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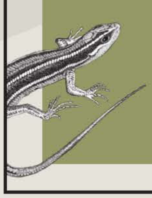

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Comparing angling, underwater visual census, and video sampling methods to refine [fishery independent] long-term monitoring of a reef fish assemblage in a temperate marine reserve.

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ABSTRACT

Robust marine reserve assessment requires managers to understand the biases of their sampling methods. As marine reserve managers, we investigated the comparability of fish assemblage data collected using hook and line (HnL) angling, unbaited remote underwater video (RUV), and diver-based underwater visual censuses (UVC) to optimize long-term monitoring within Redfish Rocks Marine Reserve, a temperate no-take reserve in Oregon. Sequential surveys were performed at the same spatial locations to compare (1) species richness and frequency of occurrence, (2) community composition, and (3) size structure of temperate reef fishes among methods. We also evaluated sampling efficiency (i.e. sample size, and cost) to detect change. The occurrence of common species was similar among the three methods while less common, solitary species exhibited differences in encounter rates among methods. HnL observed the highest proportion of commercially important species and most diverse assemblage. The least abundant and diverse fish assemblage was observed by RUV, likely due to poor detection of cryptic species and low encounter rates of solitary species. For the dominant schooling rockfish taxa (*Sebastes melanops* and *Sebastes mystinus/diaconus)* frequency of occurrence was lower for HnL compared to UVC, likely due to spatial sampling extent, and hook selectivity reducing observations of these small mouthed taxa. Larger individuals were also observed using HnL compared to UVC, likely due to hook selectivity limiting the catch of smaller individuals. While there were differences in mean size, the length-frequency distribution shape did not differ between methods for many species, suggesting data could be integrated across methods with a correction factor. HnL approaches were more cost-effective and time-efficient to detect significant change in community and species-specific abundances, though for select species, UVC offered an efficient alternative to HnL. Therefore, we suggest discontinuing RUV surveys from future long-term monitoring efforts at Redfish Rocks Marine Reserve. Instead, we propose using available resources to increase the sample size of both the Hook and Line and UVC surveys to increase the statistical power to detect changes over time in this marine reserve.

INTRODUCTION

Marine reserves, where fishing activities have been either reduced or excluded, may confer benefits to the conservation of marine ecosystems and fisheries production (Gaines et al. 2010; Roberts et al. 2005; Wilson et al. 2014). Yet, this potential for marine reserves to act as both a conservation and fishery management tool has often been difficult to substantiate due to challenges in attributing temporal changes unequivocally to marine reserve protection (Hilborn et al. 2004; Willis et al. 2000). Part of the challenge arises from how monitoring of reserves is conducted. Often reserve assessments have been hindered by inappropriate sampling methods, limited knowledge of sampling methods biases, lack of statistical power, and limited temporal datasets using consistent methods (Cole et al. 1990; Willis et al. 2000; Willis et al. 2003). Marine reserve monitoring is increasingly conducted using multiple sampling methods, creating a need to understand how data collected from these different methods compare and if these data can be aggregated or integrated across different methodologies. Investigating the comparability of data generated by different monitoring methods to understand inherent method bias and evaluating their cost-effectiveness to assess statistically relevant change is key to optimizing any long-term monitoring in these managed areas.

Choosing the most suitable sampling method is often a compromise between the questions to be addressed, the available resources, understanding of sampling bias, and the precision required (Mallet et al. 2014). For marine reserve evaluation, the effect size may be small, resources are often limited, the biases poorly understood, and the precision needed high. Therefore, methods research is fundamental to marine reserve assessments in order to understand the biases of each method and identify the most efficient approach to detect real spatial and temporal change in the marine community targeted by reserve protection (Harvey et al. 2001; Watson et al. 2005). It is erroneous to assume that the detection probability for an individual is equal among all species and proportional to abundance (MacNeil et al. 2008). Rather, sampling biases exist which cause heterogeneity in detection (MacNeil et al. 2008; Willis et al. 2000). Quantifying sampling biases is challenging because the subsampled population cannot be readily compared to the (often unknown) true population. Hence, researchers often compare one method against another to understand their respective strengths and limitations (Holmes et al. 2013; Langlois et al. 2010; Parker et al. 2016).

In the nearshore waters of California and Oregon, numerous no-take marine reserves have recently been implemented (Saarman and Carr 2013). Long-term monitoring of the fish communities within these reserves is underway using a variety of fishery-independent sampling methods, including: hook and line (angling) surveys, remote underwater video (RUV) surveys from stationary lander platforms, and SCUBA-based underwater visual census (UVC) surveys. The Oregon Department of Fish and Wildlife's (ODFW) Marine Reserve Program uses these three methods to monitor the fish communities in and around Oregon's five marine reserves. By comparing the variability, bias, and sampling efficiency of these three methods, this study can inform the development of an effective long-term monitoring strategy for assessing change in the temperate reef fish assemblage within Oregon's marine reserves.

Previous studies provide a foundation for understanding some of the strengths and limitations of these three sampling approaches. Hook and line (angling) is a simple, affordable method that yields estimates of relative abundance from experimental catch and effort data as well as accurate length data from having fish 'in-hand' (Murphy and Jenkins 2010). Yet, hook and line surveys are both species- and size-selective depending on the terminal gear used (Alós et al.

2008) resulting in fewer species observed compared to visual methods (Bacheler et al. 2017; Harvey et al. 2012; Parker et al. 2016). Other limitations to hook and line surveys include hook saturation (Somerton et al 1988) and difficulty determining area and habitats surveyed. Underwater visual census (UVC) surveys are non-destructive and non-size-selective, providing density, size, and community structure data. Compared to other methods, UVC surveys have also been found to observe high diversity of species (Bacheler et al. 2017; Karnauskas and Babcock 2012). However, the UVC approach has several limitations, including: divers influencing fish behavior, inaccurate diver estimates of fish sizes, high inter-observer variability, size selective, and constrained diving depths (Harvey et al. 2001; Sale and Sharp 1983; Smith 1989; Thompson and Mapstone 1997; Watson et al. 2005). Forward-facing RUV surveys can sample a wide range of fish species across trophic levels in temperate waters (Watson et al. 2005; Watson and Huntington 2016). Yet, RUV surveys also have limitations estimating abundance from a single point in time, difficulty in determining the area surveyed to establish densities (Watson and Huntington 2016; Willis and Babcock 2000), and limitations due to water clarity (Bacheler et al. 2014).

