Methods to incorporate known habitat in indices of abundance for rocky reef associated species and applications to management

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Abstract

Indices of abundance developed from fishery-dependent data are typically subject to a number of assumptions about the area and habitat fished due to the aggreation of the catch at the level of a fishing trip.

In California, two surveys occur onboard the recreational charter boats fleet and samplers record location-specific data on the catch and effort during individual fishing f stops throughout a trip. This location specific information coupled with high-resolution maps of the bottom substrate allowed us to subset the survey data to areas of rocky reef habitat. The six species of rockfish (*Sebastes* spp.) modeled in this paper as example all have high affinity to rocky habitat. We compared the indices of abundance developed with and without including information on rocky reef habitat. The identification of the rocky reefs also allowed us to weight the index of abundance by the area of available habitat with predefined regions. We show that in general the finer scale trends are variable and weighting the indices by the amount of habitat within finer scale area decrease the variance around the estimates.

We also show how the estimates of available habitat can be used to portion catches across management areas.

Keywords: fisheries dependent data, habitat association, groundfish, index of abundance

1. Introduction

Information on the known area of available habitat provides unique opportunities for incorporation into the data processing of stock assessments and management decisions. We present methods and examples for incorporating the area of available habitat for reef-associated species within indices of abundance for stock assessments and allocation of yield for management decisions.

It is not often the case where high-resolution habitat data and fishing location information are both available, and for many fishery-dependent surveys an analyst will have to determine which subset of the data to use based on available information. The availability of a 20+ year time series of onboard observer data from California CPFVs, coupled with high-resolution habitat maps of rocky reef habitat, provides us with an opportunity to evaluate the effectiveness of the Stephens-MacCall method and compare standardized indices of abundance derived from data sets that differ in terms of spatial and temporal resolution.

One of the major recreational targets in California are groundfish species, a group of which includes dozens of rockfish species (*Sebastes spp.*). Rockfish species' affinity to rocky habitat

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differs by species and ranges from the territorial gopher rockfish (*S. carnatus*) that resides within rocky crevices and maintains small home ranges of less than $20m^2$ (Larson, 1980), to a the schooling, mid-water black rockfish (*S. melanops*) that haa an average home range of $0.25km^2$, and exhibits diurnal movement offshore (**?**). Tagged black rockfish have also been recovered hundreds of miles from the initial capture location (California Collaborative Fisheries Research Program, unpublished data). The association of *Sebastes* with rocky habitat makes them ideal candidates for exploring the ability to predict effective effort from fishery-dependent data based on known habitat. In addition, the area of known rocky reef habitat data creates an opportunity to weight the index of abundance by the calculated area of rocky reef habitat along the California coast.

Indices of abundance are commonly used to provide a stock assessment model with information about the stock's trend over time (Harley et al., 2001; Hilborn and Walters, 1992). For many fish stocks, only fishery-dependent survey data are available. Fishery-dependent survey data are more readily available than fishery-independent scientific survey data due to factors including the lower cost to collect data, more frequent sampling opportunities, and ability to collect data at large spatial scales where the fisheries operate.

Modelling fishery-dependent data requires making a number of assumptions due to the nature of the data being reliant on the behavior of the fishing fleet. A common metric for modelling fishery-dependent data is catch per unit effort (CPUE), which is often used under the assumption that the estimated trends are proportional to the true abundance of the stock (Maunder and Punt, 2004). However, catch rates are more likely to reflect local densities than total abundance (Haggarty and King, 2006; ?), in which case standardized trends in CPUE (relative density) should be multiplied by habitat area, when available, to estimate trends in relative abundance. Additionally, fishery-dependent data are reliant on the behavior of the fishermen and must be standardized to account for spatial and temporal changes in fishing activity (Campbell, 2015a; Hilborn and Walters, 1992).

An analyst must also consider factors such as the targeting of multiple species when developing an index of abundance. The recreational for-hire partyboat fleet may target multiple species during a trip. The target species for a recreational trip is dependent on a number of factors including weather that could limit transit to some fishing grounds, bag limit regulations, angler preference and experience, duration of the trip, and the captain's experience level. All of these factors affect the catch during a trip. For example, a recreational trip in California, USA may set out to target a particular rockfish (*Sebastes spp.*) species associated with hard substrate, but if fishing is unsuccessful or if bag limits are reached, the captain may spend a portion of the trip targeting sanddab species (*Citharichthys spp*) that inhabit areas of soft substrate.

Therefore, an analyst must determine which samples within a survey represent the effective effort directed towards the target species. The granularity of the calculation of fishing effort is dependent on the survey. A survey that interviews an angler or group of anglers at the dock or pier after the fishing trip concludes provides fishing effort at the level angler-days or angler hours. On the opposite end of the spectrum is an onboard observer survey (onboard survey) where a sampler rides along during a trip and records information on the catch and effort, often from a subset of anglers, at every fishing location during the trip. For these data, both temporal resolution (trip vs. drift) and spatial resolution (location of landing vs. location of fishing) are improved.

Here we focus on data available from fishery-dependent onboard observer surveys of California's recreational partyboat fleet, also referred to as commercial passenger fishing vessels (CPFV). The onboard observer data provide an opportunity to explore what information we gain from explicit knowledge of fishing locations. There are two surveys of the California recreational CPFV fleet (Monk et al., 2014). The California Department of Fish and Wildlife (CDFW) surveys active ports throughout the state and the California Polytechnic State University San Luis Obispo (Cal Poly) surveys vessels with home ports in San Luis Obispo County. In addition, we are able to utilize high resolution bathymetric data to define appropriate habitat for a target species.

We utilized the onboard survey data to create develop methods that account for the available habitat within fine scale areas. We utilized the fishing drift level data with known location from the onboard observer surveys and subset data based on the proximity to rocky reef habitat. For this data set we also evaluated the effect of weighting by reef habitat area. We applied these methods across six nearshore rockfish species with different life histories, habitat preferences and commonness in the data.

Stock assessment models estimate an Overfishing Limit (OFL) for a single stock or a subarea of a stock. On the West Coast of the U.S., the Pacific Fishery Management Councils currently manages the nearshore rockfish complex based on their depth distributions and at a biogeographic break near Cape Mendocino, California (40 10), which means the yield produced in California is divided into two separate management areas.

found in the waters off California are typically modelled recognizing the biogeographic and CDFW management breaks at Point Conception and Cape Mendocino (reference map). Fisheries data are collected independently by each state (Washignton, Oregon, and California) on the fisheries in the waters off their respective coasts. Stock assessment boundaries may be drawn at political boundaries and not at the management boundaries. This creates a question on how to divide the OFL between areas.

We applied weights to sub-areas of habitat across California for and also calculated the amount of available habitat within and outside California's network of Marine Protected Areas to account for the area within the area open and closed to fishing from a fishery-independent survey. The amount of availale habitat by management areas that do not align with the spatial extent of a stock structure allowed us to decompose the Annual Catch Limit (ACL) by management area.

We utilized two data sets, one fishery-independent an one fishery-dependent that represent two methods of incorporating known habitat data in the development of indices of abundance. The fihsery-dependent data source is a combination of a CDFW and Cal Poly surveys of the recreational CPFV fleet that fishes with hook-and-line and targets groundfish species. The fishery-independent data source is an MPA monitoring survey along the central coast of California, the California Collaborative Fisheries Reserach Program (CCFRP). The CCFRP expanded to cover additional monitoring areas in 2017, but we limit the the data in this paper to the core sampling area. The incorportaion of habitat data is made possible by the California Seafloor Mapping Program (CSMP) that collected bathymetry and interpretted the data for nearly all of California's state waters.

A number of methods are currently used to allocate an OFL with the stock boundary does not align with a management boundary. Allocation of the OFL could, ideally, be based on a fishery-independent survey of abundance, but lacking that information several alternatives exist. Previous allocations have used catch as a proxy for abundance when no other information was available (Dick and MacCall, 2010; Dick et al. 2011). Allocation of the OFL proportional to catch works if the catch is proportional to biomass, which is unlikely in many cases. Allocation based on catch may also allocate catch to areas where harvest excedes the OFL. When fishery-independent survey data are avaialble allocation can be based on estimates of survey biomass. This requires that the survey covers the entire area of the stock assessment, which is not often the case.

