BASELINE CHARACTERIZATION OF NEARSHORE ROCKY REEF FISHES FOUND IN NORTHERN CALIFORNIA MARINE PROTECTED AREAS

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ABSTRACT

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The nearshore rocky reef habitat along California's North Coast supports a diverse assemblage of ecologically, economically, and culturally important fishes. In December 2012, a network of Marine Protected Areas (MPAs) was established in Northern California with the goal of protecting these species. Our study utilized collaborative hook and line fishing methods, while employing local charter fishing vessels, to establish a baseline of rocky reef fishes associated with four MPAs and four unprotected reference sites. These baseline data were then used to inform generalized additive models (GAMs) to explore potential drivers of relative abundance, size, and diversity of fishes. Understanding what factors drive initial conditions in paired sites will allow managers to track fluctuations in fish communities associated with rocky reefs, and properly attribute changes to MPA effects over time. This is especially important in the Pyramid Point and Sea Lion Gulch MPAs, where catch per unity effort was significantly different from their associated reference sites. These differences are likely a function of different levels of historical fishing pressure between MPAs and reference sites. Distance from port, a proxy for historical fishing pressure, and depth, were the most important predictors of fish catch per unit effort and diversity in the North Coast MPA Region.

Continued monitoring of MPAs in the North Coast region will be critical in the evaluation of MPA effects and provide much needed fishery-independent data that can be used to improve management strategies in this area.

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INTRODUCTION

Rocky reefs are iconic features of the California coast that help support a highly productive and diverse ecosystem. Species of the genus *Sebastes*, known as rockfishes, dominate the fish communities of many California rocky reefs and support significant commercial and recreational fisheries. Despite their economic and cultural importance, the abundance and distribution of rockfishes and other fish species associated with rocky reefs are not well understood (Lenarz 1987, Parker et al. 2000, Williams and Ralston 2002, Iampietro et al. 2008). Many species of rockfish prefer high relief rocky structure; this prohibits the use of groundfish bottom trawls that have traditionally been used in stock assessments of bottom fish over rocky outcrops and the continental shelf (Love et al. 1998, Jagielo et al. 2003, Iampietro et al. 2008). Moreover, visual surveys (i.e. SCUBA and remotely operated underwater vehicles) are time intensive, expensive, and spatially limited (Langlois et al. 2010, Young et al. 2010). Consequently, fisheries independent data describing fish communities associated with rocky reefs are limited (Dick and MacCall 2010).

The genus *Sebastes* is incredibly diverse, containing more than 60 species inhabiting the waters from California to the Gulf of Alaska (Love et al. 2002, Allen et al. 2006). Rockfish can be found at depths ranging from the intertidal to greater than 2000 meters (Parker et al. 2000, Yoklavich et al. 2000). A large number of rockfish species have a lifespan between 20 and 60 years, and in extreme examples may reach ages of 100 years or more (Love et al. 2002, Beamish et al. 2006). In addition to being long lived, many species of rockfish are also slow growing; not reaching sexual maturity until age five or later (Love et al. 1990, Love et al. 2002). Furthermore, rockfishes have highly variable recruitment success, largely dependent on oceanographic processes that drive prey availability and larval transport (Hollowed et al. 2001, Wheeler et al. 2017). Similar to many fish species, larger, older females produce a larger number of more fit larvae (Hixon et al. 2014). These life history strategies make rockfish particularly susceptible to overfishing and prolonged recovery periods (Parker et al. 2000, Field and Ralston 2005). In fact, the Pacific Fishery Management Council (PFMC), responsible for managing all groundfish fisheries along the United States Pacific coast, currently lists five *Sebastes* species as overfished (Boccaccio, *Sebastes paucispinis*; cowcod, *S. levis*; darkblotched rockfish, *S. cramen*; Pacific ocean perch, *S. alutus*; and yelloweye rockfish, *S. rubberrimus*; PFMC 2016a). Furthermore, decreased catch rates in many other rockfish species have been observed since the 1970s (Bloeser 1999, PFMC 2016b). Strategies for managing these overfished species have traditionally included catch limits, fishing depth restrictions, shortened fishing seasons, and limiting fishing fleets (Johannes 1978, Palmer 2004). More recently, Marine Protected Areas (MPAs) have become a popular strategy to protect overfished species and prevent further overexploitation of rocky reef associated fishes.

MPA Baseline Characterization

Marine protected areas are a relatively new form of marine conservation and fisheries management designed to combat the rapid degradation of ocean resources (Lubchenco et al. 2003, Scholz et al. 2004). Publications and reports concerning MPAs have seen a dramatic increase in recent years (Jones 2002) as researchers attempt to understand the trade-offs between biological (conservation) goals and socio-economic concerns (Badalamenti et al. 2000, Brown et al. 2001, Christie 2004, Klein et al. 2008). At its most basic level, a marine protected area is meant to maintain or restore biomass, biodiversity, and ecosystem function to a more natural (unfished) state by limiting or eliminating extractive activities over a period of time (Pomeroy 2004). If successful, MPAs can positively impact fisheries through the spillover of exploited species from protected areas into fishable grounds (McClanahan and Mangi, 2000).

The California legislator adopted the Marine Life Protection Act (MLPA) in 1999 with goals to redesign California's system of MPAs to function as a network. This act aimed to protect the natural diversity and abundance of marine life and to conserve the economic and cultural value of marine fisheries by creating and managing a statewide network of MPAs. An ecologically connected MPA network can replenish itself through the movement of adults and juveniles -- as well as by larval dispersal -- between MPAs, thus restoring biodiversity and biomass to depleted areas (Cowen et al. 2006, Botsford et al. 2009). This connectivity can provide increased resilience to environmental impacts from climate change (i.e., increasing ocean temperatures and ocean acidification) or other large or small scale disturbances (McLeod et al. 2009). Moreover, properly designed and managed MPA networks can protect a larger variety of habitats and species than a single MPA (Gleason et al. 2010).

To make the MPA planning and siting process more manageable, the 1,800 kilometers of California coastline was split into four different regions: the South Coast (California/Mexico border to Point Conception), the Central Coast (Point Conception to Pigeon Point), the North Central Coast (Pigeon Point to Alder Creek near Point Arena), and the North Coast (Alder Creek to California/Oregon border). A baseline survey was conducted in each region after the conclusion of the MPA siting process in order to establish ecological and socioeconomic benchmarks for future MPA monitoring efforts. This thesis will focus on fisheries data collected as part of the baseline survey of nearshore rocky reef habitat in the North Coast MPA region.

The North Coast MPA Study Region extends from Alder Creek, just north of Point Arena, to the California/Oregon border. The region stretches more than 400 kilometers and includes some of California's most rugged and remote coastline. With only three protected ports offering full vessel services and two semi-protected mooring basins, the north coast region presents a unique set of challenges for those conducting marine research. Lack of infrastructure to support research vessels limits the collection of reliable fisheries independent data. Furthermore, much of the suitable habitat inhabited by commercially and recreationally important fish species is not easily accessible from a fishing port. These factors have led to substantial data gaps in North Coast rocky reefs. In an effort to quantify these gaps, Steinberg (2008) assembled a database of available peerreviewed literature, agency reports, graduate theses, and geospatial information systems (GIS) data. The author reported large data gaps in the nearshore rocky reef habitat compared to more easily accessible habitats such as the intertidal zone and estuaries. Additionally, the spatial distribution of available data was skewed toward regions in close proximity to Humboldt State University, located in Humboldt County, and was sparse in other parts the region (Mendocino and Del Norte Counties). It is vital that existing data gaps in rocky reef associated fish stock assessment and community structure be filled as the stressors associated with climate change and exploitation from fisheries continue to impact these important ecosystems (Doney et al. 2012).

The MLPA identified over 25 species of nearshore rocky reef associated fishes, mostly rockfishes, likely to benefit from a California network of MPAs. Species expected to benefit most from protection are those with high site fidelity and directly targeted by fisheries or captured as bycatch (Mosquera et al. 2000, Blyth-Skyrme 2006). It is widely accepted that properly designed and enforced MPAs can have positive effects on ecosystems through increasing biomass, density, species richness, and size of organisms protected (McClanahan and Mangi 2000, Willis et al. 2003, Micheli et al 2004, Tissot et al. 2004, Tetreault and Ambrose 2007, Harmelin-Vivien et al. 2008, Lester et al. 2009, Maggs et al. 2013). The timing and extent of these MPA effects varies greatly across the world depending upon the size of the MPA, taxonomic groups protected, life history of species protected, oceanographic regime, and the age of the MPA (Starr et al. 2015). Starr et al. (2015) examined trends in hook and line catch per unit effort (CPUE) and lengths of rocky reef associated fishes in the Central California MPA Region between 2007, when MPAs in this region were established, and 2013. While catch rates varied annually for some species of rocky reef fishes, significant changes in CPUE and size were not detected between MPAs and associated reference sites over the seven years of monitoring. However, in the portion of the Point Lobos MPA that has been protected since 1973, fish density and size was found to be significantly higher than recently established MPA and reference sites, suggesting a delayed MPA effect. Due to the life history of rocky reef associated fishes in Central California and the highly variable eastern boundary current ecosystem, the authors suggest that significant MPA effects may take upwards of 20 years before being detected (Starr et al. 2015). This same delayed MPA effect is expected for rocky reef associated fishes in Northern California MPAs as ocean conditions and species life histories are similar to those found in Central California.

To this end, establishing a reliable baseline of relative species abundance, size, and diversity inside new Northern California MPAs is of great importance. These data will allow for effective MPA monitoring and provide valuable fisheries independent fish community data in these traditionally understudied habitats.

Fish Community Drivers

As MPAs have become a more popular tool in marine conservation, the need for detailed information concerning habitat preferences of species of interests has grown as well (Young et al. 2010). Understanding species habitat associations is essential, not only for the MPA siting process, but for subsequent monitoring as well. Recent advancements in acoustic technology have allowed for extensive high resolution mapping of benthic habitat (Mitchell 1996, Kostylev et al. 2001, Anderson et al. 2009). Habitat characteristics acquired from these new techniques can be combined with fish community data and used to generate models to examine trends in fish abundance, size, and diversity (Young et al. 2010). Additionally, these models (e.g. generalized linear models (GLMs) and generalized additive models (GAMs)) can incorporate a number of habitat, spatial, and environmental covariates to predict species occurrence and distribution across broad spatial extents (Guisan et al. 2002, Nasby-Lucas et al. 2002, Iampietro et al. 2008, Young et al. 2010, Young an Carr 2015, McLean et al. 2016). Depth, slope, aspect, rugosity, habitat type, and latitude are among the most commonly utilized predictors included in these species habitat distribution models.

In addition to habitat and spatial variables, historical fishing pressure can have a large impact on rockfish abundance, diversity, and size structure of exploited species. The majority of rockfish species classified as “overfished” on the Pacific Coast have been depleted through commercial bottom trawling 200 to 500 meters deep (Schroeder and Love 2002, Williams and Ralston 2002, Hilborn et al. 2012). However, recreational harvest can also have significant negative effects on rockfish populations (Karpov et al. 1995, Love et al. 1998, Mason 1998, Williams et al. 2010). In a study conducted in Monterey Bay, California, Mason (1998) discovered that ten rockfish species highly targeted by commercial passenger fishing vessels (CPFV) saw declines in mean length between 1960 and 1994. Moreover, Love et al. (1998) reported a significant decrease in CPFV CPUE and mean lengths of many rockfish species from 1980 to 1996 in the Southern California Bight. Authors suggest these trends are most likely the result of overfishing of adult fish by the recreational fleet, leading to poor recruitment.

Quantifying historical fishing pressure in a data poor region like northern California can be a challenge. Spatially explicit and reliable quantitative data on fishing pressure is scarce. Access to much of the suitable habitat along the north coast of California is limited by the number of protected ports from which fishers can launch or harbor their vessels. Most fishing effort is concentrated in waters relatively close to the few ports to save on costly fuel, increase the proportion of time spent fishing, and avoid unpredictable changes in weather (Beverton and Holt 1957, Barrett et al. 2012).

In this study, I constructed a suite of generalized additive models using hook and line catch data from the North Coast baseline characterization project to explain variability in relative abundance, size, and diversity of important rocky reef associated fish species utilizing depth, rugosity, percent rough substrate, latitude, and distance from port as explanatory variables. Understanding what factors drive initial conditions in newly established MPAs will allow managers to track fluctuations in fish communities and properly attribute changes to MPA effects over time.

METHODS

Site Selection

The North Coast MPAs were enacted in December, 2012, and protect 355 square kilometers (13% of North Coast) of beach, estuary, and offshore rocky reef habitat. The network consists of 20 MPAs: 6 State Marine Reserves (SMR), 13 State Marine Conservation Areas (SMCA), 1 State Marine Recreational Management Area) and 7 special closures (Figure 1, Table 1). Over the course of two years (2014 – 2015) four different MPA sites and four associated reference sites were sampled. Each pair of sites was accessed from one of four ports along the north coast (listed north to south): Crescent City (Figure 2), Eureka (Figure 3), Shelter Cove (Figure 4), and Fort Bragg (Figure 5 Within each site, we selected four 500 by 500 meter stations with depths between 10 and 50 meters, and at least 20 percent rough substrate (indicating rock) based on data from the California Seafloor Mapping Project (2010). MPA sites sampled, from north to south, included: Pyramid Point State Marine Conservation Area (SMCA), South Cape Mendocino State Marine Reserve (SMR), Sea Lion Gulch SMR, and Ten Mile SMR. These MPAs were selected because they contain rocky reef structure representative of the Northern California nearshore environment and span almost the entire spatial extent of the North Coast MPA Region. Their paired reference sites, with respect to the MPA sites listed above, were: Damnation Creek, North Cape Mendocino, Point Delgada, and

Westport. Each reference site has a similar depth profile, habitat type, and experience similar oceanographic conditions as its paired MPA site.

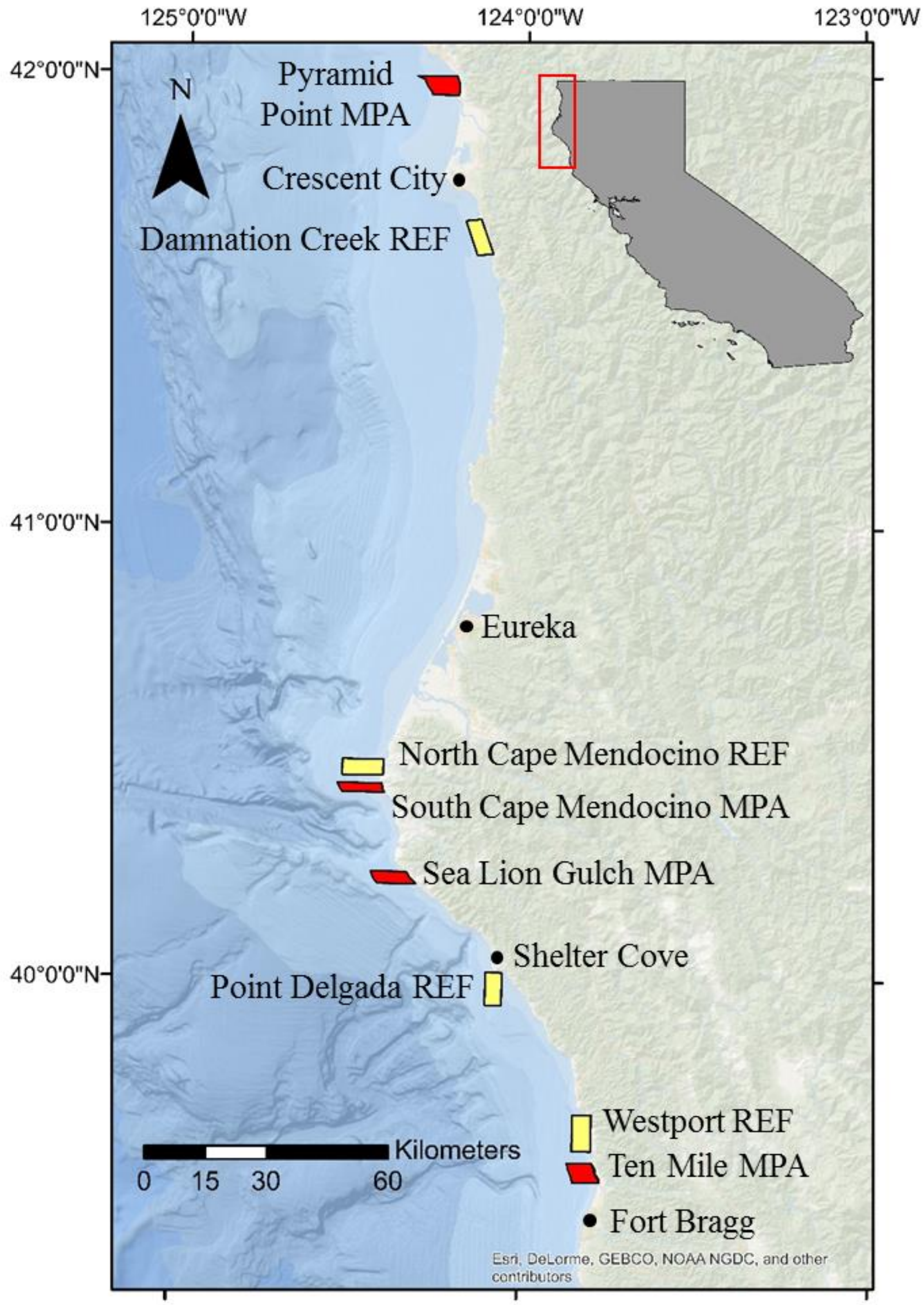

Figure 1. Map of the North Coast Marine Protected Area (MPA) Study Region with four Marine Protected Areas (MPA) and four reference sites (REF) sampled.

Table 1. Description and number of the three types of MPAs and special closures in the North Coast Marine Protected Area Study Region.

Number	**Type**	**Description**
6	State Marine Reserve (SMR)	An MPA designation that prohibits damage or take of all marine resources (living, geologic, or cultural) including recreational and commercial take
13	State Marine Conservation Area (SMCA)	An MPA designation that may allow some recreational and/or commercial take of marine resources (restrictions vary)
1	State Marine Recreational Management Area(SMRMA)	An MPA designation that limits recreational and commercial take of marine resources while allowing for legal waterfowl hunting.
7	Special Closure	An area designated by the Fish and Game Commission that prohibits access or restricts boating activities in waters adjacent to sea bird rookeries or marine mammal haul-out sites (restrictions vary)

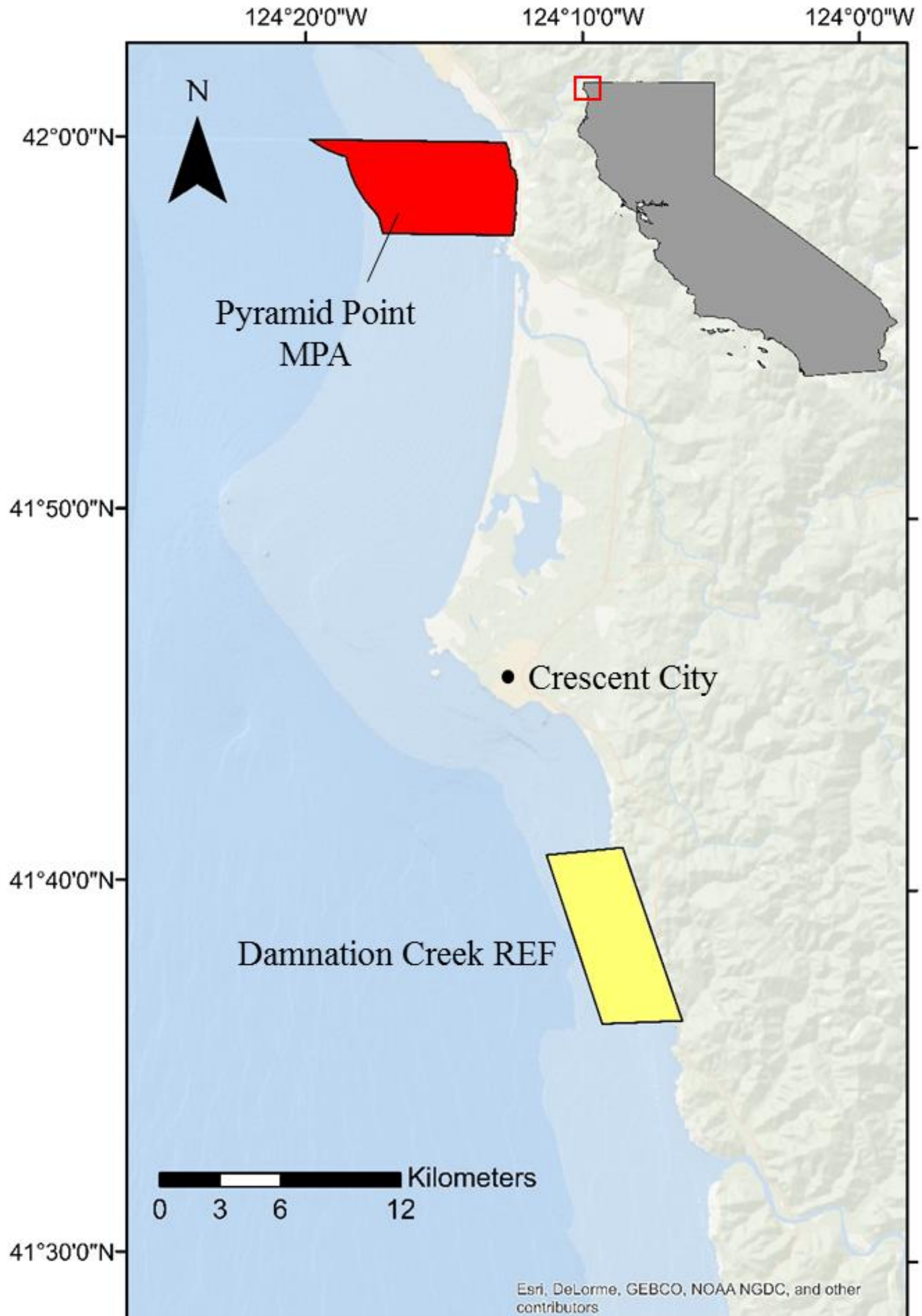

Figure 2. Map of Crescent City Marine Protected Area (MPA) and reference site (REF).

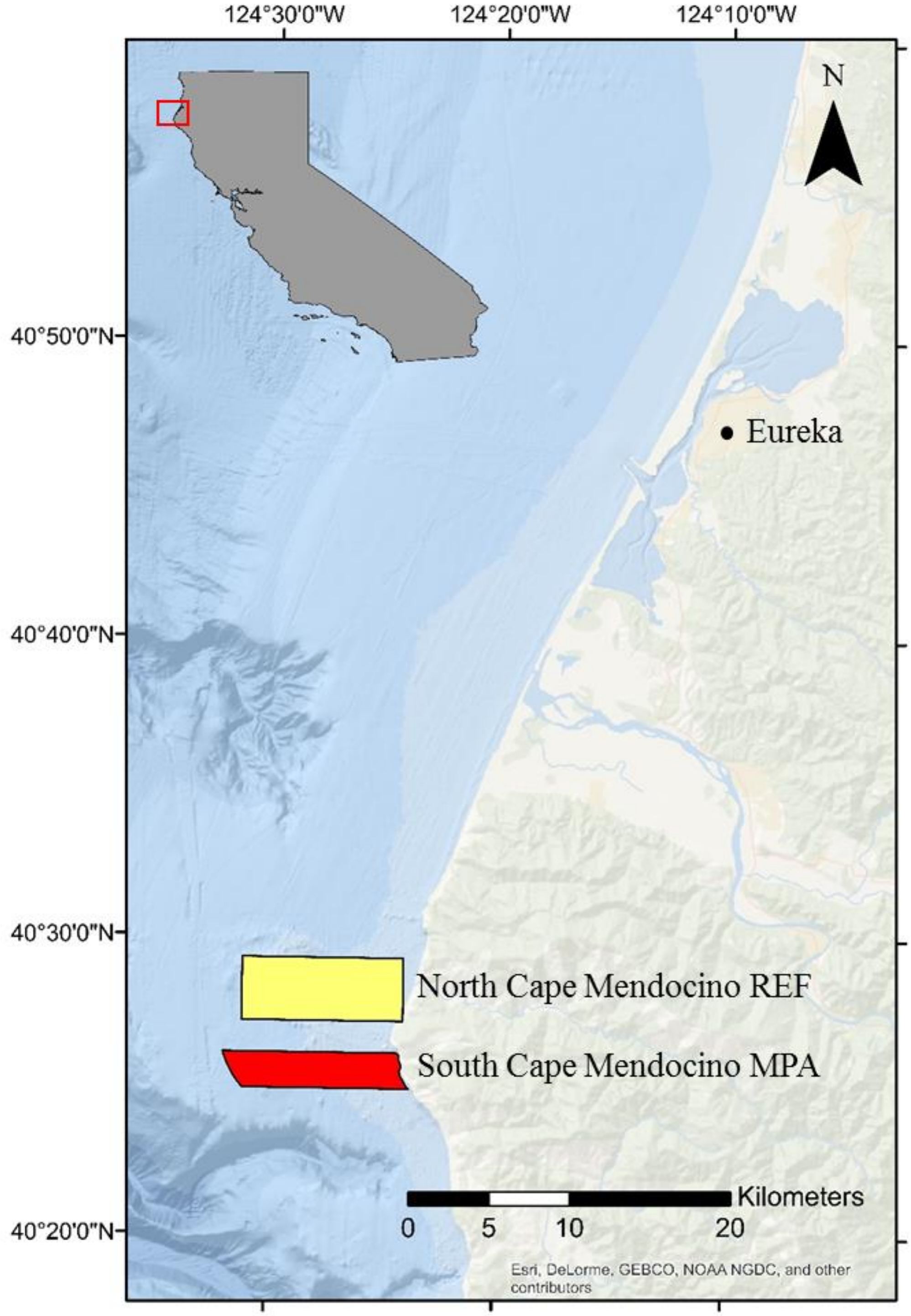

Figure 3. Map of Eureka Marine Protected Area (MPA) and reference site (REF).

