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Habitat Associations and Predictive Distribution Models of Commercially Important Rockfish Species Along California's Central Coast

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HABITAT ASSOCIATIONS AND PREDICTIVE DISTRIBUTION MODELS OF COMMERCIALLY IMPORTANT ROCKFISH SPECIES ALONG CALIFORNIA'S CENTRAL COAST

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ABSTRACT

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While commercially important, the red rockfish complex, Vermilion Rockfish (*Sebastes miniatus*), Canary Rockfish (*Sebastes pinniger*) and Yelloweye Rockfish (*Sebastes ruberrimus*), is emblematic of our limited knowledge of the distribution and habitat associations of ecologically and economically important fishes along California's central coast. We used videographic and photographic imagery from a remotely operated vehicle (ROV), coupled with high resolution multibeam derived maps of the seafloor to determine a) the fine scale habitat associations of red rockfishes along California's central coast, and b) the potential distribution of small Canary Rockfish (10-40 centimeters TL) beyond surveyed areas using predictive species-specific distribution models. Across the study region, small Canary Rockfish were more frequently observed than Vermilion and Yelloweye Rockfishes, and the highest abundance of red rockfishes were observed in Bodega Bay, California. Nearly all of the Canary Rockfish observed were small, while Vermilion and Yelloweye Rockfishes were subadults and adults. At fine scales (meters), small Canary Rockfish switched their association from sand to rock as total length increased but remained close (12 to 24 meters) to rock-sand interfaces. Predictive models of small Canary Rockfish presence were 74-77% accurate, and bathymetry and distance from interface were important environmental predictor variables. The imagery-based analyses provided important ecological information about each species, while the predictive modeling allowed us to extrapolate beyond the relatively limited area transected by the ROV to the broader study region. This approach of combining methods is applicable to other species and geographies where we have to manage more than we can sample.

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INTRODUCTION

The spatial distribution, behavior and life history of rockfishes (*Sebastes spp.*) are all linked directly to attributes of the seafloor with which they associate (O'Connell & Carlile 1993, Johnson et al. 2003, Grober-Dunsmore et al. 2008), including physical substrates (Stein et al. 1992, Yoklavich et al. 2002, Johnson et al. 2003, Laidig et al. 2009) and biogenic structures (Auster et al. 2003, Auster 2005, Tissot et al. 2006). However these fish-habitat associations tend to be species-specific (Richards 1986, Yoklavich et al. 2000, Love et al. 2006) and can also change with life history (Overholtz & Tyler 1985, NOAA 1990, Auster et al. 2003, Laidig et al. 2009).

Along the west coast of North America, the red rockfish complex, comprised of Vermilion Rockfish (*Sebastes miniatus*), Canary Rockfish (*Sebastes pinniger*) and Yelloweye Rockfish (*Sebastes ruberrimus*), has overlapping depth and geographic ranges but behave differently within those ranges. Vermilion Rockfish are common from central California to Baja, while Yelloweye and Canary Rockfishes are most common from Alaska to central California (Love et al. 2002). Vermilion Rockfish, classified as demersal aggregators (Love & Yoklavich 2006), associate with high relief rocky substrate at depths of 50-150 meters (Love et al. 2002). Vermilion Rockfish are observed predominantly in deep crevice habitat (Love et al. 2006), rarely ascending more than a few meters off of the bottom (Love & Yoklavich 2006). Canary Rockfish are classified as midwater aggregators (Love & Yoklavich 2006), forming dense aggregations 0-30 meters above high relief rock and are most common at depths of 80-200 meters (Love et al. 2002). Yelloweye Rockfish are classified as demersal non-aggregators that associate with complex habitat and exist as solitary individuals close to the substrate (Love & Yoklavich 2006). Yelloweye Rockfish are most common at depths of 91 to 180 meters in high relief rocky areas, near caves or overhangs (Love et al. 2002).

Canary and Yelloweye Rockfishes are both designated as threatened by the Endangered Species Act and monitored by the Pacific Fisheries Management Council and California Department of Wildlife (CDFW), while Vermilion Rockfish are vulnerable to overfishing or are currently overfished (Cope et al. 2011). Information on the distribution of these species is currently lacking but is needed to inform spatially explicit management strategies, including protected area analyses and stock assessments along the west coast (CDFG 2008, PFMC 2005). This study provides new information about the distribution of each species across the landscape, as well as their potential distribution relative to marine protected area boundaries. Spatial information is also beginning to be incorporated into stock assessments as a way to improve population abundance estimates (PFMC 2007). Trawling studies to collect distribution information have occurred since 1977 (Gunderson and Sample 1980), however, little is known about the distribution of rockfishes over untrawlable habitat in California, especially for Canary Rockfishes (PFMC 2005). Knowing how rockfishes are distributed over untrawlable habitats near protected area boundaries will help inform rebuilding timelines, and stock replenishment in deeper areas to help overfished populations recover (PFMC Status 2007).

Quantitative assessment of fish populations that live in deeper waters (greater than 30 meters) and associate with hard substrate has been difficult and imprecise using traditional sampling methods such as trawl and hook and line (Uzmann et al. 1977, Butler et al. 1991, O'Connell and Carlile 1994, Adams et al. 1995). Since the 1980s, ROV and human-occupied submersibles have been used to study fine scale habitat distribution and association patterns of rockfishes, behavior of rockfishes, and for studies over rock or cobble where trawling is difficult (Stein et al. 1992, Auster et al. 2003, Busby et al. 2005, Wakefield et al. 2005). On Heceta Bank, Oregon, the abundance and habitat associations of schooling and non-schooling rockfishes were quantified (Stein et al. 1992). In Stellwagen Bank National Marine Sanctuary, juvenile *Sebastes* *fasciatus* were observed over boulder reefs, while adults were observed in adjacent cerianthid habitat (Auster et al. 2003). Studies in shallower waters have illustrated that species-specific responses to habitat features at different spatial scales is important in management decisions to protect the species (Kendall et al. 2003, Grober-Dunsmore et al. 2008). However, few underwater visual surveys in deeper waters (greater than 30 meters) have investigated the response of rockfishes to habitat at multiple spatial scales (Anderson & Yoklavich 2007, Pittman & Brown 2011).

Coupling imagery-derived data with acoustic mapping methods greatly improves the extrapolation of data collected on distribution, abundance and fish-habitat associations at a relatively fine scale (meters) to the scale of kilometers (Nasby-Lucas et al. 2002, Whitmire et al. 2007, Iampietro et al. 2008, Moore et al. 2010, Young et al. 2010). Nasby-Lucas et al. (2002) introduced a method of segmenting transects by areas of similar habitat or patches and correlating these direct habitat observations with sonar data. Observational habitat data and calculated fish densities were combined with sonar data to assess fish abundances in adjacent areas. Young et al. (2010) created species-specific habitat models from fine scale sonar data to predict presence over a broad geographic range. Predictive species-specific models could be used to estimate the percentage of predicted area encompassed by protected areas over a broad area, a valuable assessment tool for managers.

In the present study we sought to determine a) the fine scale habitat associations of red rockfishes along California's central coast, and b) the potential distribution of small Canary Rockfish (10-40 centimeters TL) beyond surveyed areas using predictive species-specific distribution models.

METHODS

Study Region

This research was conducted at four locations along the west coast of California, from the Farallon Islands to Point Arena, in 2010-2011 (Figure 1). Overall, the study region is composed of approximately 94% unconsolidated sediment and 6% rock (Davis et al. 2013) with granitic rock dominating to the north of Point Reyes, and sedimentary rock to the south (CDFG 2007). Three treatment areas were identified at each of the four locations: inside protected areas (state marine reserves and conservation areas), outside protected areas and an unprotected reference site.

