AN ABSTRACT OF THE THESIS OF

Ryan Reid Easton for the degree of Master of Science in Marine Resource Management presented on November 30, 2012
Title: Video on the Rocks: Use of a Video Lander Platform as a Survey Tool for a High-relief Nearshore Temperate Rocky Reef

Abstract approved:

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The nearshore waters off the Oregon coast (< 73 meters) are a region of high productivity and economic value, with a variety of habitats that include rock outcrops. Temperate reef habitats are important to many commercially important fishes inhabiting the Pacific coast, including canary rockfish (*Sebastes pinniger*) and yelloweye rockfish (*Sebastes ruberrimus*), which are currently listed as "overfished" by the Pacific Fishery Management Council. Along the Pacific coast of North America, nearshore rocky reefs have been designated as essential fish habitat (EFH), while comprising approximately just seven percent of Oregon's territorial sea. Despite this EFH designation, the use of visual (SCUBA, remotely operated vehicles (ROVs), human occupied vehicles (HOVs)) and non-visual (bottom trawl) survey methods within this region has been infrequent and scattered, providing limited information on species-habitat associations and species assemblages within nearshore waters. It is logistically difficult and costly to survey nearshore reefs. The factors that have led to the paucity of surveys include the depth (too deep for SCUBA surveys but too shallow for larger survey vessels), high seas limiting available days for field work, and the high-relief nature of the habitat (precluding the use of bottom trawls).

In an effort to better understand species-habitat associations and community structure of Oregon's nearshore reefs, an autonomous underwater drop-camera termed the "video lander" was employed at the Three Arch Rocks reef, a nearshore reef off of Oceanside, Oregon. Video lander footage was used to identify and groundtruth habitat types, as well as species assemblages over two distinct seasons: spring/summer ($n=272$) and winter ($n=108$). Many species-habitat associations were statistically significant: yelloweye rockfish (large boulder $p<0.0073$), canary rockfish (small boulder $p<0.0006$), kelp greenling (*Hexagrammos decagrammus*) (bedrock outcrop $p<0.0162$), and quillback rockfish (*Sebastes maliger*) (large boulder $p<0.0016$). Summer and winter surveys revealed similar habitat associations and distributions for these species.

I found no significant difference in species composition between the northern and southern regions of the reef (Bray-Curtis dissimilarity index (BCDI) = 71.71, ANOSIM $p>0.1447$), but a significant difference between spring/summer and winter seasons was identified on the outer section of the reef, due to the presence of spotted ratfish (*Hydrolagus colliei*) in the winter (BCDI =76.41, ANOSIM $p < 0.0155$). My study shows that data provided by the video lander can fill existing gaps in our understanding of nearshore distribution and habitat associations of temperate rocky-reef fishes off the Oregon coast.

Video on the Rocks: Use of a Video Lander Platform as a Survey Tool for a High-relief Nearshore Temperate Rocky Reef

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Ryan Reid Easton, Author

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

Page

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF APPENDIX FIGURES

In loving memory of Stephanie Quinn Easton

Video on the Rocks: Use of a Video Lander Platform as a Survey Tool for a High-relief Nearshore Temperate Rocky Reef

Chapter 1: General Introduction

Oregon's nearshore rocky reef habitat

The nearshore coastal waters off Oregon (< 73 meters), which lie within the California Current Large Marine Ecosystem, are highly productive and economically valuable (Schwing et al. 1996, Hickey & Banas 2003, ODFW-MRP 2006, Gunderson et al. 2008). The rocky reefs in this region are home to many species of demersal and pelagic fishes that are of commercial and recreational importance (Starr et al. 1996, Williams & Ralston 2002, Johnson et al. 2003, Parker et al. 2006). However, these nearshore reefs comprise only a relatively small fraction of the Oregon territorial sea (within three miles of the shoreline), approximately seven percent, with the remainder of these regions composed generally of areas of sandy and unconsolidated sediment (ODFW 2012b).

Oregon's submerged reefs represent the majority of the currently recognized nearshore habitat for local populations of temperate rocky reef fishes, including many species of Pacific rockfish (*Sebastes* spp.), lingcod (*Ophiodon elongatus*), kelp greenling (*Hexagrammos decagrammus*) and cabezon (*Scorpaenichthys marmoratus*) (PFMC 2011). This patchy network of reefs along the nearshore Pacific coast has been designated as Essential Fish Habitat (EFH) for many nearshore pelagic and demersal fishes currently managed by the Pacific Fishery Management Council

(PFMC) (PFMC 2005, PFMC 2011). EFH, as defined by the Magnuson-Stevens Fishery Conservation and Management Act (1996, 2007), is ‘those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity” (U.S. Department of Commerce 1996). However, despite the EFH designation of these nearshore waters and the habitat within them, we know relatively little about their function and the fine-scale habitat associations of the fish that utilize them (Gunderson et al. 2008). It is logistically difficult and costly to survey nearshore reefs; factors that have led to the paucity of surveys include the depth (too deep for SCUBA surveys but too shallow for larger survey vessels) and the high-relief nature (inappropriate for bottom trawls) of the habitat (Johnson et al. 2003).

Species-habitat associations, distributions, and fish assemblage compositions are three of the primary factors influencing the designation of EFH for many nearshore reef species. Additionally, hard-bottom habitat has been described by the Groundfish Essential Fish Habitat Review Committee for PFMC as being one of the least abundant, yet most important benthic habitats for groundfish (PFMC 2012). Previous studies have demonstrated the higher importance of both rock and high relief habitat, in comparison with sandy habitat, to many Pacific rocky-reef species (O'Connell & Carlile 1993, Love et al. 2006). Despite this, minimal information is currently available regarding the habitat associations and distributions for many rocky-reef species which would aid in refining our understanding of fish associations with designated EFH, with the vast majority of this research occurring outside of Oregon waters (Carlson & Straty 1981, Johnson et al. 2003, Martin et al. 2006, Rooper et al. 2010).

Many Pacific rockfish species, and other nearshore fishes, that have been fished for many years by both commercial and recreational fisherman are present on various portions of nearshore rocky reef complexes. Many Pacific rockfishes, which generally comprise the largest portion of the nearshore species assemblage, are characterized as being long lived, slow growing, and late maturing (Love et al. 2002). The maximum ages of some of these species include 121years for yelloweye rockfish (*Sebastes ruberrimus*), 92yrs. for quillback rockfish (*Sebastes maliger*), and 84yrs. for canary rockfish (*Sebastes pinnniger*) (Munk 2001, Munk 2012). Despite the importance of nearshore reefs to many of these temperate fishes, limited research has been directed towards the nearshore reefs off the Oregon coast. Many of these species (*i.e.* copper rockfish (*Sebastes caurinus*), quillback rockfish, and China rockfish (*Sebastes nebulosus*)) remain poorly understood with regards to their individual habitat associations, distribution across nearshore reef structures, and relative abundance in the nearshore. These characteristics make Pacific rockfish species susceptible to overfishing and challenging to recover from severe depletion (Berkeley et al. 2004, Grove & Shull 2008, Magnuson-Ford et al. 2009).

The lack of ample fishery-independent data for these nearshore species is primarily due to the high financial and logistical costs associated with current survey methods (visual surveys are expensive and complex while bottom-trawl surveys avoid high-relief rocky reefs due to the potential loss or destruction of gear) (Johnson et al.

2003, Hannah & Blume 2012). The limitations of fishery-independent data sources for nearshore species highlight the need for a tool which can survey high-relief nearshore rocky-reefs and gather information on species presence and habitat type.

Current survey methods

Fisheries resource managers and stock assessors currently utilize data-rich survey methods, such as bottom-trawl and acoustic surveys, for management and assessment purposes, because of their large spatial coverage. These methods include; the National Oceanic and Atmospheric Administration National Marine Fisheries Service (NOAA/NMFS) West Coast Bottom Trawl surveys and acoustic Pacific whiting survey, state commercial and recreational catch data, and the International Pacific Halibut Commission's (IPHC) Pacific halibut longline survey. While these data sources are quite extensive in both space and time, they primarily provide information on relative abundance, not the species-habitat associations that are needed for marine spatial planning (Adams et al. 1995, Williams & Ralston 2002, Zimmermann 2003, Yoklavich et al. 2007). Additionally, the inability to trawl in high-relief rocky habitat, due to loss and destruction of trawl gear, has potentially led to the underestimation of population biomass and distribution for key demersal species such as yelloweye rockfish (Krieger 1993, Jagielo et al. 2003).

Furthermore, commercial and recreational catch data can be of limited use for many of the nearshore Pacific rocky reef species because many of the demersal species are only a small component of total catches (*i.e.* quillback rockfish, china rockfish, tiger rockfish (*Sebastes nigrocinctus*)). Likewise, catch restrictions for some species have introduced management challenges from a data perspective in that they have reduced or removed large scale commercial and recreational catch information records from the assessment process (Wallace 2001, Gunderson et al. 2008).

While deeper rock habitats of northeastern Pacific waters have been surveyed with visual techniques including human occupied vehicles (HOVs), and remotely operated and autonomous underwater vehicles (ROVs and AUVs), these surveys have tended to be sporadic, limited in scope, and designed for research objectives that are not directly related to fisheries management (Pearcy et al. 1989, Johnson et al. 2003, Laidig et al. 2009). The low frequency of these survey methods can largely be attributed to perceived high technological and logistical costs, as large crews of support staff and larger survey vessels are often required for operation and deployment (Adams et al. 1995, Starr et al. 1996, Roberts et al. 2005, Pacunski et al. 2008). These types of non-extractive, fishery-independent surveys can be more comprehensive than bottom-trawl surveys, because they are able to maneuver around rocky habitat that is deliberately avoided by trawlers (Pearcy et al. 1989, Adams et al. 1995, Ellis & DeMartini 1995, Yoklavich et al. 2002, Johnson et al. 2003, Yoklavich et al. 2007, Grove & Shull 2008, Williams et al. 2010). However, the high costs of these visual survey techniques, as well as their limited area covered, have steered fisheries managers and stock assessors towards the more data rich methods mentioned above.

The video lander

The video lander, an autonomous underwater video camera system developed by the Oregon Department of Fish and Wildlife's (ODFW) Marine Resource Program (MRP), was selected for evaluation as a potential tool to fill in data gaps which exist for nearshore rocky reef fishes (Hannah & Blume 2012). The video lander is a non-extractive, non-destructive to habitat, fishery-independent video survey device designed explicitly for deployment on deep high-relief rocky habitat. Both video and still-photo landers have previously been shown to be an effective tool for surveying rocky-reef fishes, as have baited and stereo video landers (Gledhill et al. 1996, Willis & Babcock 2000, Willis et al. 2000, Roberts et al. 2005, Cappo et al. 2006, Harvey et al. 2007). The video lander employed for this survey was a non-baited, standard-definition, single camera unit, designed not to intentionally attract fish to its location. This configuration was chosen because a main objective of this study was to describe species-habitat associations, which could be biased with a baited lander.

This methodology has multiple advantages over ROVs and HOVs, including a lower cost to assemble and maintain (the video lander costs approximately $10,000 USD to assemble as opposed to ROV's which can be upwards of $100,000 USD), and to deploy (Hannah & Blume 2012). The video lander operates remotely, with no umbilical or attachment to the vessel, and is deployed and retrieved much like a commercial crab pot. The lack of an umbilical enables rapid deployment and retrieval, giving it the ease of repeated intensive use that is lacking in other survey methods such as ROVs and HOVs which have more complex operational methods. This allows a relatively large area to be surveyed each day, over a wide depth range which would restrict or prohibit SCUBA surveys, while doing it at a fraction of the cost of an ROV or HOV survey. Additionally, the video lander has the capability to ground-truth habitat types in areas that have been geophysically mapped, increasing the utility of these seafloor images.

The video lander also allows for greater ease of use and deployment, requiring fewer field personnel to operate and handle, providing the ability to survey large areas quickly and inexpensively. The primary limitation of the video lander is the small amount of habitat viewed in any single deployment, requiring it to be used across a distributed grid of stations.

The video lander platform has recently been illustrated as a dependable survey tool able to: identify demersal rockfish species in their natural habitat, describe the benthic habitat on which the fish are located, and perform consistently over a wide range of ocean conditions (Hannah & Blume 2012). Video landers have been successfully deployed in Oregon's nearshore and waters over 110 meters; however the work in shallow temperate reef areas has been primarily exploratory, with more intensive and comprehensive surveys occurring in deeper waters.

Aims and hypotheses

While some information has been collected on the large scale distribution and life history of multiple species of Pacific rocky reef fishes, less is known of the distribution and fine-scale habitat associations in both space and time. The objective of this study was to describe fine-scale species-habitat associations of nearshore

Pacific rocky reef fishes, and estimate composition and distribution across a nearshore rocky-reef through a comprehensive grid-based survey in both spring and winter months.

The Three Arch Rocks rocky reef complex located off of Oceanside, Oregon was chosen as the study site for its known diversity of nearshore reef species, wide range of depth and habitat types, and value in regional commercial and recreational fisheries. An additional objective was to further evaluate the video lander as a nearshore rocky reef survey tool for fishery managers studying nearshore rocky reef fish assemblages and distribution to investigate possible seasonal differences between spring and winter (Chapter 2). The third chapter of this thesis is devoted to my personal observations and recommendations for using the video lander as a survey tool.

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Chapter 2: Video lander data reveals fish assemblage patterns on a nearshore temperate reef

Introduction

Temperate nearshore rocky-reefs provide essential fish habitat for dozens of fish species along the Pacific coast of North America, including rockfishes, lingcod, kelp greenling and cabezon (PFMC 2005, Love et al. 2006, PFMC 2011). These marine fishes are valuable economic resources for commercial and recreational fisherman as well as regional native tribes (Williams & Ralston 2002, Fox et al. 2004, ODFW-MRP 2006, Gunderson et al. 2008). However, monitoring fisheries resources and habitat in temperate reefs is difficult, due to their high relief structural complexity and the depth (Adams et al. 1995, Williams et al. 2010). Annual trawl surveys currently cover the continental shelf from Cape Flattery, Washington to the U.S. – Mexico border, but this survey method is unable to adequately catch fish that typically reside among rock escarpments and boulders (Zimmermann 2003, Cordue 2007). There have been repeated calls for more comprehensive sampling, particularly for reef-associated species that are considered to be below or near overfishing thresholds (Yoklavich et al. 2007, Williams et al. 2010).

Nearshore rocky-reefs within Oregon's territorial sea make up only a small fraction of the total area, approximately seven percent, with the remaining area comprised of sand and unconsolidated sediments (ODFW 2012b). The reefs constitute much of the Essential Fish Habitat[1] (EFH) designated for many pelagic and demersal fishes which currently inhabit the nearshore region (PFMC 2005, PFMC 2011). EFH as defined by the Magnuson-Stevens Fishery Conservation and Management Act (1996, 2007), is 'those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity" (U.S. Department of Commerce 1996). It is an essential requirement of any fishery management plan (FMP) to identify the EFH for each life stage of each species, and as of 2002 maps of the EFH must also be contained in the plan. However, we still have little understanding of the species assemblage patterns on temperate reefs at different times of year and along depth gradients. More information is needed on how the reefs function as critical habitat and the fine-scale habitat associations of the fish that utilize them (Gunderson et al. 2008).

Visual survey tools such as remotely operated vehicles (ROVs) and human occupied vehicles (HOVs) are useful to survey untrawlable rocky habitats. These methods collect valuable information regarding the distribution, abundance, and species-habitat associations of various fish species, further aiding EFH designation (Stein et al. 1992, Krieger 1993, Adams et al. 1995, Johnson et al. 2003, Yoklavich et al. 2007).

In Oregon waters, high seas through much of the year restrict comprehensive sampling of nearshore temperate reef fishes with visual survey tools like ROVs and HOVs. Mean monthly "significant wave heights" off the coast of Oregon and

[1] http://www.habitat.noaa.gov/protection/efh/index.html

Washington, as measured by NOAA's National Data Buoy Center (NDBC) and the Coastal Data Information Program (CDIP) operated by the Scripps Institution of Oceanography, show that wave heights peak in November through February, with a minimum from July to August (Elson, Tillotson & Komar 1997, Allan & Komar 2000, Bromirski et al. 2005). Thus, much of the research conducted along the Pacific coast of North America takes place between spring and fall during the summer upwelling season, when weather and ocean conditions are most amenable to at-sea research and before the onset of the strong winter storm season (Fox & Davis 1978, Parker et al. 2007). Sampling for abundance and community composition only in summer months could be problematic due to seasonal distribution shifts, particularly by fishes that spawn in winter months (Love et al. 2002). However, fewer days of acceptable sea conditions available to safely survey the nearshore for any extended period has led to a lack of visual surveys performed during the winter months, resulting in little available information on underwater visibility during the winter.