There is an urgent need for methods comparison research studying nearshore subtidal populations in Oregon. At this nascent stage of Oregon's marine reserve system, ODFW's Marine Reserves Program is focused on obtaining precise and accurate data on the diversity and abundance of focal populations. In the temperate reef systems of the nearshore Northeast Pacific this is a challenge given favorable sea states (including visibility) are limited. These challenging ocean conditions have limited nearshore temperate reef fish assemblage studies off Oregon's coast (but see Watson and Huntington 2016 and Huntington and Watson 2017). This lack of nearshore research has led to the need for ODFW's Marine Reserve Program to refine sampling methods and tools, evaluate alternative study designs, increase data collection over space and time, and work with partners to expand monitoring efforts to collect the long-term monitoring data needed to evaluate Oregon's system of marine reserves and inform adaptive management. Since the marine reserve effort in Oregon is built upon the foundation of adaptive management, this framework is currently being applied to the ecological monitoring efforts during these early stages of marine reserve implementation in order to allow for the improvement, refinement, and adaptation of existing monitoring methods to produce precise and accurate data. As is the case with most marine reserve monitoring programs around the world, programs like ODFW's are limited in their ability to achieve goals due to limited staff, financial, logistical, and technical support (Pomeroy et al 2005). Given these restraints, there is an increasing need to evaluate and understand the effectiveness of monitoring methods in order to establish effective and efficient long-term monitoring programs.

In this study, we compared the performance of hook and line, RUV, and UVC methods to sample the temperate reef fish community. To our knowledge, this is one of the first studies comparing these three methods in temperate reef systems, where issues such as underwater visibility, habitat complexity, and richness can yield different conclusions from evaluations of the same methods in tropical systems (see Watson and Huntington 2016). Often studies do not account for temporal variation and spatial differences when comparing sampling methods (Karnauskas and Babcock 2012; Langlois et al. 2012), introducing confounding temporal and spatial effects that can influence the fish assemblage (Starr et al. 2010; Willis and Babcock 2000). The aim of this study was not to directly compare relative abundance of fishes between tools given the inherent differences among each method (Starr et al. 2010; Karnauskas and Babcock 2012; Willis and Babcock 2000). Rather, the goal of this study was to assess the data generated from each method to formulate management recommendations to guide long-term monitoring of Oregon's Marine Reserves. To achieve this goal, surveys using each method were performed at the same spatial locations within one hour of each other to allow us to directly compare response variables of (1) species richness and frequency of occurrence, (2) composition, and (3) size structure of temperate reef fish communities. Lastly, the sampling efficiency of these methods to detect significant change in the fish assemblage were compared in terms of sample size and personnel costs.

METHODS

Study Site

Surveys occurred within the no-take Redfish Rocks Marine Reserve (RRMR) and two nearby (<15km) comparison areas where fishing is allowed: Humbug Comparison Area (HCA) and Orford Reef Comparison Area (OCA) (Figure 1). RRMR is a small (6.8 km^2), relatively shallow (<40m) reserve established in 2012 within Oregon state waters. This area includes emergent rocks and islands surrounded by high-relief rocky reef and bedrock, intermixed with cobble and boulder fields. Kelp beds are found in between the emergent rocks and towards shore. Surveys were conducted over four days in September 2014 during daylight hours to minimize effects of crepuscular activity and when sea conditions were favorable. Two survey days were completed in RRMR, one in HCA, and one in OCA (due to weather constraints preventing additional days of sampling in the comparison areas).

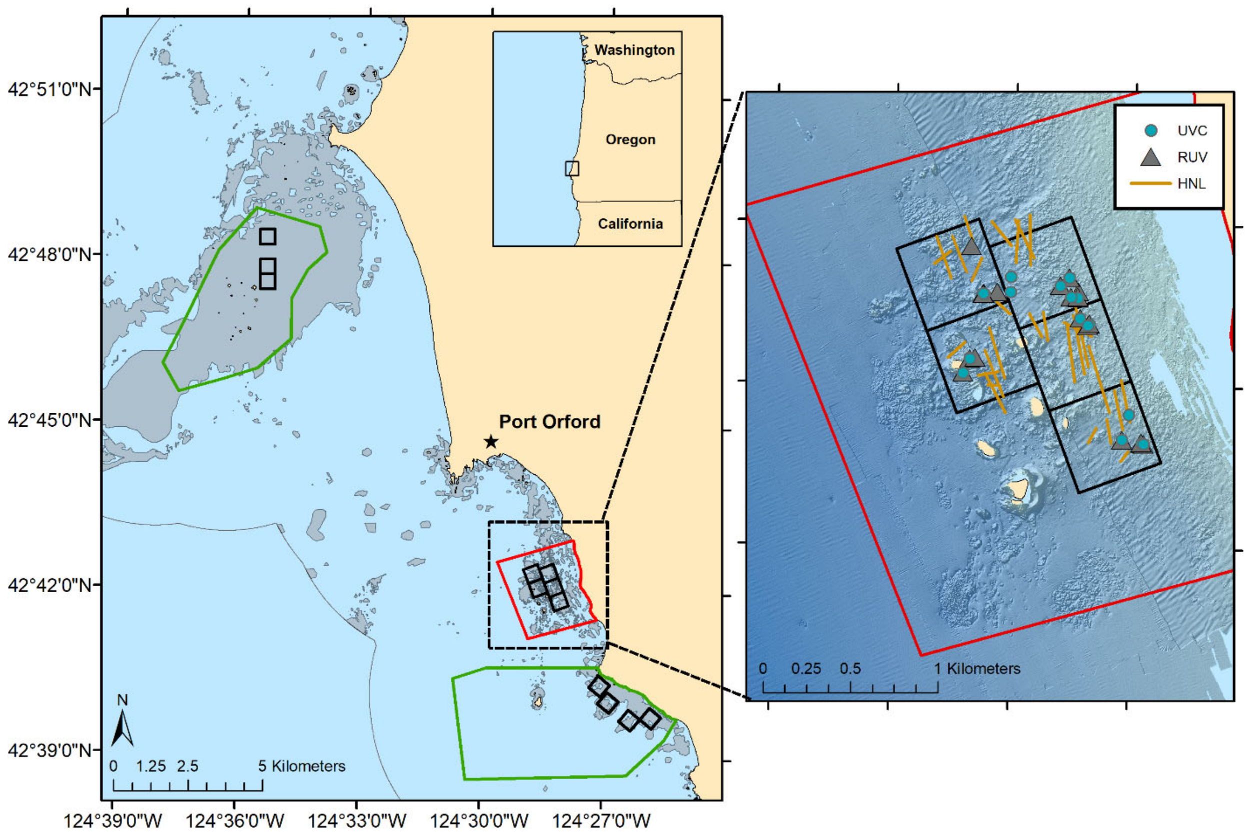

Figure 1: The left panel shows the Redfish Rocks Marine Reserve (MR) boundary in red and comparison area (CA) boundaries in green. OCA is located north of the RRMR and HCA is located south of the MR. Rocky reef habitat is denoted in grey polygons and the grid cells randomly selected for survey in black boxes. The right panel shows location of the three survey methods within the MR. HnL = hook and line; RUV = remote underwater video; UVC = underwater visual census. The bathymetry layer depicting rocky habitat is incomplete in the shallow regions (light blue).