Imagery Collection

Underwater surveys were conducted at each location in the study region using the Vector M4 ROV (owned by The Nature Conservancy and operated by Marine Applied Research and Exploration), from 20-116 meters water depth (Table 1). The ROV was equipped with forward-looking video and HD, down-looking video and digital still, rear facing video, two Quartz halogen and HMI lights, paired forward- and down-looking lasers, and a strobe for still photos. The ROV was also equipped with an altimeter, forward-facing multibeam sonar, and a CTD. The ROV was flown at a mean altitude of 0.2 meters above the substrate and at a speed of 0.5 to 0.75 knots. The position of the ROV relative to the vessel was monitored using a Trackpoint III system with an angular accuracy of 0.1 degrees.

Data Extraction

All observations of Vermilion, Canary and Yelloweye Rockfishes were collected from non-overlapping forward-looking video "quadrats", including species name, number observed, and total length using paired lasers for fishes greater than or equal to 10 centimeters in total length. A complex category contained Vermilion, Canary and Yelloweye Rockfishes that could not be distinguished from each other in ROV video.

Substrate type directly below each fish was recorded using a four character code that represented primary (50%) and secondary (20%) substrate type within a frame (Stein et al. 1992). Substrate type was based on grain size, including four categories: sand, small rock, large rock and continuous rock (Greene et al. 1999). Sand was defined as unconsolidated substrate with undistinguishable grains less than six centimeters. Small and large rock were defined as loose, individual rocks with grain size less than 20 centimeters and greater than 20 centimeters, respectively. Continuous rock was defined as an outcropping or bed of solid rock.

Analyses

The location and size class (total length), as well as fine scale habitat directly below each rockfish observation, was plotted against observation counts and visual comparisons were made between each species. Additional fine scale analyses were conducted for Canary Rockfish, plotting size class (total length) versus the proportion of fish associated with rock or sand. We tested the null hypothesis that there was no difference in the proportion of fish of different size classes over rock or sand.

We expected distance from the rock-sand interface to serve as a good environmental predictor variable for Canary Rockfish presence after repeatedly observing Canary Rockfish at rock-sand interfaces in ROV video. Several terrestrial and marine studies have used distance from rock or edge as an environmental predictor variable (Pereira & Itami 1991, Friedlander & Parrish 1998, Pittman et al. 2004, Dorenbosch et al. 2005, Pittman et al. 2007, Young et al. 2010). Distance from rock, however, measures only one direction and we were interested in whether there was a difference in the number of Canary

Rockfish in any direction around an interface. We normalized the count of small Canary Rockfish by the effort spent in each two-meter distance zone. We tested the null hypothesis that there was no difference in the number of Canary Rockfish adjacent to the rock-sand interface. Our expectation, based on video observations, was that there was a difference in the proportion of Canary Rockfish adjacent to the rock-sand interface. If there was a difference we also wanted to know whether the distribution of Canary Rockfish spread further over rough or smooth substrate. High resolution (two meter) vector ruggedness measure (VRM) and hillshade rasters enabled us to differentiate rough and smooth substrate, identify the rock-sand interfaces and finally to generate a distance from interface raster to sample at georeferenced fish locations (Figure 2).

We used generalized linear models (GLMs) to predict the occurrence of Canary Rockfish outside of surveyed areas. Seven environmental predictor variables were selected as good predictors of Canary Rockfish presence based on scientific literature (Love et al. 2002, Love & Yoklavich 2006), similar studies (Iampietro et al. 2005, Young et al. 2010) and from observations of ROV video. We tested the null hypothesis that there was no relationship between the environmental predictor variables and the response variables. A high resolution (two meter) bathymetric digital elevation model was downloaded from the California Seafloor Mapping Project Library and topographic position index (TPI), slope, northness, eastness, vector ruggedness measure (VRM) rasters were derived from it.

An equal number of absence points to presence points were generated in ArcGIS from one second navigation data (X and Y coordinates were recorded every second along transects). Ten sets of randomly selected absence points were paired with presence points in an attempt to detect variability in model performance. The marine geospatial ecology tool (MGET) was used to split the data, fit the GLM, test the model and create a predictive raster (Roberts et al.

2010). Eighty percent of the combined presence and absence points were used to fit the model and twenty percent were reserved for testing the model since our sample size was relatively small. Histograms and a correlation scatterplot were created to determine which environmental predictor variables were potentially important predictors of Canary Rockfish presence. Environmental predictor variables that were correlated at 0.6 or higher were not included in models together.

The overall accuracy, Cohen's kappa and area under the receiver operator characteristic (ROC) curve were generated to aid in the assessment of model performance. Guidelines for values of Cohen's kappa are $K < 0.40$ is poor agreement, $0.41 > K > 0.60$ is moderate agreement, $0.61 > K > 0.80$ is substantial agreement (Landis & Koch 1977). An area under the curve value of 0.5 meant there was no discrimination between presence and absence, whereas a value of 1 meant there was perfect discrimination. We wanted to maximize true positives and minimize false positives and false negatives, so agreement among all three tests should suggest a strong model. The GLM equation and ROC cutoff value were used to create a binary prediction model of Canary Rockfish presence and absence across Bodega Bay, California.

RESULTS

Broad Scale Distribution

The overall abundance of red rockfishes was highest in Bodega Bay, followed by the Farallon Islands, Point Arena and Point Reyes (Table 2). Canary Rockfish were observed most frequently across the study region, followed by Vermilion and Yelloweye Rockfishes (Table 2).

A majority of the Canary Rockfish observed in this study were small (juveniles and subadults could not be distinguished from ROV video alone) based on fifty percent maturity estimates of 39-43 centimeters (Echeverria 1987;

Figure 3). In contrast, the size distribution of Vermilion Rockfish was normally distributed. It is possible that some Vermilion Rockfish in this study were adults based on fifty percent maturity estimates of 37-38 centimeters (Echeverria 1987; Figure 4). The size distribution for the ten Yelloweye Rockfish was also normally distributed (1 x 10-15, 1 x 15-20, 2 x 20-25, 3 x 30-35, 1 x 35-40, 2 x 40-45 centimeters). It is unlikely that the Yelloweye Rockfish in this study were adults based on fifty percent maturity estimates of 46-54 centimeters (Echeverria 1987).

Fine Scale Fish-Habitat Associations

Small Canary Rockfish associated with rock and sand, whereas Vermilion and Yelloweye Rockfish associated primarily with rock (Figure 5). In a comparison of size class versus substrate type, small Canary Rockfish associated with sand and switched to rock as total length increased (Figure 6). Pearsons Chi-square analysis and the post-hoc Marascuilo test were used to evaluate differences in counts and multiple proportions (Marascuilo 1966, Zwick & Marascuilo 1984, Levine 2000). Not all counts were equal (Chi-square p value = 4.445×10^{-9}) and significant differences were found between size classes 10-15 and >30 centimeters for sand and rock (Marascuilo p value < 0.05).

The majority of small Canary Rockfish were associated with the rock-sand interface. We used Fisher's Exact test to evaluate where the significant breakpoints, or changes in the number of small Canary Rockfish, were relative to the interface, at each location. In Bodega Bay there was a significant difference in the count per unit effort of fishes 24 meters from the interface (p value = 0.02335), in the Farallones the breakpoint was 22 meters (p value = 0.03694), in Point Arena the breakpoint was 12 meters (p value = 1.167×10^{-10}) and in Point Reyes there was no breakpoint. Small Canary Rockfish were distributed further from the interface over smooth substrate.