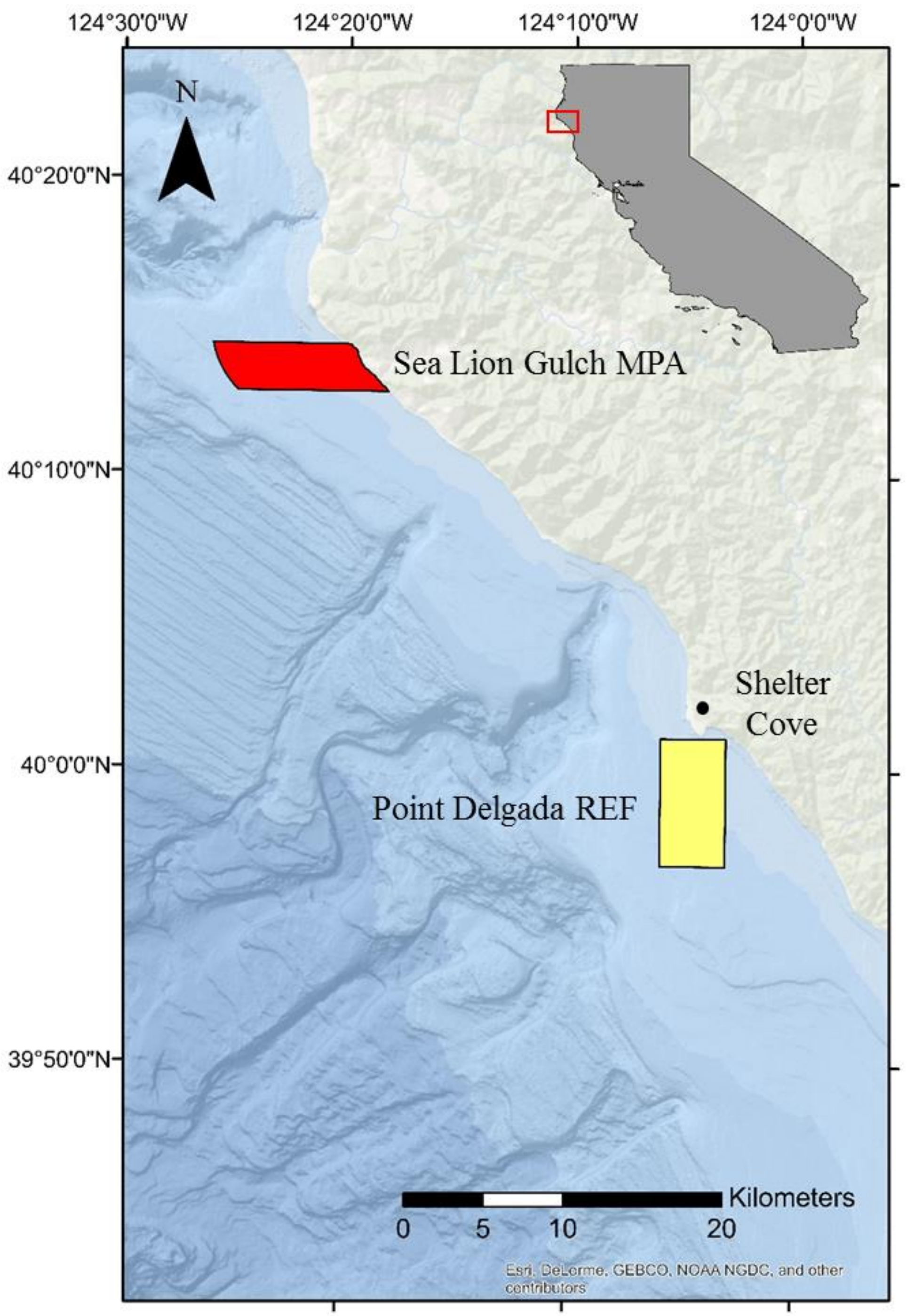

Figure 4. Map of the Shelter Cove Marine Protected Area (MPA) and reference site (REF).

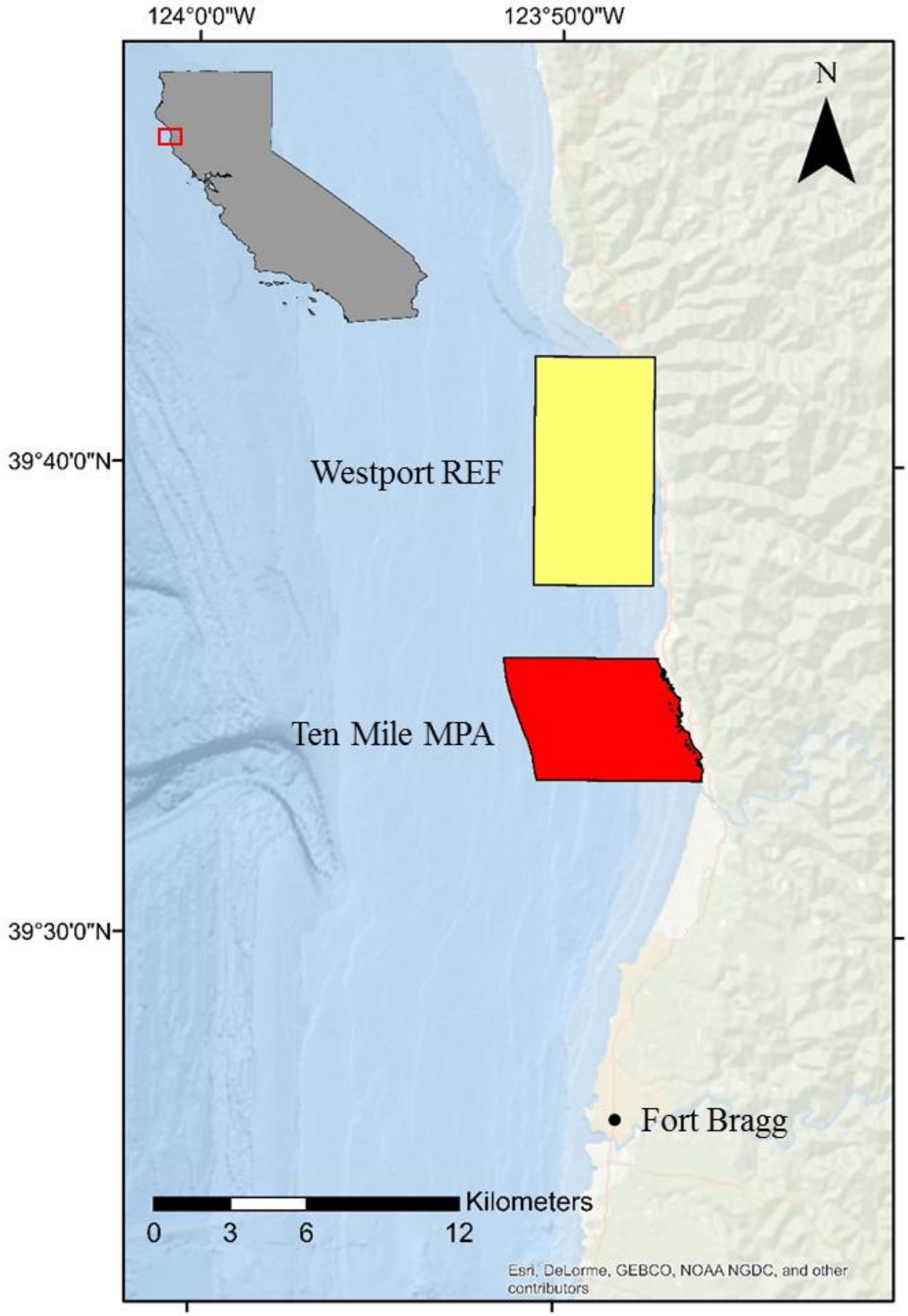

Figure 5. Map of the Fort Bragg Marine Protected Area (MPA) and reference site (REF).

MPA Baseline Characterization

Sampling crews consisted of four anglers comprised of volunteers and paid technicians, one fish processor, and one data recorder. Volunteers were recruited from local fishing clubs (e.g. Humboldt Area Saltwater Anglers), previous collaborative fisheries projects, Humboldt State University marine science programs (e.g. Fisheries Biology, Oceanography, Marine Biology), as well as from public outreach events. Occasionally, a deckhand would serve as a volunteer angler or fill in for an angler that was experiencing seasickness. The fish processor was responsible for identifying, measuring, tagging, and releasing the fish once on board. The data recorder recorded the information called out by the fish processor and kept track of the time spent actively fishing, and the number of drifts completed in each station. Each site was sampled three times between June and October, 2014 and twice between May and August, 2015.

Fishes were collected using hook and line gear designed to mimic methods used by local recreational anglers and modeled after the standardized sampling protocol developed by the California Collaborative Fisheries Research Program (CCFRP) for baseline characterization and monitoring of Central Coast MPAs (Starr 2010; IACUC # 13/14.F.01-A). Four anglers actively fished each of the four stations for forty-five minutes equaling three hours of sampling effort per site. Each angler used a different category of hook and line fishing gear including: 1) two red or white size 4/0 shrimp-flies baited with 1-2 inch strip of squid, 2) two un-baited red or white size 4/0 shrimp-flies, 3) a diamond or bar style metal jig paired with a single un-baited red or white size 4/0 shrimp-fly tied 2-4 feet above the jig, and 4) a lead jig-head fitted with a swimbait style soft plastic jig paired with a single un-baited red or white size 4/0 shrimp-fly tied 2-4 feet above the jig (Figure 6). Poles were rigged with the lightest metal bar, jig head, or sinker (weight ranged from 4-12 ounces) that would allow anglers to fish on the bottom.

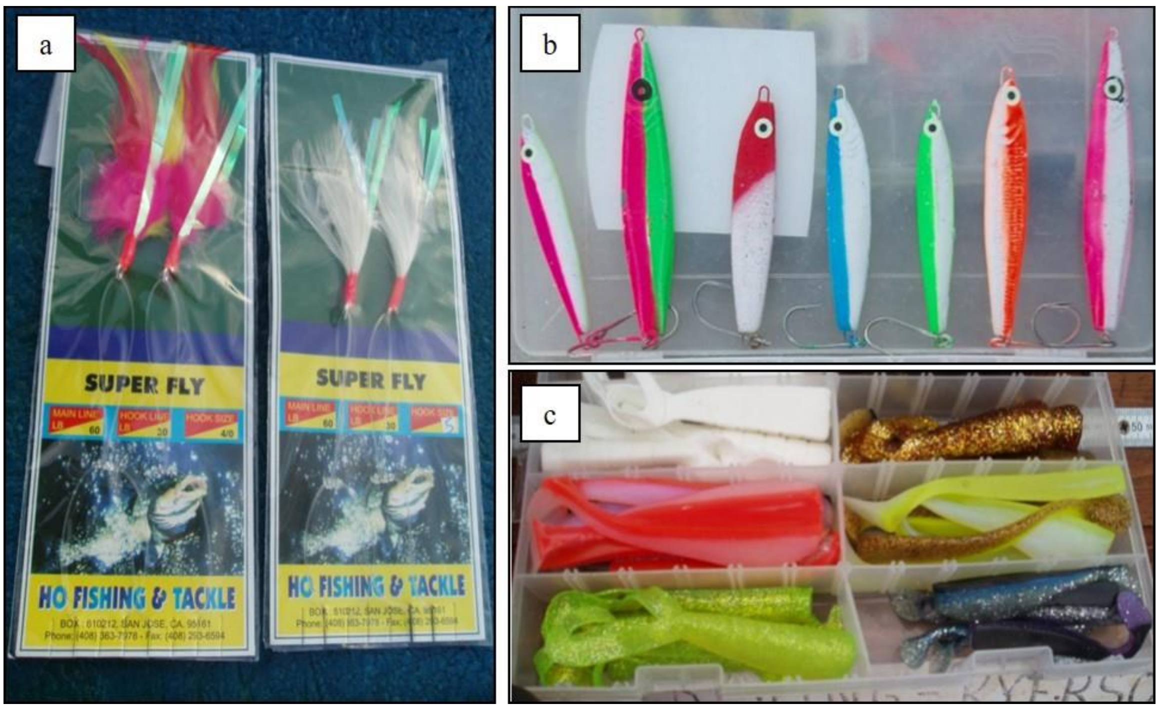

Figure 6. Gear used during hook and line sampling. a) Red and white size 4/0 shrimp flies. b) Bar style metal jig. c) Swimbait style soft plastic jig.

CPFV captains were instructed to position the vessels to drift over as much rocky reef habitat as possible within each station. Drift location and direction in each station was selected by the captain with the intent of sustaining a fifteen minute drift targeting suitable habitat. Captains were required to complete a minimum of three drifts during each forty-five minute sampling period to cover at least three separate areas of suitable habitat within each station. If high winds and/or quick currents did not allow for three fifteen minute drifts, the captain would reset the drift in a similar position, and multiple drifts would be utilized until fifteen minutes of active fishing was completed in one portion of the station before moving to another part of the station. Under slow drifting conditions the captain would use the motor intermittently to speed up the drift and cover ample habitat across the station.

All fish landed were identified to species and measured (fork length) on a wooden v-board. Fish with a fork length greater than 230 millimeters, and in good condition, were tagged with an external T-bar anchor tag implanted through the dorsal pterygiophores and released. Fish exhibiting symptoms of barotrauma were descended with a customized weighted milk crate or a weighted inverted hook and assigned. The time fish spent on deck was minimized in order to reduce stress and incidental mortality. When high catch rates lead to a backup in processing the fish on board, active fishing was stopped and the fish on board were processed and released before fishing resumed.

Percent species composition was calculated for each year separately, and both years combined, at each site, and compared across the entire study area. Multi-dimensional scaling (MDS) was used to visually illustrate similarities and differences in species compositions within and between paired MPA and reference sites. A Bray-Curtis similarity matrix of relative catch compositions of the nine most abundant species was created in Program R using the “vegdist” function in the “vegan” package. A MDS plot was created from the Bray-Curtis similarity matrix to graphically express similarity in species compositions among sites. The distance between sites on the MDS plot represents the similarity in species compositions. Sites clustered together are more similar than those spaced further apart.

Catch per unit effort (CPUE), species richness, Shannon Diversity index, and mean fish length were used as metrics to describe fish communities inside MPAs and reference sites. These fish community metrics describe both biological diversity and relative abundance of the nearshore rocky reef fish community, and are commonly used metrics to assess MPA effects (Halpern 2003, Starr et al. 2010).

CPUE was described as the number of fish caught per angler hour, and calculated by dividing the number of fishes caught by the total angler hours of fishing in a station in a day. Fishing effort during this project was consistent across stations, 45 minutes (0.75 hours) per visit. Four angler fished for 0.75 hours in each station, resulting in three total angler hours of fishing pressure per station visit. To this end, the number of fish caught was divided by three to attain the CPUE for each station visit. Station CPUE values were then averaged across paired MPA and reference sites. Species lengths were calculated for each site by averaging individual fork lengths for all five sampling occasions over the two sampling seasons.

Biological diversity was described using two common fish diversity metrics, species richness and the Shannon Diversity index (H). Species richness at each site was calculated as the average number of species caught over the five site visits. Shannon Diversity is a function of both species richness and species evenness, calculated as:

$$H = -\sum_{j=1}^{S} p_{\mathrm{i}} ln(p_i) \qquad \text{(Equation 1)}$$

Where p is the fraction of the total number of individuals belonging to the *i*th species during a visit to the *i*th site. Shannon Diversity was attained using the “diversity” function in the “vegan” community ecology package in Program R (Oksanen et al. 2016). The Shannon Diversity values were averaged across all five site visits to attain a mean H value for both sampling seasons. Annual comparisons were not made between mean species richness and Shannon Diversity due to varying sampling effort between the two sampling years. Additionally, low sample sizes in 2015, when only two sampling occasions per site were completed, may not be representative of the true species richness and diversity during that year. Pooling all five sampling occasions result in a more robust estimation of species diversity metrics for this baseline study.

Welch’s unequal variance t-tests were conducted in Program R to test for significant differences in fish community metrics between paired MPA and reference sites. A Welch’s t-test was chosen to allow for the comparison of data that violates the equal variance assumption required by the more common Student’s t-test (Ruxton 2006). Fish community metrics were evaluated for normality prior to analysis. A square root transformation was applied to species CPUE to satisfy the normality assumption. Species lengths, Shannon Diversity, and species richness values were normally distributed and did not require a transformation.

Fish Community Drivers

Relationships between nearshore rocky reef fish community structure and habitat and historical fishing pressure covariates were examined through the same four fish community metrics used in the baseline characterization analysis (species CPUE, mean length, species richness, and the Shannon Diversity index). Many recent species-specific habitat based assessments have utilized individual fish locations acquired through visual surveys from manned or unmanned underwater vehicles (Iampietro et al. 2008, Young et al. 2010). While these studies are useful in describing specific species habitat preferences on a fine scale, they are expensive and time intensive. This is especially true in an area such as the north coast, with very few ports to facilitate the use of larger research vessels. Utilizing community data acquired from the baseline characterization hook and line surveys, and high resolution habitat data provided by the California Seafloor Mapping Project, relationships between nearshore rocky reef associated fishes and habitat predictors were examined without the costs associated with operating large research vessels.

Unlike visual surveys, hook and line surveys do not provide data on the specific location of each individual fish. Consequently, specific fine scale species habitat associations will not be presented in this study. In these analyses, each 500 meter by 500 meter station, used in the MPA baseline characterization survey, was used as a sampling unit (n = 32). This study tested if habitat associations could be determined for rocky reef fishes at this larger scale using hook and line data.

Species CPUE and length analysis was examined for the four most abundant species captured during this study; black rockfish, blue rockfish (*Sebastes mystinus*), lingcod (*Ophiodon elongates*), and canary rockfish (*Sebastes pinniger*). These four species utilize a variety of habitats and have historically been captured in high numbers along the entire North Coast MPA Region (Love et al. 2002). Species richness and Shannon Diversity of all fish caught and only rockfish species were examined as well. All response variables were tested for normality visually by examining the distribution of values via histograms, and quantitatively by using a Shapiro-Wilk Test in Program R. A fourth root transformation was applied to species CPUE of black rockfish and blue rockfish, and a square root transformation was applied to canary rockfish and lingcod CPUE. No transformations were necessary for species length or diversity metrics.

Predictor Variables

Station level habitat data were derived from high resolution depth and substrate layers provided by the California Seafloor Mapping Project (CSMP, 2010). Mean station depth was calculated by overlaying station polygons with the two meter resolution digital elevation model (DEM) and applying the GIS zonal statics tool in ArcMap 10.2.2. This tool uses all pixels inside a zone, in this case each station, to calculate the mean value of that zone. Similar methods were used to calculate mean station rugosity and percent rough substrate. Rugosity data was extracted from the two meter resolution vector ruggedness measure (VRM) layer. The VRM layer contains values that capture the variability in both slope and aspect into a single measure. Flat and smooth areas have a

VRM close to zero and higher values (up to one) are associated with higher relief and rougher terrain areas (Young et al. 2010). VRM values for natural terrains range between zero and 0.4. Prior to calculating mean station rugosity, all habitat classified as smooth (VRM < 0.0005) was reclassified as "No Data" and therefore not included in the calculation of the mean station rugosity. As a result, mean station rugosity represents only the ruggedness of rough habitat within each station. The percent of each station containing rough substrate was calculated using the substrate layer provided by the CSMP. Substrate was classified as rough or smooth based on examinations of the VRM. Raster cells with a VRM value greater than 0.0005 were classified as rough while cells with a VRM less than or equal to 0.0005 were considered smooth. Calculating the mean of a raster containing ones and zeros, with ones representing rough substrate and zeros representing smooth substrate, resulted in the percent of the station containing rough substrate.

A measure of latitude was attained from the midpoint of each station using the Universal Transverse Mercator (UTM) Zone 10 North projection in the 1983 North American Datum. Latitude measures in UTM coordinates are known as northing values. These values represent the distance, in meters, north of the equator. Therefore, higher UTM coordinates represent sites located further north. The North Coast MPA region ranges from about 4,312,043 meters north of the equator at Point Arena to 4,650,290 meters north of the equator at the California Oregon border.

Similar to Barrett et al. (2012), distance from the nearest fishing port was used as a proxy for historical fishing pressure. Distance to each station (in kilometers) was measured from the port they were sampled out of during this project, with the exception of the Pyramid Point SMCA. The Port of Brookings, Oregon, is significantly closer to the Pyramid Point SMCA than Crescent City. Therefore, Brookings was used to calculate the distance from port for the four stations at the Pyramid Point SMCA.

Generalized Additive Models

Generalized additive models (GAMs) were used to elucidate relationships between fish community response variables and habitat and spatial predictors. GAMs are a semi-parametric extension of GLMs in that explanatory variables can be modeled non-parametrically, but a probability distribution (e.g., Gaussian, Poisson, binomial) must be specified for the response variable (Hastie and Tibshirani 1990, Guisan et al. 2002). The underlying assumption when fitting a GAM is that the response is a function of the sum of "smoothed" nonparametric functions (Stoner et al. 2001). These smoothers allow the data to determine the shape of the response curve, rather than being limited by the shapes available in a parametric model like a GLM. The shape of the response curve can range from a straight linear relationship to curves of increasing complexity (e.g., bimodal). The complexity of the response curve a GAM produces can be controlled by specifying the maximum degrees of freedom of each smoothing function (Wood 2006). If the degrees of freedom for a smoothed predictor variable is set to a max of one, the relationship between that predictor and the response is constrained to be linear. Increasing the maximum degrees of freedom allows the data to drive the response curve and can result in a more complex relationship (Jowett and Davey 2007).

Previous studies have found GAMs to be a useful tool for examining relationships between fish community metrics and habitat predictors (Stoner et al. 2001, Buchheister et al. 2013, Rees et al. 2014), as well as identifying thresholds in habitat selection (Jowett and Davey 2007). The ability of a GAM to capture non-linear relationships between the response variable and a set of predictor variables makes this style of model particularly useful for our data.

GAMs were fit in Program R using the “gam” function within the package “mgcv” (Wood 2011). Although GAMs can be applied to presence-absence data using a binomial distribution (Stoner et al. 2001, Francis et al. 2005), these analyses utilize continuous response variables with a Guassian (normal) distribution and an identity link. Smooth functions were fit using thin plate regression splines (TPRS). The maximum possible degrees of freedom were set to three (k = 3) for all predictor variables. Three degrees of freedom were selected to allow the model to identify potential thresholds in the relationship between predictors and the response, but also remain biologically realistic and avoid overfitting the model.

Prior to model fitting, predictor variables were tested for multi-collinearity using the Pearson’s correlation coefficient calculated using the “cor.test” function in Program R (Table 2). Pearson’s correlation coefficients were less than 0.7, and therefore all five predictors were retained.

Table 2. Pearson correlation values for each predictor variable. Values range between negative one and one with zero being not correlated.

Predictor	Latitude	Rugosity	Mean Depth	% Rough Substrate	Distance From Port
Latitude	–				
Rugosity	-0.47	–			
Mean Depth	-0.56	0.21	–		
% Rough Substrate	-0.19	0.35	0.29	–	
Distance From Port	-0.27	0.21	0.50	0.28	–

A candidate set of 31 GAMs including all variations of the five predictor variables was created for each of the twelve response variables (Appendix A). Mean station depth, percent rough substrate, mean rugosity of rough substrate, distance from port, and latitude were used as the five predictors of CPUE and mean length of the four species of interest, as well as Shannon Diversity and species richness. The full model was written as:

$$Y_i \sim S_1(\text{mean depth}_i) + S_2(\text{\% rough sub}_i) + S_3(\text{mean rugosity}_i) + S_4(\text{distance from port}_i) + S_5(\text{latitude}_i) \quad \text{(Equation 2)}$$

where y is the given response variable at station *i*, and each function, S(x), has a linear component and a nonlinear smoothing component fit with TPRS.

All 31 GAMs, for each response variable, were compared using Akaike's information criterion corrected for small sample sizes (AICc). The most parsimonious model, within two AICc units of the top ranked model, was chosen as the best model. Partial effects plots with confidence intervals (+/- 2 standard errors) were used to describe the effect of each predictor on the response after accounting for all other predictors in the best models (Blumer et al. 1987). Percent deviance explained was used to evaluate goodness-of-fit of each GAM. Estimated degrees of freedom (edf), F-statistic, and standard error for each covariate included in the best model was presented to describe the nature of the relationship between the response and predictor variable. Finally, the normality and equal variance assumptions were examined for each of the best GAMs using the "gam.check" function in the "mgcv" package.

RESULTS

MPA Baseline Characterization

This survey consisted of 40 total sampling trips, 24 in 2014 and 16 in 2015. Each MPA and reference site was sampled with an equal amount of effort in individual sampling seasons. In 2014, 288 angler hours of effort (36 angler hours/site) were deployed across all sites combined and 192 angler hours of effort (24 angler hours/site) were used in 2015. We engaged with 40 total volunteers and collaborated with six captains aboard eight different Commercial Passenger Fishing Vessels (Table 3). Volunteer skill level ranged from first time ocean fishers to anglers with more than 50 years' fishing experience. Of the 40 total volunteers, 18 participated in at least two fishing trips and 10 participated in three or more trips.

Table 3. Commercial Passenger Fishing Vessel (CPFV) captains who participated in collaborative hook and line surveys of Northern California Marine Protected Areas, 2014-2015.

Port	**Captain**	**Vessel**
Crescent City	Craig Strickhouser	CPFV Tally Ho II
Eureka	Matt Dallam	CPFV Fishy Business
	Tim Klassen	CPFV Reel Steel
Shelter Cove	Jared Morris	CPFV C'mon
	Kevin Riley	CPFV Outcast &
		CPFV Squirrel
Fort Bragg	Kurt Akin	CPFV Fish on &
		CPFV Bella Bleu

Over two seasons of sampling (2014 and 2015), a total of 4,237 fish, representing six families, were caught and identified over all sites sampled (Table 4 and Table 5). Of those, 3,491 were released with a tag. Excluding the 185 black rockfish sacrificed for otolith collection, 87% of fish landed were tagged and released over the course of this survey. Eighteen tagged fish (0.5%) have been recaptured as of November, 2017 (Table 6). Returns were dominated by black rockfish (n = 9) and lingcod (n=7). Fish recaptured in the same sampling station as their release were assigned a net movement of zero. The majority of recaptured fish were caught within 10 kilometers of their release. Four black rockfish recaptures moved at least 300 kilometers, all to the north. The largest displacement was an individual tagged in the South Cape Mendocino SMR and recaptured 680 kilometers north, off of Willapa Bay, WA after 586 days at liberty.

