15)	0.14*(0.07)	0.26(0.14)	0.08(0.07)			
3	-2.38 ***(0.17)	0.36*(0.15)	0.16*(0.07)	0.34*(0.16)		0.12(0.17)		
4	-2.35 ***(0.13)	0.45**(0.16)	0.19**(0.07)	0.27(0.16)	0.11(0.08)		0.02(0.10)	0.13(0.10)

<i>Model Rank</i>	<i>N</i>	<i>AICc</i>	<i>Delta</i>	<i>Weight</i>	<i>df</i>
1	81	303.9	0	0.335	4
2	81	305.1	1.15	0.189	5
3	81	305.7	1.81	0.136	5
4	81	306.3	2.37	0.103	7

2.4 Discussion

2.4.1 Do AR fish communities resemble those on NRs?

Groundfish communities in our study system were markedly different on ARs and NRs. Bray-Curtis dissimilarity tests revealed that no spatially coupled artificial and natural reef pair exceeded 50% similarity to one another. Both mean rockfish density and mean groundfish species richness differed between AR and NR groups, suggesting the number of rockfish and number of groundfish species were influenced by reef type. Overall, ARs had greater mean rockfish abundance than NRs, while NRs had greater groundfish species richness, implying that particular ARs may have species-specific benefits relative to local NRs. However, there was much greater variation in rockfish abundance values at AR sites than NR sites, suggesting AR rockfish conservation benefits are inconsistent among reefs. Differences in site habitat characteristics may be responsible for the observed variation in fish communities between ARs.

2.4.2 Rockfish Abundance, Habitat, and Conservation Applications

A common objective of AR deployment is to increase abundance and productivity of fish by providing equivalent or better quality habitat than NRs (Seaman 2002). Our analyses show some potential for ARs to meet this objective in BC coastal waters. ARs had appreciably greater rockfish abundances in seven of 13 reef pairs, while NRs had higher abundances in the remaining six. ARs had greater mean abundance across all reefs, however GLMs showed NRs to have a small increase in rockfish abundance over ARs. This discrepancy is likely due to the high variation in abundance on ARs, some with contrastingly low abundances, while NRs were more consistent. Results from high abundance ARs corroborate trends of high relative fish abundance associated with AR

habitats across a variety of marine systems (Rilov and Benayahu 2000, Arena et al. 2007, Folpp et al. 2013, Reubens et al. 2013).

Local habitat characteristics influenced rockfish abundance across both ARs and NRs. Depth is a known determinant of rockfish abundance and demography (Richards 1986, Love et al. 2002, Johnson et al. 2003, Haggarty et al. 2016b), and was an important variable in both natural and artificial habitats in our temperate northern system. This implies that depth range of target rockfish species must be considered when creating new ARs. Rockfish also descend in the water column as they mature (Love et al. 2002). Because we were surveying the shallower extent of many species' depth ranges, our sample is likely reflective of younger individuals whose age classes are most responsible for long-term viability of the population. Similarly, relief characteristics of ARs should be considered during planning, as older rockfish typically show strong preference for high relief habitat, while younger rockfish associate with low relief habitats (Matthews 1988, West et al. 1994, Love et al. 2002). As we observed a weak positive association between rockfish abundance and low relief habitat, results may indicate a high proportion of our observations were young rockfish. Higher abundance of young rockfish is indicative of more recent successful recruitment at surveyed reefs.

Finally, and unexpectedly, rockfish were more abundant on ARs and NRs if they were farther from the nearest conservation area (RCA). If RCAs are meeting their objectives, theoretically rockfish within the boundaries should survive longer, reaching sexual maturity, reproducing and acting as larvae sources for neighbouring habitats (Love et al. 2002, Hilborn et al. 2004). However, if RCAs are acting as intended in our system, it is not apparent in rockfish abundances at nearby NRs and ARs. This trend may be

explained by RCAs having been established in unsuitable habitats (Haggarty & Yamanaka 2018), or a lack of fishing compliance within conservation areas (Haggarty et al. 2016a, Lancaster et al. 2017, Haggarty and Yamanaka 2018). Alternatively, there may have been more rockfish further from RCA boundaries due to harvesters “fishing the line”; where harvested species are depleted immediately outside a reserve boundary (Kellner et al. 2007).

2.4.3 Groundfish Community Species Richness on ARs and NRs

Greater groundfish species richness and Shannon Diversity on NRs than ARs suggests that some species in our study may benefit from ARs, while others do not. NRs had greater numbers of spotted ratfish *Hydrolagus colliei*, yellowtail rockfish, tiger rockfish, brown rockfish, and kelp greenling *Hexagrammos decagrammus* than ARs (Table A.2). ARs and NRs in other systems typically differ in terms of community composition, but mechanisms responsible for such differences remain unresolved, (Bohnsack 1989, Becker et al. 2017). Some have identified ARs with superior species richness and diversity relative to NRs (Rilov and Benayahu 2000, Arena et al. 2007, Fowler and Booth 2013). However, such trends are by no means a consensus as ARs have also been observed to support lesser species richness, similar to our findings (Burt et al. 2009, Aguilera et al. 2014). The broad definition of ARs allows for different shapes, sizes, environments, and target communities to be compared in conservation success.

We may have observed lower species richness on ARs for a variety of reasons. NRs may offer greater habitat heterogeneity and spatial diversity, providing refuge for a greater variety of species than ARs (Aguilera et al. 2014). The uniformly shaped ARs in our study exhibited modest structural diversity, appealing to a smaller subset of species

who prefer specific shared structural characteristics, resulting in lesser diversity than surveys at NR counterparts (Paxton et al. 2017). Species specific preferences for substrate may also be responsible for differences in species richness, as all ARs were composed of metal, mainly steel, while NRs were composed of rock (Hanner et al. 2006, Santos et al. 2011). Alternatively, because ARs are intrinsically younger and smaller than NRs, they are less likely to support the same number of species as NRs (Jan et al. 2003, Perkol-Finkel et al. 2005, Hanner et al. 2006, Leitao et al. 2008, Burt et al. 2011). Though correlation plots within the group of ARs did not show significant groundfish community trends for reef age or size, more robust analyses are needed to fully eliminate these variables as sources of variation (Appendix A, Figure A.5 – A.6). A greater sample size and finer-scale habitat data would be useful in determining species specific responses to AR or NR habitat.

Groundfish species richness was influenced by similar physical habitat characteristics to rockfish abundance. Reef type, depth and relief were each significant variables explaining species richness patterns. Groundfish species are known to segregate by depth, and deeper transects of our surveys encapsulated more overlaps of groundfish home ranges (ex. tiger rockfish occupy deeper waters than copper rockfish but both can be found at 30 m), the observed pattern of increasing richness with depth was expected (Richards 1986, Matthews 1990, Love et al. 2002, Yoklavich et al. 2002, Tolimieri 2007, Zintzen et al. 2012). This result highlights a potential conflict between recreational objectives (shallow ARs for recreational divers), and conservation objectives: greater benefit at increasing depths. Greater species richness was expected in areas of high relief, due to greater variation in depths (i.e. more varied habitat) in a smaller area, and

increased potential for upwelling by vertical bottom topography in conjunction with current (Crawford and Thomson 1991, Yanagi and Nakajima 1991, Rilov and Benayahu 2000). Counter to expectations, some of our most groundfish-species diverse natural sites were boulder fields with low relief. Low relief boulder fields are often proximate to mixed habitats of complex rock and mud – areas where rockfish diversity is highest (Yoklavich et al. 2000).

Despite greater species richness on NRs, ARs may still be useful in conservation. The same numerically dominant species were found at both reef types: quillback rockfish, copper rockfish, yellowtail rockfish, and lingcod. However, ARs had greater numbers of quillback rockfish (listed as *Threatened*) and yelloweye rockfish (listed as *Special Concern*). Additionally increased productivity of bocaccio rockfish, *Sebastes paucispinis* (an endangered species in BC) have been demonstrated on ARs in California (Love et al. 2006). With proper design and management, ARs could be effective components in groundfish conservation.

2.4.4 Caveats

Some factors may have inhibited our ability to capture full ecological inference from our data. Because our analyses were not robust enough to measure rockfish productivity, we must be sensitive to the fact that greater abundance may not actually indicate successful attainment of conservation goals. Our trends may instead be suggestive of reef attraction, where fish have been redistributed from neighbouring habitats (Lindberg 1997). To truly differentiate between abundance and productivity, analyses considering total biomass, fish movement and mortality (both natural and human harvest) should be included (Valentine-Rose et al. 2011, Claisse et al. 2014b).

High levels of variation in rockfish abundance among ARs may have been driven by differences in age or size that we could not account for in modelling due to collinearity with reef type. Coarse-grained examinations of correlation coefficients suggest a weak positive relationship between age and rockfish density, and weak negative relationship between vessel size and rockfish density, however more robust analyses within the artificial reef grouping may suggest otherwise.

A lack of fishing compliance within RCAs may have also contributed to between-site variation in rockfish abundance (Haggarty et al. 2016a, Lancaster et al. 2017, Haggarty and Yamanaka 2018). Five of our AR sites lie outside of RCA boundaries and four inside, however compliance with fishing closures was not measured. ARs may also be susceptible to different fishing pressure than NRs. If fishers know the AR is likely to support a high abundance of fish, an increase in fishing pressure could result (Brochier et al. 2015), or alternatively the complex structure of ARs could promote gear entanglement, reducing fishing pressure (Wilson et al. 2002, Gonzalez-Correa et al. 2005). Better monitoring of fishing compliance and enforcement of fishing closures is necessary in understanding relationships between fish harvest and rockfish abundance on ARs and NRs in RCAs.

Lessons learned from ROV sampling provide recommendations for alterations to improve data quality, allowing for more fine scale questions and detailed data. A GPS tracking system would have allowed for more precise transect tracking and area measurements than sonar alone. Due to equipment limitations, the ROV was not equipped with lasers for sizing individual fishes. Fish size data would have allowed for biomass estimates, more informative data than abundance alone. Further research should

use biomass to quantify primary and secondary productivity at northern temperate ARs and model them against structural data to determine which sites are the most productive and why. Other limitations of this study included our use of only one spatial scale for the surrounding habitat analysis. Since fish movement varies by species, different species were likely differentially influenced by external habitat availability and we may have failed to see trends on other scales. Finally, our study would have benefitted from greater resolution benthic data surrounding our sites. This would improve accuracy in the estimation of neighbouring suitable habitat.

2.4.5 Conclusion

Northeast Pacific inshore ARs may not provide adequate habitat to support the same diversity of fish species as NRs, however they appear to have the potential to facilitate greater abundance than NRs. The variation between rockfish abundance on ARs highlights the need for further research. These results have implications for AR planning, and potential rockfish conservation strategies. If success of high-density ARs is better understood, ARs may become a useful tool in boosting northern Pacific rockfish populations. An adaptive management approach may be applied to ARs to understand which are most effective at meeting their goals and why (Seaman 2000, Bortone 2011). Dependent on specific conservation goals, purpose-built ARs should be created to support target species for conservation objectives. This research is the first step to understanding variability between fish communities on ARs in our study system, and which reef attributes facilitate successful contributions to conservation. Though some ARs may be useful in the conservation of threatened species, to get diverse fish communities, preserving older, more heterogeneous NRs may be the best option.

Chapter 3

Comparing structural habitat and variation in fish communities on temperate artificial reefs: conservation implications in the Northeast Pacific

This chapter is in preparation for publication with co-authors John P. Volpe and Jason T. Fisher

3.1 Introduction

The abundance and diversity of organisms at a given location are largely a function of the quantity and quality of nearby habitat (Anderson et al. 1989, Connell and Jones 1991, Thrush et al. 2005, Yeager et al. 2011). As widespread human impact continues to degrade fisheries, understanding which structural features best support the biotic and abiotic requirements of species of conservation concern is imperative (Turner et al. 1999, Halpern et al. 2008, Worm et al. 2009). Conservation initiatives rely on detailed species-habitat association studies to understand how oceanic processes may relate to fish abundance, species richness, and distribution across spatial scales and seascapes (Pickrill and Todd 2003, Bostrom et al. 2011, Brown et al. 2012). However, less than 18% of the ocean floor is mapped, and an even smaller amount at biologically-relevant high resolutions (Mayer et al. 2018), generating difficulty in consistently evaluating fine-scale habitat structure. Emerging technologies are beginning to resolve such challenges. Optical and acoustic sensors create three-dimensional scans of the underwater environment that can be transformed into bathymetric maps (Singh et al. 2007). While

optical methods like photogrammetry are increasingly used in tropical environments, they are less practical in deeper low-light habitats and temperate environments with variable visibility. Advances in sonar technology allow for high resolution bathymetric data without the visibility constraints of optical sensors (Brown et al. 2011). Finally, corresponding advances in geographic information systems provide a platform for performing structural measurements on bathymetry to explain species-habitat relationships (Cameron et al. 2014, Hill et al. 2014, Walbridge et al. 2018).

Accurate fine-scale physical habitat measurements are prerequisite to understanding habitat-diversity and abundance relationships in both natural and artificial seascapes. Artificial reefs (ARs) are synthetic structures placed on the ocean floor, and used worldwide for recreation, fisheries enhancement, research, and conservation (Seaman 2000). AR implementation offers a unique opportunity to provide optimal habitat for target species, providing species-habitat relationships in each situation is well understood (Seaman 2002). The inherent complexities of such relationships are evidenced by the fact that only 50-60% of fisheries and conservation-focused ARs meet their objectives (Baine 2001, Becker et al. 2018), rendering AR-mediated restoration of marine communities controversial. ARs are often opportunistically created from waste material, are not exclusively designed for biological purpose, and may prioritize economic benefits over conservation (Baine 2001); e.g., the sinking of derelict ships, underwater sculptures. AR development often lacks consideration of successional change in structural and biological features over time, which may translate to variations in conservation performance (Svane and Petersen 2001, Santos et al. 2011, Farinas-Franco

and Roberts 2014). Regular surveys and accurate measurements of performance are important in goal assessment and future AR design or improvement (Baine 2001).

Several biologically meaningful metrics are used to assess habitat quality for fish communities on temperate reefs and can be efficiently measured using three-dimensional technology (Hayden-Spear and Gunderson 2007, Gunderson et al. 2008, Cameron et al. 2014). For example, structural complexity is a significant predictor of community diversity and species abundance in temperate reef communities (Willis and Anderson 2003, Gregor and Anderson 2016, Parsons et al. 2016). Using conventional SCUBA methods, complexity is measured using the “chain and tape method” to derive a rugosity value (Risk 1972, McCormick 1994), however measurements from three-dimensional habitat models are being adopted as an accurate and improved measure of surface roughness (Du Preez 2015). Community structure, species richness and density all vary with depth and relief on reefs (West et al. 1994, Arreola-Robles and Elorduy-Garay 2002, Garrabou et al. 2002, Tolimieri 2007, Zintzen et al. 2012), Similarly, in artificial habitats, size of the reef influences fish abundance and community structure (Jan et al. 2003, Leitao et al. 2008). Relief is often measured categorically, while detailed variation in depth and reef dimensions are difficult to capture on a reef-wide scale. Using three-dimensional models, specific degree of incline for given locations on a structure can be measured, and surface area of structures can be calculated and compared on multiple scales (Walbridge et al. 2018). All of these measurements are efficiently and accurately calculated using three-dimensional technology and can be used to inform conservation initiatives.