Potential Distribution Using Predictive Models

Two predictive models were developed for small Canary Rockfish based on the partitioning of sand and rock by size class (10-15 vs. greater than 15 centimeters TL; Figure 6). In ten trials of each model, bathymetry and distance from interface were significant predictors of small Canary Rockfish presence in 19 of 20 trials. The three highest performing trials for Canary Rockfish 10-15 centimeters TL each included bathymetry, distance from interface and topographic position index, while the trials for Canary Rockfish greater than 15 centimeters TL included bathymetry, distance from interface and either slope, eastness or both variables (Table 3). The majority of trials showed agreement in model performance, and several trials of each model showed strong agreement among all three accuracy statistics. Trials 2, 5, 8, and 10 for the 10-15 centimeters TL distribution model and Trials 2, 5 and 9 for the >15 centimeters TL distribution model (bolded in Table 4) all showed greater than 80% overall accuracy, substantial agreement and good overall fit with the data. The 10-15 centimeters TL distribution model was on average 74% accurate, while the greater than 15 centimeters TL distribution model was on average 77% accurate (Figure 7).

The predicted area encompassed by the State Marine Reserve (SMR) and State Marine Conservation Area (SMCA) for Canary Rockfish 10-15 centimeters TL was 58% (Figure 8) and 75% for Canary Rockfish greater than 15 centimeters TL (Figure 9).

DISCUSSION

The combination of fine scale fish-habitat associations observed in ROV video and high resolution multibeam maps of the seafloor, demonstrated that small Canary Rockfish (juveniles and subadults) switched habitats as they increased in total length but remained close to rock-sand interfaces. Depth and distance from interface were most significant to small Canary Rockfish distribution, and useful when we extrapolated across a broad region to identify areas with a high probability of occurrence. Canary specific predictive distribution models were accurate (74-77%) and predicted that a high percentage of potential Canary Rockfish habitat was currently protected in state reserves and conservation areas. We also discovered that there was a high degree of interspecific variability in size class distributions, abundance and habitat associations between small Canary, Vermilion and Yelloweye Rockfishes along the central coast of California.

Our finding, that Canary Rockfish 10-15 centimeters in TL associated with sand and Canary Rockfish greater than 15 centimeters in TL associated with rock, fills a gap in their life history. No studies to our knowledge have focused on the fine scale habitat associations of juvenile Canary Rockfish, however, similar studies have found differences in rockfish habitat associations depending on life history stage (NOAA 1990, Auster et al. 2003, Grober-Dunsmore et al. 2008). Our results make sense in context of what is known about young of the year and adult Canary Rockfish and the ontogenetic shift that most rockfishes complete (Love et al. 1991). Young of the year Canary Rockfish have been observed on SCUBA at the rock-sand interface at the edge of kelp forests and were also found to be nocturnally active, moving out over sand (Anderson 1983). A second study found significant numbers of young of the year Canary Rockfish from 15-30 meters deep in rippled scour depressions, depressions of coarser unconsolidated sediment that are distinct from surrounding areas. The authors suggested that these depressions may serve as a nursery to young of the year Canary Rockfish (Hallenbeck et al. 2012). Adult Canary Rockfish have been observed repeatedly over rock and high relief rock from 80 to 200 meters depth (Love et al. 2002, Love & Yoklavich 2006). The wider implication of our research is a more complete understanding of the ontogenetic shift for Canary Rockfish, moving from shallow unconsolidated substrates, towards intermediate depths with transitional substrates, ending in deep rocky substrates.

Small (juvenile and subadult) Canary Rockfish were found to associate with rock-sand interfaces delineated using multibeam maps, which confirmed our initial ROV video observations. Their relative closeness to interfaces (24 meters in Bodega Bay, 22 meters in the Farallones and 12 meters in Point Arena) indicates that small Canary Rockfish respond to these structural features in the environment. Many studies have been conducted in terrestrial ecology on edge effects and a review by Ries et al. (2004) suggested four possible mechanisms for increases in abundance near edges: ecological flows (materials, organisms, energy), access (resources that exist in different habitats), resource mapping (organisms are tracking with their resources) and species interactions (e.g. predator-prey). One marine study found the abundance and diversity of fishes to be highest at reef edges and speculated that this could be due to increased water movement, prey, predators, migrators and spawners (Friedlander & Parrish 1998). The most plausible explanations for our results may be ecological flows and species interactions. Krill in the water column in 2010-2011 could have kept small Canary Rockfish near high-flow interfaces. In addition, smaller Canary Rockfish may venture out over the sand at night to avoid predators or larger rockfishes. From a management standpoint, the association of small Canary Rockfish with rock-sand interfaces has implications for the accuracy of stock assessments, used to set recovery timelines and catch levels. Traditionally, trawlers collecting stock assessment data avoid rocky areas for fear of snags, thus, they may be recording lower abundances of small Canary Rockfish than are actually present.

Our two predictive models, partitioned based on Canary Rockfish TL (10-15 versus greater than 15 centimeters) because of their switch from sand to rock substrates, were moderately strong models. Model results appeared to be somewhat dependent on the random location of absence points, which is understandable given the transitional substrate in Bodega Bay, CA. However, the ten trials we ran of each model and agreement of three accuracy statistics substantiated our confidence in model strength. In practice, models with 75-85% predictive accuracy have been presented to management for use in decision making (Congalton et al. 1999, Zabel et al. 2002). This supports the utility of our predictive models to regional and federal fishery and conservation managers. Ecologically, our results elevate the importance of rock-sand interface habitats from 20-116 meters deep for small Canary spatial distribution. The combination of videographic data and high resolution multibeam maps can be used to generate presence predictions for managers who want to maximize the conservation benefit or improve the design of protected areas where no data currently exist. In geographies where we manage more than we can sample, or for other species, this approach is broadly applicable. To minimize model uncertainty, avoid extrapolating across ecological thresholds (Miller et al. 2004), include resource and direct environmental predictor variables when available that can discriminate presence and absence over a broad region (Guisan & Zimmerman 2000, Iampietro et al. 2008, Murray et al. 2011), and ensure representative habitats are sampled (Turner 1989).

Our recommendation to those developing predictive models at similar scales for small Canary Rockfish is to include at a minimum, bathymetry and distance from interface as environmental predictor variables in their models. Future research would benefit from higher rockfish abundance across a broader spatial scale, as well as surveys at night. Rasters of direct environmental variables such as temperature or water currents and resource gradients such as krill presence could improve model results.

The variability in red rockfish species size distributions and abundances observed along the central coast is likely a result of differences in depth and water temperature at the four locations sampled, and reduced sampling effort in Point Arena. Adult Canary Rockfish are commonly observed from 80-200 meters and adult Yelloweye Rockfish from 91 to 180 meters deep, so it makes sense that very few adults would be observed in our study, conducted from 20 to 116 meters deep. In addition, adult Vermilion Rockfish are commonly found at 50 to 150 meters deep, but may be observed much shallower north of Point Conception (Burge & Shultz 1973, Love et al. 2006). Fewer transects were attempted due to severe weather in Point Arena in 2011, and this may have contributed to very low abundances of adult Canary and Yelloweye Rockfishes observed in the study. A secondary explanation for the high abundance of small Canary Rockfish in Bodega Bay might be optimal environmental conditions, for instance premium habitat, increased food availability etc. The available habitat along surveyed transects did not explain the observed fish-habitat associations. According to multibeam sonar data, the majority of available habitat in all four locations within the study region was sand (52% in Bodega Bay, 67% in the Farallon Islands, 70% in Point Arena and 87% in Point Reyes). These results provide a baseline of broad scale size class distribution, as well as abundances and habitat associations for comparison with future studies.