Table 4. Summary of years sampled, days fished, number of fish, and species richness in each Marine Protected Area (MPA) and reference (REF) site during hook and line surveys conducted in summer 2014 and 2015.

Ports	**Year Sampled**	**Days Fished MPA/REF**	**Fish Caught MPA/REF**	**Species Richness MPA/REF**
Crescent City	2014	3/3	137/222	5/10
	2015	2/2	83/193	5/9
	Total	5/5	220/415	6/11
Eureka	2014	3/3	390/310	13/10
	2015	2/2	182/172	9/10
	Total	5/5	572/482	13/11
Shelter Cove	2014	3/3	768/221	14/16
	2015	2/2	439/116	17/13
	Total	5/5	1207/337	17/16
Fort Bragg	2014	3/3	258/355	16/14
	2015	2/2	200/191	14/12
	Total	5/5	458/546	18/15
Grand Total	MPA/REF	20/20	2457/1780	21/18
Grand Total	All Areas	40	4237	23

Table 5. Total number of individuals and percent composition of each family represented by hook and line surveys over both sampling seasons (2014 and 2015).

Family	**Number Caught**	**% Total Catch**
Sebastidae	3549	83.8
Hexagrammidae	652	15.4
Cottidae	27	0.6
Salmonidae	4	0.1
Pleuronectidae	3	0.1
Paralichthyidae	2	< 0.1

Table 6. Tag return data as of November 2017, including species, date tagged and recaptured, days at liberty, and distance traveled (km). Distance traveled was recorded as zero if the fish was recaptured in the same sampling station it was released.

Species	**Date Tagged**	**Date Recaptured**	**Days at Liberty**	**Distance Traveled (km)**
Black rockfish	10/5/2014	7/6/2015	274	0
Black rockfish	7/16/2014	8/11/2014	26	0
Black rockfish	6/26/2014	7/24/2015	393	0
Black rockfish	6/19/2014	8/9/2015	416	0
Black rockfish	6/26/2014	8/30/2015	430	6.7
Black rockfish	7/25/2014	3/26/2016	610	300
Black rockfish	6/23/2014	4/16/2016	663	330
Black rockfish	10/9/2014	8/28/2016	689	370
Black rockfish	8/28/2014	4/5/2016	586	680
Lingcod	6/19/2014	5/22/2015	337	0
Lingcod	8/29/2014	7/25/2015	330	0
Lingcod	8/13/2014	7/29/2016	716	0
Lingcod	8/13/2014	9/10/2016	759	0
Lingcod	10/3/2014	9/17/2016	715	0
Lingcod	9/15/2014	8/28/2016	713	4.4
Lingcod	8/30/2014	8/12/2016	713	6
Pacific halibut	5/31/2015	7/6/2016	402	0
Yelloweye rockfish	6/12/2014	8/2/2014	51	0

Species Composition

A total of 23 different species of fish were caught and identified, including 14 (84% of all fish captured) species of rockfish (Table 7). The nine most abundant species captured during this survey made up 95.6 percent of the total catch, with black rockfish alone accounting for 39.0 percent, followed by blue rockfish (18.7%), lingcod (14.6%), canary rockfish (8.2%), yellowtail rockfish (6.7%), china rockfish (*Sebastes nebulosus;* 2.4%), copper rockfish (*Sebastes caurinus;* 2.4%), quillback rockfish (*Sebastes maliger;* 1.8%), and vermillion rockfish (*Sebastes miniatus;* 1.8 %). Eight species yielded a catch of less than five individuals (0.1% or less of the total catch). Deacon rockfish (*Sebastes diaconus*), first described in 2015, were captured over the course of the study, but were identified as blue rockfish (Frable et al. 2015).

Table 7. Total number and percent composition for all species captured during hook and line surveys over both sampling seasons (2014 and 2015).

Common Name	**Scientific Name**	**Number Caught**	**% Total Catch**	**Mean Length (mm)**
Black rockfish	*Sebastes melanops*	1652	39.0	375 ± 52
Blue rockfish	*Sebastes mystinus*	791	18.7	290 ± 57
Lingcod	*Ophiodon elongatus*	618	14.6	604 ± 109
Canary rockfish	*Sebastes pinniger*	347	8.2	339 ± 81
Yellowtail rockfish	*Sebastes flavidus*	284	6.7	316 ± 79
China rockfish	*Sebastes nebulosus*	100	2.4	339 ± 26
Copper rockfish	*Sebastes caurinus*	100	2.4	428 ± 50
Quillback rockfish	*Sebastes maliger*	78	1.8	395 ± 48
Vermilion rockfish	*Sebastes miniatus*	75	1.8	466 ± 56
Olive rockfish	*Sebastesserranoides*	43	1.0	375 ± 60
Yelloweye rockfish	*Sebastes ruberrimus*	37	0.9	514 ± 76
Kelp greenling	*Hexagrammos decagrammus*	34	0.8	346 ± 29
Rosy rockfish	*Sebastes rosaceus*	24	0.6	281 ± 25
Cabezon	*Scorpaenichthys marmoratus*	22	0.5	510 ± 42
Gopher rockfish	*Sebastes carnatus*	13	0.3	324 ± 31
Buffalo sculpin	*Enophrys bison*	4	0.1	325 ± 57
Chinook salmon	*Oncorhynchus tshawytscha*	4	0.1	755 ± 49
Brown Rockfish	*Sebastes auriculatus*	3	0.1	341 ± 10
Pacific halibut	*Hippoglossus stenolepis*	2	< 0.01	984 ± 51
Pacific sanddab	*Citharichthys sordidus*	2	< 0.01	210 ± 62
Widow rockfish	*Sebastes entomelas*	2	< 0.01	289 ± 57
Petrale sole	*Eopsetta jordani*	1	< 0.01	449
Red Irish lord	*Hemilepidotus*	1	< 0.01	385

Species catch compositions over both sampling seasons combined varied more between the Crescent City and Shelter Cove paired sites than paired sites sampled out of Eureka and Fort Bragg (Figure 7). At the Pyramid Point SMCA black rockfish (85.5%) made up the overwhelming majority of the total catch (Table 8). The most frequently caught species at this MPA's reference site were black rockfish (54.3%), canary rockfish (12.3%), lingcod (11.8%), and blue rockfish (11.1%). At the Sea Lion Gulch SMR, black rockfish (40.0%) and blue rockfish (30.0%) combined to make up 70% of the total catch. At its reference site, Point Delgada, black rockfish (26.4%) and lingcod (24.3%) were the most commonly captured species, with blue rockfish comprising just 7.7 percent of the total catch (Table 9). Species compositions were similar in the Eureka and Fort Bragg paired sites. Black rockfish (42.1%), canary rockfish (17.1%), and lingcod (13.5%) made up the most significant portion of the total catch at the South Cape Mendocino SMR (Table 10). At its reference site (North Cape Mendocino), black rockfish (39.8%), lingcod (14.7), canary rockfish (13.7%), and blue rockfish (13.7%) were the most common species. Black rockfish, blue rockfish, and lingcod were the three most captured species in both the Ten Mile SMR and Westport reference site, all consisting of at least 20 percent of the total catch (Table 11).

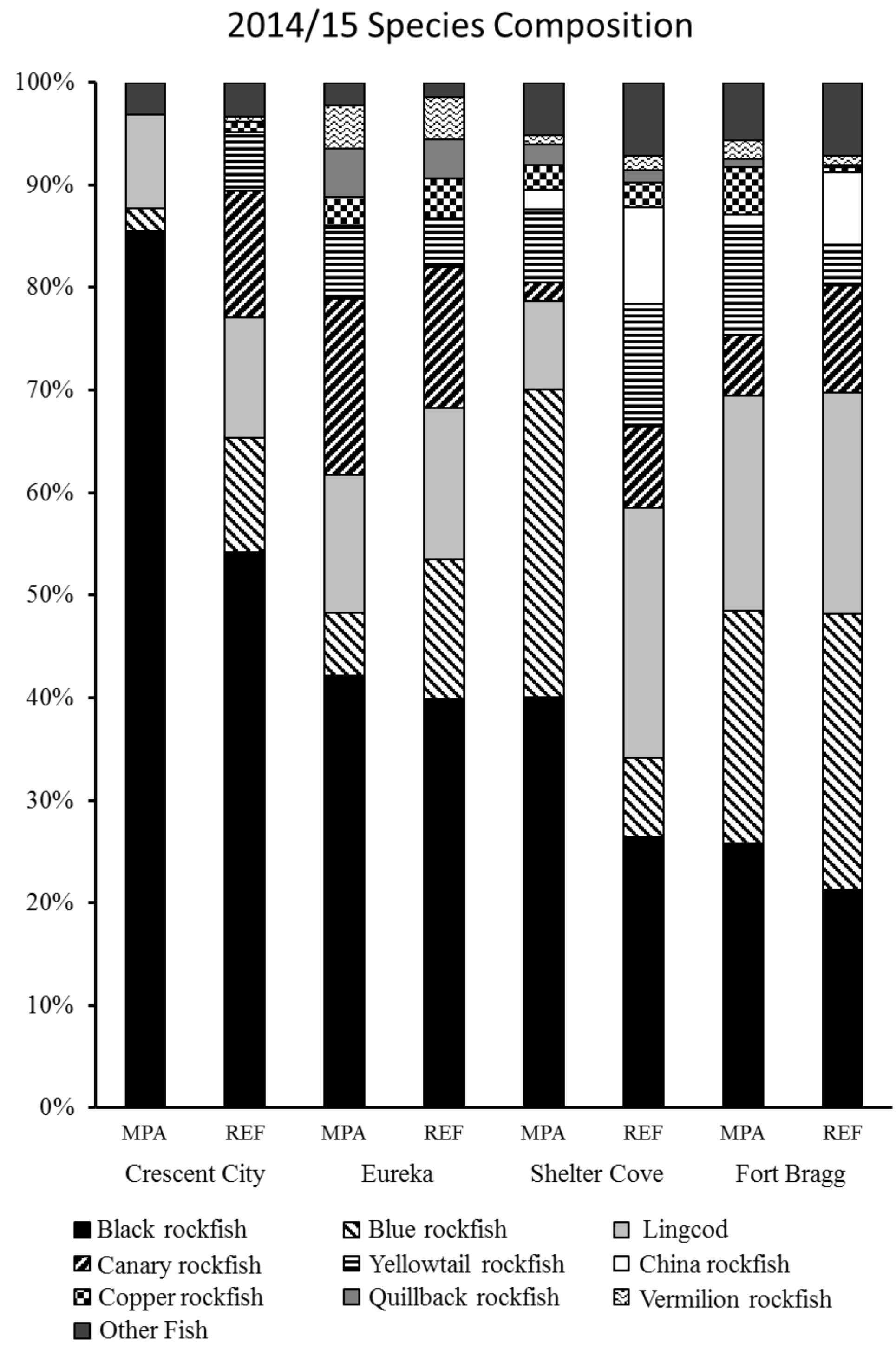

Figure 7. Species composition by site, Marine Protected Area (MPA) and reference (REF) of the top nine most commonly captured species in 2014 and 2015 sampling season combined. All other species captured are grouped into “Other” category.

Table 8. Species composition and number of species captured during hook and line surveys at the Crescent City Marine Protected Area (MPA) and reference (REF) sites; 2014, 2015, both years combined. Values are percentage of total catch (total number in parentheses).

	Crescent City 2014		**Crescent City 2015**		**Crescent City All Years**	
Species	MPA (137)	REF (222)	MPA (83)	REF (193)	MPA (220)	REF (414)
Black rockfish	87.6	58.6	81.9	49.2	85.5	54.2
Blue rockfish	2.9	4.5	1.2	18.7	2.3	11.1
Buffalo sculpin			1.2	0.5	0.5	0.2
Cabezon	1.5	0.9	3.6	0.5	2.3	0.7
Canary rockfish		9.5		15.5		12.3
Copper rockfish		0.9		1.0		1.0
Kelp greenling	0.7	3.6		0.5	0.5	2.2
Lingcod	7.3	15.3	12.0	7.8	9.1	11.8
Red Irish lord		0.5				0.2
Vermilion rockfish		0.9				0.5
Yellowtail rockfish		5.4		6.2		5.8
Total Number Species	5	10	5	9	6	11
Total Rockfish Species	2	6	2	5	2	6

Table 9. Species composition and number of species captured during hook and line surveys at the Shelter Cove Marine Protected Area (MPA) and reference (REF) sites; 2014, 2015, both years combined. Values are percentage of total catch (total number in parentheses).

	Shelter Cove 2014		**Shelter Cove 2015**		**Shelter Cove All Years**	
Species	MPA (768)	REF (221)	MPA (439)	REF (116)	MPA (1207)	REF (337)
Black rockfish	49.6	26.7	23.2	25.9	40.0	26.4
Blue rockfish	21.6	10.9	44.6	1.7	30.0	7.7
Cabezon		0.5	0.2	0.9	0.1	0.6
Canary rockfish	1.4	5.9	2.3	12.1	1.7	8.0
China rockfish	2.1	11.3	1.8	6.0	2.0	9.5
Chinook salmon			0.2		0.1	
Copper rockfish	2.1	2.3	3.0	2.6	2.4	2.4
Gopher rockfish		0.9				0.6
Kelp greenling	0.3	0.5	0.5		0.3	0.3
Lingcod	6.9	25.8	11.8	21.6	8.7	24.3
Olive rockfish	2.5	0.5	0.2	4.3	1.7	1.8
Pacific halibut		0.5				0.3
Pacific sanddab			0.2		0.1	
Quillback rockfish	1.8	1.4	2.3	0.9	2.0	1.2
Rosy rockfish	1.2	1.8	1.6	2.6	1.3	2.1
Vermilion rockfish	1.0	0.5	0.7	3.4	0.9	1.5
Widow rockfish	0.1		0.2		0.2	
Yelloweye rockfish	1.3	1.4	1.6	1.7	1.4	1.5
Yellowtail rockfish	8.1	9.5	5.5	16.4	7.1	11.9
Total Number Species	14	16	17	13	17	16
Total Rockfish Species	12	12	12	11	12	12

Table 10. Species composition and number of species captured during hook and line surveys at the Eureka Marine Protected Area (MPA) and reference (REF) sites; 2014, 2015, both years combined. Values are percentage of total catch (total number in parentheses).

	Eureka 2014		**Eureka 2015**		**Eureka All Years**	
Species	MPA (390)	REF (310)	MPA (182)	REF (172)	MPA (572)	REF (482)
Black rockfish	48.7	38.1	28.0	43.0	42.1	39.8
Blue rockfish	7.9	11.9	2.2	16.9	6.1	13.7
Canary rockfish	11.3	14.5	29.7	12.2	17.1	13.7
China rockfish	0.3				0.2	
Chinook salmon	0.3				0.2	
Copper rockfish	2.8	5.2	2.7	1.7	2.8	3.9
Kelp greenling		0.6		0.6		0.6
Lingcod	10.5	14.2	19.8	15.7	13.5	14.7
Olive rockfish	0.3				0.2	
Pacific halibut				0.6		0.2
Petrale sole	0.3				0.2	
Quillback rockfish	4.4	4.5	5.5	2.3	4.7	3.7
Vermilion rockfish	3.1	5.2	6.6	2.3	4.2	4.1
Yelloweye rockfish	1.0	1.0	3.3		1.7	0.6
Yellowtail rockfish	9.2	4.8	2.2	4.7	7.0	4.8
Total Number Species	13	10	9	10	13	11
Total Rockfish Species	10	8	8	7	10	8

Table 11. Species composition and number of species captured during hook and line surveys at the Fort Bragg Marine Protected Area (MPA) and reference (REF) sites; 2014, 2015, both years combined. Values are percentage of total catch (total number in parentheses).

	Fort Bragg 2014		**Fort Bragg 2015**		**Fort Bragg All Years**	
Species	MPA (258)	REF (355)	MPA (200)	REF (191)	MPA (458)	REF (546)
Black rockfish	34.9	28.7	14.0	7.3	25.8	21.2
Blue rockfish	19.8	22.0	26.5	36.1	22.7	26.9
Brown Rockfish	0.4		1.0		0.7	
Buffalo sculpin	0.4			0.5	0.2	0.2
Cabezon	0.4	0.3	1.0	3.7	0.7	1.5
Canary rockfish	3.5	11.5	9.0	8.4	5.9	10.4
China rockfish	1.6	7.0	0.5	6.8	1.1	7.0
Chinook salmon	0.8				0.4	
Copper rockfish	2.3	0.8	7.5		4.6	0.5
Gopher rockfish	0.8	1.1	2.0	0.5	1.3	0.9
Kelp greenling	0.8	1.4	3.0	1.6	1.7	1.5
Lingcod	17.4	20.0	25.5	24.6	21.0	21.6
Olive rockfish		2.5		3.7		2.9
Pacific sanddab	0.4				0.2	
Quillback rockfish		0.3	2.0		0.9	0.2
Rosy rockfish			0.5		0.2	
Vermilion rockfish	0.8	0.6	3.0	1.6	1.7	0.9
Yelloweye rockfish	0.4	0.3			0.2	0.2
Yellowtail rockfish	15.5	3.4	4.5	5.2	10.7	4.0
Total Number Species	16	14	14	12	18	15
Total Rockfish Species	10	11	11	8	12	11

These relationships were represented visually in Bray-Curtis MDS scaling plots attained from multivariate analysis on species compositions in each MPA and reference site (Figure 8). Points representing the Eureka and Fort Bragg MPA and reference sites were closely grouped on the plot, indicating species compositions at these sites are more similar. Conversely, Crescent City and Shelter Cove MPA and reference sites were further apart on the scale, representing species compositions that are less similar.

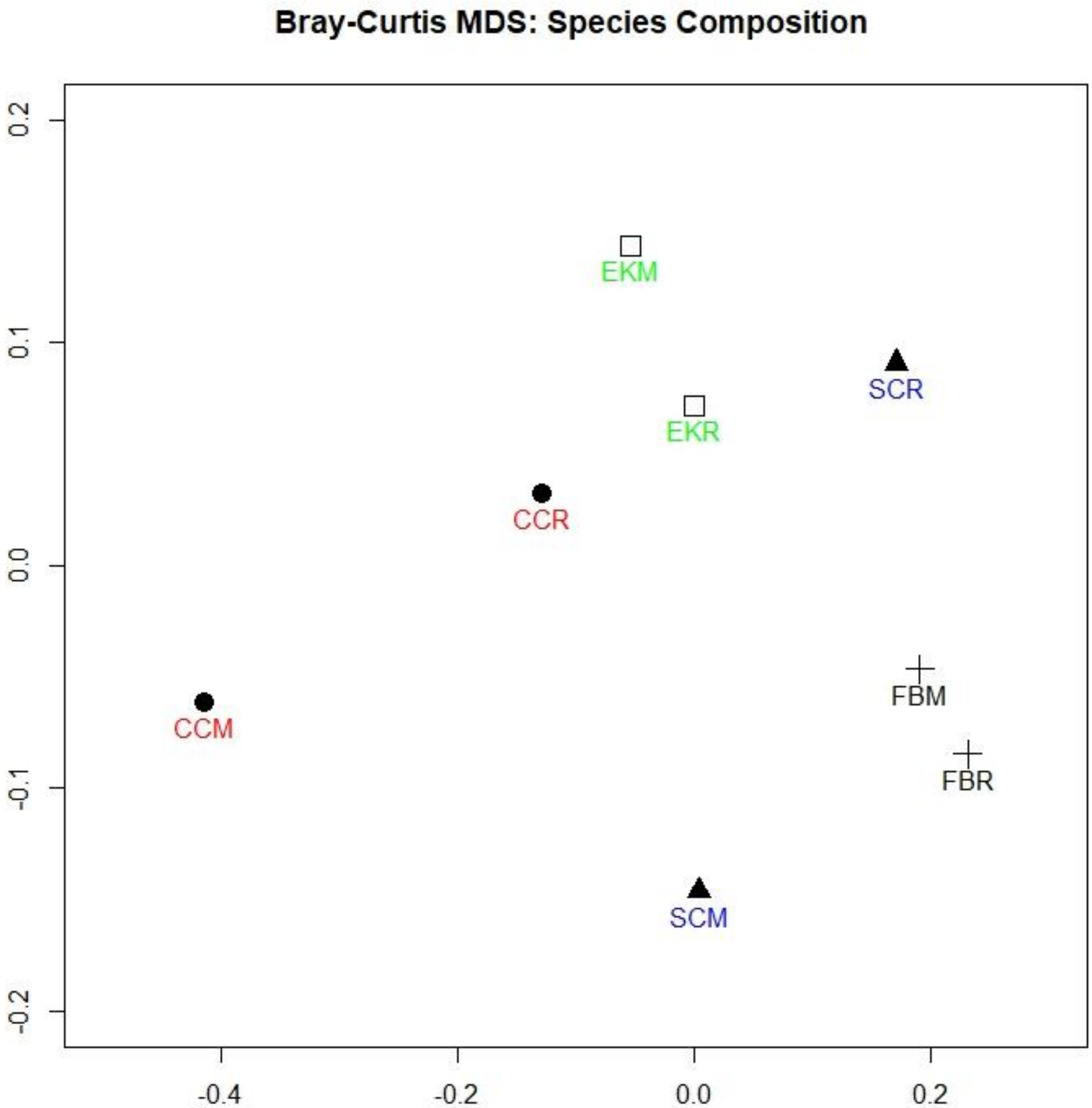

Figure 8. Bray-Curtis Multi-Dimensional Scaling plot for comparisons of species compositions of the nine most captured species among sites during hook and line surveys conducted in 2014 and 2015 combined. CC = Crescent City, EK = Eureka, SC = Shelter Cove, FB = Fort Bragg, M = MPA, and R = Reference site.

A latitudinal trend in percent composition of black rockfish was examined when combining sampling seasons. At the northernmost sites, Pyramid Point SMCA and Damnation Creek, black rockfish represent 85.5 and 54.2 percent of the total catch, respectively. At the Eureka and Shelter Cove sites, located in the central portion of the North Coast Region, black rockfish comprised of between 26.4 and 42.1 percent of the total catch, and only 25.8 and 21.2 percent at the southernmost sites of Ten Mile SMR and Westport reference site, respectively.

Catch composition was similar between 2014 and 2015 sampling seasons for most species and sites (Figure 9). One notable exception was the change in the percent of black rockfish and blue rockfish at the Sea Lion Gulch SMR, Ten Mile SMR, and Westport reference site. At the Sea Lion Gulch SMR, black rockfish comprised 49.6 percent of the catch in 2014 but decreased to 23.2 percent in 2015, while blue rockfish increased from 21.6 percent in 2014 to 44.6 percent in 2015. A similar pattern was observed at the Fort Bragg sites; Black rockfish decreased from 34.9 percent in the Ten Mile SMR site and 28.7 percent in the Westport reference site to 14.1 percent and 7.3 percent in the MPA and reference sites, respectively, from 2014 to 2015. Blue rockfish increased from 19.8 percent in the MPA and 22.0 percent in the reference site in 2014, to 26.6 percent and 36.1 percent, respectively, in 2015.

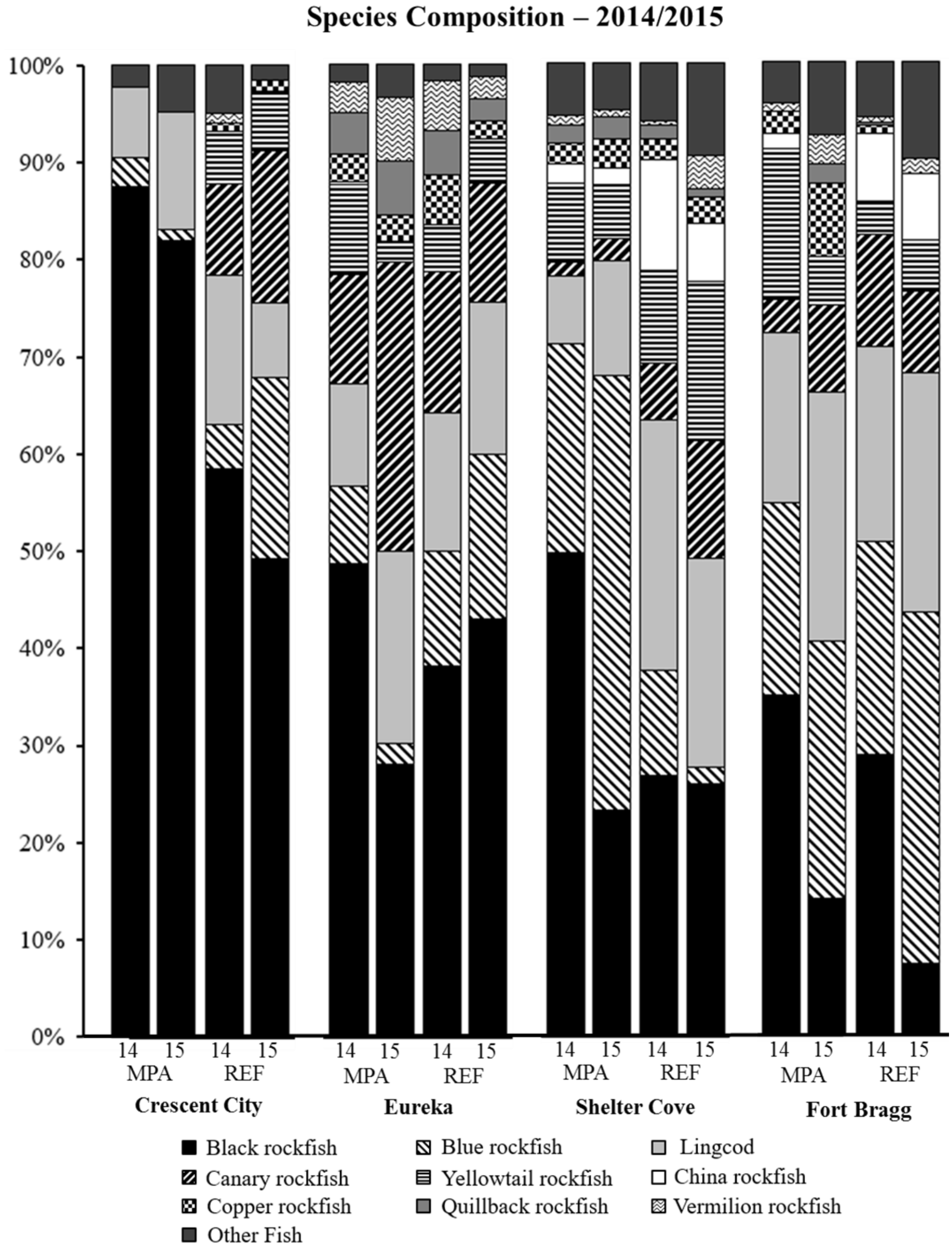

Figure 9. Species composition by site, Marine Protected Area (MPA) and reference (REF), of the top nine most commonly captured species in individual sampling season (2014 and 2015). All other species are grouped into "Other" category.

