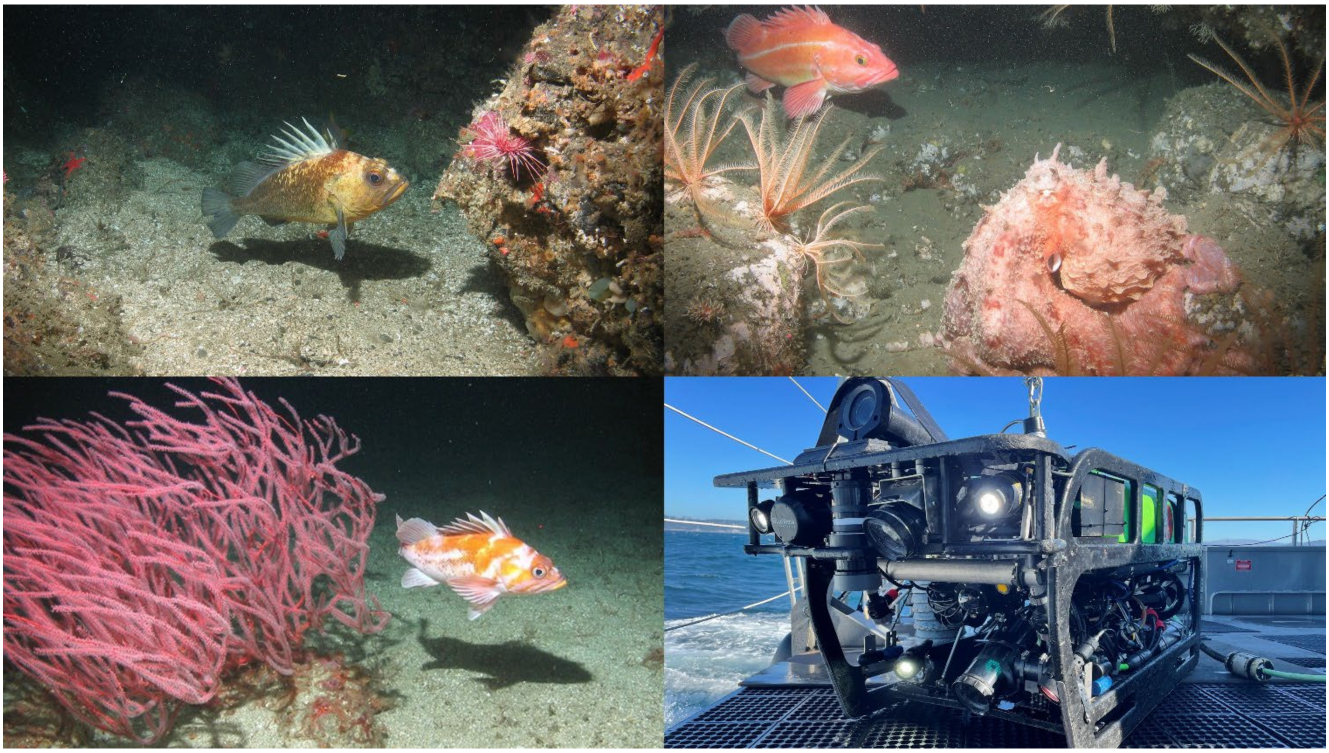
Analysis of a time-series of remotely operated vehicle surveys: temporal trends and MPA effects in mid-depth reefs across California's MPA Network



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Executive summary

Mid-depth (30-100 m) reefs across California's marine protected area (MPA) Network have been monitored using a remotely operated vehicle (ROV) by CDFW/MARE since the establishment of the first MPAs in the Channel Islands in 2003. Monitoring of mid-depth reefs is a critical component of the wider MPA monitoring program, as these depths encompass the majority of nearshore reefs along the coast and hence the majority of important habitat for many targeted fish species. This report undertook the analysis of this spatially and temporally extensive data set with the aim of quantifying statewide, regional and MPA specific trends in the density and size structure of key focal species, and in particular, to determine whether any MPA specific differences could be found. Defined management bioregions (North, Central, and South) for long-term monitoring were used for all regional models. For this report a shortlist of 11 focal species were chosen for analysis, due to being key species that have undergone historical fishing pressure: copper rockfish, vermilion rockfish, California sheephead, canary rockfish, gopher rockfish, quillback rockfish, yelloweye rockfish, brown rockfish, lingcod, kelp greenling, and a species grouping of important benthic species. A modeling approach was used that accounted for important environmental factors such as distance along the coast, depth, and habitat as well as spatial autocorrelation (SAC) in the data. SAC refers to the presence of systematic spatial variation in the data, with the tendency for nearby sampling units or locations to have similar values. The presence of SAC is typical in ecological data sets such as the ROV data analyzed, and when not taken into account can lead to biases in the conclusions drawn.

Statewide and regional recoveries in the density of focal species, both inside and outside of MPAs, were found for 25 out of the 29 species-region combinations modeled. Increases in the numbers of large fish were also found in 18 of 26 species-region combinations modeled. These strong signals of recovery in the abundance and size structure of the focal fish species indicate the success of a number of fisheries management measures over recent decades including fisheries quotas and spatial closures including MPAs.

The effects of MPAs on the density of focal species and large fish were found to be more detectable at the larger spatial scales modeled, with all statewide models showing positive MPA effects for species with statewide distributions. Positive MPA effects were also found for the density of 14 out of the 24 species- bioregion combinations modeled, and for the density of large fish for 7 out of the 22 species-bioregion combinations modeled. MPA effects at individual MPAs were more variable, with higher associated uncertainty in effect sizes. Despite this additional uncertainty a significant number of positive MPA effects were found across individual MPAs, with some MPAs such as Bodega Bay SMR showing positive responses for a large number of the species modeled. SAC was found to be an important factor in modeling ROV data and should be included in future modeling efforts.

The findings of this report demonstrate the ability of a spatially and temporally extensive ROV data set across mid-depth reefs across California's MPA Network to detect regional trends of recovery and the positive influence of MPAs. A robust modeling approach, which incorporates important environmental factors such as depth and habitat as well as SAC, is presented as a suitable path forward for ongoing modeling of ROV monitoring data. The large number of positive MPA effects found, particularly at larger spatial scales, point to the importance of a well-designed spatially and temporally replicated survey design. Resource managers should take these findings into account when designing ongoing monitoring plans to ensure that key questions can be answered.

Background

The California Marine Protected Area (MPA) Network has now been established for over a decade and management priorities have now shifted to the long-term monitoring of MPA effectiveness. Mid-depth habitats (30 - 100 m) comprise at least 75% of the area protected by MPAs across the California Network (Starr et al. 2021). Therefore, quantifying changes that occur in mid-depths is a crucial component of the long-term monitoring of MPA effectiveness. Remotely Operated Vehicles (ROVs) provide a powerful tool for surveying mid-depths, capable of covering large spatial extents, with the geo-located video footage able to quantify the abundance and sizes of fish and invertebrates and how they are associated with different habitats and depths. This report explores a time-series of ROV surveys conducted by California Department of Fish and Wildlife (CDFW) and Marine Applied Research and Exploration (MARE) across MPA and reference sites since shortly after the establishment of the first MPAs in the Channel Islands in 2003. Since then, CDFW and MARE have conducted surveys of 23 individual MPAs in all three defined MPA management bioregions (North: California/Oregon border to San Francisco Bay; Central: San Francisco Bay to Point Conception; and South: Point Conception to the California/Mexico border, hereafter referred to as 'bioregions') combined. This data set provides a unique opportunity to assess how the MPA Network is performing with respect to meeting two of the specific goals of the Marine Life Protection Act (MLPA) 1999: protecting the natural abundance of marine life and rebuilding depleted stocks of previously fished species.

The rate and timeline of expected recovery of previously targeted species in MPAs differs due to the varied life histories of individual species and prior fishing effort (White et al. 2013, Kaplan et al. 2019). Differing responses of individual species means that monitoring at a species level is often a management focal point. Expected timelines of recovery for individual species can then be compared with monitoring data in an adaptive management framework (Nickols et al. 2019). Modeling suggests that timelines to detect MPA effects may be in the order of decades and that abundances of previously targeted species may go through transient fluctuations in the first 10-20 years after MPA establishment (Micheli et al. 2004, White et al. 2013, Starr et al. 2015, Nickols et al. 2019). However, the ability to detect expected recoveries will also be dependent on the quantity and quality of monitoring data collected. For example, detecting a response at an individual MPA may require considerable sampling effort, while harnessing information across several MPAs may greatly improve the power to detect changes (Perkins et al. 2020b).

Metrics for quantifying the effectiveness of MPAs include changes in the abundance or density, changes in the number or proportion of larger individuals, and changes in biomass of focal species. The latter metrics are focused on the expected increase in larger size classes of individuals that have been previously subjected to fishing pressure. Theoretical expectations are that metrics related to size-structure such as the abundance of larger individuals or biomass may be more sensitive, particularly in the earlier stages of MPA monitoring (Kaplan et al. 2019, Perkins et al. 2020b). Typically, sampling within MPAs is coupled with the sampling of nearby reference sites that continue to be subjected to fishing pressure. Changes through time of metrics within MPAs can then be compared with those in reference sites to test whether there is a divergence. However, rates of change will be influenced by many factors including prior fishing effort, levels of ongoing fishing effort in reference areas, timing and size of recruitment events, and large-scale disturbances such as marine heatwaves. Data on many of these factors, in particular prior and ongoing fishing effort, is often lacking, making predictions of the timeline of responses problematic. Also, potential differences in important environmental conditions such as depth and habitat between MPAs and their associated reference areas should be accounted for when quantifying MPA effectiveness.

Environmental conditions can greatly affect the abundance and distribution of species and are therefore not only interesting to explore from an ecological perspective, but differences should also be accounted for in statistical analyses. Factors such as depth, temperature, habitat type (e.g., rocky reef vs sediment), habitat quality (e.g., reef complexity) are known drivers of where species are likely to occur. In a statistical sense these are often referred to as ‘covariates’, as the modelled ‘response’ (e.g., the abundance of fish) will co-vary (increase or decrease) along with their value. For large-scale monitoring programs, such as the monitoring of California’s MPA Network, there is likely to be considerable variation in environmental covariates both in geographical space, and also in samples collected over time. Ideally, sampling programs should collect environmental covariate information concurrently with collecting data on the abundance of focal species or other metrics to quantify MPA effectiveness.

One of the advantages of ROVs as a sampling platform is the ability to collect environmental data alongside observations of target species over relatively large spatial scales. Species can be directly observed across the habitats and depths they occupy. ROVs such as the one used in the MARE program can typically cover over 10 kilometers of total transect distance in a single day, encompassing a much larger area and range of potential environmental covariates than is typically covered by methods such as SCUBA surveys or drop-camera systems. Furthermore, as observations are GPS located, the locations of target species can be matched with seafloor multibeam mapping. Seafloor mapping can be used to create additional environmental covariates (hereafter referred to as ‘bathymetric covariates’) based on the seafloor topography such as rugosity (a measure of bottom complexity) and slope. Bathymetric covariates have been shown to be important predictors in certain situations (e.g., Young et al. 2010, Young et al. 2015, Perkins et al. 2020a); however, they can be calculated across different scales and care needs to be taken in choosing ecologically relevant scales.

Despite, or perhaps due to the large amount of data collected by ROVs, the analysis of ROV data provides several challenges. MPAs and reference sites are unlikely to be perfectly balanced in terms of depths and quantity of habitats, and thus survey data is also unlikely to be balanced across these important factors. This makes comparisons of MPAs and paired reference sites with traditional statistical methods that assume a balanced experimental design (e.g., analysis of variance) problematic. Also, counts of fish are unlikely to follow statistical assumptions about normality of error distributions. Generalized Linear Models (GLMs) provide a tool for analyzing such data, with models being able to account for non-normal data distributions while also incorporating and estimating the importance of variables such as depth and habitat. GLMs can be extended to also include spatial autocorrelation present in the data, further reducing biases and improving confidence in the conclusions drawn.

Spatial autocorrelation (SAC) refers to systematic spatial variation, for example in the counts of fish, with positive correlation indicating the tendency for sampling units closer together to have similar values. SAC can be driven by habitat preferences that are not accounted for in the model, or by biological factors such as fish schooling or aggregating behavior, home ranges, and larval dispersal distances. Many statistical analyses assume that the data being used represents a true random sample, which is unlikely to be the case with spatial survey data collected across a region. For example, where the aim is to quantify regional MPA effects, data that has been collected at specific MPAs and reference sites, targeting specific habitats, and along transect lines is unlikely to represent a true random sample of the region.

Failure to account for SAC can lead to biases in estimates, under-estimation of errors and confounding of subsequent conclusions drawn (Legendre 1993, Legendre et al. 2002). Previous work has shown that for the majority of ecological data, the magnitude, direction, and error associated with estimates can be dramatically altered when not accounting for spatial autocorrelation (e.g., Dormann 2007). Therefore, models that incorporate SAC present in the data should be preferred. The modeling approach used in this report explicitly models SAC by using a GLM approach that incorporates the location of each sampling unit and estimates the SAC present in the data for each species.

In this report we explore the effect of MPA protection for a subset of focal fish species and for a grouping of key benthic species by analyzing the 17-year time series of ROV data collected by MARE and CDFW. We examine MPA effectiveness within each bioregion (South, Central and North), statewide for a subset of species that occur across all bioregions, within individual MPAs, and across a section of coastline that spans two bioregions for brown rockfish (*Sebastes auriculatus*). We report on the impact of MPA protection on the density of focal species and on the density of larger fish, which are expected to increase in abundance following protection. Our overarching aims are to explore the evidence to date for MPAs meeting goals of increasing the abundance and rebuilding of depleted stocks of previously targeted fish, and to make recommendations for the ongoing long-term monitoring of California’s MPA Network.

Methods

Data collection and conditioning for analysis

ROV data collection and post processing methods used were developed and tested by CDFW and MARE from 2003-2004 and formalized starting in 2005. ROV survey sites were identified using high resolution seafloor maps and were placed perpendicular to the prevailing depth contour. Each site was 500 m wide and spanned the targeted rocky substrate from deep to shallow. Within MPAs and reference sites, the 500-meter transect lines starting points were randomly generated and distributed to maximize the area sampled within each site. The number of transects selected at each site was based on the total percentage of rocky habitat present and the amount of transect effort needed to cover at least 3 km of that rocky habitat. The collected video imagery was analyzed to characterize substrate types present and to identify and estimate all demersal and epibenthic finfish and macro-invertebrate species. A full description of data collection and conditioning methods used can be found in Lauermann et al. (2017). The ROV time-series data available for this report spanned surveys that began in 2005 in the southern bioregion up until 2021 (Table 1).

Table 1. Summary of the time series of 500-meter ROV transects conducted across each bioregion and MPA group. The total number of transects and the number of time-series year replicates are included in the total columns. Highlighted MPAs were included in the analyses presented in this report. SMR = State Marine Reserve, SMCA = State Marine Conservation Area.

