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Quantification of Habitat and Community Relationships among Nearshore Temperate Fishes Through Analysis of Drop Camera Video

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Abstract
    Temperate nearshore reefs along the Pacific coast of North America are highly valuable to commercial and recreational fisheries yet comprise a small fraction of the seabed. Monitoring fisheries resources in this region is difficult; high-relief structural complexity and adverse sea conditions have led to a paucity of information on temperate reef species assemblage patterns. Reliable, inexpensive tools and methods for monitoring are needed, as many traditional tools are both logistically complicated and expensive, limiting the frequency of their implementation over a large scale. Video drop cameras of varying designs have previously been employed to estimate fish abundance and distribution. We surveyed a nearshore rocky reef off the northern Oregon coast with a video lander (a video camera mounted on a landing platform so it can be dropped to the seafloor) over the spring and winter of 2011. We designed a 272-point systematic grid to document the species assemblage and the distribution and habitat associations of the reef species, including two overfished rockfishes: Canary Rockfish *Sebastes pinniger* and Yelloweye Rockfish *Sebastes ruberrimus*. Species assemblages differed significantly across the reef by depth and by season for the outer part of the reef. Well-defined habitat associations existed for many species; Canary Rockfish were associated with complex moderate-relief habitat types such as large boulders and small boulders, while Yelloweye Rockfish were associated with high-relief habitats like vertical walls. Species associations were evaluated pairwise to identify nearshore complexes. We compared our site with five exploratory reef sites off the central Oregon coast and found that nearshore reefs differed from our site, while offshore reefs were more similar. Video landers provide a solution to the need for increased sampling of temperate reef systems that are subject to difficult conditions and can contribute to habitat mapping, fish abundance indices, and fish assemblage information for monitoring and management of fisheries resources.

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Temperate nearshore reefs along the Pacific coast of North America represent areas of valuable economic resources for commercial and recreational fisherman (Williams and Ralston 2002; Fox et al. 2004; Gunderson et al. 2008). In Oregon's territorial sea (out 5.6 km), nearshore rocky reefs make up only a small fraction of the total area (∼7%), with the remaining region comprised predominately of sand and unconsolidated sediments (D. Fox, Oregon Department of Fish and Wildlife, personal communication). However, these reefs constitute much of the Essential Fish Habitat designated for many pelagic and demersal fishes, which currently inhabit the nearshore region (PFMC 2005; PFMC 2011).

Monitoring fisheries resources and habitat in temperate reefs is difficult due to their high-relief structural complexity, adverse sea conditions that are common in temperate regions, and depths that often exceed those safe for visual surveys by scuba (Adams et al. 1995; Williams et al. 2010). Therefore, there is a paucity of information on species assemblage patterns on temperate reefs at different times of the year and along depth gradients. More information is needed to determine how the reefs function as critical habitat and to refine the fine-scale habitat associations of the fish that utilize those habitats (Gunderson et al. 2008). Annual trawl surveys conducted by the National Marine Fisheries Service currently cover the continental shelf from Cape Flattery, Washington, to the USA–Mexico border, but this survey does not come close to shore and trawls are 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).

Visual survey tools, such as remotely operated vehicles (ROVs) and human-occupied vehicles, are useful to survey untrawlable rocky habitats. These methods collect valuable information regarding the distribution, relative abundance, and species–habitat associations of various fish species, further aiding Essential Fish Habitat designation (Stein et al. 1992; Krieger 1993; Adams et al. 1995; Johnson et al. 2003; Yoklavich et al. 2007). However, the expense and expertise required for these methods, as well as confounding depth and sea conditions, can make them prohibitive to employ over a large scale within shallow (<70 m), highly productive nearshore waters. Recently, in the nearshore waters of the U.S. West Coast, there have been efforts to establish Marine Protected Areas and Marine Reserves, as well as to expand comprehensive multibeam seafloor mapping. Reliable, inexpensive tools and methods to monitor the effects of protected areas on local fish stocks are needed, as traditional tools (ROVs, autonomous underwater vehicles, and human-occupied vehicles) are both logistically complicated and expensive, generally limiting the frequency of their implementation. Video lander systems (a video camera mounted on a landing platform so it can be dropped to the seafloor) may be the solution to the increased

sampling needed to ground-truth habitat maps and determine the relative abundance and distribution of nearshore fisheries resources over broad areas and in winter months.

In northeastern Pacific Ocean waters, highly variable and changing conditions represent obstacles to those researchers who are looking to obtain nonextractive visual data on nearshore Pacific rocky-reef fishes. Video drop cameras of varying designs have previously been employed as noninvasive tools for estimating fish abundance and distribution. Baited underwater video stations and baited remote underwater video stations have been shown to be effective in estimating the relative abundance of many fish that are mobile or solitary and that have low population sizes or avoid other visual survey methods (Ellis and DeMartini 1995; Priede and Merrett 1996; Willis and Babcock 2000; Cappo et al. 2004; Harvey et al. 2007; Stobart et al. 2007; Hannah and Blume 2012; Wakefield et al. 2013). Nonbaited underwater photo and video lander platforms 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, which would bias potential species–habitat associations (Gledhill et al. 1996; Roberts et al. 2005; Hannah and Blume 2012).

The objectives of this research were multifaceted, with a primary aim to determine the ability of a low-cost drop camera system to comprehensively survey a temperate nearshore rocky reef. We documented the species assemblage and the distribution and habitat associations of nearshore Pacific rocky-reef fishes in spring and winter to describe the distribution of key fished species, including two overfished rockfishes that are under intensive "stock rebuilding plans" by the Pacific Marine Fisheries Council. The video lander was evaluated as a survey tool for monitoring protected areas in nearshore temperate reef complexes, while concurrently assessing the ability to be used as a comprehensive ground-truthing tool to identify habitat types that are currently used by multibeam sonar surveys. Finally, we analyzed fish community composition with a recently developed quantitative method that measures pairwise species co-occurrence (Stone and Roberts 1990; Ulrich and Gotelli 2010; Groundfish Management Team 2013).

METHODS

The video lander we used is an autonomous underwater video system designed and built for use in high-relief rocky habitat by the Oregon Department of Fish and Wildlife's Marine Resources Program (Hannah and Blume 2012). The video lander is composed of an aluminum tube frame, a Deep Sea Power and Light (DSPL) Multi-SeaCam 2060, dual DSPL LED Ritelites (850 lm, 3,000 K), and an aluminum pressure housing containing two 13.2V rechargeable NiMH battery packs, a controller board, a Sony TRV-11 digital camcorder (recording video received from the DSPL Multi-SeaCam 2060) recording onto 60-min Mini DVC cassette tapes, and either a depth activated pressure switch used in waters deeper

than 18 m or a push activated switch for shallower depths (Figure 1). 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 the retrieval probability in high-relief rocky habitat. The digital video footage from each lander drop was transferred from the original Sony DVC 60-min cassettes into digital format on a personal desktop computer with Adobe Premiere Pro through a fire-wire-connected Sony GV-HD700 portable video recorder deck. The video lander was deployed unbaited to avoid drawing in fish from other habitat types near the sampling point.