Data Collection

A randomized sampling protocol was developed using bathymetry and benthic habitat maps generated by the Oregon State Waters Mapping Program (Goldfinger 2010; Romsos et al. 2007). Sampling cells measuring 500m x 500m were generated in the reserve and comparison areas. Each sampling cell encompassed rocky reef habitat, at depths of 10-25m, and overlapped with known fishing locations based on local captain knowledge that were targeted historically for the marine reserve and currently for the comparison areas (Figure 1). Since depth and habitat have been found to influence abundance metrics of temperate nearshore fish species (Starr et al. 2010), cells that did not meet the stated criteria (e.g. habitat, depth) were excluded from the sampling design. Despite restricting our sampling to grid cells spanning a narrow depth range and surveying only rocky reef habitats within these cells, we assume the rock habitat within in a cell is not heterogeneous. Hence, methods with greater spatial sampling extents (such as hook and line) that encounter more habitat heterogeneity are hypothesized to observe greater species richness of fishes. Each survey day, 4-5 cells were randomly selected within one of the three reef areas (i.e. marine reserve or one of the two comparison areas) and surveyed using three vessels. One vessel executed unbaited hook and line surveys. The two other vessels each carried an unbaited video lander and a SCUBA dive team to execute RUV and UVC surveys. Given SCUBA surveys are inherently unbaited and that bait has no effect on fish response for RUV surveys in the temperate nearshore waters (Watson and Huntington 2016) the hook and line surveys were unbaited so as to remove any influence of fish response to bait in this methods comparison. Though it is impossible to conduct multiple methods simultaneously in the same location without having one method bias the data collection of another method, we made an effort to reduce temporal variation. To reduce temporal variation, the three methods were conducted sequentially within an hour of one another randomly within the cell and the method order varied among cells. To reduce spatial variation, all three methods were conducted in the same sampling cells and targeted rocky habitats within the restricted depth range.

Hook and line sampling was conducted aboard a charter fishing vessel carrying five volunteer anglers due to vessel capacity. Terminal gear consisted of industry standard gear (i.e. six ounce diamond jig) with a barbless 2/0 double hook with no bait. Following the established Oregon Marine Reserves Ecological Monitoring hook and line sampling method, which mirrors the California MPA surveys developed by the California Collaborative Fisheries Research Program (CCFRP) (Starr et al. 2015), three replicate drifts of 15 min each were fished within each sampling cell over rock habitat. Anglers were instructed to fish along the bottom (bottom jigging). Drifts ended after 15 min or when the vessel drifted outside the selected cell boundary once anglers could retrieve all the deployed gear; the captain then reset the vessel within the sampling cell to execute replicate drifts. Spatial position, depth, and fishing time were recorded for each drift. Fish caught were identified to species, measured (fork length, cm), and released either at the surface or at depth using a SeaQualizer™ if barotrauma symptoms were present. Catch per unit effort (CPUE) expressed as fish angler^{-1} hr^{-1} was calculated as an index of abundance from the hook and line surveys.

The RUVs were equipped with three GoPro Hero® 3+ Black edition cameras separated by 120° and mounted 42cm above the base (Watson and Huntington 2016). Unbaited video landers were deployed from the dive vessels for an eight min duration following recommendations from Watson and Huntington (2016) that longer video durations (i.e. 20min) and bait had no influence on observed nearshore reef fish diversity or abundance. Landers were retrieved and then redeployed at another location within the sampling cell for increased replication. All videos were initially reviewed to confirm the lander oriented upright and the benthic environment in view met pre-determined conditions of visibility, view, and rocky reef habitat. Visibility was scored as an index based on water clarity, while view reflected whether the field of view was obstructed when the lander settled onto the seafloor. Primary habitat was recorded as the most abundant geological habitat in the field of view. Videos with a visibility score of 0 (unusable), a view score of 1 (poor), or not encountering rocky habitats were excluded from further analysis (Huntington et al. 2015). On average three replicate drops per cell met video review requirements. For a given deployment, the camera with the highest scores based on visibility, view, and habitat was retained for analysis; if all cameras scored equally, one was randomly selected. All fish species identifications were reviewed prior to data analysis, with quality control completed by one analyst to improve identification consistency. The relative abundance of each species observed from video was quantified using the conservative metric of MaxN (Harvey et al. 2007). Due to the use of a single camera no fish size data were obtained from this tool.

UVC surveys used methods developed by the Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO) for fish surveys in subtidal rocky reef habitats (http://www.piscoweb.org/kelp-forest-sampling-protocols). The same divers were used for the study duration, all of which had previous experience with this UVC method, minimizing observer variability. Dive locations targeting rocky reef habitats were selected within the survey cell. Two divers conducted parallel, non-independent, belt transects (30m x 2m x 2m) separated by 1m. Divers counted and estimated the lengths (cm) of all conspicuous fishes ≥ 1cm observed within the transect sampling window. Transect data were pooled between buddy pairs due to lack of independence between transects. Divers were instructed to avoid double counting fish moving from one sampling window to another. Replicate transects within a cell were separated by a minimum of 5m with an average of four replicates per cell. Divers were restricted to depths of ≤25m for safety. Based on the criteria specified in the established methods, dives with < 3m visibility were aborted. Density per m^2 was calculated for each species observed.

Species Richness and Occurrence

The three methods were evaluated on their ability to describe nearshore fish assemblages in terms of species richness and occurrence. Unidentified fish were excluded from analysis including juvenile *Sebastes spp.* lacking morphometric characteristics to confirm species identification. Frequency of occurrence (species encounter rates among replicates) were determined for each survey method by calculating the number of samples for which each species were observed and dividing that by the total number of samples collected by each method. These replicate samples were then averaged within a survey cell for a given sampling date and survey method resulting in 16 replicates per survey method. Mean species richness was compared among methods using a one-way ANOVA after testing for assumptions of equal variance and normality.

Multivariate Community Composition

A permutational multivariate analysis of variance (PERMANOVA) was used to test for differences in community composition among survey methods. To reduce the influence of rare species, singleton species (those observed only once, irrespective of survey method) were excluded from analyses (Clarke and Warwick 2001). The sampling area was included in the PERMANOVA design to account for spatial differences that may exist between the study areas. The two-way crossed PERMANOVA design consisted of two fixed factors: survey method (with three levels: hook and line, RUV, UVC) and sampling area (with three levels: RRMR, HCA, OCA). When factors are fixed in a PERMANOVA model, the estimated components of variation are useful for comparing the relative importance of different terms in the model towards explaining overall variation. Bray-Curtis dissimilarity was calculated on square root transformed data to down weight the influence of schooling species, and the analysis was run with permutations of residuals under a reduced model. The full PERMANOVA table was constructed using Type III sum of squares due to the unbalanced design (i.e. an unequal number of individual replicate samples within each factor level). A canonical analysis of principal coordinates (CAP) was used to visualize community composition grouped by survey method. Pearson correlations (of $|r| \geq 0.5$) between individual species and the canonical axes were run to identify which fish species were driving the observed differences among the survey methods (Clarke and Warwick 2001). Multivariate analyses were conducted with PRIMER-E software (Clarke and Gorley 2006).