Region	MPA Group	Transects by year (500 m)																	Total Transects	Total Series Replicates
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021		
	Point St. George Reef Offshore SMCA										23	14					19	12	68	4
	Reading Rock SMR										19	19					20	14	72	4
	South Cape Mendocino SMR										14								14	1
	Mattole Canyon SMR										21	16							37	2
	Sea Lion Gulch SMR										15	6					18	20	59	4
	Big Flat SMCA										3								3	1
	Ten Mile SMR										19	20					20	18	77	4
	MacKerricher SMCA										12								12	1
North	Point Arena SMR/SMCA							12				17					14	12	55	4
	Saunders Reef SMCA											8							8	1
	Stewarts Point SMR											3							3	1
	Bodega Bay SMR/SMCA							31				45				38	44		158	4
	Point Reyes SMR/SMCA					21													21	1
	North Farallon Islands SMR																10		10	1
	Southeast Farallon Islands SMR/SMCA							21				27				23	23		94	4
	Montara SMR											16					19	12.5	47.5	3
	Pillar Point SMCA											8					12	9	29	3
	Ano Nuevo SMR											9				10		10	29	3
	Soquel Canyon SMCA												3						3	1
	Portuguese Ledge SMCA												15			12		10	37	3
	Pacific Grove SMCA			12									8						20	2
Central	Asilomar SMR			13	26								15						54	3
	Carmel Bay SMCA			13							10		8						31	3
	Point Lobos SMR			12	31	23							24			23		34	147	5
	Point Sur SMCA				22				25				23			22		20.5	112.5	4
	Big Creek SMR/SMCA												28				13		41	2
	Piedras Blancas SMR/SMCA												8				15		23	2
	Point Buchon SMR				24	18			40				15			14		16	127	6
	Naples SMCA										4								4	1
	Campus Point SMCA										19					18		16	53	3
	Harris Point SMR	30	24	21	21	19					23	23				24	33		218	9
	Carrington Point SMR	25	31	25	25	25					25	26				24	40		246	9
	South Point SMR	37	31	26	26	26					24	25				26	31		252	9
	Gull Island SMR	44	41	39	39	38					39	40				32	41		353	9
	Scorpion Point SMR										3	6							9	2
South	Anacapa Island SMR/SMCA	39	29	30	28	25					59	29				28	37		304	9
	Point Dume SMR										18								18	1
	Santa Barbara Island SMR										19								19	1
	Farnsworth Offshore SMCA										25						27	18	70	3
	Swami's SMCA										25						13	14	52	3
	Point Conception SMR										17					16		13	46	3
	South La Jolla SMR/SMCA										24						27	20	71	3
	Total :	175	156	191	242	195		64	65		484	357	147			327	476	281.5	**3,161**	**142**

Sub-units for analysis

The optimal sub-unit of transect to be used for analysis is a currently unresolved research question. Associations between fish and preferred habitat are likely to be on a smaller scale than 500 m transects. Therefore, it is standard practice to break longer transects into sub-units for analysis. Previously, sub-units of $50m^2$ area have been used (Karpov et al. 2010, Karpov et al. 2012) as well as sub-units of 20 m length (Budrick et al. 2019).Exploratory analysis showed that habitat tends to be patchy on scales of 10's of meters or less (Appendix A). The patchiness of habitats varied considerably amongst sites, but it was reasoned that a sampling unit that captured the smaller scales of variation was preferable. Both 10 m and 20 m sub-unit lengths were considered, with data extracted at both scales. For this report a sub-unit of 10 m length was settled upon, with a comparison between 10 m and 20 m sub-unit lengths (and potentially full 500 m transects) flagged for future research. Furthermore, seafloor mapping data in California is usually at either 2 m or 5 m resolution. Therefore, a sub-unit length of 10 m was chosen for analysis as it captures potential fine-scale habitat associations and allows a sub-unit length that can be matched back to seafloor mapping data at both 2 m and 5 m scales. In total 125,629 10 m sub-units were used in the final analyses across all regions (Figure 1).

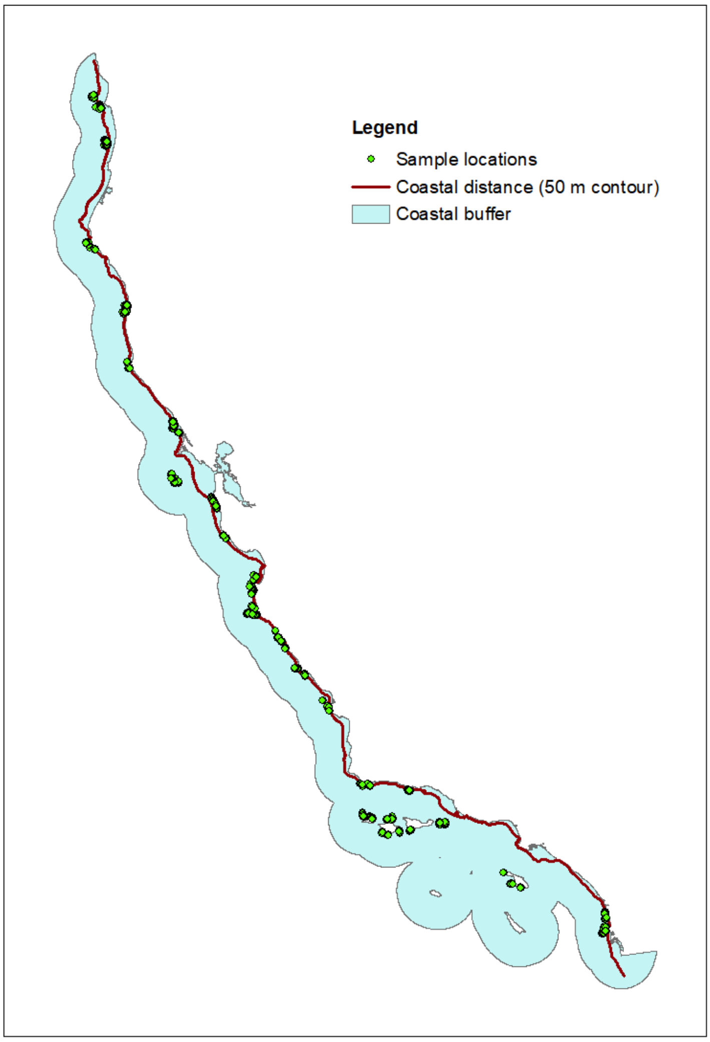

Figure 1. Map showing the California coastline, ROV sampling locations, the coastal buffer used for spatial modeling and the coastal distance variable created along the 50 m depth contour.

Selection of MPAs for analysis

A number of MPAs and their associated reference sites had two or less repeat surveys in the data set used in this report (Table 1). Due to the uncertainty introduced in estimating trends through time with two or less surveys, it was decided that these MPAs would be excluded from analysis in the current report. This subset of MPAs was used in all statewide, regional, and individual MPA models.

Filtering of sub-units prior to analysis

The splitting of the 500 m transects into 10 m sub-units resulted in some artefacts that required correction or removal prior to analysis. For example, small sub-units could occur at the end of a transect after splitting the rest of the transect into sub-units. Any 10 m sub-units with a length of less than 6 m were removed, which comprised of ~6% of the total number of sub-units. Also, any sub-units where the usable area exceeded 50 m^2 (i.e., an average of over 5 m width over a 10 m length) were removed to avoid biases from very large field of views (~0.3% of the total number of sub-units). As covariate information is required for estimation of model parameters, any sub-units that had missing depth information (typically due to sensor failure) were removed (~3% of sub-units). Finally, any sub-units with a depth > 250 m (~0.009% of sub-units) were removed to exclude sampling conducted at canyon heads, predominantly at Point Reyes.

Defining sub-units as MPA versus reference

MPAs across the California MPA Network offer different levels of protection, with specific guidelines around activities allowed. The MPAs surveyed and included in this report are designated as either State Marine Reserves (SMRs) with full no-take protection, or State Marine Conservation Areas (SMCAs) with no-take and limited-take designations (Table 1). Prior to analysis, it was determined that all surveyed SMCAs were no-take for the focal species and therefore acted in the same way as SMRs in terms of protection. Thus, SMRs and SMCAs were treated in the same way in assessing MPA effects in the analysis.

Selection of environmental covariates

Both depth and habitat are known to be important drivers of the distribution of fish species. For example, many rockfish species are known to inhabit particular depth bands, while most are associated with rocky reef habitat. Both depth and $depth^2$ were included in models to quantify the effect of depth. Depth quantifies the linear effect (e.g., does abundance decrease or increase with depth), while $depth^2$ quantifies the non-linear effect, with a significant negative value implying a negative quadratic relationship (i.e., ∩ shape) and a preference for mid-depths; and a significant positive value implying a positive quadratic relationship (i.e., U shape) and a preference for shallow and deeper depths.

Habitat was included from the visual scoring of habitat classes in the ROV video recording. The start and end points of habitat classes (rock, sand, cobble, boulder, mud, gravel) were scored continuously along transects. This allowed the subsequent calculation of the proportion of broad habitat classes (hard substrate, mixed substrate, and soft substrate) in each sampling sub-unit to be included as a habitat covariate. As proportions of habitat (hard, mixed, and soft) sum to 1, including proportion soft habitat was redundant.

To quantify large-scale spatial variation, a ‘coastal distance’ variable was included. A spline was created along the 50-meter depth contour for the entire coastline (Figure 1). This was preferred to using latitude as it captured the non-linear nature of the coastline, particularly moving from the south around Point Conception. This variable was set to zero in the north and extended to 1571 km at the southern-most surveyed site of South La Jolla. A quadratic term (i.e., Coast_dist^2) was also included, to capture non-linear effects in a similar fashion to the depth^2 term (see above).

For the central California bioregion, vector ruggedness measure (VRM), a measure of benthic complexity was calculated using bathymetric multibeam mapping available across the region at a 2-meter resolution. VRM calculates the benthic terrain ruggedness as the variation in height and orientation of grid cells within a specified neighborhood. A 3x3 neighborhood was used to capture rugosity at the finest scale. VRM has been shown to be a useful variable in previous work in California, and thus was chosen as a test bathymetric covariate to include in models. VRM was calculated for every cell within each ROV sampling rectangle. VRM was then averaged within a 20-meter radius of the center point of each sub-unit. The 20-meter radius (an area of ~1257 m^2) was used as it quantified the habitat complexity within a region surrounding the sub-unit at a scale that is likely to be relevant to a fish. For example, home ranges for lingcod, copper rockfish and quillback rockfish have been found to be on the order of ~ 1500 – 2500 m^2 (Tolimieri et al. 2009). Also, by using a buffer around the center point location, the potential spatial uncertainty of the GPS location of the ROV of 3-6 m (Budrick et al. 2019) was bounded within the radius used. Central California was chosen as a test region to examine the importance of VRM as it had the best coverage at a 2-meter resolution.

Modeling

Description of the models

All modeling was conducted using Integrated Nested Laplace Approximation (INLA; see Lindgren et al. 2011), which is a spatial regression approach that allows the incorporation of spatial effects, thereby accounting for SAC. These models use the locations (s_i) of the response variable (i.e., fish counts) and a vector of covariate values X_i (that is ith row of the covariate matrix X) at those locations to estimate the expected values (μ_i) at each location:

$$\mu_i = X_i * \beta + \omega(s_i) \qquad (1)$$

The expected values (μ_i) depend on the covariate values (X_i) which are multiplied by coefficients (β's) which are to be estimated, plus a spatial random effect ω that is estimated at each location (s_i). The spatial random effect is modeled as a multivariate normal distribution:

$$\omega(s) \sim MVN(0, \Sigma) \qquad (2)$$

with mean zero and variance-covariance matrix (Σ) that is populated using a Matern correlation function:

$$cov(i,j) = \delta * Matern(d_{ij}, \kappa) \qquad (3)$$

where the covariance between any two locations in the dataset i and j depend on their distance apart (d) the range of the Matern function (κ) and the spatial variance (δ).

Thus, the important model covariates to be estimated are the coefficients of the covariate effects (β), the variation of the spatial effect (δ), the range of the spatial effect (κ) and any residual variation. The spatial variance (δ) quantifies the magnitude of spatially dependent variation, while the spatial range (κ) quantifies the distance that the correlation occurs over.

Calculating the spatial random effects at all locations across a region is computationally intensive. INLA makes this process faster using a user-defined triangular “mesh” (Figure 2) across the region being modeled. Spatial random effects are then estimated across the nodes of the mesh using stochastic partial differential equations. The mesh can be defined with larger edges (making larger triangles) where there is no data and smaller edges where there is data or around complex features such as coastlines and islands.

A barrier model (see Bakka et al. 2019) was used for the creation of the INLA meshes (see Figure 2) that considers physical barriers such as islands or the coastline. Rather than the Matérn correlation being calculated on the shortest distance between points, a collection of paths is considered, with paths crossing physical barriers being excluded.

For the density models, the response was modeled using a negative binomial likelihood. The negative binomial distribution is often used for count data such as the ROV data and allows for additional variation than is assumed under a Poisson distribution, where the variance is equal to the mean. Additionally, previous comparisons of models with both Poisson and negative binomial likelihoods showed that the negative binomial models fitted ROV data better (Budrick et al. 2019). For the density of large fish, model comparisons showed that a Poisson model was sufficient and thus a Poisson likelihood was used. The area of each sub-unit was included as a model offset to allow for the influence of different areas for each sub-unit, resulting in the response variable being modeled as density (i.e., number of fish per unit area). This specification is necessary, as the statistical error distribution used (Poisson and negative binomial) are based on counts (i.e., integer values) which can be expressed as counts per unit area. Transforming to density prior to analysis would violate the distributional assumptions of these distributions.

Environmental covariates of depth, proportion hard, proportion mixed, and coastal distance were scaled prior to modeling, by centering on their mean and dividing by their standard deviation. This is standard practice when including covariates which are on different scales (e.g., the coastal distance parameter which is in km and ranges from 0 to ~ 1600 km versus proportion of hard habitat which ranges from 0 to 1) and avoids collinearity issues when including polynomial terms and interactions in models. Survey year was set to zero for the first year of surveys in the region being modeled.

The INLA method is Bayesian, so the output for each estimate (the β's, δ and κ estimates) is a distribution (known as a posterior). Rather than using p-values, the strength of an effect is determined by how far the posterior distribution is away from zero, with 95% credible intervals including zero generally being considered "non-significant" in the traditional sense.

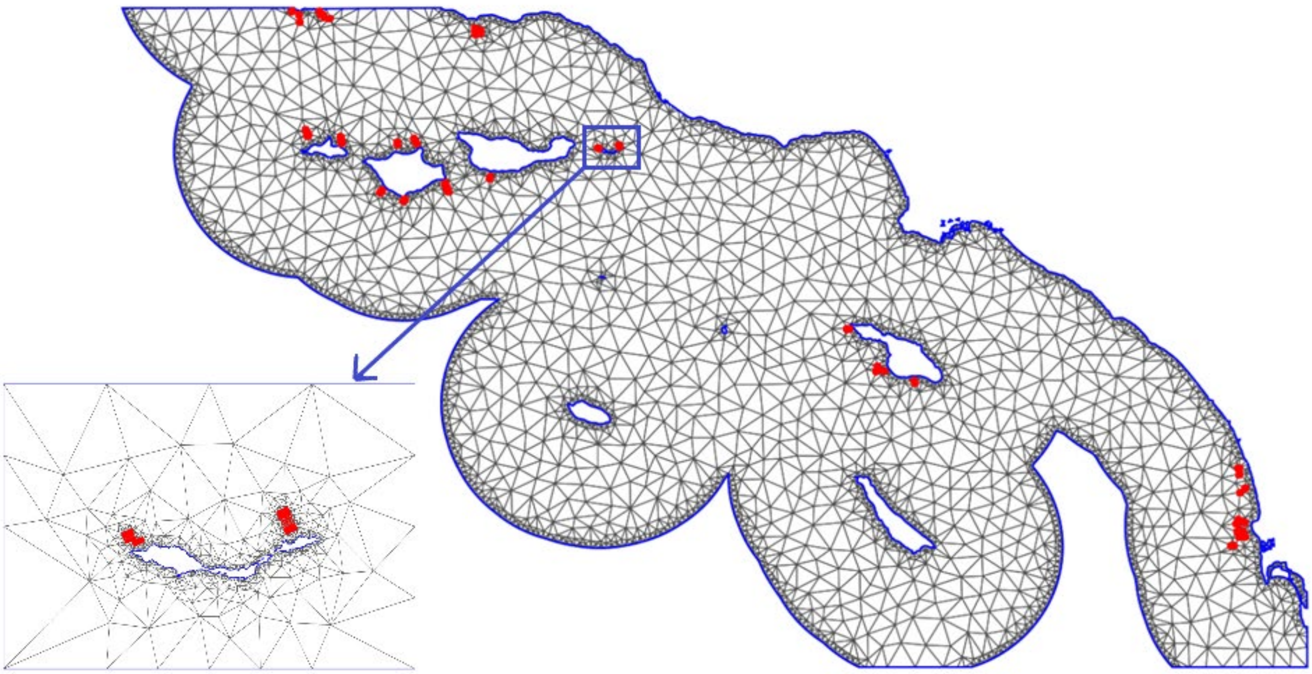

Figure 2. Example mesh for the Southern California region used for spatial modeling in the integrated nested Laplace approximation (INLA) approach. Inset shows detailed mesh around Anacapa Island. Note that the triangles of the mesh are smaller where survey sites are located and along the coastline to allow smoother effects where the data is available and a coarser resolution where there is no data. Islands and the coastline are modeled as barriers to spatial random effects. Red points show survey locations.