Relative Abundance

CPUE of all species combined (total CPUE), at individual sites, ranged from 3.67 fish per angler hour at the Pyramid Point SMCA to 20.12 at the Sea Lion Gulch SMR (Table 12). Total CPUE was significantly different within the Crescent City and Shelter Cove MPA/reference sites. In Shelter Cove, total CPUE at the Sea Lion Gulch SMR was 20.12 ± 1.67 (standard error), significantly higher than the 5.62 ± 0.70 fish per angler hour caught at the Point Delgada reference site (p-value < 0.001). In Crescent City, total CPUE was significantly higher at the Damnation Creek reference site (6.90 ± 0.94) than the Pyramid Point SMCA (3.67 ± 0.57; p-value = 0.011). Paired sites in Eureka and Fort Bragg did not have significantly different catch rates (p-value > 0.05). Total CPUE at the South Cape Mendocino SMR was slightly higher than the North Cape Mendocino reference site, 9.53 ± 1.61 and 8.03 ± 0.83, respectively. In Fort Bragg, a slightly higher total CPUE was observed at the Westport reference site (9.10 ± 1.01) compared to the Ten Mile SMR (7.62 ± 0.84). Results were similar when total CPUE of individual sampling seasons (2014 and 2015) was examined. Total CPUE was significantly higher in the Shelter Cove MPA compared to its reference site in both 2014 and 2015. In 2015, total CPUE at the Ten Mile SMR (8.29 ± 1.31) was observed to be slightly higher than its reference site (7.96 ± 1.57), while the opposite was true for the 2015 sampling season, 7.17 ± 1.12 and 9.86 ± 1.32 fish per angler hour, respectively.

Table 12. Results from a Welch's two-sample t-test conducted on mean CPUE (catch per angler hour) of paired Marine Protected Area (MPA) and reference (REF) sites Crescent City (CC), Eureka (E), Shelter Cove (SC), Fort Bragg (FB), for 2014, 2015, and both years combined. T-test results included the test statistic (t-stat), degrees of freedom (df), and p-value associated with the test.

		Mean CPUE				
Both Years		MPA (SE)	REF (SE)	t-stat	df	p-value
	CC	3.67 (0.57)	6.90 (0.94)	-2.68	37	**0.011**
	E	9.53 (1.61)	8.03 (0.83)	0.54	34	0.589
	SC	20.12 (1.67)	5.62 (0.70)	8.81	36	**<0.001**
	FB	7.62 (0.84)	9.10 (1.01)	-1.01	37	0.320
2014						
	CC	3.81 (0.87)	6.17 (0.72)	-2.31	17	**0.034**
	E	10.83 (2.52)	8.61 (0.93)	0.38	15	0.713
	SC	21.33 (2.39)	6.14 (1.02)	6.36	20	**<0.001**
	FB	7.17 (1.12)	9.86 (1.32)	-1.44	22	0.165
2015						
	CC	3.46 (0.62)	8.00 (1.93)	-1.44	9	0.185
	E	7.58 (1.30)	7.17 (1.56)	0.41	12	0.688
	SC	18.29 (2.15)	4.83 (0.86)	6.24	14	**<0.001**
	FB	8.29 (1.31)	7.96 (1.57)	0.25	14	0.806

Species-specific differences in CPUE were evaluated for the nine most commonly captured species during both sampling years combined; each accounted for at least 1.5% of the total catch. The remaining species were too rare for meaningful analysis. Significant differences in the nine most common species were found at all four paired sites when both sampling seasons were combined (Figure 10). At Crescent City paired sites, the CPUE of blue rockfish (p-value = 0.032), lingcod (p-value = 0.026), canary rockfish (p-value < 0.001), and yellowtail rockfish (p-value =0.006) at the Damnation Creek reference site was significantly higher than the Pyramid Point SMCA (Table 13). Of the nine most abundant species, only black rockfish, blue rockfish, and lingcod were captured at the Pyramid Point SMCA over both years, all three in lower numbers than at its reference site. China rockfish and quillback rockfish were not captured at either of the Crescent City paired sites. Catch rates were similar between the Eureka paired sites (Table 14). Only blue rockfish (p-value = 0.030) were caught in significantly higher numbers at the North Cape Mendocino reference site. In the Shelter Cove paired sites, five of the nine most abundant species; black rockfish (p-value = 0.017), blue rockfish (p-value < 0.001), yellowtail rockfish (p-value = 0.032), copper rockfish (p-value = 0.008), and quillback rockfish (p-value = 0.011), were observed to have significantly higher catch rates in the Sea Lion Gulch SMR compared to the Point Delgada reference site (Table 15). In the Fort Bragg paired sites, CPUE of china rockfish (p-value < 0.001) was significantly greater in the Westport reference site, while copper rockfish (p-value = 0.003) were caught in significantly greater numbers in the Ten Mile SMR (Table 16).

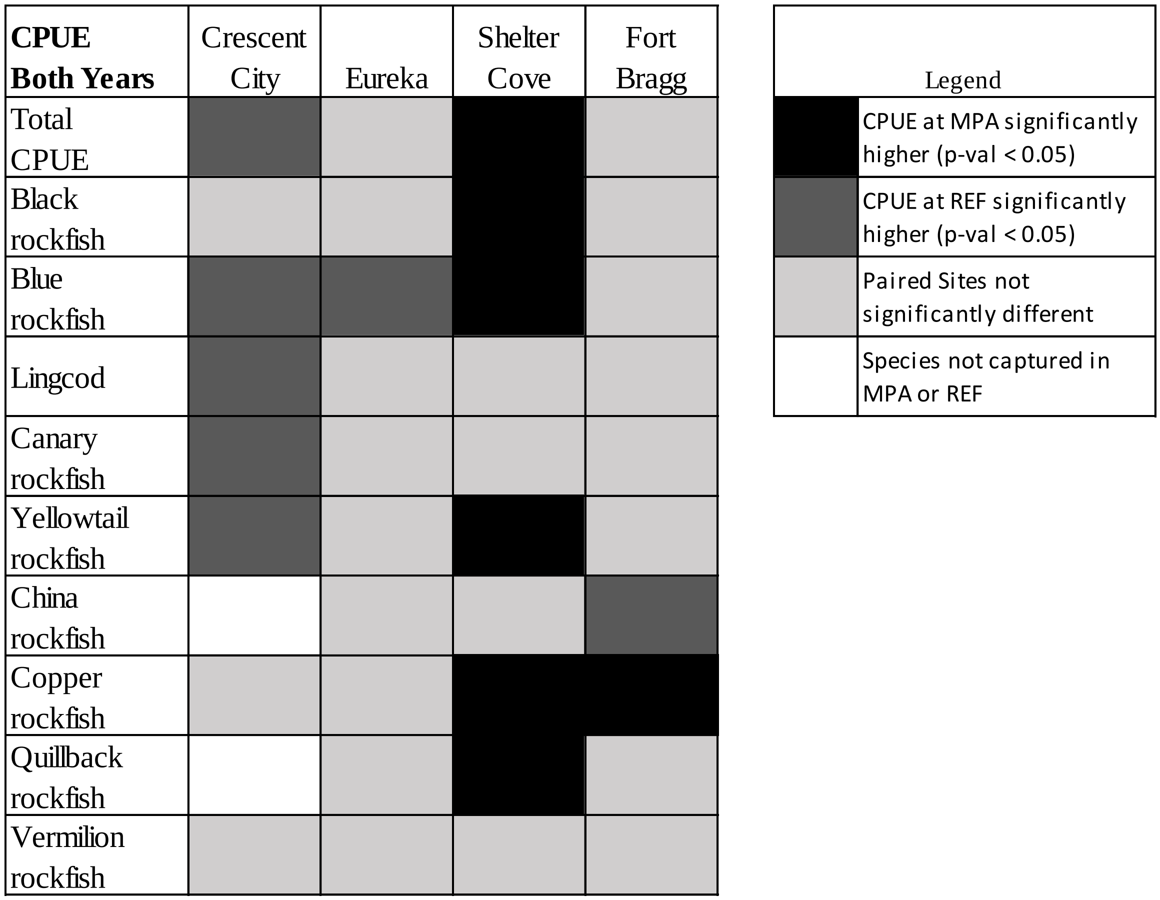

Figure 10. Results of Welch's two-sample t-test showing which species had higher CPUE in each of the paired Marine Protected Area (MPA) and reference sites (REF) over both the 2014 and 2015 sampling seasons combined. Total catch per unit effort (CPUE) represents the CPUE of all species combined.

Table 13. Results from Welch's two-sample t-test conducted on mean CPUE (catch per angler hour) of the nine most commonly caught species in the Crescent City Marine Protected Area (MPA) and reference (REF) sites during 2014 and 2015 sampling seasons combined. T-test results included the test statistic (t-stat), degrees of freedom (df), and p-value associated with the test.

Crescent City Both Years	CPUE (SE)				
Species	MPA	REF	t-stat	df	p-value
Black rockfish	3.13 (0.52)	3.75 (0.58)	-0.74	38	0.465
Blue rockfish	0.08 (0.04)	0.77 (0.36)	-2.27	24	**0.032**
Lingcod	0.33 (0.08)	0.82 (0.18)	-2.32	36	**0.026**
Canary rockfish	0.0 (0.0)	0.85 (0.18)	-6.93	19	**<0.001**
Yellowtail rockfish	0.0 (0.0)	0.4 (0.14)	-3.10	19	**0.006**
China rockfish	0.0 (0.0)	0.0 (0.0)	-	-	-
Copper rockfish	0.0 (0.0)	0.07 (0.05)	-1.45	19	0.163
Quillback rockfish	0.0 (0.0)	0.0 (0.0)	-	-	-
Vermilion rockfish	0.0 (0.0)	0.03 (0.02)	-1.45	19	0.163

Table 14. Results from Welch's two-sample t-test conducted on mean CPUE (catch per angler hour) of the nine most commonly caught species in the Eureka Marine Protected Area (MPA) and reference (REF) sites during 2014 and 2015 sampling seasons combined. T-test results included the test statistic (t-stat), degrees of freedom (df), and p-value associated with the test.

Eureka
Both Years

	CPUE (SE)				
Species	MPA	REF	t-stat	df	p-value
Black rockfish	4.02 (1.16)	3.2 (0.7)	-0.04	35	0.969
Blue rockfish	0.58 (0.26)	1.1 (0.26)	-2.25	38	**0.030**
Lingcod	1.28 (0.2)	1.18 (0.17)	0.40	38	0.692
Canary rockfish	1.63 (0.41)	1.1 (0.25)	0.91	36	0.369
Yellowtail rockfish	0.67 (0.25)	0.38 (0.10)	0.45	34	0.656
China rockfish	0.02 (0.02)	0.0 (0.0)	1.00	19	0.330
Copper rockfish	0.27 (0.09)	0.32 (0.11)	-0.17	38	0.865
Quillback rockfish	0.45 (0.15)	0.30 (0.09)	0.15	35	0.881
Vermilion rockfish	0.40 (0.10)	0.33 (0.08)	0.44	38	0.660

Table 15. Results from Welch's two-sample t-test conducted on mean CPUE (catch per angler hour) of the nine most commonly caught species in the Shelter Cove Marine Protected Area (MPA) and reference (REF) sites during 2014 and 2015 sampling seasons combined. T-test results included the test statistic (t-stat), degrees of freedom (df), and p-value associated with the test.

Shelter Cove Both Years					
	CPUE (SE)				
Species	MPA	REF	t-stat	df	p-value
Black rockfish	8.05 (2.20)	1.48 (0.63)	2.53	28	**0.017**
Blue rockfish	6.03 (1.30)	0.43 (0.25)	6.08	28	**<0.001**
Lingcod	1.75 (0.26)	1.37 (0.27)	1.14	38	0.263
Canary rockfish	0.35 (0.16)	0.45 (0.11)	-1.61	36	0.116
Yellowtail rockfish	1.43 (0.34)	0.67 (0.18)	2.23	37	**0.032**
China rockfish	0.40 (0.11)	0.53 (0.18)	-0.45	37	0.653
Copper rockfish	0.48 (0.15)	0.13 (0.05)	2.83	34	**0.008**
Quillback rockfish	0.40 (0.12)	0.07 (0.05)	2.71	28	**0.011**
Vermilion rockfish	0.18 (0.06)	0.08 (0.05)	1.62	36	0.115

Table 16. Results from Welch's two-sample t-test conducted on mean CPUE (catch per angler hour) of the nine most commonly caught species in the Fort Bragg Marine Protected Area (MPA) and reference (REF) sites during 2014 and 2015 sampling seasons combined. T-test results included the test statistic (t-stat), degrees of freedom (df), and p-value associated with the test.

Fort Bragg Both Years					
	CPUE (SE)				
Species	MPA	REF	t-stat	df	p-value
Black rockfish	1.97 (0.67)	1.93 (0.56)	-0.47	37	0.642
Blue rockfish	1.73 (0.47)	2.45 (0.72)	-0.50	36	0.623
Lingcod	1.6 (0.24)	1.97 (0.28)	-0.96	38	0.341
Canary rockfish	0.45 (0.16)	0.95 (0.23)	-1.95	37	0.058
Yellowtail rockfish	0.82 (0.28)	0.37 (0.12)	0.90	32	0.376
China rockfish	0.08 (0.04)	0.63 (0.12)	-5.03	32	**<0.001**
Copper rockfish	0.35 (0.10	0.05 (0.04)	3.23	28	**0.003**
Quillback rockfish	0.07 (0.05)	0.02 (0.02)	0.84	28	0.410
Vermilion rockfish	0.13 (0.05)	0.08 (0.04)	0.45	37	0.654

Patterns of single year CPUE by species were similar to those observed summing both years (Figure 11 and Figure 12). CPUE of black rockfish in the South Cape Mendocino SMR, Sea Lion Gulch SMR, Ten Mile SMR, and Westport reference site all decreased by at least 50 percent from 2014 to 2015 (Table 17-24). In four of the eight sites (Damnation Creek, Sea Lion Gulch SMR, Ten Mile SMR, and Westport), CPUE of blue rockfish increased by at least 0.7 fish per angler hour from 2014 to 2015 sampling seasons. CPUE of lingcod increased in all four MPA sites between 2014 and 2015, while CPUE of china rockfish decreased in all sites where at least one individual was captured during the same time.

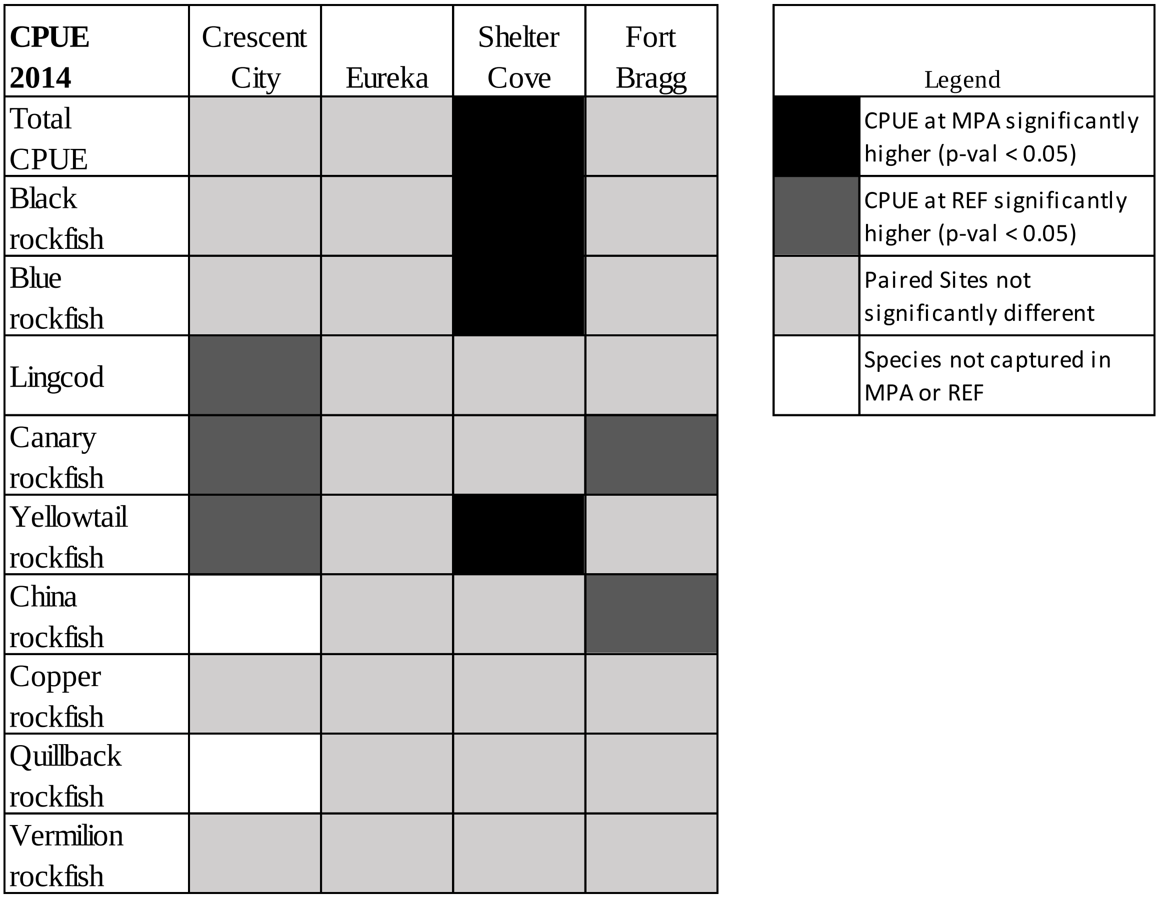

Figure 11. Results of Welch's two-sample t-test showing which species had higher CPUE in each of the paired Marine Protected Area (MPA) and reference sites (REF) in 2014. Total catch per unit effort (CPUE) represents the CPUE of all species combined.

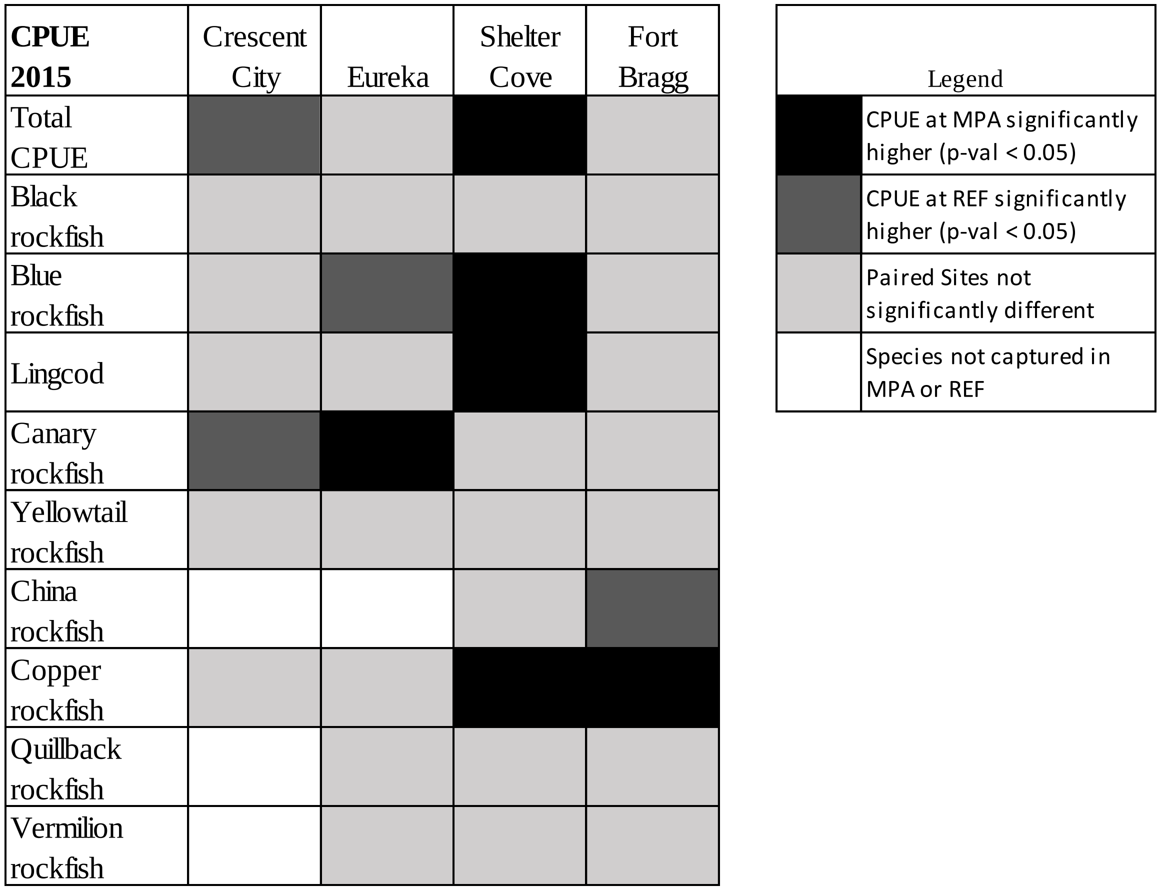

Figure 12. Results of Welch's two-sample t-test showing which species had higher CPUE in each of the paired Marine Protected Area (MPA) and reference sites (REF) in 2015. Total catch per unit effort (CPUE) represents the CPUE of all species combined.

Table 17. Results from Welch's two-sample t-test conducted on mean CPUE (catch per angler hour) of the nine most commonly caught species in the Crescent City Marine Protected Area (MPA) and reference (REF) sites during the 2014 sampling season. T-test results included the test statistic (t-stat), degrees of freedom (df), and p-value associated with the test.

Crescent City 2014	CPUE (SE)				
Species	MPA	REF	t-stat	df	p-value
Black rockfish	3.33 (0.78)	3.61 (0.57)	-0.65	19	0.523
Blue rockfish	0.11 (0.06)	0.28 (0.13)	-0.85	19	0.406
Lingcod	0.28 (0.1)	0.94 (0.27)	-2.77	21	**0.011**
Canary rockfish	0 (0)	0.58 (0.16)	-4.91	11	**<0.001**
Yellowtail rockfish	0 (0)	0.33 (0.16)	-2.25	11	**0.046**
China rockfish	0 (0)	0 (0)	-	-	-
Copper rockfish	0 (0)	0.06 (0.06)	-1.00	11	0.339
Quillback rockfish	0 (0)	0 (0)	-	-	-
Vermilion rockfish	0 (0)	0.06 (0.04)	-1.48	11	0.166

Table 18. Results from Welch's two-sample t-test conducted on mean CPUE (catch per angler hour) of the nine most commonly caught species in the Crescent City Marine Protected Area (MPA) and reference (REF) sites during the 2015 sampling season. T-test results included the test statistic (t-stat), degrees of freedom (df), and p-value associated with the test.

Crescent City 2015					
	CPUE (SE)				
Species	MPA	REF	t-stat	df	p-value
Black rockfish	2.83 (0.62)	3.96 (1.21)	-0.357	11	0.728
Blue rockfish	0.04 (0.04)	1.50 (0.84)	-2.282	8	0.053
Lingcod	0.42 (0.15)	0.63 (0.21)	-0.347	13	0.734
Canary rockfish	0 (0)	1.25 0.36)	-5.331	7	**0.001**
Yellowtail rockfish	0 (0)	0.50 (0.25)	-2.032	7	0.082
China rockfish	0 (0)	0 (0)	-	-	-
Copper rockfish	0 (0)	0.08 (0.08)	1.000	7	0.351
Quillback rockfish	0 (0)	0 (0)	-	-	-
Vermilion rockfish	0 (0)	0 (0)	-	-	-

Table 19. Results from Welch's two-sample t-test conducted on mean CPUE (catch per angler hour) of the nine most commonly caught species in the Eureka Marine Protected Area (MPA) and reference (REF) sites during the 2014 sampling season. T-test results included the test statistic (t-stat), degrees of freedom (df), and p-value associated with the test.

Eureka 2014	CPUE (SE)				
Species	MPA	REF	t-stat	df	p-value
Black rockfish	5.28 (1.78)	3.28 (0.83)	0.13	18	0.901
Blue rockfish	0.86 (0.42)	1.03 (0.27)	-1.03	20	0.315
Lingcod	1.14 (0.23)	1.22 (0.25)	-0.18	22	0.861
Canary rockfish	1.22 (0.45)	1.25 (0.23)	-0.59	19	0.561
Yellowtail rockfish	1.00 (0.38)	0.42 (0.13)	0.79	18	0.440
China rockfish	0.03 (0.03)	0 (0)	1.00	11	0.339
Copper rockfish	0.31 (0.1)	0.44 (0.16)	-0.55	22	0.588
Quillback rockfish	0.47 (0.21)	0.39 (0.15)	-0.14	21	0.893
Vermilion rockfish	0.33 (0.12)	0.44 (0.11)	-0.85	22	0.402

Table 20. Results from Welch's two-sample t-test conducted on mean CPUE (catch per angler hour) of the nine most commonly caught species in the Eureka Marine Protected Area (MPA) and reference (REF) sites during the 2015 sampling season. T-test results included the test statistic (t-stat), degrees of freedom (df), and p-value associated with the test.