Size Structure

Mean fish size between UVC and hook and line were compared using a Welch's *t*-test (due to unequal variance) for species with > 20 observed individuals. Since no size data were collected by the RUV surveys, this method was excluded from this comparison. All t-tests were preceded by a Shapiro Wilke test for normality and log-transformed when needed. Length-frequency distributions of these four species (*S. melanops, S. mystinus/diaconus, O. elongates, and H. decagrammus*) were compared between methods using a kernel density estimate (KDE) method (following Langlois et al. 2012). KDEs were generated on the untransformed length data ('location and shape') as well as standardized length data ('shape only') to identify differences due to shape of the distribution alone. Significance between the hook and line and UVC KDEs was based on permutation tests of the area between the two probability density functions compared to a null model resulting from 1000 permutations of randomly paired data using the kde.compare function. All statistical analyses were conducted using the R statistical package (R Core Team 2012) using the plyr, dplyr, pwr, and ggplot2 libraries.

Sampling Efficiency

Sampling efficiency was first evaluated by generating species accumulation curves to explore differences in the diversity of the species pool observed among the three survey methods as sample size increased. Next, sampling efficiency was calculated in terms of staff time and survey days needed for each method to meet the sample size required to detect significant change in (1) total fish abundance and (2) abundance of five commercially important species with differing life histories. Staff time included the field sampling and data processing (including video review and data entry). Survey days were estimated based on the number of replicates executable in a single day assuming a sole vessel dedicated to a single sampling method. Vessel and personnel costs were assumed to be comparable among each method and therefore not included in the analysis. Power of 0.8, α of 0.05, and Cohen's d effect size were used to determine the sample size needed to detect a 25% change in fish abundance within RRMR for each survey method. Sampling efficiency among methods was then evaluated both in terms staff time and sampling days needed.

RESULTS

A total of 44 hook and line drifts (average depth: 19.6 ± 0.6m SE), 48 RUV lander drops (average depth: 17.5 ± 0.5m SE), and 69 UVC transects (average depth: 17.2 ± 0.3m SE) samples were conducted. Even though all surveys were restricted to depths of 10-25m to reduce the impact of depth, the proportion of depths sampled, and mean depth surveyed varied between methods. Specifically, 23% of UVC replicates were conducted at depths equal to or greater than 20m, followed by 35% of RUV and 39% of hook and line surveys.

Species Richness and Occurrence

The species recorded differed among the methods (Table 1) with hook and line observing the most species (15 species), followed by UVC (12 species), and RUV (9 species). All fish observed from hook and line and UVC were identified to species, however only 66% of fishes observed from RUV were able to be identified to species. RUV observed significantly fewer species per cell replicate (mean = 2.75 ± 0.41 SE; ANOVA, $F_{2,45} = 3.814$, $P < 0.02$) compared to UVC (4.75 ± 0.6 SE). However, there were no significant differences between the mean number of species observed per cell replicate between RUV and hook and line (4.06 ± 0.5 SE) or hook and line and UVC.

Overall, the encounter rates (frequency of occurrence) for species common to the nearshore assemblage differed between methods for both solitary, demersal species and schooling species (Table 1). For the dominant schooling species in the region (*S. mystinus/diaconus*, *S. melanops* and *S. flavidus)* occurrence was 10-20% lower for hook and line compared to the UVC sampling methods. RUV encountered approximately 25-50% fewer *Ophidon elongatus* than UVC and hook and line, while UVC encountered more *Sebastes mystinus/diaconus* and *Hexagrammos decagrammus* than the other two methods. For less common species differences among methods were more pronounced. Hook and line observed *Sebastes nebulosus*, *Sebastes pinniger*, and *Scorpaenichthys marmoratus*, three commercially important species in the local fishery, with much higher frequency than the other two methods.

Table 1. Species frequency of occurrence for each survey method. HnL = hook and line; RUV = remote underwater video; UVC = underwater visual census.

	Frequency of Occurrence (%)		
Species	HnL	RUV	UVC
Anarrhichthys ocellatus	-	2	-
Embiotoca lateralis	2	13	4
Enophyrs bison	9	-	3
Hemilepidotus hemilepidotus	-	-	7
Hexagrammos decagrammus	61	50	86
Ophidon elongatus	73	15	41
Scorpaenichthys marmoratus	16	2	10
Sebastes carnatus	2	-	-
Sebastes caurinus	2	-	6
Sebastes flavidus	7	2	10
Sebastes maliger	2	-	-
Sebastes melanops	43	38	54
Sebastes miniatus	2	-	-
Sebastes mystinus/diaconus	20	31	43
Sebastes nebulosus	18	-	4
Sebastes pinniger	7	2	1
Sebastes ruberrimus	2	-	-

Community Composition

Fish community composition differed significantly among the survey methods and sampling areas (Table 2). The greatest variation in the fish community is at the level of the smallest spatial scale (the residual), in this case a single survey cell on a given date. Survey method is the next largest contributor to variation in the fish assemblage followed by area (i.e. marine reserve or comparison area), and lastly by the interaction between survey method and area (Table 2). As the point of the study was to compare differences in methods not in the areas that were sampled, the CAP analysis selected four PCO axes as the best fit parameterization explaining 94% of the variance in the data and correctly classifying 81% of the samples to the accurate survey method. Vectors displayed on a two-dimensional plot of CAP principal coordinates (CAP1 and CAP2) show species whose abundances correlate ($r > 0.5$) with particular survey methods (Figure 2). *Ophidon elongatus* and *Scorpaenichthys marmoratus* had greater relative abundance in hook and line surveys, while *S. mystinus/diaconus* had greater relative abundances in RUV surveys. *H. decagrammus* abundance was similar between hook and line and RUV surveys, while *H. hemilepidotus* was only observed on UVC surveys.

Table 2. PERMANOVA results of the reef fish assemblage in relation to survey method (Method), reef area (Area), and their interaction.

