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Comparing video and visual survey techniques for Barred Sand Bass in rocky reef ecotone habitats

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Fishery-independent data contribute estimates of the distribution and abundance of marine species that are valuable to fishery management. Here, we compared two fishery-independent survey methods: underwater visual census (UVC) and baited remote underwater videos (BRUVs) to determine the best design for a long term monitoring study of Barred Sand Bass (*Paralabrax nebulifer*) at the edges (ecotone) of inshore natural and artificial reefs in southern California. Both methods were effective at detecting Barred Sand Bass, which were significantly more abundant at artificial compared to natural reefs. Seasonal effects on Barred Sand Bass abundance were observed on UVC but not on BRUV. BRUVs detected Barred Sand Bass more frequently than UVC surveys (83% vs 46%, respectively), and a power analysis estimated that BRUVs required substantially fewer samples than UVC to detect a 100% change in the relative abundance of Barred Sand Bass over time (19 vs 52 samples, respectively). However, Barred Sand Bass exhibited territorial behavior around the bait and BRUV data were quite conservative, suggesting that UVC will perform better at generating estimates of total abundance. UVC only detected three unique species, while BRUVs detected 23, many of which were cryptic or transient and predatory. So a combination of UVC and BRUV surveys may be ideal, depending on the monitoring objective and available resources.

Key words: artificial reef, BRUV, fishery-independent, *Paralabrax nebulifer*, UVC

Reliable, long-term estimates of fish abundance are vital to fishery management. Fishery-dependent data (e.g., landings and catch-per-unit-effort) help characterize catch trends across regional and temporal scales, but they can give inaccurate estimates of fish abundance (Koslow and Davison 2016). Fishery-dependent data can be confounded by factors such as changes in angler interest, regulations, technological advancements, weather, bait availability or species behavior (Harley et al. 2001; Bishop 2006; Johnson and van Densen 2007). Alternatively, fishery-independent monitoring provides important estimates of fish abundance and biomass that can control for some of those confounding variables (Rotherham et al. 2007). Many fishery-independent survey methods such as diver surveys using underwater visual census (UVC) and netting (e.g., seining, trawling, trapping, and gillnetting) have been applied to coastal fisheries for decades but advances in video technology offer new and potentially complementary methods for fishery monitoring.

Diver surveys using UVC has been the most common non-extractive method used for subtidal surveys of fish in nearshore waters since the 1950s (Brock 1954). These surveys provide standardized estimates of fish abundance and biomass and it is an effective method for a range of habitats and species (Murphy and Jenkins 2010). However, diver surveys are labor intensive, subject to inter-observer error (depending on each diver's experience level; Bernard et al. 2013), require relatively calm, non-turbid conditions and are often depth limited. Moreover, UVC may be confounded by the response of fishes to diver presence (Dickens et al. 2011).

Video-based surveys of fish abundance, or baited remote underwater videos (BRUVs), were first used in the 1990's (Ellis and DeMartini 1995) and have since been used extensively, including on temperate rocky reefs (Whitmarsh et al. 2017). Like UVC, BRUVs offer an estimate of the relative abundance of fishes, although the sample area can vary depending on the size of the bait plume (Taylor et al. 2013) and estimates of total biomass or abundance may be conservative since BRUV counts are limited to the maximum number of fish observed at one time to avoid duplicates. Despite these factors BRUVs have proven effective for measuring changes in fish abundance over time and between locations (Hill et al. 2014; Bornt et al. 2015; Malcolm et al. 2015). In the field, BRUVs can be more time and cost-efficient since multiple BRUV units can be deployed simultaneously over a large area. They can be configured to capture more precise size and behavior data (Cappo et al. 2006) and can produce better estimates of abundance for generalist carnivores and species that are diver-averse (Colton and Swearer 2010; Langlois et al. 2010; Lowry et al. 2012). BRUVs can also replace or supplement UVC in areas that are ill-suited for diving due to depth, high currents, or high turbidity (Gilby et al. 2016; Watson and Huntington 2016). These attributes make BRUVs useful in long-term monitoring plans for fishery species (Bornt et al. 2015; Starr et al. 2016). However, their application must be considered on a species-specific basis since the effectiveness of BRUVs varies among feeding guilds (Bernard and Götz 2012).

In southern California, UVC is the primary non-destructive method for long-term monitoring of reef fish populations (Stephens, Jr. et al. 1994; Hamilton et al. 2010; Kushner et al. 2013). Although few studies have used BRUVs in this region, underwater cameras have successfully been used to monitor federally and state managed fisheries in other parts of the USA since the 1990s (Somerton and Glendhill 2005). Exploratory baited video surveys of rockfish in central California suggest this is a promising method for quantifying the abundance of carnivorous fishes in deep, high relief habitats (Starr et al. 2016).

Multiple researchers in southern California run long-term fishery-independent surveys in kelp forest habitats (Caselle et al. 2010; Kushner et al. 2013; Caselle et al. 2015) but few monitor fishes in the transition area between the reef slope and the seafloor, or ecotone. The Barred Sand Bass (*Paralabrax nebulifer*) is a focal species in southern California's recreational fishery that is resident to ecotone habitats. This species forms large, predictable, annual spawning aggregations that are extremely vulnerable to overfishing (Jarvis et al. 2014; Miller and Erisman 2014). Peak spawning season for Barred Sand Bass has historically occurred during the summer months of July through August (Jarvis et al. 2014), when fish leave their home reefs to aggregate over inshore sand flats throughout southern California (Jarvis et al. 2010), however these aggregations have been absent since 2013 (Bellquist et al. 2017). Fishery-dependent data failed to flag substantial declines in Barred Sand Bass abundance in the early 2000's because of their spawning behavior. Catch rates remained artificially high when anglers targeted spawning aggregations, while the relative abundance of Barred Sand Bass was declining (Erisman et al. 2011). Thus, fishery-independent surveys of relative abundance will be fundamental to the successful management of this species in the future.

Here we compared two survey techniques (BRUVs and UVC) for assessing the abundance of Barred Sand Bass at the ecotone of nearshore reefs in southern California. Our main objectives were to (1) assess and compare the efficiency (based on lowest variance and labor required) of the two methodologies for surveying the abundance of Barred Sand Bass and other fish species over reef ecotone habitat and (2) to identify differences in Barred Sand Bass abundance related to reef type (artificial vs natural) and sampling season (summer vs fall) to help develop a long-term monitoring strategy.