Eureka 2015

	CPUE (SE)				
Species	MPA	REF	t-stat	df	p-value
Black rockfish	2.13 (0.88)	3.08 (1.31)	-0.245	13	0.810
Blue rockfish	0.17 (0.13)	1.21 (0.53)	-2.417	11	**0.035**
Lingcod	1.5 (0.36)	1.13 (0.24)	0.874	14	0.397
Canary rockfish	2.25 (0.73)	0.88 (0.55)	1.823	14	0.090
Yellowtail rockfish	0.17 (0.09)	0.33 (0.18)	-0.479	13	0.640
China rockfish	0 (0)	0 (0)	-	-	-
Copper rockfish	0.21 (0.17)	0.13 (0.13)	0.465	14	0.649
Quillback rockfish	0.42 (0.22)	0.17 (0.06)	0.447	11	0.664
Vermilion rockfish	0.5 (0.15)	0.17 (0.06)	2.094	14	0.055

Table 21. Results from Welch's two-sample t-test conducted on mean CPUE (catch per angler hour) of the nine most commonly caught species in the Shelter Cove Marine Protected Area (MPA) and reference (REF) sites during the 2014 sampling season. T-test results included the test statistic (t-stat), degrees of freedom (df), and p-value associated with the test.

Shelter Cove 2014	CPUE (SE)				
Species	MPA	REF	t-stat	df	p-value
Black rockfish	10.58 (3.32)	1.64 (0.92)	2.13	16	**0.050**
Blue rockfish	4.61 (1.15)	0.67 (0.4)	3.62	18	**0.002**
Lingcod	1.47 (0.32)	1.58 (0.33)	-0.35	22	0.727
Canary rockfish	0.31(0.18)	0.36 (0.13)	-0.92	21	0.368
Yellowtail rockfish	1.72 (0.43)	0.58 (0.21)	2.97	22	**0.007**
China rockfish	0.15 (0.44)	0.28 (0.69)	-0.61	21	0.545
Copper rockfish	0.44 (0.24)	0.14 (0.08)	1.52	19	0.145
Quillback rockfish	0.39 (0.15)	0.08 (0.08)	1.87	18	0.078
Vermilion rockfish	0.22 (0.09)	0.03 (0.03)	2.11	15	0.052

Table 22. Results from Welch's two-sample t-test conducted on mean CPUE (catch per angler hour) of the nine most commonly caught species in the Shelter Cove Marine Protected Area (MPA) and reference (REF) sites during the 2015 sampling season. T-test results included the test statistic (t-stat), degrees of freedom (df), and p-value associated with the test.

Shelter Cove 2015					
	CPUE (SE)				
Species	MPA	REF	t-stat	df	p-value
Black rockfish	4.25 (1.81)	1.25 (0.84)	1.351	12	0.202
Blue rockfish	8.17 (2.68)	0.08 (0.08)	5.463	8	**<0.001**
Lingcod	2.17 (0.43)	1.04 (0.44)	2.350	11	**0.038**
Canary rockfish	0.42 (0.33)	0.58 (0.18)	-1.356	12	0.200
Yellowtail rockfish	1.00 (0.54)	0.79 (0.33)	0.167	14	0.870
China rockfish	0.33 (0.15)	0.29 (0.13)	0.105	14	0.918
Copper rockfish	0.54 (0.11)	0.12 (0.06)	3.043	14	**0.009**
Quillback rockfish	0.42 (0.21)	0.04 (0.04)	1.891	9	0.090
Vermilion rockfish	0.12 (0.06)	0.17 (0.13)	0.113	13	0.912

Table 23. Results from Welch's two-sample t-test conducted on mean CPUE (catch per angler hour) of the nine most commonly caught species in the Fort Bragg Marine Protected Area (MPA) and reference (REF) sites during the 2014 sampling season. T-test results included the test statistic (t-stat), degrees of freedom (df), and p-value associated with the test.

Fort Bragg 2014	CPUE (SE)				
Species	MPA	REF	t-stat	df	p-value
Black rockfish	2.50 (1.01)	2.83 (0.85)	-0.67	21	0.509
Blue rockfish	1.42 (0.36)	2.17 (0.71)	-0.74	21	0.465
Lingcod	1.25 (0.28)	1.97 (0.38)	-1.31	22	0.203
Canary rockfish	0.25 (0.12)	1.14 (0.36)	-2.21	18	**0.040**
Yellowtail rockfish	1.11 (0.43)	0.33 (0.07)	0.88	14	0.395
China rockfish	0.06 (0.11)	0.16 (0.69)	-3.82	20	**0.001**
Copper rockfish	0.17 (0.06)	0.08 (0.06)	1.17	21	0.257
Quillback rockfish	0 (0)	0.03 (0.03)	-1.00	11	0.339
Vermilion rockfish	0.06 (0.04)	0.06 (0.06)	0.30	22	0.767

Table 24. Results from Welch's two-sample t-test conducted on mean CPUE (catch per angler hour) of the nine most commonly caught species in the Fort Bragg Marine Protected Area (MPA) and reference (REF) sites during the 2015 sampling season. T-test results included the test statistic (t-stat), degrees of freedom (df), and p-value associated with the test.

Fort Bragg 2015					
	CPUE (SE)				
Species	MPA	REF	t-stat	df	p-value
Black rockfish	1.17 (0.69)	0.58 (0.2)	0.190	10	0.853
Blue rockfish	2.21 (1.06)	2.88 (1.51)	0.000	13	1.000
Lingcod	2.13 (0.37)	1.96 (0.42)	0.278	14	0.785
Canary rockfish	0.75 (0.36)	0.67 (0.19)	-0.368	12	0.719
Yellowtail rockfish	0.38 (0.2)	0.42 (0.28)	0.317	13	0.756
China rockfish	0.04 (0.04)	0.54 (0.19)	-3.164	10	**0.010**
Copper rockfish	0.63 (0.21)	0 (0)	3.899	7	**0.006**
Quillback rockfish	0.17 (0.11)	0 (0)	1.528	7	0.170
Vermilion rockfish	0.25 (0.1)	0.12 (0.06)	0.345	13	0.735

Species Diversity

Mean species richness, over all sites and years, ranged from 4.00 ± 0.32 species per site visit at the Pyramid Point SMCA to 13.40 ± 0.81 species per site visit at the Sea Lion Gulch SMR (Figure 13, Table 25). Richness for rockfish species alone ranged from 1.80 ± 0.20 rockfish per station visit (Pyramid Point SMCA) to 11.00 ± 0.45 (Sea Lion Gulch SMR). On average, richness of just rockfish species was 2.23 species per site visit lower than richness when all species were considered. Mean station richness of all species (p-value = 0.007) and rockfish species (p-value = 0.003) was significantly higher in the Damnation Creek reference site compared to the Pyramid Point SMCA. Species richness at the remaining three paired sites were not significantly different. The mean Shannon Diversity index per site visit for all species and years ranged from 0.54 ± 0.04 at the Pyramid Point SMCA to 1.84 ± 0.15 at the Point Delgada reference site (Table 26). Shannon Diversity for rockfish species ranged from 0.11 ± 0.03 (Pyramid Point SMCA) to 1.67 ± 0.15 (Point Delgada), and on average, was 0.26 lower than mean station Shannon Diversity of all species. Mean Shannon Diversity of all species (p-value < 0.001) and rockfish only (p-value = 0.002) was significantly higher at Damnation Creek, and virtually identical in the Eureka and Fort Bragg paired sites.

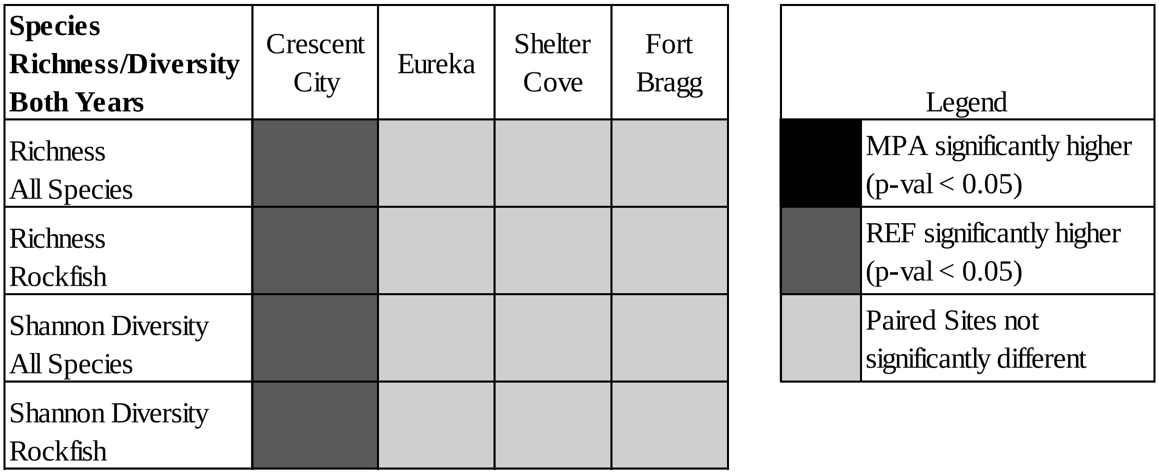

Figure 13. Results of Welch's two-sample t-test showing differences in species richness and Shannon Diversity of all fishes and only rockfishes between paired Marine Protected Area (MPA) and reference sites (REF) in 2014 and 2015 sampling seasons combined.

Table 25. Results from Welch's two-sample t-test conducted on mean species richness of all species and only rockfish species in Marine Protected Area (MPA) and reference (REF) sites during the 2014 and 2015 sampling season combined. Species richness values were averaged across all five sampling visits to each MPA and reference site and were presented with standard error values (SE). T-test results included the test statistic (t-stat), degrees of freedom (df), and p-value associated with the test.

Species Richness	**MPA (SE)**	**REF (SE)**	**t-stat**	**df**	**p-value**
Crescent City					
All Species	4.00 (0.32)	7.4 (0.75)	-4.19	5	**0.007**
Rockfish	1.80 (0.20)	4.60 (0.51)	-5.11	5	**0.003**
Eureka					
All Species	9.40 (0.68)	9.00 (0.55)	0.46	8	0.659
Rockfish	8.00 (0.55)	7.20 (0.37)	1.21	7	0.267
Shelter Cove					
All Species	13.40 (0.81)	10.20 (1.43)	1.95	6	0.097
Rockfish	11.00 (0.45)	8.40 (1.08)	2.23	5	0.073
Fort Bragg					
All Species	10.60 (0.98)	10.00 (0.45)	0.56	6	0.599
Rockfish	7.60 (1.12)	7.60 (0.51)	0.00	6	1.000

Table 26. Results from Welch's two-sample t-test conducted on mean Shannon Diversity of all species and only rockfish species in Marine Protected Area (MPA) and reference (REF) sites during the 2014 and 2015 sampling season combined. Shannon Diversity values were averaged across all five sampling visits to each MPA and reference site and were presented with standard error values (SE). T-test results included the test statistic (t-stat), degrees of freedom (df), and p-value associated with the test.

Shannon Diversity	**MPA (SE)**	**REF (SE)**	**t-stat**	**df**	**p-value**
Crescent City					
All Species	0.54 (0.04)	1.32 (0.08)	-8.51	6	**<0.001**
Rockfish	0.11 (0.03)	0.94 (0.13)	-6.28	4	**0.002**
Eureka					
All Species	1.67 (0.05)	1.70 (0.10)	-0.29	6	0.782
Rockfish	1.46 (0.05)	1.48 (0.10)	-0.18	6	0.866
Shelter Cove					
All Species	1.59 (0.10)	1.84 (0.15)	-1.37	7	0.212
Rockfish	1.40 (0.11)	1.67 (0.15)	-1.49	7	0.179
Fort Bragg					
All Species	1.77 (0.11)	1.78 (0.10)	-0.09	8	0.930
Rockfish	1.53 (0.15)	1.50 (0.10)	0.14	7	0.889

Species Length

Mean lengths between MPAs and reference sites were significantly different for four of the five most abundant species when data from both the 2014 and 2015 sampling seasons were pooled (Figure 14, Table 27). Blue rockfish (p-value < 0.001) and yellowtail rockfish (p-value < 0.05) were significantly larger at both the Sea Lion Gulch and Ten Mile SMRs compared to their reference sites (Table 28 and Table 29). At the Eureka sites, black rockfish (p-value < 0.001) and canary rockfish (p-value = 0.001) were significantly larger in the South Cape Mendocino SMR compared to its reference site (Table 30). Blue rockfish at Damnation Creek was the only species found to be significantly longer in any reference site compared to its paired MPA site (p-value < 0.001; Table 31). However, these results may be due to a low sample size of blue rockfish at the Crescent City MPA (n = 5). Additionally, because no canary rockfish or yellowtail rockfish were caught in the Pyramid Point SMCA, size comparison could not be conducted with its reference site. An interannual comparison of length data was not conducted due to small sample sizes from some sites and species.

Mean Length Both Years	Crescent City	Eureka	Shelter Cove	Fort Bragg
Black rockfish				
Blue rockfish				
Lingcod				
Canary rockfish				
Yellowtail rockfish				

	Legend
	Length at MPA significantly higher (p-val < 0.05)
	Length at REF significantly higher (p-val < 0.05)
	Paired Sites not significantly different
	Lengths not available in MPA or REF

Figure 14. Results of Welch’s two-sample t-test showing differences in mean species fork lengths in the five most captured species, between paired Marine Protected Area (MPA) and reference sites (REF) in 2014 and 2015 sampling seasons combined.

Table 27. Mean fork length (cm), with standard error in parenthesis, of the five most commonly caught species for each site, Marine Protected Area (MPA) and reference (REF), combining both sampling season (2014, 2015). Number of individuals measured for each species and site are listed below each mean length value.

	Crescent City		**Eureka**		**Shelter Cove**		**Fort Bragg**	
	MPA	REF	MPA	REF	MPA	REF	MPA	REF
	Mean (SE)	Mean (SE)	Mean (SE)	Mean (SE)	Mean (SE)	Mean (SE)	Mean (SE)	Mean (SE)
Species	Number	Number	Number	Number	Number	Number	Number	Number
Black rockfish	35.5 (0.5)	34.6 (0.5)	40.6 (0.3)	39.0 (0.3)	38.8 (0.2)	37.9 (0.5)	35.3 (0.4)	35.0 (0.5)
	185	215	229	187	468	86	115	111
Blue rockfish	18.7 (1.2)	26.4 (0.9)	30.5 (0.9)	31.6 (0.2)	31.6 (0.2)	26.9 (1.0)	27.7 (0.5)	24.0 (0.5)
	5	43	35	66	340	25	101	145
Lingcod	60.8 (2.9)	64.8 (1.7)	60.3 (1.6)	59.7 (1.3)	58.4 (1.0)	57.8 (1.4)	63.1 (1.0)	60.6 (0.9)
	18	43	69	65	94	72	90	111
Canary rockfish	- (-)	28.0 (0.9)	38.5 (0.9)	33.7 (1.1)	34.3 (0.7)	36.2 (1.1)	31.2 (1.0)	31.9 (0.9)
	0	51	96	62	21	25	26	56
Yellowtail rockfish	- (-)	23.1 (0.6)	28.7 (1.2)	30.3 (1.3)	38.5 (0.6)	31.2 (1.0)	29.8 (0.9)	25.2 (1.6)
	0	24	38	23	82	39	48	20

Table 28. Results from Welch's two-sample t-test conducted on fork lengths of the five most captured species during the 2014 and 2015 sampling seasons combined in the Shelter Cove Marine Protected Area (MPA) and reference (REF) sites. T-test results included the test statistic (t-stat), degrees of freedom (df), and p-value associated with the test.

Shelter Cove					
	Mean Length (cm)				
	MPA	REF	t-stat	df	p-value
Black rockfish	38.8	37.9	1.68	104	0.097
Blue Rockfish	31.6	26.9	4.51	26	<0.001
Lingcod	58.4	57.8	0.33	134	0.743
Canary rockfish	34.3	36.2	-1.39	40	0.172
Yellowtail rockfish	38.5	31.2	6.35	69	<0.001

Table 29. Results from Welch's two-sample t-test conducted on fork lengths of the five most captured species during the 2014 and 2015 sampling seasons combined in the Fort Bragg Marine Protected Area (MPA) and reference (REF) sites. T-test results included the test statistic (t-stat), degrees of freedom (df), and p-value associated with the test.

Fort Bragg	**Mean Length (cm)**				
	MPA	REF	t-stat	df	p-value
Black rockfish	35.3	35.0	0.46	217	0.647
Blue Rockfish	27.7	24.0	4.97	232	<0.001
Lingcod	63.1	60.6	1.81	187	0.072
Canary rockfish	31.2	31.9	-0.50	63	0.621
Yellowtail rockfish	29.8	25.2	2.51	32	0.017

Table 30. Results from Welch's two-sample t-test conducted on fork lengths of the five most captured species during the 2014 and 2015 sampling seasons combined in the Eureka Marine Protected Area (MPA) and reference (REF) sites. T-test results included the test statistic (t-stat), degrees of freedom (df), and p-value associated with the test.

Eureka	**Mean Length (cm)**				
	MPA	REF	t-stat	df	p-value
Black rockfish	40.6	39.0	4.51	409	<0.001
Blue Rockfish	30.5	31.5	-0.93	61	0.356
Lingcod	60.3	59.7	0.28	129	0.783
Canary rockfish	38.5	33.7	3.45	135	0.001
Yellowtail rockfish	28.7	30.3	-0.89	53	0.378

Table 31. Results from Welch’s two-sample t-test conducted on fork lengths of the five most captured species during the 2014 and 2015 sampling seasons combined in the Crescent City Marine Protected Area (MPA) and reference (REF) sites. T-test results included the test statistic (t-stat), degrees of freedom (df), and p-value associated with the test. Dashes represent sites were no length data was available.

Crescent City	**Mean Length (cm)**				
	MPA	REF	t-stat	df	p-value
Black rockfish	35.5	34.6	1.36	394	0.175
Blue Rockfish	18.7	26.4	-5.13	10	<0.001
Lingcod	60.8	64.8	-1.15	30	0.258
Canary rockfish	-	28.0	-	-	-
Yellowtail rockfish	-	23.2	-	-	-

Fish Community Drivers

Predictors

Independent habitat predictors (depth, rugosity, percent rough substrate, and distance from port) varied across all stations (Table 32). Mean station depth ranged from 14 to 45 meters over all 32 stations. The shallowest stations were found at the northernmost site in the Pyramid Point SMCA while the Sea Lion Gulch SMR consisted of some of the deepest stations. Mean rugosity of rough substrate in each station ranged from 0.003 to 0.014. Pyramid Point SMCA and the South Cape Mendocino SMR contained some of the least rugose stations while Sea Lion Gulch SMR and North Cape Mendocino reference site contained some of the most rugose stations. The percent of each station containing rough substrate ranged from 30 percent in stations sampling few patch reefs (Pyramid Point SMCA and South Cape Mendocino SMR) to nearly 100 percent in stations over much larger reef complexes (Sea Lion Gulch SMR and North Cape Mendocino). Distance from port, a proxy for historical fishing pressure, also varied between stations. Stations at the South Cape Mendocino SMR and North Cape Mendocino reference site were the furthest from a fishing port, ranging from 50 to 55 kilometers from Eureka. Point Delgada and Pyramid Point SMCA were both less than 10 kilometers from the nearest port, Shelter Cove and Brookings, Oregon, respectively.

Table 32. Predictor variables used in Generalized Additive Models (GAM) in each of the 32 stations sampled over the 2014 and 2015 seasons. TM = Ten Mile SMR, West = Westport, PD = Point Delgada, SLG = Sea Lion Gulch SMR, SCM = South Cape Mendocino SMR, NCM = North Cape Mendocino, DC = Damnation Creek, PP = Pyramid Point SMCA.

Site	Station #	Latitude (UTM)	Mean Rugosity	Mean Depth (m)	% Rough Substrate	Distance From Port
TM	1	4381299	0.011	18.7	77.62	18.17
TM	2	4382301	0.008	41.2	30.93	18.73
TM	3	4382795	0.009	20.8	52.14	19.35
TM	4	4383294	0.008	33.9	81.21	19.74
West	5	4388297	0.011	31.2	51.17	24.76
West	6	4389797	0.010	25.4	80.34	26.22
West	7	4392797	0.008	25.0	69.47	29.16
West	8	4393795	0.008	23.5	82.26	30.18
PD	9	4425276	0.005	29.0	87.02	5.92
PD	10	4426299	0.006	32.8	62.89	4.95
PD	11	4427794	0.006	41.0	72.42	3.98
PD	12	4427803	0.005	28.3	67.91	3.36
SLG	13	4452781	0.011	28.2	57.52	32.40
SLG	14	4453301	0.012	32.8	83.99	33.87
SLG	15	4453801	0.013	41.2	78.77	34.92
SLG	16	4454803	0.011	45.2	73.72	36.32
SCM	17	4476290	0.004	39.8	86.08	54.53
SCM	18	4476303	0.005	38.0	84.42	54.05
SCM	19	4476297	0.003	35.1	42.82	53.44
SCM	20	4476303	0.005	24.5	30.25	52.67
NCM	21	4479801	0.014	27.4	96.66	50.41
NCM	22	4480800	0.012	31.4	98.79	49.15
NCM	23	4480788	0.004	38.0	83.27	51.67
NCM	24	4482278	0.005	36.9	87.15	49.68
DC	25	4608791	0.007	23.6	81.71	15.00
DC	26	4611804	0.005	15.3	54.35	12.01
DC	27	4612300	0.004	22.9	70.01	11.27
DC	28	4613806	0.005	21.3	60.69	9.72
PP	29	4647292	0.005	14.6	37.61	6.51
PP	30	4648311	0.005	15.1	53.72	7.62
PP	31	4649810	0.004	14.2	39.29	8.71
PP	32	4650297	0.006	14.7	80.45	9.49

Generalized Additive Models

Between one and three predictor variables were included in each of the 12 best models determined by AICc; four species CPUE models, four species mean length models, two species richness, and two species diversity models (Table 33, Appendix A). Percent null deviance explained by these models ranged from 29.3 to 76.8 percent (mean 60.0%). Mean depth and distance from port were the most common predictors in the best models selected. Both these predictors were included in all models describing species CPUE (black rockfish, blue rockfish, lingcod, and canary rockfish) and richness. The best models fit to examine predictor relationships with species CPUE explained between 51.4 and 71.8 percent (mean 63.0%) of the model deviance. Mean depth was included in all four models describing species richness and Shannon Diversity, and model deviance ranged from 65.5 to 76.8 percent (mean 72.3%). GAMs did a poor job in explaining deviation of species lengths, where the best models of three of the four species examined, explained less than 45 percent of the model deviance (mean 44.9%).

Table 33. Best model chosen for all response variables analyzed using Generalized Additive Models (GAM) and the percent of the model deviance (% Dev) that model explained. The most parsimonious model within two Akaike information criterion (AIC) values was chosen as the best model.

Predictor	**Group**	**Model**	**% Dev**
CPUE	Black rockfish	CPUE ~ S_1(Depth) + S_2(Distance from Port)	61.1
	Blue rockfish	CPUE ~ S_1(Depth) + S_2(Distance from Port)	71.8
	Lingcod	CPUE ~ S_1(Depth) + S_2(Distance from Port) + S_3(Latitude)	67.5
	Canary rockfish	CPUE ~ S_1(Depth) + S_2(Distance from Port) + S_3(Rugosity)	51.4
Shannon Diversity	All Species	H ~ S_1(Depth) + S_2(% Rough Substrate) + S_3(Latitude)	65.5
	Rockfish	H ~ S_1(Depth) + S_2(% Rough Substrate) + S_3(Latitude)	75.3
Richness	All Species	S ~ S_1(Depth) + S_2(Distance from Port)	76.8
	Rockfish	S ~ S_1(Depth) + S_2(Distance from Port)	71.4
Mean Length	Black rockfish	Length ~ S_1(Distance from Port)	44.9
	Blue rockfish	Length ~ S_1(Latitude) + S_2(% Rough Substrate)	65.2
	Lingcod	Length ~ S_1(Depth)	29.3
	Canary rockfish	Length ~ S_1(Latitude)	40.1

Black rockfish CPUE was strongly influenced by depth and distance from port, resulting in 61.1 percent of the model deviance explained (Tables 33 and 34). Black rockfish CPUE was highest at shallow depths (~15-30 meters) then began to decrease as depth increased to 50 meters (Figure 15). A positive effect was examined between black rockfish CPUE and distance from port, with the highest catch rates recorded at sites located at least 30 kilometers from the nearest fishing port. According to AICc, the best and most parsimonious GAM for black rockfish mean length included only the distance from port predictor and explained 44.9 percent of the model deviance (Tables 33 and 35). Distance from port had a significant effect on black rockfish length, where the largest fish were predicted to be found at sites furthest from port.

Table 34. Summary results from the best Generalized Additive Models (GAM) describing black rockfish, blue rockfish, lingcod, and canary rockfish mean catch per unit effort (CPUE). Table values indicate the estimated degrees of freedom (edf), F-statistic (F-stat), and standard error (Std. Error) associated with each predictor variable included in the best model.

Best Species CPUE Models	**Smoothed Predictors**	**edf**	**F- stat**	**Std. Error**
Black rockfish	Mean Depth	1.89	21.00	0.22
	Distance from Port	0.88	3.09	0.06
Blue rockfish	Mean Depth	1.03	6.13	0.06
	Distance from Port	1.98	22.90	0.17
Lingcod	Mean Depth	0.81	2.91	0.04
	Distance from Port	1.79	0.05	0.13
	Latitude	0.80	5.12	0.03
Canary rockfish	Mean Depth	1.75	5.64	0.21
	Distance from Port	0.80	1.70	0.05
	Mean Rugosity	0.93	3.31	0.07

Table 35. Summary results from the best Generalized Additive Models (GAM) describing black rockfish, blue rockfish, canary rockfish, and lingcod mean fork lengths. Table values indicate the estimated degrees of freedom (edf), F-statistic (F-stat), and standard error (Std. Error) associated with each predictor variable included in the best model.