We selected the Three Arch Rocks rocky-reef complex located off Oceanside, Oregon, approximately 11 km south of the entrance to Tillamook Bay, for its broad depth range and known species diversity (Figure 2). The structure of the reef is a horseshoe pattern, running approximately 5 km east–west and 2 km north–south (Figure 3). Three Arch Rocks reef has a broad depth range, from surface to approximately 75 m as it runs east to west, and is known to support a high diversity of marine species (E. Schindler, Oregon Department of Fish and Wildlife, personal communication).

The video lander was initially deployed on the Three Arch Rocks reef on 12 separate days between April 17 and June 28,
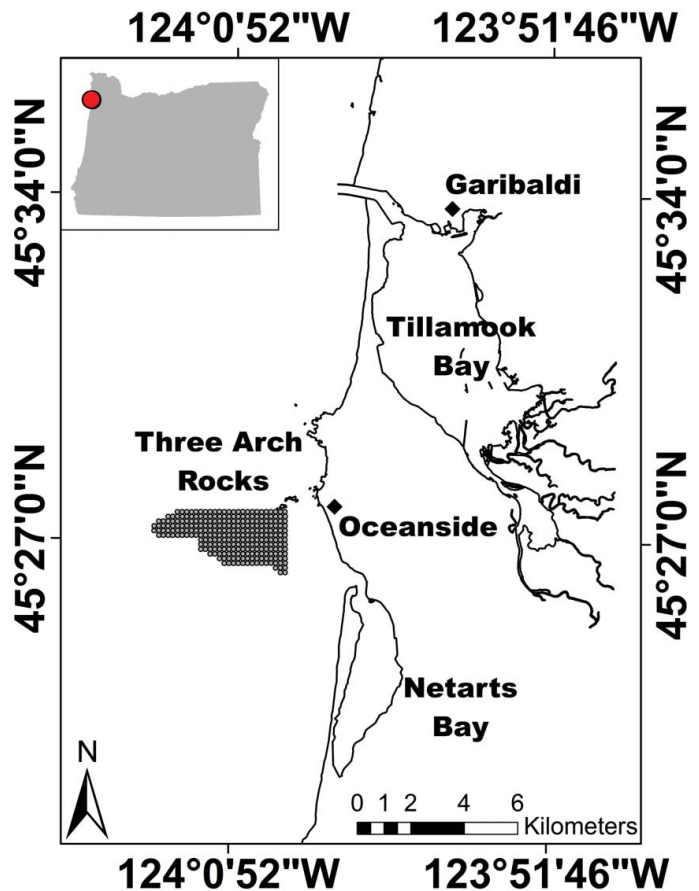

FIGURE 2. Three Arch Rocks rocky-reef study area off of Oceanside, Oregon, located approximately 11 km south of the entrance to Tillamook Bay. The study area covers approximately 15 km^2.

2011. A systematic grid consisting of 272 individual drop points, spaced 175 m apart, was designed to maximize coverage of the reef structure while capturing all possible habitat types throughout the reef's entire depth range (Figure 3). The grid spacing was designed to maintain independence, while reducing the possibility for double counting individual fish during any given sampling day (Matthews 1990a, 1990b, 1992; Pacunski and Palsson 2002). The entire grid was blocked into seven regions prior to the survey, with the goal of completing at least one blocked section each day. The video lander platform used for the spring survey was again employed for winter sampling in December 2011, with the addition of a set of 10-cm paired scaling lasers to better quantify substrate grain size. Two separate attempts were made to complete the grid between December 1 and December 9, 2011; however, due to poor underwater visibility conditions we were only able to successfully survey a contiguous block of 70 drops comprising the outer quarter of the grid.

The video lander was deployed for a fixed duration during daylight hours at each sampling location, following the protocols in Hannah and Blume (2012). Each video sample consisted of 5 min of recorded bottom time, beginning at

FIGURE 1. The video lander platform utilized at Three Arch Rocks reef. Displayed in the photo are the Deep Sea Power and Light (DSPL) Multi-Sea-Cam 2060 (1), dual DSPL LED Mini-Sealites (2), pressure tube containing batteries and Sony TRV-11 digital camcorder (3), sacrificial (breakaway) base (4), and steel-rod weight bar (5), with arrows showing the break-away connection points.
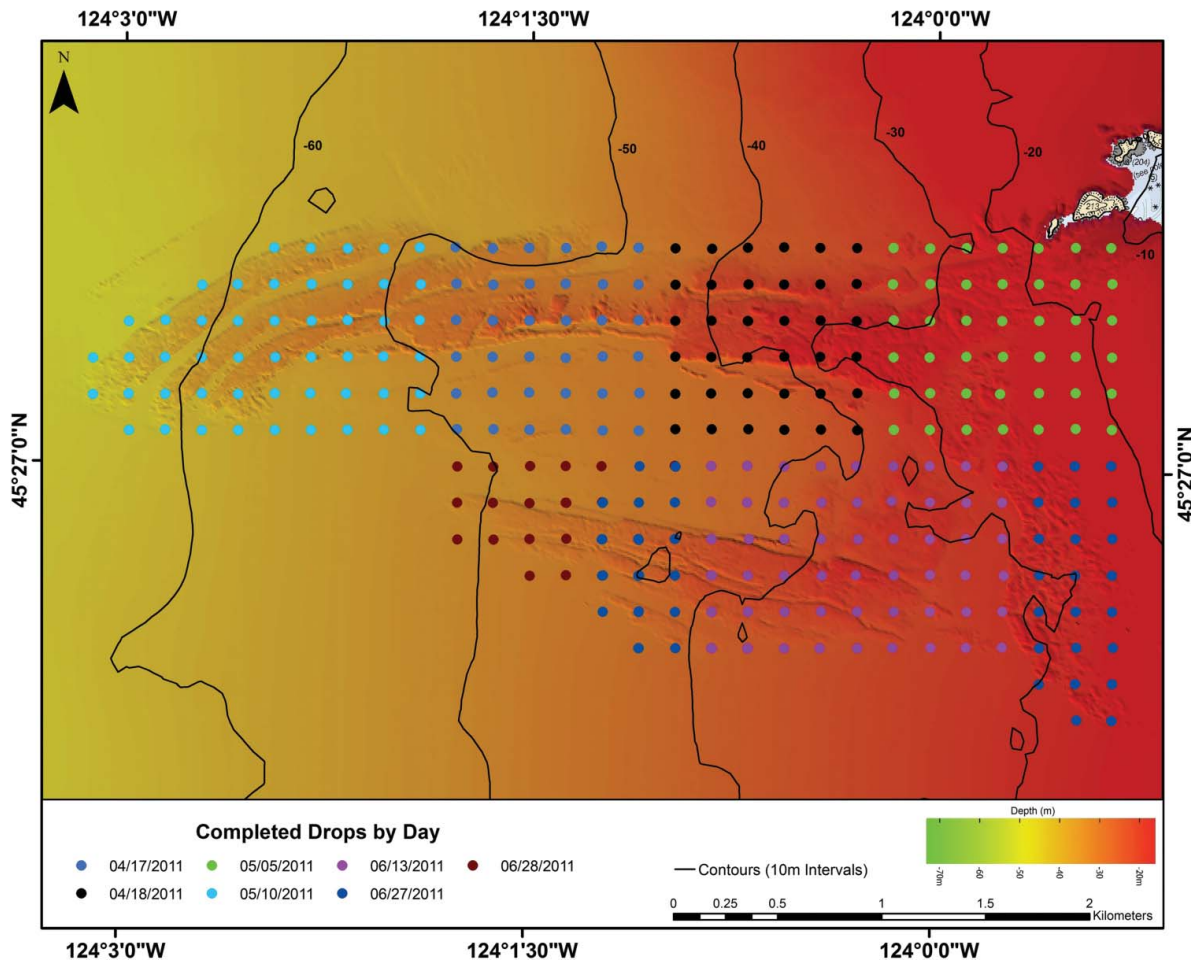
FIGURE 3.   The video lander systematic survey grid of the Three Arch Rocks reef completed in the spring (April–June) of 2011. Each point represents an individual drop site within the grid by calendar day (175-m spacing).