Rockfish (*Sebastes* spp.) are important recreational and commercial fish worldwide. They are highly susceptible to overfishing due to late reproductive maturity, susceptibility to barotrauma, and inconsistently successful reproductive years (Love et al. 2002). In the Northeast Pacific, several rockfish species are listed as Threatened or Special Concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Long lifespan, philopatry, and association with specific substrate and patchy distributions (Yoklavich et al. 2000, Love et al. 2002, Lowe et al. 2009), make rockfish excellent candidates for testing hypotheses on AR efficacy, and highlight the need for precise, fine scale habitat monitoring to come to biologically relevant conclusions (Love et al. 2002, Anderson et al. 2005). At present, Fisheries and Oceans Canada (DFO) has implemented 164 Rockfish conservation areas (RCAs) (DFO 2000, Yamanaka and Logan 2010, DFO 2016) attempting to mitigate concerns of overfishing. RCAs are defined as areas in which rockfish harvest is reduced or eradicated through the restriction of conventional angling gear (Yamanaka and Logan 2010). However, failure to adhere to fishing regulations and flawed RCA spatial planning have resulted in inadequate, if any detectable benefit of RCAs to rockfish (Haggarty et al. 2016a, Haggarty et al. 2016b, Lancaster et al. 2017). Several species of rockfish inhabit shallow inshore rocky reefs of British Columbia, Canada (BC) (Kramer et al. 1986, Love et al. 2002). These include quillback rockfish, (*S. maliger*), copper rockfish (*S. caurinus*), black rockfish (*S. melanops*), brown rockfish (*S. auriculatus*), tiger rockfish (*S. nigrocinctus*), china rockfish (*S. nebulosus*), yellowtail rockfish (*S. flavidus*), and yelloweye rockfish (*S. ruberrimus*) along with other economically significant species of groundfish such as lingcod (*Ophiodon elongatus*). If RCAs are effective in contributing

to AR efficacy, effects of RCAs on fish mortality should be evident in the fish communities on ARs as indicated by abundance and diversity. Alternatively, if ARs consistently have abundant rockfish and diverse fish communities, regardless of RCA status, they may provide a direct contribution to conservation where RCAs are lacking.

Remotely operated underwater vehicle (ROV) surveys are a favourable tool in evaluating underwater habitat and sampling groundfish populations (Johnson et al. 2003, Haggarty et al. 2016b, Laidig and Yoklavich 2016). Sampling with ROVs enables longer deployment times, larger survey areas, leading to greater species identification confidence in comparison to conventional SCUBA-based surveys (Rosen et al. 2016). As cost and size continue to decline, ROV surveys become a more accessible and popular method to survey data-poor AR habitats.

We used ROV surveys to measure groundfish abundance and diversity on ARs, with the goal of understanding which were most successful at meeting conservation objectives. We created three-dimensional models to overcome challenges associated with fine-scale surveying of AR structures in temperate environments. Using shipwreck ARs as a case study, we ask which features are most important in future AR design with a rockfish and groundfish conservation focus. We hypothesize that variability in spatial, structural and temporal characteristics on ARs will explain variation in the fish communities inhabiting them. This is the first quantitative comparison of reef structure and fish communities associated with BC ARs. Marine conservation policy depends on a clear resolution of whether BC's ARs are providing their assumed conservation benefits, and how future ARs may meet conservation objectives. We contend a measure for this success is rockfish abundance and diversity, comparable between ARs.

3.2 Methods

3.2.1 Study Location

Surveys were conducted along the South Coast of BC, Canada, between Vancouver Island and mainland BC (Figure 3.1). Sample sites were selected within the inshore waters within Discovery Passage (Johnstone Strait) and the Strait of Georgia. These areas are characterized by variable benthic habitats, currents and nutrient inputs, creating a gradient of environmental conditions across AR sites (Crawford and Thomson 1991).

All ARs used in the final analysis were created through the intentional scuttling of vessels by the Artificial Reef Society of BC (ARSBC). AR positions were derived from DFO (2006), REEF (2017) and (ARSBC 2017) databases. Only shipwreck ARs composed of steel were chosen to control for gross structure, composition, and decomposition rates. Survey depths at each site ranged between 15 and 40 metres. Reefs ranged from 15 – 135m in length and were sunk between 1991 and 2015 (Appendix B, Table B2).

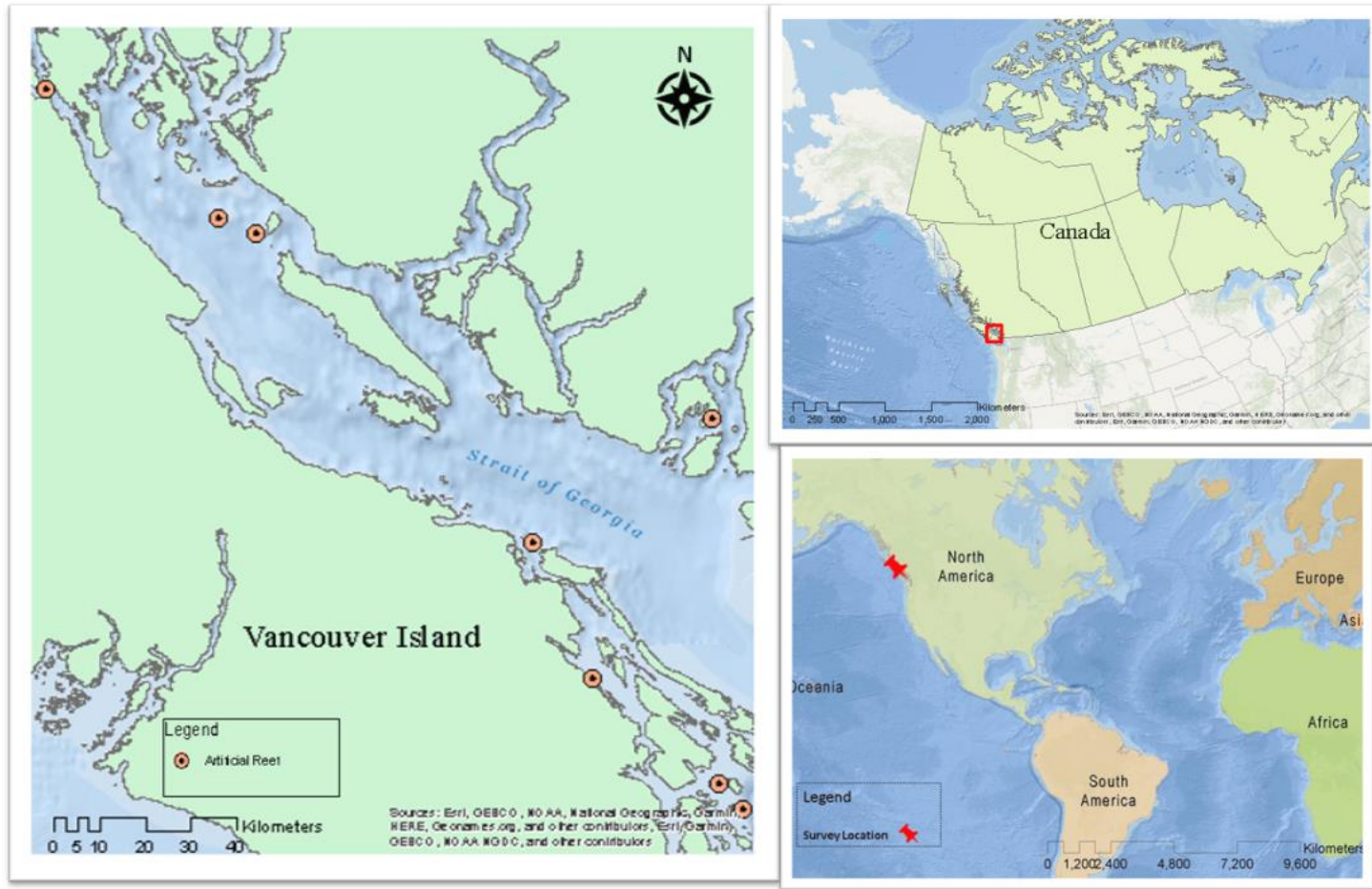


Figure 3.1 Study Area maps, artificial reef survey locations along the South Coast of BC, Canada. 18 sites were surveyed across a variety of benthic habitats, currents and nutrient inputs in September and early October 2017.

3.2.2 Sampling Methods

We surveyed nine ARs in September and early October of 2017. ROV sampling was conducted aboard the University of Victoria research vessel *Jolly Seber* (10m). A *Saab Seaeye Falcon* ROV, equipped with a 400m fibre optic umbilical was used to collect roving video data at varying depths (Ajemian et al. 2015). The ROV followed wreck landmarks to maintain consistent depth (e.g. top deck, port side). We employed a stratified systematic sampling design to ensure a balanced sample of depths. We spatially referenced video footage by estimating ROV position relative to the vessel, by following floats affixed to the ROV tether; and underwater using an onboard compass as well as visual landmarks. The ROV was manually operated topside, accounting for the effects of current and to maintain a position of ~2-3m away from the vessel. We constantly monitored streaming video during piloting to identify navigation cues and to ensure the ROV remained on course. Speed was estimated *post hoc* using sonar data and video timestamps (mean speed 0.25 ms^{-1}). The ROV was equipped with two forward facing 75-watt tungsten halogen flood lights that were used during all surveys which occurred during daylight hours between 7:00am and 7:00pm. We recorded video using a 480 TVL *Seaeye* camera with a 91° field of view. Video data were saved onto external hard drives topside using a *Dazzle* analog to digital converter and open source video recording software (*AmarecTV*; Appendix B, Figure B.2). An *Imagenex 881L* sonar system was positioned behind the camera and used in conjunction with camera angle to estimate field of view. We recorded sonar data in real-time with *881L* software on a separate laptop. We measured visibility with sonar and defined it as the distance (m) from the camera at which the research vessel's anchor line was no longer discernable.

Upon completion of surveys, video was annotated using Video Miner (Version 3.0.8), a DFO-proprietary marine video annotation program. All groundfish were counted and identified to the lowest taxonomic level possible. We removed portions of unusable video, due to technical difficulties (ex. temporary loss of resolution, tether entanglement, loss of maneuverability; ~10% of total footage). An initial pilot study determined 30 second blocks ensured fish turnover rate sufficient to render independence of sampling units, therefore we annotated video from each site in 30 second blocks to capture fish community variation across each site. Blocks were randomized for annotation order to avoid bias due to observer learning. A random subset of video clips (~ 10% total footage) was re-annotated by Pacific groundfish identification professionals to confirm accuracy of identification. For each video segment, a single *relief* value (high (> 2 m) or low (< 2 m)) and mean depth (m) were recorded (Pacunski and Palsson 2001). Linear field of view was calculated using simple trigonometry functions using the camera-vessel distance and 91 ° angle of view (mean linear field of view was ~2.2 m; Appendix B.1.). Field of view measurements were combined with survey length at each site to estimate the total survey area (m²).

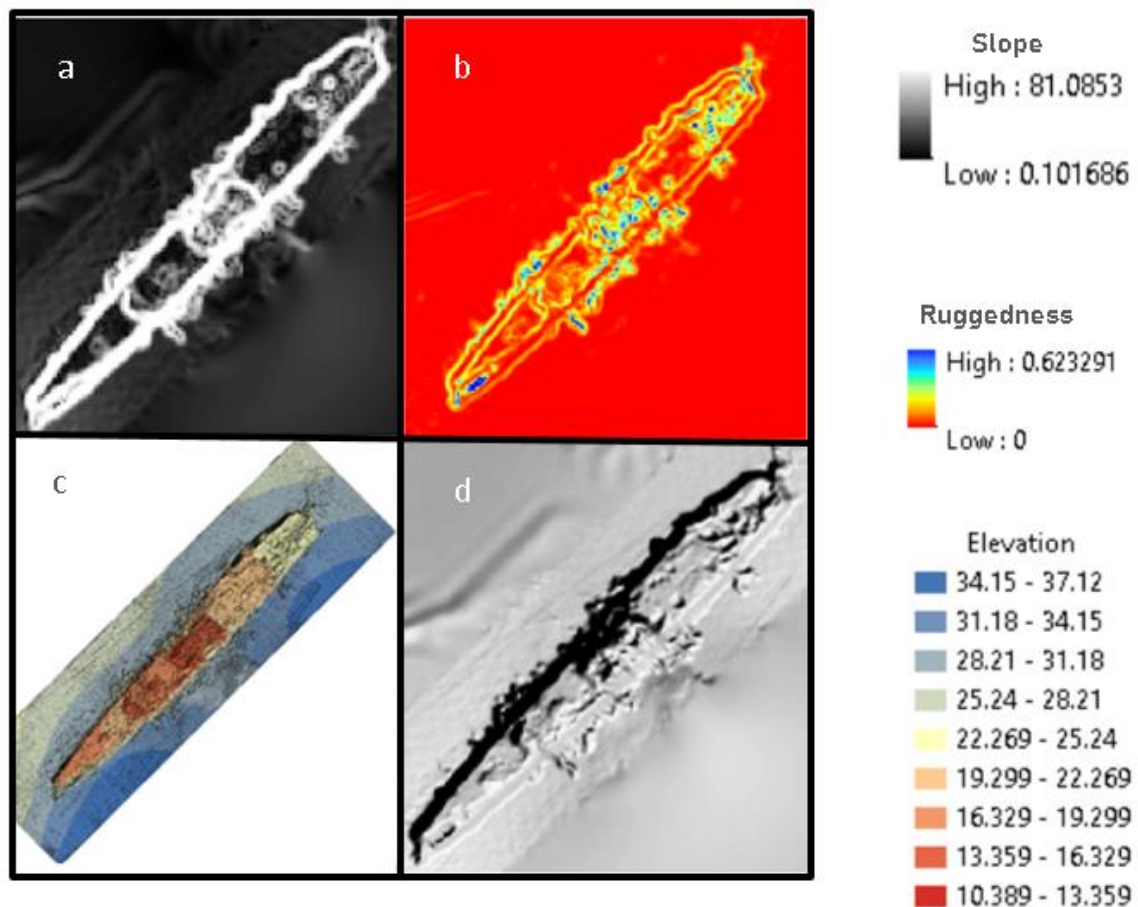


Figure 3.2 Artificial reef visualizations of the Annapolis wreck in Howe Sound, BC. Images created in ArcGIS starting from raw multibeam sonar point data: a) Slope b) Terrain Ruggedness (VRM) c) Elevation (Triangular Irregular Network) d) 3D Image (Hillshade)

To quantify structural characteristics at each site, we used high resolution multi-beam sonar data (courtesy of Canadian Hydrographic Services) to create 3D models of each wreck in ArcGIS (ArcMap 10.2; Figure 3.2). Because data were collected at varying resolutions (between 0.25 m and 5 m), the raster processing *Resample* tool was used to convert all data to the coarsest resolution using cubic convolution. Polygons were created to denote the extent of each wreck, then used to clip the surrounding sandflat bathymetry from each site. We then used the *benthic terrain modeler 3.0* toolbox to calculate

structural data for each site (Walbridge et al. 2018). Arc-chord ratio (Du Preez 2015), depth statistics (mean, variance, standard deviation, interquartile range), slope models, terrain ruggedness models, and surface area were derived for each site.