Best Species Length Models	**Smoothed Predictors**	**edf**	**F- stat**	**Std. Error.**
Black rockfish	Distance from Port	1.84	9.83	20.81
Blue rockfish	Latitude	1.94	16.20	23.36
	% Rough Substrate	1.73	3.10	20.67
Lingcod	Mean Depth	1.52	5.79	19.95
Canary rockfish	Latitude	1.85	7.65	21.40

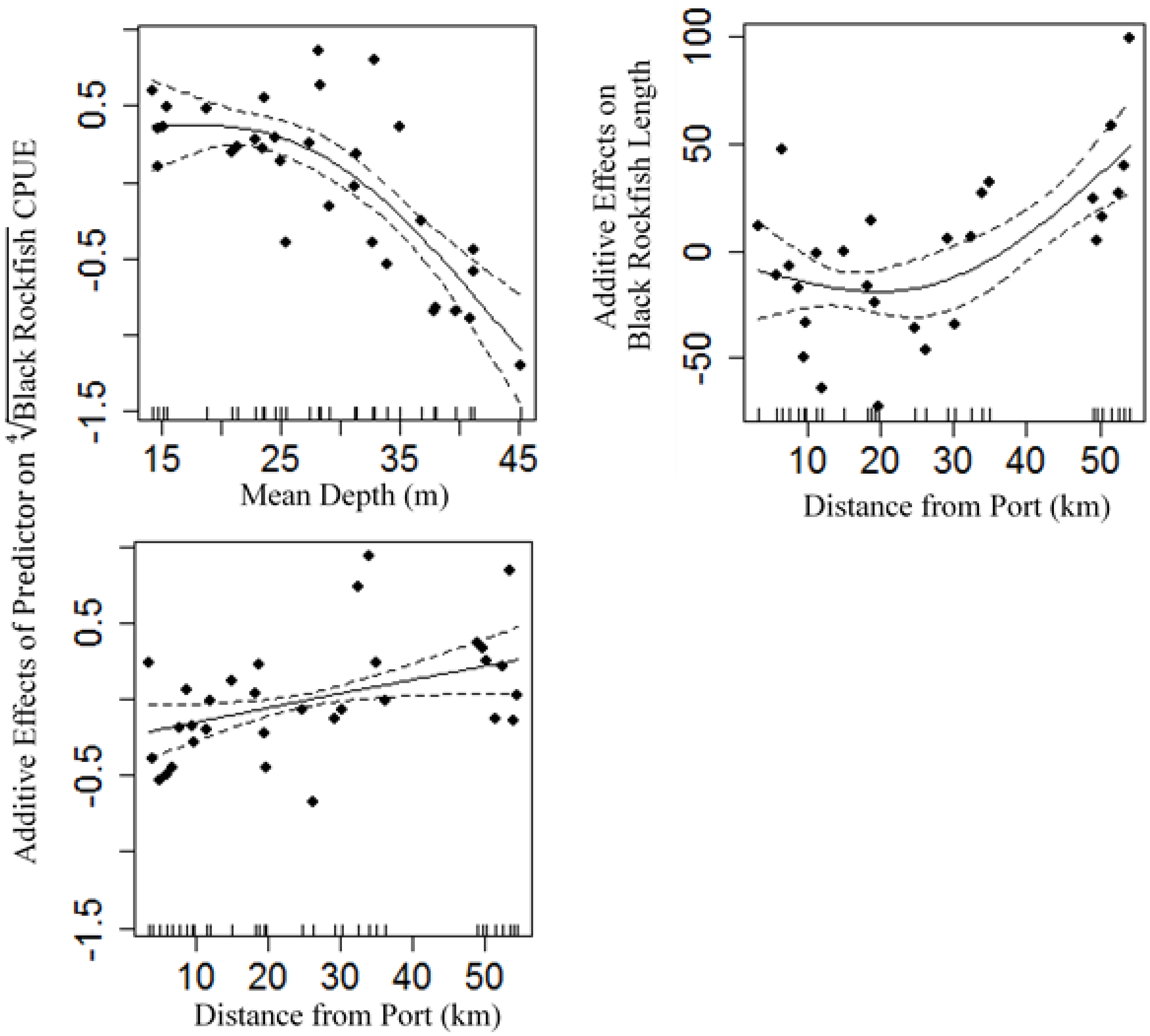

Figure 15. Generalized Additive Model (GAM) results for mean catch per unit effort (CPUE) and mean fork lengths for black rockfish. Plots show the additive effect of each variable included in the best model on the response and the partial residuals. Dotted lines represent ± 2 standard error ranges around the main effects and the vertical dashes at the bottom of the plots show the distribution of points entered into the model.

Blue rockfish CPUE was best described by the GAM including distance from port and mean depth parameters, and accounted for 71.8 percent of the model deviance (Tables 33 and 34). Blue rockfish CPUE was predicted to increase with increasing distance from port prior to declining, with this transition occurring at ~30 kilometers from port (Figure 16). Additionally, blue rockfish CPUE was predicted to increase with increasing depth. Latitude and percent rough substrate were important predictors of blue rockfish lengths, with the best model explaining 65.2 percent of the deviance (Tables 33 and 35). This model predicts a parabolic relationship between blue rockfish length and latitude, with the largest fish located in the mid-latitudes of the north coast region. Blue rockfish lengths appear to be greater in areas with less rough substrate, however, due to wide confidence intervals at both high and low percent rough substrate values, it is difficult to make strong conclusions about this relationship.

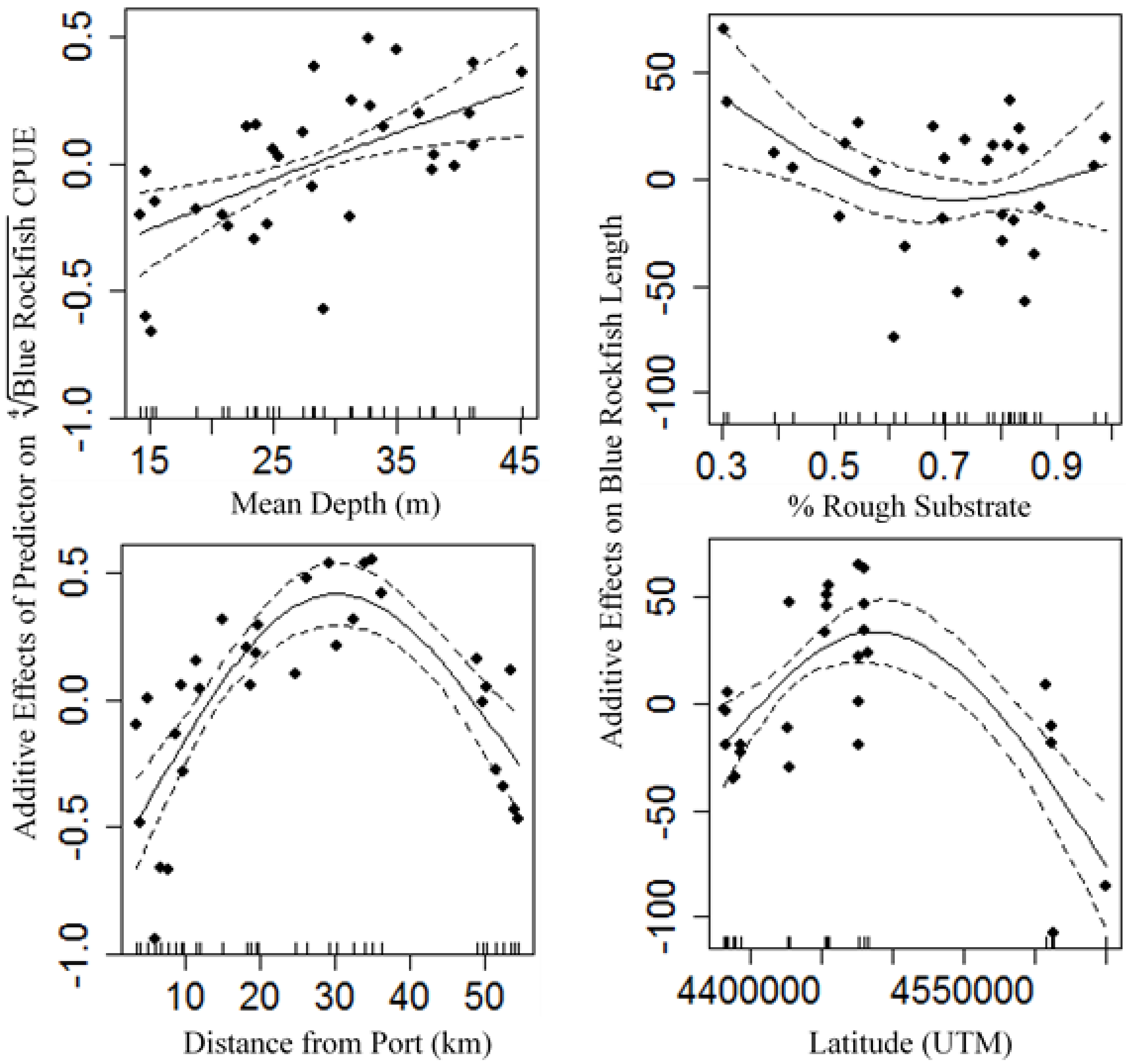

Figure 16. Generalized Additive Model (GAM) results for mean catch per unit effort (CPUE) and mean fork lengths for blue rockfish. Plots show the additive effect of each variable included in the best model on the response and the partial residuals. Dotted lines represent ± 2 standard error ranges around the main effects and the vertical dashes at the bottom of the plots show the distribution of points entered into the model.

Lingcod CPUE was best described by the GAM that included latitude, mean depth, and distance from port, and described 67.5 percent of the model deviance (Tables 33 and 34). Lingcod catch rates were predicted to increase with depth and from north to south in the North Coast region (Figure 17). Lingcod CPUE and distance from port displayed a parabolic relationship, indicating peak catch rates at sites ~25-35 kilometers from port. Model parameters were not as useful in describing trends in lingcod length on the north coast. The top model for lingcod length only included mean depth, and explained 29.3 percent of the model deviance, the lowest of any model (Tables 33 and 35). Depth had a negative relationship with lingcod length, with the largest fish predicted to be caught at shallow sites.

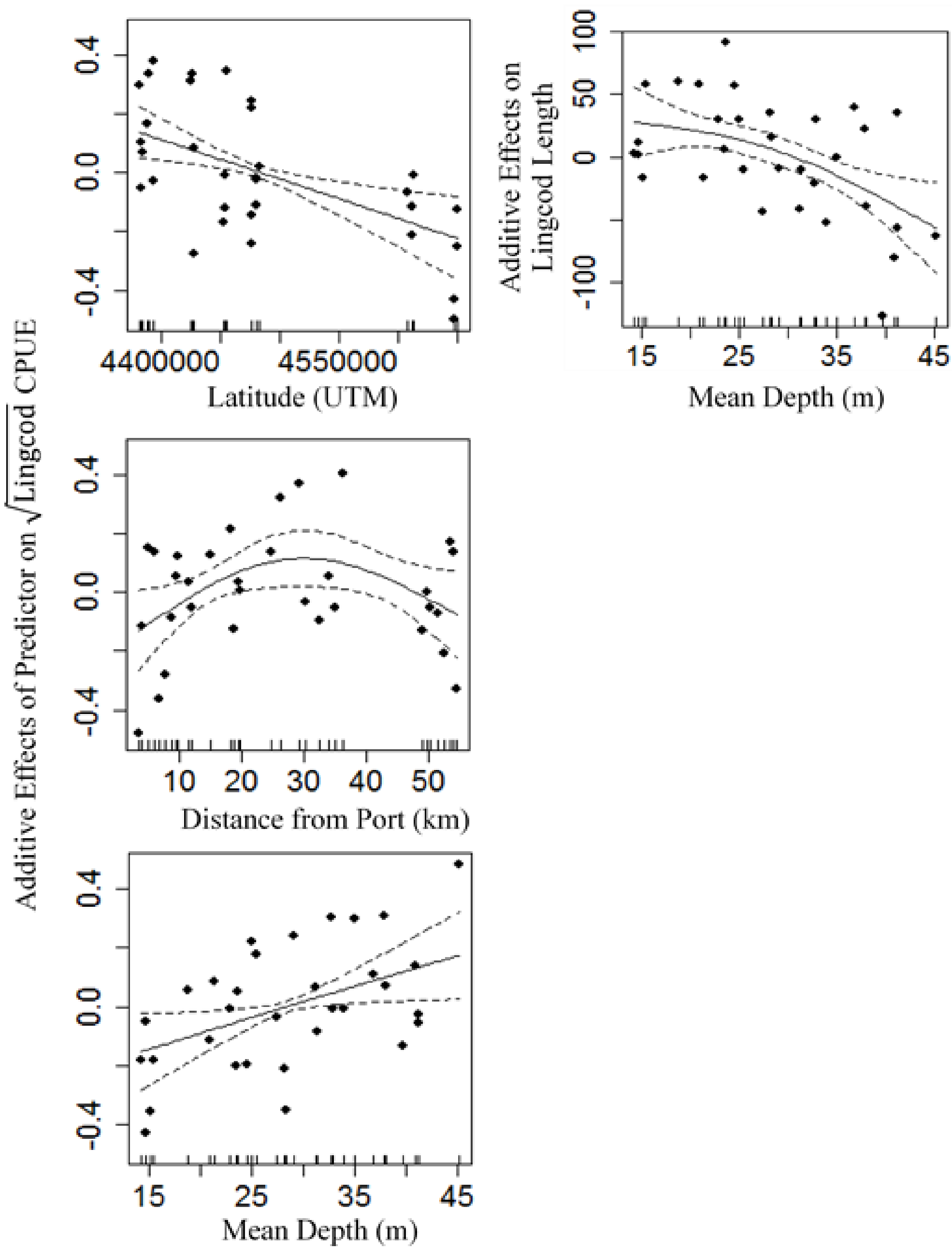

Figure 17. Generalized Additive Model (GAM) results for mean catch per unit effort (CPUE) and mean fork lengths for lingcod. Plots show the additive effect of each variable included in the best model on the response and the partial residuals. Dotted lines represent ± 2 standard error ranges around the main effects and the vertical dashes at the bottom of the plots show the distribution of points entered into the model.

Depth, rugosity, and distance from port were included in the best model describing canary rockfish CPUE, and accounted for 51.4 percent of the null deviance (Tables 33 and 34). Canary rockfish CPUE increased with depth until reaching ~35 meters where it reached an asymptote (Figure 18). Additionally, canary rockfish catch rates increased linearly with distance from port and decreased with mean rugosity, however, confidence intervals were wide at both tails of these relationships. The best GAM fit to describe canary rockfish length included only latitude (deviance explained = 40.1%, Tables 33 and 35). Canary lengths were predicted to be smallest at the northern end of the region and similar throughout the rest of the region.

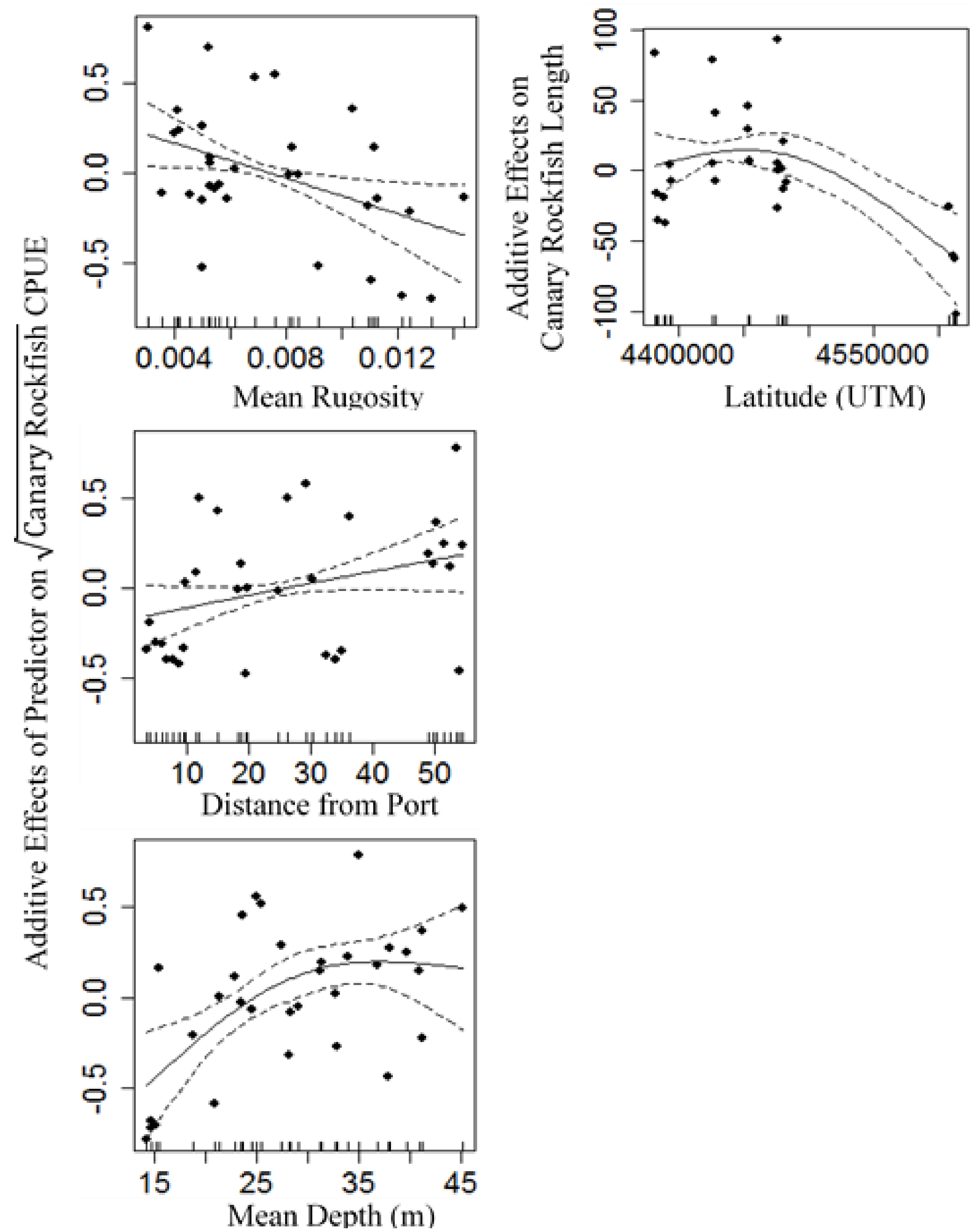

Figure 18. Generalized Additive Model (GAM) results for mean catch per unit effort (CPUE) and mean fork lengths for canary rockfish. Plots show the additive effect of each variable included in the best model on the response and the partial residuals. Dotted lines represent ± 2 standard error ranges around the main effects and the vertical dashes at the bottom of the plots show the distribution of points entered into the model.

On average, GAMs explained a higher percent of the model deviance in the two metrics of species diversity -- species richness and the Shannon Diversity index -- than species CPUE or mean lengths. When considering all species caught, richness was best described by a GAM including depth and distance from port, that explained 76.8 percent of the null deviance (Table 36). Similar to CPUE of blue rockfish and lingcod, species richness displayed a parabolic relationship with distance from port, with peak species richness predicted between 25 and 35 kilometers from port (Figure 19). The best model for richness of only rockfish species included mean depth and distance from port, and explained 71.4 percent of the model deviance. The relationships between these predictors and the response were almost identical to those describing species richness of all species.

Table 36. Summary results from the best Generalized Additive Models (GAM) describing richness of all species and only rockfish species. Table values indicate the estimated degrees of freedom (edf), F-statistic (F-stat), and standard error (Std. Error) associated with each predictor variable included in the best model.

Best Species Richness Models	**Smoothed Predictors**	**edf**	**F- stat**	**Std. Error**
All Species	Mean Depth	1.19	20.64	0.30
	Distance from Port	1.95	11.94	0.64
Rockfish Species	Mean Depth	1.09	15.16	0.26
	Distance from Port	1.91	6.67	0.65

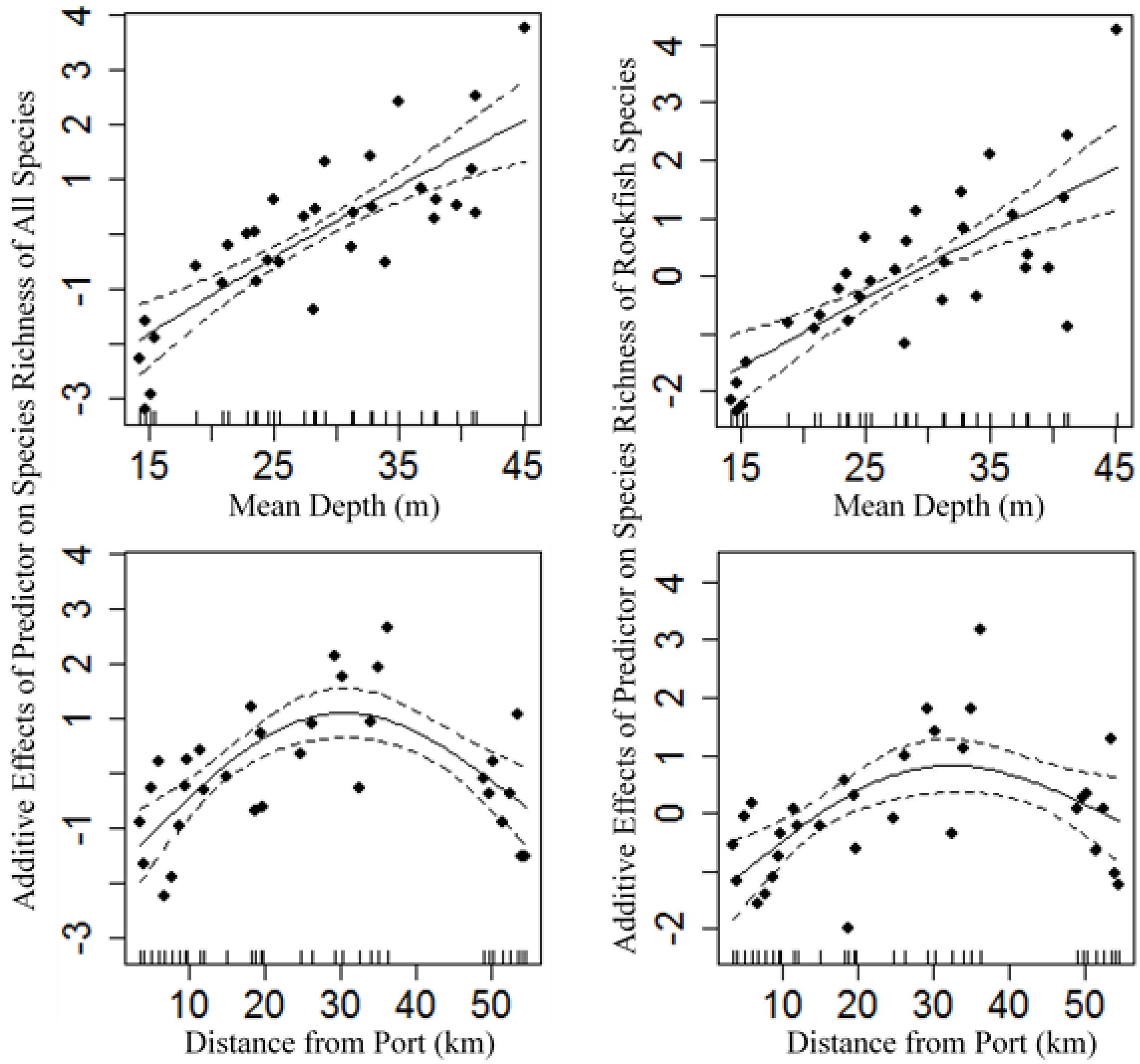

Figure 19. Generalized Additive Model (GAM) results for richness of all species and only rockfish species. Plots show the additive effect of each variable included in the best model on the response and the partial residuals. Dotted lines represent ± 2 standard error ranges around the main effects and the vertical dashes at the bottom of the plots show the distribution of points entered into the model.

When using the Shannon Diversity of all species as the response, the best GAM according to AICc included depth, percent rough substrate, and latitude, and the deviance explained was 65.5 percent (Table 37). Diversity was modeled to increase significantly with both percentage of rough substrate and depth (Figure 20). Higher Shannon Diversity is also predicted at sites further south and decreases as one moves north in the region. Shannon Diversity, when considering only rockfish species, included the same three predictors and described 75.3 percent of the model deviance. The effects of depth, percent rough substrate, and latitude were almost identical to the model used to describe the Shannon Diversity of all fishes.

Table 37. Summary results from the best Generalized Additive Models (GAM) describing Shannon Diversity of all species and only rockfish species. Table values indicate the estimated degrees of freedom (edf), F-statistic (F-stat), and standard error (Std. Error) associated with each predictor variable included in the best model.