the estimated time of the lander reaching the seafloor and ending when retrieval began. Five minutes of recorded bottom time allowed for sufficient sediment settling, as well as capturing a maximum count of species present. Completed video tapes were reviewed aboard the vessel to determine underwater visibility and if any drops needed to be repeated based on low water clarity, camera orientation, or visual obstruction.

During the spring survey, 415 individual drops were completed over 12 boat-days, providing over 48.5 h of video footage. Of the 12 total sampling days, 7 d showed good bottom visibility, 1 d showed moderate bottom visibility, and 4 d showed little to no underwater visibility on the bottom, where turbidity obscured the view to the point that neither habitat nor fish were discernable, thus requiring resampling of these sites. A total of 143 drops had to be repeated due to poor underwater visibility or an obstructed view. The final sample size for analysis was 272 drops, a single drop for each of the 272 sampling locations. We used the drop with the highest score for visibility and view in cases when an individual site required resampling because habitat type or species were indiscernible due to

high turbidity or marine snow. 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. Of these 108 usable drops, a continuous block of 70 drops comprising the outer reef section were used for species composition comparison with the spring survey results.

Following the field deployments, videos were reviewed in the laboratory by the primary author. Video review consisted of two separate components. The initial review was used to describe camera visibility and view, as well as topographic relief (Table 1). Topographic relief was defined as flat, low, or high depending on the observed habitat type at each drop location. We did not have a way to accurately measure distance sampled by the camera but roughly classified visibility conditions on a scale from 0 to 2 (poor, medium, good) following the criteria in Table 1 (Hannah and Blume 2012). Primary habitat (dominant habitat type in the camera's view) and secondary habitat (second most abundant habitat feature in view) were classified for each drop based on the habitat criteria shown in Table 2 (Hannah and Blume 2012). Drops that had

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

Category	Class	Description
Relief	0	Flat (sand, flat bedrock, gravel or 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 or marine snow or both
	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

view and visibility scores of 0 were excluded from analysis. The second review was used to identify fish observed on the video, which were identified to the lowest taxonomic level possible, usually to species. The maximum count of individuals from each species in any single frame (MaxN) 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 included in the maximum count. Habitat observations made from the review of video lander footage were compared with a habitat classification map of the Three Arch Rocks region developed and provided by the Active Tectonics and Seafloor Mapping Lab (ATSML) at Oregon State University. The ATSML habitat maps are developed from multibeam sonar scans that collect data on a 4-m × 4-m (16 m^2) grid pixel size. To develop a habitat map, these grid boxes are smoothed into 10-m × 10-m (100 m^2) mapping units for which the dominant habitat type is displayed in a habitat box.

We investigated the species–habitat associations of the 9 most abundant fish species observed on the Three Arch

Rocks reef during the spring survey and the 10 most abundant fish species observed during the winter survey. These included the following: Black Rockfish *Sebastes melanops*, Blue Rockfish *Sebastes mystinus*, Canary Rockfish *Sebastes pinniger*, Quillback Rockfish *Sebastes maliger*, Yelloweye Rockfish *Sebastes ruberrimus*, Yellowtail Rockfish *Sebastes flavidus*, Lingcod *Ophiodon elongatus*, Kelp Greenling *Hexagrammos decagrammus*, Spotted Ratfish *Hydrolagus colliei* (winter only), and Pile Perch *Damalichthys 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 of the primary and secondary habitat types identified. Unidentified adult fish were excluded from all analyses; however, unidentified juvenile rockfish *Sebastes* spp. were included in the analyses and treated as their own category.

Differences in species assemblages and relative abundance (maximum count per drop in a single frame; MaxN) between sections of the reef were analyzed with a pairwise one-way

TABLE 2. Habitat criteria used to classify the primary and secondary habitat types observed at the Three Arch Rocks reef complex from video lander survey footage (Hannah and 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 in diameter (includes angular blocks broken off from bedrock)
SB	Small boulder	Boulders approximately 0.25–1.00 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 0.06–2.00 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° to the horizontal
HA	Hash	Small broken bits of shells

analysis of similarity (ANOSIM), adjusted for multiple comparisons with a step-down sequential Bonferroni correction, using the software package Paleontological Statistics 2.15. The degree of difference in the species composition was then measured using the Bray–Curtis dissimilarity index (BCDI) in the SIMPER routine (Bray and Curtis 1957; Hammer et al. 2001; Hannah and Blume 2012). Every drop, including those with no observations, was included in both analyses. The relative abundance of each species observed among sections of the study site was compared using a nonparametric Wilcoxon test, as has been previously used with video lander data (Hannah and Blume 2012). Additionally, the species assemblage at Three Arch Rocks reef was compared with the species assemblages of five exploratory sites surveyed by a video lander and presented in Hannah and Blume (2012). This assemblage comparison was again performed using pairwise one-way ANOSIMs, adjusted for multiple comparisons using a step-down sequential Bonferroni correction in Paleontological Statistics 2.15.