CONCLUSION

Only by coupling direct observations from ROV video with high resolution multibeam maps, were we able to distinguish fine scale habitat associations of small (juvenile and subadult) Canary Rockfishes. Distance from interface was also developed as a new and significant environmental predictor variable for predicting the potential distribution of small Canary Rockfish. At a broad scale, we found a high degree of interspecific variability in size class distributions and abundance between small Canary, Vermilion and Yelloweye Rockfishes along the central coast of California. Distribution and abundance information for these threatened (Canary and Yelloweye Rockfishes) and potentially overfished species (Vermilion Rockfish) will be useful to state and federal fishery managers.

Results of this study will inform the first adaptive management review of marine protected areas for this region, and provide an approach for studying the distributions of other species across coastal habitats.

REFERENCES

Adams PB, Butler JL, Baxter CH, Laidig TE, Dahlin KA, Wakefield WW. 1995. Population estimates of Pacific coast groundfishes from video transects and swept-area trawls. Fishery Bulletin 93:446-455.

Anderson TJ, Yoklavich MM. 2007. Multiscale habitat associations of deepwater demersal fishes off central California. Fishery Bulletin 105:168-179.

Anderson TW. 1983. Identification and development of nearshore juvenile rockfishes (Genus *Sebastes*) in Central California kelp forests [MA Biology thesis]. Fresno (CA): California State University, Fresno. 187 p.

Auster PJ, Lindholm J, Valentine PC. 2003. Variation in habitat use by juvenile Acadian redfish, *Sebastes fasciatus*. Environmental Biology of Fishes 68:381-189.

Auster PJ. 2005. Are deep-water corals important habitats for fishes? In: A Freiwald and JM Roberts, editor. Cold-water corals and ecosystems. Berlin: Springer-Verlag; p. 747–760.

Burge RT, Schultz SA. 1973. The marine environment in the vicinity of Diablo Cove with special reference to abalones and bony fishes [Manuscript]. Marine Resources Technical Report No.19. 429 p [Internet]. [cited 2012 August 12]. Available from: http://aquaticcommons.org/755/1/Technical_Report_1973_No._19_A.pdf.

Busby MS, Mier KL, Brodeur RD. 2005. Habitat associations of demersal fishes and crabs in the Pribilof Islands region of the Bering Sea. Fisheries Research 75: 15-28.

Butler JL, Wakefield WW, Adams PB, Robison BH, Baxter CH. 1991. Application of line transect methods to surveying demersal communities with ROVs and manned submersibles [Internet]. [cited on 2012 March 3]. Available from: http://swfsc.noaa.gov/publications/CR/1991/9119.pdf.

[CDFG] California Department of Fish and Game. 2007 September 28. California MLPA Master Plan Science Advisory Team Draft Work Group Responses to Science Questions Posed by the NCCRSG at its July 10-11, 2007 Meeting [Internet]. [cited 2012 August 12]. Available from: http://www.dfg.ca.gov/mlpa/pdfs/agenda_100107b.pdf.

[CDFG] California Department of Fish and Game. 2008. California Marine Life Protection Act. Master plan for protected areas [Internet]. [cited 2012 August 12]. Available from: http://www.dfg.ca.gov/marine/pdfs/revisedmp0108.pdf.

Cope JM, DeVore J, Dick EJ, Ames K, Budrick J, Erickson DL, Grebel J, Hanshew G, Jones R, Mattes L, Niles C, Williams S. 2011. An approach to defining stock complexes for US west coast groundfishes using vulnerabilities and ecological distributions. North American Journal of Fisheries Management 31(4):589-604.

Congalton RG, Green K. 1999. Assessing the Accuracy of Remotely Sensed Data: Principles and Practices. New York: Lewis Publishers.

Davis ACD, Kvitek RG, Mueller CBA, Young MA, Storlazzi CD, Phillips EL. 2013. Distribution and abundance of rippled scour depressions along the California coast. Continental Shelf Research Volume 69:88-100.

Dorenbosch M, Grol MGG, Nagelkerken I, van der Velde G. 2005. Distribution of coral reef fishes along a coral reef–seagrass gradient: edge effects and habitat segregation. Marine Ecology Progress Series 299:277–288.

Echeverria TW. 1987. Thirty-four species of California Rockfishes: maturity and seasonality of reproduction. Fishery Bulletin 88 (2):229-250.

Friedlander AM, Parrish JD. 1998. Habitat characteristics affecting fish assemblages on a Hawaiian coral reef. Journal of Experimental Marine Biology and Ecology 224:1–30.

Greene HG, Yoklavich MM, Starr RM, O'Connell VM, Wakefield WW, Sullivan DE, McRea Jr. JE, Cailliet GM. 1999. A classification scheme for deep seafloor habitats. Oceanologica Acta 22(6):663-678.

Grober-Dunsmore R, Frazer TK, Beets JP, Lindberg WJ, Wick P, Funicelli NA. 2008. Influence of landscape structure on reef fish assemblages. Landscape Ecology 23:37-53.

Guisan A, Zimmermann NE. 2000. Predictive habitat distribution models in ecology. Ecological Modelling 135:147-186.
Gunderson DR, Sample TM. 1980. Distribution and abundance of rockfish off Washington, Oregon, and California during 1977. Marine Fisheries Review 42 (3-4):2-16.

Hallenbeck TR. Kvitek RG, Lindholm J. 2012. Rippled scour depressions add ecologically significant heterogeneity to soft-bottom habitats on the continental shelf. Marine Ecology Progress Series 468:119-133.

Iampietro PJ, Young MA, Kvitek RG. 2008. Multivariate Prediction of Rockfish Habitat Suitability in Cordell Bank National Marine Sanctuary and Del Monte Shalebeds, California, USA. Marine Geodesy 31(4):359-371.

Johnson SW, Murphy ML, Csepp DJ. 2003. Distribution, habitat, and behavior of rockfishes, *Sebastes spp.*, in nearshore waters of southeastern Alaska: observations from a remotely operated vehicle. Environmental Biology of Fishes 66:259-270.

Kendall MS, Christensen JD, Hillis-Starr Z. 2003. Multi-scale data used to analyze the spatial distribution of French grunts, *Haemulon flavolineatum*, relative to hard and soft bottom in a benthic landscape. Environmental Biology of Fishes 66:19-26.

Laidig TE, Watters DL, Yoklavich MM. 2009. Demersal fish and habitat associations from visual surveys on the central California shelf. Estuarine, Coastal and Shelf Science 83(4):629-637.

Landis JR, Koch GG. 1977. The measurement of observer agreement for categorical data. Biometrics 33:159-174.

Levine DM 2000. Chi-Square Tests and Nonparametric Tests [Internet]. [cited 2014 March 9]. Available from: http://www.prenhall.com/behindthebook/0136149901/pdf/Levine_CH12.pdf.

Love MS, Carr MH, Haldorson LJ. 1991. The ecology of substrate-associated juveniles of the genus *Sebastes*. Environmental Biology of Fishes 30:225-243.

Love MS, Yoklavich M, Thorstinson L, editors. 2002. The rockfishes of the northeast Pacific. Berkeley, Los Angeles or London: University of California Press.

Love MS, Schroeder DM, Lenarz B, Cochrane GR. 2006. Gimme shelter: The importance of crevices to some fish species inhabiting a deeper-water rocky outcrop in southern California. California Cooperative Ocean Fishing Investigation Report 47:119-126.