Source	*df*	MS	*F*	*P(perm)*	*Estimated Variation*
Method	2	4764.7	8.7245	0.001	325.51
Area	2	4467.9	8.1809	0.001	278.88
Method x Area	4	1520.5	2.7841	0.003	207.86
Residual	39	546.13			546.13
Total	47				

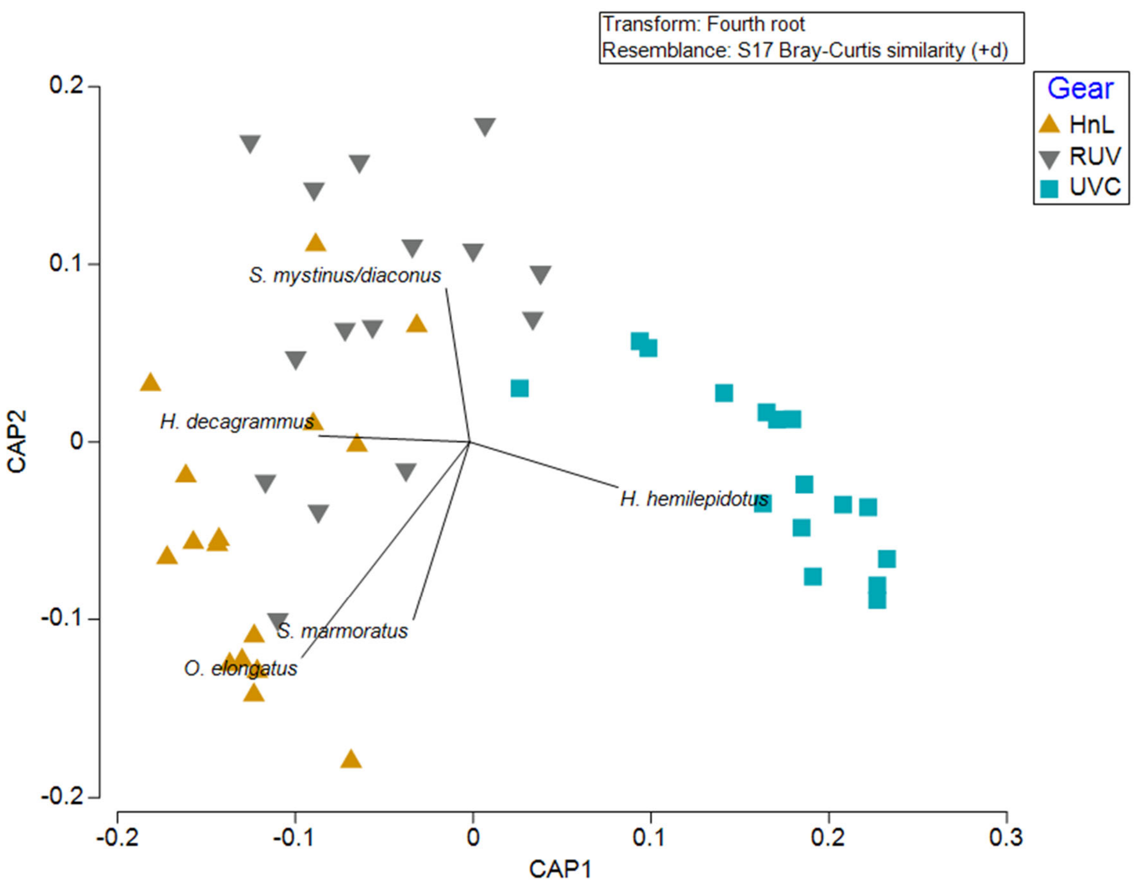

Figure 2: Visualization of CAP analysis showing fish community composition among the three survey methods. Vectors show species whose abundances correlate (Pearson coefficient > 0.5) with the different survey methods. HnL = hook and line; RUV = remote underwater video; UVC = underwater visual census.

Size Structure

For most species, hook and line sampled larger individuals compared to UVC. For three species (*S. melanops*, *S. mystinus/diaconus*, and *O. elongates*), this difference in mean length was significant (Table 3). Conversely, UVC surveys sampled a broader size range of fishes than the hook and line survey. Significant differences in the location and shape of the length-frequency KDEs were detected for three fish species: *S. melanops*, *S. mystinus/diaconus,* and *O. elongatus* (Table 3). Hook and line length distributions were unimodal for all three species, but UVC distributions were broader in range and bi- or multi-modal for the same species (Figure 3). However, once the length data were standardized to remove the influence on location (i.e. position of the distribution along the x-axis), only *S. melanops* showed a significant difference in size distribution between the two methods (Figure 3).

Table 3. Sample size (N), size range (cm), and mean size (cm) (SE) from hook and line (HnL) and underwater visual census (UVC) surveys. Results from Welch's t-tests comparing mean size for the four most abundant species are shown. Significant p-values are shown. Significant p-values are shown. Significant p-values are shown in bold.

	Hook and line			UVC			Welch's ttest	
Species	N	Size Range	Mean Size ± (SE)	N	Size Range	Mean Size ± (SE)	p value	
S. melanops	50	30 - 50	39.2(±0.45)	479	10 - 56	37.23(±0.41)	0.001	HnL > UVC
S. mystinus/ diaconus	21	21 - 36	27.48(±0.97)	289	5 - 48	22.59(±0.66)	<0.001	HnL > UVC
E. bison	3	28 - 34	31.67(±1.85)	3	20 - 30	26.67(±3.33)	--	
S. marmoratus	8	38 - 52	46.5(±1.94)	9	37 - 65	47.89(±3.18)	--	
S. pinniger	3	17 - 39	28.33(±6.36)	7	20 - 45	30.71(±4.36)	--	
S. nebulosus	9	33 - 40	36(±0.69)	4	25 - 40	33.25(±3.5)	--	
S. caurinus	1	50	50	4	10 -37	20.75(±5.8)	--	
H. decagrammus	42	24 - 42	35.98(±0.57)	146	10 - 54	36.03(±0.76)	0.951	--
O. elongatus	87	40 - 95	60.21(±1.06)	36	26 - 80	51.69(±2.42)	0.002	HnL > UVC
H. hemilepidotus	--	--	--	5	20 - 40	32.4(±3.54)	--	
E. lateralis	1	33 - 33	33	6	12 - 35	26.5(±3.3)	--	
S. miniatus	1	50 - 50	50	--	--	--	--	
S. ruberrimus	1	53 - 53	53	--	--	--	--	
S. flavidus	5	30 - 44	35.2(±2.6)	18	5 - 40	25.39(±2.72)	--	