Copper rockfish (*Sebastes caurinus*) is a nearshore species ranging from northern Baja Mexico to the Gulf of Alaska. They inhabit sub-tidal depths as junveile as juveniles and are commonly encountered in depths up to 180 m as adults(Love et al., 2002; **?**). Copper rockfish prefer low-relief rocky habitat and have high site fidelity. These characteristics make copper rockfish an ideal species to illustrate the benefits of incorporating known habitat. Additional examples and more details on each of the datasets we utlize are available in a number of groundfish stock assessments (cite assessments).

keep or remove? We also examined the assumption that effort might be pro-

portional to reef area by obtaining effort estimates for the CPFV trips (cite RecFIN) and comparing the area of rocky reef habitat to the effort in each region.

2. Methods

We present methods to define areas of rocky habitat within California's state waters. We then describe how the known habitat allows us to filter fishery-dependent data with known fishing locations and comparisons of indices of abundance with and without accounting the area of known habitat. Using a fishery-independent survey that monitors California's network of marine protected areas we demonstrate the ability to account for closed areas in an index of abundance. Lastly, we present and compare four methods for allocating yield with and without consideration of available habitat.

2.1. Mapping and Identification of Rocky Reefs

We predicted rocky reef habitat using high resolution seafloor mapping of California state waters (out ot 3nm) north of Point Conception California (34.45). The California Seafloor Mapping Project (CSMP) collected bathymetry and backscatter data collected from 20xx to 20xx (Golden, 2013; Bay, 2014). The CSMP mapped the mainland California state waters at a 2 m resolution from the California-Mexico border to the California-Oregon border. The mapped area does not include very shallow areas close to shore (the "white zone"), which extend approximately 200-500 m from the shoreline. Maps of the white zone are not yet available and we assume proportionality in the area of habitat in the white zone and the mapped area.

We created a mosaic from 137 CSMP substrate blocks that ranged in size from 16 km^2 to more than 400 km^2. The CSMP identified rough and smooth substrates, surface:planar area, and a vector ruggedness measure (VRM) of the bathymetric digital elevation model [#fig-map2]. The CSMP set a varying VRM threshold for each of the substrate blocks, removed any artifacts, and the product is considered a conservative estimate of rough habitat.

We converted the digital mosaic of 137 CSMP substrate raster blocks with pixels designated as rough habitat (our rocky reef habitat proxy) from a raster format to polygons. We applied a 5 m buffer region around the rough habitat polygon to allow for any small errors in positional accuracy. Contiguous polygons of rocky reef substrate were treated as a single rocky reef, regardless of size. Polygons separated by 200 m were treated as separate reefs; the 200 m cutoff is based upon expert knowledge and a consensus that it represented a distance that most rockfish species would traverse over sandy habitat. We calculated the area of each reef defined and retained those greater than or equal to 100m^2. We conducted all spatial analyses and overlay of the data sources on the rocky reef habitat in ArcMap 10.3 (ESRI citation).

The data in this paper included only areas north of Point Conception ($34°27'N$) due to gaps in the bathymetric layers to interpret habitat coverage further south. Point Conception is a significant biogeographic boundary (Valentine (1966)), and the composition of the fish communities in southern California differ, potentially reducing the effectiveness of methods that rely on species associations, such as the method of Stephens and MacCall (Stephens and MacCall (2004)). The recreational fisheries south of Point Conception are also fundamentally different, with a higher percentage of CPFV trips targeting mixed species and pelagic and highly migratory species. The availability of accessible rocky habitat in southern California is also less in the southern California nearshore areas compared to northern California.

2.2. Fishery-Dependent Onboard Observer Survey

The CDFW began a fishery-dependent onboard observer survey of the recreational CPFV fleet in 1999. In 2004, the CDFW integrated it into their California Recreational Fisheries Survey (CFRS), designed to estimate catch and effort. In response to a request from the fishing industry, Cal Poly San Luis Obispo began a supplemental onboard observer survey in 2001 of the CPFV fleet based in Port Avila and Port San Luis along California's Central Coast [#fig-map]. Both the CDFW and the Cal Poly onboard observer surveys continue through present day. Management of California's recreational fisheries is complex and has undergone spatial and temporal changes since 1999. Between 1999 and 2003, the recreational regulations evolved from no restriction on the number of lines or hooks an angler could deploy to a one line and two-hook maximum, as well as implementation of depth restrictions that vary across the coast. Subsequent management and recovery of overfished species allowed a relaxation of depth restrictions beginning in 2017 that shifted fishing effort relative to the 2004-2016 period (Monk et al.).

The National Marine Fishery Service's Southwest Fisheries Science Center (SWFSC) developed a relational database for the CDFW onboard observer survey (2014) for the years 1999-2011 and is updated annually with data from the CDFW. The Cal Poly data are also provided to the SWFSC annually. All data were checked for potential errors at the drift-level by SWFSC staff. The data sets were filtered for errors within the relational database before analyses were conducted, and the data used here reflect changes from the QA/QC process that may not be reflected in the raw data available directly from the CDFW.

While only a small portion of the total CPFV trips taken are sampled as part of the onboard observer survey, the onboard observer survey collects a large amount of data during each trip. During each trip the sampler records information for each fishing drift, defined as a period starting when the captain announces "lines down" to when the captain instructs anglers to reel their lines up. Just prior to the start of each fishing drift, the sampler selects a subset of anglers to observe, at a maximum of 15 anglers per drift. The sampler records all fish encountered (retained and discarded) by the subset of anglers as a group, i.e., catch cannot be attributed to an individual angler. Samplers also record the start and end times of a drift, location of the fishing drift (start latitude/longitude and for most drifts, end latitude/longitude), and minimum and maximum bottom depth. Fish encountered by the group of observed anglers are recorded as either retained or discarded. This provides information on the catch (count of each species) and effort (time and number of anglers fished) during each fishing drift. While both surveys include records of discarded fish, we only used the retained catch in these analyses. Discarded fish can often represent a different size structure than retained fish, either due to size limits or angler preference, or represent fish encountered during a temporal or spatial closure.

We assigned survey locations to rocky reefs based on the recorded start location of a drift, given that the end locations were not always recorded. We calculated the cumulative distribution of distance to rocky reef (in meters) for drifts that retained copper rockfish with a distance cutoff of 90%. We applied further data filters to address possible errors in the data. We removed drifts in the upper and lower 1% of the recorded time fished and recorded observed anglers, as these may not accurately define a successful fishing drift or may represent data entry errors. Similarly, we filtered the data to retain 99% of all drifts based on average drift depth. We calculated average depth from the recorded minimum and maximum depths when available or the imputed minimum and maximum depth from the bathymetry layer described below.

2.3. Fishery-Independent MPA Monitoring Survey

The California Collaborative Fisheries Research Program (CCFRP) is a fishery-independent hook-and-line survey designed to monitor nearshore fish populations at a series of sampling locations both inside and adjacent to MPAs (**??**). The CCFRP survey began in 2007 along the central coast of California and was designed in collaboration with academics, NMFS scientists and fishermen. From 2007-2016 the CCFRP project was focused on the central California coast, and has monitored four MPAs consistently. In 2017, the CCFRP expanded coastwide within California. The index of abundance was developed from the four MPAs sampled consistently (Año Nuevo and Point Lobos by Moss Landing Marine Labs; Point Buchon and Piedras Blancas by Cal Poly).