Model priors

Bayesian models require the specification of prior distributions for parameters to be estimated. In particular, for a spatial model the specification of priors for the spatial random effects (the spatial variance δ, and the spatial range κ) are important considerations. We used the 'penalized complexity' priors (Fuglstad et al. 2018), and specified a prior probability that the spatial range was less than 2 km of 0.1, and a prior probability that the spatial standard deviation was greater than 1 of 0.1. The prior intercept determines the scale of the model, and the prior is specified for the precision (equal to the inverse of the variance), which was set at 0.0625. The priors for the precision of the remaining model coefficients were all set at 0.25.

Quantifying the MPA effect and trends through time

To quantify the "MPA effect", the cumulative effect of years of MPA implementation, "years since implementation" (YSI), on density was estimated. All samples outside of MPAs (i.e., in reference areas) have zero years of implementation throughout the time-series, whereas samples within MPAs were attributed the number of years since the MPA was established, which ranged from zero (surveys conducted in the first year after establishment) to 17 years (MPAs in the Channel Islands established in 2003 and last surveyed in 2020). The response was modelled using a log (τ +1) transformation, where τ is the number of years since implementation. Thus, for surveys in an MPA in the first year of implementation this formulation will set the cumulative effect at zero as log (0 + 1) = 0. The MPA effect (β_{MPA}) is thus quantified by a power relationship:

Considering that a negative binomial likelihood with a log-link was used to model the expected density $E(y)$ of a species, then:

$$\log\big(E(y)\big) = \beta_0 + \beta_{MPA} * \log(YSI + 1) + \beta_1 x_1 + \cdots \beta_z x_z \qquad (4)$$

where β_0 represents the model intercept and $\beta_1 x_1 + \cdots \beta_z x_z$ represent other covariate effects. Then, ignoring the other covariate effects:

$$E(y) = e^{\beta_0} + e^{\beta_{MPA} * \log(YSI+1)} = (YSI + 1)^{\beta_{MPA}} * e^{\beta_0} \qquad (5)$$

Given that β_0 will be a value representing the mean density at the start of the survey ignoring all other covariates, the MPA effect will have an exponentially increasing effect when the β_{MPA} coefficient is greater than 1 (green line Figure 3), but is expected asymptote through time with coefficient values greater than zero but less than one (e.g., black line in Figure 3), whereas negative effects where the coefficient is less than 1 (red line Figure 3) are not expected, but allowed for by the model.

The MPA effect was explored graphically for statewide models (see below) by using the mean estimated MPA effect and intercept and then calculating the ratio of density (and hence abundance) at the start of the survey through time, using equation (5) above.

A linear term for survey year was also included in all models to quantify the general trends for decrease/increase in density across each region modeled. Modeling the MPA effect and regional trends in this way means that the additional cumulative effect of MPA implementation is quantified on top of any overall regional trend.

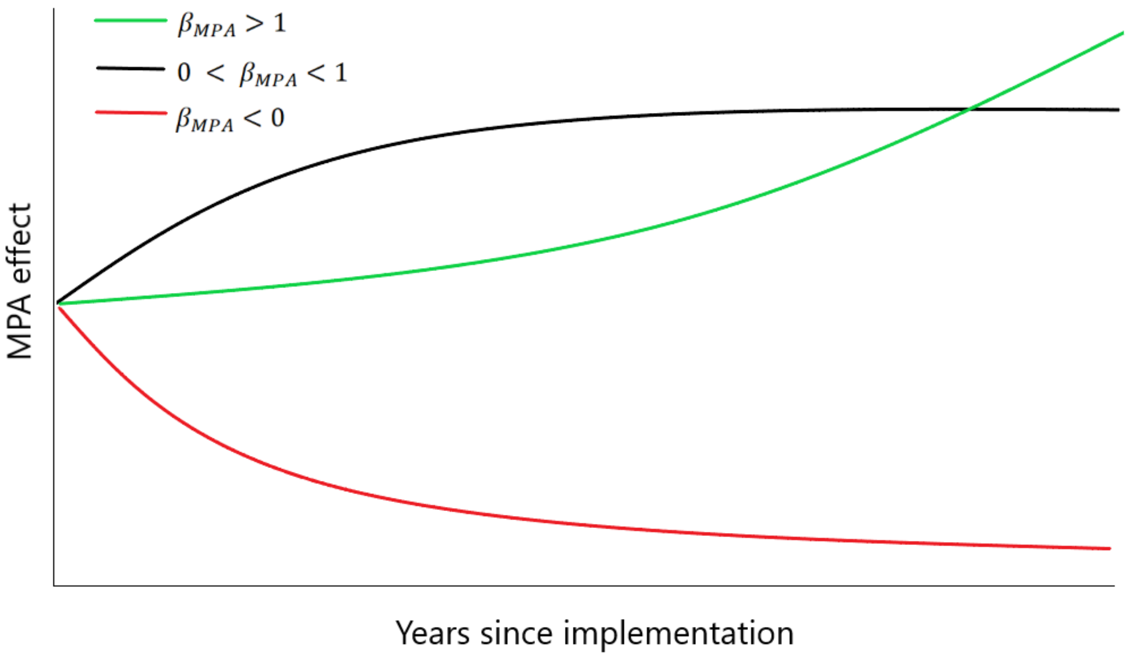

Figure 3. Illustration of model specification used for the "MPA effect". The coefficient for the MPA effect (β_{MPA}) when β_{MPA}> 1 results in an increasing trend bounded at zero below with no upper limit; when 0 < β_{MPA} < 1 results in an increasing trend bounded by zero below and tending to an asymptote; and when β_{MPA} < 0 resulting in a decreasing trend with an asymptote at zero.

Species modeled

Analyses were conducted for a subset of species and one species grouping for two metrics: (i) density; and (ii) the density of larger fish (> 30 cm for rockfish species and > 55 cm for lingcod). Data was available on size structure for ROV surveys from 2014 onwards. These two metrics were chosen as they are both expected to be positively affected by MPAs. Expectations are that differences in abundance between MPAs and fished areas may take longer to detect, whereas the filling in of the size structure of larger size classes is likely to be detectable in a shorter time (e.g., Kaplan et al. 2019). Species chosen for modeling were copper rockfish, vermilion rockfish, California sheephead, canary rockfish, gopher rockfish, quillback rockfish, yelloweye rockfish, brown rockfish, lingcod, and kelp greenling. These species were chosen as they are benthic species whose presence is likely to be captured consistently by the ROV survey methodology and are species that are actively targeted by fishers. Analysis of the density of larger fish was not conducted for gopher rockfish due to the much smaller length at maturity, and California sheephead because of their diandric nature. The species treated as grouped species were copper rockfish, vermilion rockfish, China rockfish, quillback rockfish, gopher rockfish, canary rockfish, yelloweye rockfish, treefish, brown rockfish, flag rockfish, kelp rockfish, and tiger rockfish.

Statewide, regional and MPA models

For each focal species analysis was restricted to the bioregions (North, Central, and South) that they occurred in in sufficient densities. Thus, grouped species, copper rockfish, vermilion rockfish and lingcod densities were modeled within all bioregions. California sheephead and blacksmith were only modeled in the Southern region. Canary rockfish, yelloweye rockfish, and kelp greenling were modeled in the Central and North regions. Quillback rockfish were only modeled in the North region.

As management interest included network-wide effects, regional effects and individual MPA effects three separate models were used:

1. **Statewide models**

   Statewide models were conducted for grouped species, copper rockfish, vermilion rockfish, gopher rockfish and lingcod. All these species have distributions that span the entire state of California and therefore have sufficient data to support a statewide model. Bioregions and individual MPA effects were not considered. The year effect (overall trend) was considered across the whole state.

2. **Regional models**

   Regional models were used for each focal species considering the regions that contained sufficient densities. The YSI term was nested within each bioregion to allow quantification of the regional effect. The year effect was also nested within each bioregion to allow reporting of regional trends in density through time.

3. **Individual MPA models**

   To explore individual MPA effects analysis was once again restricted to the bioregions where sufficient densities occurred (at least 20 fish observed in the region through time). For these models the YSI term was nested within each MPA to allow quantification of the MPA effect. For these models the year effect was also nested within each bioregion to allow reporting of regional trends in density through time.

For brown rockfish, the core range spanned the Central and North bioregions. For this species we conducted analysis on a region defined by Año Nuevo SMR in the South to Reading Rock SMR in the North. This region is reported as "North*" in the results. A nested MPA model was also used across this region.

For the density of large fish, the subsetting to only large fish combined with a shorter time-series of data available (2014 onwards) resulted in less data to inform models. For this reason, only statewide and regional models were considered for the density of large fish as there was generally insufficient data at the individual MPA level. Also, there was insufficient data in the North region to allow for a statewide model for the density of large gopher rockfish.

Model outputs

The primary focus of this report is to inform managers on the effectiveness of the California MPA Network in protecting the natural abundance of marine life and rebuilding depleted stocks of a focal group of previously fished species (Appendix B; CDFW and OPC 2018, Hall-Arber et al. 2021). This was explored at scales ranging from statewide (where appropriate), to bioregions (North, Central, and South) through to individual MPAs. Effectiveness was quantified in the model coefficient for our 'years since implementation' (YSI) term. This coefficient captures the change in density through time when compared to reference areas still subject to fishing. While actual changes in density need to take into account other model parameters such as starting densities and environmental covariate importance, this coefficient is directly comparable between species and regions modeled. Managers are interested in this effect at various scales ranging from network-wide to individual MPAs (CDFW and OPC 2018), and so we report on this effect at scales ranging from statewide for a subset of the focal species distributed across the state; to defined long-term bioregions (North, Central and South; CDFW and OPC 2018); and finally individual MPAs.

Plots showing the MPA effect size (i.e., the coefficient of the YSI term) along with 95% credible intervals were produced across the state (where modeled), bioregions and individual MPAs to allow easy visual comparison. Effects that include zero in the credible intervals are considered non-significant in the traditional frequentist statistical sense and are colored **black** in the plots, effects colored **green** indicate a positive effect, and effects colored **red** indicate a negative effect. Alongside the MPA effect plots, the regional trend plots are shown in a similar fashion with the same color scheme for effects.

Models also included a term for the survey year, which captured overall (increasing or decreasing) trends in density through time in each region that was not directly attributable to differences inside MPAs. The coefficients for survey year were tabulated in a similar way to the MPA effects, with the same color coding used for non-significant, positive, and negative effects.

Plots of model-based estimates of density differences between MPA and reference sites through time within regions were made by taking 5000 joint posterior sample draws from the model and then calculating mean trends and credible intervals across all draws. Mean depth and habitat within the survey data for each region were used for all calculations.

Exploration of the importance of spatial autocorrelation and incorporating rugosity from seafloor mapping

To explore the potential utility of incorporating rugosity into analyses as well as the importance of modeling SAC for inference, a nested modeling approach was used whereby more complex models had all terms from simpler models nested within. Vermilion rockfish in Central California were chosen as the example due to their relatively high abundance across most MPAs in this region. Model outputs were compared and contrasted across three separate models:

(1) A ‘base’ model that included all previously used covariates, but did not include rugosity and SAC
(2) A ‘rugosity’ model that included rugosity but not SAC
(3) A ‘full’ model that included all covariates, rugosity, and SAC

The improvement in model fit for each model was assessed by examining the change in the marginal log-likelihoods (MLL) between models. Kass and Raferty (1995) define evidence provided by changes in the MLL as: 0 – 0.5 ‘not worth a bare mention’, 0.5-1 ‘substantial’, 1-2 ‘strong’, and > 2 ‘decisive’.

Results

We first present results of the estimated 'year' effects on the density of focal species and larger focal species. These results highlight the overall regional and statewide trends in the densities of focal species across the survey period excluding any MPA specific effects. This is followed by the results of the MPA effect estimates, which quantify any additional changes in densities associated with MPAs. The MPA results are first presented for statewide and regional effects before presenting results for individual MPAs. Finally, we present the results of models for vermilion rockfish in the Central coast region that compare non-spatial models with spatial models, and with models that incorporate an additional habitat rugosity variable derived from seafloor mapping. Full model summary outputs are provided in Appendix B.

Overall statewide and regional trends in the density of focal species

Overall regional and statewide trends in the density of focal species, excluding MPA-specific effects, displayed positive trajectories for almost all the species (26 out of the 29 species/regions) modeled across the survey period (Table 2). The exception to this was kelp greenling, where results were non-significant in the Central and North regions and lingcod, which showed a negative trend in the North region. Coefficient estimates for trajectories ranged from a mean of -0.064 for lingcod in the North to a mean of 0.232 for gopher rockfish in the North (Table 2).

The year effect coefficients are on the linear predictor (log) scale, and therefore when exponentiated provide a multiplicative effect for each unit of change (i.e., for each year). For example, considering the statewide model for vermilion rockfish, there was a mean year effect of 0.067 (see Appendix B), which equates to a multiplicative effect of $\exp(0.067) = 1.07$, a 7% increase in density each year over the surveyed period. Taking into account the model intercept of -6.858 (see Appendix B), which quantifies the mean density (per m^2) of vermilion rockfish across the state at the start of the survey period on the log scale, so: $\exp(-6.265) = 0.0019$ fish per m2 = 19.0 fish per hectare. Therefore, the increase in density in the first year is 19.0*1.07 = 20.3 fish per hectare, the second year 20.3*1.07 = 21.7 fish per hectare and so on. These calculations are ignoring all other modeled effects (e.g., spatial, depth and habitat differences).

Notably, the credible intervals were narrowest for the statewide models and regional models for the South, where the most data (statewide) and longest time-series (statewide and South region) were available for estimation.

*Table 2. Year effect trend estimates for the density of focal species in each region. Results are for coefficients on the linear predictor (log) scale. When credible intervals incorporate zero the effect is considered non-significant. Effects colored green are positive estimated effects, red are negative estimated effects and non-shaded are non-significant effects. * For brown rockfish, a region was defined region from Año Nuevo in the south to Reading Rock in the north (see Methods) and is included in the North results.*

Species	Statewide	North	Central	South
Grouped species	0.096 (0.09, 0.102)	0.124 (0.107, 0.141)	0.132 (0.117, 0.147)	0.095 (0.088, 0.103)
Copper rockfish	0.111 (0.100, 0.123)	0.088 (0.042, 0.134)	0.161 (0.111, 0.213)	0.111 (0.098, 0.123)
Vermilion rockfish	0.067 (0.058, 0.076)	0.172 (0.134, 0.212)	0.106 (0.082, 0.130)	0.062 (0.052, 0.073)
Gopher rockfish	0.157 (0.146, 0.170)	0.232 (0.178, 0.289)	0.183 (0.163, 0.204)	0.174 (0.159, 0.189)
Lingcod	0.044 (0.033, 0.054)	-0.063 (-0.085, -0.042)	0.042 (0.021, 0.063)	0.071 (0.057, 0.086)
California sheephead				0.122 (0.110, 0.133)
Canary rockfish		0.078 (0.048, 0.078)	0.041 (0.003, 0.080)	
Quillback rockfish		0.129 (0.096, 0.162)		
Yelloweye rockfish		0.116 (0.086, 0.147)	0.116 (0.051, 0.184)	
Kelp greenling		-0.011 (-0.029, 0.007)	-0.024 (-0.053, 0.004)	
Brown rockfish *		0.117 (0.128, 0.228)		

Overall statewide and regional trends in the density of large focal species

Overall regional trends in the density of large fish, excluding any MPA-specific effects, also showed positive trends for most species modeled (Table 3). For grouped species, copper rockfish, and vermilion rockfish modeled statewide and regional responses were positive. Lingcod showed positive trends in the North region, but negative trends in the statewide, Central and South regions implying a decrease in the abundance of large lingcod in those regions over the survey period. Kelp greenling also showed negative responses in the North and Central regions. Canary rockfish in the Central region, quillback rockfish in the North region, and yelloweye rockfish in the Central region showed non-significant results for the density of large fish. Brown rockfish showed an increase in the modeled region (Año Nuevo – Reading Rock). Coefficient estimates for trajectories ranged from a mean of -0.174 for lingcod in the North to a mean of 0.326 for gopher rockfish in the Central region (Table 3).