These highly variable and changing conditions represent obstacles to those researchers who are looking to obtain non-extractive visual data on nearshore Pacific rocky-reef fishes. Video landers of varying designs have previously been employed as non-extractive, non-habitat altering methodologies for estimating fish abundance and distribution. Baited underwater video (BUV) and baited remote underwater video (BRUV) stations have shown to be effective in estimating the relative abundance of many fish which are mobile, solitary, have low population sizes, or avoid other visual survey methods (Ellis & DeMartini 1995, Priede & Merrett 1996, Willis & Babcock

2000, Cappo et al. 2004, Harvey et al. 2007, Stobart et al. 2007). Non-baited underwater photo and video lander platforms on the other hand offer a tractable alternative to conventional extractive fishery survey methods and have been effective in capturing accurate and repeatable fish and habitat data throughout a wide range of depths and habitat types without artificially attracting fish with bait (Gledhill et al. 1996, Roberts et al. 2005, Hannah & Blume 2012).

Limited video lander work has been performed in the northeast Pacific within shallow (< 70 meters), highly productive nearshore waters where underwater visibility may be lower and more variable. Deployment of ROV and HOV tools is difficult and expensive in these areas, but sampling is needed to ground-truth habitat maps and determine the abundance and status of Oregon's nearshore fisheries resources. This study was designed to test a simple video lander platform designed for use on temperate high-relief rocky-reefs to evaluate species-habitat associations and species compositions over various habitats and depths in spring and winter months.

The objectives of this research were multifaceted: to explore the species assemblage, distribution and habitat associations of nearshore Pacific rocky reef fishes in different seasons, to describe the distribution of key fished species, including two overfished rockfishes that are under intensive "stock rebuilding plans", and to see if the video lander can be used to identify habitat types that are currently used by multibeam sonar surveys. As part of this study I tested a hypothesis, based on fisherman's knowledge concerning the distribution of fishes on a rocky reef off Oregon, that the southern region of the reef would differ significantly from the northern region in species composition and abundance, a primary objective of this research was to investigate this assumption. To accomplish this, the video lander was employed to survey an Oregon nearshore rocky-reef complex that is of interest to the state management agency (Oregon Department of Fish and Wildlife) and community resource teams for its potential as a marine reserve or protected area[2].

Materials and Methods

Video lander design

The video lander, an autonomous underwater video system developed by the Oregon Department of Fish and Wildlife's Marine Resources Program (Hannah & Blume 2012), was designed and built for use in high-relief rocky habitat. It is composed of an aluminum tube frame, a Deep Sea Power and Light Multi-SeaCam® 2060 and dual LED RiteLites™, an aluminum pressure housing containing; batteries, controller board, a Sony TRV-11camcorder, all activated by a depth-activated pressure switch for waters deeper than 18 meters, and a push activated switch for shallower depths (Figure 1). The entire lander frame is attached to a sacrificial base made of bent steel rod resembling a commercial crab trap and secured with cable ties on the feet of the lander. The sacrificial base is designed so that, if stuck in rocky habitat, the lander can release from the base and rotate around multiple attachment points to maximize retrieval probability in high-relief rocky habitat (Figure 1).

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[2] www.oregonocean.info

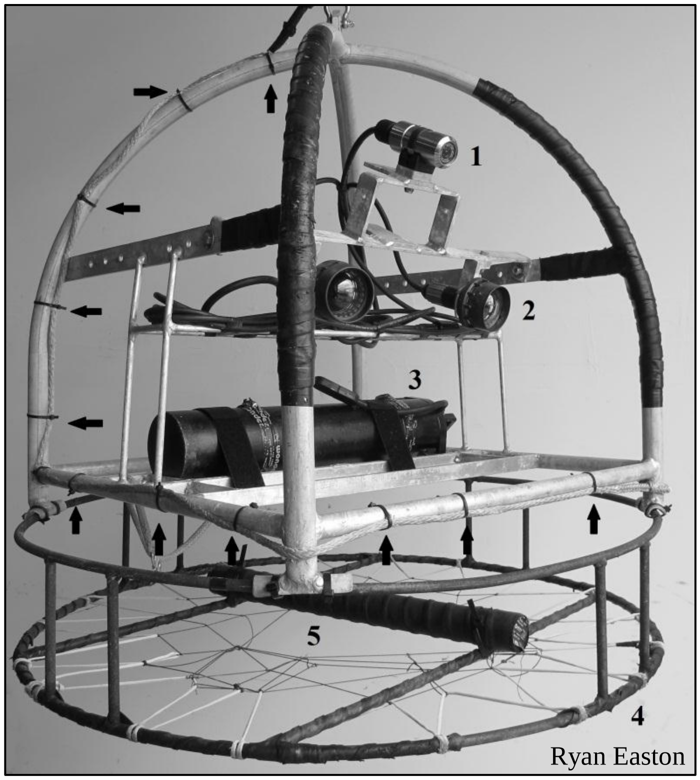

Figure 1. The video lander platform. Displayed in the photo are the (1) camera, (2) lights, (3) pressure tube containing batteries and recorder, (4) sacrificial (breakaway) base, (5) steel-rod weight bar, and arrows showing break-away connection points.

The objective of this survey was to investigate species-habitat associations and species composition, not to attract fish to the lander from distant and potentially different habitats (Stobart 2007). Baited underwater video landers (BUVs) and baited remote underwater video stations (BRUVS) have shown an ability to assess relative abundance of fish species which are in low density or are reclusive; however these platforms are of little use in assessing species-habitat associations as they draw fish in from a distance (Willis & Babcock 2000, Willis et al. 2000, Cappo et al. 2006, Harvey et al. 2007, Sivaguru 2007, Stobart et al. 2007). Our survey did not include bait, and the video lander was deployed for a fixed duration (five minutes) at each sampling location following Hannah and Blume 2012.

Study site

The reef complex selected for this study was Three Arch Rocks rocky reef, located off Oceanside, Oregon approximately 11 kilometers south of the Tillamook Bay bar. The nearshore rocky reef structure closest to shore is the submerged region of the 15 acre Three Arch Rocks National Wildlife Refuge (composed of nine exposed rock outcrops)[3]. It is part of the Oregon Islands National Wildlife Refuge, and the oldest refuge of its kind in the western U.S., having been established in 1907 (OPAC 1994, ODFW-MRP 2006). The structure of the reef is a horseshoe pattern, running approximately five kilometers east/west, and two kilometers north/south (Figure 3). Three Arch Rocks reef has a broad depth range to ~75 meters as it runs east to west, and is known to support a high diversity of marine species (ODFW 2011). The availability of previously developed habitat maps of the region, created from previously collected multibeam sonar surveys provided increased insight into the structure and layout of the reef, aiding the development and planning of the video lander survey design.

[3] http://www.fws.gov/oregoncoast/3archrocks/

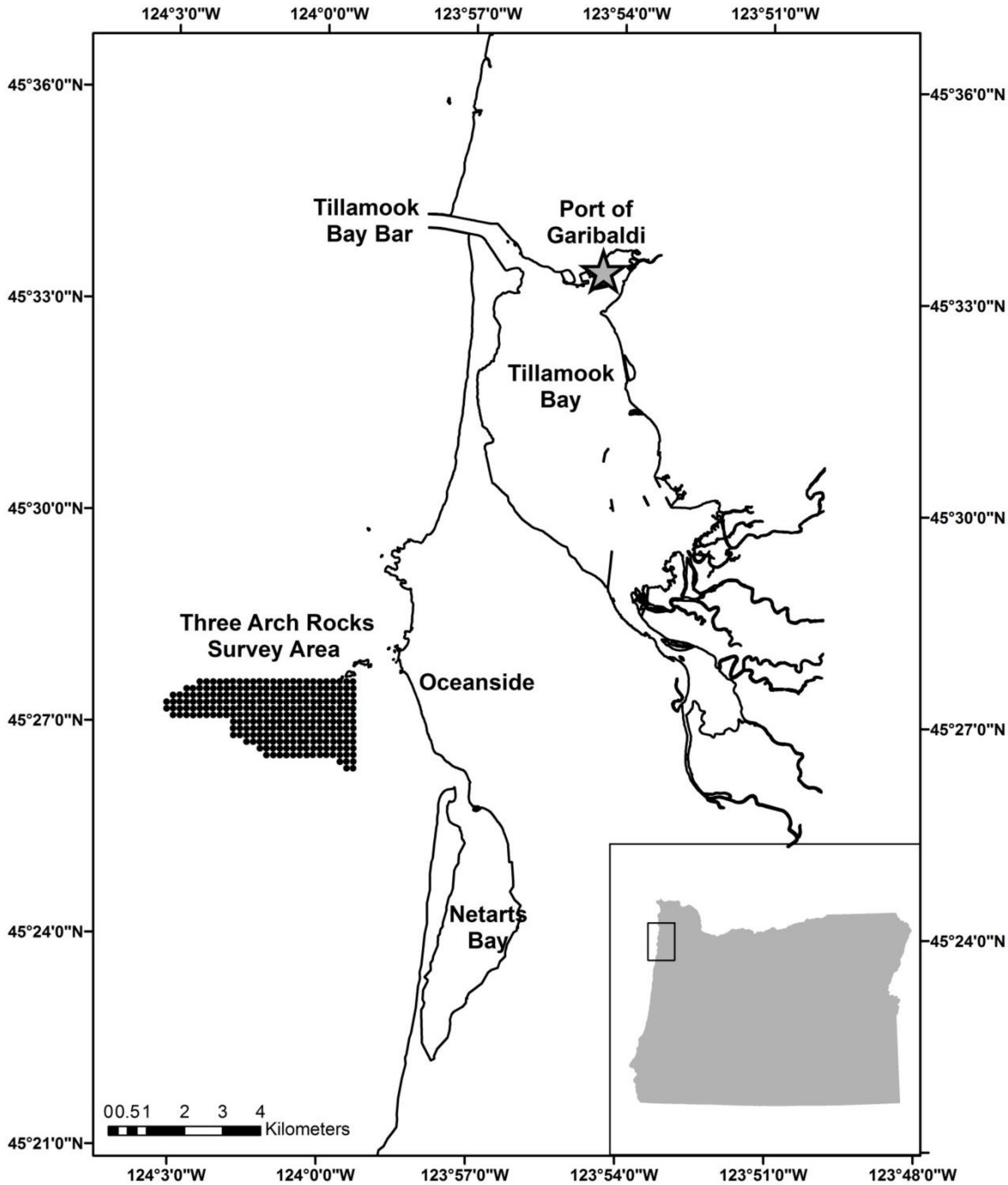

Figure 2. Three Arch Rocks rocky reef study area off of Oceanside, Oregon. Survey grid located approximately 11 kilometers south of the Tillamook Bay bar. Oregon map inset for orientation of the study site.

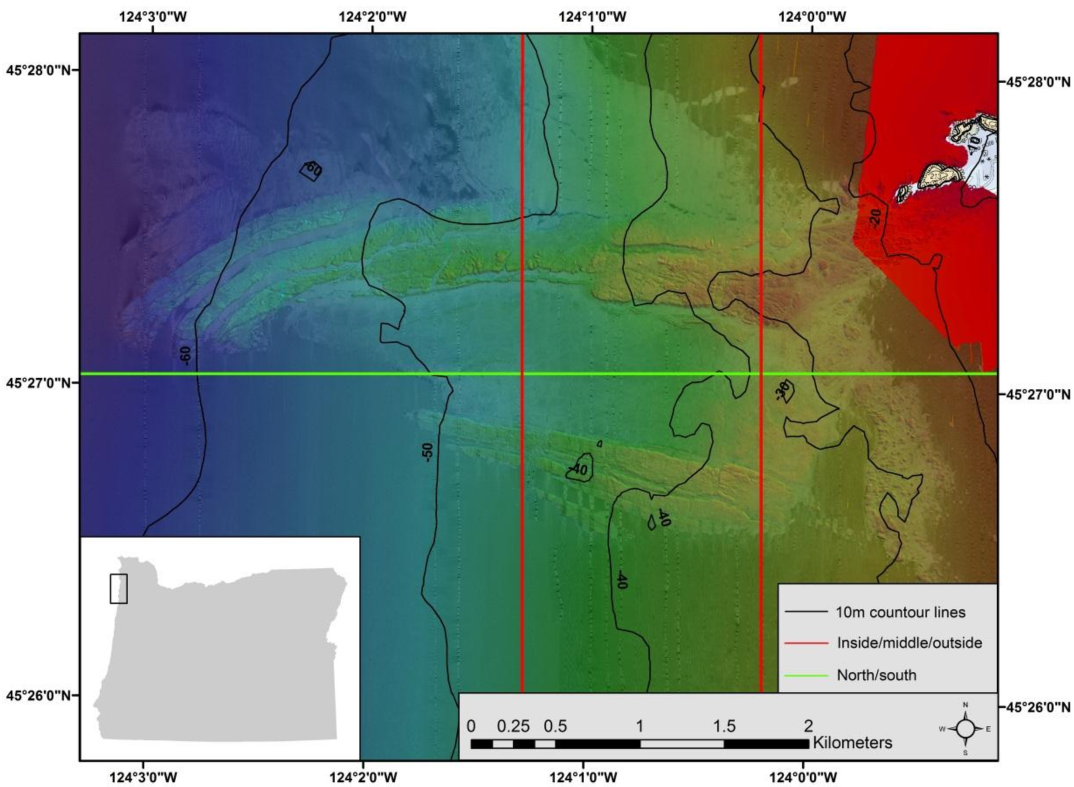

Figure 3. Three Arch Rocks submerged rocky reef structure multibeam sonar habitat map with backscatter data overlay collected by Oregon State Universities Active Tectonics and Seafloor Mapping Lab. 10 meter depth contour lines, along with north/south and inside/middle/outside grid divisions overlaid.

The Three Arch Rocks reef is a prime example of an area where user groups intersect; as it is a region heavily exploited by commercial, charter, and recreational fishing vessels primarily out of the ports of Garibaldi and Tillamook, Oregon (Package & Conway 2010). Between 2003 and 2011, a total of 12,135 charter and private bottom-fishing trips left the port of Garibaldi alone, with 9,345 of these trips explicitly stating that they fished in the Three Arch Rocks area (ODFW 2011).

Sampling plan

A systematic grid consisting of 272 individual drop points, spaced 175 meters apart, was developed using the National Parks Service AlaskaPak v2.2 toolkit for ESRI's Arc GIS 9.3 geographic information systems (GIS) software (Figure 4). The grid was designed to maximize coverage of the reef structure while capturing all possible habitat types throughout the reefs entire depth range and maintaining independence of the observations at adjacent stations based partly on previous movement studies (Matthews 1990, Matthews 1992, ODFW 2012a).

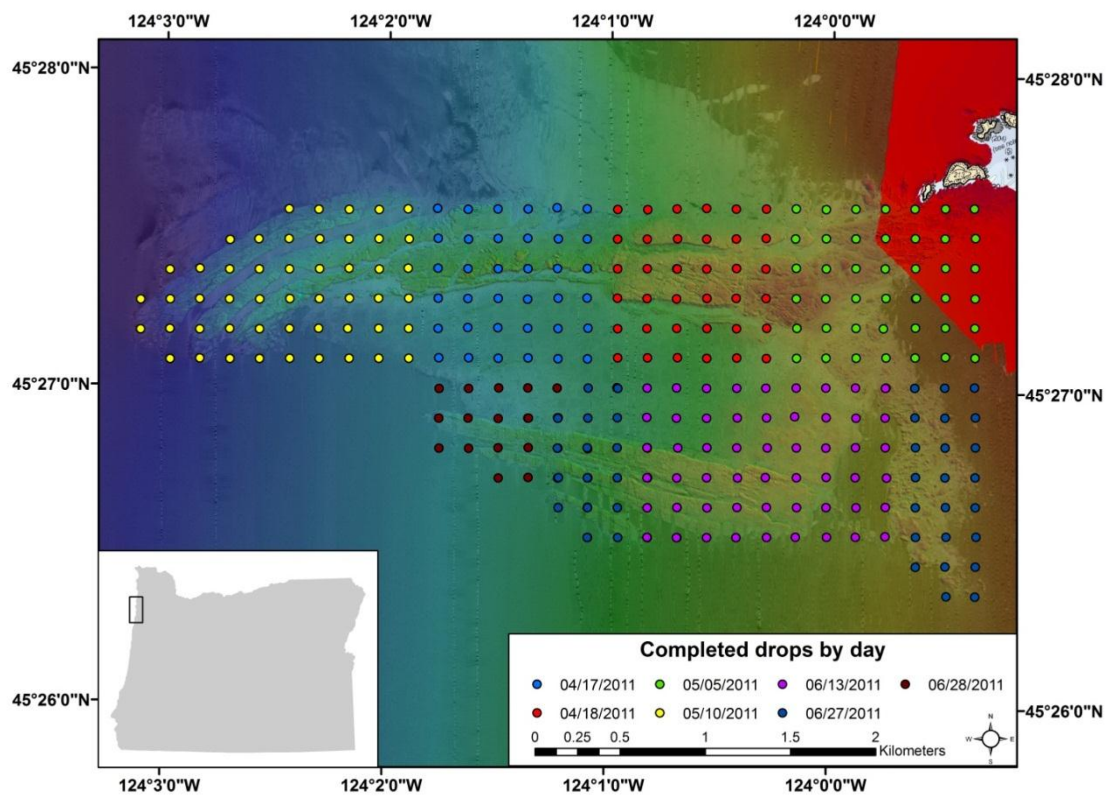

Figure 4. Completed spring (April-June 2011) video lander systematic survey grid of the Three Arch Rocks reef (175 meter spacing), with each point representing an individual drop within the grid.