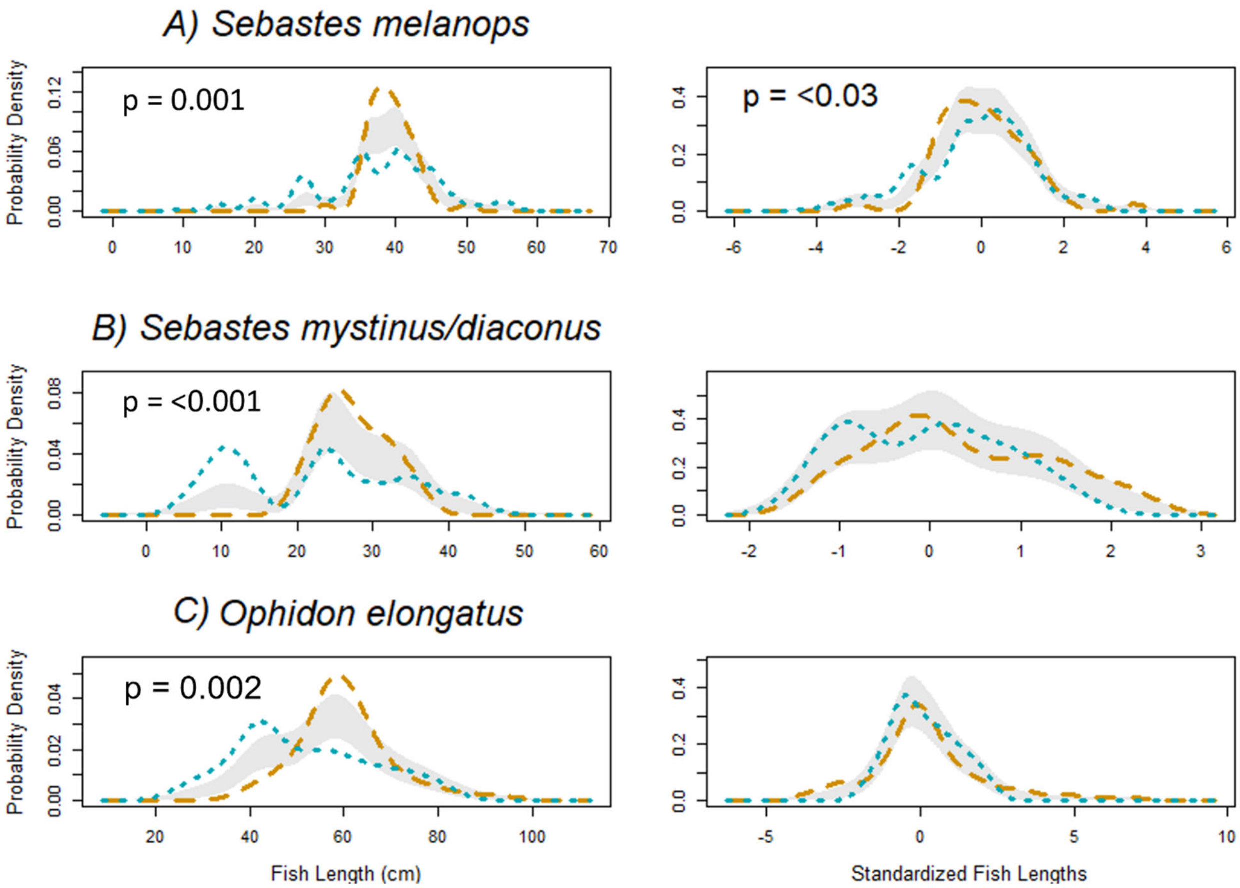

Figure 3: Kernel density estimate (KDE) probability functions for the fish species where significant differences (p <0.05) were detected between hook and line (yellow) and UVC (blue) were based on permutation tests of the area between the two density functions using the untransformed length data (top panel) and the standardized length data (bottom panel). The grey area represents one standard error either side of the null model of no difference in the KDEs for each method.

Sampling Efficiency

Species-accumulation curves for the hook and line and RUV surveys continue to increase with sample size, indicating that more species would be observed with increased sampling effort (Figure 4). The curve for the UVC surveys was accumulating fewer species with increasing replicates, indicating that additional sampling would yield minor increases to the number of species observed.

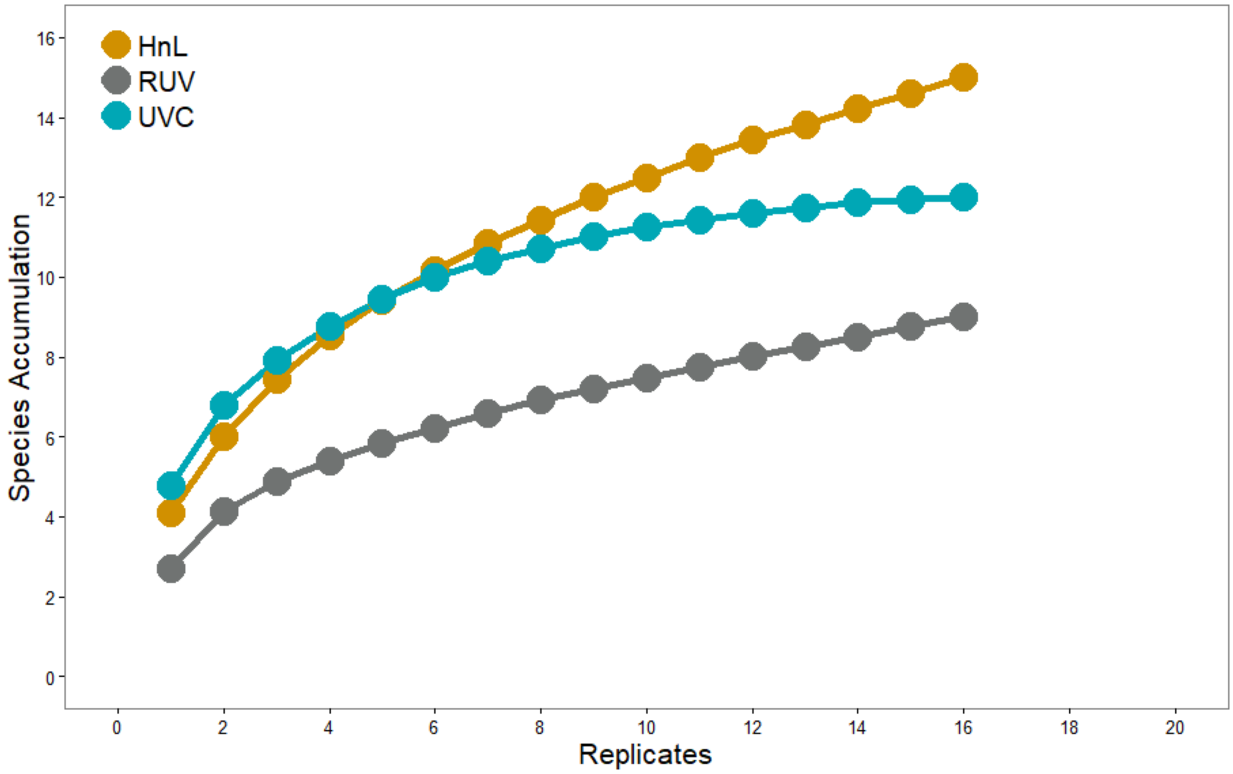

Figure 4: Species-accumulation curves for the three sampling methods. HnL = hook and line; RUV = remote underwater video; UVC = underwater visual census.