The year effect coefficients are again on the linear predictor (log) scale and equate to multiplicative effects when exponentiated. For example, considering the statewide model for large vermilion rockfish, there was a mean year effect of 0.275 (see Appendix B), which equates to a multiplicative effect of $\exp(0.275) = 1.32$, an 32% increase in density each year over the surveyed period. Taking into account the model intercept of -7.417 (see Appendix B), which quantifies the mean density (per m^2) of vermilion rockfish across the state at the start of the survey period on the log scale, so: $\exp(-7.417) = 0.0006$ fish per m2 = 6 large fish per hectare. Therefore, the increase in density in the first year is 6*1.32 = 7.92 fish per hectare; the second year 7.92*1.32 = 10.45 and so on. These calculations are ignoring all other modeled effects (e.g., spatial, depth and habitat differences).

Like the density results for the year effect, the credible intervals were narrowest for the statewide models and regional models for the South, where the most data (statewide) and longest time-series (statewide and South region) were available for estimation. However, credible intervals were wider for the density of large fish results likely due to the shorter time-series of data available (2014 onwards).

*Table 3. Year effect trend estimates for the density of large focal species in each region. Results are for coefficients on the linear predictor (log) scale. When credible intervals incorporate zero the effect is considered non-significant. Effects colored green are positive estimated effects, red are negative estimated effects and non-shaded are non-significant effects. * For brown rockfish, a region was defined region from Año Nuevo in the south to Reading Rock in the north (see Methods) and is included in the North results.*

Species	Statewide	North	Central	South
Grouped species	0.088 (0.075, 0.101)	0.08 (0.056, 0.103)	0.086 (0.050, 0.122)	0.087 (0.070, 0.105)
Copper rockfish	0.074 (0.051, 0.097)	0.059 (0.003, 0.116)	0.101 (0.030, 0.174)	0.111 (0.098, 0.123)
Vermilion rockfish	0.096 (0.079, 0.112)	0.130 (0.085, 0.177)	0.142 (0.098, 0.187)	0.084 (0.063, 0.104)
Lingcod	-0.077 (-1.02, - 0.052)	0.055 (0.015, 0.095)	-0.174 (-0.227, -0.122)	-0.158 (-0.206, -0.111)
Gopher rockfish			0.326 (0.213, 0.446)	0.182 (0.105, 0.260)
Canary rockfish		0.093 (0.050, 0.137)	-0.039 (-0.106, 0.028)	
Quillback rockfish		0.042 (-0.007, 0.092)		
Yelloweye rockfish		0.084 (0.031, 0.137)	-0.059 (-0.192, 0.074)	
Kelp greenling		-0.069 (-0.094, -0.044)	-0.152 (-0.201, -0.104)	
Brown rockfish *		0.151 (0.082, 0.222)		

Statewide and regional MPA effects: density of focal species

Significant positive MPA effects on density were found for all species modeled statewide, and for 14 out of the 24 species/bioregion combinations modeled (Figure 4). No negative coefficients for MPA effects were found, with significant positive MPA effects found for grouped species, copper rockfish, lingcod, canary rockfish, quillback rockfish and kelp greenling in the North; grouped species, copper rockfish, vermilion rockfish, gopher rockfish, and lingcod in the Central region; copper rockfish and California sheephead in the South region; and for brown rockfish in the north-central region from Año Nuevo to Reading Rock used for this species. Coefficients for positive MPA effects ranged from 0.108 for vermilion rockfish in the statewide model to 0.679 for gopher rockfish in the Central region. Therefore, all positive MPA effects fell within the range of $0 < \beta_{MPA} < 1$, which describes a positive trajectory tending towards an asymptote through time (see Figure 3).

Based on the model-based mean estimates of the MPA effect and the intercepts for the statewide models, the ratio of density (and hence abundance) over the 17-year survey period shows the strongest response for gopher rockfish, followed by copper rockfish, lingcod, and vermilion rockfish (Figure 5). For gopher rockfish the MPA effect estimate indicates there has been an almost three-fold increase in density inside MPAs, an approximate 2.75-fold increase in copper rockfish, an approximate 1.25-fold increase for lingcod and vermilion rockfish when compared to reference areas.

Like the year effect results in previous sections, credible intervals for the coefficient of MPA effects were narrowest in the statewide and South region models where the most data was available for estimation.

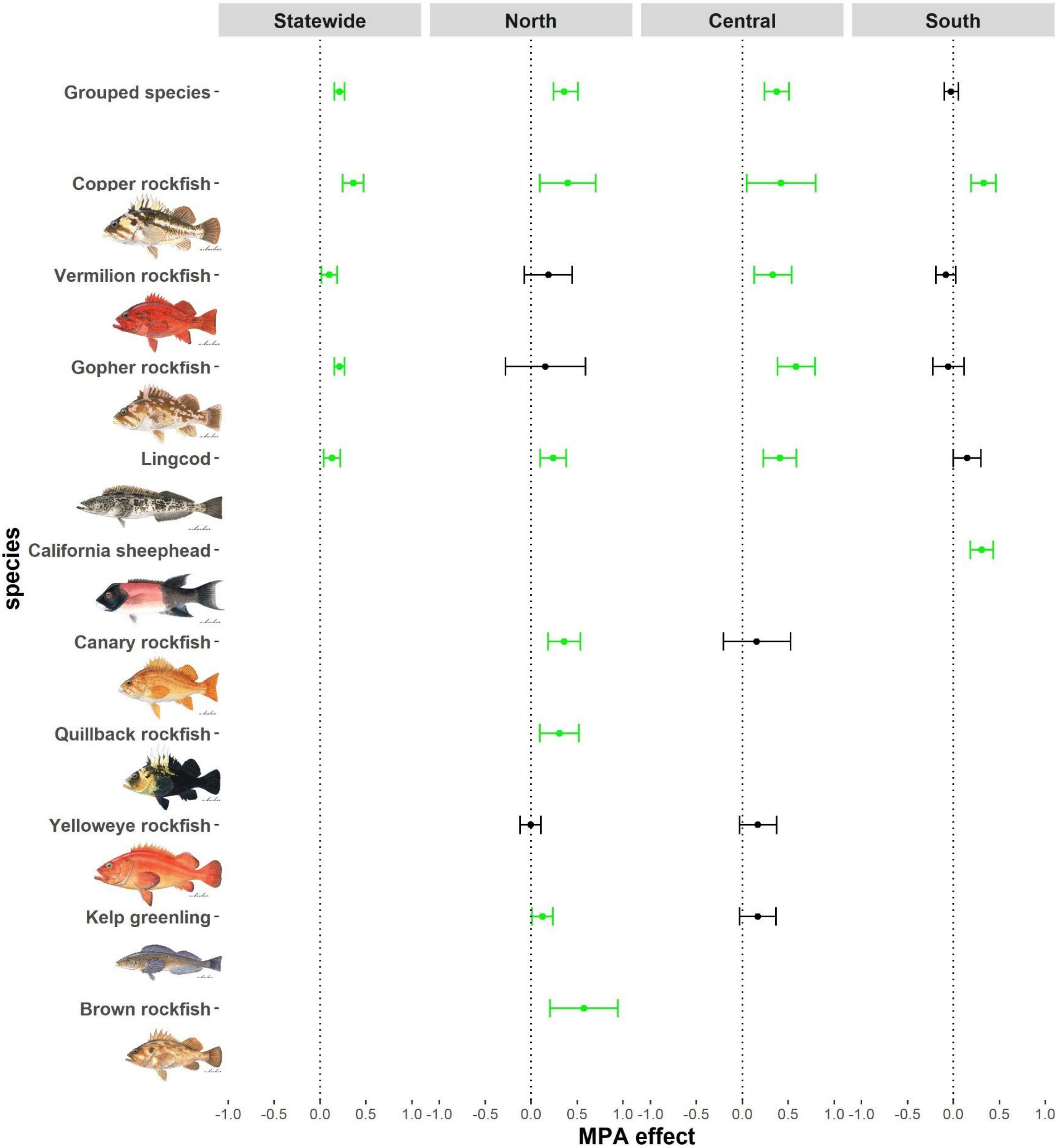

*Figure 4. Statewide and regional MPA effects for modeled focal species. Results are for coefficients on the linear predictor (log) scale. The dashed line represents a zero effect and when credible intervals incorporate zero the effect is considered non-significant. Dots and error bars colored green are positive estimated effect, red are negative estimated effects and black are non-significant effects. * For brown rockfish, a region was defined region from Año Nuevo in the south to Reading Rock in the north (see Methods) and is included in the North results.*

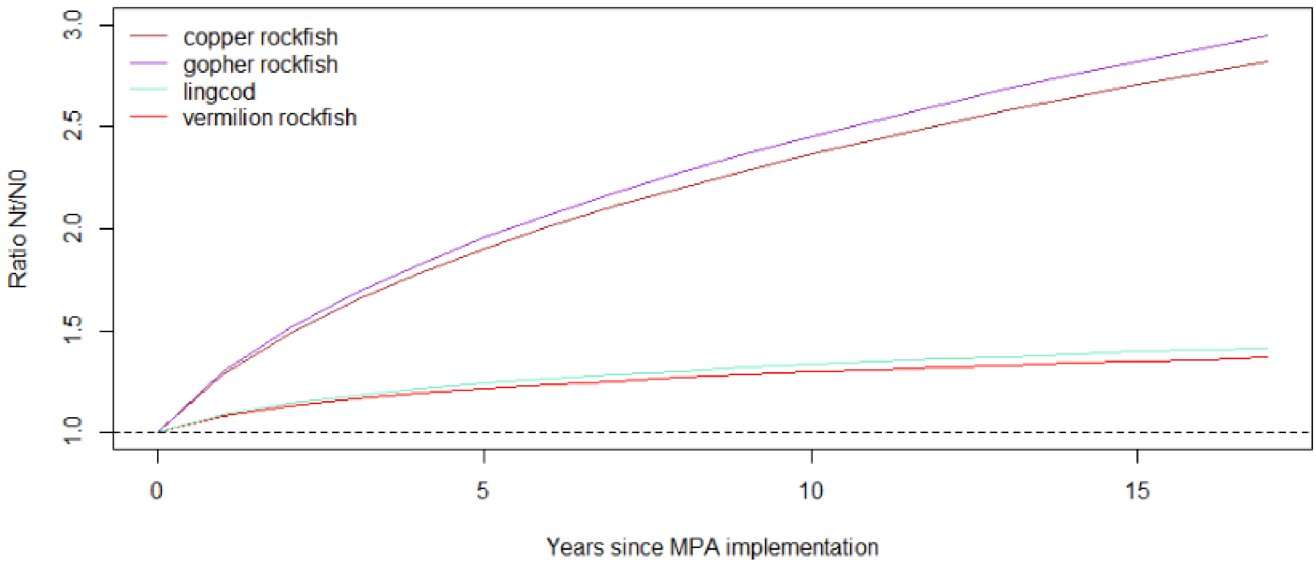

Figure 5. The mean MPA effect based on the statewide models for copper rockfish, gopher rockfish, lingcod and vermilion rockfish shown as a ratio through time compared to the abundance at the start of the survey (Nt/N0). The dashed line illustrates no change (multiplication factor of 1) for comparative purposes.

Regional MPA effects: density of large focal species

Significant positive MPA effects on density of large fish were found for all species modeled statewide, and for 7 out of the 22 species/bioregion combinations modeled (Figure 6). Significant positive effects found for grouped species, copper rockfish, and quillback rockfish in the North; grouped species in the Central region; and grouped species, copper rockfish, vermilion rockfish in the South region. Negative coefficients for MPA effects were found for gopher rockfish and lingcod in the South region. Coefficients for positive MPA effects ranged from 0.234 for grouped species in the South region to 0.681 for grouped species in the Central region. Therefore, all positive MPA effects once again fell within the range of $0 < \beta_{MPA} < 1$, which describes a positive trajectory tending towards an asymptote through time (see Figure 3). However, positive MPA effect sizes tended to be larger for the density of large fish compared to the density of all fish for a given species.

Based on the model-based mean estimates of the MPA effect and the intercepts for the statewide models, the ratio of density (and hence abundance) over the 17-year survey period shows the strongest response for large copper rockfish, followed by lingcod and vermilion rockfish (Figure 7). For large copper rockfish the MPA effect estimate indicates there has been an approximate 4.5-fold increase in density of large copper rockfish inside MPAs, an approximate two-fold increase for lingcod and an approximate 1.75-fold increase for vermilion rockfish when compared to reference areas.

Like the year effect results in previous sections, credible intervals for the coefficient of MPA effects were narrowest in the statewide and South region models where the most data was available for estimation.

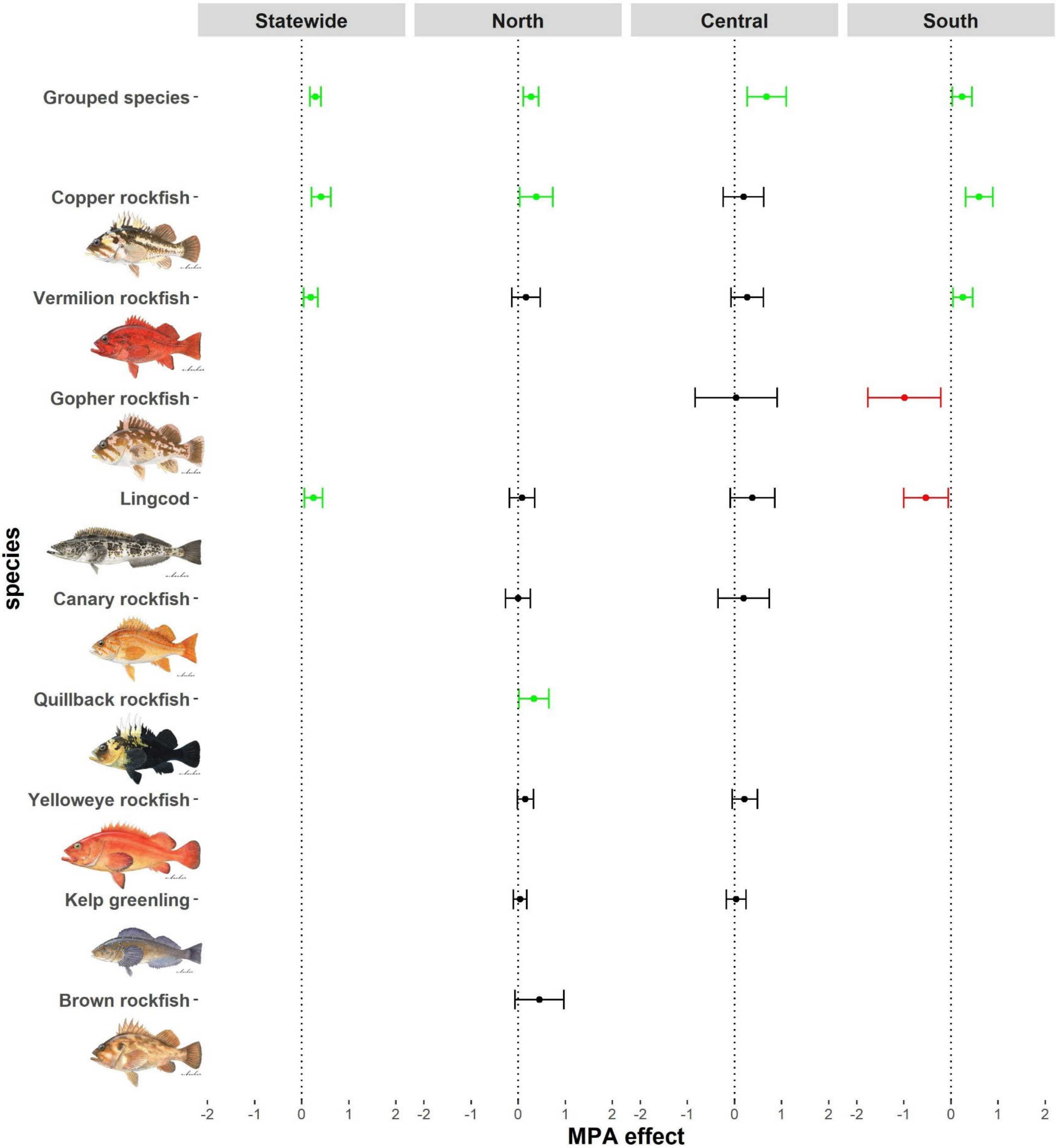

*Figure 6. Statewide and regional MPA effects for large (> 30 cm for rockfish and kelp greenling, and > 55 cm for lingcod) modeled focal species. Results are for coefficients on the linear predictor (log) scale. The dashed line represents a zero effect and when credible intervals incorporate zero the effect is considered non-significant. Dots and error bars colored green are positive estimated effect, red are negative estimated effects and black are non-significant effects. * For brown rockfish, a region was defined region from Año Nuevo in the south to Reading Rock in the north (see Methods) and is included in the North results.*