The entire Three Arch Rocks reef survey grid was stored on a Panasonic fully-rugged Toughbook 31, equipped with Fugawi™ Global Positioning System (GPS) navigation software loaded with Navionics® electronic charts. A Garmin handheld 76CSX GPS unit connected to the Toughbook was used to record the position of the vessel while navigating between drop points. The Fugawi® software was used to record the actual position of each video lander drop. A 19-inch monitor was used to mirror the Toughbook's screen in the wheelhouse where the captain was able to view the vessels position within the grid, and navigate between drop points. Completed video tapes were reviewed aboard the vessel using a Sony GV-HD700 portable video recorder deck to determine underwater visibility and if any drops needed to be repeated based on low water clarity, camera orientation or visual obstruction.

Video lander drops were conducted only during daylight hours, and consisted of five minutes of recorded bottom time for each drop, beginning at the estimated time of the lander reaching the seafloor, and ending when retrieval began. Each drop point therefore required around 10 minutes of total operating time, with six to nine drops fitting on a 60 minute video tape, depending on depth.

Spring survey

The video lander was deployed on the Three Arch Rocks reef on 12 separate days between April 17 and June 28, 2011. Field research was conducted aboard the 36' CPFV *Blue Water Too*. Field conditions were generally restricted to swells less than 10 feet in height, and winds under 20 knots. If conditions were poor for the collection of video due to bad underwater visibility, where identifying fish or substrate was not possible, drops were repeated on a later day. The entire grid was blocked into 7 distinct regions prior to the survey, with the goal of completing at least one blocked section each day.

Winter survey

Field operations for the winter survey took place aboard the 56' foot retrofitted commercial vessel R/V *Pacific Surveyor* out of the port of Florence, Oregon. In contrast to the spring survey, the winter survey departed out of the port of Newport, Oregon and was a multi-day live-aboard survey. Provided with an acceptable weather window, two separate attempts were made to complete the grid between December 1-9, 2001; however, we were not able to survey the entire grid due to poor underwater visibility conditions.

The video lander platform used for the spring survey was again employed for winter sampling. A set of 10-cm paired scaling lasers were added to the video lander frame just below the video camera (Deep Sea Power and Light Dual SeaLasers™ 100) to better quantify substrate grain size.

Video analysis

The digital video footage from each lander drop was transferred from the original Sony DVC 60 minute cassettes into digital format on a Dell PC with Adobe Premiere Pro® through a fire-wire-connected Sony GV-HD700 portable video recorder deck. Once in digital format the video was reviewed and scored for underwater visibility, quality of the camera view and relief using the criteria shown in Table 1. Primary habitat (dominant habitat type viewed) and secondary habitat (second most abundant habitat feature in view) were classified for each drop based on the criteria shown in Table 2. Fish observed on the video were identified to the lowest taxonomic level possible. The maximum count of individuals from each species in any single frame was recorded for each drop, to eliminate the potential for double counting of individuals (Harvey et al. 2007). Fish observed as the video lander was being retrieved were not considered in determining the maximum count.

Table 1. Criteria used to classify relief, underwater visibility and view when reviewing video lander footage from Three Arch Rocks. Video footage had to receive at least a 1 in the Visibility and View categories to be used in further analysis.

Category	Class	Description
Relief	0	Flat (Sand, Flat Bedrock, Gravel/pebble, Hash)
	1	Low (Cobble, Small Boulder, Bedrock)
	2	High (Large Boulder, Vertical Wall, Crevice)
Visibility	0	Poor - view of surrounding substrate completely obscured by turbidity or marine snow
	1	Medium - view of surrounding substrate is not obscured but viewing distance is limited by variable turbidity and/or marine snow
	2	Good - view of surrounding substrate is clear to the limit of the lighted area
View	0	Completely obscured by habitat very close to the camera (includes lander tipped on side, looking down, or up)
	1	Partially restricted by habitat very close to the camera
	2	Unrestricted view

Table 2. Primary and secondary habitat types described at the Three Arch Rocks reef complex from video lander survey footage (Hannah & Blume 2012).

Abbreviation	Substrate Interpretation	Description
FLB	Flat Bedrock	Rock with little to no relief
BR	Bedrock outcrop	Solid rock with some relief extending across the view
LB	Large Boulder	Boulders approximately 1-3 m diameter (includes angular blocks broken off from bedrock)
SB	Small boulder	Boulders approximately 0.25 - 1 m in diameter
CO	Cobble	Cobble approximately 6 - 25 cm in diameter
GP	Gravel Pebble	Gravel or pebble approximately 2-60 mm in diameter
SA	Sand	Sand or mud with grain size 0.06 - 2 mm in diameter
CR	Crevice	Crevices in rock up to 1 m high by 1-3 m wide
VW	Vertical wall	Rock wall higher than 2 m and greater than 80 degrees to the horizontal
HA	Hash	Small broken bits of shells

Habitat observations made from the review of video lander footage were compared to a habitat classification map of the Three Arch Rocks region developed and provided by the Active Tectonics and Seafloor Mapping Lab (ATSML)[4] at Oregon State University.

Habitat associations and species assemblages

We investigated the species-habitat associations of the nine most abundant species observed on the Three Arch Rocks reef during the spring survey and the ten most abundant species observed during the winter survey. These included: black rockfish (*Sebastes melanops*), blue rockfish (*Sebastes mystinus*), canary rockfish, quillback rockfish (*Sebastes maliger*), yelloweye rockfish, yellowtail rockfish (*Sebastes flavidus*), lingcod (*Ophidon elongatus*), kelp greenling (*Hexagrammos decagrammus*), spotted ratfish (*Hydrolagus colliei*), and pile perch (*Rhacochilus vacca*). The number of individual fish species was totaled for each drop location to determine species richness. A Fisher's exact test was used to compare presence/absence data for each of the most abundant fish species on the reef to both primary and secondary habitat types identified. Unidentified adult fish were excluded from all analyses. Unidentified juvenile rockfish were included in the analyses, and treated as their own category.

To evaluate the ability of the video lander to capture high quality video to identify differences in species assemblages across the reef, the grid was partitioned in two different ways. First, the grid was divided into northern (n = 164) and southern (n

[4] http://activetectonics.coas.oregonstate.edu/

= 108) sections to test the hypothesis that the northern region of the Three Arch Rocks reef differed significantly from the southern region in species composition and relative abundance. Second, the grid was divided into three sections east to west; inside (inner 89 drops), middle (middle 95 drops) and the outside (outer 88 drops) to investigate how species composition changes across the reef by depth. Additionally, the species composition of the 70 drops on the outer section of the reef was compared between the spring and winter surveys to examine the seasonal change in species composition.

Differences in species assemblages and abundance between sections of the reef were analyzed in Paleontological Statistics (PAST) 2.15. Pairwise one-way ANOSIMS, adjusted for multiple comparisons using a step-down sequential Bonferroni correction, were used to compare species composition between the north and south regions of the reef. The degree of difference in the species composition was then measured using the Bray-Curtis dissimilarity index (BCDI) in the SIMPER routine (Bray & Curtis 1957, Hammer et al. 2001, Hannah & Blume 2012). The relative abundance of each species observed between sections of the study site was compared using a nonparametric Wilcoxon test, as has been previously used with video lander data (Hannah & Blume 2012).

Results

During the spring survey (April 17-June 28, 2011), 415 individual video lander drops off the CPFV *Blue Water Too* were completed over 12 boat-days, providing over 48.5 hours of video footage. Of the 12 total sampling days, seven days showed good bottom visibility, one showed moderate bottom visibility, and four showed little to no underwater visibility on the bottom. A total of 143 drops had to be repeated due to poor underwater visibility or obstructed view. The final sample size for analysis was, 272 useable drops, a single drop for each of the 272 sampling locations, each approximately 175 meters apart (Figure 4). The video lander was successfully retrieved during each of the 415 video lander drops, and was never lost, destroyed, or damaged beyond repair. During the course of the survey approximately six sacrificial bases were lost, and the break-away lines were tripped frequently to allow the lander to dislodge from the habitat and allow easy retrieval.

Acceptable weather for the winter survey occurred between December 6 and 9, 2011, and yielded a total of 108 usable drops across the Three Arch Rocks reef grid (Figure 5). A decrease in visibility over the four day sampling period prevented sampling of all of the planned sites. Of these 108 usable drops, a block of 70 drops comprising the outer reef were used for species composition comparison with the spring survey results.

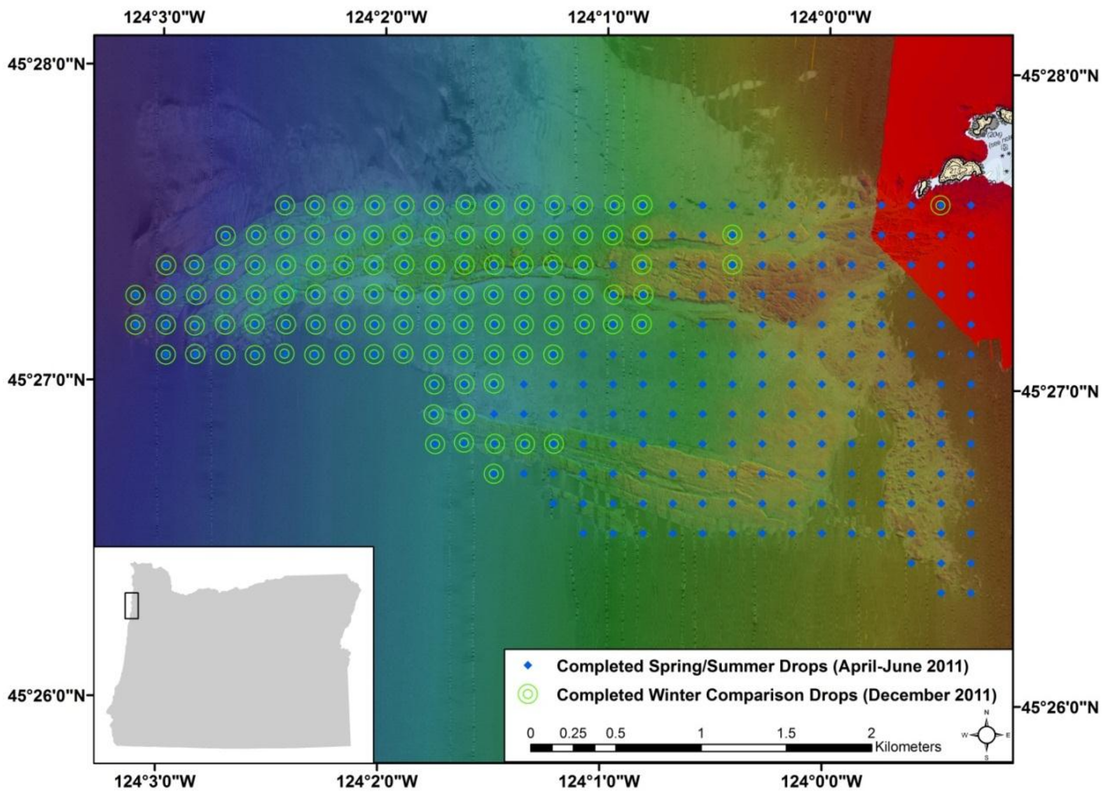

Figure 5. Comparison of the complete spring (April-June 2011) video lander survey grid of 272 stations with the 108 usable winter (December 2011) video lander survey stations at Three Arch Rocks reef. Multibeam sonar seafloor bathymetry and lithography by Oregon State University's Active Tectonics (ATSML) and Seafloor Mapping Lab.

Habitat

Both video lander surveys covered a wide variety of habitat types (Figure 6) and depth ranges (10.8 to 73.3 meters). During the spring survey, sand was the most abundant habitat type for both primary (41.2%) and secondary (35.3%) habitat. Bedrock outcrop was the second most frequent primary habitat type (21.7%), with the high relief habitat types such as large boulder, vertical wall, and crevice registering lower in overall frequency (Figure 6).

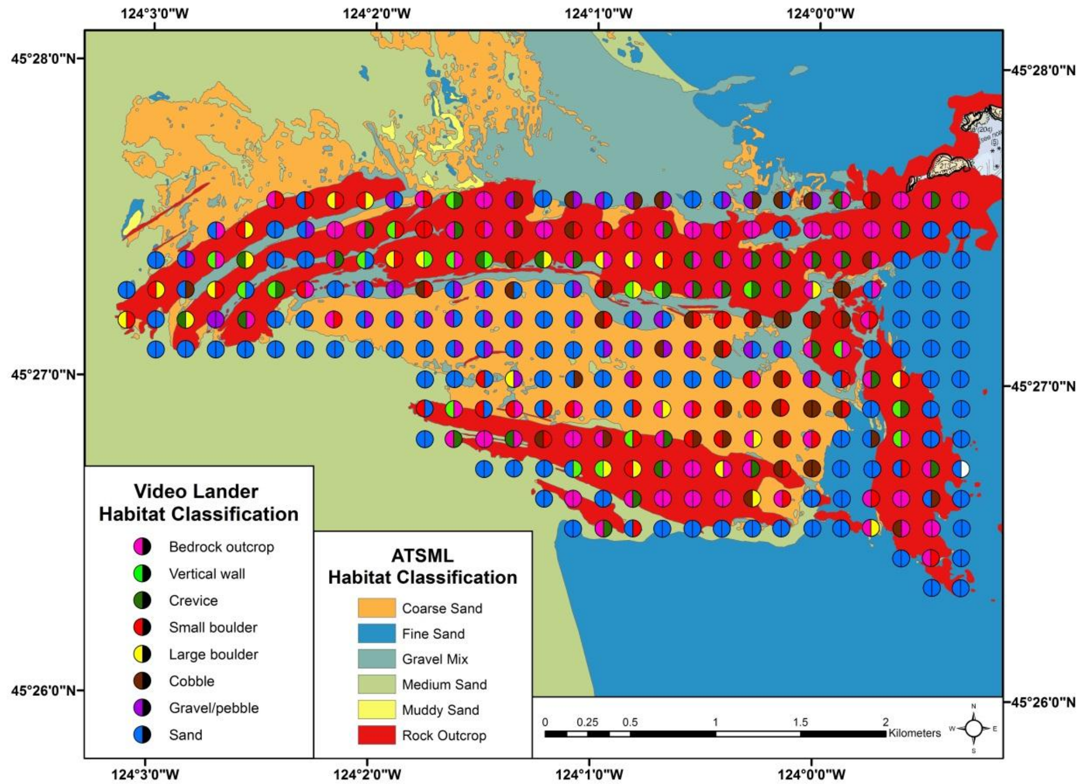

Figure 6. Total distribution of habitat types (Table 2) across the Three Arch Rocks reef as observed by the video lander (April through June 2011) overlaid on a habitat classification map developed by Oregon State University's Active Tectonics and Seafloor Mapping Lab (ATSML).

A comparison of the habitat classifications characterized from the review of video lander footage with habitat maps developed by Oregon State University's Active Tectonics and Seafloor Mapping Lab revealed an 80.1% agreement between the two methods (Figure 6). Differences in agreement between the two methodologies lies primarily in scale; with the video lander viewing a relatively small area while habitat maps generated from multibeam sonar and backscatter data generally blend multiple similar habitat types into more uniform classifications.

Of the 108 total usable drops collected during the winter survey, sand was the most abundant primary (47.2%) and secondary (36.1%) habitat type observed. Bedrock outcrop was the second most abundant habitat type overall (16.7% primary, 18.5% secondary), with more complex and higher relief types in lower overall abundance, as was the case for the spring survey.

Based on the frequency of habitat types classified from the 272 drops from the spring survey, there was no significant difference between the overall habitat compositions between the north and south regions of the reef (BCDI > 77.69, ANOSIM $p > 0.10$). However, crevice and gravel/pebble habitat types, as primary and secondary features, were more prevalent in the north region than the south. The only observation of hash habitat was in the southern region, as a secondary feature. Otherwise the overall abundance of each habitat classification between the two surveys was quite similar.

Spring survey fish observations

Eight species of rockfish were observed with the video lander, as well as 10 other rocky-reef fishes (Table 3). While many of the drops performed over the course of the survey did not have any fish species present, the majority of the sites surveyed by the video lander had one or more fish species present (Figure 7a). Black rockfish were the most abundant fish observed, with a summed maximum count of 277 individuals across all stations, followed closely by canary rockfish with a summed maximum count of 225 individuals. Kelp greenling were the most abundant non-*Sebastes* species with a summed maximum count of 90 individuals followed closely by lingcod with a total summed maximum count of 61. All told, 745 individual rockfish were observed, among 939 total individual fish of all species as well as 17 Dungeness crab (*Metacarcinus magister*) (Table 3).

Winter survey fish observations

As was the case during the spring survey, the vast majority of fishes observed were rockfishes. While many drops were devoid of any fish species, the majority of stations had at least one fish species present (Figure 7b). The most abundant of these were yellowtail rockfish with a total maximum count of 92 individuals, followed by canary rockfish with a total maximum count of 40 individuals. Two fishes which were unique to the winter survey were spotted ratfish with a total maximum count of 20 individuals, and northern anchovy (*Engraulis mordax*) which were mostly observed in large bait balls with a total maximum observed count of upwards of 1,500 individuals. In total, 213 identified rockfish were observed, among 273 total fishes (excluding northern anchovy) and one Dungeness crab (Table 3).