Sample sizes needed to detect differences in total fish abundance were consistently lower than the species-specific abundances (Table 4). Similarly, fish with solitary life histories (e.g. *S. marmoratus* and *S. nebulosus*) required higher sample sizes than schooling species (e.g. *S melanops*) or commonly observed species (e.g. *O. elongatus* and *H. decagrammus*). When comparing efficiency of survey methods, hook and line surveys consistently required the smallest sample sizes, fewest staff hours, and shortest sampling effort to detect differences in both total fish and species-specific abundances (Table 4). *H. decagrammus* was the sole exception to this result with RUV requiring the smallest sample size to detect a significant change in abundance. Despite the lower sample size needed by RUV and UVC, the sample size (and corresponding time and effort) to detect a significant change in *H. decagrammus* abundance using hook and line is still low overall for this species compared to the other species analyzed. Remote underwater visual surveys required the greatest amount of staff time to process the data (due to video review). In contrast to RUV, UVC surveys require minimal staff time per replicate making UVC an efficient visual survey alternative.

Table 4. Sampling efficiency results based require sample size, time, and effort needed to detect a 25% difference in fish total abundance and four species-specific abundances within RRMR. N refers to total number of cells required (not replicate samples within cells). HnL = hook and line; RUV = remote

underwater video; UVC = underwater visual census.

Response	Method	Estimated N	Estimated Staff time (hrs)	Estimated Sampling Effort (Days)
Fish Abundance	HnL	51	26	10
	RUV	118	177	17
	UVC	177	35	44
S. melanops	HnL	87	44	17
	RUV	172	258	25
	UVC	198	40	50
S. marmoratus	HnL	139	70	28
	RUV	1,141	1712	163
	UVC	247	49	62
S. nebulosus	HnL	252	126	50
	RUV	*na*	*na*	*na*
	UVC	346	69	87
O. elongatus	HnL	78	39	16
	RUV	144	216	21
	UVC	108	22	27
H. decagrammus	HnL	81	41	16
	RUV	71	107	10
	UVC	48	10	12

DISCUSSION

In this gear comparison study, our objective was to compare three methods used to survey fish communities within one of Oregon's marine reserves to understand the strengths and limitations of each method and develop an efficient long-term sampling strategy. Comparing data among three methods has limitations (Watson et al. 2005) – several of which impacted this study. There are inherent spatial sampling footprints differences between the three methods. Hook and line by nature has the largest sampling footprint followed by UVC, and RUV. This is a challenge of method comparisons at large when comparing transect vs point based surveys (lander vs diver) with differing spatial extents (Murphy and Jenkins 2010). This is especially challenging when comparing estimates of relative abundances with inherent differences in the units of measurement (Starr et al. 2010). As such, this study seeked to assess the data generated from each of the three methods currently used within the state of Oregon's Marine Reserve Monitoring Program to formulate management recommendations to guide long-term monitoring. This includes assessing what data on commercially important species are generated by each method, understanding the biases and limitation of each method, and comparing the cost effectiveness to detect significant change in key metrics characterizing the fish community that may result from this management tool of no-take spatial closures.

With these goals in mind, this study found that while the number of species observed did not vary greatly among methods, the rate of species accumulation indicated that additional sampling could lead to higher observed diversity for hook and line and RUV methods, but not for UVC. This has important implications for long-term monitoring and the need to ensure a balanced sampling design between reserves and comparison areas such that any observed difference in species richness between protected and open areas are indeed the result of management and not unbalanced sample sizes between study areas. The reduced UVC diversity observed in this study compared to previous work (Bacheler et al. 2017; Harvey et al. 2001; Karnauskas and Babcock 2012) is likely a consequence of difficulty detecting cryptic species, low encounter rate with solitary species due to sampling spatial extent, and behavioral avoidance of divers. Even though all surveys were constrained to a narrow depth range (10-25m) and average depth between the three methods differed by < 3m UVC did not observe several species important within the local fishery. These species included *S. maliger* and *S. miniatus* as well as a species of high management interest – the designated "overfished" *S. ruberrimus.* One potential explanation is that since all of these species' habitat ranges exceeds 25m that the porportion of sampling effort conducting in these deeper depths could be driving this pattern. As conservation of biodiversity is a goal of marine reserve protection, methods capable of sampling a broader spatial extent and depth range (thus a greater proportion of the species pool) like hook and line and RUV are favorable over diver-based sampling (Bell 1983). However, the species assemblage detected by each method is only one consideration when determining recommendations for long-term monitoring strategies.

Further differences between the three methods were detected when incorporating species abundance into the analysis. Community composition differed among methods. Despite our attempts to reduce temporal and spatial variation by restricting sampling to rocky reef habitats at comparable depths, some of these differences likely reflect small but important differences in the extent of the habitats surveyed by each method within the grid cell in addition to biases in detection inherent to the sampling method. Similar to findings by Karnauskas and Babcock (2012) and Starr et al. (2010) spatial extent differences between methods is potentially driving differences in the species communities surveyed by each of these methods. Hook and line sampling covers larger areas of the cell compared to the stationary lander and relatively short (30m) UVC transects. Thus, hook and line has a greater potential to encounter solitary, demersal species with small home ranges (e.g. *S. nebulosus* and *S. maliger*). Even though all surveys were restricted to depths of 10-25m to reduce the impact of depth, the proportion of depths sampled and mean depth surveyed, though still within a narrow band, could have contributed to differences in composition. On average, hook and line transects sampled slightly deeper reef habitats within the cell than either RUV or UVC, resulting in fewer observations of shallower species like *E. lateralis* and more observations of species whose abundances tend to increase over this narrow depth range (e.g. *S. miniatus* and *S. ruberrimus).* In accordance with Willis et al. (2000), we also found potential impacts from behavioral responses to survey methods. *E. lateralis* was common in RUV samples, but rarely observed by the divers despite the shallower depths they surveyed, suggesting a behavioral avoidance bias. Lastly, a potential bias that must be considered is the potential for underestimation of true abundance by the RUV due to the use of the relative abundance metric MaxN. Schobernd et al. 2013 found MaxN to underestimate true abundances for high densities, hence this potential underestimating could influence results for abundant schooling species like *S. melanops* and *S. mystinus/diaconus*. These inherent differences among these methods currently in use in Oregon are worth considering in light of cost-effectiveness to detect change over time in a marine reserve.

In agreement with Parker et al (2016), we also found size selectivity in hook and line sampling to yield larger length-frequencies and altered abundances compared to UVC. For example, small mouthed species that are more susceptible to hook selectivity. Therefore, the *S. mystinus/diaconus* complex were less frequently encountered in the hook and line dataset, and when caught, were of larger average size than in the UVC data. The same pattern was observed for the small mouthed greenling (*H. decagrammus).* Size selection between angling and UVC may be eliminated by using a range of hooks sizes enabling the landing of smaller fish (Langlois et al. 2012). However, hook and line terminal gear are standardized to reduce the variance in CPUE data, albeit with the trade-off of increasing size selection. Interestingly, when the length-frequencies were standardized and then compared between hook and line and UVC, the difference between the length distributions disappeared for some species---indicating that the two methods sample comparably shaped length-frequency distributions for these species, but are shifted in position along the x-axis from one another (Langlois et al. 2015). Though this indicates the presence of selectivity for these given methods by applying a correction factor to mathematically account for this shift in position enables the integration of length data among the two methods, thereby increasing the sample size and power for detecting changes in fish lengths (Parker et al. 2016c). As increased fish size is one potential 'reserve effect' (Barrett et al. 2007; Edgar et al. 2014), this result has important ramifications for managers charged with evaluating reserve performance but often with limited means to execute monitoring surveys. We suggest intermittently repeating the KDE analysis on standardized length frequencies as part of ongoing monitoring to determine if pooling is appropriate between methodologies as sample sizes grow.