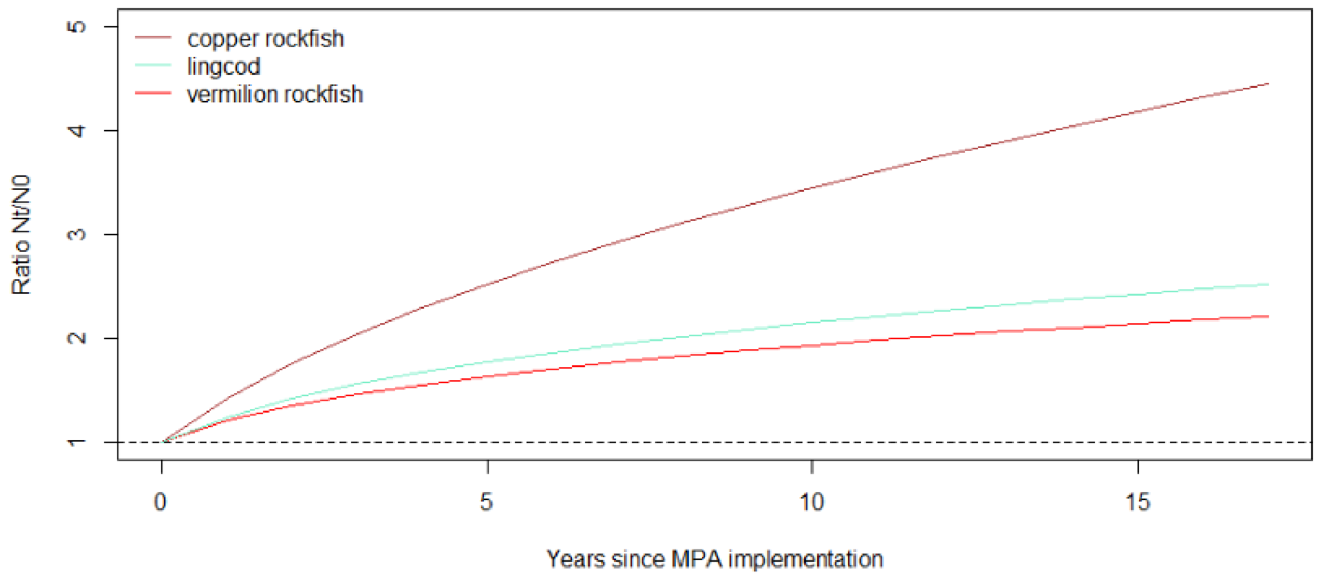

Figure 7. The mean MPA effect based on the statewide models for large copper rockfish, lingcod and vermilion rockfish shown as a ratio through time compared to the abundance of large fish at the start of the survey (Nt/N0). The dashed line illustrates no change (multiplication factor of 1) for comparative purposes.

Individual MPA effects: density of focal species

Estimates for individual MPA responses were much more varied than in the statewide and regional models, with some mean effect sizes exceeding 1 and -1, and much wider credible intervals (Figure 8). A number of MPAs were found to be having positive effects on the density of a number of the focal species modeled, and generally, positive effects were found for more than one species at MPAs where positive effects were found, with the exception being California sheephead at Anacapa Island SMR (Figure 8).

In the North region, Bodega Bay SMR showed the most positive responses, with positive MPA effects for all species modeled except gopher rockfish and yelloweye rockfish which showed non-significant responses. The Southeast Farallon Islands SMR/SMCA had 5 out of the 10 species showing a positive MPA effects, with positive MPA effects for grouped species, copper rockfish, lingcod, canary rockfish, and quillback rockfish. Reading Rock SMR showed positive responses for 4 out of the 10 species modeled, with grouped species, lingcod, quillback rockfish, yelloweye rockfish and kelp greenling all showing positive responses. Point Arena SMR/SMCA showed positive MPA effects for 4 out of 9 species modeled, with positive MPA effects for grouped species, lingcod, canary rockfish, and quillback rockfish. Point St. George Reef Offshore SMCA showed positive responses for lingcod and kelp greenling. Wide credible intervals were found for gopher rockfish across MPAs in the North region, likely connected to lower abundances and more variation in densities across the time-series related to these lower densities.

In the Central region, Point Lobos SMR showed the most positive responses, with positive MPA effects for 6 out of the 8 species modeled, including grouped species, copper rockfish, gopher rockfish, lingcod, canary rockfish, and kelp greenling. Point Sur SMR/SMCA showed positive MPA effects for 3 out of 8 species modeled, with grouped species, vermilion rockfish, and gopher rockfish all showing positive effects. Point Buchon SMR also had positive MPA effects for grouped species, vermilion rockfish, and gopher rockfish. Montara/Pillar Point SMR/SMCA (treated as a combined MPA) showed positive MPA effects for vermilion rockfish and gopher rockfish.

In the South region, responses were more varied with Gull Island SMR showing positive responses for 4 out of the 6 species modeled, and South Point SMR showing positive responses for 3 out of 6 species modeled. Gull Island SMR had positive MPA effects for grouped species, copper rockfish, lingcod, and California sheephead. At South Point SMR there were positive responses for grouped species, copper rockfish and lingcod. Harris Point SMR showed positive MPA effects for copper rockfish and lingcod. South La Jolla SMR/SMCA showed positive MPA effects for grouped species and California sheephead. Swami's SMCA showed positive MPA effects for grouped species and vermilion rockfish. Anacapa Island SMR/SMCA only showed a positive MPA effect for California sheephead. Credible intervals of estimates were mostly smaller for species in the South region compared to the other regions.

Some negative coefficients were found for particular MPA-species combinations. These were, in the North region: vermilion rockfish at Point St. George Reef Offshore SMCA, and lingcod and kelp greenling at Ten Mile SMR; in the Central region: grouped species and kelp greenling at Montara/Pillar Point SMR/SMCA, and grouped species, copper rockfish, canary rockfish, and lingcod at Portuguese Ledge SMCA; and in the South region: grouped species, vermilion rockfish, gopher rockfish and lingcod at Anacapa Island SMR/SMCA, vermilion rockfish and lingcod at Campus Point SMCA, grouped species and vermilion rockfish at Carrington Point SMR, lingcod at Farnsworth Offshore SMCA, gopher rockfish and lingcod at Point Conception SMR, and lingcod at South La Jolla SMR/SMCA. In the south, negative coefficients for effects were therefore spatially around northern mainland MPAs and Anacapa Island SMR/SMCA in the eastern part of the Channel Islands. They were also mainly found for vermilion rockfish, lingcod and grouped species. It should be noted that vermilion rockfish are dominant in the species composition of grouped species in the south, comprising of between 42% (in 2015) and 69% (in 2007) of the grouped species through time. Therefore, patterns seen in vermilion species are likely to have a large influence on the grouped species response.

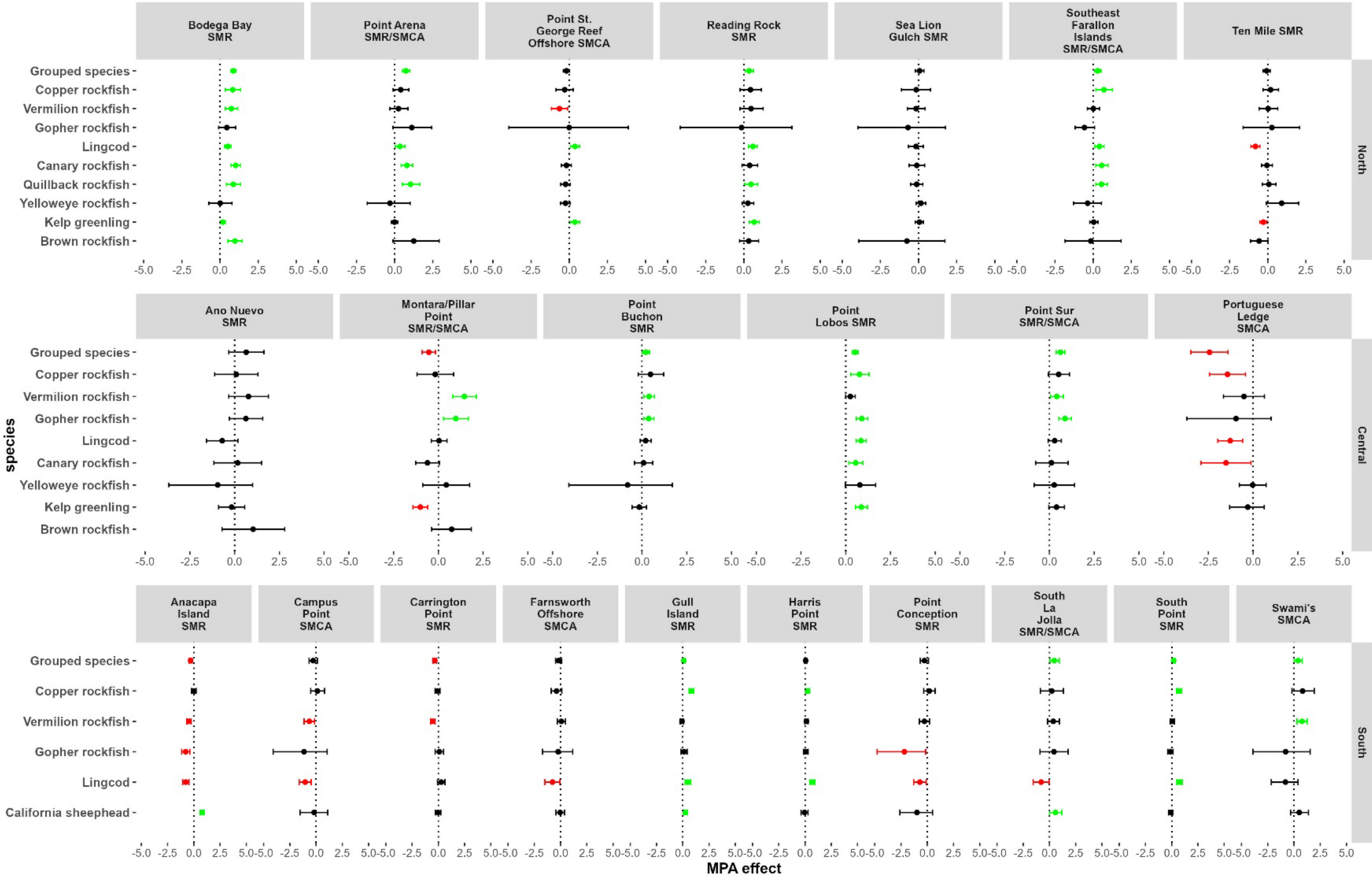

*Figure 8. Individual MPA effects for MPAs nested within bioregions. Results are for coefficients on the linear predictor (log) scale. The dashed line represents a zero effect and when credible intervals incorporate zero the effect is considered non-significant. Dots and error bars colored green are positive estimated effect, red are negative estimated effects and black are non-significant effects. * For brown rockfish, a region was defined region from Año Nuevo in the south to Reading Rock in the north (see Methods) and is included in the North results. Note that credible intervals are much wider (from -5 to 5) than results shown for statewide and regional model outputs.*

Model comparison: statewide versus regional versus individual MPA

Comparison of model fits to the data using marginal log-likelihoods showed consistent strong improvements in the model fits to the data when moving from statewide, to regional, to MPA-specific model specifications (Table 5 and Appendix B). This indicates that additional variation is being captured at either the regional or MPA level that is not captured by the spatial random effects in the statewide or regional models respectively.

Table 4. Model marginal log-likelihoods for selected species for statewide, regional, and nested MPA specific models. Higher values indicate improved model fits to the data. All model marginal log-likelihoods can be found in Appendix B.

Species	Statewide	Regional	MPA
Grouped species	-63677.74	-63552.47	-63479.67
Vermilion rockfish	-29001.41	-28924.53	-28903.44
Copper rockfish	-16643.79	-16641.61	-16613.69
Lingcod	-21526.32	-21431.75	-21328.33

The importance of spatial autocorrelation and incorporating rugosity

For the density models presented in the previous sections, estimates for the mean of the spatial range parameter spanned from 2.3 km to 293.5 km, but mostly around 3-6 km. Mean spatial standard deviations from 1.7 to 3.6 (Appendix B). This is indicative of moderate-to-high levels of spatial autocorrelation (quantified by the spatial standard deviation) operating over scales that typically encompass individual MPAs and their nearby reference areas. For the density of large fish models spatial range parameters were as large as 314 km (for yelloweye rockfish), and spatial standard deviations spanned from 0.45 to 6.46 (Appendix B). This is indicative of low-to-very high levels of spatial autocorrelation potentially operating over large scales, but generally on smaller MPA-specific scales.

For the three models compared for vermilion rockfish in the Central region, inferences drawn are markedly different, in particular for the MPA effects (Figure 9). All models have positive estimates for Point Sur SMR, but the non-spatial models both had positive effect for Point Lobos SMR and Año Nuevo SMR, while the spatial model had non-significant MPA effects for both these MPAs. Also, the full spatial model had positive MPA effect estimates for Point Buchon SMR and Montara/Pillar Point SMR/SMCA, while the non-spatial models had either non-significant or negative effects for these MPAs. Credible intervals for all fixed effects were wider in the full spatial model, especially for the MPA effects and coastal distance effects.

Interpretation of the importance of environmental covariates was largely the same for all three models, with positive effects for depth, proportion hard, proportion mixed, and year, and negative effects for depth-squared (Figure 9). However, coastal distance and coastal distance squared were both positive effects in the base model, and negative and positive respectively in the rugosity model, but became non-significant in the full spatial model. Rugosity had a positive effect on density in both models where it was included as a covariate, indicating an increased density of vermilion rockfish is correlated with increasing rugosity at a scale of 20 meters.

The model fit diagnostics based on the change in marginal log-likelihood (MLL) of the model's showed a large improvement in model fit when including rugosity in the model, and a dramatic improvement in model fit when including SAC (Table 5 and Appendix B).

Improvements in the MLL both indicative decisive evidence for the improvement in model fit to the data when including rugosity, and especially when incorporating spatial effects where a marked improvement in model fit was observed.

Table 5. Model marginal log-likelihoods for the three tested models for vermilion rockfish in the Central region

Model	Marginal log-likelihood (MLL)	Change in MLL
Base model	-4341.57	-
Rugosity model	-4333.39	8.18
Full Spatial model	-4319.22	22.35

Estimates for the spatial parameters in the full spatial model were a spatial range of 8.287 km (95% credible intervals 3.817 – 15.868 km) and a spatial standard deviation of 1.299 (95% credible intervals 0.628 – 2.385). This indicates that moderate to high spatial autocorrelation exists in this data at scales that encompass MPAs and their nearby reference areas. A plot of the resultant spatial random field from this model (Figure 10) shows that there are areas of higher and lower residual SAC that cannot be explained by the model covariates (environmental covariates including rugosity, year effects and MPA effects) alone. Note that in areas where there is no survey data the spatial effects are zero.