METHODS

Sampling location

Barred Sand Bass are typically found in low densities outside of spawning aggregations (Anderson et al. 1989; Semmens and Parnell 2014). Therefore, we considered a stratified sampling design ineffective. Instead, we chose survey locations where Barred Sand Bass have been observed consistently in past UVC surveys (California Department of Fish and Wildlife and Occidental College's Vantuna Research Group, unpublished data). We sampled six sites in Los Angeles County monthly between June and October 2017 (Figure 1, Table 1). Summer and fall sampling were done because these months offer the best conditions for survey field work (calm weather combined with adequate visibility), and historical fishing knowledge suggests large numbers of Barred Sand Bass are found on reefs in the early fall (Bedford 2001). Three sites consisted of artificial boulder reef, and three were natural rocky reefs. Based on previous research, Barred Sand Bass are most commonly observed on artificial reefs (Martin and Lowe 2010, McKinzie et al. 2014), but natural reefs were included to test this assumption.

The survey sites at the artificial reef were located along the exposed western, middle and eastern sections of the Los Angeles and Long Beach Harbor Breakwater (Figure 1). The breakwater is exposed to west and south swells and is composed of large granite boulders, descending vertically to a gently sloping sand and silt seafloor at ~15 m. There was a narrow canopy of giant kelp (*Macrocystis pyrifera*) in ~6 meters depth along the edge of the wall, but most of the deep reef substrate was covered in sessile invertebrates (e.g., golden gorgonians [*Muricea californica*], tunicates [*Styela montereyensis*], bryozoa spp.). The two natural reef sites along the Palos Verdes Peninsula are rock and boulder reefs with giant

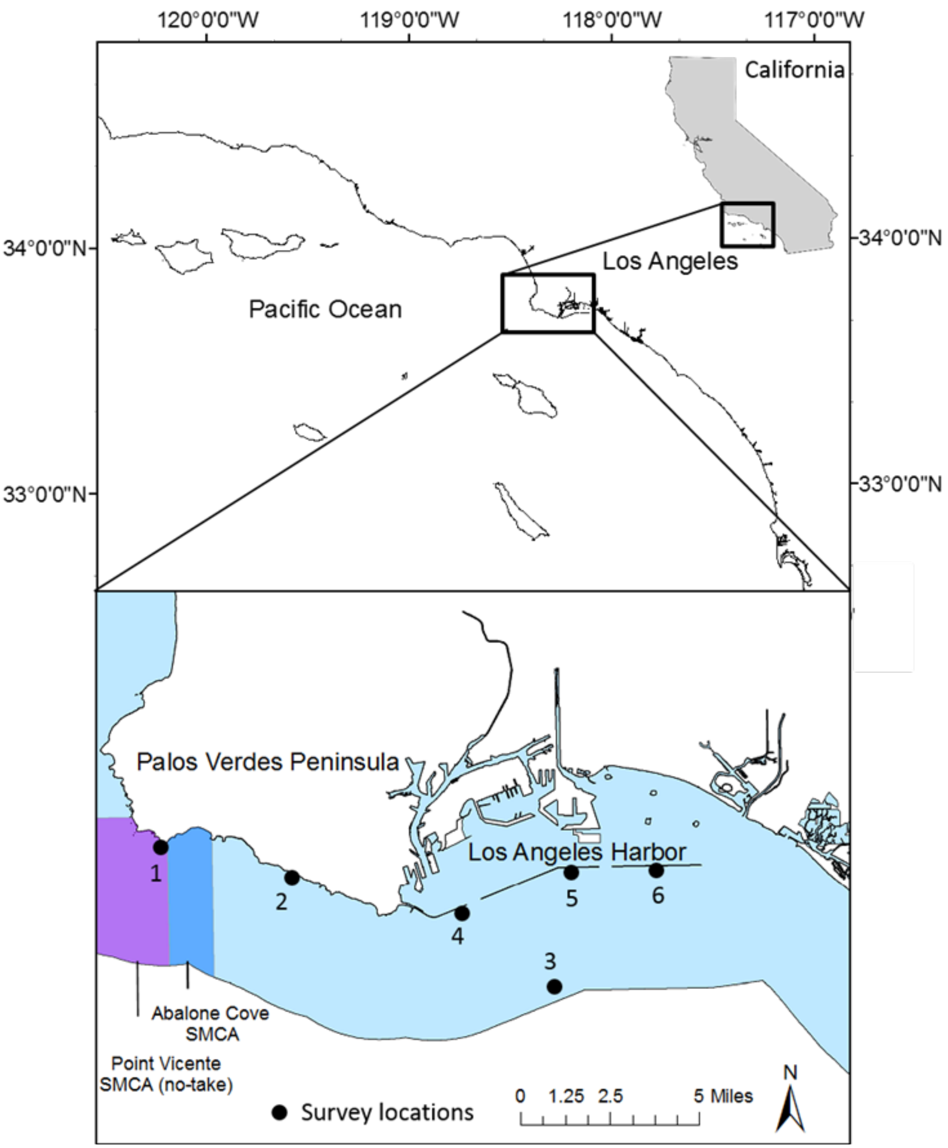

Figure 1. Survey sites in Los Angeles County at natural reefs near Palos Verdes Peninsula (1-3), and artificial reefs at the Los Angeles Breakwater (4-6). SMCA = State Marine Conservation Area.

kelp canopies bordering a sand edge in ~15 m of water. The westernmost reef site is located within a no-take marine conservation area, but protection was not expected to have a major effect on Barred Sand Bass abundance since they are most vulnerable to fishing over sand flats during summer spawning aggregations. The third natural reef site, Horseshoe Kelp, is an isolated patch reef of low relief rock fingers covered in low canopy kelps (e.g. *Laminaria farlowii* and *Pterygophera californica*) at ~20 m depth.

BRUV surveys

We constructed three replicate BRUV frames out of PVC pipe (Figure 2). Each unit stood 0.5 m off the seafloor with a single GoPro Hero 4 camera mounted to an aluminum crossbar inside the frame. We weighted the frames with 6 kg of dive weights and rebar and attached a 1.5 m bait arm with a black plastic mesh bait pocket that extended in front of the camera, level with the substrate. A small subsurface buoy was attached to the surface rope just above the frame with a longline snap to prevent the floating line from obstructing the camera's frame of view.

At each site, we baited the BRUVs with 500 grams of chopped Pacific mackerel (*Scomber japonicus*) and dropped them within 3 meters of the reef edge for 60 minutes. We felt a 60-minute soak time would be conservative since studies in other temperate environments found soak times between 30 and 60 minutes were effective for achieving MaxN (Whitmarsh et al. 2017). We deployed the BRUVs by hand, with the camera facing the reef, from the deck of a research vessel. Each BRUV was marked with a surface buoy and collected using a pot puller. We tested Pacific Sardine (*Sardinops sagax*), Market Squid (*Loligo opalescens*) and Red Sea Urchins (*Strongylocentrotus fransiscanus*) as baits in pilot surveys but Pacific Mackerel was the most effective attractant since few to no fishes approached the camera when other baits were used. At each site the first BRUV was deployed at a specific coordinate, while the second two units were deployed along the reef at 200-m intervals following the same depth contour. We completed all video deployments between 0700 and 1300 hours on days with slack high tides in the morning to reduce potential variability in bait plume size and fish behavior related to diel and tidal cycles. The number of BRUV replicates varied among sample days depending on deployment success since frames occasionally landed too far out over the sand away from the reef ecotone or the frame of view was blocked by kelp or boulders (Table 1).