Pairwise species co-occurrence was evaluated using the checkerboard score (C-score) metric to provide a single score of co-occurrence of a pair of species using presence–absence data (Stone and Roberts 1990; Ulrich and Gotelli 2010; Groundfish Management Team 2013):

$$C_{ij} = \frac{(K_i - S_{ij}) \times (K_j - S_{ij})}{K_i \times K_j},$$

where K_i = the number of occurrences of species i, K_j = the number of occurrences of species j, and S_{ij} = the number of co-occurrences of species i and j. The C-score analysis provides a normalized value of 0–1, where 1 indicates perfect segregation between the two species and 0 indicates complete overlap. The Groundfish Management Team considers C-scores above 0.70 as a strong indication that the two species are segregated and scores of 0.30 and below as the two species exhibiting a high degree of overlap.

FIGURE 4.   Total distribution of habitat types (see Table 2) across the Three Arch Rocks reef as observed by the video lander (April through June 2011) overlaid on a habitat classification map ($\geq$ 100-m^2 mapping unit patch size) developed by Oregon State University's Active Tectonics and Seafloor Mapping Lab (ATSML) for the state waters mapping project. Video-lander-observed habitat classifications are shown as a divided circle with primary habitat type on the left and secondary habitat type on the right; if only one habitat type was observed the circle is shown as a contiguous color. (For simplification, the video lander habitat classification legend shows only the reference color of the primary habitat type observed).

RESULTS

Habitat characterization over the entire survey grid revealed that 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 (large boulder [4.0%], vertical wall [5.9%], and crevice [3.7%]) and moderate-to-low-relief habitat types (cobble [9.2%], gravel–pebble [5.9%], and small boulder [8.4%]) registering lower in overall frequency (Figure 4). We compared the habitat classifications characterized from the review of video lander footage with habitat maps developed by Oregon State University's ATSML for the state waters mapping project. We found an 80.1% agreement of primary habitat type between our habitat classifications and the ATSML classifications at the lowest resolution of the two classifications. Differences in agreement between the two methodologies is primarily due to scale; the video lander provides a view over a relatively small area, while habitat maps generated from multibeam sonar and backscatter data generally blend multiple similar habitat types into more uniform classifications. This habitat smoothing inherently leads to a loss of fine-scale habitat resolution in multibeam sonar habitat mapping, which is information the video lander is able to provide. Discrepancies along the edges between habitat types may indicate important areas for resampling.

Species Abundance and Distribution

While many (46% in spring, 36% in winter) of the drops performed over the course of the survey did not have any fish observed, the majority of the sites surveyed by the video lander had one or more fish species present. Over the course of the spring survey, the nine most abundant species observed by the video lander showed distinct habitat and depth associations,

TABLE 3. Habitat associations (based on P-values obtained from Fisher's exact test) 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. Kelp Greenling is the only fish with clear sexual dimorphism that could be observed in the videos. Significant P-values are color-coded by survey period: yellow = spring significant positive association, blue = winter significant positive association, green = spring and winter significant positive association, and red = significant negative association. If a significant P-value was identified during both survey periods, the "less significant" of the two seasons is presented. The abbreviations for habitat type are as follows: bedrock outcrop (BR), large boulder (LB), small boulder (SB), crevice (CR), vertical wall (VW), cobble (CO), gravel–pebble (GP), and sand (SA).

Common and scientific name	Primary habitat type							
	BR	LB	SB	CR	VW	CO	GP	SA
Black *Rockfish* *Sebastes melanops*	0.0068	0.0357	>0.1000	0.0004	>0.1000	>0.1000	>0.1000	<0.0001
Blue Rockfish *Sebastes mystinus*	>0.1000	0.0335	>0.1000	0.0255	0.0024	>0.1000	>0.1000	0.0005
Canary Rockfish *Sebastes pinniger*	>0.1000	0.0081	0.0372	>0.1000	0.0743	0.0492	>0.1000	<0.0001
Quillback Rockfish *Sebastes maliger*	>0.1000	0.0016	0.0535	>0.1000	0.0791	0.0701	>0.1000	<0.0001
Yelloweye Rockfish *Sebastes ruberrimus*	0.0552	0.0073	>0.1000	0.0004	0.0362	>0.1000	>0.1000	<0.0001
Yellowtail Rockfish *Sebastes flavidus*	>0.1000	0.0157	>0.1000	0.0156	0.0017	>0.1000	>0.1000	0.0003
Kelp Greenling *Hexagrammos decagrammus*	0.0162	0.0008	0.0110	>0.1000	>0.1000	>0.1000	>0.1000	<0.0001
Male	0.0033	0.0070	0.0432	>0.1000	>0.1000	>0.1000	>0.1000	<0.0001
Female	>0.1000	>0.1000	>0.1000	>0.1000	>0.1000	0.0421	>0.1000	0.0051
Lingcod *Ophiodon elongatus*	0.0845	>0.1000	>0.1000	0.0794	>0.1000	>0.1000	>0.1000	<0.0001
Pile Perch *Damalichthys vacca*	>0.1000	>0.1000	>0.1000	0.0874	>0.1000	>0.1000	>0.1000	0.0005
Spotted Ratfish *Hydrolagus colliei*	>0.1000	>0.1000	>0.1000	>0.1000	>0.1000	0.0475	>0.1000	>0.1000

(*extended on next page*)

while three other identified fishes (Copper Rockfish *Sebastes caurinus*, Cabezon *Scorpaenichthys marmoratus*, and unidentified juvenile rockfishes) were not observed with enough regularity to identify any significant associations (Table 3).

In total, 745 individual rockfish were observed, among 939 total individual fish of all species, as well as 17 Dungeness crab *Metacarcinus magister* (Table 4). Over the course of the spring survey, Black Rockfish was the most abundant species overall (34 stations, 277 individuals), with Canary Rockfish being the second most abundant (41 stations, 225 individuals) (Table 4). The most abundant and frequently observed demersal rockfish species was Yelloweye Rockfish (22 stations, 27 individuals) (Table 4). Kelp Greenlings were the most frequently observed fish other than rockfish on the reef (67 stations, 90 individuals), while Lingcod were second (48 stations, 61 individuals) (Table 4). These two hexagrammid fishes

were also the species with the broadest habitat associations and depth distributions.

During the winter survey, pelagic schooling rockfish (Black Rockfish, Blue Rockfish, and Yellowtail Rockfish) were the most abundant group of fishes observed on the reef, with Yellowtail Rockfish (14 stations, 92 individuals) being the single most abundant and frequently observed of the three (Table 4). Canary Rockfish (19 stations, 40 individuals) was the second most abundant species overall, excluding Northern Anchovy *Engraulis mordax*, and were observed in the greatest frequency (Table 4). The most abundant and frequently observed demersal rockfish was Yelloweye Rockfish (10 stations, 15 individuals), followed by Quillback Rockfish (4 stations, 5 individuals) (Table 4).