Love MS, Yoklavich M. 2006. Deep Rock Habitats. In: Allen LG, Pondella DJ, Horn MH, editors. The Ecology of Marine Fishes, California and Adjacent Waters. Berkeley and Los Angeles: University of California Press; p. 253-266.

Marascuilo LA. 1966. Large-sample multiple comparison. Psychological Bulletin 65:280-290.

Miller JR, Turner MG, Smithwick EAH, Dent, CL, Stanley EH. 2004. Spatial Extrapolation: the science of predicting ecological patterns and processes. BioScience 54(4):310-320.

Moore CG, Harvey ES, Van Niel K. 2010. The application of predicted habitat models to investigate the spatial ecology of demersal fish assemblages. Marine Biology 157:2717-2729.

Murray JV, Low Choy S, Mcalpine CA, Possingham HP, Goldizen AW. 2011. Evaluating model transferability for a threatened species to adjacent areas: implications for rock-wallaby conservation. Austral Ecology 36:76-89.

Nasby-Lucas N, Embley B, Hixon MA, Merle SG, Tissot BN, Wright DJ. 2002. Integration of submersible transect data and high-resolution multibeam sonar imagery for a habitat-based groundfish assessment of Heceta Bank, Oregon. Fishery Bulletin 100:739-751.

[NOAA] National Oceanic and Atmospheric Administration. 1990. Life history aspects of 19 rockfish species (Scorpaenidae: *Sebastes*) from the Southern California Bight [Internet]. [cited 2012 August 12]. Available from: http://spo.nwr.noaa.gov/tr87.pdf.

O'Connell VM, Carlile DW. 1993. Habitat-specific density of adult yelloweye rockfish *Sebastes ruberrimus* in the Eastern Gulf of Alaska. Fishery Bulletin 91:304-309.

O'Connell VM, Carlile DW. 1994. Comparison of a remotely operated vehicle and a submersible for estimating abundance of demersal shelf rockfishes in the Eastern Gulf of Alaska. North American Journal of Fisheries Management 14:196-201.

Overholtz WJ, Tyler AV. 1985. Long-term responses of the demersal fish assemblages of Georges Bank. Fishery Bulletin 83(4):507-520.

Pereira JMC, Itami RM. 1991. GIS-based habitat modeling using logistic multiple regression: a study of the Mt. Graham Red Squirrel. Photogrammetric Engineering and Remote Sensing 57(11):1475-1486.

[PFMC] Pacific Fishery Management Council. 2005. Canary Rockfish, STAR Panel Report. [Internet]. [cited on April 12, 2014]. Available from: http://www.pcouncil.org/wp-content/uploads/Canary_Mopup_STAR.pdf.

[PFMC] Pacific Fishery Management Council. 2007. Status of cowcod, *Sebastes levis*, in the Southern California Bight. [Internet]. [cited on April 12, 2014]. Available from: http://www.pcouncil.org/wp-content/uploads/certified_cowcod_Dec_2007.pdf.

[PFMC] Pacific Fishery Management Council. 2007. Status of the U.S. canary rockfish resource in 2007. In Status of the Pacific coast groundfish fishery through 2008, stock assessment and fishery evaluation: stock assessments, STAR panel reports, and rebuilding analyses [Internet]. [cited on 2014 August 18]. Available from: http://swfsc.noaa.gov/publications/CR/2008/2008Mac1.pdf.

Pittman SJ, McAlpine CA, Pittman KM. 2004. Linking fish and prawns to their environment: a hierarchial landscape approach. Marine Ecology Progress Series 283:233-254.

Pittman SJ, Brown KA. 2011. Multi-Scale approach for predicting fish species distributions across coral reef seascapes. PLoSONE 6(5):1-12.

Pittman SJ, Christensen JD, Caldow C, Menza C, Monaco ME. 2007. Predictive mapping of fish species richness across shallow-water seascapes in the Caribbean. Ecological Modelling 204:9–21.

Richards L. 1986. Depth and habitat distributions of three species of rockfish (*Sebastes*) in British Columbia: observations from the submersible PISCES IV. Environmental Biology of Fishes 17(1):13-21.

Ries L, Fletcher RJ Jr., Battin J, Sisk TD. 2004. Ecological responses to habitat edges: mechanisms, models, and variability explained. Annual Review of Ecological and Evolutionary Systems 35:491-522.

Roberts JJ, Best BD, Dunn DC, Treml EA, Halpin PN. 2010. Marine geospatial ecology tools: an integrated framework for ecological geoprocessing with ArcGIS, Python, R, MATLAB, and C++. Environ Model Software 25:1197–1207.
Stein DL, Tissot BN, Hixon MA, Barss W. 1992. Fish-habitat associations on a deep reef at the edge of the Oregon continental shelf. Fishery Bulletin 90(3):540-551.

Tissot BN, Yoklavich MM, Love MS, York K, and Amend M. 2006. Benthic invertebrates that form habitat on deep banks off southern California, with special reference to deep sea coral. Fishery Bulletin 104:167-181.

Turner MG. 1989. Landscape Ecology: the effect of pattern on process. Annual Review of Ecology and Systematics 20:171-197.

Uzmann JR, Cooper RA, Theroux RB, Wigley RL. 1977. Synoptic comparison of three sampling techniques for estimating abundance and distribution of selected megafauna: submersible vs camera sled vs otter trawl. Marine Fisheries Review 39(12):11-19.

Wakefield WW, Whitmiren CE, Clemons JER, Tissot BN. 2005. Fish habitat studies: combining high-resolution. American Fisheries Society Symposium 41:119-138.

Whitmire CE, Embley RW, Wakefield WW, Merle SG, Tissot BN. 2007. A quantitative approach for using multibeam sonar data to map benthic habitats. In Todd BJ and Greene HG, editors. Mapping the Seafloor for Habitat Characterization: Geological Association of Canada, Special Paper 47, p. 111-126.

Young MA, Iampietro PJ, Kvitek RG, Garza CD. 2010. Multivariate bathymetry-derived generalized linear model accurately predicts rockfish distribution on Cordell Bank, California, USA. Marine Ecology Progress Series 415:247-261.

Yoklavich MM, Greene GH, Caillet GM, Sullivan DE, Lea RN, Love MS. 2000. Habitat associations of deep-water rockfishes in a submarine canyon: an example of a natural refuge. Fishery Bulletin 98:625-641.

Yoklavich M, Cailliet G, Lea RN, Greene GH, Starr R, de Marignac J, Field J. 2002. Deepwater habitat and fish resources associated with the Big Creek Marine Ecological Reserve. Reports of California Cooperative Oceanic Fisheries Investigations 43:120-140.

Zabel CJ, Dunk JR, Stauffer HB, Roberts LM, Mulder BS, Wright A. 2003. Northern Spotted Owl habitat models for research and management application in California. Ecological Applications 13(4):1027-1040.

Zwick R, Marascuilo LA. 1984. Selection of pairwise multiple comparison procedures for parametric and nonparametric analysis of variance models. Psychological Bulletin 95(1):148-155.

APPENDIX A. TABLES AND CAPTIONS

Table 1. ROV dives conducted in 2010-2011 at four locations along California's central coast.

	Bodega Bay	Farallon Islands	Point Arena	Point Reyes
2010	8	11	7	0
2011	11	10	2	13

Table 2. Relative abundance of red rockfishes across four locations along California's central coast. The complex category includes Vermilion, Canary and Yelloweye Rockfishes that could not be distinguished from ROV video.