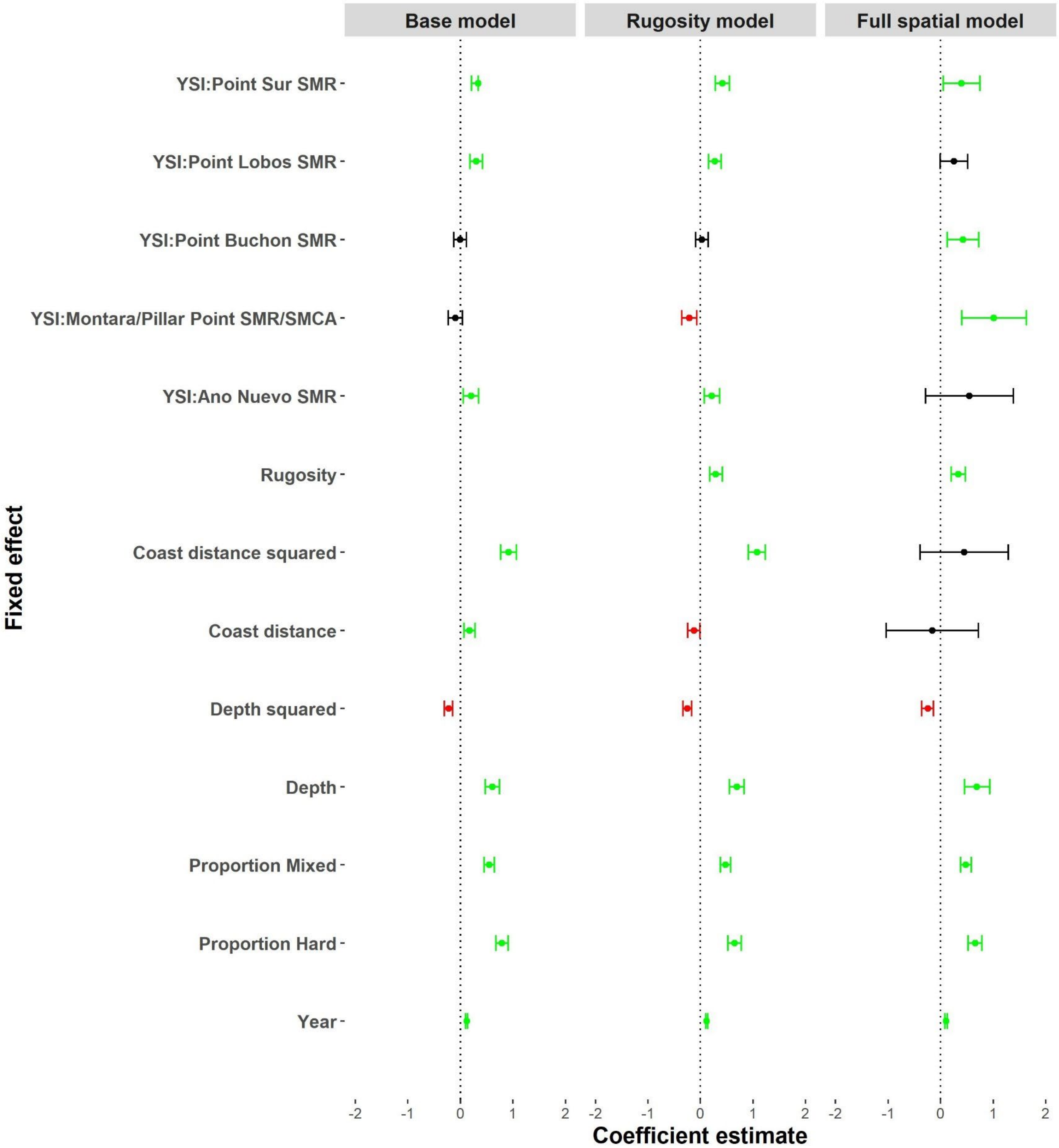

Figure 9. Model coefficient estimates for the three models tested for vermilion rockfish density in the Central region. Results are for coefficients on the linear predictor (log) scale. The dashed line represents a zero effect and when credible intervals incorporate zero the effect is considered non-significant. Dots and error bars colored green are positive estimated effect, red are negative estimated effects and black are non-significant effects. The base model was non-spatial and included all environmental covariates except rugosity, the rugosity model was non-spatial and included all environmental covariates and rugosity, and the full spatial model included all environmental covariates, rugosity, and spatial random effects.

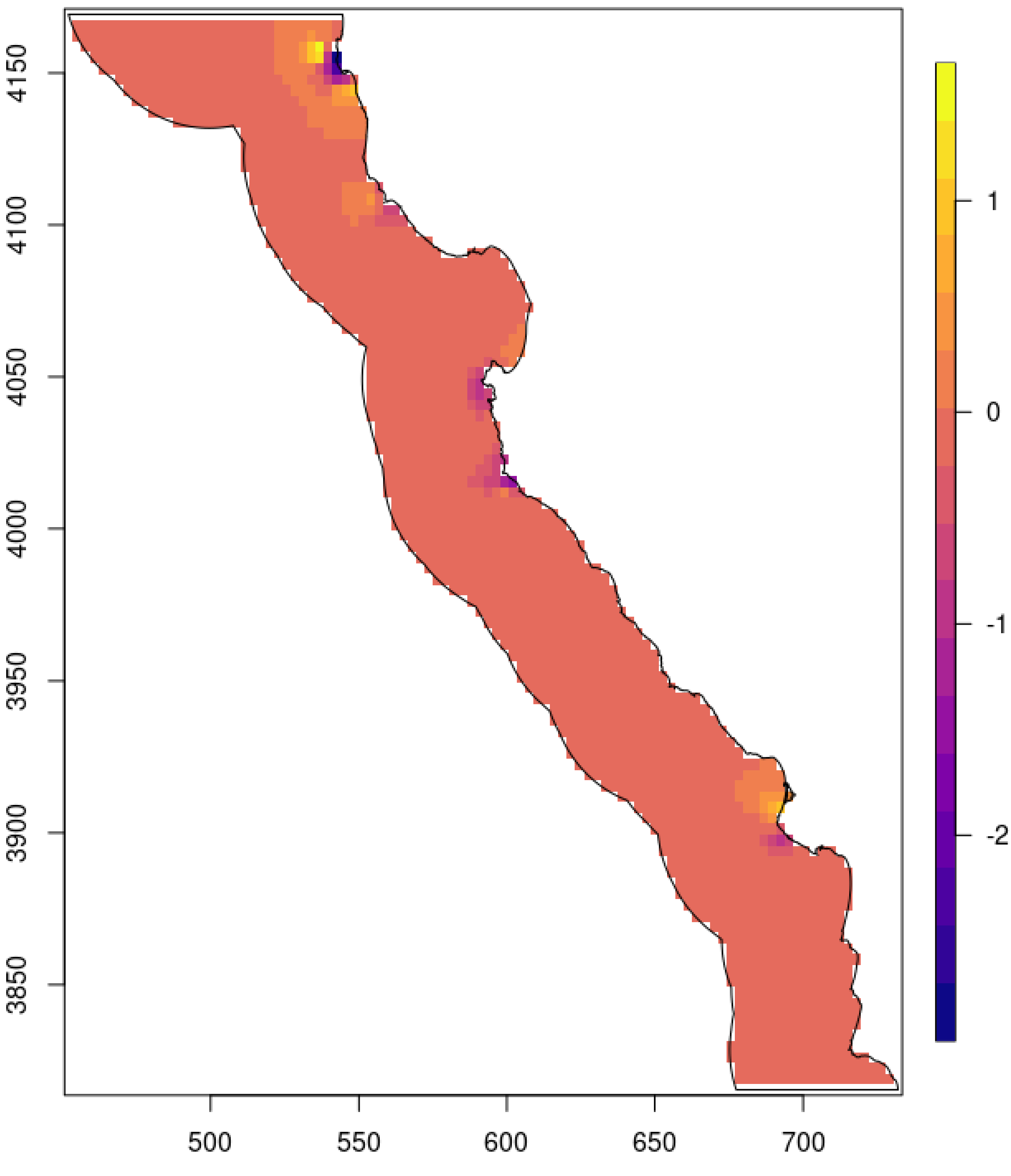

Figure 10. Modeled spatial random field for the full spatial model for vermilion rockfish across the Central region. The scale bar on the right shows the scale of the spatial effects with lighter (yellow) colors indicating higher than explained densities and darker (purple) colors indicating lower densities than explained by model covariates.

Discussion

Spatially and temporally extensive surveys of mid-depth reefs across California's MPA Network using an ROV have reveled encouraging signs of statewide and regional recovery in density and size structure, and the positive contribution of MPAs, for a number of key focal species. This suggests successful management of stocks over recent decades through a combination of fisheries management efforts such as quota setting, spatial closures such as rockfish conservation areas, and the establishment of MPAs. While the contribution of each of these measures may be hard to disentangle, results presented in this report show that the establishment of a statewide network of MPAs is benefiting the density and size structure of many previously fished species within MPA boundaries. Due to increases in density and the density of larger fish inside MPAs, MPAs are also likely to be having positive effects on larval supply and hence density outside MPAs across the Network; however, the magnitude of this 'seeding effect' remains to be quantified. Also, MPAs may also be benefitting reference areas through 'spillover effects' where fish inside MPAs move outside MPA boundaries; however, this also needs to be quantified in future work such as tagging studies. Results presented in this report show that the effects of MPAs are consistently more detectable at larger regional and statewide scales, that is, network-wide effects, compared to effects at the individual MPA level where considerably larger uncertainty exists. Statewide MPA Network effects were positive for all focal species modeled at the statewide scale (i.e., grouped species, vermilion rockfish, copper rockfish, gopher rockfish and lingcod). Positive regional effects on density were found for 14 of the 24 species/region combinations tested and for 7 out of 22 species/region combinations when considering larger fish. Despite the increased uncertainty when examining individual MPA effects, positive effects were found for a number of MPA-species combinations, with some individual MPAs such as Bodega Bay SMR showing positive MPA effects for the majority of species modeled.

The models used for the ROV data in this report incorporated important environmental covariates such as distance along coast (a proxy for latitude), depth, and habitat, and included spatial dependence in the data by explicitly modeling the effect of spatial autocorrelation (SAC). While the importance of environmental covariates such as depth and habitat on fish density is well established, the influence of SAC is less commonly explored. We show that the inclusion of spatial effects is crucial in our study, as both the direction of effects and the associated uncertainty may be quite different if SAC is not accounted for, and inferences drawn would be markedly different.

The findings of this report are important as they: (i) highlight the capability of ROV-based surveys of mid-depth reefs to detect regional changes and MPA effects; (ii) provide a robust modeling approach for ROV data that incorporates environmental covariates and SAC, which is shown to be important for ROV data; (iii) emphasize the importance of collecting spatially and temporally extensive data when aiming to quantify regional and network-wide MPA effects; and (iv) point to some important considerations for survey design when developing an ongoing monitoring program for California's MPA Network. We discuss these findings in more detail below and make recommendations for ongoing monitoring and next steps to be taken with the data set.

Statewide, regional, and individual MPA effects

A pattern of increasing detectability of positive MPA effects with smaller associated uncertainties was found with the increasing spatial scale of analysis. Positive effects of MPA establishment were found network-wide for all species modeled that had distributions spanning the state. Also, a larger proportion of positive MPA effects were found in regional models compared to MPA specific models, where there was much higher uncertainty around effect sizes. This pattern is likely to be driven by more data being available as a larger number of MPAs and their reference sites are included, providing more certainty in estimates. These findings align with expectations from previous work on ROV data, which showed that the greatest improvements in the statistical power to detect change were achieved by including more sites (Perkins et al. 2020b). This previous work showed that while considerable effort is likely to be required at an individual MPA, incorporating data from just three MPAs across a simulated time-series of expected MPA effects vastly improved the ability to detect change. This finding is echoed in a similar study that tested the ability to detect changes in abundance through time, which found that including more sites with less frequent revisits had a much larger influence in detecting temporal trends compared to more frequent revisits to a smaller number of sites (Andersen et al. 2019). The statewide models included data from 23 MPAs, and the regional models 7, 6 and 10 MPAs for the North, Central and South regions respectively. Furthermore, additional MPAs that currently have short associated time-series of surveys will be included in upcoming efforts further expanding the spatial and temporal extent of data available. These findings have important implications when considering ongoing monitoring designs which are discussed in more detail below.

Smaller uncertainties in MPA effects were also observed with increasing time-series available within regions and at individual MPAs. The importance of a sufficiently long time-series (typically > 15-20 years; Starr et al. 2015, Kaplan et al. 2019, Perkins et al. 2020b) to detect trends is also emphasized by the large number of positive results found for the Central region in this report compared to an earlier report which did not include the 2021 data, where many MPA effects were suggestive of a positive effect but not yet statistically significant (Perkins and Lauermann 2022). Also, smaller credible intervals in MPA effects were observed in the South region, where the longest time-series of surveys was available. However, a larger number of non-significant or negative coefficients for MPA effects were also found in the South region. The reason for this is currently unclear but could possibly be related to poor recruitment years over the survey period. Also, the South region is complex and includes large biogeographical differences across mainland and Channel Island MPAs (Caselle et al. 2015). Hamilton et al. (2010) showed that incorporating biogeography into models of the Channel Islands SCUBA survey data vastly improved model fits. This suggests an avenue of future exploration with the ROV data through incorporation of additional covariates such as bioregions, other habitat variables that include the occurrence of other species (e.g., kelp cover inshore or invertebrate cover), measures of fishing effort such as distance from port, recruitment sources/sinks based on ocean circulation etc. and testing their influence on the patterns observed.

A comparison of models using the marginal log-likelihoods showed that MPA specific models fit the data better than regional models, which in turn fit the data better than statewide models. This indicates that models that include regional or MPA-specific trends are capturing additional variation that is not being modeled by the spatial random effects. This result is perhaps not surprising and implies that models that include MPA specific effects are to be preferred as they capture trends at individual MPAs better than using spatial random effects alone. However, if reporting at a regional or statewide scale is a management priority then the alternative regional and statewide models are necessary. Furthermore, patterns in a much larger data set may be more evident as the results in this report show that there are large spatial differences between MPAs that are not captured well with the covariates currently being used.

Quantifying the MPA effect

The specification used to quantify the MPA effect in this study was chosen as it aligns with theoretical expectations of population recovery with MPA establishment, where population densities within MPAs reach an asymptote through time as they return to pre-fished levels (e.g., White et al. 2013, Kaplan et al. 2019, Nickols et al. 2019). Other possible specifications such as the response ratio (MPA/reference) or a simple linear term can be interpreted in a similar fashion, with positive and negative coefficients relating to positive or negative linear trends through time. However, the expected reaching of an asymptote through time as density-dependent effects are reached will not be captured with simple linear terms. If the expected response is an asymptote, this means that as the time series accumulates the slope of a linear term such as a response ratio, which quantifies the MPA effect will become smaller through time as the slope of the line flattens. Therefore, care would need to be taken in misinterpreting this as a reduction in the MPA effect, when in fact it is an expected result. The use of a functional form for expected time-series responses has been used elsewhere (e.g., Vanhatalo et al. 2017) and should be considered where ecological theory suggests such a form is warranted.