In winter, Kelp Greenlings (16 stations, 17 individuals) exhibited a broad distribution across depth and habitat, while

TABLE 3. Extended.

Common and scientific name	Secondary habitat type							
	BR	LB	SB	CR	VW	CO	GP	SA
Black Rockfish *Sebastes melanops*	0.0087	0.0351	>0.1000	0.0024	>0.1000	>0.1000	0.0532	<0.0001
Blue Rockfish *Sebastes mystinus*	>0.1000	0.0072	0.0009	<0.0288	>0.1000	>0.1000	>0.1000	0.0003
Canary Rockfish *Sebastes pinniger*	>0.1000	0.0085	0.0095	>0.1000	>0.1000	>0.1000	>0.1000	<0.0001
Quillback Rockfish *Sebastes maliger*	>0.1000	0.0560	0.0143	0.0269	>0.1000	>0.1000	>0.1000	0.0045
Yelloweye Rockfish *Sebastes ruberrimus*	>0.1000	0.0003	0.0626	>0.1000	>0.1000	>0.1000	>0.1000	0.0343
Yellowtail Rockfish *Sebastes flavidus*	>0.1000	>0.1000	0.0067	<0.0001	>0.1000	>0.1000	>0.1000	0.0130
Kelp Greenling *Hexagrammos decagrammus*	0.0105	0.0487	>0.1000	0.0177	>0.1000	>0.1000	>0.1000	<0.0001
Male	0.0053	0.0224	>0.1000	0.0030	>0.1000	0.0868	0.0529	<0.0001
Female	>0.1000	>0.1000	>0.1000	0.0955	>0.1000	>0.1000	>0.1000	0.0019
Lingcod *Ophiodon elongatus*	0.0431	>0.1000	0.0010	0.0332	0.0814	>0.1000	>0.1000	0.0206
Pile Perch *Damalichthys vacca*	>0.1000	>0.1000	0.0569	>0.1000	>0.1000	>0.1000	>0.1000	0.0225
Spotted Ratfish *Hydrolagus colliei*	>0.1000	>0.1000	0.0008	>0.1000	>0.1000	>0.1000	>0.1000	>0.1000

TABLE 4. Maximum count (n), number of drop sites each species was observed at (Drops), relative abundance (%; n/total number of fish observed), 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.

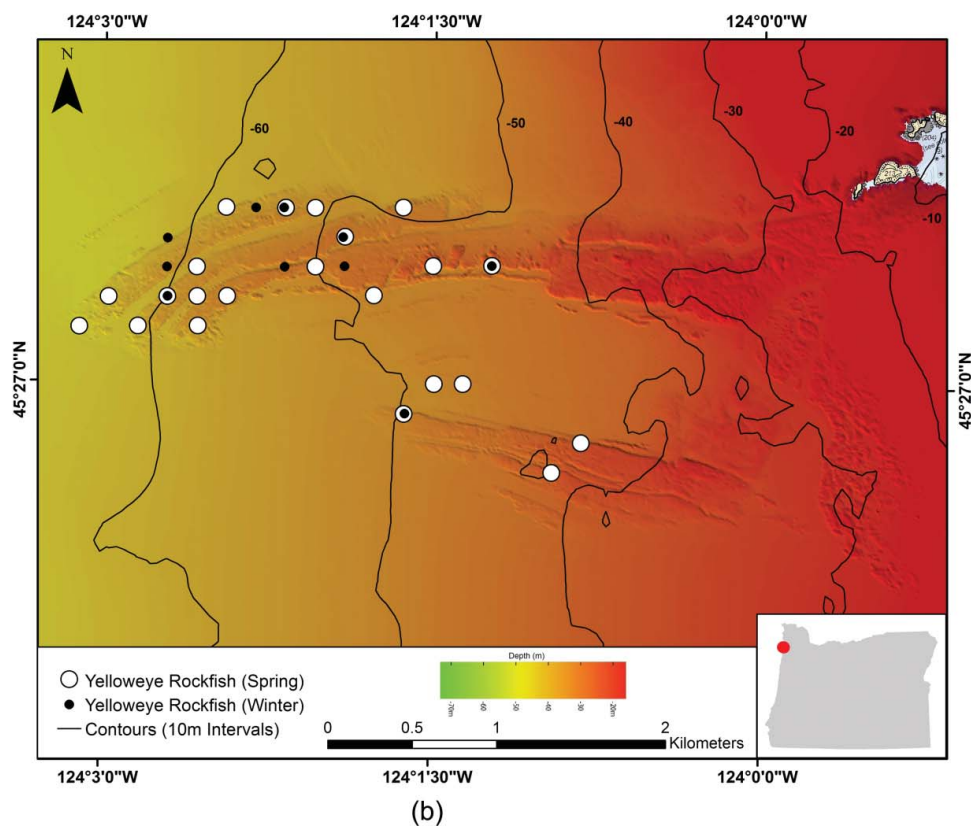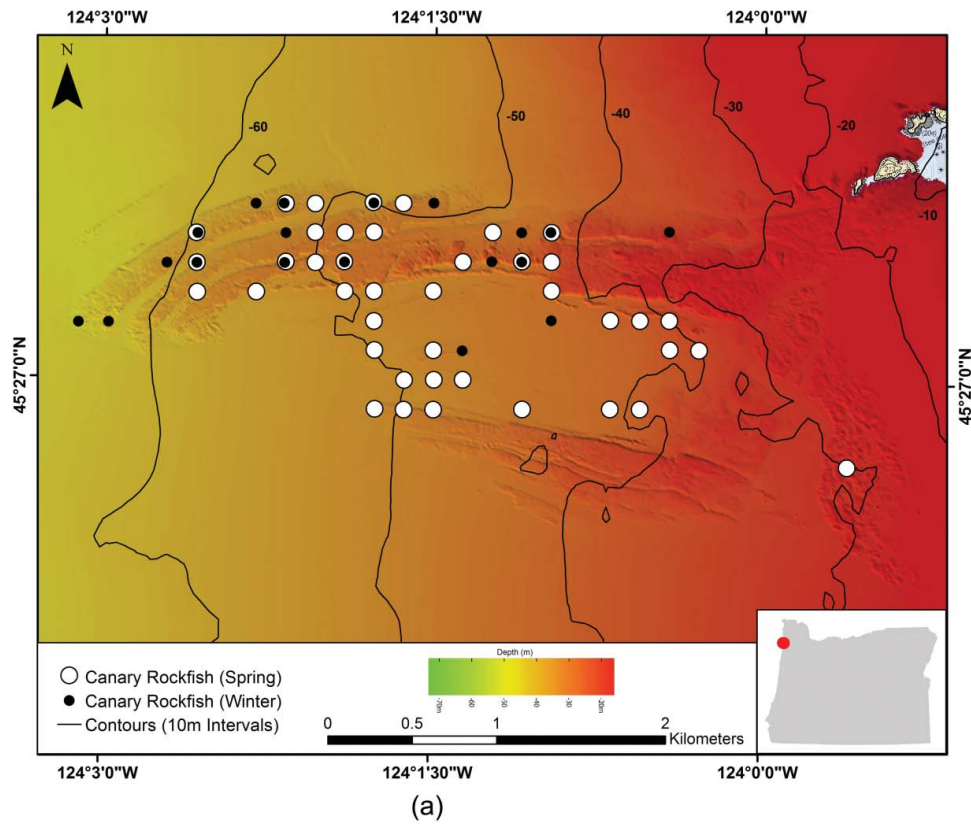| Common and scientific name and totals	Total		Spring (272 drops)				Winter (108 drops)				Spring and winter comparison	
	n	Rank	n	Drops	%	Rank	n	Drops	%	Rank	Spring (70 drops) n	Winter (70 drops) n
Black Rockfish *Sebastes melanops*	303	1	277	34	29.5	1	26	6	9.5	3	6	0
Canary Rockfish *Sebastes pinniger*	265	2	225	41	24.0	2	40	19	14.7	2	154	28
Yellowtail Rockfish *Sebastes flavidus*	147	3	55	55	5.9	6	92	14	33.7	1	35	84
Blue Rockfish *Sebastes mystinus*	139	4	124	19	13.2	3	15	9	5.5	6	11	6
Kelp Greenling *Hexagrammos decagrammus*	107	5	90	67	9.6	4	17	16	6.2	5	27	9
Lingcod *Ophiodon elongatus*	67	6	61	48	6.5	5	6	5	2.2	10	16	6
Yelloweye Rockfish *Sebastes ruberrimus*	42	7	27	27	2.9	7	15	10	5.5	6	21	14
Quillback Rockfish *Sebastes maliger*	26	8	21	18	2.2	9	5	4	1.8	11	12	5
Pile Perch *Damalichthys vacca*	24	9	24	14	2.6	8	NA	0	NA	NA	9	0
Spotted Ratfish *Hydrolagus colliei*	20	10	NA	NA	NA	NA	20	11	7.3	4	0	18
Unidentified fish	20	10	5	4	0.5	12	15	2	5.5	6	2	15
Unidentified rockfish *Sebastes* spp.	19	12	5	5	0.5	12	14	5	5.1	9	1	12
Unidentified flatfish, order Pleuronectiformes	10	13	9	6	1.0	10	1	1	0.4	13	2	1
Unidentified juvenile rockfish *Sebastes* spp.	9	14	4	2	0.4	14	5	3	1.8	11	1	5
Copper Rockfish *Sebastes caurinus*	6	15	6	6	0.6	11	NA	NA	NA	NA	1	0
Cabezon *Scorpaenichthys marmoratus*	3	16	2	2	0.2	15	1	1	0.4	13	2	0
Unidentified surfperch, family Embiotocidae	2	17	2	2	0.2	15	NA	NA	NA	NA	0	0
Tiger Rockfish *Sebastes nigrocinctus*	1	18	NA	NA	NA	NA	1	1	0.4	13	0	1
Wolf-eel *Anarrhichthys ocellatus*	1	18	1	1	0.1	16	NA	NA	NA	NA	1	0
China Rockfish *Sebastes nebulosus*	1	18	1	1	0.1	16	NA	NA	NA	NA	0	0
Northern Anchovy *Engraulis mordax*	>1,500	NA	NA	NA	NA	NA	>1,500	16	NA	NA	0	>1,500
Dungeness crab *Metacarcinus magister*	18	NA	17	4	NA	NA	1	1	NA	NA	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