We recorded spatial characteristics that may influence rockfish abundance or groundfish diversity for each reef (Table 3.1). Direction and speed of currents as well as topography surrounding ARs affect the likelihood of landing in an environment suitable for settlement (Gaines et al. 2003). Rockfish dispersal is influenced by currents and habitat preferences dependent on life-stage (Carlson and Straty 1981, Matthews 1990, West et al. 1994, Love et al. 2002, Johansson et al. 2008). To account for this variability, we calculated proximity of the focal reef to adjacent reefs using maps of suitable habitat (defined as proportion of high rugosity-hard bottomed habitat within a 2km buffer of the study area) generated in ArcGIS (ArcMap 10.2) using bathymetry derivatives from BC Marine Conservation Analysis (2017). We also created maps of current speed and direction using a combination of ArcGIS software and the Webtide Tidal Prediction Model (version 0.7.1) (Bedford Institute of Oceanography 2015; BC Marine Conservation Analysis 2017; Figure 3.3). Groundfish species are known to segregate by depth (Richards 1986, Matthews 1990, Love et al. 2002, Yoklavich et al. 2002, Tolimieri 2007, Zintzen et al. 2012), we recorded mean depth for each video segment to account for this variability. To account for effects of fishing closures on fish mortality, we overlaid sites with an RCA map to determine whether fish communities showed effective protection from traditional angling gear.

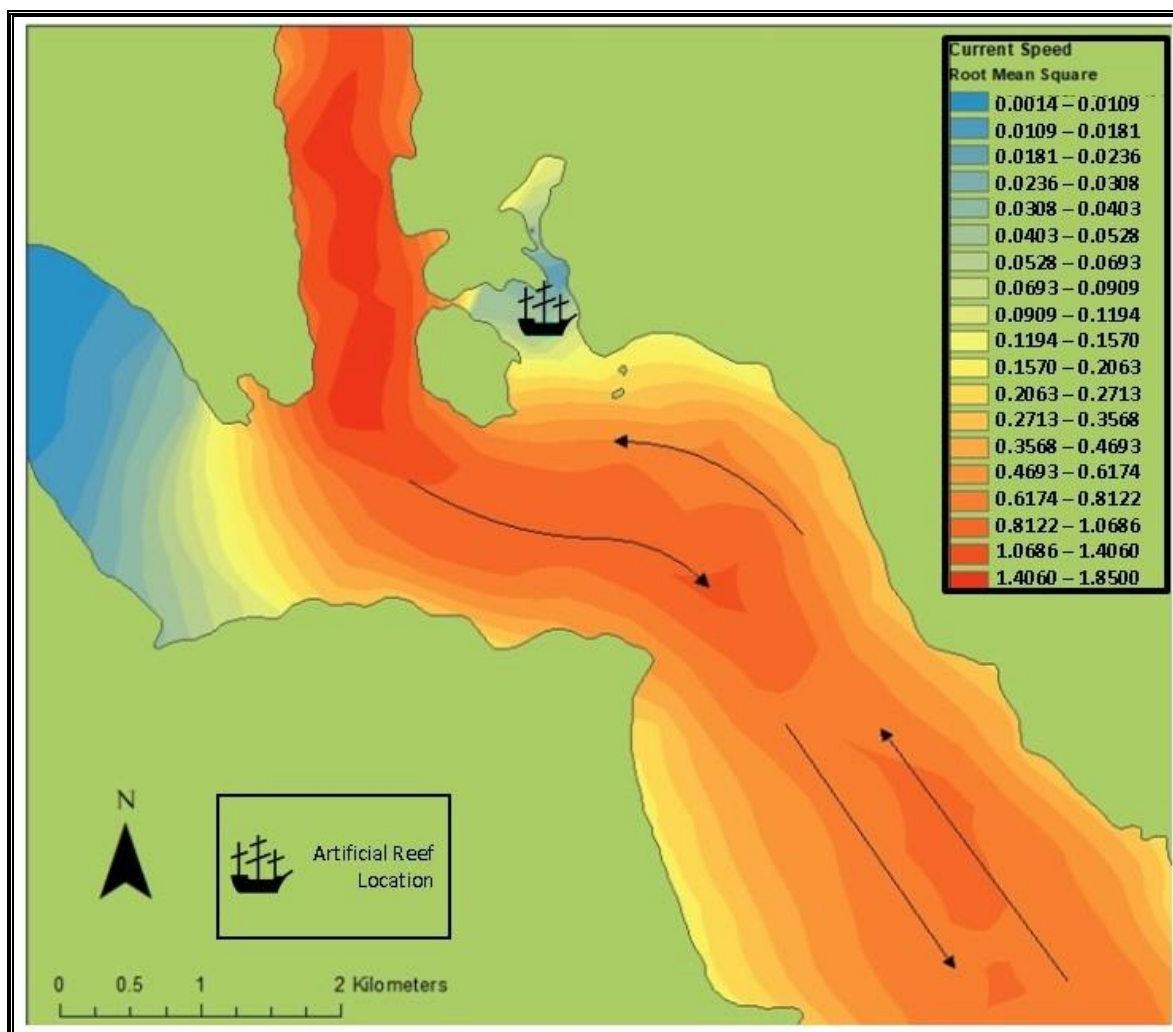


Figure 3.3 Example of current mapping around the Columbia Wreck (black ship symbol), located near Campbell River, BC. Arrows denote direction of dominant current, shading indicates current strength.

To account for changes in groundfish communities over time, reef age in years from sink date was recorded for each site. Interaction terms were included with time and

each of the other variables to determine whether relationships with explanatory variables were different between old and new wrecks.

3.2.3 Statistical Analysis

We used regression analyses to test whether ARs of different ages, locations and physical characteristics had distinguishably different groundfish communities, and which habitat characteristics most influenced these patterns. Three of nine reefs were ultimately removed from analysis due to data deficiency, leaving six AR sites for comparison (Table). Following an exploratory analysis of data as per Zuur et al. (2010), generalized linear models were created using the *lme4* and *MuMIn* packages in R statistical software (Bates et al. 2015; Barton 2018; R Core Development Team 2018). Rockfish abundance and groundfish species richness were response variables with habitat characteristics as explanatory variables (Table 2). We calculated total rockfish abundance by summing all rockfish observations within each 30 second video block. Species richness was calculated using the *vegan* package in R (Oksanen et al. 2017). Data were positive and non-normally distributed. A negative binomial distribution with a log link was used to model rockfish abundance, as a Poisson distribution resulted in overdispersion (variance of fish counts that exceeded the mean). Species richness was plotted using a Poisson distribution. Though there were repeated samples at each vessel site, we presume all pertinent environmental variables that may influence the response variables were accounted for, and thus a random effect was not included. Models were plotted by “Site” and examined for clustering of datapoints to assess for spatial pseudoreplication within results.

Next, we used Burnham and Anderson's (2002) information theoretic approach to compare directly competing hypotheses. To standardize continuous variables, we subtracted the mean and divided by standard deviation. Multiple explanatory models were tested for each response variable, including single predictor models and a global model representing cumulative effects. Hypotheses were ranked using Akaike information criterion (AIC) to compare goodness of fit of each model. When competing models differed by less than 2 delta AIC, we selected the most parsimonious model. Visual inspection of residuals versus the fitted values plots, quantile-quantile plots, and correlation coefficients between variables were used to verify assumptions of normality of the residuals and independence of variables.

Table 3.1 Explanatory variables grouped by model sets hypothesized to influence total rockfish abundance and groundfish diversity.

Mechanism influencing fish community	Model Variables	Hypothesis: Total Rockfish Abundance (Δ) is influenced by:	Variable description
Structural Features	Relief	Slope of substrate	Categorical – High relief = steep slope, low relief = shallow slope
	Rugosity	Complexity/Roughness	Continuous – arc-chord ratio – measure of surface roughness de-coupled from slope
	Surface Area	Reef Size	Continuous – Surface area calculated from 3D model
Spatial Features	MaxCurrent	Current Speed	Continuous - Current speed in m/s derived from mean current ebb/flow data collected in the spring months by BC Marine Conservation Analysis (site level)
	SuitableHabitat	Area of suitable habitat surrounding the site	Continuous - % Hard Bottom High rugosity substrate - 2km buffer. Radius derived from DFO AR spacing recommendations (Smiley et al. 2006).
	Depth	Depth	Continuous - mean depth for video clip
	RCA	Rockfish Conservation Area Boundary	Categorical - Protected status. 1 = within RCA boundaries, 0 = outside RCA boundaries
Temporal Features	Age	Reef Age	Continuous - Time in years between ship sink date and survey date min = 2.5, max = 26.8

3.3 Results

We analyzed 595 video segments from 6 ARs. Artificial reef ages ranged between 2.5 and 26.8 years old (Appendix B, Table B.2). Artificial reef length ranged from 15 to 137.4 metres. Video collected at sites occurred at depths between 10 and 40 metres. In total, we observed 11 species of groundfish with quillback rockfish being the most abundant species (Appendix B, Table B2).

Rockfish had greater abundance with increasing depth and rugosity ($p < 0.001$). Reef age had the greatest effect size with more rockfish on older ARs ($p < 0.001$). ARs in RCAs had higher rockfish abundance ($p < 0.05$), and more rockfish were found on low relief areas of the ship. The best fit model carried 33.3% of the AIC weight of evidence (AICw), with approximately twice as much explanatory power as the next top models (AICw = 832.84, Null deviance = 428.13 on 594 df, Residual deviance = 284.45 on 589 df ; Appendix B, Table B.3).

Table 3.2 Comparison of top models for rockfish abundance

Rockfish relative abundance top models in order within top five delta AIC, including model estimates of fixed effects. Model 1 (AICw 33.3%) included depth, RCA, relief, rugosity and age as predictors. Model 2 (AICw 18.2%) shared variables of RCA, relief and rugosity, with the addition of current, surface area, and an interaction between time and depth. Model 3 (14.3%) shared variables of depth, RCA and relief with the top model with the addition of current, surface area and an interaction between rugosity and age. Standard error displayed in brackets. Significance: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$. models ranked by AIC(x).

Top model for rockfish abundance: RF Abund ~ Depth + RCA + Relief + Rugosity + Age

Model Rank:	1	2	3	4	5
(Intercept)	-2.38 *** (0.41)	-2.44 *** (0.33)	-1.85 *** (0.39)	-2.49 *** (0.43)	-2.44 *** (0.43)
Depth	0.66 *** (0.19)		0.96 *** (0.27)	0.66 *** (0.19)	0.74 ** (0.24)
RCA	0.85 * (0.40)	1.80 *** (0.43)	-0.03 (0.49)	1.01 * (0.43)	0.94 * (0.44)
ReliefLow	0.58 (0.30)	0.81 ** (0.30)	0.90 ** (0.33)	0.61 * (0.30)	0.66 * (0.33)
Rugosity	0.71 *** (0.11)	0.42 ** (0.13)		0.69 *** (0.11)	0.69 *** (0.11)
Age	1.24 *** (0.30)			1.25 *** (0.30)	1.15 *** (0.34)
MaxCurrent		-0.17 (0.17)	0.80 *** (0.22)	-0.14 (0.16)	
Surf_Area		-0.46 * (0.19)	-0.84 *** (0.22)		-0.10 (0.19)
Depth:Age		0.92 ** (0.29)			
Rugosity:Age			1.80 *** (0.28)		
N	595	595	595	595	595
AIC	832.84	862.19	840.09	834.05	834.57
Delta	0	1.21	1.73	2.62	3.05
Weight	0.333	0.182	0.140	0.090	0.072

Table 3.3 Comparison of top models for groundfish species richness

Groundfish species richness top models in order within top five delta AIC, including model estimates of fixed effects. Model 1 (AICw 32.5%) included RCA, relief, current, surface area, rugosity and an interaction between depth and age as predictors. Model 2 (AICw 12.2%) shared variables of RCA, relief, current and rugosity, but lacked an interaction between time and depth variables. Model 3 (12.1%) contained a similar suite of variables but excluded current. Standard error displayed in brackets. Significance: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$. models ranked by AIC(x).

Top model for groundfish species richness: Richness \sim RCA + Relief + Current + Size + Rugosity + Depth: Age

Model Rank:	1	2	3	4
(Intercept)	-2.73 *** (0.29)	-2.75 *** (0.39)	-2.66 *** (0.36)	-2.76 *** (0.40)
RCA	1.50 *** (0.37)	0.87 * (0.36)	0.78 * (0.36)	0.87 * (0.36)
ReliefLow	0.88 *** (0.23)	0.67 ** (0.23)	0.83 *** (0.25)	0.65 * (0.28)
MaxCurrent	-0.23 (0.14)	-0.30 * (0.13)		-0.33 (0.24)
Surf_Area	-0.46 ** (0.14)		-0.28 (0.15)	0.05 (0.29)
Rugosity	0.05 (0.10)	0.24 ** (0.08)	0.23 ** (0.08)	0.24 ** (0.09)
Depth:Age	0.62 * (0.24)			
Depth		0.43 * (0.17)	0.62 ** (0.20)	0.39 (0.25)
Age		1.16 *** (0.27)	0.85 ** (0.29)	1.22 ** (0.46)
N	595	595	595	595
AIC	641.59	643.55	643.56	643.58
Delta	0	1.96	1.97	1.97
Weight	0.325	0.122	0.121	0.121

GLM modelling for species richness demonstrated positive and significant relationships with RCA ($p < 0.001$), relief ($p < 0.001$), and depth-age interaction ($p < 0.05$). A negative and significant relationship was observed with surface area ($p < 0.01$), and a weak positive relationship with rugosity. The best-fit model carried 32.5% of the AIC weight of evidence (AICw= 0.325, Null deviance = 468.07 on 594 df, Residual deviance = 395.35 on 588 df; Appendix B, Table B4). The second model differing by only 1.96 AIC, was more parsimonious with the exclusion of the surface area variable. RCA, relief, current and rugosity were consistent variables within the highest ranked models (top 5 AIC; Table 2.3). Quantile-quantile plots, residuals versus fitted values plots, and correlation coefficients between variables confirmed assumptions of normality, homoscedasticity of the residuals, and independence of variables appeared to be met.

3.4 Discussion

3.4.1 Artificial reef attributes and groundfish conservation success

We used advances in sonar technology to compare three-dimensional structures of temperate ARs and their fish communities under different temporal and spatial conditions. We aimed to understand which variables most influence rockfish abundance and groundfish diversity to inform conservation initiatives. Our survey provides evidence that a combination of structural, spatial, temporal and regulatory characteristics influence groundfish communities on temperate ARs. We found that depth, conservation status, rugosity, and reef age significantly explained variation in rockfish abundance. Groundfish species richness was significantly associated with conservation status, relief, reef size,

and an interaction between depth and reef age. Together, these variables may help guide AR planning decisions, and explain variation in conservation efficacy between reefs.