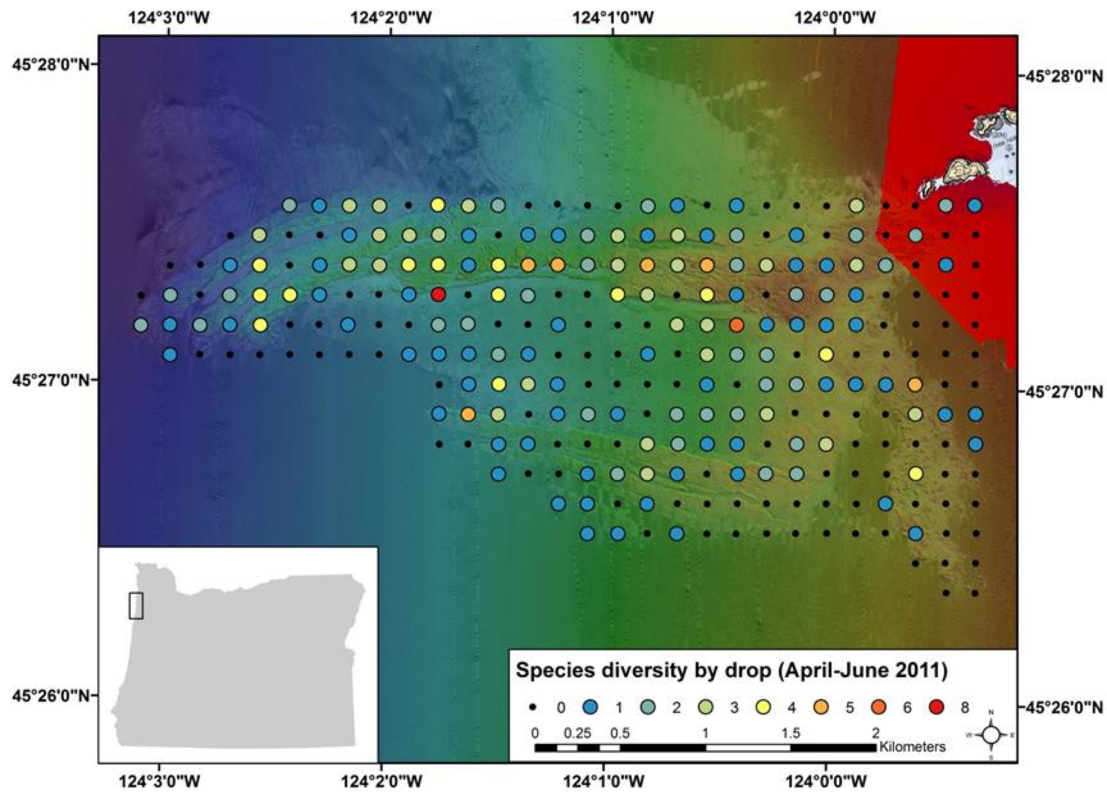

Figure 7a. Total number of fish species observed by the video lander at each of the 272 spring drop locations at Three Arch Rocks reef (April-June 2011).

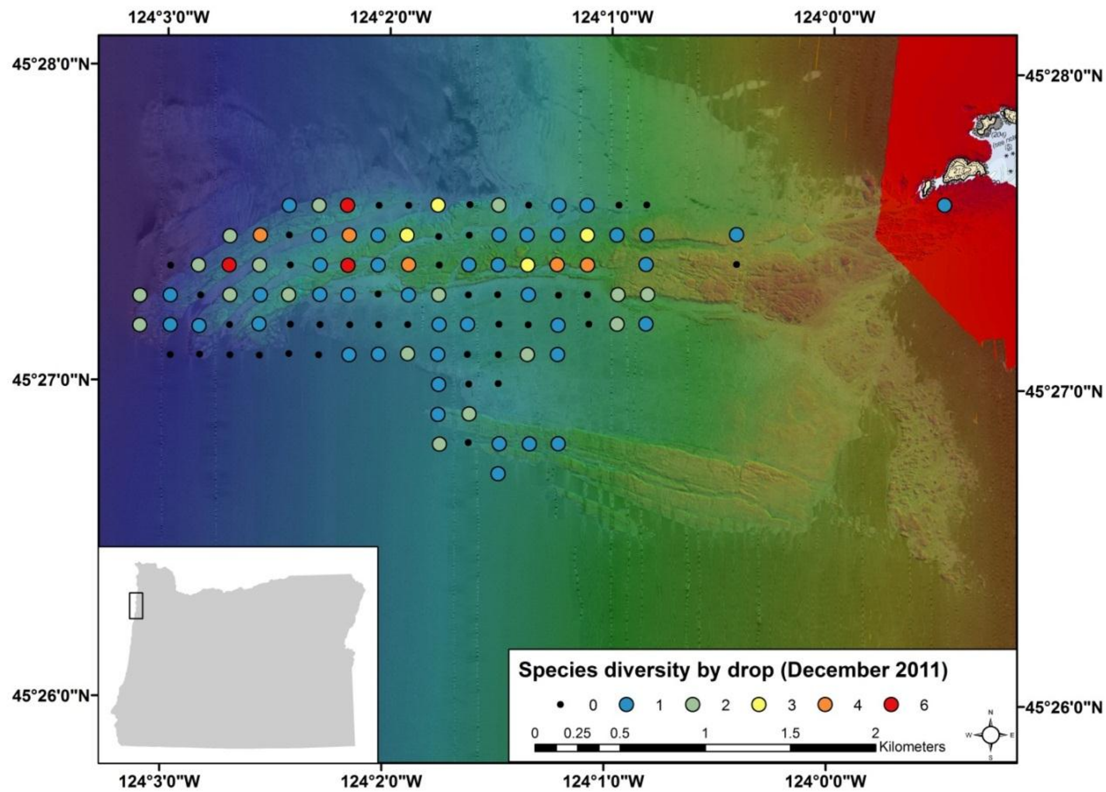

Figure 7b. Total number of rocky-reef fish species observed by the video lander at each of the 108 winter drop locations at Three Arch Rocks reef (December 2011).

Table 3. Maximum count (n), relative abundance (%), and rank abundance of observed fish taxa on the Three Arch Rocks reef over both the spring (April-June 2011) and winter (December 2011) surveys. (NA denotes lack of observation)

		Total		Spring (272 drops)			Winter (108 drops)			Spring and Winter comparison: Spring (70 drops)	Spring and Winter comparison: Winter (70 drops)
Scientific name	**Common name**	**n**	**Rank**	**n**	**%**	**Rank**	**n**	**%**	**Rank**	**n**	**n**
Sebastes melanops	Black rockfish	303	1	277	29.5%	1	26	9.5%	3	6	0
Sebastes pinniger	Canary rockfish	265	2	225	24.0%	2	40	14.7%	2	154	28
Sebastes flavidus	Yellowtail rockfish	147	3	55	5.9%	6	92	33.7%	1	35	84
Sebastes mystinus	Blue rockfish	139	4	124	13.2%	3	15	5.5%	6	11	6
Hexagrammos decagrammus	Kelp greenling	107	5	90	9.6%	4	17	6.2%	5	27	9
Ophiodon elongatus	Lingcod	67	6	61	6.5%	5	6	2.2%	10	16	6
Sebastes ruberrimus	Yelloweye rockfish	42	7	27	2.9%	7	15	5.5%	6	21	14
Sebastes maliger	Quillback rockfish	26	8	21	2.2%	9	5	1.8%	11	12	5
Rhacochilus vacca	Pile surfperch	24	9	24	2.6%	8	NA	NA	NA	9	0
Hydrolagus colliei	Spotted ratfish	20	10	NA	NA	NA	20	7.3%	4	0	18
	Unidentified fish	20	10	5	0.5%	12	15	5.5%	6	2	15
Sebastes spp.	Unidentified rockfish	19	12	5	0.5%	12	14	5.1%	9	1	12
	Unidentified flatfish	10	13	9	1.0%	10	1	0.4%	13	2	1
Sebastes spp.	Unidentified juvenile rockfish	9	14	4	0.4%	14	5	1.8%	11	1	5
Sebastes caurinus	Copper rockfish	6	15	6	0.6%	11	NA	NA	NA	1	0
Scorpaenichthys marmoratus	Cabezon	3	16	2	0.2%	15	1	0.4%	13	2	0
Family *Embiotocidae*	Unidentified surfperch	2	17	2	0.2%	15	NA	NA	NA	0	0
Sebastes nigrocinctus	Tiger rockfish	1	18	NA	NA	NA	1	0.4%	13	0	1
Engraulis mordax	Northern anchovy	>1,500	NA	NA	NA	NA	>1500	NA	NA	0	>1,100
Sebastes nebulosus	China rockfish	1	18	1	0.1%	16	NA	NA	NA	0	0
Anarrhichthys ocellatus	Wolf eel	1	18	1	0.1%	16	NA	NA	NA	1	0

Table 3(continued). Maximum count (n), relative abundance (%), and rank abundance of observed fish taxa on the Three Arch Rocks reef over both the spring (April-June 2011) and winter (December 2011) surveys.

		Total		Spring (272 drops)			Winter (108 drops)			Spring and Winter comparison: Spring (70 drops)	Spring and Winter comparison: Winter (70 drops)
Scientific name	**Common name**	**n**	**Rank**	**n**	**%**	**Rank**	**n**	**%**	**Rank**	**n**	**n**
Metacarcinus magister	Dungeness crab	18		17			1			0	1
Total number of rockfish		958		745	79.3%		213	78.0%		242	155
Total number of fish (Excluding northern anchovy)		1,212		939			273			301	205

Species-habitat relationships

Over the course of the spring survey, the nine most abundant species (black rockfish, canary rockfish, blue rockfish, yellowtail rockfish, yelloweye rockfish, quillback rockfish, kelp greenling, lingcod and pile perch) observed by the video lander showed distinct habitat and depth associations, while three other identified fishes (copper rockfish (*Sebastes caurinus*), cabezon (*Scorpaenichthys marmoratus*) and unidentified juvenile rockfishes (*Sebastes* spp.)) were not observed with enough regularity to identify any significant associations (Table 3).

Black rockfish was the most abundant species overall (34 stations, 277 individuals), while canary rockfish were the second most abundant (41 stations, 225 individuals). The most abundant and frequently observed demersal rockfish species was yelloweye rockfish (22 stations, 27 individuals), with quillback rockfish second (18 stations, 21 individuals) (Table 4). The fish species with the broadest distributions by depth, habitat, and location during the spring survey were the two most frequently observed demersal, non-*Sebastes* species (kelp greenling and lingcod). Kelp greenling were the most frequently observed non-*Sebastes* fish on the reef (67 stations, 90 individuals), while lingcod were second (48 stations, 61 individuals) (Table 4).

The 10 most abundant species (excluding northern anchovy) observed during the winter survey each showed distinct habitat associations with primary and secondary habitat types. Three other species; cabezon, tiger rockfish (*Sebastes nigrocinctus*), and unidentified juvenile rockfish were also observed during the survey, however their numbers were too low overall to draw any conclusions about habitat associations.

As with the spring survey, pelagic schooling rockfish (black, blue, and yellowtail) were the most abundant group of fishes observed on the reef, with yellowtail rockfish being the single most abundant (and most frequently observed at 14 stations, 92 individuals) of the three. Canary rockfish was the second most abundant species overall, excluding northern anchovy, and were observed in the greatest frequency (19 stations, 40 individuals). The most abundant and frequently observed demersal rockfish was yelloweye (10 stations, 15 individuals), followed by quillback (4 stations, 5 individuals) (Table 4).

Of the non-*Sebastes* species, kelp greenling (16 stations, 17 individuals) exhibited a broad distribution during the winter survey, across depth and habitat, while lingcod appeared noticeably absent (5 stations, 6 individuals). Spotted ratfish, a species which was not observed during the spring survey, were observed at 11 stations during December, over multiple habitat types. Additionally, schools of northern anchovy, also not observed during the spring survey, were observed at 16 drop stations across the reef in December (Table 4).

Table 4. Maximum count of fish observed for the 15 most abundant identified fish species on the Three Arch Rocks reef with associated depth information over both the spring (April-June 2011) and winter (December 2011) surveys.

	Spring survey (April-June 2011)					**Winter survey (December 2011)**				
Fish Species	**Max Count**	**Drops**	**Depth of observations (m)**			**Max Count**	**Drops**	**Depth of observations (m)**		
Rockfish			Min.	Max.	Avg.			Min.	Max.	Avg.
Black rockfish *S. melanops*	277	34	10.79	53.04	31.39	26	6	13.17	45.9	35.08
Blue rockfish *S. mystinus*	124	19	28.71	51.94	36.45	15	9	34.2	59.44	45.98
Canary rockfish *S.pinniger*	225	41	28.9	60.9	49.53	40	19	33.83	70.96	53.04
Copper rockfish *S. caurinus*	6	6	24.51	52.12	35.23	NA	NA	NA	NA	NA
Quillback rockfish *S. maliger*	21	18	32.37	64.56	48.03	5	4	46.45	59.44	54.13
Unidentified juvenile rockfish *S.* spp.	4	2	44.3	70.4	57.35	5	3	52.85	56.14	54.62
Yelloweye rockfish *S. ruberrimus*	27	22	39.14	70.41	46.21	15	10	45.9	67.3	55.59
Yellowtail rockfish *S. flavidus*	55	16	28.53	60.9	54.4	92	14	46.45	61.45	53.15
Tiger rockfish *S. nigrocinctus*	NA	NA	NA	NA	NA	1	1	59.4	59.4	59.4
Other species										
Lingcod *Ophiodon elongatus*	61	48	17.01	63.09	42.3	6	5	42.06	58.7	50.37
Kelp Greenling *Hexagrammos decagrammus*	90	67	13.35	69.13	40.52	17	16	34.02	65.84	51.31
Pile Perch *Rhacochilus vacca*	24	14	25.42	58.88	41.12	NA	NA	NA	NA	NA
Spotted ratfish *Hydrolagus colliei*	NA	NA	NA	NA	NA	20	11	48.28	71.87	59.05
Northern anchovy *Engraulis mordax*	NA	NA	NA	NA	NA	>1,500	16	44.07	71.87	54.17
Cabezon *Scorpaenichthys marmoratus*	2	2	48.09	52.3	50.2	1	1	38.59	38.59	38.59

Furthermore, some of the species observed during the spring survey were also observed at the same site in the winter survey (Table 5). For instance, of the 10 sites yelloweye rockfish were observed at in December, five were the same as the spring survey, while kelp greenling were observed again at 8 of 16 total sites (Table 5).

Table 5. Comparison of species observations, between the spring (April-June 2011) video lander survey and the winter (December 2011) survey, at the same drop stations.

Fish species	**Same sites (April/June & December)**	**New sites (December)**	**Total (December)**	**%**
Black rockfish *S. melanops*	4	1	5	80.00%
Blue rockfish *S. mystinus*	3	6	9	33.33%
Canary rockfish *S. pinniger*	8	11	19	42.11%
Quillback rockfish *S. maliger*	2	4	6	33.33%
Yellowtail rockfish *S. flavidus*	5	9	14	35.71%
Yelloweye rockfish *S. ruberrimus*	5	5	10	50.00%
Lingcod *Ophiodon elongatus*	1	4	5	20.00%
Kelp Greenling *Hexagrammos decagrammus*	8	8	16	50.00%

Pelagic rockfish species (black, blue, and yellowtail) all showed strong qualitative associations with the reef structure itself, and significant associations with many of the primary habitats which make up the reef (Table 6). All of the 10 most abundant species except for spotted ratfish showed significant negative associations with sand habitat (Table 6).

Table 6. Habitat associations of the 10 most abundant species observed by the video lander during both the spring (April-June 2011) and winter (December 2011) surveys of the Three Arch Rocks reef complex (Habitat codes from Table 2).