FIGURE 5.   Distribution of **(A)** Canary Rockfish and **(B)** 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. Slight differences in position location between spring and winter are due to the current shifting the final recorded drop location between seasons.
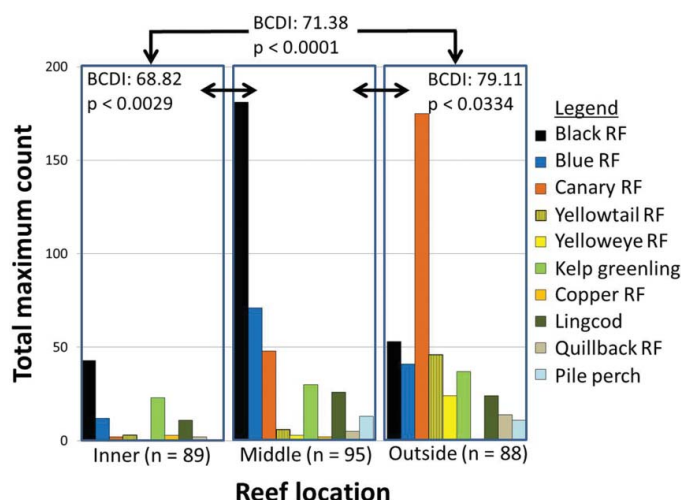
FIGURE 6. Spring (April–June 2011) species composition of Three Arch Rocks reef divided into three depth categories; inner (89 drops), middle (95 drops), and outside (88 drops) across the reef based on video lander video analysis (arrows represent the reef sections compared for species composition and abundance with corresponding Bray–Curtis dissimilarity index [BCDI] values and *P*-values from pairwise one-way ANOSIMs); RF = rockfish.

Lingcod appeared noticeably absent (5 stations, 6 individuals) (Table 4). This absence of Lingcod may be due to spawning migration, as Lingcod are known to nest in shallow-water habitats in winter months (Matthews 1992; O'Connell 1993; Martell et al. 2000). Spotted Ratfish, which were not observed during the spring survey, were observed at 11 stations during December over multiple habitat types. Additionally, schools of varying size of Northern Anchovy, also not observed during the spring survey, were observed at 16 drop stations across the reef in December (Table 4). In total, 213 identified rockfish were observed, among 273 total fish (excluding Northern Anchovy) and one Dungeness crab (Table 4). Some of the species showed consistency in sighting locations between spring and winter surveys. For instance, of the 10 sites where

Yelloweye Rockfish were observed in December, 5 were the same as the spring survey, while Kelp Greenlings were observed again at 8 of 16 total sites. It is impossible to know if these were the same individual fish, but consistency does provide strong evidence for habitat association.