Long-term ecological monitoring must also consider the sampling efficiency – asking whether the methods survey the desired assemblage and if the costs are reasonable given the needed sample sizes to detect change. Direct costs can vary widely depending on the particular situation of the researcher or study, and data processing costs (i.e. staff time) can make a cost-effective approach in the field untenable. Unfortunately, many gear comparison studies do not consider sampling efficiency and cost in their evaluations (Langlois et al. 2010; but see Pita et al. 2014; Stobart et al. 2007). Based on variability, bias, and costs (in time and sampling days) evaluated in this study, we suggest a sampling approach similar to that recommended by Bennett et al. (2009) to survey the fish community within temperate marine reserves in South Africa, and Starr et al.(2010) to survey the fish community within temperate marine reefs in California. Namely, that hook and line sampling be the primary sampling method and that UVC can be supplemented where appropriate. Though hook and line surveys can be confounded by angler experience, hook saturation, and variable survey area due to drift speed, our study like previous studies in other systems (Karnauskas and Babcock 2012; Starr et al. 2010) found this method is preferable since it is more likely to sample the population targeted by fishing effort and is highly efficient. UVC transects generated less variable estimates of relative density and therefore greater power than RUV deployments. Depending on the species of interests both the UVC and hook and line methodologies could provide useful information for assessments of fish abundance and diversity. An added benefit of UVC surveys are the additional data streams (i.e. habitat type, area surveyed, and water clarity metrics) that are collected which could be influencing survey variability in visual and non-visual surveys (Rodgveller et al. 2011; Ward 2008). However, both RUV and UVC were found to require an impractical number of sampling days to detect significant change in abundance for the fish community. In temperate, often turbid waters, hook and line methods have an additional advantage over underwater visual surveys (from video or diver) – they are not dependent on visibility. In a practical sense, this translates to more workable sampling days for hook and line which is not restrained to minimum thresholds of visibility. Since increasing the number of methods used equates to partitioning capacity (funding and personnel) among workable sea state days, prioritizing multiple methods essentially limits the ability to obtain desired sample sizes to detect change. A final consideration is the ability of the methods to generate positive species identifications for the individual fishes observed; a clear weakness for the RUV method in which only 66% of fishes could be confidently identified. The introduction of bait, which in other tropical systems has been found to increase species identification, has not been found in these turbid nearshore waters to improve the identification rate. Given each methods strengths and limitations, we concur with previous studies (Karnauskas and Babcock 2012; Murphy and Jenkins 2010; Starr et al. 2010; Starr et al. 2006) which have suggested the most effective by implementing a combination of UVC and hook and line approaches when monitoring species of management interest for the long-term monitoring of the fish communities in Oregon's marine reserves.

Our sampling design reduced some of the confounding spatial and temporal variations that lead to detection heterogeneity (Mallet et al. 2014). Yet, we found that variance was highest between our cell + date sampling unit and spatial variation among the study areas contributed to variation in the fish community composition. Surveys were restricted to grid cells that met requirements of depth and habitat and known fishing activity. Yet, despite these controls, the fish community differed significantly among the survey areas, underscoring the influence of small-scale variations in depth and habitat complexity to influence fish community composition (Starr et al. 2010; Stobart et al. 2007) and limiting our confidence to extrapolate these results to other systems. It is possible these area-specific differences could be attributed to reserve protection. However, RRMR was only recently closed to fishing in 2012 and therefore is a young reserve, particularly for a temperate system. A more parsimonious explanation is that habitat differences between the three study areas (such as depth, proximity to kelp forest or emergent rocks, and reef relief) drove differences in community composition despite our efforts to constrain sampling to cells to similar habitat attributes. Though differences in area were not the focus of this study, the difficulty to control for spatial variability has ramifications for marine reserve evaluation and stresses the importance of a Before-After-Control-Impact (BACI) long-term monitoring study design. Even ODFW's careful selection of the best available comparisons (control) areas and employing sampling designs stratified by depth and habitat type (Huntington et al. 2014), existing spatial variation can influence the fish community and has the potential to mask marine reserve impacts over time (Huntington et al. 2010). Hence, evaluating reserve performance between the control (e.g. comparison areas) and impact (e.g. reserve areas) sites alone runs the risk of attributing differences resulting from natural spatial variance erroneously to reserve protection. A BACI design is imperative to account for these spatially driven in the analyses to isolate true reserve effects.

Despite these limitations, this study does demonstrate the value for other long-term monitoring programs to carefully evaluate the sampling methods early in the long-term monitoring process. Our objective was to understand the strengths and limitations of initial monitoring efforts conducted in Oregon's marine reserves and use this knowledge to make informed decisions about how to sample and where to integrate data moving forward. In Oregon's Redfish Rocks Marine Reserve, hook and line sampling will enable a broader depth range and larger spatial extent (and therefore species assemblage) to be surveyed while also cost-effectively providing data on fish community composition and size structure. Furthermore, though the species abundances differed, we suggest that length data has the potential to be integrated for select species between hook and line and UVC methods, resulting in larger sample sizes to evaluate reserve impacts.

Comparing sampling methods and efficiencies early within the marine reserve process supports the goal of establishing long-term datasets capable of assessing marine reserve performance over time. Given Oregon is tasked with understanding how fish communities change over time at all five of their marine reserves (Huntington et al. 2014), the applicability of our results to Oregon's other marine reserves is limited. Each of Oregon's marine reserve sites are unique in their shape, size, habitats, and biological characteristics (Huntington et al. 2015). In addition, each reserve has experienced different types and levels of fishing pressure before closure. On the central Oregon coast, Cascade Head Marine Reserve offers a comparable site to that of Redfish Rocks Marine Reserve given similarities in habitats, depths, historic fishing pressure, and reef fish assemblages. Thus, results from this study could be applicable at this site which employs similar tools to track change. In contrast, the Otter Rock Marine Reserve is a small, shallow reserve where hook and line vessels are unable to operate, making the results of this study not applicable. We suggest that site characteristics be closely evaluated when applying the results of this paper to other marine reserves and recommend that when assessing monitoring methods to consider the importance of continuity between marine reserve sites, thereby allowing inter-site and regional comparison. As the numbers of marine reserves and protected areas in temperate waters continues to grow, we encourage other management programs to take a similar approach to evaluating the strengths and limitations of their monitoring efforts.

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