The survey design for CCFRP consists 500 x 500 m cells both within and adjacent to each MPA. On any given survey day site cells are randomly selected within a stratum (MPA and/or reference cells). CPFVs are chartered for the survey and the fishing captain is allowed to search within the cell for a fishing location. During a sampling event, each cell is fished for a total of 30-45 minutes by volunteer anglers. Each fish encountered is recorded, measured, and released (or descended to depth) and can later be linked back to a particular angler. The CCFRP samples shallower depths to avoid barotrauma-induced mortality. Starting in 2017, a subset of fish have been retained to collect otoliths and fin clips that provide needed biological information for nearshore species. For the index of abundance, CPUE was modeled at the level of the drift, similar to the fishery-dependent onboard observer survey described above. The CCFRP data are quality controlled at the time data were entered by each project partner.

2.4. Indices of Abundance

We generated standardized indices of abundance for copper rockfish from the fishery-dependent onboard observer data and the fishery-independent CCFRP data. For each, we developed an index wihout any habitat weighting and one that weighted the the index by the amount of available habitat. We modeled all indices using Bayesian generalized linear models (GLMs) and the delta GLM method (Lo et al., 1992; Stefánsson, 1996). The delta GLM method is commonly used to standardize catch per unit effort for stock assessments [citations]. The delta method models the data with two separate GLMs; one for the probability of encountering the species of interest using a binomial likelihood and a logit link function, and the second GLM for the positive encounters assuming either a gamma or lognormal error structure. The error structure of the positive model was selected via the Akaike Information Criterion (AIC) from models with the full suite of considered explanatory variables.

The response variable for the positive models was angler-retained catch per unit effort. The full suite explanatory variables modeled and model selection processes can be found in the supplemental material. Year was always included in as an explanatory variable in model selection, even if it was not significant, because the goal of the index of abundance was to extract the year effect. The area-weighted index included a year/rocky reef interaction term, even if it was not statistically significant, to allow us to weight the index by the area of rocky reef.

Model selection for the binomial and positive observation models was based on AIC using the lme4 package in R, and unless very different predictors were selected, the same predictors were used in each of the two Bayesian models. The Bayesian models were run with 5,000 iterations and weakly informative priors. Posterior predictive model checks were examined for both the binomial and positive observation models, including the predicted percent positive compared to the maximum likelihood estimates. We constructed the unweighted annual index by multiplying the back-transformed posterior draws from the year coefficients from the binomial model by the exponentiated positive model draws from the year coefficients, and taking the mean and standard deviation of the distribution of the product for each year.

The area-weighted, habitat-informed index was developed by extracting the posterior draws of the unweighted index, and then summing across the product of the back-transformed posteriors weighted by the fraction of total area within each reef. To compare the indices across the three data filtering methods and the area-weighted index, each index was scaled to its mean value.

2.5. Allocating Yield to Management Areas

We present four methods to allocate yield for copper rockfish at the management boundary near Cape Mendocino, California (40-10). These include mehtods referred to as catch-based, habitat-based, CPUE-only and habitat-weighted CPUE.

The catch-based method is derived using from the total estimated catch for the time period 2020-2022 (can change) north of Point Conception in California. The proportion north and south of Cape Mendocino equals the allocation of yield. For the habitat-based method, if we assume the average density of copper rockfish is constant over the assessed area (Point Conception to the California/Oregon border), the fraction of copper rockfish occurring north of Cape Mendocino would be equal to the fraction of habitat in the same area.

The assumption of equal density may not be accurate, and no direct estimates of density are available from a fishery-independent survey with adequate spatial coverage. We propose an alternative method that combines existing habitat information with a proxy for fish density, using catch per unit effort. Although data from the onboard CPFV observer surveys are more precise in terms of total catch, effort, and location, the sampling rate north of Cape Mendocino does not provide adequate data given the number of 6-pack vessels in northern California. Sampling coverage for the CRFS dockside survey is spatially more complete, in that numerous samples exist in the northern management area. Therefore used the private boat CPUE data to develop an index of abundance for the CPUE-only method, assuming CPUE is proportional to density. For the habitat-weighted CPUE method, we multiplied the area-specific CPUE estimates by the area of habitat to produce a spatial index of relative abundance. Data were filtered using the same methods detailed in the 2023 copper rockfish stock assessment for the CRFS private boat dockside index. We compare the allocations of yield among these four methods.

still from blue - but a placehold - Years prior to 2013 were subsequently dropped, to create an index that is representative of recent catch rates in each area. Sample sizes (number of trips) for the final data set are shown in Table D3.

3. Results

3.1. Survey Data and Rocky Reef Habitat

Prior to any filtering a total of 19,425 drifts that aggregated to 2,270 trips were available for the analyses. Approximately 21% of all the CPFV trips observed by CDFW from 2004-2016 occurred north of Point Conception. It is important to note that north of Bodega Bay, California, the majority of charter boats are smaller six-pack vessels that may not have the capacity to carry a sampler onboard. As a result, sample sizes in this part of the state are smaller than areas to the south. The addition of the Cal Poly onboard observer survey to the CDFW survey more than doubled the sample sizes of observed trips in San Luis Obispo County, with an average annual increase of 155% from 2004-2016.

From 2004-2016 the drift-level data contained a total of 19,425 fishing drifts, and after removing drifts with missing effort information (time fished and/or observed anglers), 19,180 drifts remained. The filter removing the upper and lower 1% of the time fished and number of observed anglers resulted in fishing drifts lasting between three and 96 minutes and three to 15 observed anglers, and reduced the data to 18,591 fishing drifts. The remaining data filter for depth resulted in a cutoff of 46.6 fathoms, and retained 18,405 drifts based on average drift depth. A filter on the minimum depth was not included here because the recreational fleet was not limited to a minimum fishing depth and all of the fishing drift locations were verified during the QA/QC process. In the final, filtered drift-level data set the average time fished was X minutes with a standard deviation (SD) of X. The average number of observed anglers was X (SD=X), and average estimated depth was X (SD=X).

We define 108 areas of rocky habitat within California state waters from the California/Oregon border to Point Conception. The two meter resolution of the substrate shows the patchiness and heterogeneity of the rocky substrate (Figure 1). We characterize rocky habitat using thresholds as determined by the CSMP (Bay (2014)). While the location-specific data from the fishing fleet is governed by confidentiality and cannot be displayed here, 85% of the fishing drifts were within 5 m of rocky habitat. The recreational fishing fleet's targeting of rockfish species was verified by the distributions of the distance from rocky habitat for each of the six species. The distance from rocky habitat cutoff (retaining 90% of drifts encountering each species) was six meters for blue, China and gopher rockfish, eight meters for vermilion rockfish, 14 meters for black rockfish and 16 meters for brown rockfish. The percentage of drifts and trips encountering the target species can be found in Table 2.

Based on exploratory analyses and consideration of the available data, we aggregated the areas of rocky habitat grouped into six regions to ensure adequate sample sizes for developing indices of abundance (Figure 2). While covering a small area (5% of the rocky habitat), the number of observed fishing drifts within state waters around the Farallon Islands off the coast of San Francisco was high enough to warrant keeping it as a separate area of rocky habitat. The region defined from the California/Oregon border to San Francisco encompasses 49% of the total rocky habitat in state waters by area, but only 12% of the observed drifts (2,637). Each of the four remaining regions of rocky habitat defined from San Francisco to Point Conception contained an average of 12% of the available habitat (Table X). The CDFW estimated fishing effort by management district, which does not exactly align with our areas of grouped reef habitat. Only considering the fishing effort north of Point Conception, CDFW estimated an average of 9% of the CPFV trips occurred from the California/Oregon border through Mendocino County, 38% from Sonoma through San Mateo County, and 53% from Santa Cruz to Point Conception.

The differences in latitudinal distribution of the six species is apparent from the maps of percent of positive observations (Figure 3). The distribution of black rockfish tapers off south of San Francisco, whereas percent of fishing drifts encountering vermilion, gopher, and blue rockfish are higher south of San Francisco. Brown rockfish is distributed across all of coastal California, with slightly higher encounter rates south of San Francisco and the percentage of drifts retaining China rockfish was low coastwide. The average CPUE was highest for blue rockfish between San Francisco south to Big Sur (Figure 4). The average CPUE for black rockfish average was higher in the north, while gopher rockfish CPUE was generally consistent across the coast, albeit slightly higher south of Big Sur. China rockfish CPUE catch was typically low coastwide, with slightly higher catch rates in the Farallon Island reefs.