3.4.2 Effects of spatial decisions and surrounding AR habitat on rockfish abundance and groundfish richness

Rockfish abundance: Several variables associated with selected reef location may affect the fish communities inhabiting a temperate AR. The positive relationship between rockfish abundance and depth in our results suggests that placing ARs at deeper depths may increase conservation benefits for rockfish species. This finding is consistent with previous literature suggesting depth is predictor of rockfish abundance (Richards 1986, Love et al. 2002, Johnson et al. 2003, Haggarty et al. 2016b).

A lack of apparent RCA efficacy as measured by rockfish abundance has been reported in recent years (Marliave and Challenger 2009, Haggarty et al. 2016b, Burke 2018), with one prominent critique being the potential deficiency of suitable habitat within boundaries (Haggarty and Yamanaka 2018). We found rockfish abundance to be greater at ARs within RCAs suggesting AR decision-making processes should take conservation area boundaries into consideration. Establishment of ARs within conservation area boundaries may augment conservation performance through provision of additional habitat to target species. Conversely, the abundance of suitable habitat within a two kilometer radius offered no additional explanatory power in our rockfish abundance models. This result calls into question assumed source-sink dynamics of marine protected areas, however it may also suggest that using a single spatial scale did not adequately reflect fish movement, which varies by species in our study (Matthews

1988, Yeager et al. 2011). Current speed likewise offered little explanatory power in rockfish abundance models.

Groundfish richness: The distribution of groundfish species across reefs revealed differential responses to spatially mediated characteristics of each reef. There were significantly more species observed in samples taken from ARs located within RCA boundaries, than in those outside boundaries. This suggests that ARs may be more effective if used in conjunction with protected areas, conclusions which align with other work (Claudet and Pelletier 2004, Brochier et al. 2015). As previously mentioned, a recent critique of RCAs is a potential lack of high-quality habitat within boundaries due to low resolution habitat maps (Haggarty and Yamanaka 2018). Our work shows potential to remedy this situation through the creation of finer scale natural habitat maps to improve RCA planning, or the implementation of artificial habitats in protected areas to ensure high-quality habitat where confidence in map resolution is low. Our work also indicated higher groundfish species richness in areas of lower current. Many species of larval groundfish initially depend on currents to disperse to new habitats for settlement (Kashef et al. 2014). Our results parallel other literature, where some species of groundfish had lower recruitment success in areas of high tidal current (Markel et al. 2017), however more research should be done across species. Instead, areas of high fetch affecting surface currents may positively influence larval groundfish influx, and current-topography interactions may affect entrainment of larvae to settle on a reef (Gaylord and Gaines 2000). Further research is necessary to understand the complex role of current in explaining variance in patterns of groundfish species richness.

3.4.3 *Effects of AR structural characteristics on rockfish abundance and groundfish richness*

We overcame challenges associated with fine-scale surveying of AR structures in poor-visibility temperate environments. As a result, while other studies have classified AR structure based on categorical criteria (Perkol-Finkel et al. 2006, Ajemian et al. 2015), we used new technologies to provide an efficient method for quantitatively measuring AR attributes. Using fine scale sonar data to create three-dimensional models allowed us to measure reef rugosity, slopes and surface areas to include in analyses. These measures are applicable to a variety of reef structures and can be extended to compare natural reefs and non-shipwreck ARs.

Rockfish abundance: The distribution of rockfish across reef features revealed several responses explained by structural attributes. As expected, we found higher abundances of fish on ARs with higher rugosity, consistent with other rockfish habitat association studies (Love et al. 2002, Haggarty et al. 2016b, Frid et al. 2018), and global trends of positive fish abundance-complexity relationships (Luckhurst and Luckhurst 1978, Charbonnel et al. 2002, Willis and Anderson 2003, Hunter and Sayer 2009, Trebilco et al. 2015). We found low relief areas to have higher rockfish abundance. This may be explained by the possibility of our observations being dominated by younger adult rockfish, who show preference for low relief areas (Matthews 1988, West et al. 1994, Love et al. 2002), though this cannot be confirmed without fish size data.

Groundfish richness: We found more groundfish species in low relief areas, suggesting that the low relief features on vessel wrecks are more attractive to not only rockfish but a variety of groundfish species. These areas were often located on the top

deck of the ship. For upper level trophic species like rockfish and lingcod, this elevation may be perceived as a better vantage point for locating prey or other predators. The steepest (high relief) areas of the vessels tended to be the vertical walls, which often lacked complexity in comparison to the rest of the structure. Avoidance of these areas may reflect a lack of predator refuges (Gregor and Anderson 2016), which may be resolved by adding complex structures to vessel walls. We also found more species of groundfish on smaller vessels with less surface area. Smaller ARs tended to have fewer large expanses of flat featureless deck space, areas which may be perceived as dangerous due to a lack of hiding places from predators. Similarly, predators may be less successful at foraging in areas with less complex features (Willis and Anderson 2003, Warfe and Barmuta 2004), and less likely to inhabit open spaces during daylight hours when all of our sampling was carried out (Petrie and Ryer 2006). Because sampling was carried out evenly across sites regardless of size, a higher proportion of area on smaller wrecks was surveyed which may have influenced species richness patterns. We also found a weak positive relationship between groundfish diversity and rugosity, indicating there were more groundfish species on reefs with more complex features. This finding is consistent with expectations of more complex habitat providing a wider variety of habitats to support fish diversity (Ferreira et al. 2001, Hunter and Sayer 2009). Specific GPS locations of each fish observation to compare with mapped structural data would be useful in disentangling habitat associations on this scale.

3.4.4 Temporal effects on rockfish abundance and groundfish diversity across artificial reefs

Temporal effects on AR fish communities were apparent in both rockfish abundance and groundfish diversity models. The observed relationship between reef age and increasing rockfish abundance and groundfish diversity was consistent with our expectations based on successional processes and patterns in other systems (Sousa 1979, Golani and Diamant 1999, Anderson 2007, Santos et al. 2011, Lowry et al. 2014, Becker et al. 2017). However, abundance and species richness should stabilize once carrying capacity is reached, patterns we did not observe. This is likely due to a lack of replicates, or alternatively an absence of successional mature reefs in our study. The positive interaction between reef age and depth, suggests the effect of AR age on groundfish species richness was more pronounced at deeper depths. Because many of the species involved in our study descend within the water column as they mature (Love et al. 2002), older ARs may have increasing numbers of species living deeper in the water column as more fish age with the reef (Richards 1986, Matthews 1990, Love et al. 2002, Yoklavich et al. 2002, Tolimieri 2007, Zintzen et al. 2012). Similarly, groundfish species segregate by depth, and deeper surveys on the wrecks captured more overlaps of groundfish depth ranges.

3.4.5 Caveats

Some aspects of our project design may have inhibited our ability to capture full ecological inference from our study. Due to the limited availability of high-resolution acoustic data, we were only able to include six ARs in our work. Future work should continue mapping ARs to gain a broader dataset, and more statistical power for influencing management decisions. Though we only included one measure of structural complexity in our analyses, three-dimensional technology provides the opportunity to

look at species-complexity relationships in greater detail (Gonzalez-Rivero et al. 2017). New measures of complexity should be included in future analyses to better understand which specific aspects of structural complexity drive the increased rockfish abundance patterns and how to incorporate these features into AR design and rockfish conservation. New mapping approaches may be applied to classify different areas of an AR to make more readily comparable to NRs (Appendix B, Figure B1).

Our analyses lacked the power to measure rockfish productivity, and so we must be cognisant of the fact that greater abundance may not actually indicate successful achievement of conservation goals. Our trends may instead suggest redistribution of fish from neighbouring habitats, reef attraction (Lindberg 1997). To confidently differentiate between abundance and productivity, analyses considering total biomass, fish movement and mortality (natural and human induced) should be included in future analyses (Valentine-Rose et al. 2011, Claisse et al. 2014b).

ROV field methods could be improved to obtain higher quality, detailed data, allowing for more fine scale questions to be asked. A GPS system would have enabled more precise sample tracking and georeferenced species observations to be recorded. Further studies should conduct fine scale spatial analyses with georeferenced fish observations to better understand within-reef fish distribution. GPS would also allow for more precise area measurements than sonar alone. Fish size data would have allowed for biomass estimates, more informative data than relative abundance. Due to equipment limitations, the ROV was not equipped with lasers for sizing individual fishes. Further research should use biomass to quantify primary and secondary productivity at ARs and model them against three-dimensional structural data to determine which AR are the most

productive and why. Since fish movement varies by species, different species were likely differentially influenced by external habitat availability and we may have failed to see trends on other scales due to our use of only one buffer size for the surrounding habitat analysis. Our research would benefit from conducting species specific analyses and testing a variety of buffer sizes for explanatory power. Because we sampled each site equally regardless of size, a higher proportion of the structure on smaller wrecks was surveyed than on larger wrecks, this may have influenced the result of higher species richness on wrecks with lower surface area and should be considered when interpreting results.

3.4.6 Conclusion

This research is a first step in understanding causal mechanisms for differences between fish communities on shipwreck artificial reefs, and which reef attributes facilitate successful contributions to conservation. Our work suggests that ARs should be placed deeper in the water column, within conservation area boundaries to achieve maximum groundfish conservation benefits. High current areas may negatively affect groundfish species richness. Our study species were associated with features on the high rugosity, low relief areas of ARs. Smaller vessels worked better per unit of area to conserve species diversity than larger ones. Older reefs were more highly effective at supporting both high rockfish abundance and groundfish diversity.

Given that a critical component of artificial reef success is structure, using three-dimensional technologies can be used as a tool to understand species-habitat association on existing reefs and help predict the success of future reefs. The structural measurements used in this study are not exclusive to shipwrecks as artificial reefs and can

be extended to other AR structures in efficacy assessments and fish habitat association studies to further our understanding of which structural criteria species of concern need to survive.

Chapter 4

Conclusions on the conservation efficacy of British Columbia's ARs

4.1 Review of Findings

Though artificial reefs (ARs) have long been regarded as a fisheries management tool, controversy remains surrounding their efficacy (Baine 2001, Becker et al. 2018). Conservation initiatives may employ ARs to offset marine habitat losses and aid in restoration of species at risk, however caution must be used when assuming positive environmental benefits (Seaman 2000, Seaman 2002). Understanding how reef characteristics affect species and community composition are key in enhancing AR use in conservation initiatives. I tested the ability of northern temperate ARs to support marine fish communities of conservation interest. My research assessed rockfish abundance and groundfish diversity on artificial and natural reefs to meet two goals: 1) evaluate the conservation efficacy of artificial reefs in comparison to natural reefs (NRs), and 2) understand habitat characteristics that contribute to the variation in AR conservation success. My research contributes to the sparse body of literature on northern temperate ARs and aims to inform future conservation initiatives that may employ the use of ARs to support species of concern.

In my second chapter, I investigated differences between reef types and found that ARs differed from NRs in their ability to support fish communities. ARs had high variability in rockfish abundance, while NRs consistently supported intermediate rockfish

abundances. This chapter suggests that ARs do not consistently replicate the habitat of NRs, and each reef type has its strengths with respect to groundfish conservation objectives. Responses of rockfish abundance and groundfish diversity to habitat characteristic models indicated that AR implementation should strongly consider relief and depth profile of the AR to ensure successful fish conservation. However, this work was limited to a small sub-sample of faunal communities on ARs, highlighting the need to conduct community-wide comparisons between ARs and NRs.

In my third chapter, I quantified structural characteristics of ARs via three-dimensional models and their relative contributions to explaining rockfish abundance and groundfish diversity. I also considered spatial and temporal factors associated with reef location and time since sinking. I found that AR planning should consider depth, conservation status, rugosity, and reef age if reef objectives plan to enhance rockfish abundance; while initiatives to maximize groundfish species richness should consider conservation status, relief, reef size, and an interaction between depth and reef age. My findings indicate that multiple variables are important in conservation success of an AR. However, this study was subject to small sample sizes, emphasizing the need for more fine-scale data and detailed habitat-association studies.

My results have local management implications and contribute to a growing body of AR literature. I compare the relative conservation contributions of ARs and natural rocky reefs in a northern temperate system. I propose causal mechanisms for differences between groundfish communities on ARs and NRs. This is a first step in understanding which reef attributes facilitate successful contributions to Canadian groundfish conservation and furthers the knowledge of ARs as fish habitat along the northeast

Pacific coastal shelf. More broadly, my work outlines how future AR monitoring may be conducted and the potential for using three-dimensional technologies as a tool to understand species-habitat association on existing reefs. ARs may positively influence conservation of some threatened species, however, to sustain diverse fish communities, protection of heterogeneous NRs may be the best option. Rigorous planning and monitoring must be employed to understand differences between current ARs, to improve conservation success and maintain a high quality of AR habitat. With long term research and adaptive management, monitoring may be used to predict the success of future ARs and refine each reef for its specified objectives.

4.2 Future Research

ARs have the potential to be used as invaluable conservation tools. However, effectively offsetting human disturbance with ARs requires purposefully thought-out research to inform defined conservation objectives, and continued monitoring of marine communities. Future studies seeking to evaluate the efficacy of artificial reefs should employ thorough monitoring designs, focusing on ecosystem-wide effects and longevity of AR efficacy. This will be most effectively accomplished through long term research, and increased sample sizes using marine technology to minimize costs and maximize quantity of data. When AR objectives include conservation of species of concern, reef design should be guided by species-specific habitat requirements.

While my research suggests that ARs and NRs provide different habitat for groundfish communities, driven by a combination of habitat characteristics, future studies should evaluate fish distributions at finer spatial scales and with sharper analyses. Further work on specific dimensions of complexity may expose ecological mechanisms for fish

distribution that we were unable to evaluate without fine-scale fish location data (Gonzalez-Rivero et al. 2017). Special focus should be given to confidently assessing conservation contribution of ARs through the calculation of conservation-targeted species' productivity (Valentine-Rose et al. 2011, Claisse et al. 2014b). Data should be collected to consider total fish biomass, movement and mortality.

Effectively extending current knowledge of temperate AR efficacy requires research across different spatial and temporal contexts. As depth was an important variable in both data chapters, groundfish or rockfish -targeted ARs should be tested for success at deeper depths. The ideal purpose-designed AR structure may involve a variety of platforms at different depths to support various rockfish life-stages (Love et al. 1991, Love et al. 2002, Claisse et al. 2014a). Future AR implementation should involve baseline community surveys prior to deployment so detailed cost-benefit community analyses can be conducted. The strong relationship between reef structure and fish abundance and diversity highlights the need to study a broader range of AR structural configurations including purpose-built ARs to match the habitat preferences of target species.

Although ARs are frequently used with the intent of supporting biological functions, socio-economic drivers are catalysts for AR deployment. The balance between achieving environmental, economic and socially positive results is precarious and requires synergy of expertise between different research fields. This work aims to inform how to best achieve environmental results in the hopes that ecosystem services will be restored to improve human systems. However, further research is needed in optimizing economic and social benefits, while maintaining biological goals.