		Primary Habitat Type								Secondary Habitat Type							
Common name	**Scientific name**	**BR**	**LB**	**SB**	**CR**	**VW**	**CO**	**GP**	**SA**	**BR**	**LB**	**SB**	**CR**	**VW**	**CO**	**GP**	**SA**
Black rockfish	*Sebastes melanops*	0.0068	0.0357	>0.10	0.0004	>0.10	>0.10	>0.10	<0.0001	0.0087	0.0351	>0.10	0.0024	>0.10	>0.10	0.0532	<0.0001
Blue rockfish	*Sebastes mystinus*	>0.10	0.0335	>0.10	0.0255	0.0024	>0.10	>0.10	0.0005	>0.10	0.0072	0.0009	<0.0288	>0.10	>0.10	>0.10	0.0003
Canary rockfish	*Sebastes pinniger*	>0.10	0.0081	0.0006	>0.10	0.0743	0.0492	>0.10	<0.0001	>0.10	0.0085	0.0095	>0.10	>0.10	>0.10	>0.10	<0.0001
Quillback rockfish	*Sebastes maliger*	>0.10	0.0016	0.0535	>0.10	0.0791	0.0701	>0.10	<0.0001	>0.10	0.0560	0.0143	0.0269	>0.10	>0.10	>0.10	0.0045
Yelloweye rockfish	*Sebastes ruberrimus*	0.0552	0.0073	>0.10	0.0004	<0.0001	>0.10	>0.10	<0.0001	>0.10	0.0003	0.0626	>0.10	>0.10	>0.10	>0.10	0.0343
Yellowtail rockfish	*Sebastes flavidus*	>0.10	0.0157	>0.10	0.0156	0.0011	>0.10	>0.10	0.0003	>0.10	>0.10	0.0067	<0.0001	>0.10	>0.10	>0.10	0.0130
Kelp greenling	*Hexagrammos decagrammus*	0.0162	0.0008	0.0110	>0.10	>0.10	>0.10	>0.10	<0.0001	0.0105	0.0487	>0.10	0.0177	>0.10	>0.10	>0.10	<0.0001
Male	*Hexagrammos decagrammus*	0.0033	0.0070	0.0432	>0.10	>0.10	>0.10	>0.10	<0.0001	0.0053	0.0224	>0.10	0.0030	>0.10	0.0868	0.0529	<0.0001
Female	*Hexagrammos decagrammus*	>0.10	>0.10	>0.10	>0.10	>0.10	0.0421	>0.10	0.0051	>0.10	>0.10	>0.10	0.0955	>0.10	>0.10	>0.10	0.0019
Lingcod	*Ophiodon elongatus*	0.0845	>0.10	>0.10	0.0794	>0.10	>0.10	>0.10	<0.0001	0.0431	>0.10	0.0010	0.0332	0.0814	>0.10	>0.10	0.0206
Pile surfperch	*Rhacochilus vacca*	>0.10	>0.10	>0.10	0.0874	>0.10	>0.10	>0.10	0.0005	>0.10	>0.10	0.0569	>0.10	>0.10	>0.10	>0.10	0.0225
Spotted ratfish	*Hydrolagus colliei*	>0.10	>0.10	>0.10	>0.10	>0.10	0.0475	>0.10	>0.10	>0.10	>0.10	0.0008	>0.10	>0.10	>0.10	>0.10	>0.10

Spring significant positive association*

Winter significant positive association*

Spring and winter significant positive association*

Significant negative association*

*All p-values obtained from Fisher's exact test

Habitat types

Bedrock outcrop (BR), Large boulder (LB), Small boulder (SB), Crevice (CR), Vertical wall (VW), Cobble (CO), Gravel/pebble (GP), Sand (SA)

Schooling pelagic rockfish (black, blue, and yellowtail) each exhibited significant associations to both moderate and high relief rocky habitat, as well as a significant negative association with sand habitat (Table 6). However, the most interesting observation of this group was that each of these species exhibited a strong qualitative relationship with the reef structure, exhibiting a distribution pattern which mirrored the shape of the reef (Figure 8). This suggests an association with structure for these species that may not be evident from trawl surveys on less rugose substrates.

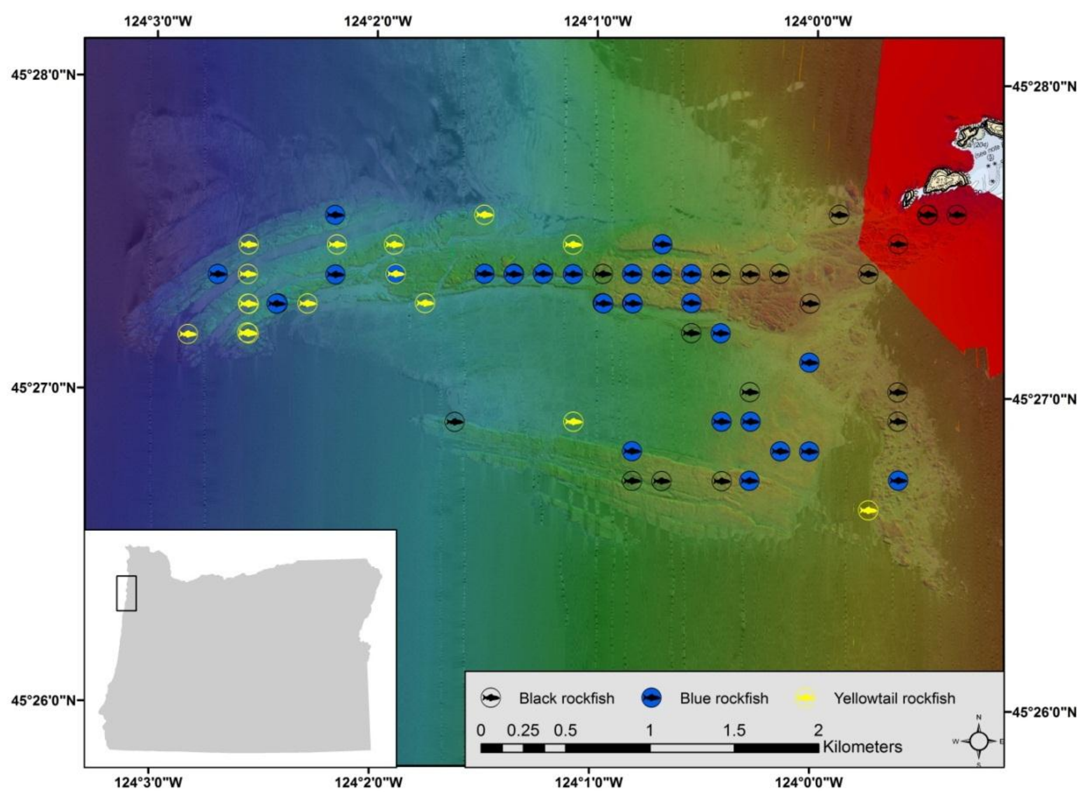

Figure 8. Distribution of black, blue, and yellowtail rockfish across the Three Arch Rocks reef as observed by the video lander for both the spring (April-June 2011) and winter (December 2011) surveys combined.

Yelloweye and canary rockfish each exhibited significant associations with a variety of habitat types across the Three Arch Rocks reef (Table 6). Canary rockfish during each survey period had the broadest distribution across depths and habitat types of any of the observed rockfish species, including sand (Figure 9a). Yelloweye rockfish on the other hand, while exhibiting significant relationships with high vertical relief habitat types (Table 6), showed a more restricted distribution than canary, with the vast majority of observations occurring on the outer third portion of the reef (Figure 9b).

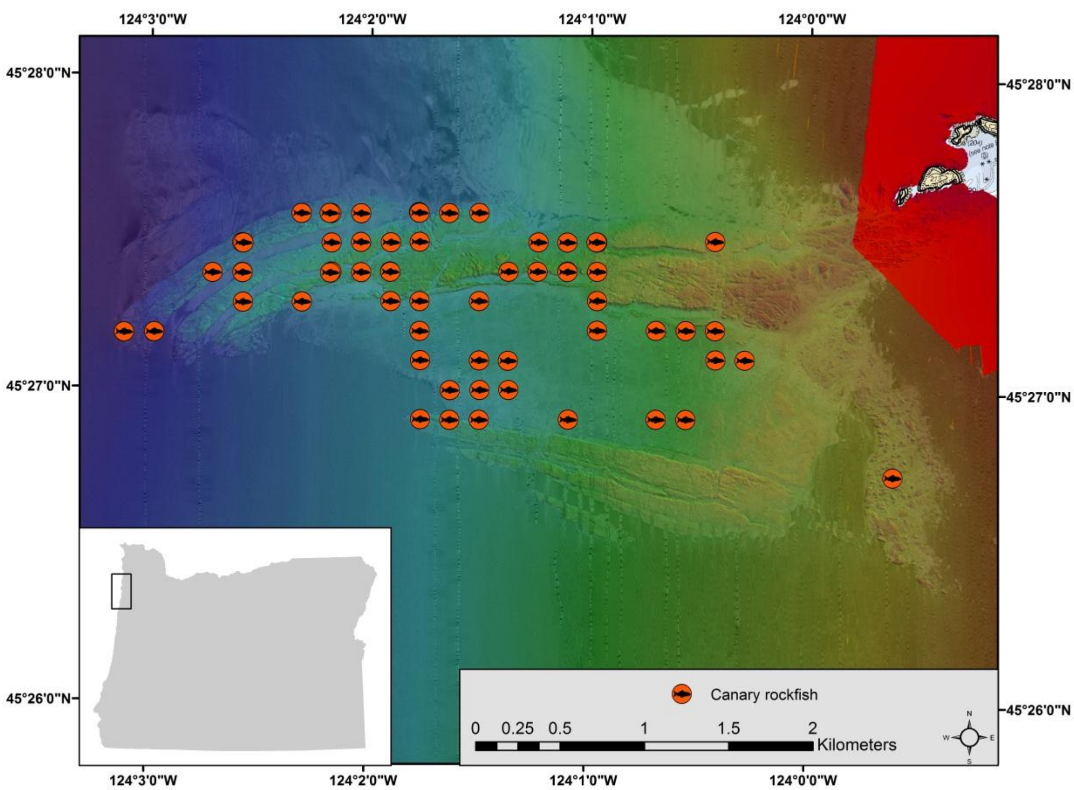

Figure 9a. Distribution of canary rockfish across the Three Arch Rocks reef as observed by the video lander over both the spring (April-June 2011) and winter (December 2011) surveys combined.

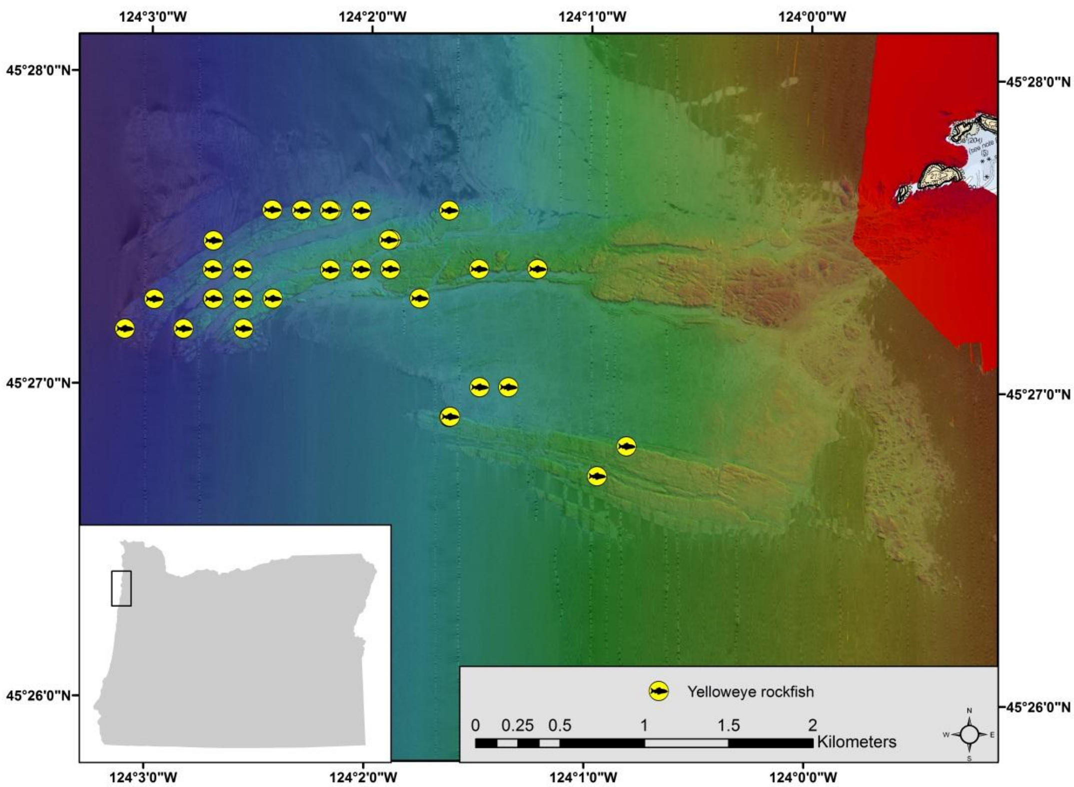

Figure 9b. Distribution of yelloweye rockfish across the Three Arch Rocks reef as observed by the video lander over both the spring (April-June 2011) and winter (December 2011) surveys combined.

Many other species were observed over the course of the survey which showed significant habitat associations, as well as interesting spatial distributions across Three Arch Rocks reef (See Appendix A).

Species assemblage

An analysis of the species composition between the north and south regions of the reef was conducted to investigate species composition and abundances differences between these two distinct regions of the reef. Overall species composition did not vary between the north and south region of the Three Arch Rocks reef (Bray-Curtis

Dissimilarity Index (BCDI) 71.71, ANOSIM $p > 0.1447$); however canary rockfish (Wilcoxon $p < 0.0202$), kelp greenling (Wilcoxon $p < 0.0002$), lingcod (Wilcoxon $p < 0.0406$) and pile perch (Wilcoxon $p < 0.0019$) were more abundant in the north than they were in the south. Male kelp greenling were more abundant in the north (Wilcoxon $p < 0.0009$) than the south, while the observed females showed no significant difference (Wilcoxon $p > 0.2424$).

Additionally, an analysis of the species composition across the reef by location was conducted to investigate how species composition changed with depth and location. The survey grid was divided into three segments moving east to west across the reef: inside (inner 89 drops), middle (middle 95 drops) and the outside (outer 88 drops). Comparison of the habitat composition across the three reef sections (inside, middle, outside) showed that only the inner and outer sections differed significantly (BCDI = 75.88, ANOSIM $p < 0.0427$). This difference was primarily driven by differences in sand, bedrock, and small boulder (secondary habitat) between these two regions of the reef. The species assemblages of the three sections all differed significantly in composition (Figure 10). The inside section, dominated primarily by black rockfish and kelp greenling, had the lowest overall total species abundance. This section also differed significantly in species composition from the middle (BCDI 68.82, ANOSIM $p < 0.0029$), and the outside (BCDI 71.38, ANOSIM $p < 0.0001$). The middle section was dominated by black rockfish, having the greatest abundance of this species on the reef, followed by blue rockfish and canary rockfish. The middle section also differed significantly from the outside section (BCDI 79.11, ANOSIM p <

0.0334) which was dominated by canary rockfish, but also had the highest abundance of yellowtail rockfish, yelloweye rockfish, and quillback rockfish.

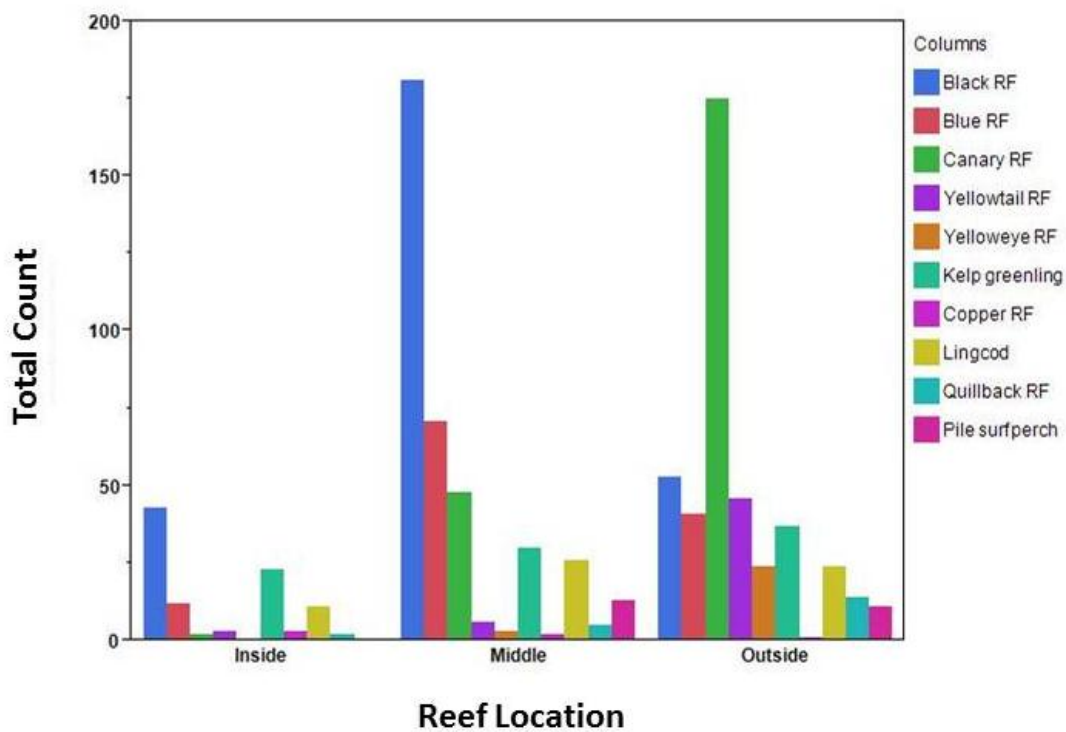

Figure 10. Spring (April-June 2011) species composition of Three Arch Rocks divided into three depth categories; inside (inner 89 drops), middle (middle 95 drops) and the outside (outer 88 drops) across the reef based on video lander video analysis.