The final aggregation of the reefs and total area within each region are found in Table 1. The fraction of drifts retained for the indices of abundance was high for all six species (80% or greater), indicating that fishing effort represented by these data occurred mainly near areas of rocky habitat.

3.2. Indices of Abundance

Model selection using AIC resulted in all but three of the 24 indices of relative abundance bineg modeled with a lognormal distribution for positive observations. The trip-level indices for black, blue and gopher rockfish were modeled using a gamma (refer to the supplementary material for AIC scores). All of the covariates (year, reef, and wave) were selected as main effects for both the binomial and positive models for all species in the habitat-informed drift level index. For instances where the wave. However, the difference in AIC relative to the best model (delta-AIC) was less than ten so we chose to maintain the model with year, reef and wave.

(LMK and I can put these in a table in the doc) The full model that included the reef:year interaction was selected by AIC for all species except for China rockfish. For China rockfish the positive binomial model selected the interaction covariate, but the model without the interaction was select for the positive lognormal model by an difference in AIC of 22. However, in order to look at the effects of the area-weighting on the index, we included the year:reef interaction in the final model for China rockfish.

For both the drift-level and trip-level Stephens-MacCall filtered data, year, county and wave were selected for black rockfish, blue rockfish, gopher rockfish, and vermilion rockfish and the drift-level index for brown rockfish. The model incorporate in year and county was selected for the trip-level Stephens-MacCall filtered index for brown rockfish and both Stephens-MacCall filtered indices for China rockfish.

In general, the larger increases and decreases in the indices were similar among the four indices developed for each species (Figure 6). The generalized approach used in this paper to create indices with comparable methods resulted in different results for each species. The area-weighted indices are reflective of the total available habitat and use all of the available high resolution habitat and fishing drift data. However, differences among the four indices were different for each species. The average CVs between the drift-level area-weighted index and the drift-level habitat informed indices were similar, as expected, since they both used the same data with the only difference being the year:area interaction in the models (Table 3). However, the average CV between drift-level habitat-informed filtering and Stephens-MacCall filtering for the drift-level data differed by species.

The area-weighting for black rockfish, a species distributed predominantly north of Santa Cruz, California did have an effect on the index for a number of years, most notably in 2013 where the area-weighted estimate is lower than all three other indices(Figure 6a). The effect of the area-weighting is also apparent for black rockfish in 2005, 2007, and 2009.The average CV decreased from the trip-level index (0.671) to to the area-weighted index (0.443).

Interestingly, the average CV was lowest overall for the drift-level Stephens-MacCall index (0.364) which also modeled much smaller data with a high proportion of positive catches of black rockfish (Table 2).

Blue rockfish is ubiquitous across the study area and was one of the two species for which the index was weighted by the six regions of rocky reef habitat. The area-weighted index differs from the other three in 2006 with an estimated higher relative abundance and in 2014 with an estimated lower relative abundance. Even during the years from 2009 to 2012 when the estimated relative abundance was low for all of the indices, there were differences among the four trends with the drift-level habitat-informed index estimating the lowest relative abundance.

All four indices for brown rockfish suggested differing trends, with this species having the highest estimated error for both the trip-level and drift-level Stephens-MacCall filtered data (Figure 6c). In ten of the years the area-weighted index estimated a either the largest or smallest relative abundance compared to the other indices. For brown rockfish the two habitat-informed indices were more similar than the Stephens-MacCall filtered data. The average CV for brown rockfish from the Stephens-MacCall filtering was large (0.679) compared to the habitat informed filtering (0.142).

China rockfish is the only species for which the trip-level Stephens-MacCall filtered index had the lowest average coefficient of variation that increased with the habitat-informed filtering (Table 3). Although the trends among the four indices were similar, this is the only species for which the highest error was consistently estimated for both habitat-informed drift-level indices (Figure 6d). China rockfish is one of the less common species observed in the data with the highest average CPUE from catches the Farallon Islands, which is an overall small percentage of the total habitat (Table 1).

The observed trends for gopher rockfish were similar among all indices and the trip-level Stephens-MacCall index had the highest average CV (0.626) compared to the average CVs of less than two from all of the other drift-level indices. China rockfish is the only species for which the trip-level index had the lowest average coefficient of variation, which increased with the habitat-informed filtering . For all other species, the habitat-informed filtering resulted indices with a lower average CV than the trip-level filtering.

The indices of relative abundance for vermilion rockfish were relatively similar in trends across the time series (Figure 6f). Vermilion rockfish is the second species for which all six areas of rocky reef habitat remained dis-aggregated in the models. For vermilion rockfish, while the trends are similar among all four indices, the effect of area-weighting dampens the increase modeled from the habitat-informed drift level data from 2004-2006, where the area-weighting down-weighted the relative abundance from the drift-level habitat informed index.

3.3. Allocation of Yield

4. Discussion

Fishery-dependent indices of abundance will continue to be incorporated in fisheries stock assessments. We demonstrated the effects of subsetting fishery-dependent survey data to samples representing effective effort at varying levels of data resolution. The estimated indices of abundance illustrated the changes in trends and variance to create a subset of samples representing the effective effort for a target species, and how that selection affected the trends in indices of relative abundance. The combination of fine-scale CPUE data coupled with the available habitat data creates allows us to model an index of relative density, rather than abundance. The fishery-dependent onboard observer survey conducted by CDFW and Cal Poly is a benchmark recreational fishery-dependent time series. The survey provides many elements that would usually only be collected from research surveys, including fishing locations, fishing depth, time fished, and speciated catch and discard information, and currently has over a 20 year time series.

We also demonstrated that the habitat-informed data filtering provides a method to select samples with effective fishing reduces the subject decision points required when filtering multispecies data by utilizing known habitat characteristics. This also allows us to create an area-weighted index that accounts for variable species density along the coast. This not only addressed a key assumption of identifying effective fishing effort for a multispecies fishery, but also appropriately weights the sample data based on the known area of habitat.

The addition of habitat information a The Stephens-MacCall filtering method has several subjective decision points, including which species to include in the analysis, the threshold to determine which samples to retain or remove, and the spatial extent of data to include. The Stephens-MacCall filter is useful in identifying co-occurring or non-occurring species, but it assumes all effort was exerted in pursuit of a single target species. Stephens-MacCall filtering is most often used for data collected at the trip-level in the absence of known fishing locations. If more than one species or species complex was targeted during a trip it can result in co-occurrence of species in the trip-level catch that do not truly co-occur. This was clearly shown in the differences between the trip-level Stephens-MacCall filtering and the drift-level Stephens-MacCall filtering that reflects species co-occurrence at a finer scale. If the fishing drifts covered small enough areas the Stephens-MacCall filter at the drift-level inherently contains information on habitat preferences and community structure.

The choice of a threshold value to use from the Stephen-MacCall method has been a topic explored within stock assessments for both commercial and recreational data (Dettloff (2021); Cope et al. (2015);Ducharme-Barth et al. (2018)). There is currently no guidance on best practices for the decision points in the Stephens-MacCall method that may lead to additional bias in data selection. For instance, all of the observations in the onboard observer survey are recorded by trained samplers who are assumed to correctly identify species. With this assumption, we retained all of the samples observing the target species regardless of the probability estimated from the Stephens-MacCall model. The drift-level habitat informed data retained a larger number of drifts than the drift-level Stephens-MacCall filtered data, as a result of the majority of drifts occurring over hard bottom habitat. However, one caveat of the rocky reef habitat data is that there is currenlty only a binomial classification of hard and soft substrate available, and we assume that all rocky habitat is suitable habitat. We know from the variability in rugosity and relief displayed in Figure (Figure 1) that these characteristics can change at small spatial scales. The *Sebastes spp.* complex north of Point

Conception have differential hard bottom preferences, which have been verified by visual surveys (Laidig et al. (2009); Anderson and Yoklavich (2007); Haggarty and King (2006)) and from discussions with experienced fishermen.