MPA effects compared to theoretical expectations

Theoretical expectations of magnitudes and rates of change in the abundance and size structure of previously fished populations following MPA establishment can allow comparisons with empirical responses in an adaptive management framework (Nickols et al. 2019). Previous modeling of individual species responses to MPA establishment highlighted that life history traits combined with recruitment variability and pre-establishment fishing effort could be used to project likely recovery times and response sizes (Kaplan et al. 2019). These models predicted the time it would take for species abundance and biomass to reach asymptotes and the magnitude of these asymptotes (see Appendix C for modeled outputs of abundance responses). Results show that theoretical expectations for changes in abundance of the species modeled in the present study are for the largest and most detectable response to be from vermilion rockfish (2.23-fold change with an asymptote at 24 years), followed by copper rockfish (1.79-fold change with an asymptote at 22 years), California sheephead (1.78-fold change with an asymptote at 9 years), brown rockfish (1.76-fold change with an asymptote at 15 years), lingcod (1.72-fold change with an asymptote at 9 years), gopher rockfish (1.72-fold change with an asymptote at 9 years), and kelp greenling (1.69-fold change with an asymptote at 10 years). Our results, based on the density of focal species statewide, show the largest change in abundance due to MPA establishment was for gopher rockfish with an almost three-fold increase over 17 years followed by copper rockfish with an approximate 2.75-fold increase in MPAs compared to reference areas. Thus, for both gopher and copper rockfish MPA effects at a statewide scale are currently exceeding theoretical expectations. For lingcod, there was an approximate 1.25-fold increase in the statewide model, indicating a lower-than-expected response compared to expectations. For vermilion rockfish also, there was a markedly lower than expected response with only an approximate 1.25-fold increase over 17 years, with a greater than two-fold increase expected at the 17-year mark. However, vermilion rockfish are expected to take longer to reach theoretical asymptotes (24 years), and therefore trajectories over the next decade should be monitored closely. Also, research shows that vermilion rockfish are part of a complex that includes both vermilion and sunset rockfish, which are hard to distinguish morphologically (Hyde et al. 2008, Keller et al. 2022). Vermilion and sunset rockfish occupy different but overlapping depth and latitudinal gradients, and different trends in the populations of each could complicate any patterns observed. For example, observations could include ontogenic migration from shallower kelp beds to deeper waters for both species, with sunset rockfish adults finally settling in deeper (> 100 m) waters (Hyde et al. 2008).

Metrics for quantifying the MPA effect

In the present study, two metrics for quantifying the MPA effect were explored: density and the density of large fish. Density was chosen as it directly addresses questions of recovery in the abundance of previously fished species, while the density of large fish quantifies the recovery of larger individuals in the size structure of populations which have been previously truncated due to fishing pressure. Metrics that relate to the size structure of populations are expected to be detectable earlier than measures of abundance such as density, which may be highly variable in the early stages after MPA establishment (White et al. 2013, Nickols et al. 2019). We found that positive MPA effect sizes, where detected, were generally larger for the density of large fish, therefore aligning with expectations. However, the shorter time-series of size-structure data available in this study (only 2014 onwards) is likely hampering the ability to detect MPA effects in some cases and could be addressed with scoring the size structure of pre-2014 deployments. Another potential is to use length at maturity for each species as a size-based cut-off, which would allow quantification of spawning biomass, aligning with stock assessments. Biomass is another alternative metric that simultaneously captures the abundance and size of populations and could be explored in future work with the ROV data set. Biomass is expected to provide larger effect sizes than abundance and therefore provide a metric that allows improved detectability of MPA effects. However, any errors in length measurement will be amplified when converting to biomass due to the power relationship required to convert length to weight. Therefore, an assessment of the accuracy of sizing information from ROV imagery would be informative prior to further exploration of metrics that incorporate size information.

Implications for long-term monitoring

As focus shifts to the long-term monitoring plan for California's MPA network, the results of spatially and temporally extensive surveys conducted to-date, such as the present study, contain important messages for ongoing survey design. The large number of positive effects found at statewide and regional levels in this study highlight how including a larger number of MPAs aids in detecting MPA effects at these larger scales. In contrast, a smaller number of positive effects were found at individual MPAs. Increasing the level of sampling at an individual MPA will increase the power to detect the influence of protection at that MPA in a shorter timeframe. Increased sampling (more transects) at a smaller number of MPAs has been suggested as possible path forward for future monitoring with the ROV to allow better detection of individual MPA effects (Starr et al. 2021). A simulation study based on the current ROV methodology showed that while increasing the number of transects at an individual MPA will reduce the time to detect changes at those MPAs, including 3 MPAs provides a larger increase in power to detect MPA effects (Perkins et al. 2020b). This is supported by the findings in this report, where regional and statewide effects are evident when a large number of MPAs (7-23) are included compared to examining individual MPAs. Furthermore, individual MPA effects were detected at some individual MPAs, with reduced uncertainty with longer time-series, implying the importance of revisiting MPAs that already have an established time-series in an ongoing monitoring plan. Thus, prioritizing increasing survey effort at a smaller number of MPAs may help with detecting change sooner at those MPAs, but if this is done at the expense of including other MPAs in ongoing plans, network-wide effects may be harder to detect or biased by the results of the limited number of MPAs chosen.

‘Preferential’ or ‘judgement’ sampling is the selection of sampling units hand-picked by researchers and/or managers, usually with the aim to be “representative” (Olsen et al. 1999, McDonald 2003). Such a survey design excludes any probabilistic sampling process and has an underlying assumption that sampled units are representative of non-sampled units. In California’s MPA Network, which has been demonstrated to exhibit high spatial and temporal variability in both this study and elsewhere (e.g., Hamilton et al. 2010, Caselle et al. 2015), such an assumption is likely to be hard to justify. Furthermore, without sampling other MPAs the representativeness of selected MPAs cannot be assessed. Thus, resource managers should carefully consider the focal questions for ongoing monitoring and how these questions should best be prioritized with different monitoring designs. For example, if the primary focus is quantifying network-wide effects then incorporating sufficient spatial coverage and number of MPAs in ongoing surveys should be prioritized in the monitoring plan. Survey designs that strike a balance between temporal revisits and the sites that are visited through time exist, and ideally should be informed by existing knowledge of spatial and temporal variability across the system (Urquhart and Kincaid 1999, Larsen et al. 2001, McDonald 2003, Urquhart 2012, Perkins et al. 2017). Given the reduction in uncertainty observed with the increased number of revisits in the present work, perhaps revisits to MPAs that currently have a small number of temporal repeats should be prioritized. Designing a comprehensive monitoring plan is undoubtedly a complex process that needs to be informed by current best knowledge of system dynamics and guided by clear and concise research questions.

The importance of incorporating spatial autocorrelation

Spatial autocorrelation in data sets, if ignored, can lead to deflated estimates of uncertainty and biases in model coefficient estimates (Dormann 2007, Mets et al. 2017, Guélat et al. 2018, Gaspard et al. 2019). In worst-case scenarios model-based estimates for the main effects of interest, such as the MPA effect in this study, can be in the wrong direction (e.g., negative when the effect is positive and vice-versa). Large changes in model coefficients and even reversals have been reported elsewhere (e.g., Kühn 2006, Dormann 2007). Despite the known importance of SAC, direct comparisons of models that incorporate SAC with those that do not are rare in the ecological literature (Gaspard et al. 2019). We found decisive evidence for better model fits to ROV data when accounting for SAC, and significant changes including the reversal of MPA effect directions when SAC was considered. In the full spatial model tested for vermilion rockfish in the Central region, the spatial random effects are performing a dual purpose: capturing MPA specific effects (e.g., higher, or lower starting densities or higher or lower trends through time) through modeling residual SAC not captured by the covariates, as well as creating a spatial smooth effect in two dimensions across the created INLA mesh. Current evidence points to strong spatial effects acting over relatively small scales generally encompassed by individual MPAs and their reference sites. These findings highlight the importance of using statistical methods that account for SAC when dealing with data such as the ROV data used in this study.

Beyond being considered as a ‘nuisance’ that needs to be accounted for, SAC can also provide ecological insights that would otherwise remain obscured (Legendre 1993). SAC was found to be important on scales of approximately 2-15 km for the density of the majority of species and 2-300 km for large fish. For the abundance of species, this implies that there are spatial processes operating on the scale of individual MPAs and their reference sites that are not accounted for by the current model covariates (i.e., distance along coast, habitat, depth and MPA effects). These processes could be related to factors such as differential fishing pressure pre and post MPA establishment or oceanographic processes resulting in certain areas being larval sinks. Quantification of these and other effects at an appropriate scale for inclusion in models and testing of their effect on model inference would be a useful next step.

Conclusion

Results presented in this report demonstrate the ability of a well-designed spatially and temporally replicated ROV-based monitoring program to detect regional trends and MPA effects on the density and size-structure of previously fished species across the California MPA Network following more than a decade of protection. These results show encouraging signs of recovery in the abundance and size structure of these species statewide since 2003, and that MPAs are a contributing factor to this trajectory. Modeling showed that these effects were more detectable at larger spatial scales (regional and statewide) where data from a larger number of MPAs was included. At the statewide level the rates of change associated with MPA establishment exceeded theoretical expectations for some species (copper and gopher rockfish), while for other species such as vermilion rockfish the length of MPA establishment may not yet be long enough to fully realize recovery potentials. Cycles of recruitment success are likely to be a large factor driving these patterns and should be further explored in relations to the findings presented here. The density of large fish, a metric that captures the shift in size structure of populations following protection from fishing pressure, showed larger effect sizes than density where positive effects were detected. However, the shorter time-series of data available to analyze metrics related to size structure in the current ROV data set may be hampering the detection of a larger number of positive MPA effects. The increased detectability of MPA effects at larger scales and with longer time-series highlight the importance of collecting spatially extensive and temporally replicated data for large-scale monitoring programs such as the long-term monitoring of California’s MPA Network. Resource managers should carefully consider ongoing monitoring designs across the Network to ensure that research questions can be addressed. Given the high spatial variability in responses across the Network, making sure spatial coverage is maintained should be prioritized if network-wide responses are a key focus.

Next steps

- Designing the ongoing monitoring plan is a current key priority. The MARE/CDFW ROV monitoring to date has generated data that has identified a number of positive MPA responses, but also information about the spatial and temporal variability in the abundance of key species. This information can be used to help design ongoing monitoring using simulation studies and manipulation of existing data. For example, the implication of removing temporal revisits or MPAs from existing data sets where positive effects have been detected could be explored to test their relative importance.
- Incorporation of other potentially useful covariates into models and testing of their importance. These potentially include but are not limited to: measures of fishing effort, indexes of recruitment, biogeographical covariates that capture oceanographic features, and other bathymetric covariates from seafloor mapping. Seafloor mapping covariates are often scale dependent, so this could include an exploration of the importance of scale.
- Some MPAs were found to have a positive effect on a large number of species (e.g., Bodega Bay SMR). Exploration of characteristics of MPAs (e.g., size) that may make some MPAs more effective than others could be included in future modeling.
- The current report has focused on key focal fish species. Future work could also incorporate patterns in invertebrate species through time, particularly for other species that are subject to fishing pressure such as sea cucumber.
- Modeling approaches that explore changes in species assemblages through time also exist and could be used in the assessment of the effect of MPAs on the patterns in assemblages through time.
- Earlier ROV surveys (pre-2014) have not currently been scored for the size of individual fish. Scoring of this imagery would allow for a longer time-series of size information to test the ability of models for the density of larger fish (or alternatively biomass) in detecting MPA effects compared to density models. Also, length at maturity for each species could be used as an alternative cut-off to explore size-structure-related MPA effects.
- Exploration of the observed and potential impact of other disturbances such as marine heatwaves through examining data before and after the ‘blob’ warming event over 2014-2016.
- A transect sub-unit size of 10 m was used in the current study to capture fine-scale habitat associations. A future study exploring alternative sub-unit sizes and their influence on model outputs would be useful in determining the appropriateness of a fixed sub-unit length for ongoing work.

Acknowledgements

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Appendix A: habitat patchiness analysis

Three MPAs and their associated reference sites were assessed for the patchiness of habitat: Bodega Bay SMR, Montara SMR and Año Nuevo SMR. For the visual habitat data, the 2015 survey data was used to explore the lengths of continuous habitat classes along the transects within each MPA. These three MPAs were chosen as previous research had been conducted on seafloor mapping products at these three MPAs (see Perkins et al. 2020b). Substrate categories in the data were hard, soft, mixed, boulder, cobble and mud. The median length of each substrate class was determined across the data at each MPA.

A patchiness analysis was also conducted for seafloor mapping data at Bodega Bay SMR using the seafloor character layer with habitat classes of hard, mixed and soft across four rectangular ROV sites (BB1, BB2, BB4, BB5; for more details see Perkins et al. 2020b). The R package 'landscapemetrics' (Hesselbarth et al. 2019) was used to assess the median, maximum and minimum patch size (in m^2) of each substrate category across. As ROV transects are linear, the patch width, assuming a circular patch was also calculated.

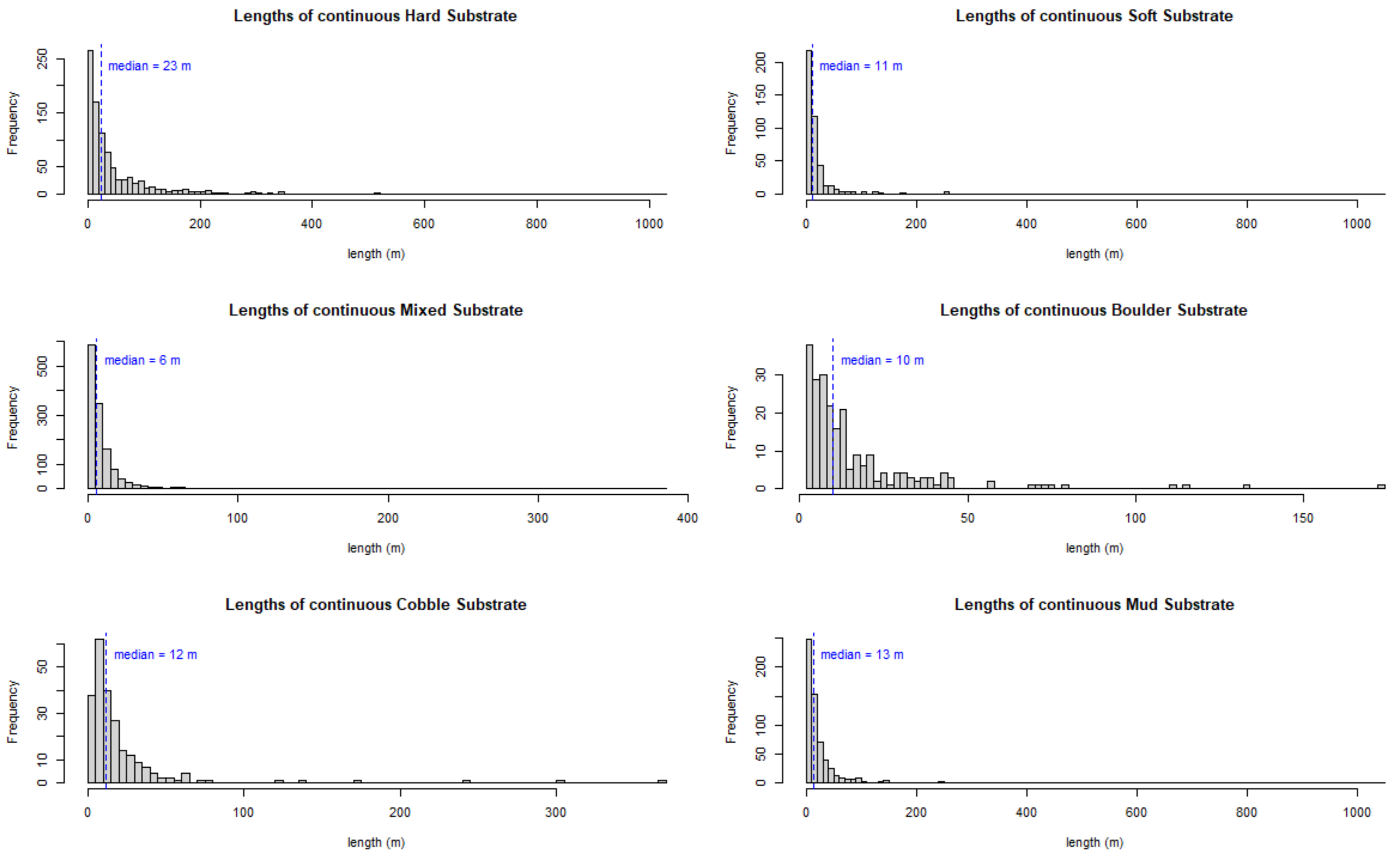

Figure A1. Lengths of continuous substrate classes at Bodega Bay SMR. Habitat classes are based on visual assessment of start and end points of habitat classes along the transects. Blue dashed lines and values show median lengths in each category.