UVC surveys.—At each study site, conditions permitting, SCUBA divers did six replicate 30 m x 2 m x 2 m UVC belt transects (transect area = 60 m^2 or 120 m^3) to count and estimate the length of all fish to the nearest 5 cm. Three transects ran parallel to the reef along the ecotone and three transects ran perpendicular to the reef across the sand (sand transects were ultimately discarded from analysis due to high zero counts). Transects began at a designated GPS point identical to the coordinate used for the BRUVs and the diver teams swam in opposite directions along the depth contour. Typically, two diver teams surveyed each site (i.e. totaling six ecotone transects per site); however, if time allowed, we completed extra transects. One diver swam forward continuously just above the seafloor and recorded fish counts and size classes while a second diver swam side-by-side deploying the transect tape and maintaining the compass heading. At the end of each transect, divers moved forward 2 meters before beginning the next survey to ensure independent areas of reef were sampled. The same divers recorded fish counts on all surveys to reduce inter-observer error. UVC transects were done during the same days and timeframes as the BRUV deployments if visibility remained >3 m. We completed replicate BRUV and SCUBA surveys within a four-day period each month, with sampling occurring on at least three of the four days, to control for temporal variability, except when we rescheduled due to adverse weather conditions on two occasions. UVC surveys were rarely done after a BRUV deployment, but if so, they were done >2 hours later to eliminate any effect of bait plumes on survey results.

Although each reef site was visited monthly from June through October, field conditions dictated the final sampling effort (Table 1). UVC surveys were not done at some sites

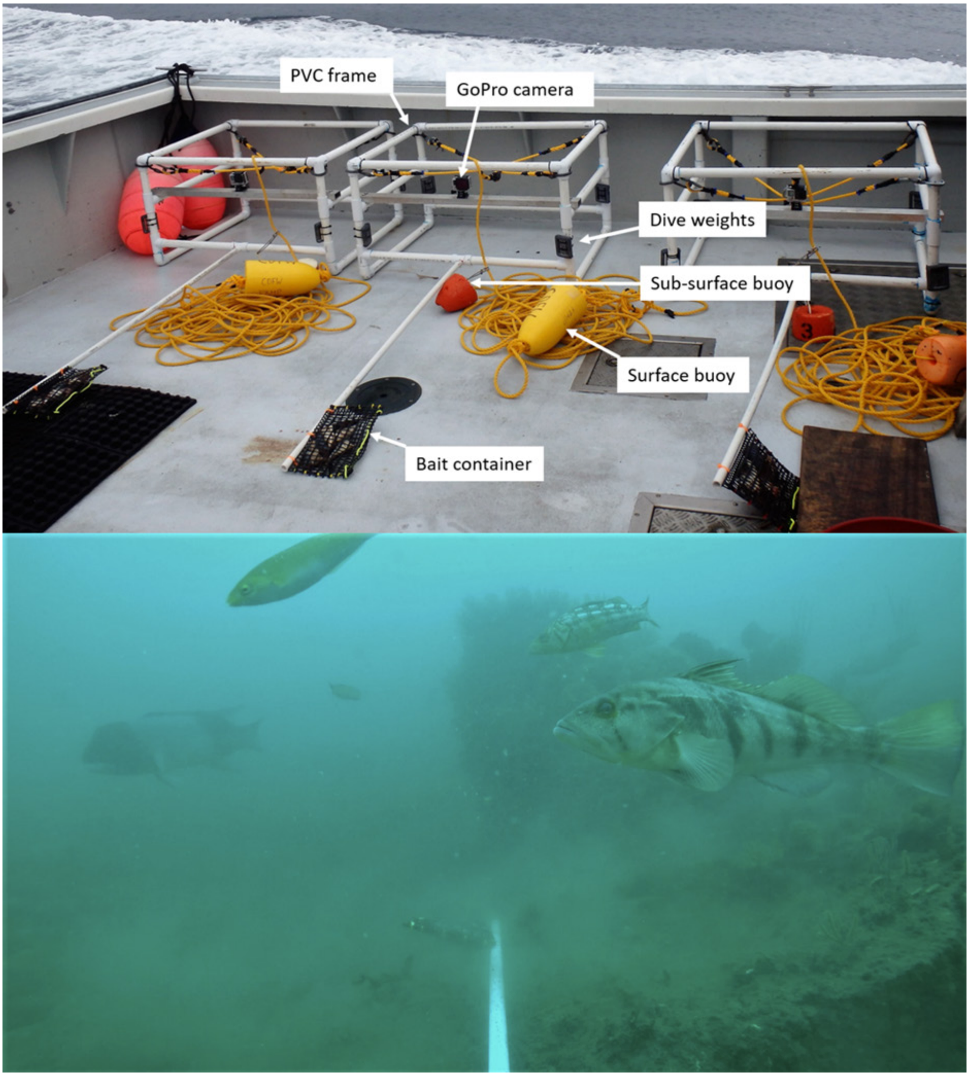

Figure 2. (a) Baited remote underwater video stations (BRUVs) used in this study and (b) a still image from a BRUV showing a Barred Sand Bass, Kelp Bass, Señorita and California Sheephead over ecotone habitat at the Los Angeles Breakwater.

during July and August due to adverse diving conditions (high surge, visibility <3 m). Also, fewer UVC replicates were done on some sample days due to reduced visibility on different parts of the reef.

Data processing

We transferred BRUV video files from cameras to external hard drives and reviewed the first 60 minutes in full, using standard video editing software (e.g., VLC media player). To ensure accuracy and precision, we only evaluated files where the bait pocket was visible throughout the entire recording, and only recorded fish that passed ~ 2 m from the camera

Table 1. Average depth (m) and structure of survey sites in Los Angeles County and the number (n) of replicate BRUV and UVC surveys completed at the reef ecotone each month over a four-day sampling window.

				BRUV Surveys (n)					UVC Surveys (n)				
Site	**Location**	**Reef type**	**Depth (m)**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
1	3 Palms West - PV	Natural	18	1	3	3	3	3	10	9	6	6	4
2	Long Point - PV	Natural	17	3	2	3	3	3	3	4		3	3
3	Horseshoe Kelp	Natural	20	5	3	3	3	3	2		2	5	5
4	LA Breakwater WEST	Artificial	15	2	3	2	3		3	6	3	3	3
5	LA Breakwater MIDDLE	Artificial	15	1	3	3	3	3	2	7		3	3
6	LA Breakwater EAST	Artificial	18	2	2	2	2	3	2			3	3

(within 0.5 m from the end of the bait arm). The 2 m distance was estimated by the technician, but usually only included fish actively visiting the bait and excluded fishes passing by further from the camera. We did not include surveys in the analysis if the frame of view was obscured for more than a minute at a time during the 60-minute deployment (by boulders/kelp/poor visibility), excluding periodic obstruction by waving kelp. Surveys from BRUVs that landed upside down or facing away from the reef (toward the sand) were also discarded. We used a measure of MaxN (the maximum number of individuals present in the field of view at any one time throughout the one-hour deployment) to assess the abundance of all species. MaxN is the most accepted measure of abundance for video surveys because it prevents the same fish from being counted multiple times during a given deployment (Willis et al. 2000; Harvey et al. 2012).