Habitat associations were often significant but varied for some species between winter and spring sampling (Table 3). Nearly all of the species we observed showed negative correlations with sand habitat. Schooling pelagic rockfish (Black Rockfish, Blue Rockfish, and Yellowtail Rockfish) all showed a qualitative relationship with the reef structure, exhibiting a distribution pattern that mirrored the shape of the reef. Yelloweye Rockfish and Canary Rockfish, both currently managed as overfished stocks on the West Coast, exhibited significant associations with a variety of habitat types across the Three Arch Rocks reef (Table 3). During each survey period, Canary Rockfish had the broadest distribution across depths and habitat types of any of the observed rockfish species (Figure 5A). Yelloweye Rockfish on the other hand, while exhibiting significant relationships with high-vertical-relief habitat types (Table 4), showed a more restricted distribution than Canary Rockfish, with the vast majority of observations occurring on the outer third portion of the reef (Figure 5B).

Reef Fish Community Composition

We conducted an analysis of the species composition across the reef 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 (89 drops), middle (95 drops), and outside (88 drops) (Figure 6). 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 result was primarily driven by differences in

TABLE 5. Normalized *C*-scores (pairwise associations) of the 10 most abundant species observed by the video lander during the spring survey. A *C*-score of 0 indicates the total overlap of two species, while a *C*-score of 1 would indicate that the two species are never found together. In general, *C*-scores less than 0.3 (dark gray) are thought to signify species pairs that commonly associate, scores between 0.3 and 0.7 (light gray) indicate moderate association, while scores over 0.7 indicate very low association (unshaded).

Fish species	Blue Rockfish	Canary Rockfish	Yellowtail Rockfish	Yelloweye Rockfish	Kelp Greenling	Copper Rockfish	Lingcod	Quillback Rockfish	Pile Perch
Black Rockfish	0.15	0.70	0.59	0.79	0.47	0.46	0.56	0.84	0.40
Blue Rockfish		0.71	0.36	0.65	0.51	0.79	0.54	0.89	0.66
Canary Rockfish			0.40	0.37	0.49	0.46	0.32	0.51	0.41
Yellowtail Rockfish				0.32	0.57	0.58	0.69	0.58	0.87
Yelloweye Rockfish					0.61	0.80	0.58	0.48	0.78
Kelp Greenling						0.65	0.43	0.55	0.52
Copper Rockfish							0.47	0.79	0.77
Lingcod								0.58	0.29
Quillback Rockfish									0.88

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 6). The inside section, dominated primarily by Black Rockfish and Kelp Greenling, had the lowest overall species abundance and richness. 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: $P < 0.0001$) sections of the reef. The middle section was dominated by Black Rockfish, 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 6).

A comparison of the species composition between the spring and winter surveys, restricted to the contiguous outermost 70 stations of the Three Arch Rocks reef survey that were sampled in both seasons, revealed significant differences in species 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 winter abundance of Canary Rockfish (Wilcoxon test: $P < 0.0168$), Kelp Greenling ($P < 0.0241$), and Lingcod ($P < 0.0456$).

We investigated species correlations using the technique utilized by the Northwest Fisheries Science Center to identify species that commonly associate with others (*C*-score; Groundfish Management Team 2013) (Table 5). Black Rockfish and Blue Rockfish were commonly associated, with *C*-scores of 0.15 and 0.07 in the spring and winter, respectively. During the winter survey, strong pairwise associations were observed for Yelloweye Rockfish and Quillback Rockfish, Blue Rockfish and Yellowtail Rockfish, and Yelloweye Rockfish and Canary Rockfish. Other species pairs exhibited intermediate scores, likely due to low sample sizes (Table 5).

Nearshore Species Assemblage Variation on the Oregon Coast

The presence or absence and relative abundance of nearshore temperate fishes is likely to be quite variable from reef to reef due to differences in environmental conditions and fishing pressure, as well as year-to-year or seasonal movements and recruitment events (Gunderson et al. 2008). 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 temperate Pacific reef fishes. We compared our results from the spring survey with those from five exploratory sites, four nearshore (Cape Perpetua, East Siletz, West Siletz, and Seal Rocks) and one offshore (Stonewall Bank), off the central Oregon coast (presented in Hannah and Blume 2012) and found some interesting differences (Table A.1 in the appendix). The species assemblage at the Three Arch Rocks

reef was significantly different from that of Cape Perpetua, approximately 150 km south (BCDI = 86.02; ANOSIM: $P < 0.0011$). The Cape Perpetua reef, which runs north to south, showed greater relative abundances of Canary Rockfish and juvenile rockfish but lower relative abundances of Kelp Greenling and Black Rockfish during the July survey (Table A.1 in the appendix). The differences were less conclusive for the February survey at Cape Perpetua (BCDI = 81.07; ANOSIM: $P < 0.064$), but this was likely due to the smaller numbers of fish observed in winter months. 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 and Kelp Greenling at the Eastern Siletz site (Table A.1 in the appendix). Similar results were observed when comparing with 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 A.1 in the appendix). In contrast, the Western Siletz reef site was more similar to Three Arch Rocks (BCDI = 78.62; ANOSIM: $P < 0.0721$) (Table A.1 in the appendix). 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 there but also the greater relative abundance of Lingcod at Three Arch Rocks (Table A.1 in the appendix).

DISCUSSION

Assessing and monitoring 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). Our study provides a comprehensive look at how video drop camera survey data can be analyzed to contribute to our understanding of nearshore fishes and their habitat associations.

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 and 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 currently used sampling methods

for nearshore rocky-reef species. Previous work has demonstrated that surveys utilizing various direct video observation techniques, such as video landers, baited underwater video stations, and scuba, are effective at surveying nearshore, shallow-water fish populations (Watson et al. 2005; Langlois et al. 2010; Hannah and Blume 2012). Additionally, video data analyzed from direct observations has been shown to provide relative abundance estimates of a variety of fish species through nonextractive, fishery-independent means (Gledhill et al. 2006; Yoklavich et al. 2007; Coleman et al. 2011; Merritt et al. 2011). Much of this work, however, has been performed in areas such as Hawaii, southern California, and the Gulf of Mexico— regions which are not inhibited to the same extent by the survey challenges present in the highly productive and often turbulent waters of the northeastern Pacific Ocean. Our research demonstrates that a video lander platform can comprehensively survey a temperate nearshore reef under difficult conditions, collecting broad-scale fish assemblage, relative abundance, and habitat data. This illustrates the opportunity for video landers to be developed into a more widely utilized, cost-effective survey tool to monitor nearshore rocky reefs along the Pacific coast of North America and other poorly surveyed systems.