If we intend to conserve the oceans, we must look to effective solutions to offset human-inflicted damages. ARs may be a useful tool in mitigating ecosystem collapse and restoring marine populations in a changing environment. The health of our oceans is critical in not only for worldwide ecosystem balance, but to support humans' economic, social and physical wellbeing (Sala and Knowlton 2006, Worm et al. 2006, Mora et al. 2011). Understanding how conservation initiatives can be met in a changing and heavily human-impacted world, is critical to ensure a positive future for the planet.

Bibliography

- Aguilera, M. A., B. R. Broitman, and M. Thiel. 2014. Spatial variability in community composition on a granite breakwater versus natural rocky shores: Lack of microhabitats suppresses intertidal biodiversity. *Marine Pollution Bulletin* **87**:257-268.
- Ajemian, M. J., J. J. Wetz, B. Shipley-Lozano, and G. W. Stunz. 2015. Rapid assessment of fish communities on submerged oil and gas platform reefs using remotely operated vehicles. *Fisheries Research* **167**:143-155.
- Anderson, K. J. 2007. Temporal patterns in rates of community change during succession. *American Naturalist* **169**:780-793.
- Anderson, T. J., M. M. Yoklavich, and S. L. Eittem. 2005. Linking fine-scale groundfish distributions with large-scale seafloor maps: Issues and challenges of combining biological and geological data. *Benthic Habitats and the Effects of Fishing* **41**:667-678.
- Anderson, T. W., E. E. Demartini, and D. A. Roberts. 1989. The relationship between habitat structure, body size and distribution of fishes at a temperature artificial reef. *Bulletin of Marine Science* **44**:681-697.
- Arena, P. T., L. K. B. Jordan, and R. E. Spieler. 2007. Fish assemblages on sunken vessels and natural reefs in southeast Florida, USA. *Hydrobiologia* **580**:157-171.
- Arreola-Robles, J. L., and J. F. Elorduy-Garay. 2002. Reef fish diversity in the region of La Paz, Baja California Sur, Mexico. *Bulletin of Marine Science* **70**:1-18.
- ARSBC. 2017. ARTIFICIAL REEF SOCIETY OF BC.
- Baine, M. 2001. Artificial reefs: a review of their design, application, management and performance. *Ocean & Coastal Management* **44**:241-259.
- Ban, N., and J. Alder. 2008. How wild is the ocean? Assessing the intensity of anthropogenic marine activities in British Columbia, Canada. *Aquatic Conservation-Marine and Freshwater Ecosystems* **18**:55-85.
- Barton, K. 2018. MuMIn: Multi-Model Inference.

- Bates, D., M. Machler, B. Bolker, and S. Walker. 2015. Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software* **67**:1--48.
- Becker, A., M. D. Taylor, H. Folpp, and M. B. Lowry. 2018. Managing the development of artificial reef systems: The need for quantitative goals. *Fish and Fisheries* **19**:740-752.
- Becker, A., M. D. Taylor, and M. B. Lowry. 2017. Monitoring of reef associated and pelagic fish communities on Australia's first purpose built offshore artificial reef. *ICES Journal of Marine Science* **74**:277-285.
- Bohnsack, J. A. 1989. Are high-densities of fishes at artificial reefs the result of habitat limitation or behavioral preference. *Bulletin of Marine Science* **44**:631-645.
- Bohnsack, J. A., and D. L. Sutherland. 1985. Artificial reef research - a review with recommendations for future priorities. *Bulletin of Marine Science* **37**:11-39.
- Bortone, S. A. 2011. *Artificial reefs in fisheries management*. CRC Press, Boca Raton, FL.
- Bostrom, C., S. J. Pittman, C. Simenstad, and R. T. Kneib. 2011. Seascape ecology of coastal biogenic habitats: advances, gaps, and challenges. *Marine Ecology Progress Series* **427**:191-217.
- Brochier, T., P. Auger, N. Thiam, M. Sow, S. Diouf, H. Sloterdijk, and P. Brehmer. 2015. Implementation of artificial habitats: Inside or outside the marine protected areas? Insights from a mathematical approach. *Ecological Modelling* **297**:98-106.
- Brown, C. J., J. A. Sameoto, and S. J. Smith. 2012. Multiple methods, maps, and management applications: Purpose made seafloor maps in support of ocean management. *Journal of Sea Research* **72**:1-13.
- Brown, C. J., S. J. Smith, P. Lawton, and J. T. Anderson. 2011. Benthic habitat mapping: A review of progress towards improved understanding of the spatial ecology of the seafloor using acoustic techniques. *Estuarine Coastal and Shelf Science* **92**:502-520.

- Burke, L. A.-M. 2018. Comparison of underwater visual methods for assessing temperate rocky reef fish communities and the effectiveness of spatial marine conservation areas. University of Victoria.MSc Thesis.
- Burt, J., A. Bartholomew, and P. F. Sale. 2011. Benthic development on large-scale engineered reefs: A comparison of communities among breakwaters of different age and natural reefs. *Ecological Engineering* **37**:191-198.
- Burt, J., A. Bartholomew, P. Usseglio, A. Bauman, and P. F. Sale. 2009. Are artificial reefs surrogates of natural habitats for corals and fish in Dubai, United Arab Emirates? *Coral Reefs* **28**:663-675.
- Cameron, M. J., V. Lucieer, N. S. Barrett, C. R. Johnson, and G. J. Edgar. 2014. Understanding community-habitat associations of temperate reef fishes using fine-resolution bathymetric measures of physical structure. *Marine Ecology Progress Series* **506**:213-229.
- Carlson, H. R., and R. R. Straty. 1981. Habitat and nursery grounds of Pacific rockfish, *Sebastes* spp, in rocky coastal areas of southeastern Alaska. *Marine Fisheries Review* **43**:13-19.
- Carr, M. H., and M. A. Hixon. 1997. Artificial reefs: The importance of comparisons with natural reefs. *Fisheries* **22**:28-33.
- Charbonnel, E., C. Serre, S. Ruitton, J. G. Harmelin, and A. Jensen. 2002. Effects of increased habitat complexity on fish assemblages associated with large artificial reef units (French Mediterranean coast). *ICES Journal of Marine Science* **59**:S208-S213.
- Claisse, J. T., D. J. Pondella, M. Love, L. A. Zahn, C. M. Williams, J. P. Williams, and A. S. Bull. 2014a. Oil platforms off California are among the most productive marine fish habitats globally. *Proceedings of the National Academy of Sciences of the United States of America* **111**:15462-15467.
- Claisse, J. T., D. J. Pondella, M. Love, L. A. Zahn, C. M. Williams, J. P. Williams, and A. S. Bull. 2014b. Oil platforms off California are among the most productive marine fish habitats globally. *Proceedings of the National Academy of Sciences of the United States of America* **111**:15462-15467.

- Claudet, J., and D. Pelletier. 2004. Marine protected areas and artificial reefs: A review of the interactions between management and scientific studies. *Aquatic Living Resources* **17**:129-138.
- Connell, S. D., and G. P. Jones. 1991. The influence of habitat complexity on postrecruitment processes in a temperate reef fish population. *Journal of Experimental Marine Biology and Ecology* **151**:271-294.
- Crain, C. M., K. Kroeker, and B. S. Halpern. 2008. Interactive and cumulative effects of multiple human stressors in marine systems. *Ecology Letters* **11**:1304-1315.
- Crawford, W. R., and R. E. Thomson. 1991. Physical oceanography of the western Canadian continental-shelf. *Continental Shelf Research* **11**:669-683.
- Dafforn, K. A., T. M. Glasby, L. Airoidi, N. K. Rivero, M. Mayer-Pinto, and E. L. Johnston. 2015. Marine urbanization: an ecological framework for designing multifunctional artificial structures. *Frontiers in Ecology and the Environment* **13**:82-90.
- DFO. 2000. Inshore Rockfish. Science Stock Status Report. Fisheries and Oceans Canada.
- DFO. 2016. Integrated Fisheries Management Plan Summary - Groundfish.
- Doney, S. C. 2010. The Growing Human Footprint on Coastal and Open-Ocean Biogeochemistry. *Science* **328**:1512-1516.
- Du Preez, C. 2015. A new arc-chord ratio (ACR) rugosity index for quantifying three-dimensional landscape structural complexity. *Landscape Ecology* **30**:181-192.
- Farinas-Franco, J. M., and D. Roberts. 2014. Early faunal successional patterns in artificial reefs used for restoration of impacted biogenic habitats. *Hydrobiologia* **727**:75-94.
- Ferreira, C. E. L., J. E. A. Goncalves, and R. Coutinho. 2001. Community structure of fishes and habitat complexity on a tropical rocky shore. *Environmental Biology of Fishes* **61**:353-369.

- Folpp, H., M. Lowry, M. Gregson, and I. M. Suthers. 2013. Fish Assemblages on Estuarine Artificial Reefs: Natural Rocky-Reef Mimics or Discrete Assemblages? *PLoS One* **8**:14.
- Fowler, A. M., and D. J. Booth. 2013. Seasonal Dynamics of Fish Assemblages on Breakwaters and Natural Rocky Reefs in a Temperate Estuary: Consistent Assemblage Differences Driven by Sub-Adults. *PLoS One* **8**:12.
- Frid, A., M. McGreer, K. S. P. Gale, E. Rubidge, T. Blaine, M. Reid, A. Olson, S. Hankewich, E. Mason, D. Rolston, and E. Tallio. 2018. The area-heterogeneity tradeoff applied to spatial protection of rockfish (*Sebastes* spp.) species richness. *Conservation Letters* **11**:8.
- Gaines, S. D., B. Gaylord, and J. L. Largier. 2003. Avoiding current oversights in marine reserve design. *Ecological Applications* **13**:S32-S46.
- Garrabou, J., E. Ballesteros, and M. Zabala. 2002. Structure and dynamics of north-western Mediterranean rocky benthic communities along a depth gradient. *Estuarine Coastal and Shelf Science* **55**:493-508.
- Gaylord, B., and S. D. Gaines. 2000. Temperature or transport? Range limits in marine species mediated solely by flow. *American Naturalist* **155**:769-789.
- George, R. D., C. R. In, R. K. Johnston, P. F. Seligman, R. D. Gauthier, and W. J. Wild. 2005. Seawater leaching investigation of polychlorinated biphenyls from solid matrices. *Oceans 2005, Vols 1-3*:1492-1500.
- Glasby, T. M., S. D. Connell, M. G. Holloway, and C. L. Hewitt. 2007. Nonindigenous biota on artificial structures: could habitat creation facilitate biological invasions? *Marine Biology* **151**:887-895.
- Golani, D., and A. Diamant. 1999. Fish colonization of an artificial reef in the Gulf of Elat, northern Red Sea. *Environmental Biology of Fishes* **54**:275-282.
- Gonzalez-Correa, J. M., J. T. Bayle, J. L. Sanchez-Lizasa, C. Valle, P. Sanchez-Jerez, and J. M. Ruiz. 2005. Recovery of deep *Posidonia oceanica* meadows degraded by trawling. *Journal of Experimental Marine Biology and Ecology* **320**:65-76.
- Gonzalez-Rivero, M., A. R. Harborne, A. Herrera-Reveles, Y. M. Bozec, A. Rogers, A. Friedman, A. Ganase, and O. Hoegh-Guldberg. 2017. Linking fishes to multiple

metrics of coral reef structural complexity using three-dimensional technology. *Scientific Reports* **7**:13965.

Granneman, J. E., and M. A. Steele. 2015. Effects of reef attributes on fish assemblage similarity between artificial and natural reefs. *ICES Journal of Marine Science* **72**:2385-2397.

Gregor, C. A., and T. W. Anderson. 2016. Relative importance of habitat attributes to predation risk in a temperate reef fish. *Environmental Biology of Fishes* **99**:539-556.

Gunderson, D. R., A. M. Parma, R. Hilborn, J. M. Cope, D. L. Fluharty, M. L. Miller, R. D. Vetter, S. S. Heppell, and H. G. Greene. 2008. The challenge of managing nearshore rocky reef resources. *Fisheries* **33**:172-179.

Hachich, N. F., M. B. Bonsall, E. M. Arraut, D. R. Barneche, T. M. Lewinsohn, and S. R. Floeter. 2015. Island biogeography: patterns of marine shallow-water organisms in the Atlantic Ocean. *Journal of Biogeography* **42**:1871-1882.

Haggarty, D., and L. Yamanaka. 2018. Evaluating Rockfish Conservation Areas in southern British Columbia, Canada using a Random Forest model of rocky reef habitat. *Estuarine, Coastal and Shelf Science* **208**:191-204.

Haggarty, D. R., S. J. D. Martell, and J. B. Shurin. 2016a. Lack of recreational fishing compliance may compromise effectiveness of Rockfish Conservation Areas in British Columbia. *Canadian Journal of Fisheries and Aquatic Sciences* **73**:1587-1598.

Haggarty, D. R., J. B. Shurin, and K. L. Yamanaka. 2016b. Assessing population recovery inside British Columbia's Rockfish Conservation Areas with a remotely operated vehicle. *Fisheries Research* **183**:165-179.

Halpern, B. S., S. Walbridge, K. A. Selkoe, C. V. Kappel, F. Micheli, C. D'Agrosa, J. F. Bruno, K. S. Casey, C. Ebert, H. E. Fox, R. Fujita, D. Heinemann, H. S. Lenihan, E. M. P. Madin, M. T. Perry, E. R. Selig, M. Spalding, R. Steneck, and R. Watson. 2008. A global map of human impact on marine ecosystems. *Science* **319**:948-952.

Hanner, S. E., T. L. McIntosh, and S. M. Blair. 2006. Development of benthic and fish assemblages on artificial reef materials compared to adjacent natural reef

assemblages in Miami-Dade County, Florida. *Bulletin of Marine Science* **78**:57-70.

- Hayden-Spear, J., and D. R. Gunderson. 2007. Nearshore habitat associations of young-of-year copper (*Sebastes caurinus*) and quillback (*S. maliger*) rockfish in the San Juan Channel, Washington. *Journal of Marine Research* **65**:1-15.
- Hilborn, R., K. Stokes, J. J. Maguire, T. Smith, L. W. Botsford, M. Mangel, J. Orensanz, A. Parma, J. Rice, J. Bell, K. L. Cochrane, S. Garcia, S. J. Hall, G. P. Kirkwood, K. Sainsbury, G. Stefansson, and C. Walters. 2004. When can marine reserves improve fisheries management? *Ocean & Coastal Management* **47**:197-205.
- Hill, N. A., V. Lucieer, N. S. Barrett, T. J. Anderson, and S. B. Williams. 2014. Filling the gaps: Predicting the distribution of temperate reef biota using high resolution biological and acoustic data. *Estuarine Coastal and Shelf Science* **147**:137-147.
- Hunter, W. R., and M. D. J. Sayer. 2009. The comparative effects of habitat complexity on faunal assemblages of northern temperate artificial and natural reefs. *ICES Journal of Marine Science* **66**:691-698.
- Jan, R. Q., Y. H. Liu, C. Y. Chen, M. C. Wang, G. S. Song, H. C. Lin, and K. T. Shao. 2003. Effects of pile size of artificial reefs on the standing stocks of fishes. *Fisheries Research* **63**:327-337.
- Johansson, M. L., M. A. Banks, K. D. Glunt, H. M. Hassel-Finnegan, and V. P. Buonaccorsi. 2008. Influence of habitat discontinuity, geographical distance, and oceanography on fine-scale population genetic structure of copper rockfish (*Sebastes caurinus*). *Molecular Ecology* **17**:3051-3061.
- Johnson, S. W., M. L. Murphy, and D. J. Csepp. 2003. Distribution, habitat, and behavior of rockfishes, *Sebastes* spp., in nearshore waters of southeastern Alaska: observations from a remotely operated vehicle. *Environmental Biology of Fishes* **66**:259-270.
- Jones, A. T., R. W. Welsford, and Ieee. 1997. Artificial reefs in British Columbia, Canada. *Oceans '97 Mts/Ieee Conference Proceedings, Vols 1 and 2*:415-418.
- Kashef, N. S., S. M. Sogard, R. Fisher, and J. L. Largier. 2014. Ontogeny of critical swimming speeds for larval and pelagic juvenile rockfishes (*Sebastes* spp., family Scorpaenidae). *Marine Ecology Progress Series* **500**:231-243.