	Bodega Bay	Farallon Islands	Point Arena	Point Reyes	Total
Canary	216	119	84	83	502
Vermilion	6	40	27	12	85
Complex	4	13	10	5	32
Yelloweye	2	2	5	1	10
Total	228	177	126	101	629

Table 3. Two predictive distribution models were tested for small (juvenile and subadult) Canary Rockfish, and ten trials were run for each model. The three highest performing trials for Canary Rockfish 10-15 centimeters TL each included bathymetry (bat), distance from interface (int) and topographic position index (tpi), while the trials for Canary Rockfish greater than 15 centimeters TL included bathymetry (bat), distance from interface (int) and either slope (slo), eastness (eas) or both variables. An asterisk denotes significance at the specified alpha level.

Canary Rockfish 10-15 centimeters TL

Trial #	Variable	Coefficient	P Value
2	intercept	-2.91	<0.01*
	tpi	-1.64	>0.05
	int	-0.0168	>0.05
	bat	-0.0627	<0.01*
5	intercept	-2.73	<0.05*
	tpi	-17.2	>0.05
	eas	0.516	>0.05
	int	-0.0227	<0.05*
	bat	-0.0687	<0.01*
10	intercept	-5.25	<0.01*
	tpi	-2.60	<0.05*
	int	-0.0178	<0.01*
	slo	0.191	<0.05*
	bat	-0.0998	<0.001*

Canary Rockfish >15 centimeters TL

Trial #	Variable	Coefficient	P Value
2	intercept	-5.67	<0.001*
	nor	0.556	<0.05*
	int	-0.00944	<0.05*
	slo	0.126	<0.05*
	bat	-0.106	<0.001*
5	intercept	-3.71	<0.001*
	eas	0.423	>0.05
	int	-0.0152	<0.001*
	bat	-0.0811	<0.001*
9	intercept	-3.69	<0.001*
	tpi	-0.652	>0.05
	eas	0.363	>0.05
	int	-0.0188	<0.001*
	slo	0.0835	>0.05
	bat	-0.0768	<0.001*

Table 4. Two predictive distribution models were tested for small (juvenile and subadult) Canary Rockfish. The highest performing trials for each model are bolded, indicating strong agreement between three model accuracy statistics, overall accuracy, Cohen's Kappa and area under the curve. Acc = overall accuracy, K = Cohen's Kappa, AUC = area under the curve.

Canary Rockfish 10-15 centimeters TL

Trial #	Acc	K	AUC
1	0.750	0.500	0.819
2	**0.821**	**0.632**	**0.792**
3	0.571	0.226	0.561
4	0.750	0.505	0.749
5	**0.821**	**0.639**	**0.846**
6	0.679	0.357	0.633
7	0.690	0.359	0.659
8	**0.815**	**0.630**	**0.835**
9	0.679	0.417	0.783
10	**0.821**	**0.650**	**0.877**

Canary Rockfish >15 centimeters TL

Trial #	Acc	K	AUC
1	0.754	0.496	0.753
2	**0.836**	**0.643**	**0.860**
3	0.732	0.464	0.681
4	0.789	0.573	0.811
5	**0.804**	**0.607**	**0.837**
6	0.679	0.357	0.723
7	0.782	0.552	0.809
8	0.768	0.539	0.763
9	**0.804**	**0.607**	**0.839**
10	0.789	0.580	0.858

APPENDIX B. FIGURES AND CAPTIONS

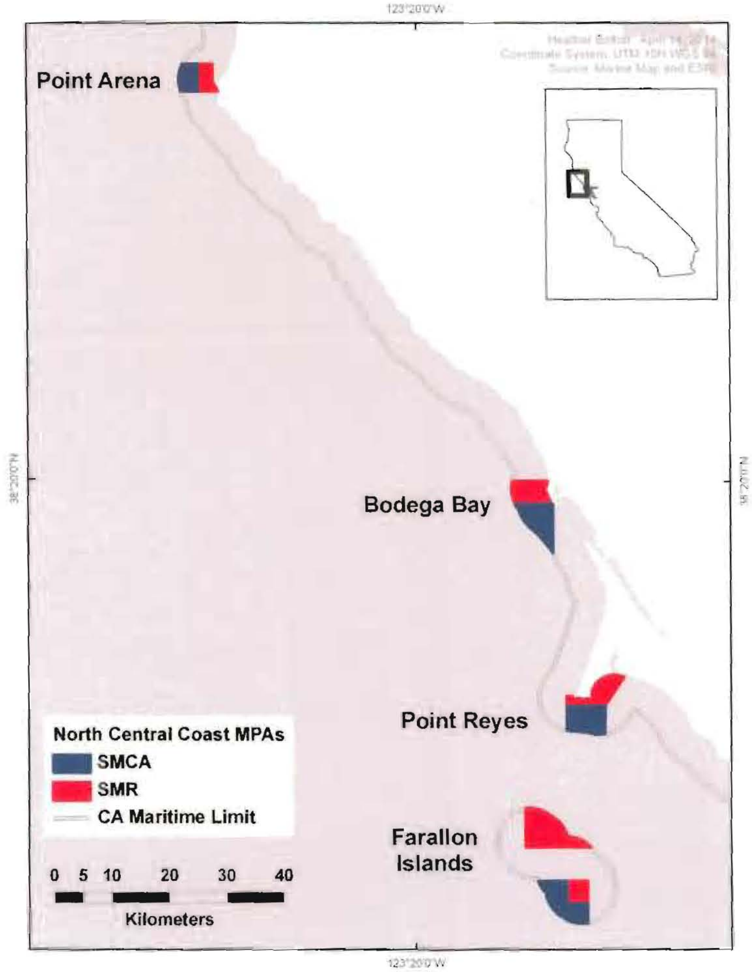

Figure 1. Map of the four locations sampled using the ROV, showing boundaries of the State Marine Reserves and State Marine Conservation Areas as well as the three-mile limit demarcating state waters.

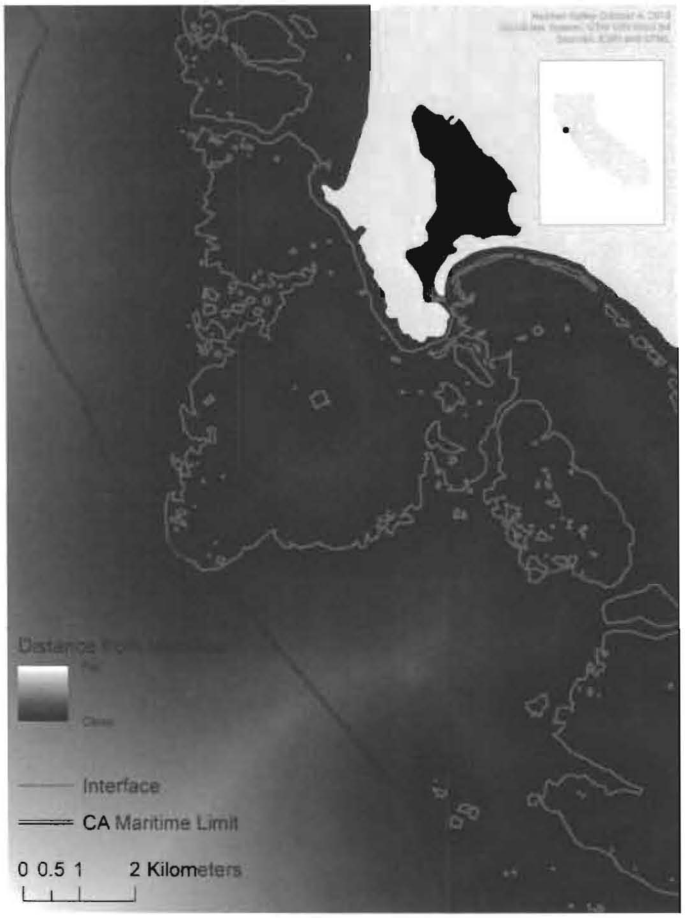

Figure 2. Simplified map (25 meter resolution) showing distance from rock-sand interfaces in Bodega Bay, California.