Visual surveys, however, are not without their own limitations. Visibility is 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. The video lander has an advantage over other visual methods in its simplicity and ease of use and deployment, allowing minimal time and effort for data collection relative to conventional ROVs or submersibles (Stein et al. 1992; Krieger and Ito 1999; Johnson et al. 2003; Yoklavich et al. 2007; Pacunski et al. 2008). The 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 data from this study provide information on habitat associations for overfished and rarely surveyed species in both spring and winter seasons that can further contribute to stock assessment and spatial management. The species–habitat associations of many demersal species determined from the spring survey were reinforced by the winter survey (e.g., Yelloweye Rockfish), while others were expanded upon (e.g., Quillback Rockfish) (Table 3). However, due to the low sample size of these species, more drops will be required to refine and substantiate these results. Additionally, the ability of the video lander to accurately identify species–habitat associations for pelagic schooling rockfish (Black Rockfish, Blue Rockfish, and Yellowtail Rockfish) may be limited and requires further investigation. Furthermore, these species have reduced interactions with the benthic substrate compared with demersal species (i.e., Yelloweye Rockfish, Quillback Rockfish), with much of their time spent schooling in the water column, potentially decreasing the capacity of the video lander to survey these species.

As with previous studies, the video lander exhibited limitations in its ability to identify and count flatfishes and very cryptic species like Cabezon due to the oblique angle of the camera and the standard definition resolution of the camera system (Hannah and Blume 2012). Additionally, we were unable to identify juvenile rockfish and other small fish to species due to the low resolution of standard-definition video, as well as some fish being too distant from the camera, an issue that will be improved with advances in high-definition and stereo video camera systems (Hannah and Blume 2014). The extent to which the video lander attracts or repels fish, as well as the limited and highly variable size of the area viewed, represent potential sampling biases which are currently not quantified. Despite this, extensive research has shown maximum counts from video surveys to be an accurate, although conservative, index of relative abundance (Willis and Babcock 2000; Stoner et al. 2008; Merritt et al. 2011). Other research has suggested using a mean count of fish observed in single snapshots over the entire course of the video in place of a single maximum count to improve the estimate of true abundance (Schobernd et al. 2014). Continued analysis of these methods of estimating relative abundance will be needed to further evaluate the video lander as an effective survey tool.

The C-score analysis of the video lander datasets offers another dimension with which to examine the distribution of nearshore species across the reef. Previous C-score analysis focused on deepwater slope rockfish and "other" roundfish found in trawl samples enumerated by the West Coast Groundfish Observer Program and the Alaska Fisheries Science Center (Groundfish Management Team 2013). These are robust datasets, both spatially and temporally, but are lacking in nearshore species like those observed by the video lander at Three Arch Rocks. Because C-scores are calculated from presence–absence data, the video lander provides ideal high-resolution data amenable to C-score analysis, enabling it to contribute to an additional assessment need. The video lander provides data on both overlap and segregation of species pairs, allowing for potential targeted management actions at the species, or species pair, level. Further surveys are required to expand on the results as many of the observed species had low total counts; however, preliminary analysis shows the versatility and robustness of video lander data for this type of analysis. Our analysis of C-scores for key groundfish species compliments the analyses performed by the Groundfish Management Team by providing results for nearshore, high-relief habitats that are not sampled in existing surveys.

Our comparison of observations at Three Arch Rocks reef to those of other experimental survey sites off the central Oregon coast displays the uniqueness and complexity of the species assemblage at different sites (Table A.1 in the appendix). While these locations are within 150 km of Three Arch Rocks reef, the east-to-west distribution of Three Arch Rocks reef creates a larger depth range and distance from shore, with a reef structure that is home to both shallow (Blue Rockfish and

Black Rockfish) and deeper-water (Yelloweye Rockfish and Canary Rockfish) species. This combination of depths and species diversity at Three Arch Rocks reef highlights the ecological diversity of this area and the need for additional surveys to characterize nearshore species assemblages and habitats in Oregon.

The ability to survey nearshore reefs off the Pacific coast is sporadic, and the weather windows are generally short. The video lander therefore is an ideal tool to use in all seasons 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 at Three Arch Rocks reef. While visibility issues plagued the winter survey, it provided new insight into this nearshore rocky-reef environment in winter. Given acceptable ocean conditions, the video lander has the capability to perform at the same level in the winter as it did in the spring.

Finally, the video lander may serve as a critical tool for evaluations of Marine Protected Areas and Marine Reserves, which have recently been employed as a conservation tool in Oregon and elsewhere in the United States. Nonextractive monitoring methods are needed, as many of these areas are closed to fishing, even for scientific study. The high spatial coverage, low operational and logistical cost, and nonextractive nature of video lander surveys make them an ideal tool for Marine Protected Area or Marine Reserve assessment, monitoring, and habitat ground-truthing. Further refinement of video quality, processing, and distance-area sampling will make video landers essential components of nearshore reef monitoring.

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APPENDIX: Nearshore Species Assemblage Variation on the Oregon Coast

Table A.1. Comparison of video lander survey data, including the 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 data not from the Three Arch Rocks reef was obtained from Hannah and Blume 2012.

Fish species, totals, and depth	Three Arch Rocks (Apr–Jun, $n = 272$)	Three Arch Rocks (Dec, $n = 108$)	Cape Perpetua (Feb, $n = 30$)	Cape Perpetua (Jul, $n = 30$)	Seal Rocks ($n = 43$)	East Siletz ($n = 36$)	West Siletz ($n = 30$)	Stonewall Bank ($n = 173$)
Black Rockfish	277	26	62	72	182	15	11	0
Blue Rockfish	124	15	2	1	18	187	47	54
Brown Rockfish *Sebastes auriculatus*	0	0	3	1	0	0	0	0
Canary Rockfish	225	40	173	156	47	18	74	202
China Rockfish	1	0	0	0	0	0	0	0
Copper Rockfish	6	0	6	2	5	0	0	0
Unidentified juvenile rockfish	4	5	7	47	56	3	0	281
Quillback Rockfish	21	5	9	8	6	2	3	1
Rosethorn Rockfish *Sebastes helvomaculatus*	0	0	0	0	0	0	0	18
Tiger Rockfish	0	1	0	0	0	0	0	0
Unidentified rockfish	5	14	0	0	0	0	0	0
Yellowtail Rockfish	55	92	44	14	18	2	5	95
Yelloweye Rockfish	27	15	3	0	1	6	3	22
Cabezon	2	1	2	3	0	0	0	0
Kelp Greenling	90	17	14	18	23	16	8	13
Lingcod	61	6	8	7	15	23	12	13
Northern Anchovy	0	>1,500	0	0	0	0	0	0
Pacific Halibut *Hippoglossus stenolepis*	0	0	0	0	0	0	0	8
Pile Perch	24	0	68	11	6	0	2	0
Spotted Ratfish	0	20	0	0	0	0	0	0
Unidentified fish	5	15	0	0	0	0	0	0
Unidentified flatfish	9	1	0	0	0	0	0	0
Unidentified sculpin, family Cottidae	0	0	1	1	0	2	0	4
Unidentified surfperch	2	0	0	0	0	0	0	0
Wolf-eel	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)	41.0	52.8	51.3	51.3	30.7	33.6	40.4	54.3