- Kramer, D. E., V. M. O'Connell, P. Alaska Sea Grant College, Alaska, and G. Department of Fish and. 1986. Guide to northeast Pacific rockfishes. Alaska Sea Grant College Program, University of Alaska, Fairbanks, AK.
- Laidig, T. E., and M. M. Yoklavich. 2016. A comparison of density and length of Pacific groundfishes observed from 2 survey vehicles: a manned submersible and a remotely operated vehicle. *Fishery Bulletin* **114**:386-396.
- Lancaster, D., P. Dearden, D. R. Haggarty, J. P. Volpe, and N. C. Ban. 2017. Effectiveness of shore-based remote camera monitoring for quantifying recreational fisher compliance in marine conservation areas. *Aquatic Conservation: Marine and freshwater ecosystems* **27**:804-813.
- Lee, M. O., S. Otake, and J. K. Kim. 2018. Transition of artificial reefs (ARs) research and its prospects. *Ocean & Coastal Management* **154**:55-65.
- Leitao, F., M. N. Santos, K. Erzini, and C. C. Monteiro. 2008. Fish assemblages and rapid colonization after enlargement of an artificial reef off the Algarve coast (Southern Portugal). *Marine Ecology-an Evolutionary Perspective* **29**:435-448.
- Leslie, H. M., and K. L. McLeod. 2007. Confronting the challenges of implementing marine ecosystem-based management. *Frontiers in Ecology and the Environment* **5**:540-548.
- Lindberg, W. J. 1997. Can science resolve the attraction-production issue? *Fisheries* **22**:10-13.
- Lotze, H. K., H. S. Lenihan, B. J. Bourque, R. H. Bradbury, R. G. Cooke, M. C. Kay, S. M. Kidwell, M. X. Kirby, C. H. Peterson, and J. B. C. Jackson. 2006. Depletion, degradation, and recovery potential of estuaries and coastal seas. *Science* **312**:1806-1809.
- Love, M. S., M. H. Carr, and L. J. Haldorson. 1991. The ecology of substrate-associated juveniles of the genus *Sebastes*. *Environmental Biology of Fishes* **30**:225-243.
- Love, M. S., D. M. Schroeder, W. Lenarz, A. MacCall, A. S. Bull, and L. Thorsteinson. 2006. Potential use of offshore marine structures in rebuilding an overfished rockfish species, bocaccio (*Sebastes paucispinis*). *Fishery Bulletin* **104**:383-390.

- Love, M. S., M. M. Yoklavich, and L. K. Thorsteinson. 2002. The rockfishes of the northeast Pacific. University of California Press, Berkeley.
- Lowe, C. G., K. M. Anthony, E. T. Jarvis, L. F. Bellquist, and M. S. Love. 2009. Site Fidelity and Movement Patterns of Groundfish Associated with Offshore Petroleum Platforms in the Santa Barbara Channel. *Marine and Coastal Fisheries* **1**:71-89.
- Lowry, M. B., T. M. Glasby, C. A. Boys, H. Folpp, I. Suthers, and M. Gregson. 2014. Response of fish communities to the deployment of estuarine artificial reefs for fisheries enhancement. *Fisheries Management and Ecology* **21**:42-56.
- Luckhurst, B. E., and K. Luckhurst. 1978. Analysis of influence of substrate variables on coral-reef fish communities. *Marine Biology* **49**:317-323.
- Markel, R. W., K. E. Lotterhos, and C. L. K. Robinson. 2017. Temporal variability in the environmental and geographic predictors of spatial-recruitment in nearshore rockfishes. *Marine Ecology Progress Series* **574**:97-111.
- Marliave, J., and W. Challenger. 2009. Monitoring and evaluating rockfish conservation areas in British Columbia. *Canadian Journal of Fisheries and Aquatic Sciences* **66**:995-1006.
- Matthews, K. R. 1988. Habitat preference and movement behavior of demersal rockfishes. *American Zoologist* **28**:A81-A81.
- Matthews, K. R. 1990. A comparative-study of habitat use by young-of-the-year, subadult, and adult rockfishes on 4 habitat types in central puget sound. *Fishery Bulletin* **88**:223-239.
- Mayer, L., M. Jakobsson, G. Allen, B. Dorschel, R. Falconer, V. Ferrini, G. Lamarche, H. Snaith, and P. Weatherall. 2018. The Nippon Foundation-GEBCO Seabed 2030 Project: The Quest to See the World's Oceans Completely Mapped by 2030. *Geosciences* **8**:18.
- McCormick, M. I. 1994. Comparison of field methods for measuring surface-topography and their associations with a tropical reef fish assemblage. *Marine Ecology Progress Series* **112**:87-96.

- Mills, K. A., P. A. Hamer, and G. P. Quinn. 2017. Artificial reefs create distinct fish assemblages. *Marine Ecology Progress Series* **585**:155-173.
- Mora, C., O. Aburto-Oropeza, A. A. Bocos, P. M. Ayotte, S. Banks, A. G. Bauman, M. Beger, S. Bessudo, D. J. Booth, E. Brokovich, A. Brooks, P. Chabanet, J. E. Cinner, J. Cortes, J. J. Cruz-Motta, A. C. Magana, E. E. DeMartini, G. J. Edgar, D. A. Feary, S. C. A. Ferse, A. M. Friedlander, K. J. Gaston, C. Gough, N. A. J. Graham, A. Green, H. Guzman, M. Hardt, M. Kulbicki, Y. Letourneur, A. L. Perez, M. Loreau, Y. Loya, C. Martinez, I. Mascarenas-Osorio, T. Morove, M. O. Nadon, Y. Nakamura, G. Paredes, N. V. C. Polunin, M. S. Pratchett, H. R. Bonilla, F. Rivera, E. Sala, S. A. Sandin, G. Soler, R. Stuart-Smith, E. Tessier, D. P. Tittensor, M. Tupper, P. Usseglio, L. Vigliola, L. Wantiez, I. Williams, S. K. Wilson, and F. A. Zapata. 2011. Global Human Footprint on the Linkage between Biodiversity and Ecosystem Functioning in Reef Fishes. *PLoS Biology* **9**:e1000606.
- OWCA. 2018. Annapolis Biodiversity Index Study. Ocean Wise Conservation Association - Vancouver Aquarium.
- Pacunski, R. E., and W. A. Palsson. 2001. Macro-and micro-habitat relationships of adult and sub-adult rockfish, lingcod, and kelp greenling in Puget Sound. *Puget Sound Research* **1**.
- Parsons, D. F., I. M. Suthers, D. O. Cruz, and J. A. Smith. 2016. Effects of habitat on fish abundance and species composition on temperate rocky reefs. *Marine Ecology Progress Series* **561**:155-171.
- Paxton, A. B., E. A. Pickering, A. M. Adler, J. C. Taylor, and C. H. Peterson. 2017. Flat and complex temperate reefs provide similar support for fish: Evidence for a unimodal species-habitat relationship. *PLoS One* **12**:22.
- Perkol-Finkel, S., N. Shashar, O. Barneah, R. Ben-David-Zaslow, U. Oren, T. Reichart, T. Yacobovich, G. Yahel, R. Yahel, and Y. Benayahu. 2005. Fouling reefal communities on artificial reefs: Does age matter? *Biofouling* **21**:127-140.
- Perkol-Finkel, S., N. Shashar, and Y. Benayahu. 2006. Can artificial reefs mimic natural reef communities? The roles of structural features and age. *Marine Environmental Research* **61**:121-135.

- Petrie, M. E., and C. H. Ryer. 2006. Hunger, light level and body size affect refuge use by post-settlement lingcod *Ophiodon elongatus*. *Journal of Fish Biology* **69**:957-969.
- Pickrill, R. A., and B. J. Todd. 2003. The multiple roles of acoustic mapping in integrated ocean management, Canadian Atlantic continental margin. *Ocean & Coastal Management* **46**:601-614.
- Pulliam, H. R. 1988. Sources, sinks, and population regulation. *American Naturalist* **132**:652-661.
- R Core Development Team. 2018. R: A Language and Environment for Statistical Computing. R Studio. R Foundation for Statistical Computing, Vienna, AT.
- Reubens, J. T., U. Braeckman, J. Vanaverbeke, C. Van Colen, S. Degraer, and M. Vincx. 2013. Aggregation at windmill artificial reefs: CPUE of Atlantic cod (*Gadus morhua*) and pouting (*Trisopterus luscus*) at different habitats in the Belgian part of the North Sea. *Fisheries Research* **139**:28-34.
- Richards, L. J. 1986. Depth and habitat distributions of 3 species of rockfish (*Sebastes*) in British-Columbia - observations from the submersible Pisces-iv. *Environmental Biology of Fishes* **17**:13-21.
- Rilov, G., and Y. Benayahu. 2000. Fish assemblage on natural versus vertical artificial reefs: the rehabilitation perspective. *Marine Biology* **136**:931-942.
- Risk, M. J. 1972. Fish diversity on a coral reef in the Virgin Islands. *Atoll Res Bull No.* **153**:1-6.
- Rosen, D., A. Lauermann, and Ieee. 2016. It's All About Your Network: Using ROVs to Assess Marine Protected Area Effectiveness. *Oceans 2016 Mts/Ieee Monterey*:6.
- Sala, E., and N. Knowlton. 2006. Global marine biodiversity trends. *Annual Review of Environment and Resources* **31**:93-122.
- Santos, L. N., E. Garcia-Berthou, A. A. Agostinho, and J. D. Latini. 2011. Fish colonization of artificial reefs in a large Neotropical reservoir: material type and successional changes. *Ecological Applications* **21**:251-262.

- Seaman, W. 2000. **Artificial reef evaluation**: with application to natural marine habitats. CRC Press.
- Seaman, W. 2002. Unifying trends and opportunities in global artificial reef research, including evaluation. *ICES Journal of Marine Science* **59**:S14-S16.
- Sherman, R. L., and R. E. Spieler. 2006. Tires: unstable materials for artificial reef construction. *Environmental Problems in Coastal Regions VI: Including Oil Spill Studies* **88**:215-223.
- Singh, H., C. Roman, O. Pizarro, and R. Eustice. 2007. Advances in high resolution imaging from underwater vehicles. *Robotics Research* **28**:430-+.
- Smiley, B. D., O. O. N. Department of Fisheries and Oceans, and O. O. N. Canadian Science Advisory Secretariat. 2006. The intentional scuttling of surplus and derelict vessels: some effects on marine biota and their habitats in British Columbia waters, 2002. 1499-3848, DFO, Ottawa, ON(Canada).
- Sousa, W. P. 1979. Experimental investigations of disturbance and ecological succession in a rocky inter-tidal algal community. *Ecological Monographs* **49**:227-254.
- Steffen, W., P. J. Crutzen, and J. R. McNeill. 2007. The Anthropocene: Are humans now overwhelming the great forces of nature. *Ambio* **36**:614-621.
- Svane, I., and J. K. Petersen. 2001. On the problems of epibioses, fouling and artificial reefs, a review. *Marine Ecology-Pubblicazioni Della Stazione Zoologica Di Napoli I* **22**:169-188.
- Thrush, S. F., J. E. Hewitt, P. M. J. Herman, and T. Ysebaert. 2005. Multi-scale analysis of species-environment relationships. *Marine Ecology Progress Series* **302**:13-26.
- Tolimieri, N. 2007. Patterns in species richness, species density, and evenness in groundfish assemblages on the continental slope of the US Pacific coast. *Environmental Biology of Fishes* **78**:241-256.
- Trebilco, R., N. K. Dulvy, H. Stewart, and A. K. Salomon. 2015. The role of habitat complexity in shaping the size structure of a temperate reef fish community. *Marine Ecology Progress Series* **532**:197-211.

- Turner, S. J., S. F. Thrush, J. E. Hewitt, V. J. Cummings, and G. Funnell. 1999. Fishing impacts and the degradation or loss of habitat structure. *Fisheries Management and Ecology* **6**:401-420.
- Valentine-Rose, L., A. L. Rypel, and C. A. Layman. 2011. Community secondary production as a measure of ecosystem function: a case study with aquatic ecosystem fragmentation. *Bulletin of Marine Science* **87**:913-937.
- Walbridge, S., N. Slocum, M. Pobuda, and D. J. Wright. 2018. Unified Geomorphological Analysis Workflows with Benthic Terrain Modeler. *Geosciences* **8**:24.
- Walker, S. J., and T. A. Schlacher. 2014. Limited habitat and conservation value of a young artificial reef. *Biodiversity and Conservation* **23**:433-447.
- Warfe, D. M., and L. A. Barmuta. 2004. Habitat structural complexity mediates the foraging success of multiple predator species. *Oecologia* **141**:171-178.
- Watling, L., and E. A. Norse. 1998. Disturbance of the seabed by mobile fishing gear: A comparison to forest clearcutting. *Conservation Biology* **12**:1180-1197.
- West, J. E., R. M. Buckley, and D. C. Doty. 1994. Ecology and habitat use of juvenile rockfishes (*Sebastes* spp) associated with artificial reefs in Puget-Sound, Washington. *Bulletin of Marine Science* **55**:344-350.
- Willis, T. J., and M. J. Anderson. 2003. Structure of cryptic reef fish assemblages: relationships with habitat characteristics and predator density. *Marine Ecology Progress Series* **257**:209-221.
- Wilson, K. D. P., A. W. Y. Leung, and R. Kennish. 2002. Restoration of Hong Kong fisheries through deployment of artificial reefs in marine protected areas. *ICES Journal of Marine Science* **59**:S157-S163.
- Worm, B., E. B. Barbier, N. Beaumont, J. E. Duffy, C. Folke, B. S. Halpern, J. B. C. Jackson, H. K. Lotze, F. Micheli, S. R. Palumbi, E. Sala, K. A. Selkoe, J. J. Stachowicz, and R. Watson. 2006. Impacts of biodiversity loss on ocean ecosystem services. *Science* **314**:787-790.
- Worm, B., R. Hilborn, J. K. Baum, T. A. Branch, J. S. Collie, C. Costello, M. J. Fogarty, E. A. Fulton, J. A. Hutchings, S. Jennings, O. P. Jensen, H. K. Lotze, P. M. Mace,