Statistical analysis: UVC data.—Divers observed very few fish on UVC transects over sand habitat, so only data from ecotone habitat were considered in the analysis. We converted the observed lengths of individual fish to estimates of biomass from UVC survey data (cm) using the published length-weight relationship for Barred Sand Bass (Williams et al. 2013). We converted biomass and abundance estimates to fish density (observed per 100 m^{-2}) for ease of comparison with similar studies.

To find the best areas and timeframe for UVC surveys of Barred Sand Bass, we tested the effect of the factors "reef type" (fixed, artificial vs natural), and "season" (fixed, summer [June – August] and fall [September – October]) on fish abundance using a hurdle regression model in the 'pscl' package (Zeileis et al. 2008, Jackman et al. 2015) in R Version 3.5.2 (R Development Core Team, 2018). We used a hurdle model because the UVC count data had more zeros than would be expected from pure count data (Poisson distribution) (Barry and Welsh 2002). Hurdle models use a two-step procedure or delta approach (Serafy et al. 2007) where presence-absence data are modelled first using a binomial distribution, followed by a truncated negative binomial model which is applied only to the samples with positive counts (Zeileis et al. 2008). The negative binomial distribution allows for overdispersion in the dataset. To assess the effect of "reef type" and "season" on fish biomass density we ran a linear model on log(x+1) transformed biomass density. Assumptions of normality and homogeneity of variance were confirmed by plotting the residuals from the models.

Statistical analysis: BRUV data.—We tested the relationship between the abundance

(MaxN) of Barred Sand Bass with the same factors as UVC using a general linear model (glm) in R to assess the best areas and timeframe for BRUV surveys. A hurdle model was unnecessary since the BRUV data had few zero counts. We modeled the data with a Poisson distribution, to account for overdispersion and generated P-values using a chi-square test.

Statistical analysis: method comparison.—We ran a power analysis to assess the number of replicates required for each survey method to detect a 50% and 100% change in the number of Barred Sand Bass over time using a two-sample paired t-test with two levels (before and after) in the program "pwr" (R Core Team 2018). We pooled the mean and variance of Barred Sand Bass abundance for each survey method for sites, reef types and seasons to calculate the effect size.

To compare the fish community observed between methods and reef types, we calculated the Shannon Weaver diversity index (H) (Shannon and Weaver 1963). We also ran a Permutational Analysis of Variance PERMANOVA (PERMANOVA+ version 1.0.3) with the fixed factors "method," "reef type," and "season" and the random factor "site" on presence/absence transformed abundance data and a Sorenson resemblance matrix. The Sorensen index is recommended for binary data (Clarke et al. 2006). We included a dummy variable of 1 for all samples to calculate the resemblance for transects where no fish were counted (Clarke et al. 2006). We also tested the homogeneity of multivariate dispersions (PERMDISP) using the same design to assess whether differences observed in the PERMANOVA analysis could be attributed to differences in the dispersion of the data. We visualized the species responsible for observed differences using a PCO plot with vectors to illustrate the strength of the relationship for species with Pearson correlations > 0.6 and we tested the strength of these relationships using Dufrene-Legendre indicator species analysis using the 'labdsv' package in R (Dufrêne and Legendre 1997; Roberts 2014). Only species with significant ($P < 0.05$) indicator values ≥ 40 are presented.

RESULTS

Fish community summary

Divers completed 103 UVC transects and observed 25 different fish species from 13 families. On average, 3.9 ± 1.9 species were observed on each UVC transect. We completed a total of 78 BRUV deployments and observed 45 fish species from 26 families while reviewing the 4,680 minutes of footage. The average number of species observed on each BRUV was 8.6 ± 3.3 (mean ± SD). Fish diversity differed between reef type and survey method, with more diverse communities observed on artificial reefs than natural reefs (H = 1.55 vs. 1.04, respectively), and a higher diversity detected by BRUVs (H = 1.66) than UVC (H = 0.95). Of the 48 species recorded during the study, 22 were seen on both survey methods (46 %). All but three species observed on UVC transects were also observed on BRUVs (Table 2). However, 23 species were observed on BRUVs but not on UVC, including rockfishes, Giant Sea Bass (*Stereolepis gigas*), and elasmobranchs (Table 2). The species observed most frequently on both survey methods was California Sheephead (*Semicossyphus pulcher*), which was present in 100% of BRUV and 93% of UVC surveys, followed by Kelp Bass (*Paralabrax clathratus*) which was observed 95% and 71% of the time, respectively (Table 2).

The time of first arrival for any fish species typically occurred within the first minute of the BRUV reaching the bottom. The average time until the maximum number of species was observed on each BRUV was 37 ± 14 min, and ~40% of cameras did not detect the maximum number of species until the last 15 minutes of recording (Figure 3a). The maximum number of species occurred earlier for more BRUV units on natural reefs (after 20 minutes) than artificial reefs (most reached a maximum species count after 35 minutes). The average time until the first Barred Sand Bass arrived at each BRUV unit was 5.6 ± 5.6 min at artificial reefs and 19.0 ± 17.4 min at natural reefs. There was a bimodal distribution of MaxN counts for Barred Sand Bass on both natural and artificial reefs where 20 to 40% of surveys recorded MaxNs in the first 10 minutes, while most of the remaining surveys did not achieve MaxN until after 35 minutes (Figure 3B).

PERMANOVA results (based on presence/absence data) showed the fish community differed significantly between reef types and between survey methods, with no main effect of season (Table 3). There was a significant interaction between sampling method and reef type but not with season (Table 3, Figure 6) and post-hoc tests suggested fish community structure differed between reef types on UVC surveys ($t = 3.0$, $p = 0.025$) but not on BRUVs ($t = 1.7$, $p = 0.07$). However, PERMDISP analysis showed there was also a difference in dispersion between reef types, with more variability in species composition or beta diversity among surveys at natural reefs than at artificial reefs ($F_{1,179} = 27.45$, $p < 0.001$). This pattern was visible in the PCO plot and therefore, differences between reef types for UVC were probably due to differences in the variability of the data rather than community structure (i.e., more variability among samples on natural reefs). There was no significant difference in dispersion between survey methods (PERMDISP, $F_{1,179} = 0.85$, $p = 0.41$). Both PCO plots and Dufrene Legendre indicator species (IndVal) analysis suggested that differences in community structure between survey methods were driven by more frequent occurrence of Señorita (*Oxyjulis californicus*), kelp bass, California sheephead and Barred Sand Bass on BRUV surveys (Figure 4, Table 4). IndVal analysis suggested rock wrasse (*Halichoeres semicinctus*) were also responsible for the observed differences (Table 4).