A comparison of the species composition between the contiguous outermost 70 stations of the Three Arch Rocks reef survey, between the spring and winter surveys, revealed that they were significantly different from each other in composition (BCDI =76.41, ANOSIM $p < 0.0155$). This difference was driven by the winter presence of spotted ratfish at the reef, and the overall lower abundance of canary rockfish (Wilcoxon $p < 0.0168$), kelp greenling (Wilcoxon $p < 0.0241$), and lingcod (Wilcoxon $p < 0.0456$) observed during the winter survey.

Discussion

Evaluation of the habitat types, species assemblages and habitat associations at Three Arch Rocks using a video lander represents an important contribution to nearshore rocky-reef research. Little information currently exists for species inhabiting the nearshore region of the outer coast in the Pacific Northwest, particularly during the winter season. Recently, much effort has been focused on comprehensive seafloor mapping in Oregon's territorial sea, using multibeam sonar, which supports the creation of high-resolution maps of the seafloor. This study represents a comprehensive evaluation of the video lander survey method in a highly exploited nearshore rocky reef environment to catalog the species-habitat associations and fish assemblages of the region, while simultaneously ground-truthing the multibeam sonar images through direct observation.

Considering the high-relief topography that the video lander was able to survey, the record of success at Three Arch Rocks goes a long way to support the video lander as an effective research tool. While some fish showed an initial startle response to the video lander upon it reaching the bottom, fish were not observed to be frightened away from the lander, and appeared to behave in a manner suggesting that they were not disturbed by its presence. This is consistent with previous surveys which showed that most rocky reef fishes did not strongly react to the video lander, with some species like yelloweye, quillback and copper rockfish observed to approach the lander from a short distance (Hannah & Blume 2012). In its current configuration, it is not possible to determine the extent to which the video lander attracts fish, and from what distance fish may come in from. The attraction, or repellence, of fish from the video lander represents potential sampling biases, as does the inability of the video lander to effectively identify flatfishes, and cryptic species like cabezon.

Prior to the spring video lander survey, a review of the multibeam and backscatter data from Three Arch Rocks reef made it appear that the entire mid-section between the north and south segments of the reef was strictly unconsolidated sediment which would generally be predicted to have low fish density based on previously understood species-habitat associations. However, the video lander showed regions of large and small boulders, cobble, and bedrock outcrop which were distributed sporadically throughout regions thought to be a mix of coarse sand and gravel. These areas of scattered rocky habitat had kelp greenling, lingcod, quillback rockfish, yelloweye rockfish, and canary rockfish all inhabiting the inner region of the reef (Figures 7a & 7b). These observations by the video lander have the potential to add much needed information on the distribution and relative abundance of data-poor species, where the addition of even a few fish to a stock assessment can have a big impact on rebuilding estimates and harvest guidelines. Observations by the video lander of rocky reef species inhabiting regions previously described as areas of unconsolidated sediment highlights the need for both direct observation ground-truthing of habitat maps, and the expanded use of direct observation methods to survey nearshore rocky-reef structures.

Due to the lack of previous concerted nearshore rocky-reef surveys during the winter season, one of our research questions focused on potential differences in overall species composition by season. Due to underwater visibility issues, a complete resurvey of the grid was not possible during the time-period available; however a complete survey of the outer portion of the grid provided keen insights into the change in overall species composition between spring and winter. At least for the Three Arch Rocks reef in 2011, the species composition between spring and winter were significantly different, with this difference driven by the addition of spotted ratfish and the reduction in the relative abundance of canary rockfish, lingcod and kelp greenling. These observations provide a view as to the seasonal shifts which can occur on nearshore reef structures, warranting further surveys of Three Arch Rocks and other reefs up and down the coast across multiple seasons.

The video lander data showed that many species of nearshore rocky reef fishes exhibit significant associations with particular primary and secondary rock habitat types, and that these features have the potential to be useful predictors for species presence/absence. The individual primary and secondary habitat associations of pelagic rockfish species may be tenuous, as their pelagic lifestyle involves intermittent contact with the bottom. However, the significant negative association with sand and distinct observational pattern across the reef structure over both the spring and winter provides keen insight into their distribution on a nearshore rocky reef. It further appears that the distribution of schooling pelagic rockfish species is quite discrete across the reef by depth, with black rockfish dominating in shallow water transitioning to blue rockfish and then yellowtail rockfish in the deeper regions of the reef, a pattern similarly seen during the winter. Additional surveys may allow more detailed analysis of relative abundance and probability of habitat use, increasing our understanding of Essential Fish Habitat (EFH; (PFMC 2012)).

The data from this study provides information on habitat associations for overfished species that can contribute to assessment and spatial management. The significant habitat associations of canary rockfish with small boulder in the spring and winter, and large boulder and cobble in the winter, strongly suggests that habitat complexity may be more important than overall relief for this species. Many demersal fishes also exhibited significant associations with moderate and high relief habitat types of varying complexity, which have previously been shown to be important to many demersal rockfish species (Johnson et al. 2003). For yelloweye rockfish, associations with high relief complex habitat such as vertical walls, crevices and large boulders over both survey periods are consistent with previous findings, and proved to be strong indicators of their presence (O'Connell & Carlile 1993, Love et al. 2002, Love et al. 2006). Large and small boulder habitats provide increased habitat complexity, with potentially a greater number of cracks and crevices than flat bedrock of the same spatial extent. Thus, a reason that demersal nearshore rocky-reef fishes like yelloweye rockfish and quillback rockfish might occupy these highly complex, moderate to high relief areas is for the possible increase in potential refugia (Love et al. 2006).

The belief held by many local fishermen interviewed prior to the spring survey was that the southern region of the Three Arch Rocks reef structure would differ significantly from the northern region in both species composition and abundance; this was not supported by the data. Only small differences were present in overall habitat types, with only crevice and gravel/pebble habitat being more abundant in the northern section of the reef. Furthermore, the overall species composition between the north and south reef sections was not significantly different, even though four species (canary rockfish, kelp greenling, lingcod, and pile perch) were observed to have a higher abundance in the northern section. Interestingly, three of those species (canary rockfish, kelp greenling, and lingcod) had the broadest overall distributions of all species across the reef, and the fourth (pile perch) were only observed on the northern section. Therefore, while differences may exist in regional abundance of a few species on the reef between the north and south, the overall similarity in species composition between these two regions reveals that the Three Arch Rocks reef structure as a whole is generally uniform in species assemblage.

The inner region of the reef showed low overall fish abundance, with the middle section possessing the majority of the black rockfish, and the outer section the majority of the canary rockfish. As both depth and habitat are key indicators for species presence, the distribution seen by the lander is not completely surprising, but is insightful as to how species distribute across the reef (Love et al. 2002, Williams & Ralston 2002). Additionally, as habitat composition did not differ significantly between the middle and outer sections of the reef, the difference in species composition between the middle and outer sections can most likely be attributed to differences in depth between the two sections.

Conclusion

Over the course of the two separate surveys at the Three Arch Rocks rocky-reef complex, the video lander was able to capture both differences and similarities in species assemblages and habitat compositions over a small spatial scale. This would be of particular use to those monitoring or planning marine reserves or protected areas, to monitor the change and effectiveness of boundaries in the management of marine species. The reduced logistical and operational cost of the video lander compared to an ROV or submersible, combined with its ability to survey depths inaccessible to scuba divers, warrants continued use of the methodology on other nearshore rocky reefs.

For the Three Arch Rocks rocky-reef complex, there does appear to be a seasonal shift in the overall composition of the species assemblage, at least for the outer section of the reef. However, as we discovered many of the same species at the same drop location between spring and winter, the change is primarily driven by the abundance differences of only a few species. The addition of spotted ratfish around the reef edge, combined with the reduction in lingcod and kelp greenling highlights the fact that there is some change in species composition which occurs during the winter, for the outer region of the reef at the very least.

The individual species-habitat associations which were observed, along with the differences in composition and abundance of each species across the reef, provides unique insights into nearshore rocky reef ecological structure which have not been extensively illustrated previously. However, the video lander is not a good platform for the identification of flatfishes or small species that would be on the substrate below the view of the camera. Therefore, expanding the use of the video lander as a rocky reef survey tool will further refine nearshore Pacific reef-fish habitat associations, ground-truth broader regions of multibeam habitat data, as well as catalog and enhance the distribution data for many of these data-poor nearshore species.

This study demonstrated that with an acceptable weather window, the video lander can function as a successful survey tool of nearshore rocky reefs in both the spring and winter seasons. The habitat associations that many of the species exhibited during the spring video lander survey were further reinforced and expanded upon during the winter survey, further illustrating the video lander as an effective survey tool. While funding restrictions limited the number of possible days for the winter survey; given a longer time period, I demonstrated that it would be possible to complete the entire survey grid during the window. Overall, the combination of the spring and winter survey results validate the ability of the video lander to accurately describe species-habitat associations, reef species assemblage, and distribution during multiple seasons, and across multiple weather and ocean conditions.

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Chapter 3 - General Discussion

Why the video lander?

Assessing the distribution and abundance of fishes inhabiting rocky reef structures along the west coast of North America is a significant challenge. Typically, scientists must take a dynamic approach, utilizing a myriad of sources of data and a variety of data collection techniques to identify the relative abundance of species and their associated habitat types across geographic regions (Francis 1986, Parker et al. 2000). In order for resource surveys to be effective, a sizeable amount of planning, funding, and personnel from multiple agencies is often needed. However, even with substantial time and effort, the results of these surveys can still be highly variable, with poor representation of some habitat types in areas that are difficult to sample (Krieger 1993, Jagielo et al. 2003).

The limitations of the most commonly used survey gear types (*i.e.* bottom-trawl) are well documented, and understood both by those who employ the gear and those who utilize the data in stock assessments (Adams et al. 1995, Williams & Ralston 2002). The question, however, is how to integrate different sources of data and promote the use of novel sampling methods that can overcome the shortcomings of trawl sampling for stock assessment of rocky-reef species, especially those species which predominantly inhabit the nearshore. This creates an opportunity for the video lander to be developed into a more widely utilized survey tool for nearshore rocky reefs along the Pacific coast of North America. The ability to use a video lander to comprehensively survey a nearshore reef in a fishery-independent, non-extractive, and relatively low cost manner places it in position to support the development of a more dynamic survey methodology to comprehensively study nearshore reefs. Presently, there are no other survey methods capable of collecting visual data on distribution and species-habitat associations on deep-water rocky reefs which can be rapidly deployed across multiple seasons, for the same personnel and operating costs as the video lander.

Visual surveys, however, are not without their own limitations, with underwater visibility being the single most important factor when it comes to a successful video survey, be it with the video lander, scuba divers, an ROV or a submersible. Based on our experience with the conditions encountered in the nearshore at Three Arch Rocks, it is crucial to assess tidal cycles, river or estuarine outflow, and wind patterns and magnitude to forecast good underwater visibility potential off the Oregon coast. The upper hand that the video lander has over other visual methods is its simplicity and ease of use. The entire Three Arch Rocks video lander survey was completed by a small crew, with a relatively small survey vessel; a feat which could not be accomplished with a conventional ROV or submersible (Pacunski et al. 2008). This relative simplicity, small size, and ease of use allows for rapid deployment of the video lander when weather conditions become favorable, as well as minimal cost to abort a survey when conditions prove unsuitable for sampling.

The increase in high resolution multibeam mapping of the seafloor has provided a clearer assessment of the substrate over a broad region of the continental shelf; however, without substantive information on habitat associations of the marine fish species in these areas, these habitat maps will be of limited use to fisheries managers. This is the area where the video lander methodology can make a contribution by uniting the ability to ground-truth multibeam habitat maps with direct observation of marine fish species in a low-cost, high efficiency framework.

Limitations of the video lander

The video lander, however, did exhibit limitations in its ability to capture very cryptic species like cabezon, which was also an issue identified in previous video lander surveys (Hannah & Blume 2012). Furthermore, I was unable to identify juvenile rockfish (*Sebastes* spp.) and other small fishes to species due to the low resolution of standard definition video, as well as some fishes being too distant from the camera. Additionally, the video lander is incapable of effectively surveying flatfishes, or identifying individuals to the species level in a consistent manner.

The limited and highly variable size of area viewed restricts the video lander from accurately providing relative fish densities per unit area, a beneficial trait of ROVs and HOVs, which the video lander is unlikely to supplant. Furthermore, the extent to which the video lander attracts or repels fish is unknown. This represents a potential sampling bias which would need to be evaluated and potentially quantified, if the video lander is to become an established survey tool.

Evaluating the video lander at Three Arch Rocks

Comparison with previous video lander surveys in Oregon

Entering into the Three Arch Rocks survey, it was unknown if it was going to be possible to complete such an intensive survey of a nearshore reef. We discovered that it was indeed possible, with some careful watching of the wind, swell, and tides to capture high quality video. While 143 additional drops were required to complete the grid of 272 stations, the rapid deployment of the lander provided the ability to have a short turnaround time between poor and favorable conditions, allowing for the capture of high quality video at each station.

The general consensus entering into the winter survey was that underwater visibility would be satisfactory, and that we would most likely encounter favorable conditions if we were able to get an acceptable weather window for the survey. While we were able to take advantage of two separate weather windows, both attempts at the winter survey were marred by poor visibility likely due to increased estuarine outflow and wind driven currents. The primary exception to this was the first day of the second attempt, December 6, 2011, when the vast majority of high quality footage was collected. The ability to survey during the winter storm period off the Oregon Coast is sporadic, and the weather windows are generally short. The video lander therefore is an ideal tool to use in the winter because of its rapid, intensive survey capability combined with a short preparation and implementation schedule. The winter survey yielded interesting results, including the first video observations of spotted ratfish (*Hydrolagus colliei*) at Three Arch Rocks reef. Furthermore, the species-habitat associations of many species were reinforced from the spring survey, as discussed in Chapter 2 (yelloweye rockfish (*Sebastes ruberrimus*)), while others were expanded (quillback rockfish (*Sebastes maliger*)). Visibility issues plagued the winter survey at Three Arch Rocks; however it provided new insight into this nearshore rocky reef environment in winter. This does show that given acceptable ocean conditions, the video lander can perform at the same level in the winter as it did in the spring, with the difference being that both weather and visibility conditions in the winter appeared to deteriorate at a faster rate than in the spring.

Previous video lander work in nearshore waters has been predominantly exploratory, with a limited number of drops (between 30 and 43) performed at four nearshore reefs off the central Oregon coast (Hannah & Blume 2012). The Three Arch Rocks video lander survey was the first time that the video lander was used in a systematic and comprehensive manner on a nearshore rocky reef; producing valuable data which will help guide future nearshore surveys. At Three Arch Rocks reef in 2011, between the spring and winter surveys (Chapter 2), a total of 380 usable drops were generated. In comparison, a total of only 342 usable drops were performed at five separate reefs between October 2009 and September 2010 representing the sum total of previous video lander work in Oregon, with only 169 of those drops performed on reefs of similar distance from shore as Three Arch Rocks (data from Hannah and Blume 2012;Table 7).

Table 7. Comparison of video lander survey data, including total numbers of fish observed (summed maximum counts across stations of the 25 most abundant species between the five study locations) by species or group and survey area (n denotes the number of stations sampled) (All non-Three Arch Rocks data obtained from Hannah and Blume 2012).

Fish species	Scientific name	Three Arch Rocks (April-June, n=272)	Three Arch Rocks (December, n=108)	Cape Perpetua (February, n=30)	Cape Perpetua (July, n=30)	Seal Rocks (n=43)	East Siletz (n=36)	West Siletz (n=30)	Stonewall Bank (n=173)
Rockfish									
Black rockfish	*Sebastes melanops*	277	26	62	72	182	15	11	0
Blue rockfish	*Sebastes mystinus*	124	15	2	1	18	187	47	54
Brown rockfish	*Sebastes auriculatus*	0	0	3	1	0	0	0	0
Canary rockfish	*Sebastes pinniger*	225	40	173	156	47	18	74	202
China rockfish	*Sebastes nebulosus*	1	0	0	0	0	0	0	0
Copper rockfish	*Sebastes caurinus*	6	0	6	2	5	0	0	0
Unidentified juvenile rockfish	*Sebastes* spp.	4	5	7	47	56	3	0	281
Quillback rockfish	*Sebastes maliger*	21	5	9	8	6	2	3	1
Rosethorn rockfish	*Sebastes helvomaculatus*	0	0	0	0	0	0	0	18
Tiger rockfish	*Sebastes nigrocinctus*	0	1	0	0	0	0	0	--
Unidentified rockfish	*Sebastes* spp.	5	14	--	--	--	--	--	--
Yellowtail rockfish	*Sebastes flavidus*	55	92	44	14	18	2	5	95
Yelloweye rockfish	*Sebastes ruberrimus*	27	15	3	0	1	6	3	22
Other species									
Cabezon	*Scorpaenichthys marmoratus*	2	1	2	3	0	0	0	0
Kelp greenling	*Hexagrammos decagrammus*	90	17	14	18	23	16	8	13
Lingcod	*Ophiodon elongatus*	61	6	8	7	15	23	12	13
Northern anchovy	*Engraulis mordax*	0	>1,500	0	0	0	0	0	--
Pacific halibut	*Hippoglossus stenolepis*	0	0	0	0	0	0	0	8

Table 7 (continued). Comparison of video lander survey data, including total numbers of fish observed (summed maximum counts across stations of the 25 most abundant species between the five study locations) by species or group and survey area (n denotes the number of stations sampled) (All non-Three Arch Rocks data obtained from Hannah and Blume 2012).