Best Shannon Diversity Models	**Smoothed Predictors**	**edf**	**F- stat**	**Std. Error**
All Species	Mean Depth	0.85	4.42	0.04
	Latitude	0.82	4.19	0.04
	% Rough Substrate	1.22	3.36	0.09
Rockfish Species	Mean Depth	1.53	12.75	0.12
	Latitude	0.70	1.77	0.03
	% Rough Substrate	1.64	3.48	0.13

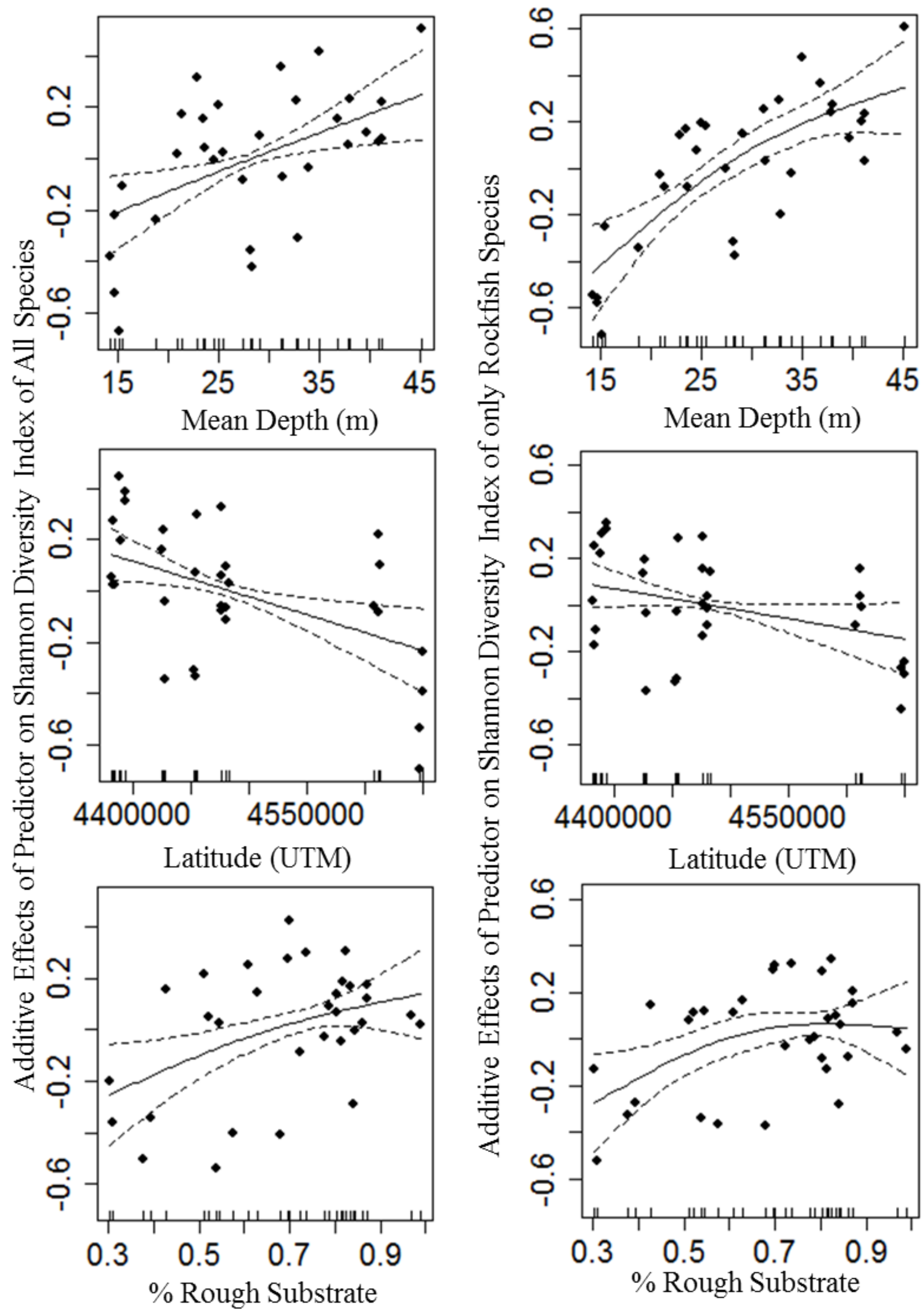

Figure 20. Generalized Additive Model (GAM) results for richness of all species and only rockfish species. Plots show the additive effect of each variable included in the best model on the response and the partial residuals. Dotted lines represent ± 2 standard error ranges around the main effects and the vertical dashes at the bottom of the plots show the distribution of points entered into the model.

DISCUSSION

Results from this baseline characterization of the North Coast MPA region suggest that initial conditions vary between and within the four paired MPA and reference sites examined. Understanding what factors drive initial conditions in paired sites will allow managers to track fluctuations in relative abundance, size, and diversity of rocky reef associated fishes, and properly attribute changes in fish communities to MPA effects over time. This is especially important in the Pyramid Point SMCA and Sea Lion Gulch SMR where total CPUE and species richness were significantly different from their associated reference sites. Additionally, species compositions were less similar in these two paired sites compared to the Eureka and Fort Bragg sites. Much of this variation is likely due to differences in historical fishing pressure between the MPA and its associated reference site. The North Coast region has a limited number of fishing ports over a large area, resulting in a substantial amount of suitable fish habitat that is difficult to access and rarely fished. In a study prior to Northern California MPA establishment, Barrett et al. 2012 documented significantly higher total CPUE of rocky reef associated fishes in sites further from fishing ports. Several other studies in tropical and temperate waters observed a negative relationship between distance from port and fishing effort (Beverton and Holt 1957, Stelzenmuller et al. 2008, Stewart et al. 2010). Differences in historical fishing pressure between MPA and reference sites can lead to different initial baseline conditions and must be accounted for when determining MPA effects via long-term monitoring.

Results from the Fort Bragg and Eureka paired sites are representative of the relationship that can be expected when habitat quality, depth, oceanographic conditions, and historical fishing pressure are controlled for between MPA and reference sites. Total fish CPUE and species diversity were not significantly different, and species compositions were similar in both paired sites (South Cape Mendocino SMR/North Cape Mendocino reference site and Ten Mile SMR/Westport reference site). Reference sites utilized here are located less than five kilometers (Figure 3 and Figure 5) from their associated MPA, mitigating differences in distance from port and therefore historical fishing pressure.

The Sea Lion Gulch SMR, located 32 kilometers from Shelter Cove, has likely experienced significantly less historical fishing pressure than its reference site, Point Delgada, located just four kilometers from port (Figure 4). Shelter Cove is the only port along a long stretch of coastline known as the Lost Coast, and offers only seasonal moorage. Vessels are beach launched by tractor, restricting the size of craft that can utilize this port. Moreover, the Sea Lion Gulch SMR is located off of Punta Gorda, notorious among local fishermen as an area notorious for its unpredictable and rapidly degrading sea conditions. The potentially dangerous ocean conditions, remote location, long distance from port, and vessel size limitations have likely limited historical fishing effort at Sea Lion Gulch SMR. The Point Delgada reference site is much closer to Shelter Cove and offers more protection from poor weather conditions associated with Punta Gorda, making this site much more accessible to small craft. Results from this paired site support the hypothesis that the Shelter Cove MPA site has experienced less historical fishing pressure than its associated reference site. Considering all fishes caught over the 2014 and 2015 sampling seasons combined; the Sea Lion Gulch SMR had significantly higher relative fish abundance than its reference site. Additionally, both black rockfish and canary rockfish were significantly larger inside the Sea Lion Gulch MPA. In fact, total CPUE at the Sea Lion Gulch SMR (20.1 fish per angler hour) is comparable to that documented at the “Old” Point Lobos MPA (24.4 fish per angler hour) in Central California, established in 1973 (Starr et al. 2008). It is possible that the Sea Lion Gulch SMR has been serving as a de facto MPA for many years because of its remote location. If properly designed and enforced, fish densities similar to those of the Sea Lion Gulch SMR could potentially be achieved at other Northern California MPAs with similar habitat structure and oceanographic conditions (e.g., South Cape Mendocino SMR and Ten Mile SMR) after MPA effects are allowed to occur over a long period of time.

The Pyramid Point SMCA yielded the lowest total CPUE, Shannon Diversity, and species richness of any site sampled during this survey. These results are likely a function of habitat quality and historical fishing pressure. The Pyramid Point SMCA contains many small patch reefs but lacks the large reef complexes seen in most other MPA and reference sites (e.g., Sea Lion Gulch SMR, North Cape Mendocino reference area) sampled during this study. Additionally, Pyramid Point is easily accessible from two popular fishing ports, Crescent City and the Port of Brookings in Oregon, located 36 and eight kilometers from the MPA, respectively. Recreational fishing boats from Brookings were observed near or in the Pyramid Point SMCA on several occasions during our sampling events. High historical fishing pressure on a relatively small amount of habitat is likely the driving force in low fish densities at the Pyramid Point SMCA. The Crescent City reference site is located roughly 10 kilometers south of the harbor, and over 50 kilometers from Brookings. It is safe to assume that the Damnation Creek site only experiences fishing pressure from the Crescent City fishing fleet. Mean CPUE and diversity of rocky reef associated fishes was significantly higher at the Damnation Creek reference site compared to the Pyramid Point SMCA. This relationship provides further evidence of the significant effects of historical fishing pressure on sites closest to fishing ports.

The relationship between fish densities and historical fishing pressure was also supported in generalized additive models fit to examine relationships between individual species CPUE and covariates describing habitat quality, depth, latitude, and historical fishing pressure. Distance from port, a proxy for historical fishing pressure, was included as a significant predictor in the best model describing trends in CPUE of all four most of captured fishes during baseline surveys. CPUE of black rockfish and canary rockfish increased linearly with distance from port. A parabolic relationship was predicted between CPUE of black rockfish and lingcod and distance from port, with catch rates peaking between 25 and 35 kilometers from port. This parabolic relationship was likely driven by the high catch rates of black rockfish and lingcod at the Sea Lion Gulch SMR, with stations located between 32 and 36 kilometers from port. As discussed above, this site is particularly hard to access and has likely experienced significantly less fishing pressure than any sites sampled for this project, including sites off of Cape Mendocino, which are actually further from the nearest fishing port (Eureka) than Sea Lion Gulch is to Shelter Cove.

The Recreational Fisheries Information Network (RecFIN) database, designed to integrate state and federal marine recreational sampling efforts, provides further proof that fishing pressure on black rockfish, lingcod, blue rockfish, and canary rockfish has been historically higher than other rocky reef species in the North Coast MPA region. These four species are the most often captured (sum of retained and released individuals) species by chartered and personal recreational craft in waters less than 3 miles offshore since 1990 (Table 38). Although few canary rockfish were harvested between 2000 and 2016, when they were protected in California, the number of canary rockfish released provides a picture of the historical catch rates from the recreational fleet.

Table 38. Thirteen most captured species attained from the RecFin database providing estimates of recreational catch from private and chartered vessels in Del Norte, Humboldt, and Mendocino County. Fish released represent the number of fish released both alive and dead.

Species	**# Fish Retained**	**# Fish Released**	**Total Fish Captured**
Black rockfish	1181629	326674	1508303
Lingcod	211366	128860	340225
Blue rockfish	152776	74527	227303
Canary rockfish	8291	69436	77728
Kelp greenling	32999	29567	62566
Vermilion rockfish	56850	3556	60406
China rockfish	42410	12176	54586
Cabezon	40974	12083	53056
Gopher rockfish	33161	4745	37906
Yellowtail rockfish	26764	7754	34517
Copper rockfish	29432	2843	32274
Quillback rockfish	17593	2858	20451
Yelloweye rockfish	886	14694	15580

Habitat covariates were less important predictors of species CPUE than depth and distance from port according to GAMs. Despite being representative of the amount of suitable habitat available, percent rough substrate was not included in the best models describing CPUE of black rockfish, blue rockfish, lingcod, and canary rockfish. The omission of this covariate in the best models was likely due to sampling design, as all four of these species are known to be highly associated with rocky substrate (Love et al. 2002). These data were collected to establish a baseline of rocky reef associated species, not to inform a species habitat distribution model. CPFV captains were instructed to target rocky habitat where these species could be found. Therefore, sampling effort was not representative of the amount of suitable habitat in a given station. Random sampling inside stations would likely result in a positive association between the numbers of rockfish captured and the percentage of rocky substrate.

Mean rugosity was included in the best model describing CPUE of canary rockfish. However, additional support from previous studies were not available at a scale similar to these analyses. Studies conducted using individual fish locations have reported canary rockfish to be associated with transition areas between mud and sand, and high relief substrate (Yoklavich et al. 2000, Saucedo 2017). It is difficult to make strong claims about the relationship between canary rockfish relative abundances and habitat complexity at a larger scale given the data available. Moreover, rugosity was not a significant predictor of species richness or Shannon Diversity according to GAMs. Several studies on both coral reefs (Friedlander and Parrish 1998, Chapman and Kramer 1999, Purkis et al. 2008, Mellin et al.2009, Walker et al. 2009) and temperate rocky reefs

(Anderson and Yoklavich 2007, Anderson et al. 2009) have found fish diversity to increase with habitat complexity on a fine scale. Complex habitats provide a greater number of niches, resources, and high productivity (Friedlander and Parrish 1998). These same relationships may be difficult to capture at larger scales used for these analysis. Similar to species CPUE, habitat predictors may not be particularly useful in describing species richness and diversity due to the sampling methods and scale of this project.

GAM results suggest that depth and fishing pressure are more reliable predictors of species CPUE when considering the methods used to collect these data and the scale at which covariates were measured. For example, the best model for black rockfish CPUE included distance from port and mean depth. PFMCb (2016) documented that black rockfish can be found in depths up to 200 meters, but are most common in depths less than 30 meters. Our study would suggest that in northern California, black rockfish are most common in depths between 10 and 25 meters and CPUE decreases up to 50 meters, where we capped our effort. Black rockfish have also been the most captured species by the Northern California recreational fishery according to RecFIN data. It is no surprise that this species was caught more frequently at sites further from port, where fishing pressure has been limited.

The best models describing Shannon Diversity and species richness were similar. Mean depth was included as a significant predictor of both species diversity metrics. In all cases, richness and diversity increased with depth. Researchers have found that rockfish species richness is highest at intermediate depths between 30 and 200 meters (Love et al. 2002). In this study, the sites with the lowest species richness and Shannon

Diversity, the Crescent City MPA and reference site, also have the lowest mean depths, with mean depths of 15 and 24 meters, respectively. Mean depths for all other sites are greater than 30 meters. Furthermore, six of the nine most commonly captured species were not caught at the Pyramid Point SMCA over both years sampled. Of those six species, five (canary rockfish, yellowtail rockfish, copper rockfish, quillback rockfish, and vermilion rockfish) are more commonly found in depths greater than 30 meters (Love et al. 2002). The absence of these species at the shallowest site further supports depth as a significant predictor of species richness and diversity. Latitude was also a significant predictor of Shannon Diversity of all species, and rockfish specifically (Table 39). GAMs predicted higher diversity at southern sites. This trend is evident in rockfish diversity in California waters, with the greatest number of species found in the Southern California Bight and the fewest number of species in the northernmost region of the state (Allen et al. 2006). Even within the North Coast MPA Region the number of rockfish species present increases from between 41 and 45 species north of Cape Mendocino to between 46 and 50 species south of Cape Mendocino (Allen et al. 2006). Generalized additive models did a poor job in explaining variation of mean lengths of black rockfish, blue rockfish, lingcod, and canary rockfish, with a mean deviance explained of 44.9 percent. Latitude was included in two of the four best models but the relationship between this covariate and fish lengths was unexpected. Species lengths were predicted to be highest at the middle latitudes and lower at the southern and northern extents of the region. This relationship was likely due to the largest fishes being caught at the Lion Gulch SMR, South Cape Mendocino SMR, and North Cape Mendocino sites located in the middle of the North Coast MPA Region. Distance from port was only a significant predictor of one of the four species evaluated. Several studies have documented a truncated size structure in rockfishes in areas with large amounts of fishing pressure (Mason 1998, Williams et al. 2010). It is possible that the sampling gear used for this project selected for larger fish, and did not accurately capture the small end of rockfish size distributions. If the smallest fish were not being caught, the effect that fishing pressure may have had on fish lengths would not be captured in these models. Additionally, mean species lengths can be affected by large recruitment events. Star et al. (2015) recorded a decrease in mean lengths of black rockfish after a large recruitment even in Central California. Including a predictor representing primary production may capture large recruitment events and therefore explain some variation in mean lengths and improve the predictability of these models.

Overall, model performance for all response variables could be improved in the future by including a suite of environmental variables (e.g., water temperature and primary productivity). These predictors, although less important when examining a snapshot of fish communities, as in this study, become more valuable in tracking fish densities and growth over time. Starr et al. (2015) was able to associate a steep decline in blue rockfish abundance to a warm, unproductive period three years prior to when decreases were documented. Adding habitat predictors to generalized additive models will make them more valuable when determining MPA effects over longer monitoring efforts.

Long-term Monitoring

Long-term monitoring of rocky reef associated fish communities will be critical for evaluating the performance of the North Coast MPAs, and the strength of the entire California MPA network. Although these communities are relatively slow to respond to protection, frequent monitoring would allow environmental and MPA effects to be parsed more easily than a one or two year snapshot of fish communities, similar to this baseline assessment. This is especially important for the North Coast region as baseline sampling took place during two years (2014 and 2015) with anomalously warm ocean temperatures and low primary production (Jacox et al. 2016, Gomez-Ocampo et al. 2017, Hu et al. 2017). Fluctuating oceanographic conditions can affect rockfish recruitment and spatial distribution and therefore influence density estimates (Hollowed et al. 2001, Wheeler et al. 2017). A long-term monitoring program makes it possible to study the effects these anomalous years have on populations and determine whether differences in densities and fish size are due to stochastic recruitment events or protection status.

Several sampling methods that have been useful in evaluating fish communities associated with rocky reefs throughout the world. The Oregon Department of Fish and Wildlife utilize a variety of different methods to monitor MPAs along the coast including ROV surveys, stationary drop cameras, scuba surveys, hook and line, and longline surveys (Watson and Huntington 2016, Huntington and Watson 2017). Using a variety of sampling methods to collect the most comprehensive data on fish community structure and account for gear bias is ideal. However, when resources are limited, choosing one sampling method that can most effectively and efficiently characterize fish populations and meet the goals of the monitoring project is important. One of the most important factors to consider when choosing a sampling method is the habitat to be surveyed. Williams et al. (2009) used SCUBA surveys to monitor yellow tang (*Zebrasoma flavescens*), a popular ornamental fish inhabiting shallow coral reefs in Hawaii. Manned or remotely operated vehicle are a commonly utilized in characterizing fish communities on offshore rocky banks over 75 meters deep (Nasby-Lucas et al. 2002, Young et al. 2010). Monitoring fish communities in the North Coast MPA region presents certain challenges, making hook and line surveys the best option for evaluating MPA effects over time. Limited infrastructure to support research vessels makes ROV surveys extremely expensive. Additionally, the number of days during each year with conditions conducive to SCUBA and drop camera sampling is even more limited than for hook and line surveys. Finally, the relationships built during collaborative hook and line studies allow scientists to interact with and educate members of the fishing community that may be skeptical of MPAs, and also allow fishermen to share their knowledge with scientists.

In 2017, the California Collaborative Fishing Research Program (CCFRP), headquartered at Moss Landing Marine Labs in central California, organized a statewide MPA monitoring effort utilizing CPFVs to conduct hook and line surveys in each of the four MPA regions. Each region is responsible for collaborating with local CPFV captains, and organizing volunteer anglers to help collect fish community data in MPAs and associated reference sites using similar scientific protocols that will allow comparison across regions. The goal of this effort is to evaluate MPAs regionally and assess the effectiveness of the entire state-wide network, all while building strong working relationships with the local fishing communities and continuing promotion of MPAs throughout the community. The CCFRP hopes to attain funding annually to distribute amongst each region to support these monitoring efforts.

In addition to evaluating MPA effectiveness, an ongoing collaborative MPA monitoring effort in Northern California will provide fishery-independent data to a region that has been traditionally understudied. This long-term dataset may also be valuable in assessing the effects of climate change on rocky reef associated fishes and the impact it may have on the commercial and recreational fishery. Finally, continuing to build relationships between scientists and the fishing community will increase trust between the two parties and facilitate the sharing of knowledge to benefit fisheries management in the future.

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APPENDIX A

Appendix A. All model selection tables used to identify the best model describing each response variable: (A) Black rockfish Catch per unit effort (CPUE), (B) Blue rockfish CPUE, (C) Lingcod CPUE, (D) Canary rockfish CPUE, (E) Black rockfish length, (F) Blue rockfish length, (G) Lingcod length, (H) Canary rockfish length, (I) Diversity of all fish, (J) Diversity of rockfish, (K) Richness of all fish, (L) Richness of rockfish. All tables include 31 models containing every combination of the five predictors measured: percent rough substrate (% Rough Sub), Depth, Rugosity, Latitude, and distance from port. The most parsimonious model with a delta-AICc less than two was chosen as the best model and bolded.

A.

Black Rockfish CPUE Model	**AICc**	**ΔAICc**
Black rockfish CPUE ~ % Rough Sub + Depth + Rugosity + Latitude + Distance from Port	28.843	0.000
Black rockfish CPUE ~ % Rough Sub + Depth + Rugosity + Latitude	28.881	0.038
Black rockfish CPUE ~ Depth + Distance from Port	**30.541**	**1.698**
Black rockfish CPUE ~ Depth + Latitude + Distance from Port	30.541	1.698
Black rockfish CPUE ~ Depth + Rugosity + Latitude + Distance from Port	30.583	1.740
Black rockfish CPUE ~ Depth + Rugosity + Distance from Port	30.583	1.740
Black rockfish CPUE ~ % Rough Sub + Depth + Latitude + Distance from Port	30.637	1.794
Black rockfish CPUE ~ % Rough Sub + Depth + Distance from Port	30.637	1.794
Black rockfish CPUE ~ % Rough Sub + Depth + Rugosity + Distance from Port	30.808	1.966
Black rockfish CPUE ~ Depth + Rugosity + Latitude	31.267	2.425
Black rockfish CPUE ~ % Rough Sub + Depth + Latitude	31.839	2.996
Black rockfish CPUE ~ Depth + Latitude	31.928	3.085
Black rockfish CPUE ~ % Rough Sub + Depth + Rugosity	33.243	4.401
Black rockfish CPUE ~ Depth + Rugosity	33.746	4.904
Black rockfish CPUE ~ Depth	35.193	6.350
Black rockfish CPUE ~ % Rough Sub + Depth	35.193	6.350
Black rockfish CPUE ~ Latitude	53.233	24.390
Black rockfish CPUE ~ Latitude + Distance from Port	53.233	24.390
Black rockfish CPUE ~ % Rough Sub + Latitude	53.233	24.390
Black rockfish CPUE ~ % Rough Sub + Latitude + Distance from Port	53.233	24.390
Black rockfish CPUE ~ Rugosity + Latitude + Distance from Port	53.284	24.441

Black Rockfish CPUE Model	AICc	ΔAICc
Black rockfish CPUE ~ Rugosity + Latitude	53.284	24.441
Black rockfish CPUE ~ % Rough Sub + Latitude + Rugosity + Distance from Port	53.399	24.557
Black rockfish CPUE ~ % Rough Sub + Rugosity + Latitude	53.399	24.557
Black rockfish CPUE ~ % Rough Sub + Rugosity	53.659	24.817
Black rockfish CPUE ~ Distance from Port	53.659	24.817
Black rockfish CPUE ~ Rugosity + Distance from Port	53.659	24.817
Black rockfish CPUE ~ Rugosity	53.659	24.817
Black rockfish CPUE ~ % Rough Sub + Distance from Port	53.659	24.817
Black rockfish CPUE ~ % Rough Sub + Rugosity + Distance from Port	53.659	24.817
Black rockfish CPUE ~ % Rough Sub	53.659	24.817

B.

Blue Rockfish CPUE Model	AICc	ΔAICc
Blue rockfish CPUE ~ Depth + DFP	**8.551**	**0.000**
Blue rockfish CPUE ~ % Rough Sub + Depth + Rugosity + DFP	8.551	1.929E-07
Blue rockfish CPUE ~ Depth + Rugosity + DFP	8.551	1.946E-07
Blue rockfish CPUE ~ % Rough Sub + Depth + Rugosity + DFP + Latitude	8.551	1.978E-07
Blue rockfish CPUE ~ % Rough Sub + Depth + DFP	8.551	1.997E-07
Blue rockfish CPUE ~ Depth + Latitude + DFP	8.551	2.001E-07
Blue rockfish CPUE ~ % Rough Sub + Depth + Latitude + DFP	8.551	2.002E-07
Blue rockfish CPUE ~ Depth + Rugosity + Latitude + DFP	8.551	2.005E-07
Blue rockfish CPUE ~ Latitude + DFP	17.824	9.273
Blue rockfish CPUE ~ Rugosity + Latitude + DFP	17.836	9.284
Blue rockfish CPUE ~ % Rough Sub + Latitude + DFP	17.848	9.297
Blue rockfish CPUE ~ % Rough Sub + Latitude + Rugosity + DFP	17.848	9.297
Blue rockfish CPUE ~ Rugosity + DFP	18.143	9.591
Blue rockfish CPUE ~ % Rough Sub + DFP	18.178	9.626
Blue rockfish CPUE ~ DFP	18.222	9.671
Blue rockfish CPUE ~ % Rough Sub + Rugosity + DFP	19.285	10.733
Blue rockfish CPUE ~ Depth + Rugosity	21.857	13.306
Blue rockfish CPUE ~ % Rough Sub + Depth + Rugosity	21.857	13.306
Blue rockfish CPUE ~ Depth + Rugosity + Latitude	21.857	13.306
Blue rockfish CPUE ~ % Rough Sub + Depth + Rugosity + Latitude	21.857	13.306
Blue rockfish CPUE ~ Rugosity + Latitude	26.542	17.990

Blue Rockfish CPUE Model	AICc	ΔAICc
Blue rockfish CPUE ~ % Rough Sub + Rugosity + Latitude	26.542	17.990
Blue rockfish CPUE ~ Rugosity	27.857	19.306
Blue rockfish CPUE ~ % Rough Sub + Rugosity	27.857	19.306
Blue rockfish CPUE ~ Depth + Latitude	32.677	24.126
Blue rockfish CPUE ~ % Rough Sub + Depth + Latitude	32.677	24.126
Blue rockfish CPUE ~ Latitude	34.007	25.456
Blue rockfish CPUE ~ % Rough Sub + Latitude	34.024	25.472
Blue rockfish CPUE ~ % Rough Sub + Depth	34.414	25.863
Blue rockfish CPUE ~ Depth	34.414	25.863
Blue rockfish CPUE ~ % Rough Sub	40.579	32.027

C.