Barred Sand Bass abundance.—We observed Barred Sand Bass consistently using both survey methods, though they were observed in nearly double the number of BRUV drops compared to UVC, on 46% of all UVC surveys and on 83% of BRUV surveys. They were present five times more often on UVC transects at artificial reefs than on natural reefs ($\chi^2_{1,102} = 61.0$, $p < 0.001$) and appeared 1.5 times more often during the fall compared to the summer months on UVC ($\chi^2_{1,102} = 11.4$, $p < 0.001$) (hurdle model on presence absence data) (Figure 5a and b). When present on UVC transects, Barred Sand Bass were also three times more abundant at artificial reefs than on natural reefs ($\chi^2_{1,46} = 15.4$, $p < 0.001$) and nearly three times more abundant during the fall than during the summer months ($\chi^2_{1,46} = 35.2$, $p < 0.001$) (hurdle model on count data, Figure 5c and d). Additionally, when Barred Sand Bass were present, five times more biomass was observed on artificial reefs than on natural reefs ($F_{1,32} = 12.87$, $p < 0.01$) and four times more biomass was observed during the fall months compared to the summer months ($F_{1,32} = 11.98$, $p < 0.01$; Figure 5e and f). In BRUV surveys, Barred Sand Bass were nearly twice as abundant on artificial reefs compared to natural reefs ($\chi^2_{1,76} = 14.3$, $p < 0.001$), but there was no significant difference in the number observed during summer and fall sampling events ($\chi^2_{1,76} = 3.8$, $p = 0.05$; Figure 5g and h).

BRUV surveys had more statistical power than UVC to detect a change in the abundance of Barred Sand Bass (Figure 6). At least 52 UVC surveys are required to detect a 100% change in abundance and at least 206 UVC surveys are required to detect a 50% change with a power of 0.8. In comparison, only 19 BRUV surveys are needed to detect a 100%

Table 2. Frequency of occurrence of the most common fishes observed on UVC and BRUV surveys over ecotone habitat, listed in order from most to least frequently observed on BRUVs.

Family	Scientific name	Common name	BRUV	UVC
Labridae	*Semicossyphus pulcher*	California Sheephead	100	93
Serranidae	*Paralabrax clathratus*	Kelp Bass	95	71
Serranidae	*Paralabrax nebulifer*	Barred Sand Bass	83	46
Labridae	*Halichoeres semicinctus*	Rock Wrasse	78	31
Labridae	*Oxyjulis californica*	Señorita	59	27
Pomacentridae	*Chromis punctipinnis*	Blacksmith	50	53
Embioticidae	*Embiotica jacksoni*	Black Surfperch	42	20
Malacanthidae	*Caulolatilus princeps*	Ocean Whitefish	36	3
Pomacentridae	*Hypsypops rubicundus*	Garibaldi	33	14
Kyphosidae	*Medialuna californiensis*	Halfmoon	26	4
Embioticidae	*Rhacocholis vacca*	Pile Perch	24	3
Kyphosidae	*Girella nigricans*	Opaleye	24	2
Scorphaenidae	*Scorpaena guttata*	California Scorpionfish	24	1
Sebastidae	*Sebastes auriculatus*	Brown Rockfish	24	0
Sebastidae	*Sebastes carnatus*	Gopher Rockfish	18	0
Embioticidae	*Rhacocholis toxotes*	Rubberlip Perch	15	4
Sebastidae	*Sebastes atrovirens*	Kelp Rockfish	12	2
Sebastidae	*Sebastes serranoides*	Olive Rockfish	12	3
Embioticidae	*Hypsurus caryi*	Rainbow Perch	10	3
Haemulidae	*Anisotremus davisonii*	Sargo	10	8
Sebastidae	*Sebastes serriceps*	Treefish	10	1
Myliobatidae	*Myliobatis californica*	Bat Ray	9	0
Polyprionidae	*Stereolepis gigas*	Giant Sea Bass	8	0
Hexagrammidae	*Oxylebius pictus*	Painted Greenling	6	1
Sebastidae	*Sebastes mystinus*	Blue Rockfish	6	3
Carangidae	*Seriola lalandi*	Yellowtail Amberjack	5	0
Embioticidae	*Phanerodon furcatus*	White Seaperch	5	0
Sciaenidae	*Atractoscion nobilis*	White Seabass	5	0
Paralichthyidae	*Paralichthyes californicus*	California Halibut	4	0
Scianidae	*Cheilotrema saturnum*	Black Croaker	4	0
Embioticidae	*Brachyistius frentus*	Kelp perch	3	0
Gobiidae	*Rhinogobiops nicholsii*	Blackeye Goby	3	0
Muraenidae	*Gymnothorax mordax*	California Moray	3	0
Sphyraenidae	*Sphyraena argentea*	Pacific Barracuda	3	0
Triakidae	*Triakis semifasciata*	Leopard Shark	3	0
Bathymasteridae	*Rathbunella hypoplecta*	Stripedfin Ronquil	1	0

Table 2 - continued.

Family	Scientific name	Common name	BRUV	UVC
Carangidae	*Trachurus symmetricus*	Pacific Jack Mackerel	1	0
Clinidae	*Heterostichus rostratus*	Giant Kelpfish	1	1
Cottidae	*Scorpaenichthys marmoratus*	Cabezon	1	0
Heterodontiae	*Heterodontus francisci*	Horn Shark	1	0
Hexanchidae	*Notorynchus cepedianus*	Broadnose Sevengill Shark	1	0
Paralichthyidae	*Citharichthys stigmaeus*	Speckled Sanddab	1	0
Pleuronectidae	*Pleuronichthys ritteri*	Spotted Turbot	1	0
Pleuronectidae	*Pleuronichthys coenosus*	C-O Sole	1	0
Sebastidae	*Sebastes dallii*	Calico Rockfish	1	0
Haemulidae	*Xenistius californiensis*	California Salema	0	3
Kyphosidae	*Hermosilla azurea*	Zebra Perch	0	4
Rhinobatidae	*Rhinobatos productus*	Shovelnose Guitarfish	0	1

change in abundance while 72 BRUV surveys are needed to detect a 50% change with a power of 0.8. Surveys using BRUVs required around three hours per survey unit (including data collection, video review, and data entry) while each UVC survey only required around one hour in total (including data collection and data entry).