Fish species	Scientific name	Three Arch Rocks (April-June, n=272)	Three Arch Rocks (December, n=108)	Cape Perpetua (February, n=30)	Cape Perpetua (July, n=30)	Seal Rocks (n=43)	East Siletz (n=36)	West Siletz (n=30)	Stonewall Bank (n=173)
Pile perch	*Rhacochilus vacca*	24	0	68	11	6	0	2	0
Spotted ratfish	*Hydrolagus colliei*	0	20	0	0	0	0	0	--
Unidentified fish		5	15	--	--	--	--	--	--
Unidentified flatfish		9	1	--	--	--	--	--	--
Unidentified sculpin	Cottidae	0	0	1	1	0	2	0	4
Unidentified surfperch	Embiotocidae	2	0	--	--	--	--	--	0
Wolf eel	*Anarrhichthys ocellatus*	1	0	0	0	0	0	0	0
Total number of rockfish		745	213	309	301	333	233	143	673
Total number of fish (excluding northern anchovy)		939	273	402	341	377	274	165	711
Mean station depth (m)		41	52.8	51.3	51.3	30.7	33.6	40.4	54.3

Three Arch Rocks reef is unique in its structure, in that it runs east to west, spanning a wide range of depths, giving it a very diverse assemblage of Pacific reef fishes (Chapter 2). The diversity in species assemblage gives it a unique composition of shallow and deep water fishes, incorporating assemblage aspects of nearshore and offshore reefs (Table 7). Comparative analysis of the species assemblages at Three Arch Rocks reef with the five exploratory sites presented in Hannah and Blume 2012 (Cape Perpetua, East Siletz, West Siletz, Seal Rocks and Stonewall Bank) yielded interesting results. In comparison to Cape Perpetua reef, which runs north to south, Three Arch rocks reef was significantly different from the July Cape Perpetua survey (Bray-Curtis Dissimilarity Index (BCDI) = 86.02, ANOSIM $p < 0.0011$), driven primarily by differences in relative abundance of canary rockfish (*Sebastes pinniger*), juvenile rockfish (*Sebastes* spp.), kelp greenling (*Hexagrammos decagrammus*), and black rockfish (*Sebastes melanops*) at the Cape Perpetua site (Table 7). On the other hand, a comparison of the spring Three Arch Rocks survey to the Cape Perpetua February survey yielded inconclusive results (BCDI = 81.07, ANOSIM $p < 0.064$), showing the species assemblages as not being significantly different, however differing in the relative abundance of canary rockfish, pile perch (*Rhacochilus vacca*), black rockfish, and kelp greenling (Table 7). The Eastern Siletz Reef showed the greatest disparity in species assemblage in comparison with the Three Arch Rocks reef (BCDI = 88.88, ANOSIM $p < 0.0001$), due to the high relative abundance of blue rockfish (*Sebastes mystinus*) and kelp greenling at the Eastern Siletz site (Table 7). Similar results were observed when comparing to the Seal Rocks site (BCDI = 85.75, ANOSIM p< 0.0002), due to the greater relative abundance of black rockfish, canary rockfish, kelp greenling and juvenile rockfish observed at Seal Rocks (Table 7). In contrast, the Western Siletz reef site was more similar to Three Arch Rocks (BCDI = 78.62, ANOSIM p < .0721) (Table 7). Similar results were observed when comparing the species assemblage to Stonewall Bank (BCDI = 70.63, ANOSIM p < 0.0574), due primarily to the absence of black rockfish at Stonewall Bank, and the relative greater abundance of canary rockfish and juvenile rockfish at Stonewall Bank, but also the greater relative abundance of lingcod (*Ophiodon elongatus*) at Three Arch Rocks (Table 7).

The mixed results when comparing the species assemblage observed by the video lander at Three Arch Rocks reef to those of other reefs off the Oregon coast of varying depths and distances from shore, displays the uniqueness and complexity of the species assemblage at Three Arch Rocks reef. The east to west distribution of the reef structure, covering a large depth range and distance from shore, means that the reef structure is home to both shallow (blue and black rockfish) and deeper-water (yelloweye and canary rockfish) species. This combination of depths and species diversity at Three Arch Rocks might explain the mix of similarities and differences observed between the species assemblages at other Oregon reef structures, further highlighting the ecological diversity at Three Arch Rocks reef.

Comparison with local notions and catch data

Due to the closure of yelloweye rockfish (*Sebastes ruberrimus*) and canary rockfish (*Sebastes pinniger*) to fishery retention in Oregon starting in 2003, the use of commercial and recreational catch records as a data source for estimating distribution and abundance of these species is no longer an option. This is shown in landings data from the Port of Garibaldi from 2003 to 2011 (Figure 11a) collected by the Oregon Department of Fish and Wildlife's Ocean Recreational Boat Survey (ORBS) when compared to the video lander data (Figure 11b). Our data suggests that canary rockfish and yelloweye rockfish comprise a relatively large portion of the nearshore reef community at Three Arch Rocks (Figure 11b), a fact which would be missed if catch records were used exclusively. Furthermore, estimates of nearshore demersal species distribution and abundance based solely on offshore trawl and longline surveys, which exclude the nearshore high-relief habitat, may be overlooking an important component of their distribution. These video lander observations further highlight the need for alternative nearshore survey methods for resource managers.

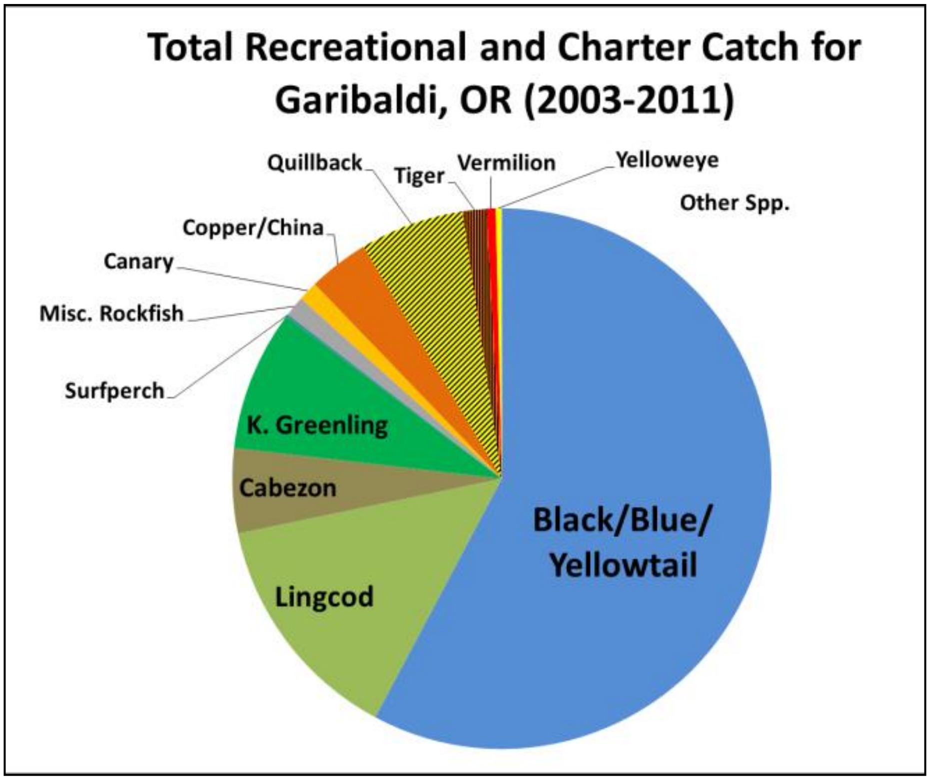

Figure 11a. Comparison between Oregon's Ocean Recreational Boat Survey (ORBS) catch data for the port of Garibaldi, OR (2003-2011) (above) and the Three Arch Rocks reef species composition observations made by the video lander during the spring survey (April through June 2011) (below).

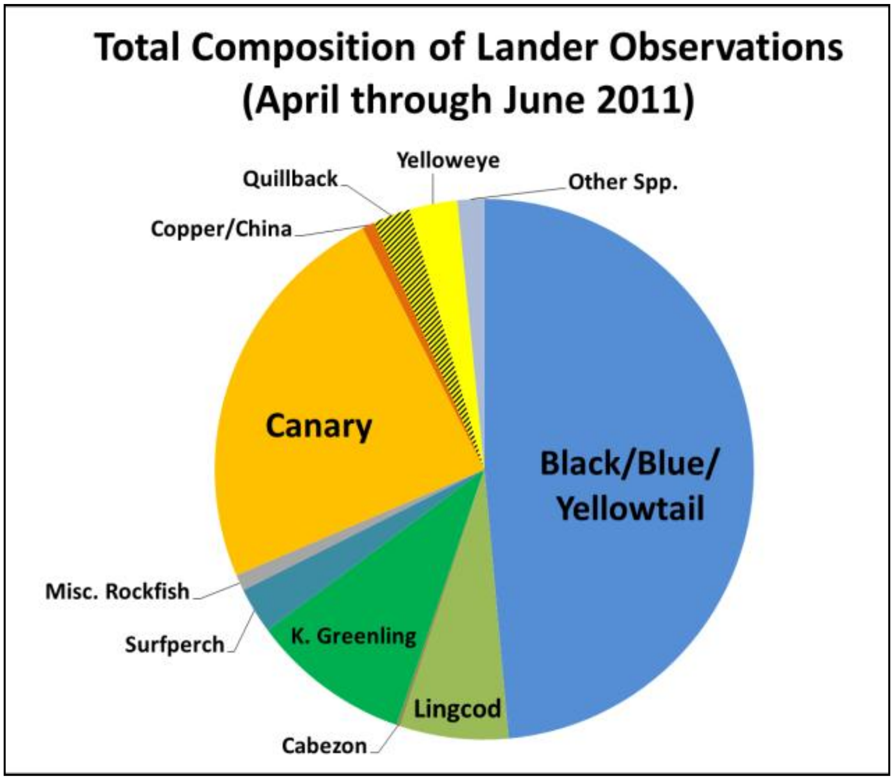

Figure 11b. Three Arch Rocks reef species composition observations made by the video lander during the spring survey (April through June 2011).

Local communications with charter fishermen in Garibaldi, Oregon leading up to the spring survey suggested that the southern section of the reef would be largely devoid of species and habitat types of interest to the study. What was discovered however was that while there were a few species which showed a greater abundance in the northern section (canary rockfish, kelp greenling, lingcod, and pile perch); the overall composition of the habitat and species were not significantly different between the areas. This suggests that the entire structure of the Three Arch Rocks reef is of significant importance to all of the fish species which inhabit the reef, not just one particular section of the reef.

The video lander also showed that as you move east to west across the Three Arch Rocks reef, different species dominate the overall species composition. The inner portion exhibited low overall fish abundance, but was mainly inhabited by black rockfish and kelp greenling. The middle section was dominated by black rockfish, where the majority of this species was observed, followed by blue rockfish and canary rockfish. Kelp greenling and lingcod also had a strong presence in the middle section of the reef. Lastly, the outer section was dominated by canary rockfish, as well as exhibiting the greatest abundance in yelloweye rockfish, quillback rockfish, and yellowtail rockfish (*Sebastes flavidus*) of any region on the Three Arch Rocks reef. These data further highlights the complexity and diversity of the species assemblage at Three Arch Rocks reef.

Management recommendations

The version of the video lander used in this study utilized a standard-definition camera. Moving forward, I would recommend a transition to a high-definition video system which would provide higher resolution images of both fish and habitat. Many of the unidentified fish and rockfish could most likely be discerned given a more high resolution system, increasing the ability of the video lander to capture more accurate species abundance and distribution data. Additionally, moving to a stereo-video camera system would further increase the capabilities of the video lander, adding the ability to calculate length and size information of the fish viewed (Harvey et al. 2004, Harvey et al. 2010, Williams et al. 2010). These additions pose an increase in the upfront assembly cost of a video lander; however the long-term benefits will likely justify this increase in cost. These modifications represent a price which would add value in data quality and richness, by providing length frequency information, as well as high-definition images.

While the video lander is useful in multiple ways, it is not my recommendation that video landers supplant the use of ROVs or HOVs for assessing relative species abundance, primarily because of the limitations in calculating the area viewed by the video lander. The true utility of the lander lies in its ability to quickly, and comparatively inexpensively, assess fish distribution, ground-truth multibeam sonar habitat data, and collect species-habitat association information for a suite of data-poor nearshore species within complex, high-relief habitats. Previous work has shown that because many nearshore rocky reef fishes are very distinct in coloration, generally large bodied, and many have a demersal orientation, they are well suited for observation with a benthic, color video lander system (Hannah & Blume 2012).

Ultimately the overarching goal of the video lander study was to evaluate a new survey tool for nearshore rocky reef fishes in high-relief habitat which fisheries managers can use as part of a more dynamic suite of assessment tools. The video lander displayed an ability to capture rocky reef fish habitat associations, as well as describe species composition across a nearshore reef between two distinct seasons. In order to further the goal of developing the video lander into an established survey tool, it will be necessary to estimate the area viewed by the video lander. This is difficult as the video lander is designed to survey uneven terrain of varying relief and underwater visibility, changing the distance viewed by the video lander from drop to drop. Potentially an indoor swimming pool could be used to develop a baseline, representing 100% visibility and the maximum area viewed, where the distance to accurately identify a fish image could be precisely determined. An index could then potentially be established to determine a gradient down from this 100% estimate of area viewed to roughly estimate the area viewed based on visibility and relief of the habitat. Additionally, developing comparison surveys between the video lander and ROVs/HOVs, where the video lander was immediately deployed systematically over a completed ROV/HOV transect would help establish an index to which future video lander survey results could be compared to other previous visual surveys.

All of the observed results provided in this thesis were accomplished over a rather small time and spatial scale in 2011, with a relatively small operating budget. Therefore, provided an opportunity to expand the survey to additional nearshore reefs, it might be possible to refine or expand upon these observations, broadening the scope of the results. This research provides solid evidence to support the video lander as a viable fishery management and survey tool, warranting further use on deep-water temperate reefs.

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Appendix

Appendix A. Additional observed species information

Many additional rocky-reef species were observed over the course of the survey which showed both significant habitat associations, as well as interesting spatial distributions.

Quillback rockfish

Quillback rockfish, the second most abundant demersal rockfish species observed during the spring survey, were consistently seen over moderate relief habitat (Figure 1). They were significantly associated with small boulder (Fisher's exact, $p < 0.0143$) as a secondary habitat type, as well as a suggestive but inconclusive (non-significant) relationship with small boulder (Fisher's exact, $p < 0.0535$) as a primary habitat type. This inconclusive primary relationship with small boulder is most likely due to the relatively low abundance of small boulder as a primary habitat type (Figure 6). Quillback rockfish also showed a significant negative relationship to sand, both as a primary habitat (Fisher's exact, $p < 0.0001$) and secondary habitat (Fisher's exact, $p < 0.0045$).

Quillback rockfish were the second most abundant demersal rockfish species observed during the winter survey (Table 3), as they were during the spring survey. Quillback rockfish had a significant association with large boulder (Fisher's exact, $p < 0.0016$) as a primary habitat type and crevice (Fisher's exact, $p < 0.0269$) as a secondary habitat type.

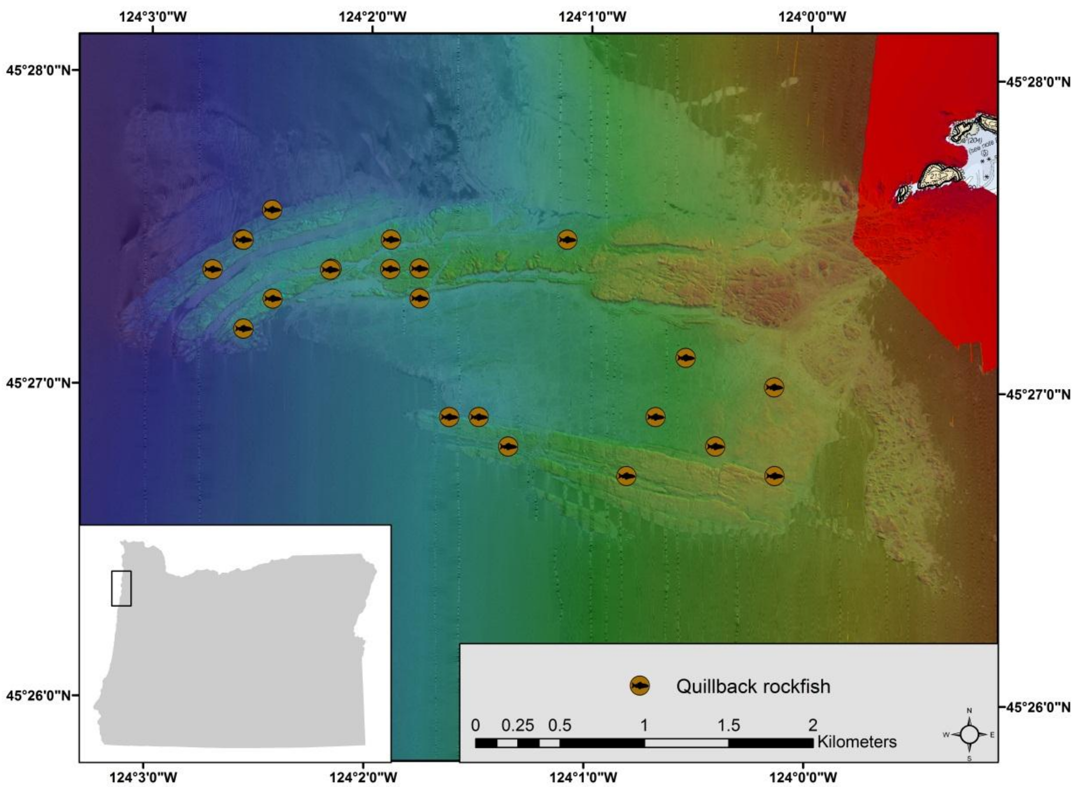

Figure 1. Distribution of quillback rockfish across the Three Arch Rocks reef as observed with the video lander over both the spring (April-June 2011) and winter (December 2011) surveys combined.