Lingcod CPUE Model	AICc	ΔAICc
Lingcod CPUE ~ Depth + Latitude + DFP	-7.099	0.000
Lingcod CPUE ~ % Rough Sub + Rugosity + Depth + Latitude + DFP	-7.028	0.072
Lingcod CPUE ~ % Rough Sub + Depth + Latitude + DFP	-7.028	0.072
Lingcod CPUE ~ Depth + Latitude	**-6.013**	**1.087**
Lingcod CPUE ~ Depth + Rugosity + Latitude	-6.013	1.087
Lingcod CPUE ~ Depth + Rugosity + Latitude + DFP	-6.013	1.087
Lingcod CPUE ~ % Rough Sub + Depth + Rugosity + Latitude	-6.005	1.094
Lingcod CPUE ~ % Rough Sub + Depth + Latitude	-6.005	1.094
Lingcod CPUE ~ % Rough Sub + Latitude	-4.239	2.860
Lingcod CPUE ~ % Rough Sub + Latitude + DFP	-4.239	2.860
Lingcod CPUE ~ % Rough Sub + Latitude + Rugosity + DFP	-4.239	2.860
Lingcod CPUE ~ % Rough Sub + Rugosity + Latitude	-4.239	2.860
Lingcod CPUE ~ Latitude	-3.937	3.162
Lingcod CPUE ~ Latitude + DFP	-3.937	3.162
Lingcod CPUE ~ Rugosity + Latitude + DFP	-3.937	3.162
Lingcod CPUE ~ Rugosity + Latitude	-3.937	3.162
Lingcod CPUE ~ Depth + DFP	-1.793	5.306
Lingcod CPUE ~ Depth + Rugosity + DFP	-1.793	5.306
Lingcod CPUE ~ % Rough Sub + Depth + DFP	-1.793	5.306
Lingcod CPUE ~ % Rough Sub + Depth + Rugosity + DFP	-1.793	5.306
Lingcod CPUE ~ Depth + Rugosity	1.118	8.218

Lingcod CPUE Model	AICc	ΔAICc
Lingcod CPUE ~ % Rough Sub + Depth + Rugosity	1.118	8.218
Lingcod CPUE ~ Depth	5.905	13.004
Lingcod CPUE ~ % Rough Sub + Depth	5.905	13.004
Lingcod CPUE ~ Rugosity + DFP	11.732	18.831
Lingcod CPUE ~ % Rough Sub + Rugosity + DFP	11.732	18.831
Lingcod CPUE ~ % Rough Sub + DFP	12.328	19.428
Lingcod CPUE ~ DFP	12.586	19.686
Lingcod CPUE ~ % Rough Sub + Rugosity	14.976	22.075
Lingcod CPUE ~ Rugosity	14.980	22.080
Lingcod CPUE ~ % Rough Sub	18.522	25.621

D.

Canary CPUE Model	AICc	ΔAICc
Canary rockfish CPUE ~ Depth + Rugosity + DFP	**31.656**	**0.000**
Canary rockfish CPUE ~ Depth + Rugosity + Latitude + DFP	31.656	5.905E-06
Canary rockfish CPUE ~ % Rough Sub + Depth + Rugosity + DFP	31.656	5.905E-06
Canary rockfish CPUE ~ % Rough Sub + Depth + Latitude + Rugosity + DFP	31.656	5.905E-06
Canary rockfish CPUE ~ Depth + Rugosity	33.684	2.028
Canary rockfish CPUE ~ Depth + Rugosity + Latitude	33.684	2.028
Canary rockfish CPUE ~ % Rough Sub + Depth + Rugosity + Latitude	33.684	2.028
Canary rockfish CPUE ~ % Rough Sub + Depth + Rugosity	33.684	2.028
Canary rockfish CPUE ~ Rugosity + Latitude + DFP	35.247	3.591
Canary rockfish CPUE ~ % Rough Sub + Latitude + Rugosity + DFP	35.247	3.591
Canary rockfish CPUE ~ Depth + DFP	36.484	4.828
Canary rockfish CPUE ~ Depth + Latitude + DFP	36.484	4.828
Canary rockfish CPUE ~ % Rough Sub + Depth + Latitude + DFP	36.484	4.828
Canary rockfish CPUE ~ % Rough Sub + Depth + DFP	36.513	4.857
Canary rockfish CPUE ~ Rugosity + DFP	37.117	5.461
Canary rockfish CPUE ~ % Rough Sub + Rugosity + DFP	37.117	5.461
Canary rockfish CPUE ~ Depth	37.459	5.803
Canary rockfish CPUE ~ % Rough Sub + Depth + Latitude	37.459	5.803
Canary rockfish CPUE ~ % Rough Sub + Depth	37.459	5.803
Canary rockfish CPUE ~ Depth + Latitude	37.459	5.803
Canary rockfish CPUE ~ Rugosity + Latitude	37.500	5.844

Canary CPUE Model	AICc	ΔAICc
Canary rockfish CPUE ~ % Rough Sub + Rugosity + Latitude	37.500	5.844
Canary rockfish CPUE ~ DFP	38.789	7.133
Canary rockfish CPUE ~ Latitude + DFP	38.789	7.133
Canary rockfish CPUE ~ % Rough Sub + Latitude + DFP	38.789	7.133
Canary rockfish CPUE ~ % Rough Sub + DFP	38.789	7.133
Canary rockfish CPUE ~ Latitude	40.955	9.299
Canary rockfish CPUE ~ % Rough Sub + Latitude	40.955	9.299
Canary rockfish CPUE ~ % Rough Sub	45.463	13.807
Canary rockfish CPUE ~ % Rough Sub + Rugosity	45.477	13.821
Canary rockfish CPUE ~ Rugosity	45.477	13.821

E.

Black Rockfish Length Model	**AICc**	**ΔAICc**
Black rockfish length ~ Depth + DFP	274.800	0.000
Black rockfish length ~ Depth + Rugosity + Latitude + DFP	274.800	7.267E-07
Black rockfish length ~ Depth + Latitude + DFP	274.800	7.267E-07
Black rockfish length ~ Depth + Rugosity + DFP	274.800	7.267E-07
Black rockfish length ~ % Rough Sub + Depth + DFP	274.800	7.268E-07
Black rockfish length ~ % Rough Sub + Depth + Rugosity + DFP	274.800	7.268E-07
Black rockfish length ~ % Rough Sub + Depth + Latitude + DFP	274.800	7.268E-07
Black rockfish length ~ % Rough Sub + Depth + Latitude + Rugosity + DFP	274.800	7.269E-07
Black rockfish length ~ DFP	**275.347**	**0.546**
Black rockfish length ~ % Rough Sub + Rugosity + DFP	275.347	0.546
Black rockfish length ~ Rugosity + Latitude + DFP	275.347	0.546
Black rockfish length ~ % Rough Sub + DFP	275.347	0.546
Black rockfish length ~ Rugosity + DFP	275.347	0.546
Black rockfish length ~ Latitude + DFP	275.347	0.546
Black rockfish length ~ % Rough Sub + Latitude + Rugosity + DFP	275.347	0.546
Black rockfish length ~ % Rough Sub + Latitude + DFP	275.347	0.546
Black rockfish length ~ Depth + Latitude	277.643	2.843
Black rockfish length ~ Depth + Rugosity + Latitude	277.643	2.843
Black rockfish length ~ % Rough Sub + Depth + Latitude	277.701	2.901
Black rockfish length ~ % Rough Sub + Depth + Rugosity + Latitude	277.701	2.901
Black rockfish length ~ % Rough Sub + Latitude	278.214	3.414

Black Rockfish Length Model	**AICc**	**ΔAICc**
Black rockfish length ~ % Rough Sub + Rugosity + Latitude	278.214	3.414
Black rockfish length ~ Latitude	278.272	3.472
Black rockfish length ~ Rugosity + Latitude	278.272	3.472
Black rockfish length ~ Depth + Rugosity	279.209	4.409
Black rockfish length ~ % Rough Sub + Depth + Rugosity	279.209	4.409
Black rockfish length ~ Depth	282.660	7.860
Black rockfish length ~ % Rough Sub + Depth	282.660	7.860
Black rockfish length ~ Rugosity	285.576	10.776
Black rockfish length ~ % Rough Sub + Rugosity	285.576	10.776
Black rockfish length ~ % Rough Sub	288.001	13.200

F.

Blue Rockfish Length Model	**AICc**	**ΔAICc**
Blue rockfish length ~ % Rough Sub + Rugosity + Latitude	288.349	0
Blue rockfish length ~ % Rough Sub + Latitude + Rugosity + DFP	288.349	1.261E-09
Blue rockfish length ~ % Rough Sub + Depth + Rugosity + Latitude	288.349	1.357E-09
Blue rockfish length ~ % Rough Sub + Depth + Latitude + Rugosity + DFP	288.349	2.023E-09
Blue rockfish length ~ % Rough Sub + Latitude	**288.769**	**0.420**
Blue rockfish length ~ % Rough Sub + Latitude + DFP	288.769	0.420
Blue rockfish length ~ % Rough Sub + Depth + Latitude	288.769	0.420
Blue rockfish length ~ % Rough Sub + Depth + Latitude + DFP	288.769	0.420
Blue rockfish length ~ Latitude	290.994	2.644
Blue rockfish length ~ Depth + Rugosity + Latitude	290.994	2.644
Blue rockfish length ~ Latitude + DFP	290.994	2.644
Blue rockfish length ~ Rugosity + Latitude + DFP	290.994	2.644
Blue rockfish length ~ Depth + Latitude + DFP	290.994	2.644
Blue rockfish length ~ Depth + Latitude	290.994	2.644
Blue rockfish length ~ Rugosity + Latitude	290.994	2.644
Blue rockfish length ~ Depth + Rugosity + Latitude + DFP	290.994	2.644
Blue rockfish length ~ % Rough Sub + Depth + Rugosity + DFP	298.470	10.120
Blue rockfish length ~ Depth + Rugosity + DFP	298.502	10.153
Blue rockfish length ~ Depth + DFP	298.622	10.272
Blue rockfish length ~ % Rough Sub + Depth + DFP	298.666	10.317
Blue rockfish length ~ Rugosity + DFP	298.849	10.500
Blue rockfish length ~ % Rough Sub + Rugosity + DFP	298.864	10.515

Blue Rockfish Length Model	**AICc**	**ΔAICc**
Blue rockfish length ~ DFP	299.059	10.709
Blue rockfish length ~ % Rough Sub + DFP	299.059	10.709
Blue rockfish length ~ % Rough Sub + Depth	302.965	14.616
Blue rockfish length ~ % Rough Sub + Depth + Rugosity	303.005	14.656
Blue rockfish length ~ Depth	304.372	16.023
Blue rockfish length ~ Depth + Rugosity	304.400	16.050
Blue rockfish length ~ % Rough Sub + Rugosity	307.331	18.981
Blue rockfish length ~ % Rough Sub	307.473	19.124
Blue rockfish length ~ Rugosity	308.649	20.300

G.

Lingcod Length Model	**AICc**	**ΔAICc**
Lingcod length ~ % Rough Sub + Depth + Latitude + DFP	333.094	0.000
Lingcod length ~ % Rough Sub + Depth + Rugosity + Latitude	333.094	1.814E-10
Lingcod length ~ % Rough Sub + Depth + Rugosity	333.094	2.453E-10
Lingcod length ~ % Rough Sub + Depth + DFP	333.094	2.668E-10
Lingcod length ~ % Rough Sub + Depth + Latitude	333.094	3.384E-10
Lingcod length ~ % Rough Sub + Depth + Rugosity + DFP	333.094	5.922E-10
Lingcod length ~ % Rough Sub + Depth + Latitude + Rugosity + DFP	333.094	1.376E-09
Lingcod length ~ % Rough Sub + Depth	333.094	1.094E-07
Lingcod length ~ Depth	**333.123**	**0.028**
Lingcod length ~ Depth + Latitude + DFP	333.123	0.028
Lingcod length ~ Depth + DFP	333.123	0.028
Lingcod length ~ Depth + Latitude	333.123	0.028
Lingcod length ~ Depth + Rugosity	333.123	0.028
Lingcod length ~ Depth + Rugosity + Latitude	333.123	0.028
Lingcod length ~ Depth + Rugosity + DFP	333.123	0.028
Lingcod length ~ Depth + Rugosity + Latitude + DFP	333.123	0.028
Lingcod length ~ % Rough Sub	339.586	6.492
Lingcod length ~ % Rough Sub + Latitude + Rugosity + DFP	339.586	6.492
Lingcod length ~ % Rough Sub + Rugosity	339.586	6.492
Lingcod length ~ % Rough Sub + Rugosity + DFP	339.586	6.492
Lingcod length ~ % Rough Sub + Latitude	339.586	6.492

Lingcod Length Model	**AICc**	**ΔAICc**
Lingcod length ~ % Rough Sub + Latitude + DFP	339.586	6.492
Lingcod length ~ % Rough Sub + DFP	339.586	6.492
Lingcod length ~ % Rough Sub + Rugosity + Latitude	339.586	6.492
Lingcod length ~ Rugosity + Latitude + DFP	340.433	7.339
Lingcod length ~ DFP	340.433	7.339
Lingcod length ~ Latitude + DFP	340.433	7.339
Lingcod length ~ Rugosity + DFP	340.433	7.339
Lingcod length ~ Rugosity	340.433	7.339
Lingcod length ~ Latitude	340.433	7.339
Lingcod length ~ Rugosity + Latitude	340.433	7.339

H.

Canary Rockfish Length Model	AICc	ΔAICc
Canary rockfish length ~ Latitude	**275.318**	**0.000**
Canary rockfish length ~ Rugosity + Latitude	275.318	7.487E-07
Canary rockfish length ~ % Rough Sub + Latitude + Rugosity + DFP	275.318	7.487E-07
Canary rockfish length ~ Latitude + DFP	275.318	7.488E-07
Canary rockfish length ~ % Rough Sub + Latitude + DFP	275.318	7.489E-07
Canary rockfish length ~ % Rough Sub + Rugosity + Latitude	275.318	7.489E-07
Canary rockfish length ~ Rugosity + Latitude + DFP	275.318	7.489E-07
Canary rockfish length ~ % Rough Sub + Latitude	275.318	7.489E-07
Canary rockfish length ~ Depth + Latitude	275.490	0.172
Canary rockfish length ~ Depth + Rugosity + Latitude	275.490	0.172
Canary rockfish length ~ % Rough Sub + Depth + Latitude	275.490	0.172
Canary rockfish length ~ % Rough Sub + Depth + Rugosity + Latitude	275.490	0.172
Canary rockfish length ~ Depth + Latitude + DFP	275.672	0.354
Canary rockfish length ~ Depth + Rugosity + Latitude + DFP	275.672	0.354
Canary rockfish length ~ % Rough Sub + Depth + Latitude + DFP	275.685	0.367
Canary rockfish length ~ % Rough Sub + Depth + Latitude + Rugosity + DFP	275.685	0.367
Canary rockfish length ~ % Rough Sub + Rugosity	284.293	8.975
Canary rockfish length ~ Rugosity	284.293	8.975
Canary rockfish length ~ DFP	284.293	8.975
Canary rockfish length ~ % Rough Sub	284.293	8.975
Canary rockfish length ~ Rugosity + DFP	284.293	8.975
Canary rockfish length ~ % Rough Sub + DFP	284.293	8.975

Canary Rockfish Length Model	AICc	ΔAICc
Canary rockfish length ~ % Rough Sub + Rugosity + DFP	284.293	8.975
Canary rockfish length ~ % Rough Sub + Depth + Rugosity + DFP	284.293	8.975
Canary rockfish length ~ Depth + Rugosity + DFP	284.293	8.975
Canary rockfish length ~ Depth + Rugosity	284.293	8.975
Canary rockfish length ~ % Rough Sub + Depth + DFP	284.293	8.975
Canary rockfish length ~ Depth + DFP	284.293	8.975
Canary rockfish length ~ % Rough Sub + Depth	284.293	8.975
Canary rockfish length ~ % Rough Sub + Depth + Rugosity	284.293	8.975
Canary rockfish length ~ Depth	284.293	8.975

I.

All Fish Shannon Diversity Model	AICc	ΔAICc
All Fish Diversity ~ % Rough Sub + Depth + Latitude	**6.489**	**0.000**
All Fish Diversity ~ % Rough Sub + Depth + Rugosity + Latitude	6.489	2.732E-08
All Fish Diversity ~ % Rough Sub + Depth + Latitude + Rugosity + DFP	6.912	0.423
All Fish Diversity ~ % Rough Sub + Depth + Latitude + DFP	6.912	0.423
All Fish Diversity ~ Depth + Latitude	9.575	3.085
All Fish Diversity ~ Depth + Rugosity + Latitude	9.575	3.085
All Fish Diversity ~ Depth + Rugosity + Latitude + DFP	9.575	3.085
All Fish Diversity ~ Depth + Latitude + DFP	9.575	3.085
All Fish Diversity ~ % Rough Sub + Depth	9.890	3.400
All Fish Diversity ~ % Rough Sub + Depth + DFP	9.943	3.454
All Fish Diversity ~ % Rough Sub + Depth + Rugosity + DFP	9.943	3.454
All Fish Diversity ~ % Rough Sub + Depth + Rugosity	10.039	3.550
All Fish Diversity ~ Depth	11.188	4.699
All Fish Diversity ~ Depth + DFP	11.188	4.699
All Fish Diversity ~ Depth + Rugosity + DFP	11.188	4.699
All Fish Diversity ~ Depth + Rugosity	11.188	4.699
All Fish Diversity ~ % Rough Sub + Latitude + DFP	11.502	5.013
All Fish Diversity ~ % Rough Sub + Latitude + Rugosity + DFP	11.612	5.123
All Fish Diversity ~ % Rough Sub + Latitude	11.633	5.144
All Fish Diversity ~ % Rough Sub + Rugosity + Latitude	11.734	5.245
All Fish Diversity ~ Latitude	14.477	7.988

All Fish Shannon Diversity Model	AICc	ΔAICc
All Fish Diversity ~ Rugosity + Latitude + DFP	14.477	7.988
All Fish Diversity ~ Rugosity + Latitude	14.477	7.988
All Fish Diversity ~ Latitude + DFP	14.477	7.988
All Fish Diversity ~ % Rough Sub + Rugosity + DFP	24.658	18.168
All Fish Diversity ~ % Rough Sub + DFP	24.658	18.168
All Fish Diversity ~ % Rough Sub	27.649	21.159
All Fish Diversity ~ % Rough Sub + Rugosity	27.649	21.159
All Fish Diversity ~ DFP	28.834	22.345
All Fish Diversity ~ Rugosity + DFP	28.834	22.345
All Fish Diversity ~ Rugosity	32.422	25.933

J.

Rockfish Shannon Diversity Model	**AICc**	**ΔAICc**
Rockfish Diversity ~ % Rough Sub + Depth + Latitude + DFP	1.543	0.000
Rockfish Diversity ~ % Rough Sub + Depth + Latitude + Rugosity + DFP	1.762	0.219
Rockfish Diversity ~ % Rough Sub + Depth + Latitude	**2.429**	**0.885**
Rockfish Diversity ~ % Rough Sub + Depth + Rugosity + Latitude	2.429	0.885
Rockfish Diversity ~ % Rough Sub + Depth + DFP	4.061	2.518
Rockfish Diversity ~ % Rough Sub + Depth + Rugosity + DFP	4.061	2.518
Rockfish Diversity ~ % Rough Sub + Depth	4.063	2.520
Rockfish Diversity ~ % Rough Sub + Depth + Rugosity	4.063	2.520
Rockfish Diversity ~ Depth + Latitude	5.003	3.460
Rockfish Diversity ~ Depth + Rugosity + Latitude + DFP	5.003	3.460
Rockfish Diversity ~ Depth + Latitude + DFP	5.003	3.460
Rockfish Diversity ~ Depth + Rugosity + Latitude	5.003	3.460
Rockfish Diversity ~ Depth	5.886	4.343
Rockfish Diversity ~ Depth + Rugosity + DFP	5.886	4.343
Rockfish Diversity ~ Depth + Rugosity	5.886	4.343
Rockfish Diversity ~ Depth + DFP	5.886	4.343
Rockfish Diversity ~ % Rough Sub + Rugosity + Latitude	8.748	7.205
Rockfish Diversity ~ % Rough Sub + Latitude	8.877	7.333
Rockfish Diversity ~ % Rough Sub + Latitude + Rugosity + DFP	8.968	7.425
Rockfish Diversity ~ % Rough Sub + Latitude + DFP	9.089	7.546
Rockfish Diversity ~ Latitude	11.135	9.591

Rockfish Shannon Diversity Model	**AICc**	**ΔAICc**
Rockfish Diversity ~ Latitude + DFP	11.135	9.591
Rockfish Diversity ~ Rugosity + Latitude + DFP	11.135	9.591
Rockfish Diversity ~ Rugosity + Latitude	11.135	9.591
Rockfish Diversity ~ % Rough Sub + DFP	25.514	23.971
Rockfish Diversity ~ % Rough Sub + Rugosity + DFP	25.514	23.971
Rockfish Diversity ~ DFP	30.670	29.127
Rockfish Diversity ~ Rugosity + DFP	30.670	29.127
Rockfish Diversity ~ % Rough Sub	31.289	29.746
Rockfish Diversity ~ % Rough Sub + Rugosity	31.289	29.746
Rockfish Diversity ~ Rugosity	36.397	34.854

K.

All Fish Richness Model	**AICc**	**ΔAICc**
All Fish Richness ~ Depth + DFP	**95.103**	**0.000**
All Fish Richness ~ Depth + Latitude + DFP	95.103	3.782E-08
All Fish Richness ~ % Rough Sub + Depth + Latitude + DFP	95.121	0.018
All Fish Richness ~ % Rough Sub + Depth + DFP	95.121	0.018
All Fish Richness ~ % Rough Sub + Depth + Latitude + Rugosity + DFP	95.348	0.245
All Fish Richness ~ % Rough Sub + Depth + Rugosity + DFP	95.348	0.245
All Fish Richness ~ Depth + Rugosity + DFP	97.733	2.630
All Fish Richness ~ Depth + Rugosity + Latitude + DFP	97.753	2.650
All Fish Richness ~ Depth + Rugosity + Latitude	97.769	2.666
All Fish Richness ~ % Rough Sub + Depth + Rugosity + Latitude	97.769	2.666
All Fish Richness ~ Depth + Rugosity	97.769	2.666
All Fish Richness ~ % Rough Sub + Depth + Rugosity	97.769	2.666
All Fish Richness ~ % Rough Sub + Latitude + DFP	97.839	2.735
All Fish Richness ~ % Rough Sub + Depth + Latitude	101.031	5.928
All Fish Richness ~ Depth + Latitude	101.287	6.184
All Fish Richness ~ % Rough Sub + Depth	102.308	7.205
All Fish Richness ~ Depth	102.484	7.380
All Fish Richness ~ % Rough Sub + Latitude + Rugosity + DFP	104.706	9.603
All Fish Richness ~ Rugosity + Latitude	104.706	9.603
All Fish Richness ~ Rugosity + Latitude + DFP	104.706	9.603
All Fish Richness ~ % Rough Sub + Rugosity + Latitude	104.706	9.603

All Fish Richness Model	AICc	ΔAICc
All Fish Richness ~ Latitude	105.214	10.110
All Fish Richness ~ Latitude + DFP	105.214	10.110
All Fish Richness ~ % Rough Sub + Latitude	105.214	10.110
All Fish Richness ~ % Rough Sub + Rugosity + DFP	114.285	19.182
All Fish Richness ~ % Rough Sub + DFP	115.204	20.101
All Fish Richness ~ Rugosity + DFP	116.430	21.327
All Fish Richness ~ DFP	116.579	21.476
All Fish Richness ~ % Rough Sub + Rugosity	121.976	26.873
All Fish Richness ~ Rugosity	122.503	27.399
All Fish Richness ~ % Rough Sub	124.712	29.609

L.

Rockfish Richness Model	AICc	ΔAICc
Rockfish Richness ~ % Rough Sub + Depth + DFP	92.352	0.000
Rockfish Richness ~ Depth + DFP	92.352	2.314E-07
Rockfish Richness ~ % Rough Sub + Depth + Latitude + DFP	92.352	2.574E-07
Rockfish Richness ~ % Rough Sub + Depth + Latitude + Rugosity + DFP	92.352	2.591E-07
Rockfish Richness ~ Depth + Latitude + DFP	92.352	2.603E-07
Rockfish Richness ~ Depth + Rugosity + DFP	92.352	2.604E-07
Rockfish Richness ~ Depth + Rugosity + Latitude + DFP	92.352	2.604E-07
Rockfish Richness ~ % Rough Sub + Depth + Rugosity + DFP	92.352	2.604E-07
Rockfish Richness ~ Depth + Rugosity + Latitude	99.452	7.100
Rockfish Richness ~ % Rough Sub + Depth + Rugosity + Latitude	99.452	7.100
Rockfish Richness ~ Depth + Rugosity	99.926	7.573
Rockfish Richness ~ % Rough Sub + Depth + Rugosity	99.926	7.573
Rockfish Richness ~ Latitude + DFP	101.147	8.795
Rockfish Richness ~ % Rough Sub + Latitude + DFP	101.147	8.795
Rockfish Richness ~ Depth + Latitude	103.554	11.201
Rockfish Richness ~ % Rough Sub + Depth + Latitude	103.588	11.236
Rockfish Richness ~ % Rough Sub + Depth	107.074	14.722
Rockfish Richness ~ Depth	107.074	14.722
Rockfish Richness ~ Rugosity + Latitude	109.994	17.642
Rockfish Richness ~ % Rough Sub + Rugosity + Latitude	109.994	17.642
Rockfish Richness ~ % Rough Sub + Latitude + Rugosity + DFP	109.994	17.642
Rockfish Richness ~ Rugosity + Latitude + DFP	109.994	17.642
Rockfish Richness ~ Latitude	110.890	18.538

Rockfish Richness Model	AICc	ΔAICc
Rockfish Richness ~ % Rough Sub + Latitude	110.890	18.538
Rockfish Richness ~ % Rough Sub + DFP	118.625	26.272
Rockfish Richness ~ % Rough Sub + Rugosity + DFP	118.625	26.272
Rockfish Richness ~ DFP	118.909	26.557
Rockfish Richness ~ Rugosity + DFP	118.941	26.589
Rockfish Richness ~ % Rough Sub + Rugosity	124.403	32.050
Rockfish Richness ~ Rugosity	124.423	32.070
Rockfish Richness ~ % Rough Sub	129.118	36.765