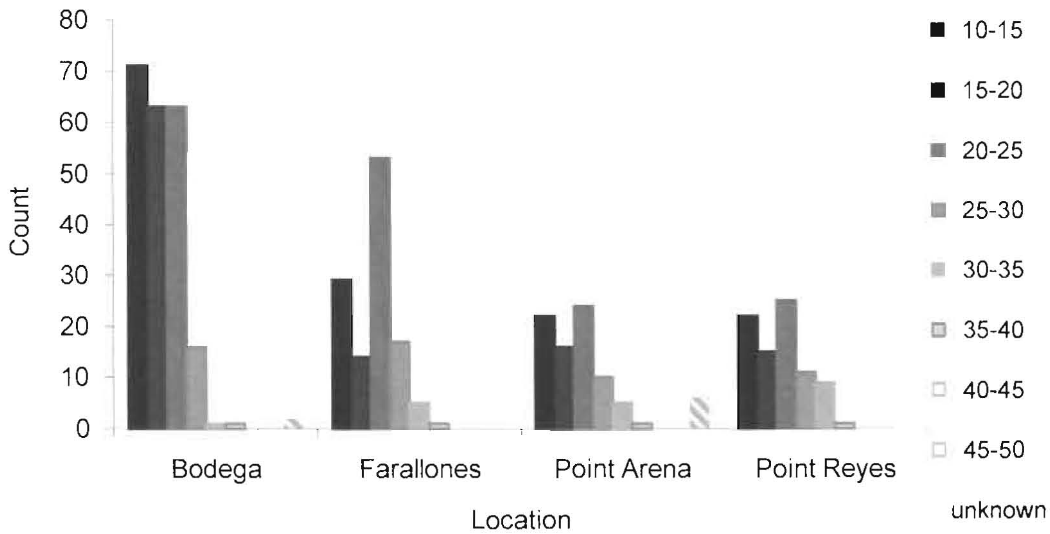

Figure 3. Right-skewed size distributions (centimeters TL) of Canary Rockfish across four locations along California's central coast.

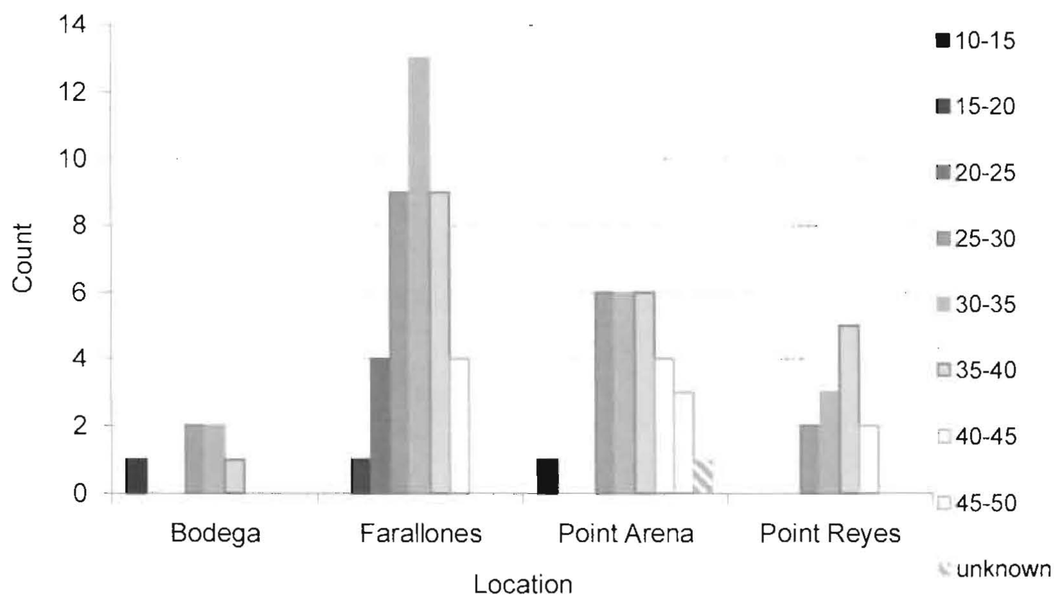

Figure 4. Normal size distributions (centimeters TL) of Vermilion Rockfish across four locations along California's central coast.

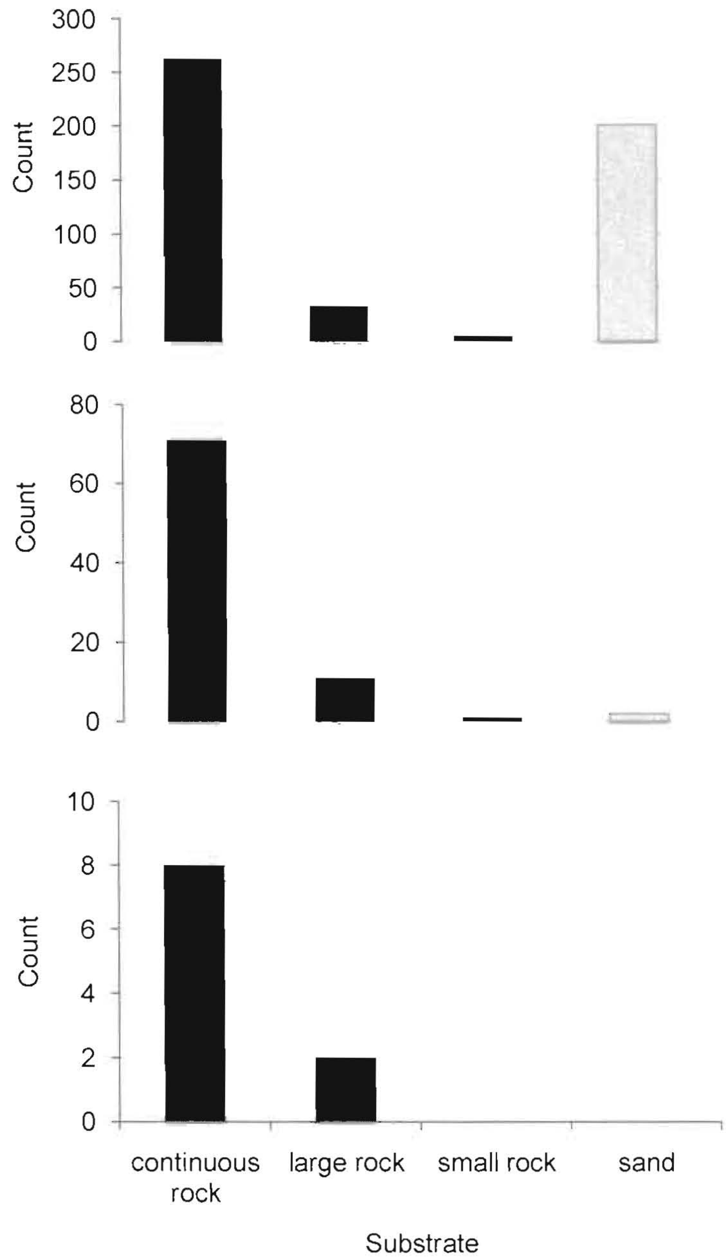

Figure 5. Fine scale habitat associations of small (juvenile and subadult) Canary Rockfish (top), Vermilion Rockfish (middle), and Yelloweye Rockfish (bottom) across four locations along California's central coast. These fish-habitat observations were made from ROV video.