Based on the current practice of retaining the false positives within the Stephens-MacCall method as described in the methods section, the trip-level data are prone to overestimate fishing effort for the less common species, and result in larger variances in the indices of abundance. Looking at the number of trips selected between the drift-level Stephens-MacCall filter and the habitat-informed filter, the Stephens-MacCall filter (based on the retention of the false negatives) may exclude too many samples that fished in the appropriate habitat, but did not meet the probability threshold (Table 2). Looking at the number of trips selected between the drift-level Stephens-MacCall filter and the habitat-informed filter, the Stephens-MacCall filter (based on the retention of the false negatives) may exclude too many samples that fished in the appropriate habitat, but did not meet the probability threshold (Table 2). The Stephens-MacCall filter may be over-selecting samples where the species was not observed if the target species is less common, e.g., China rockfish, but has a strong positive co-occurrence with a more common midwater, schooling species, e.g., blue rockfish. China rockfish in particular have a heterogenous distribution with an affinity to high relief habitat (Love et al. (2002)). The Stephens-MacCall filter may be over-selecting samples where the species was not observed if the target species is less common, e.g., China rockfish, but has a strong positive co-occurrence with a more ubiquitous species, e.g., blue rockfish. For a ubiquitous species like vermilion rockfish, the Stephens-MacCall drift-level data included 51% fewer drifts than the habitat-informed data, and for the less common China rockfish, 84% fewer total samples. The Stephens-MacCall method applied at the drift-level provides insight into the fine-scale species associations, but may also reflect targetting of species that are more common or schooling. The integration of the habitat data with the onboard observer fishing drift locations provides the most accurate information for filtering the survey data. The differences between the drift-level Stephens-MacCall filtered data and the habitat-informed filter illustrate what may represent the habitat preference of individual species.

Areas of rocky habitat that were well fished and never observed the target species should be investigated to determine if the appropriate habitat exists in that area, or if other factors such as historical fishing pressure explain the lack of target species catch. The suite of six species that we modeled in this paper is a concrete example of why habitat is important and also varies among the species. The high proportion of retained drifts across species when using habitat as a data filter indicates that hate majority of drifts occurred over, or very close to, rocky habitat. Both blue and black rockfish have high affinity to rocky habitat, but occur higher off the bottom and are both schooling species. It is not uncommon to have a fishing drift dominated by blue rockfish in central California, or black rockfish further north. However, the Stephen-MacCall approach does not account for this by modeling presence/absence. Additional factors such as latitude could be included in the logistic regression to inform the Stephens-MacCall model.

The majority of groundfish species targeted by the CPFV fleet north of Point Conception during the time period of this study all have high associations to rocky habitat. In this case, the Stephens-MacCall method can be considered a proxy for habitat when the species of interest has known associations. This can be expanded in areas where trips are known to target species of interest, but no habitat data are available the proportion of trips encountering the target species could be used as a proxy for habitat.

The differences observed in the indices of abundance and knowledge of species-specific habitat preference will allow us to fine-tune these indices on a species-specific basis. The characteristics and classification of the rocky reef habitat into more specific substrate types, e.g., boulder vs pinnacle, are currently only available for a small fraction of the mapped area. Therefore, all areas of rocky substrate are currently created equal. A number of video surveys have shown habitat associations differ by species (Love et al., 2002), and the weights applied as available habitat may vary by species and be lower than the weights used in this paper. Although we did not exclude data based on the species' distributions from the indices developed here, the habitat-informed filters also allow an analyst to subset the data and exclude areas of rocky reef habitat outside of the species' range. For instance, black rockfish have been observed as far south as Point Conception, but their distribution tapers off south of Santa Cruz, California.

Fishery-dependent indices of abundance undergo higher levels of scrutiny during stock assessment reviews due to the nature of the data being driven by angler behavior. Catch from the recreational CPFV fishery is dependent on a number of factors including weather, distance from port, the clientele preferences, angler experience and captain's knowledge.

These models also do not account for distance to the nearest port, which has been shown to significantly impact the access to fish as well as historical fishing pressure (Miller et al., 2014). There are additional key assumptions made when using the onboard observer data in a stock assessment, including that fishing behavior remains the same when samplers are not onboard the vessel.

Catch from the recreational CPFV fishery is dependent on a number of factors including weather, distance from port, the clientele preferences, angler experience and captain's knowledge. These models also do not account for distance to the nearest port, which has been shown to significantly impact the access to fish as well as historical fishing pressure. Recent studies have identified the need to investigate the assumptions and uncertainty in relative indices of abundance from visual surveys (Bacheler et al., 2015; Campbell, 2015b) and simulation studies (Siegfried et al., 2016), and the same holds true for fishery-dependent surveys like the onboard observer survey. To address the potential bias in angling data for groundfish species, Haggarty and King (2006) conducted a SCUBA dive survey followed by a research angling survey directly above the dive plots and found a strictly proportional relationship between the density estimated from the SCUBA survey and CPUE from the angling survey for copper rockfish, a species whose habitat and depth distribution were well covered by the survey. Further analyses are underway to explore the fine-scale habitat characteristics to fine-tune the habitat informed data selection methods. We also plan to explore changes in fishing behavior related to management measures and and fisher behavior to explain shifts among target species or how large recruitment events for one species may affect the index of abundance for another species. While not all of these factors can be controlled for, defining the samples with effective effort will provide the most accurate index and appropriate variance for stock assessments.

removed: However, they found no relationship between SCUBA dive survey data and the angling survey for kelp greenling (*Hexagrammos decagrammus*), which the authors hypothesized was due to the greenling's avoidance of the bait used.

removed: Further analyses are underway to explore the fine-scale habitat characteristics that will allow the methods described in this paper to be fine-tuned. We also plan to explore changes in fishing behavior related to management measures and and fisher behavior to explain shifts among target species or how large recruitment events for one species may affect the index of abundance for another species. removed: This does not hold for areas where multiple species complexes are targeted on same trip, e.g, a multi-day trip may target large pelagic species and once trip limits are reached, the trip may focus on a secondary target, which is the case for the California CPFV fleet fishing south of Point Conception.

removed: An additional source of bias in fishery-dependent data is the change in regulation over time. These can be bag limits, minimum size restrictions, and area closures that the change of available habitat. Depth restrictions have also been in place for the recreational fleet since the early 2000s, which were relaxed in 2017 and was the reason we constrained the years modeled for this study.

removed: Versions of the drift-level habitat-informed indices were approved by the Pacific Fisheries Management Council's Science and Statistical Committee for use in the 2013 stock assessments and have been used in the stock assessment process since. Comparisons should not be drawn between the indices presented here and the stock assessment documents as the indices in this paper were simplified to develop direct comparisons among methods. When filtering and modeling the onboard observer data for a stock assessment, additional filtering steps would be taken, such as excluding areas where species are rare, e.g., south of Santa Cruz for black rockfish, inclusion of depth as a covariate in the index of abundance, and an exploration of alternative error distributions.

removed: Another example is closures and retraction of the available habitat open to fishing. California developed a network of Marine Protected Areas (MPAs) in 2007, that reduced the available rocky reef habitat to the recreational fleet by approximately 23% in state waters north of Point Conception.

5. Acknowledgements

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Data attribution: CDFW acquires data from its own fisheries management activities and from mandatory reporting requirements on the commercial and recreational fishery pursuant to the Fish and Game Code and the California Code of Regulations. These data are constantly being updated, and data sets are constantly modified. CDFW may provide data upon request, but, unless otherwise stated, does not endorse any particular analytical methods, interpretations, or conclusions based upon the data it provides.

6. Tables

Table 1: Area of rocky habitat in state waters aggregated to the levels modelled for each species. The merged cells for each species indicate which areas of rocky habitat were aggregated to ensure appropriate samples sizes to explore an area-weighted index.