Kelp greenling

Kelp greenling are unique amongst temperate Pacific rocky reef fishes in that they are sexually dimorphic; exhibiting distinct coloration and pattern differences between males and females (Figure 2). Kelp greenling had a broad distribution across the reef, by both habitat type and depth, and were the most abundant non-*Sebastes* species viewed with the video lander during the spring survey, and second most abundant in winner (Table 3). Of the kelp greenling observed by the video lander over the course of both surveys, each sex exhibited separate significant habitat associations (Table 6).

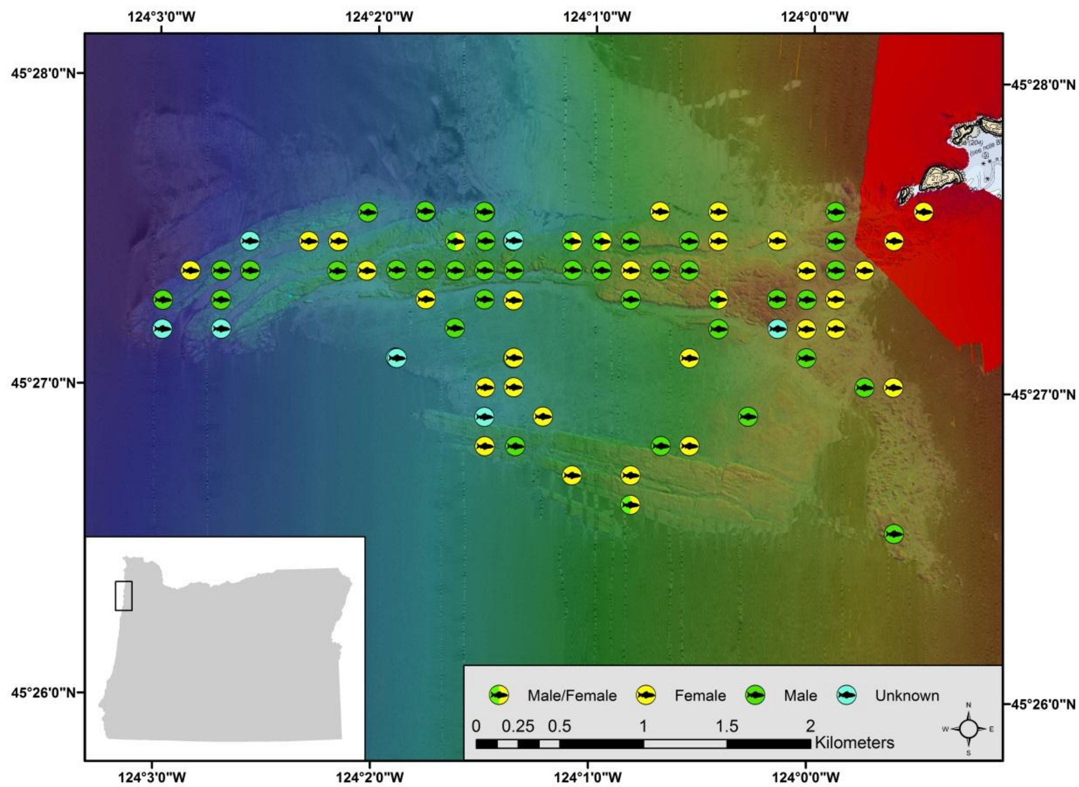

Figure 2. Distribution of kelp greenling, by sex, across the Three Arch Rocks reef as observed with the video lander for both the spring (April-June 2011) and winter (December 2011) surveys combined.

Lingcod

Lingcod, the fifth most abundant fish and second most abundant non-*Sebastes* species during the spring survey, were observed over a wide range of depth and habitat types (Figure 3). The diverse range over which lingcod were observed was reflected in the lack of significant associations found with primary habitat types (Table 6). Lingcod only exhibited significant associations with two secondary habitat types; crevice (Fisher's exact, $p < 0.0332$) and small boulder (Fisher's exact, $p < 0.0010$), as well as significant negative associations with sand as both a primary (Fisher's exact, $p < 0.0001$) and secondary (Fisher's exact, $p < 0.0140$) habitat type.

Lingcod were not frequently observed during the winter survey, with just six individuals at five separate locations observed (Table 3). Lingcod did show a significant association with bedrock outcrop (Fisher's exact, $p < 0.0431$) as a secondary habitat type; however the limited number of observations restricted the ability to identify any additional habitat associations.

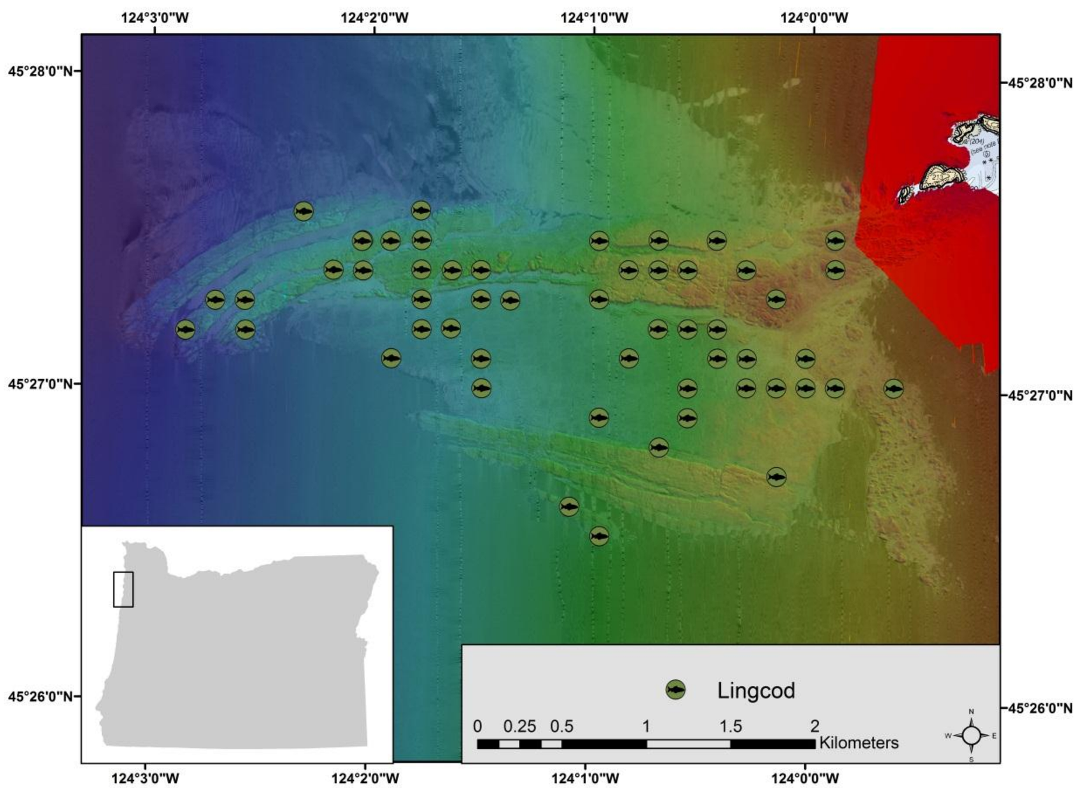

Figure 3. Distribution of lingcod across the Three Arch Rocks reef as observed with the video lander over both the spring (April-June 2011) and winter (December 2011) surveys combined.

Pile perch

Pile perch were observed with some regularity along the northern region of the reef during the spring, however were not observed during the winter survey (Figure 4).

They exhibited a similar distribution pattern to black, blue and yellowtail rockfish in that they appeared to be associated with the reef structure itself, and no individual habitat type in particular. This was evidenced by the fact that they did not show any significant habitat associations aside from a significantly negative association with sand as a primary (Fisher's exact, $p < 0.0005$) and secondary (Fisher's exact, $p < 0.0225$) habitat type (Table 6).

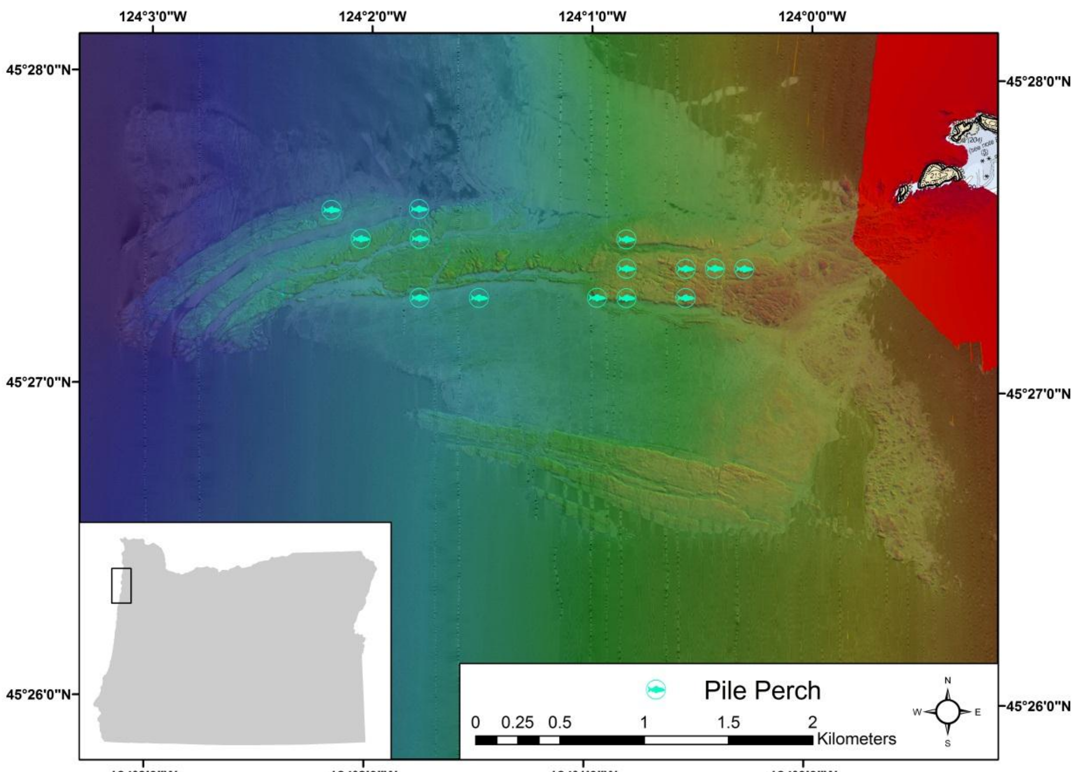

Figure 4. Distribution of pile perch across the Three Arch Rocks reef as observed with the video lander over both the spring (April-June 2011) and winter (December 2011) surveys combined.

Spotted ratfish

Spotted ratfish were observed by the video lander on the Three Arch Rocks reef structure during the winter survey only, and were the most abundant non-*Sebastes* fish observed at that time of year (Table 3). While spotted ratfish did not show any significant negative associations to rocky habitat making up the main reef structure, they demonstrated an apparent distribution around the reef edges (Figure 5), and an association with low relief habitat (Table 6).

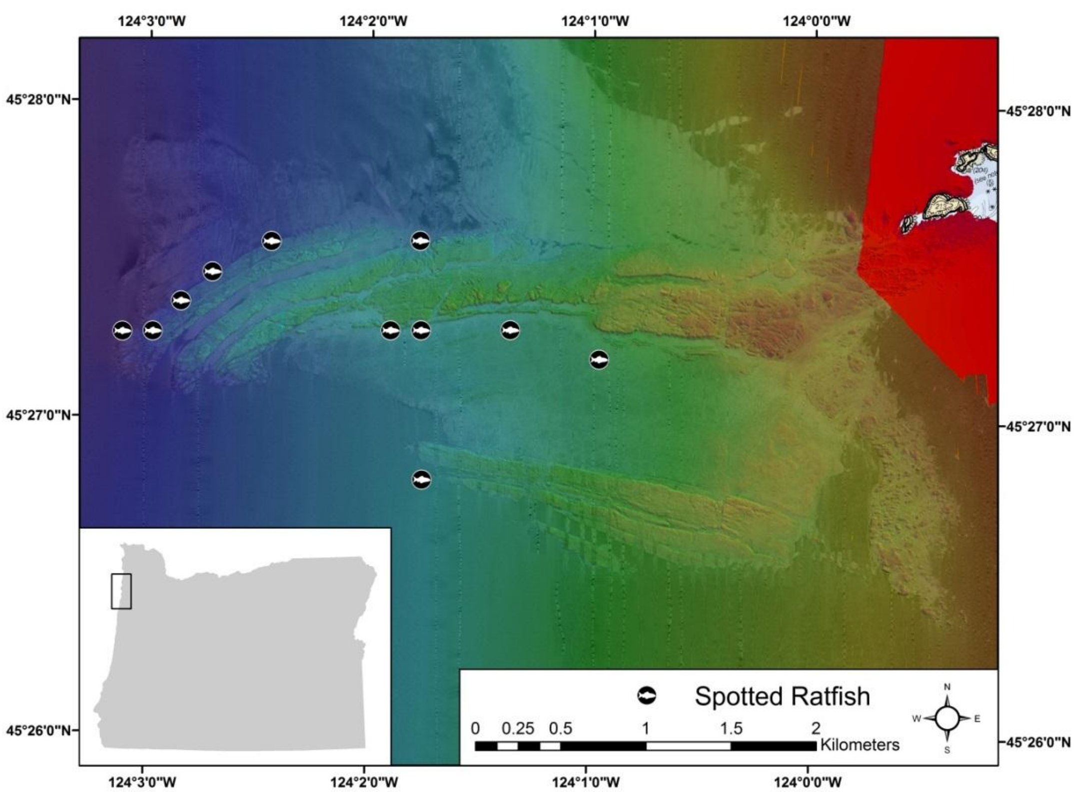

Figure 5. Distribution of spotted ratfish across the Three Arch Rocks reef as captured with the video lander for the winter (December 2011) survey.

Distribution

Video lander data provides information on habitat associations of demersal species under-represented in commercial and recreational fishing data, further enhancing our understanding of their distribution. The relationship of quillback rockfish to small boulder habitat is consistent with findings in Puget Sound, where quillback rockfish showed a strong response to habitat complexity but not to relief (Pacunski & Palsson 2002). However, this species showed a shift in their habitat association from moderate-relief habitat in the spring to high-relief crevice and large boulder habitat in the winter. This may indicate a shift in behavior; regardless, quillback were always associated with high complexity habitats, which is consistent with previous studies (Matthews 1990, Pacunski & Palsson 2002, Love et al. 2006).

The broad scale distribution of lingcod across the reef is similar to findings in Puget Sound where lingcod were associated with a variety of rocky habitats of varying complexity and relief (Pacunski & Palsson 2002). The lack of observations of lingcod on the reef structure by the video lander in December was also surprising, as previous research indicated there would be an abundance of lingcod moving in to spawn and nest-guard during this time (Shaw & Hassler 1989, Love et al. 2002, Love 2011).

Similarly to lingcod, kelp greenling were broadly distributed across the reef, exhibiting associations with a variety of habitat types. Similar observations from Puget Sound showed that kelp greenling showed low habitat specificity, being observed across a wide range of generalized habitat classifications (Pacunski & Palsson 2002). Additionally, the spatial separation and differences in significant habitat associations between kelp greenling sexes is consistent with previous findings suggesting that male and female kelp greenling would stay apart during certain times of the year (Rosenthal 1980).

The occurrence of spotted ratfish on the reef complex during the winter survey was unexpected as they were not observed during the spring survey; however this area is within the species' natural range (Barnett et al. 2009, Love 2011). Based on the observations with the video lander, spotted ratfish appear to be distributed around the reef edge, both outer and inner regions around the main reef structure (Figure 5). The mix of moderate to low relief habitat, as well as their distribution into shallower water in the late autumn/early winter period is consistent with previous studies demonstrating spawning signs during this time period, with eggs over substrate with smaller particle size like gravel and pebble (Barnett et al. 2009, Love 2011). Furthermore, there is evidence suggesting that spotted ratfish move in from offshore foraging areas to spawn and release their egg-cases during this fall/winter period, possibly explaining their appearance in the nearshore during the winter survey (Barnett et al. 2009, Love 2011).

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