DISCUSSION

This study offers the first comparison of video (BRUV) and diver surveys (UVC) for assessing fish abundance over the ecotone of rocky reefs in California. Both methods were capable of detecting Barred Sand Bass and the results indicate that fall surveys at artificial reefs would detect the largest aggregations. Surveys using BRUVs had greater power to detect changes in the abundance of Barred Sand Bass since the data were less variable and frequency of occurrence was higher. But BRUVs were also substantially more labor intensive than UVC due to processing time and the data were less reliable for making estimates of total abundance since they were conservative and affected by fish behavior. Targeted fishery species were observed more frequently on BRUV than UVC and BRUVs sampled a higher species richness by detecting more cryptic and transient predatory species.

While nearly half of all species observed during this study were detected by both BRUV and UVC, the most commonly targeted fishery species (Kelp Bass, California Sheephead, and Barred Sand Bass) were detected more frequently on BRUVs. This pattern is consistent with previous studies that found UVC surveys are less effective at detecting highly mobile, recreationally fished species (Lowry et al. 2011) and this may be attributed to biases in the survey method. For example, BRUVs may detect these fishes more often simply because they sample a larger area than UVC due to the size of the bait plume and the longer survey time (Willis et al. 2000). The sampling area for each BRUV can only be calculated if simultaneous estimates of current velocity and direction are collected (Taylor et al. 2013) and this varies temporally due to changes in tidal and sea state, but BRUVs could easily sample five times the area of a UVC transect, even if the radius of the bait plume were only 10 m.

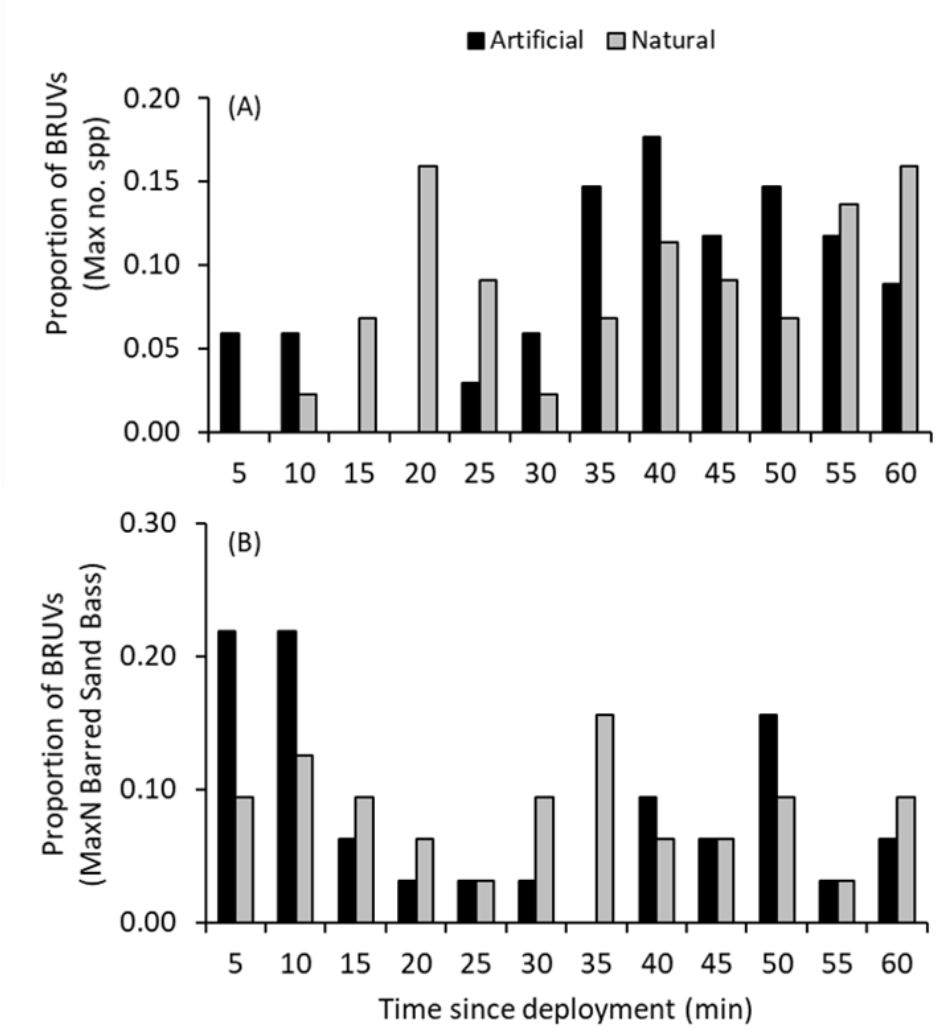

Figure 3. The proportion of BRUV survey units that reached (a) the maximum species richness and (b) the MaxN count for Barred Sand Bass summed by 5-minute bins across the 60-minute deployment.

Additionally, species-specific biases may influence the frequency that a particular species is observed on each method. For example, clear declines in the abundance of targeted fishery species have been observed in relation to diver presence (Dickens et al. 2011), but not in relation to the presence of BRUVs (Whitmarsh et al. 2018).

BRUVs detected more species than UVC, including four elasmobranchs (Leopard Shark, Sevengill Shark, Horn Shark, and Bat Ray) and four transient pelagic species (White Seabass, Yellowtail, Pacific Barracuda, and Pacific Jack Mackerel). Several species of cryptic, reef-associated predators were also observed solely on BRUV including California Moray and three species of rockfish (Calico, Brown, and Gopher Rockfish). These results agree with previous studies that found BRUVs are better than UVC at detecting invertebrate carnivores, generalist carnivores and cartilaginous fishes (Colton and Swearer 2010; Langlois

Table 3. Results of a comparison of all fish species observed using presence/absence data and a Sorenson resemblance matrix in PERMANOVA for the fixed factors reef type, method and season.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Reef Type	1	15,293	15,293	5.2	0.015	719
Season	1	1,492	1,492	0.8	0.578	9,953
Method	1	22,164	22,164	16.8	0.003	9,958
Reef Type*Season	1	1,964	1,964	1.1	0.418	9,956
Reef Type*Method	1	5,472	5,472	4.1	0.026	9,944
Season*Method	1	1,080	1,080	2.1	0.150	9,960
Reef Type*Season*Method	1	1,437	1,437	2.8	0.104	9,964

et al. 2010; Bernard and Götz 2012) since these fishes are known to display diver-averse behavior (Watson and Harvey 2007). On the other hand, prior studies found UVC surveys detect a higher species richness since divers are more effective at counting cryptic species (Colton and Swearer 2010; Lowry et al. 2011). Yet this was not observed in our study as BRUVs recorded both more predators and more species overall than UVC, including cryptic rockfishes. It is surprising that BRUVs detected more rockfish since UVC surveys using similar methods were more effective than BRUVs for these species in Canada (Burke 2018). Divers in this study may have missed cryptic species since they swam continuous transects and did not use dive lights or spend time looking under boulders, especially at the artificial reef where high relief boulders and deep crevices offered substantial shelter. Both cryptic and transient predatory species contributed considerably to species richness in our surveys, making BRUV a better method for characterizing species richness and diversity in southern California's reef ecotone habitats.