- T. R. McClanahan, C. Minto, S. R. Palumbi, A. M. Parma, D. Ricard, A. A. Rosenberg, R. Watson, and D. Zeller. 2009. Rebuilding Global Fisheries. *Science* **325**:578-585.
- Yamanaka, K. L., and G. Logan. 2010. Developing British Columbia's Inshore Rockfish Conservation Strategy. *Marine and Coastal Fisheries* **2**:28-46.
- Yamanaka, K. L., K. Picard, K. W. Conway, and R. Flemming. 2012. Rock Reefs of British Columbia, Canada: Inshore Rockfish Habitats. *Seafloor Geomorphology as Benthic Habitat: Geohab Atlas of Seafloor Geomorphic Features and Benthic Habitats*:509-522.
- Yanagi, T., and M. Nakajima. 1991. Change of oceanic condition by the man-made structure for upwelling. *Marine Pollution Bulletin* **23**:131-135.
- Yeager, L. A., C. A. Layman, and J. E. Allgeier. 2011. Effects of habitat heterogeneity at multiple spatial scales on fish community assembly. *Oecologia* **167**:157-168.
- Yoklavich, M., G. Cailliet, R. N. Lea, H. G. Greene, R. Starr, J. De Marignac, and J. Field. 2002. Deepwater habitat and fish resources associated with the Big Creek Marine Ecological Reserve. *California Cooperative Oceanic Fisheries Investigations Reports* **43**:120-140.
- Yoklavich, M. M., H. G. Greene, G. M. Cailliet, D. E. Sullivan, R. N. Lea, and M. S. Love. 2000. Habitat associations of deep-water rockfishes in a submarine canyon: an example of a natural refuge. *Fishery Bulletin* **98**:625-641.
- Zintzen, V., M. J. Anderson, C. D. Roberts, E. S. Harvey, A. L. Stewart, and C. D. Struthers. 2012. Diversity and Composition of Demersal Fishes along a Depth Gradient Assessed by Baited Remote Underwater Stereo-Video. *PLoS One* **7**:14.
- Zuur, A. F., E. N. Ieno, and C. S. Elphick. 2010. A protocol for data exploration to avoid common statistical problems. *Methods in Ecology and Evolution* **1**:3-14.

Appendix A

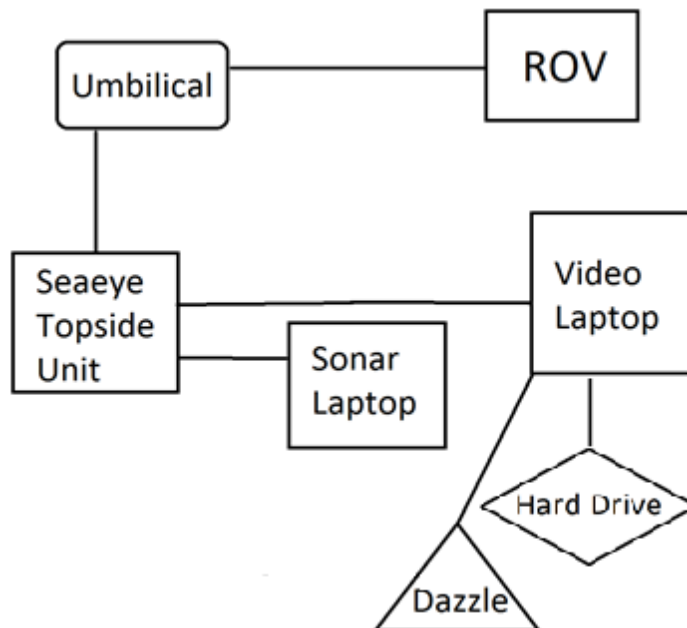


Figure A.1 Technology setup for recording data using a Saab Seaeeye Falcon ROV, Imagenex Sonar, and topside recording equipment during surveys in Fall 2017.

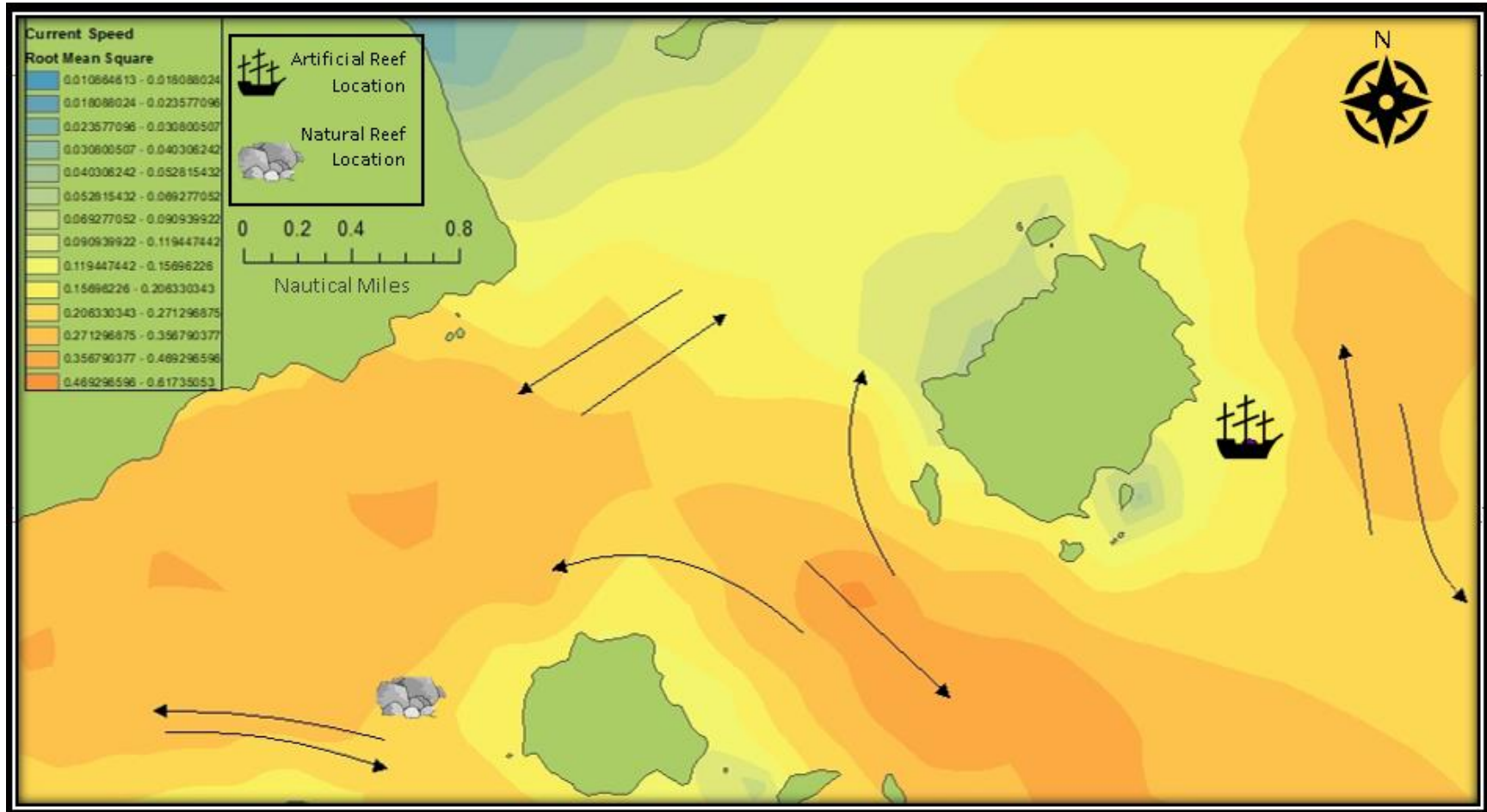


Figure A.2 Example of current mapping around the GB Church Wreck and the corresponding natural reef, located near Sidney, BC. Arrows denote direction of dominant current, shading indicates current strength.

Table A.1 Artificial Reef Site Characteristics, located between Vancouver Island and mainland British Columbia Canada

Reef_Name	Latitude	Longitude	Age(yrs)	Length (m)	Material
M.V. G.B. Church - coastal freighter	48.72205	-123.35565	26.8	15	Steel
HMCS Mackenzie - navy destroyer	48.668233	-123.286167	22.3	111.5	Steel
HMCS Columbia - navy destroyer	50.13385	-125.335833	21.3	111.5	Steel
HMCS Saskatchewan - navy destroyer	49.216	-123.8845	20.3	111.5	Steel
HMCS Cape Breton - Navy Liberty ship	49.211667	-123.885833	16	134.7	Steel
Boeing 737	48.9357	-123.718317	11.7	30	Aluminum
Annapolis	49.449117	-123.330433	2.5	113	Steel
Wreck of Shamrock (Vivian Island)	49.84	-124.700167	90.8	23.2	Steel/Iron
Wreck of the Capilano	49.870267	-124.816117	102	37.2	Steel

Table A.2 Total groundfish counts and species observed across nine artificial and nine natural reefs along the south coast of British Columbia.

Phylum	Genus	Species	Common Name	Total Fish Observed	
				AR	NR
Chordata					
Class Actinopterygii					
Order Scorpaeniformes					
	<i>Hexagrammos</i>	<i>H. decagrammus</i>	Kelp Greenling	9	58
		<i>H. stelleri</i>	Whitespotted Greenling	0	1
	<i>Ophiodon</i>	<i>O. elongatus</i>	Lingcod	75	40
	<i>Oxylebius</i>	<i>O. pictus</i>	Painted Greenling	1	2
	<i>Scorpaenichthys</i>	<i>S. marmoratus</i>	Cabezon	1	0
	<i>Sebastes</i>		Rockfish	25	42
		<i>S. auriculatus</i>	Brown Rockfish	2	20
		<i>S. caurinus</i>	Copper Rockfish	254	191
		<i>S. emphaeus</i>	Puget Sound Rockfish	65	3
		<i>S. flavidus</i>	Yellowtail Rockfish	68	149
		<i>S. maliger</i>	Quillback Rockfish	664	234
		<i>S. nigrocinctus</i>	Tiger Rockfish	0	7
		<i>S. ruberrimus</i>	Yelloweye Rockfish	5	1
Order Chimaeriformes	<i>Hydrolagus</i>	<i>H. collicii</i>	Spotted Ratfish	0	3

Table A.3

Surrounding habitat characteristics at each reef, recorded for modelling exercises to understand how site location influences groundfish abundance and diversity.

Site	SuitableHabitat (0-1)	MaxCurrent (m/s)	RCA (1=yes, 0=no)	RCADist (m)
Annapolis	0.38	0.05	0	3964.7
Arbutus	0.25	0.5	0	3187.8
Atrevida	0.31	0.2	0	693.4
BarePoint	0.28	0.1	0	306.6
Boeing	0.19	0.1	0	868.4
Bowyer	0.61	0.05	1	0
CapeBreton	0.22	0.09	1	0
Capilano	0.41	0.2	0	9627.3
Columbia	0.06	1.8	1	0
CopperCliffs	0.03	1.8	0	2654.6
GBChurch	0.02	0.5	1	0
Graham	0.1	0.8	1	0
Jesse	0.04	0.09	0	131
Mackenzie	0.29	0.8	1	0
Mystery	0.41	0.2	0	2635.1
Saskatchewan	0.23	0.09	0	144.8
Shamrock	0.28	0.2	0	8398.2
WestSnake	0.26	0.09	0	97.9

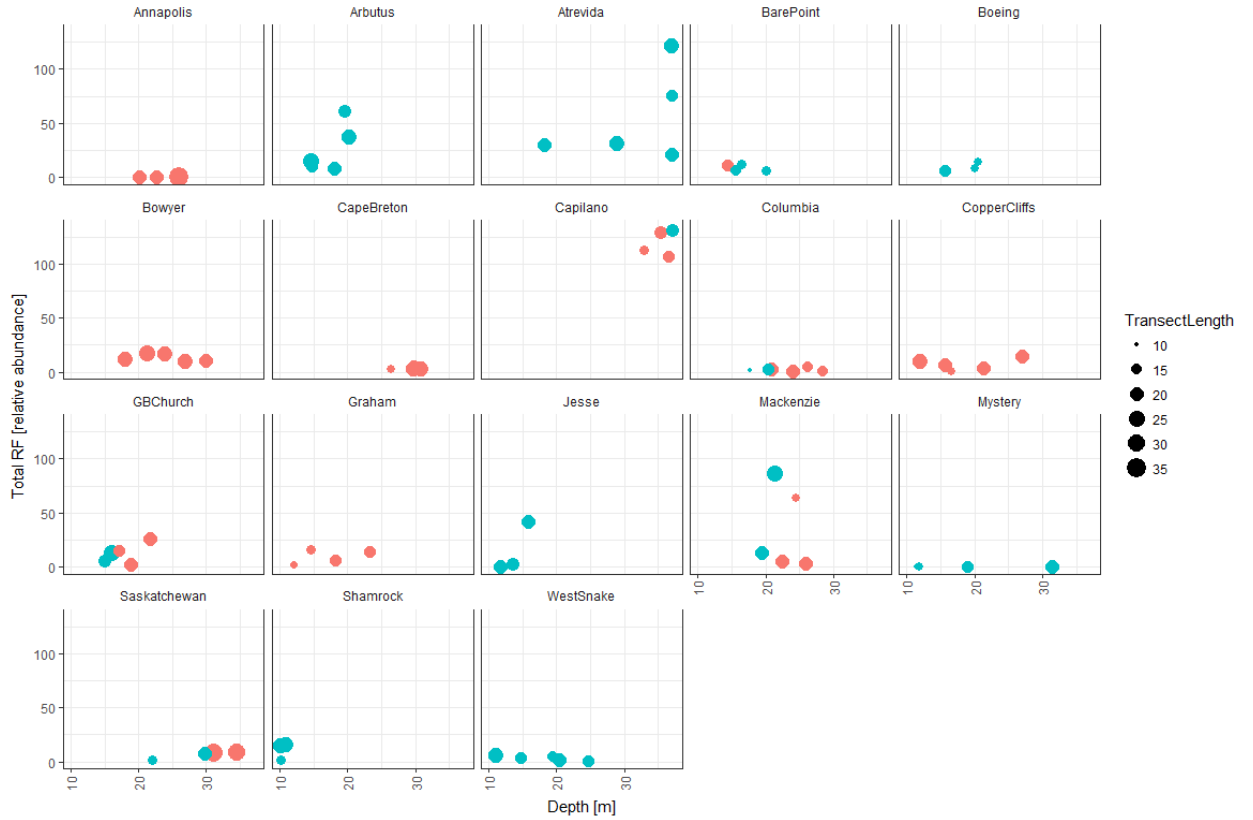


Figure A.3 : Total number of rockfish observed in each transect across sites and depth and relief. Size of point indicates length of transect (offset). Blue = high relief, Red = low relief.

Table A. 4- Table A.5: Competing model sets of variables that may influence rockfish abundance or species richness.