<table>
<tr><th>Rocky Reef Desginations</th><th>Blue rockfish & Vermilion rockfish</th><th>Black rockfish</th><th>Brown rockfish</th><th>China rockfish</th><th>Gopher rockfish</th></tr>
<tr><td>California border to San Francisco</td><td>439.546</td><td>439.546</td><td>439.546</td><td rowspan="2">547.970</td><td rowspan="4">735.825</td></tr>
<tr><td>San Francisco to Santa Cruz</td><td>108.424</td><td>108.424</td><td rowspan="2">498.967</td></tr>
<tr><td>Farallon Islands</td><td>50.252</td><td rowspan="4">390.543</td><td>50.252</td></tr>
<tr><td>Moss Landing to Big Sur</td><td>137.603</td><td rowspan="2">228.027</td><td>137.603</td></tr>
<tr><td>Big Sur to Morro Bay</td><td>90.424</td><td rowspan="2">202.688</td><td>90.424</td></tr>
<tr><td>Morro Bay to Point Conception</td><td>112.264</td><td>112.264</td><td>112.264</td></tr>
</table>

Table 2: The number of samples retained after filtering to create the index of abundance with the percent of samples that caught the species in parentheses.

	Drift-level		Trip-level
Species	Habitat-informed	Stephens-MacCall filtered	Stephens-MacCall filtered
Black Rockfish	16306 (16%)	3038 (30%)	706 (68%)
Blue Rockfish	15283 (44%)	7490 (60%)	1813 (91%)
Brown Rockfish	15736 (16%)	2740 (31%)	806 (62%)
China Rockfish	14865 (8%)	1331 (22%)	798 (57%)
Gopher Rockfish	14476 (31%)	5088 (45%)	1449 (81%)
Vermilion Rockfish	14713 (30%)	5040 (45%)	1627 (85%)

Table 3: The average Coefficient of Variation (CV) for each index of abundance, where SM-filtered is the Stephens-MacCall filtering.

	Drift-level			Trip-level
Species	Area-weighted	Habitat-informed	Stephens-MacCall filtered	Stephens-MacCall filtered
Black rockfish	0.4426091	0.4493133	0.7641099	0.8495448
Blue rockfish	0.1343866	0.1415416	0.1610735	0.3324914
Brown rockfish	0.2415686	0.2399299	0.8652880	0.9161881
China rockfish	0.3196653	0.3011640	0.4481187	0.2087114
Gopher rockfish	0.1785421	0.1831132	0.2562205	0.2535190
Vermilion rockfish	0.1519120	0.1781884	0.4224451	0.5087889

7. Figures

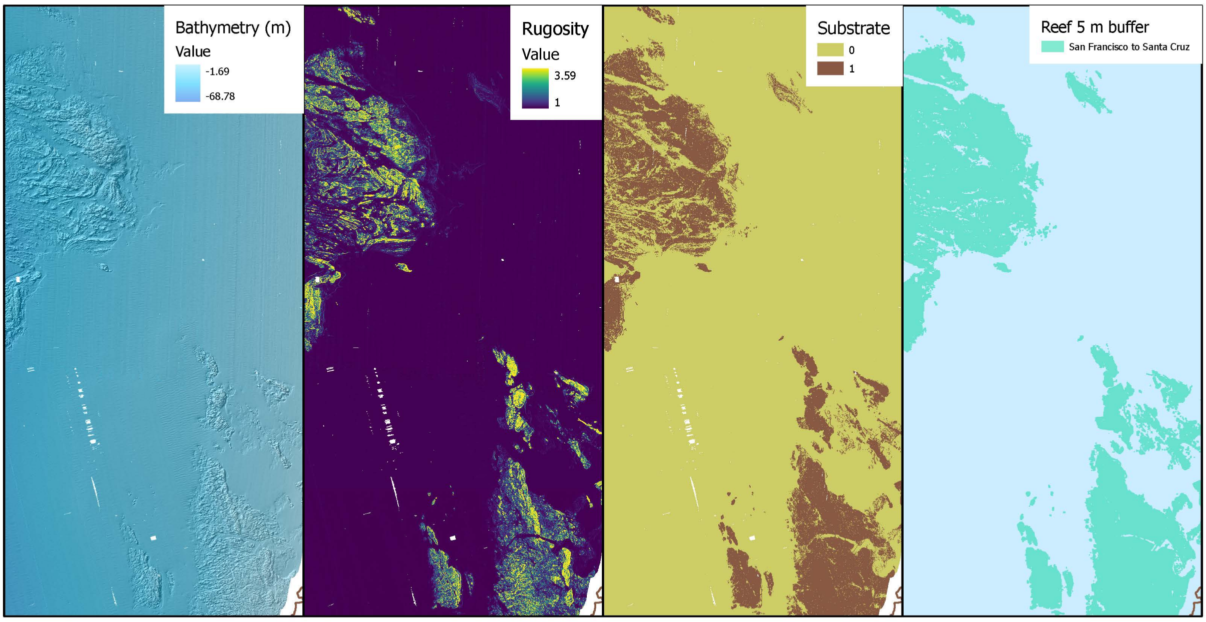


Figure 1: A example of the high resolution bathymetric data and components of bathymetry and rugosity used to define rough versus smooth substrate (where hard substrate is denoted by 1). The far right panel displays the hard substrate with the added 5 m buffer to represent the rocky reef habitat.