We found more variability in UVC fish community structure data on natural reefs when compared to UVC surveys on artificial reefs, perhaps due to the inherent variability associated with a natural benthos. Natural reef sites were widely dispersed and had differing benthic structure and protection status, while artificial reef sites were located along a single breakwater with similar benthic communities and high relief habitat. However, this trend was not observed for BRUVs, suggesting UVC surveys may be less efficient at sampling the whole fish community at each site. Data from UVC surveys may also be inherently more variable than BRUV data due to the greater heterogeneity of habitats sampled along diver transects (Langlois et al. 2010).

Trends in Barred Sand Bass abundance from BRUV and UVC showed that fall monitoring surveys on artificial reefs would detect the highest frequency of occurrence. The higher abundance and biomass of Barred Sand Bass on artificial reefs was expected based on their habitat preference and foraging strategy. Barred Sand Bass are benthic carnivores that benefit from hunting in turbid, high-sediment habitats such as the LA Breakwater (Anderson et al. 1989; Teesdale et al. 2015). The fact that arrival times for Barred Sand Bass were much shorter on average at artificial reefs compared to natural reefs was probably a function of higher density. Moreover, Barred Sand Bass may occur in higher densities during fall surveys when transient fish return from summer (June – August) spawning grounds

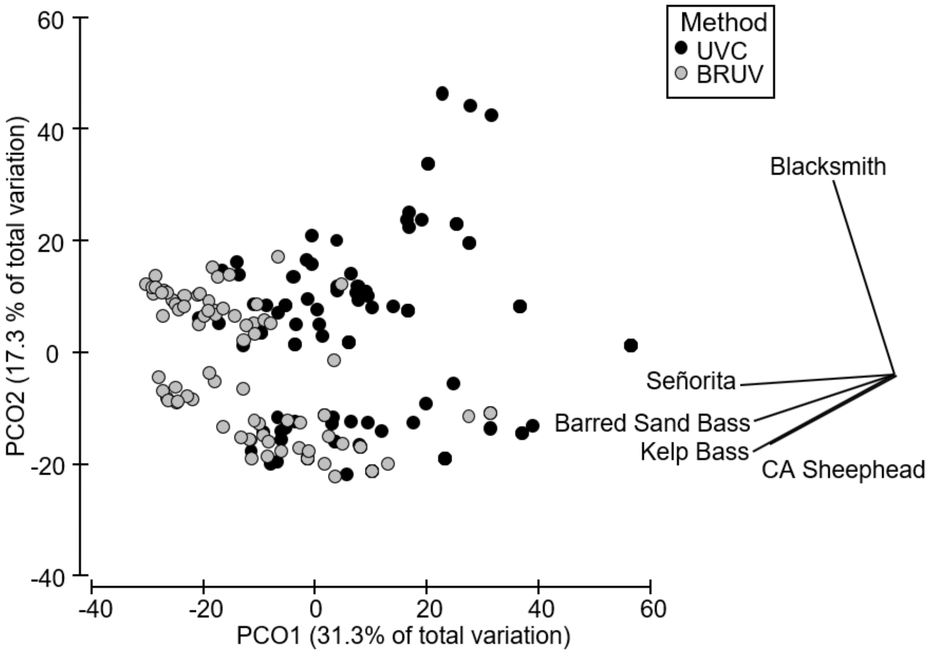

Figure 4. PCO plot comparison of the fish assemblage (presence/absence) seen on UVC versus BRUV surveys over ecotone habitat. Vectors represent species with Pearson correlations > 0.6 and longer vectors indicate stronger relationships.

(Jarvis et al. 2010; McKinzie et al. 2014). Historical observations by California Department of Fish and Wildlife divers and anglers suggest large aggregations of Barred Sand Bass are common on artificial reefs in southern California in early fall (Bedford 2001). BRUVs failed to detect a seasonal effect, potentially due to changes in fish behavior. For example, visibility was often better on fall transects (4.7 m vs 3.9 m on average) and fish may have been more wary of approaching the bait pouch, especially to avoid competitive interactions if other fish were already present.

Barred Sand Bass were detected more frequently on BRUVS, while UVC detected higher counts per transect when they were present. Although density counts are not directly comparable between the two methods since BRUVs do not sample a standardized area, it is still surprising because BRUVs have the potential to sample a much greater area than UVC. The low counts on BRUVs may be a limitation of the MaxN count method used for BRUVs, a result of territoriality of Barred Sand Bass around the bait, or a combination of these factors. Using MaxN prevents fish from being counted twice in a single survey, but it also results in a very conservative estimate of relative abundance, which can underestimate population trends (Conn 2011). This issue may be particularly problematic for an aggregative spawning fish like Barred Sand Bass. Barred Sand Bass did exhibit territorial behavior around the bait bags, often only allowing one or two fish to feed at a time. Therefore, combining BRUV and UVC data may be critical to future monitoring.

Table 4. Indicator values and significance level for species driving differences in presence/absence community structure over ecotone habitat between survey methods. Species listed were more frequently observed on BRUVs.

Species	IndVal	P-value
Rock Wrasse	0.56	0.005
Kelp Bass	0.54	0.005
California Sheephead	0.54	0.007
Barred Sand Bass	0.53	0.005
Señorita	0.40	0.005

BRUV data were less variable and therefore had a greater power to detect changes in fish abundance than UVC. This pattern should be considered with respect to the methodology however, since it may be driven by differences in the characteristics of the abundance metrics used. MaxN counts may be less variable since they are inherently conservative. They may be affected by fish behavior and can reach saturation at high counts when limited by the frame of view. Whereas UVC counts are probably better at detecting true changes in density, and are therefore more variable, and have lower power. Thus, while UVC data were more variable and require more samples to detect change, they will likely be a more sensitive metric to observing changes in total population abundance over time, which is important for fishery monitoring. Data from BRUVs on the other hand may be better suited to detecting the presence/absence of Barred Sand Bass with potential application for detecting range shifts associated with increasing biomass, climate change scenarios or settlement on new artificial reefs. Video surveys would also be useful for confirming the presence of Barred Sand Bass in deepwater habitats, outside the normal scope of diver surveys.

We found there were caveats to each survey method that are important to consider when designing a monitoring study. BRUV and UVC data differ both temporally and spatially since BRUVs sample over a longer time period, but UVC surveys cover a greater physical distance. Soak times of 30 minutes or less have been effective for BRUV surveys of fish on rocky reefs in other areas (Harasti et al. 2015; Watson and Huntington 2016) but our study found at least a 60 minute soak time was required since MaxN counts and species richness often did not peak until well past 30 minutes. The bimodal distribution of the MaxN data suggest that the cameras reaching MaxN early landed directly by the fish, while the remaining cameras probably depended on the bait as an attractant, requiring soak times of at least 35 minutes. Future surveys may consider trialing soak times longer than 60 minutes, however this would be logistically inefficient, since fewer sites could be sampled per day. UVC surveys take less time than BRUVs to complete, sample a standardized area enabling estimation of density, and data entry is simple, compared to the hours of video review required for BRUVs and the limitation of using MaxN—a conservative estimator of relative abundance. On the other hand, BRUVs require less staff expertise to implement in the field (e.g., scientific divers), are effective in low visibility conditions, and provide a permanent record that can be reviewed.