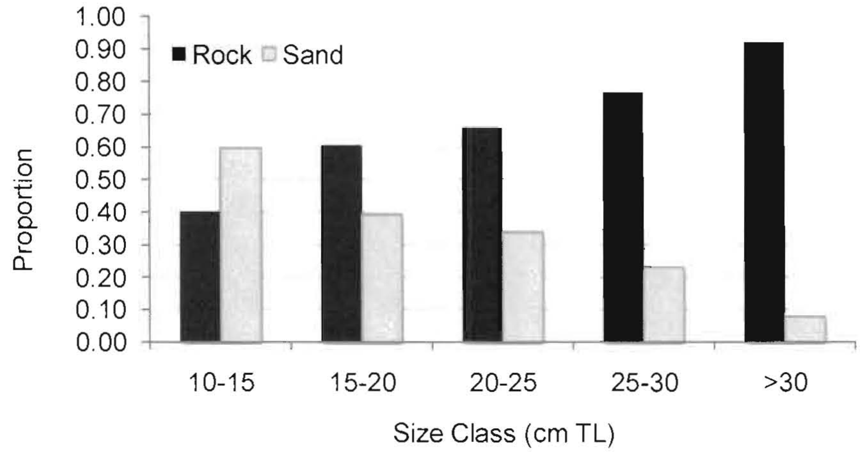

Figure 6. Small (juvenile and subadult) Canary Rockfish associated with sand but switched to association with rock as their total length increased. There were significant differences found between size classes 10-15 and >30 centimeters for sand and rock.

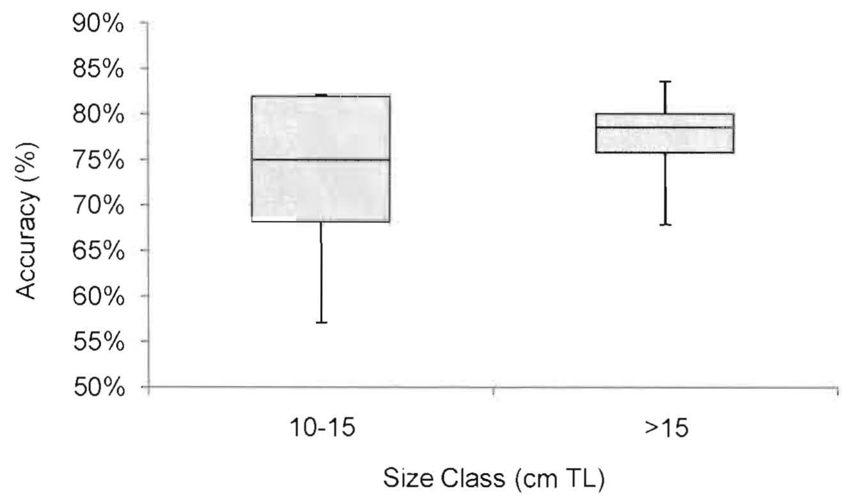

Figure 7. Average overall accuracy for the 10-15 centimeter TL distribution model (74%) was slightly lower than for the greater than 15 centimeter TL distribution model (77%)

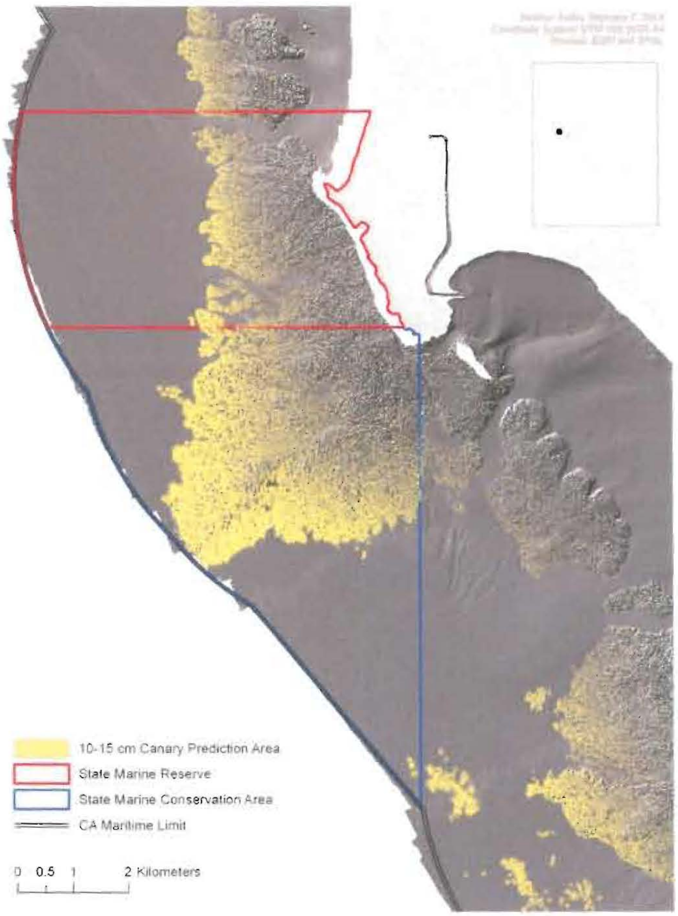

Figure 8. Nine percent and forty-nine percent of the predicted area for Canary Rockfish 10-15 centimeters TL was contained within the State Marine Reserve and State Marine Conservation Area respectively.

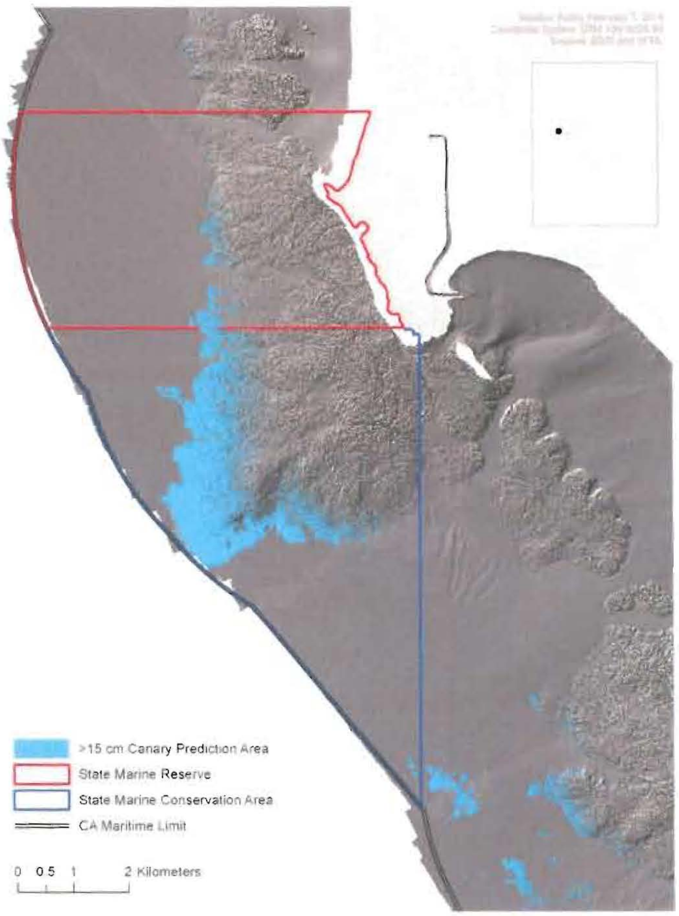

Figure 9. Four percent and seventy-one percent of the predicted area for Canary Rockfish greater than 15 centimeters TL was contained within the State Marine Reserve and State Marine Conservation Area respectively.