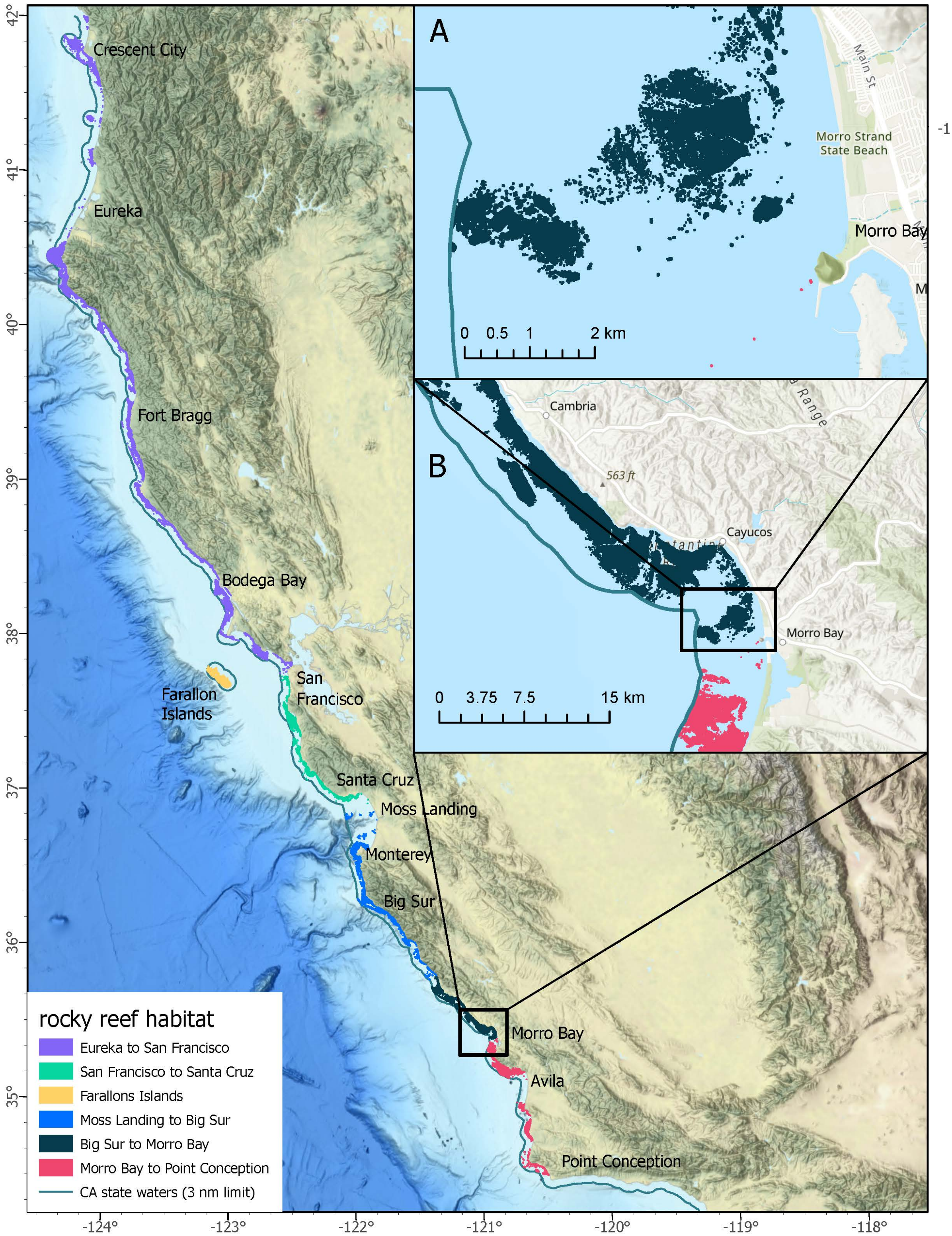


Figure 2: A maps of California state waters north of Point Conception colored by the aggregated areas of rocky reef habitat, including inset A depicting the rocky reef habitat in relation to 3 nm state water boundary state waters and inset B showing the high resolution rocky habitat in the area.

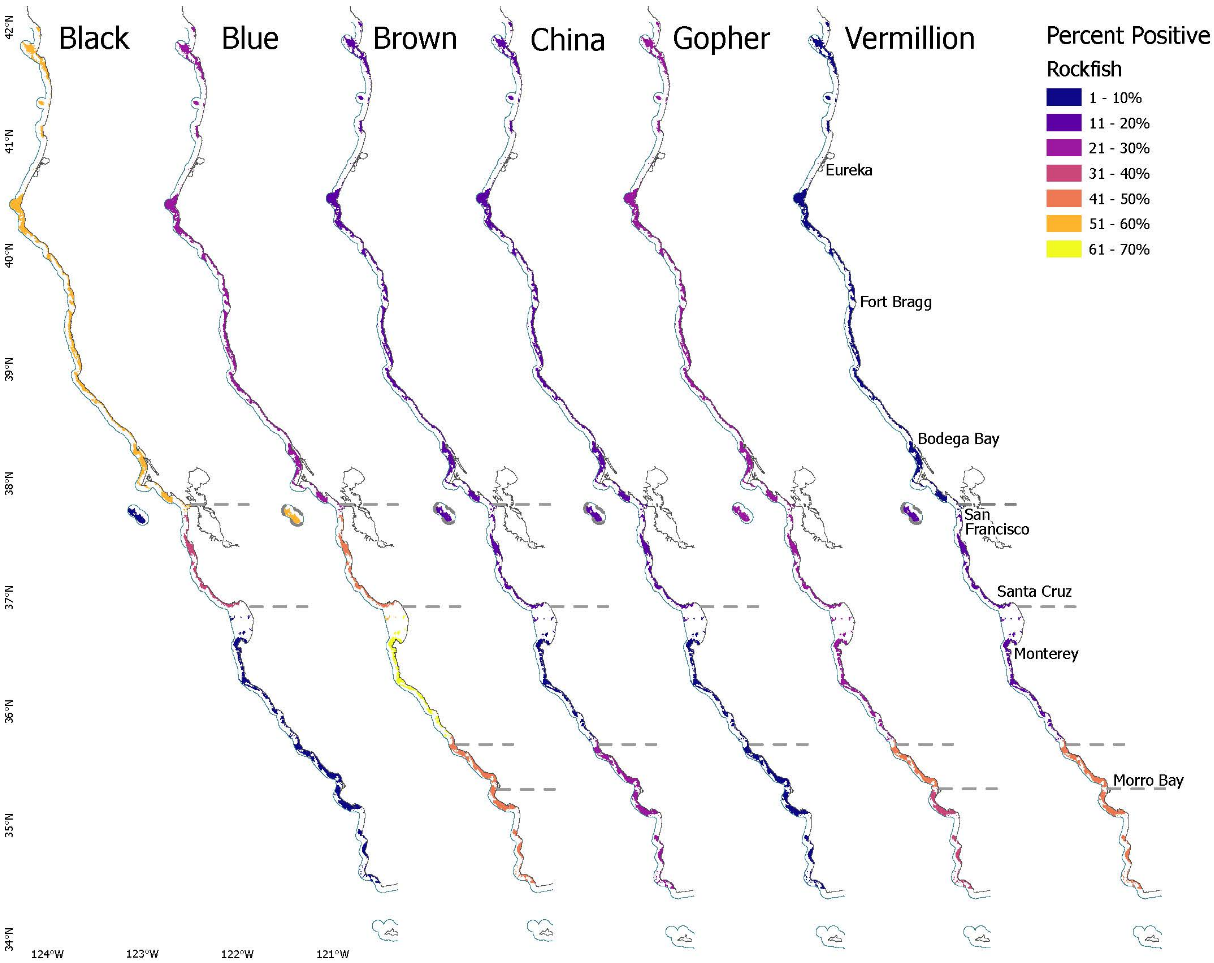


Figure 3: The percent of drifts that retained the target species, within grouped areas of rocky habitat over all years of the time series. The grey dashed lines represent the aggregated rocky habitat used to develop an index of abundance.