Response Variable	Variable Block	Rockfish abundance is influenced by:
Total Rockfish Abundance	Global	ReefType + Depth + Relief + MaxCurrent + SuitableHabitat + RCA/ RCADist
	Local Habitat	Depth + Relief
	Reef Type	ReefType
	Surrounding Habitat	MaxCurrent + SuitableHabitat
	Conservation Status	RCA/RCADist
	No local habitat	MaxCurrent + SuitableHabitat + RCA/ RCADist
	No surrounding habitat	ReefType + Depth + Relief + RCA/ RCADist
	No RCA	ReefType + Depth + Relief + MaxCurrent + SuitableHabitat
	No Reef Type	Depth + Relief + MaxCurrent + SuitableHabitat + RCA/ RCADist

Response Variable	Variable Block	Groundfish species richness is influenced by:
Total Groundfish Species Richness	Global	ReefType + Depth + Relief + MaxCurrent + SuitableHabitat + RCA/ RCADist
	Local Habitat	Depth + Relief
	Reef Type	ReefType
	Surrounding Habitat	MaxCurrent + SuitableHabitat
	Conservation Status	RCA/RCADist
	No local habitat	MaxCurrent + SuitableHabitat + RCA/ RCADist
	No surrounding habitat	ReefType + Depth + Relief + RCA/ RCADist
	No RCA	ReefType + Depth + Relief + MaxCurrent + SuitableHabitat
	No Reef Type	Depth + Relief + MaxCurrent + SuitableHabitat + RCA/ RCADist

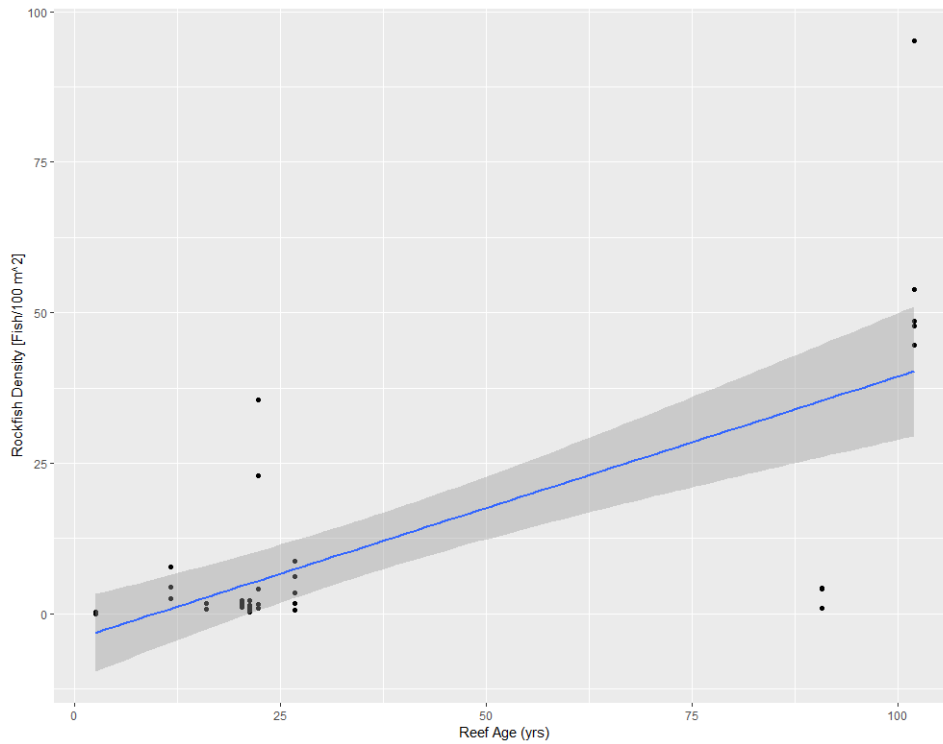


Figure A.4: Positive trend between rockfish density and reef age, possibly responsible for variation in AR abundance, buffers are 95% confidence interval

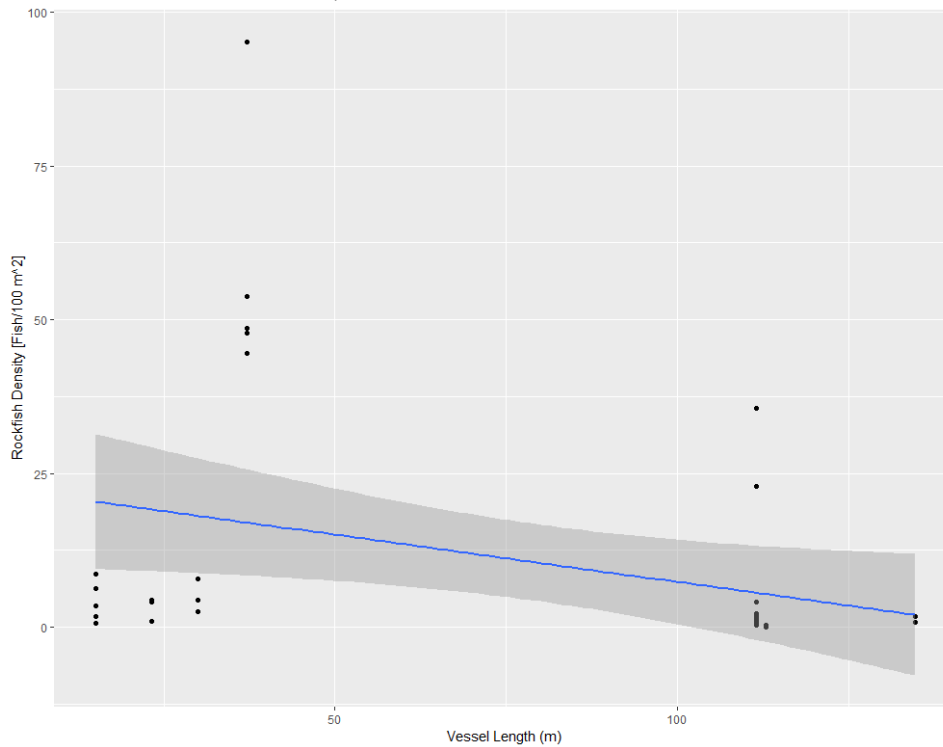
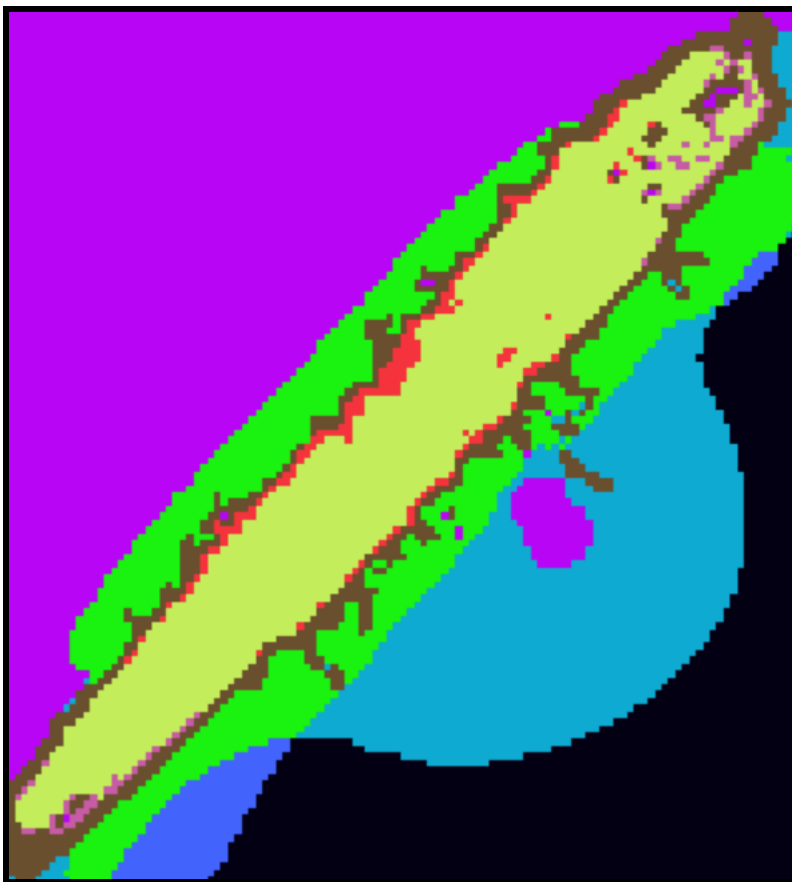


Figure A.5: Negative trend between rockfish density and vessel length, possibly responsible for variation in AR abundance, buffers are 95% confidence interval

Appendix B



ZONE

- None
- Reef Crest
- Mid-Slope Ridges
- Lower Bank Shelf
- Upper Reef Flat
- Open Slopes
- Depression
- Back Reef
- Deep Depression

Figure B.1 Example of potential methods for qualitative analysis of artificial reefs. The Annapolis artificial reef located in Howe Sound, British Columbia, classified using natural reef parameters (map created using the benthic terrain modeler toolbox in ArcGIS).

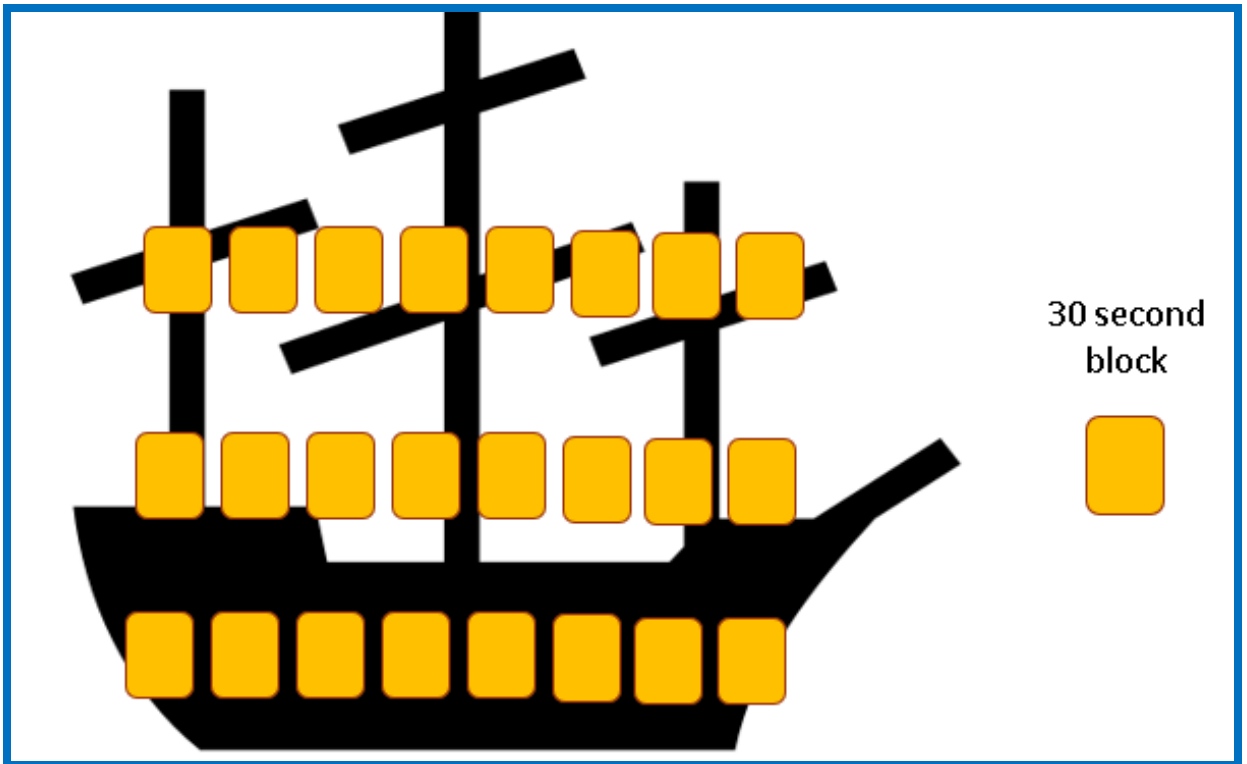


Figure B.2 I employed a stratified systematic sampling design to ensure a balanced sample of depths. Video was annotated and aggregated to 30 second intervals to ensure independence between samples.

Table B.1: Artificial Reef Site Characteristics, shaded cells were excluded from final analysis.

Reef_Name	Latitude	Longitude	Age(yrs)	Length (m)	Material
M.V. G.B. Church - coastal freighter	48.72205	-123.35565	26.8	15	Steel
HMCS Mackenzie - navy destroyer	48.668233	-123.286167	22.3	111.5	Steel
HMCS Columbia - navy destroyer	50.13385	-125.335833	21.3	111.5	Steel
HMCS Saskatchewan - navy destroyer	49.216	-123.8845	20.3	111.5	Steel
HMCS Cape Breton - Navy Liberty ship	49.211667	-123.885833	16	134.7	Steel
Annapolis	49.449117	-123.330433	2.5	113	Steel
Boeing 737	48.9357	-123.718317	11.7	30	Aluminum
Wreck of Shamrock (Vivian Island)	49.84	-124.700167	90.8	23.2	Steel/Iron
Wreck of the Capilano	49.870267	-124.816117	102	37.2	Steel

Table B.2: Total groundfish counts and species observed across nine artificial reefs along the south coast of British Columbia.

Phylum	Genus	Species	Common Name	Total Fish Observed	
				Across Surveyed ARs	ARs In final analysis
Chordata					
Class					
Actinopterygii					
Order					
Scorpaeniformes					
	<i>Hexagrammos</i>				
		<i>H. decagrammus</i>	Kelp Greenling	9	4
		<i>H. stelleri</i>	Whitespotted Greenling	0	0
	<i>Ophiodon</i>				
		<i>O. elongatus</i>	Lingcod	75	11
	<i>Oxylebius</i>				
		<i>O. pictus</i>	Painted Greenling	1	0
	<i>Scorpaenichthys</i>				
		<i>S. marmoratus</i>	Cabezón	1	1
	<i>Sebastes</i>		Rockfish	25	2
		<i>S. auriculatus</i>	Brown Rockfish	2	0
		<i>S. caurinus</i>	Copper Rockfish	254	135
		<i>S. emphaeus</i>	Puget Sound Rockfish	65	65
		<i>S. flavidus</i>	Yellowtail Rockfish	68	7
		<i>S. maliger</i>	Quillback Rockfish	664	75

Order Chimaeriformes	<i>Hydrolagus</i>	<i>S. nigrocinctus</i>	Tiger Rockfish	0	0
		<i>S. ruberrimus</i>	Yelloweye Rockfish	5	3
		<i>H. colliei</i>	Spotted Ratfish	0	0

Table B.3: Spatial habitat characteristics at each reef, recorded for modelling exercises to understand how site location influences groundfish abundance and diversity.

Site	SuitableHabitat (0-1)	MaxCurrent (m/s)	RCA (1=yes, 0=no)
Annapolis	0.38	0.05	0
Boeing	0.19	0.1	0
CapeBreton	0.22	0.09	1
Capilano	0.41	0.2	0
Columbia	0.06	1.8	1
GBChurch	0.02	0.5	1
Mackenzie	0.29	0.8	1
Saskatchewan	0.23	0.09	0
Shamrock	0.28	0.2	0