Fish stocks in California are subject to environmental instability (Koslow et al. 2015) and heavy fishing pressure (Zellmer et al. 2018). Those that form spawning aggregations, like Barred Sand Bass, are especially vulnerable to overexploitation. Long term, fishery-independent datasets are essential for detecting and predicting changes in fishery health

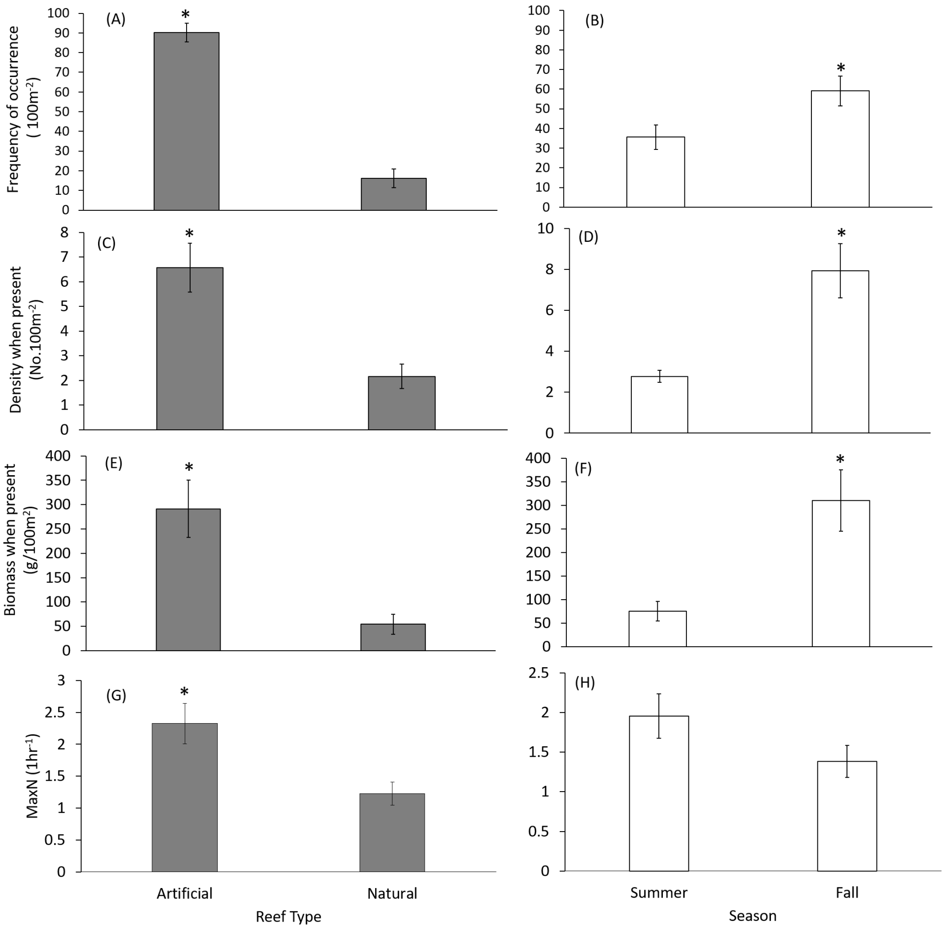

Figure 5. Abundance of Barred Sand Bass by reef type and season from UVC (a-f) and BRUV (g-h) surveys. Error bars = ±1 SE. * = significant effect ($p < 0.05$).

for these species. Both UVC and BRUV methodologies are valuable tools for monitoring Barred Sand Bass over reef ecotone habitats, and each method has strengths and weaknesses that should be considered in relation to monitoring objectives and available resources. In addition to BRUV and UVC, other survey methods should be explored if the resources are available. For example, split beam sonar can be used to estimate the size of spawning aggregations, and it may offer a useful method for estimating spawning stock biomass, a key parameter for fishery management (Won 2018). Although these methods should be tested temporally over more sites across southern California before being adopted as part of a long-term monitoring strategy. Our results also suggest future studies should consider the applicability of BRUVs for monitoring other common fishery species in southern California, such as California sheephead and kelp bass.

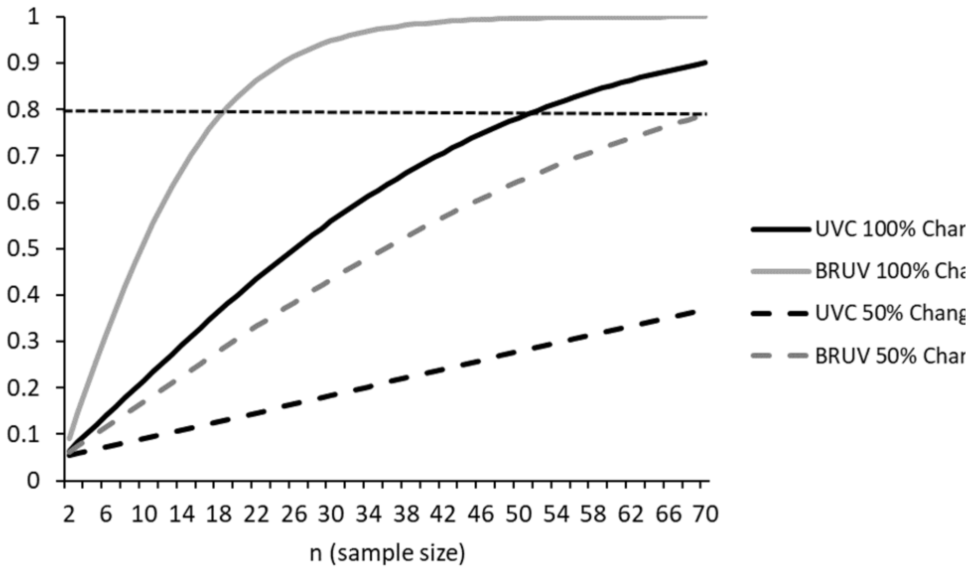

Figure 6. Power curves generated to estimate the sample size required to detect a statistically significant ($p < 0.05$) 50% and 100% change in the abundance of Barred Sand Bass sampled by UVC (black lines) and BRUV (grey lines).

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Author Contributions

Conceived and designed the study (JD, CV, MH, HG)
Collected the data (JD, MH, HG)
Performed the analysis of the data (JD)
Authored the manuscript (JD)
Provided critical revision of the manuscript (JD,CV, MH, HG)

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