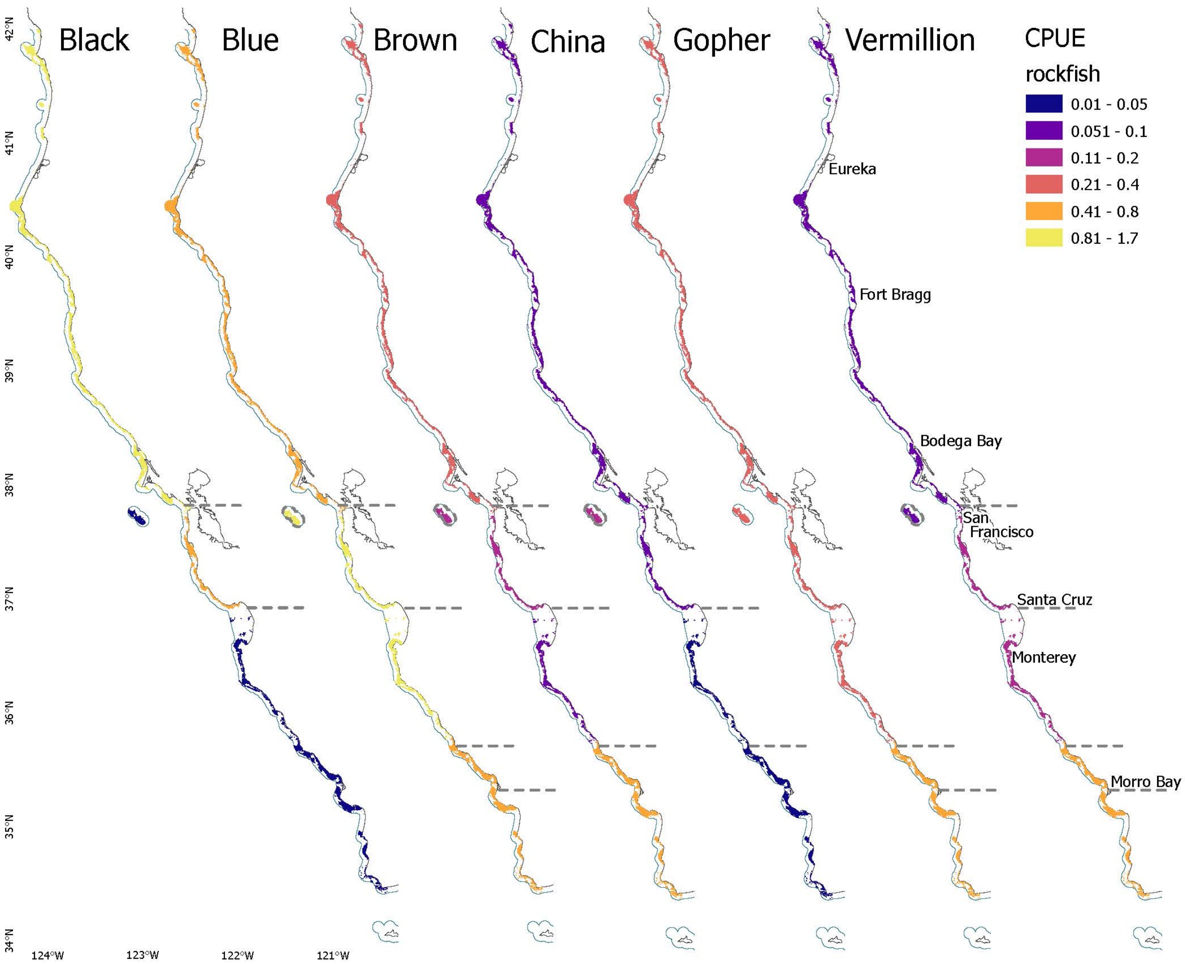
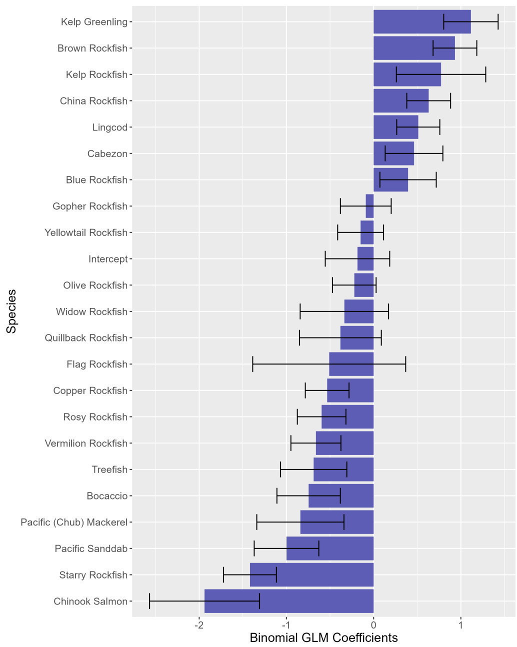
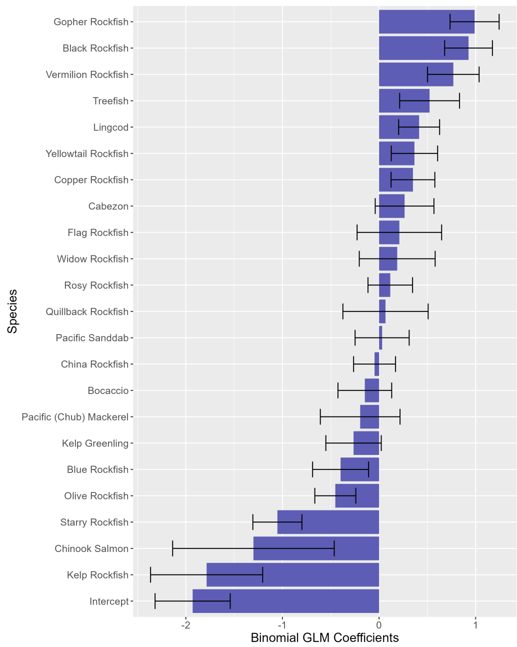


Figure 4: The average CPUE across all years of the time series for each of the six species. The grey dashed lines represent the aggregated rocky habitat used to develop an index of abundance.

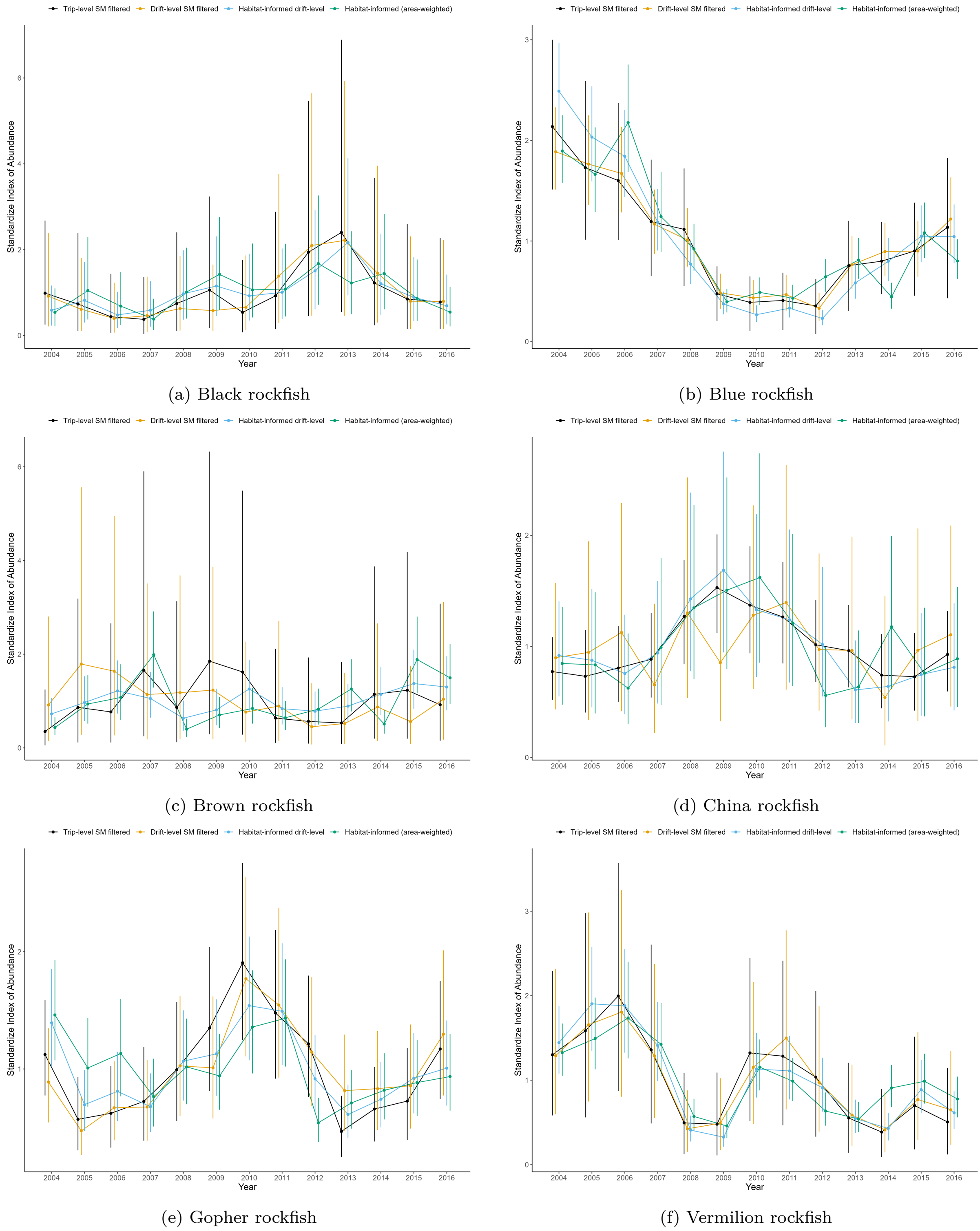


(a) Black rockfish trip-level



(b) Brown rockfish trip-level

Figure 5: Examples of the species coefficients and 95% confidence intervals for the Stephens-MacCall filtering for black rockfish (a) and brown rockfish (b) in the trip-level data. A positive coefficient indicates a species is associated with the target species and a negative coefficient indicates the species is not associated with the target species.



(a) Black rockfish

(b) Blue rockfish

(c) Brown rockfish

(d) China rockfish

(e) Gopher rockfish

(f) Vermilion rockfish

Figure 6: Indices of abundance and 95% confidence intervals for the different filtering strategies, each scaled to its mean, for the six species.

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