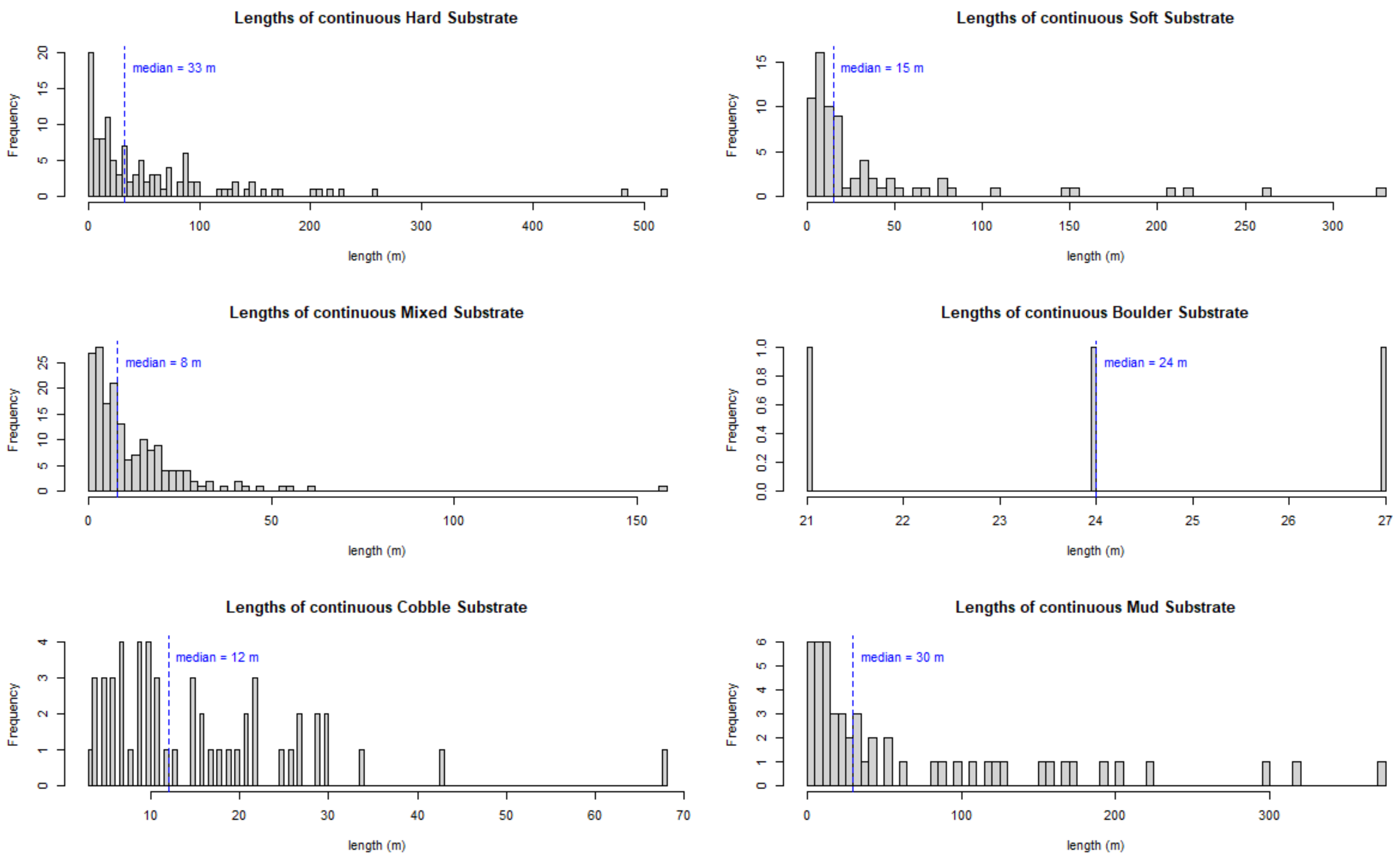

Figure A2. Lengths of continuous substrate classes at Montara SMR. Habitat classes are based on visual assessment of start and end points of habitat classes along the transects. Blue dashed lines and values show median lengths in each category.

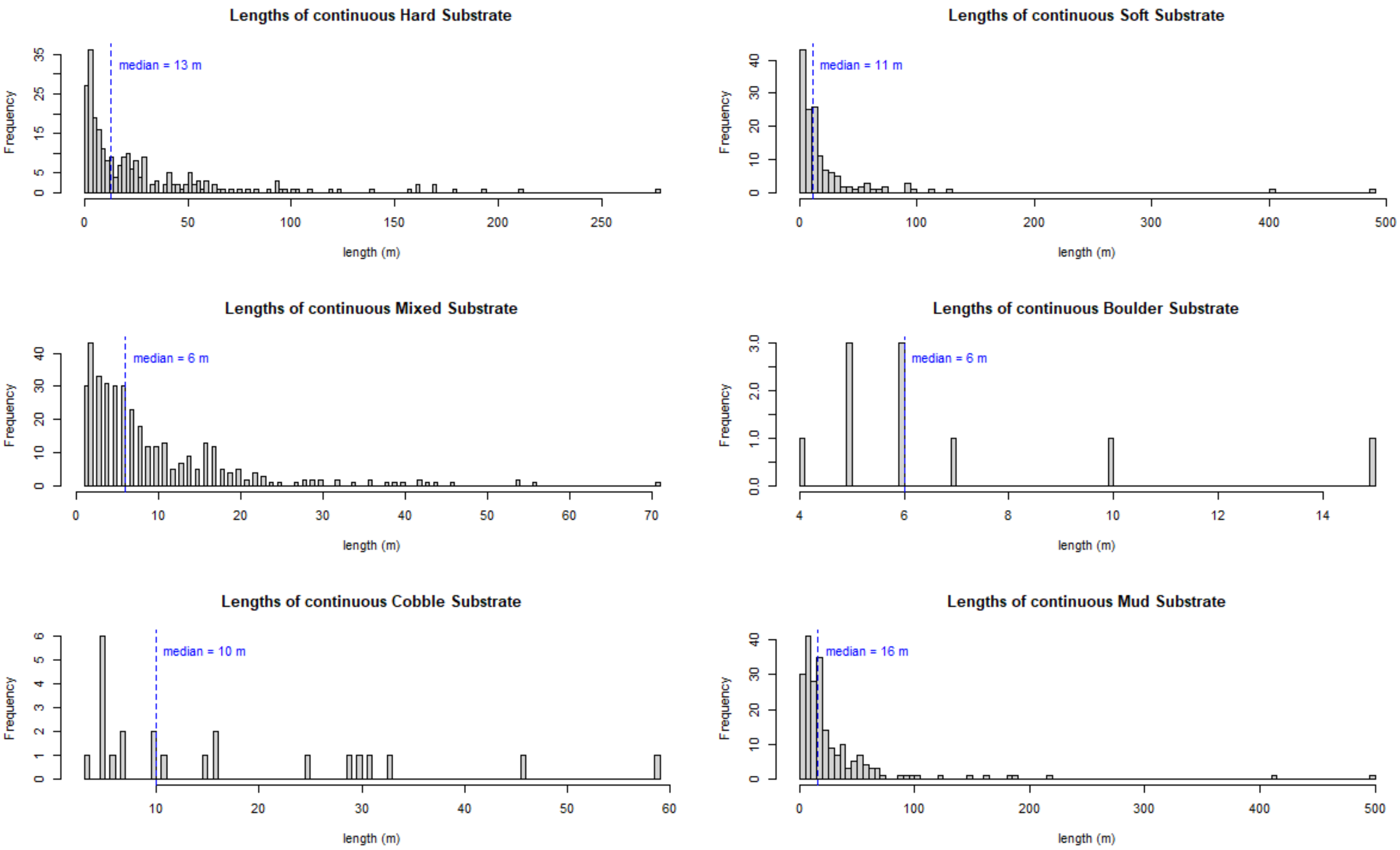

Figure A3. Lengths of continuous substrate classes at Año Nuevo SMR. Habitat classes are based on visual assessment of start and end points of habitat classes along the transects. Blue dashed lines and values show median lengths in each category.

Table A1. Output of ‘lanscapemetrics’ patchiness analysis of four ROV sites at Bodega Bay SMR for hard, mixed, and soft habitat classifications from seafloor mapping data. Minimum, median, and maximum values of patch sizes are given as areas in m^2 with values in brackets being the maximum width of the patch (i.e., the diameter) assuming a circular patch shape.

substrate		**BB1**	**BB2**	**BB4**	**BB5**
hard	min	4(2.2)	4(2.2)	4(2.2)	4(2.2)
	median	20(5.0)	24(5.6)	20(5.0)	24(5.6)
	max	397136(711.0)	451964(758.6)	275608(592.4)	104208(364.2)
mixed	min	4(2.2)	4(2.2)	4(2.2)	4(2.2)
	median	20(5.0)	16(4.6)	16(4.6)	16(4.6)
	max	219140(528.2)	107136(369.4)	209032(515.8)	534764(825.2)
soft	min	4(2.2)	4(2.2)	4(2.2)	4(2.2)
	median	16(4.6)	16(4.6)	16(4.6)	16(4.6)
	max	98880(354.8)	7832(99.8)	66364(290.6)	2748(59.2)

Appendix B: Model summary outputs

Statewide model outputs: Density of focal species

Grouped species

```
Fixed effects:
                  mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept       -5.036 0.414     -5.848   -5.036     -4.224 -5.036   0
Coast_dist      -0.589 0.329     -1.234   -0.589      0.056 -0.589   0
Coast_dist2     -0.720 0.228     -1.168   -0.720     -0.274 -0.719   0
SurveyYear       0.096 0.003      0.090    0.096      0.102  0.096   0
Years_since_imp  0.216 0.029      0.159    0.216      0.272  0.216   0
depth1           0.181 0.051      0.081    0.181      0.281  0.181   0
depth2          -0.161 0.022     -0.205   -0.161     -0.118 -0.161   0
Propn_Hard       0.822 0.013      0.797    0.822      0.847  0.822   0
Propn_Mixed      0.646 0.011      0.624    0.646      0.668  0.646   0

Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
                                                        mean    sd 0.025quant 0.5quant 0.975quant  mode
size for the nbinomial observations (1/overdispersion) 0.325 0.001      0.323    0.325      0.328 0.325
Range for i                                            4.157 0.391      3.444    4.110      5.225 4.067
Stdev for i                                            3.614 0.342      2.990    3.573      4.550 3.536

Deviance Information Criterion (DIC) ...............: 126275.50
Deviance Information Criterion (DIC, saturated) ....: -3134309.38
Effective number of parameters .....................: 265.31

Marginal log-Likelihood:  -63677.74
```

Vermilion Rockfish

```
Fixed effects:
                  mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept       -6.265 0.327     -6.906   -6.265     -5.624 -6.265   0
Coast_dist       0.250 0.247     -0.235    0.250      0.735  0.250   0
Coast_dist2     -0.491 0.181     -0.847   -0.491     -0.138 -0.490   0
SurveyYear       0.067 0.005      0.058    0.067      0.076  0.067   0
Years_since_imp  0.108 0.044      0.021    0.108      0.195  0.108   0
depth1           0.288 0.070      0.152    0.288      0.425  0.288   0
depth2          -0.265 0.035     -0.334   -0.265     -0.197 -0.265   0
Propn_Hard       0.979 0.022      0.936    0.979      1.021  0.979   0
Propn_Mixed      0.755 0.018      0.720    0.755      0.790  0.755   0

Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
                                                        mean    sd 0.025quant 0.5quant 0.975quant  mode
size for the nbinomial observations (1/overdispersion) 0.175 0.005      0.167    0.175      0.186 0.174
Range for i                                            3.460 0.357      2.825    3.436      4.229 3.381
Stdev for i                                            2.511 0.235      2.093    2.496      3.012 2.460

Deviance Information Criterion (DIC) ...............: 57374.27
Deviance Information Criterion (DIC, saturated) ....: -3450698.96
Effective number of parameters .....................: 232.58

Marginal log-Likelihood:  -29001.41
```

Copper Rockfish

```
Fixed effects:
                  mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept       -8.411 0.293     -8.986   -8.411     -7.836 -8.411   0
Coast_dist      -0.163 0.231     -0.617   -0.163      0.289 -0.162   0
Coast_dist2     -0.580 0.165     -0.906   -0.579     -0.257 -0.579   0
SurveyYear       0.111 0.006      0.100    0.111      0.123  0.111   0
Years_since_imp  0.359 0.059      0.245    0.359      0.474  0.359   0
depth1           0.898 0.072      0.756    0.898      1.040  0.897   0
depth2          -0.321 0.038     -0.398   -0.321     -0.247 -0.320   0
Propn_Hard       0.963 0.025      0.914    0.963      1.013  0.963   0
Propn_Mixed      0.736 0.021      0.695    0.736      0.777  0.735   0

Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
```

```
                                                        mean    sd 0.025quant 0.5quant 0.975quant  mode
size for the nbinomial observations (1/overdispersion) 0.375 0.023      0.328    0.377      0.415 0.384
Range for i                                            4.772 0.649      3.640    4.720      6.195 4.611
Stdev for i                                            1.714 0.157      1.408    1.714      2.026 1.725

Deviance Information Criterion (DIC) ...............: 32896.33
Deviance Information Criterion (DIC, saturated) ....: -3539908.63
Effective number of parameters .....................: 162.65

Marginal log-Likelihood:  -16643.79
```

Lingcod

```
Fixed effects:
                  mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept       -6.183 0.257     -6.687   -6.183     -5.680 -6.183   0
Coast_dist      -0.925 0.199     -1.317   -0.925     -0.534 -0.925   0
Coast_dist2     -0.578 0.135     -0.844   -0.578     -0.312 -0.578   0
SurveyYear       0.044 0.005      0.033    0.044      0.054  0.044   0
Years_since_imp  0.120 0.047      0.028    0.120      0.213  0.120   0
depth1           0.470 0.066      0.341    0.469      0.598  0.469   0
depth2          -0.158 0.027     -0.211   -0.158     -0.106 -0.157   0
Propn_Hard       0.423 0.020      0.383    0.423      0.462  0.423   0
Propn_Mixed      0.262 0.019      0.226    0.262      0.299  0.262   0

Random effects:
  Name         Model
    i SPDE2 model

Model hyperparameters:
                                                        mean    sd 0.025quant 0.5quant 0.975quant  mode
size for the nbinomial observations (1/overdispersion) 0.406 0.026      0.362    0.403      0.463 0.395
Range for i                                            5.189 1.028      3.796    4.976      7.723 4.459
Stdev for i                                            1.754 0.227      1.419    1.715      2.292 1.609

Deviance Information Criterion (DIC) ...............: 42574.84
Deviance Information Criterion (DIC, saturated) ....: -3503748.18
Effective number of parameters .....................: 205.39

Marginal log-Likelihood:  -21526.32
```

Gopher Rockfish

```
Fixed effects:
                  mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept       -7.426 0.339     -8.088   -7.427     -6.758 -7.429   0
Coast_dist       0.557 0.283     -0.001    0.557      1.110  0.559   0
Coast_dist2     -2.393 0.302     -3.002   -2.387     -1.816 -2.376   0
SurveyYear       0.157 0.006      0.146    0.157      0.170  0.156   0
Years_since_imp  0.374 0.064      0.243    0.375      0.496  0.378   0
depth1          -0.974 0.091     -1.155   -0.974     -0.796 -0.973   0
depth2          -0.530 0.062     -0.654   -0.530     -0.410 -0.529   0
Propn_Hard       1.106 0.040      1.028    1.107      1.184  1.107   0
Propn_Mixed      0.681 0.034      0.614    0.681      0.749  0.682   0

Random effects:
  Name         Model
    i SPDE2 model

Model hyperparameters:
                                                        mean    sd 0.025quant 0.5quant 0.975quant mode
size for the nbinomial observations (1/overdispersion) 0.967 0.083      0.824     0.96       1.15 0.94
Range for i                                            3.320 0.624      2.402     3.21       4.83 2.94
Stdev for i                                            2.309 0.302      1.833     2.27       3.02 2.15

Deviance Information Criterion (DIC) ...............: 23930.83
Deviance Information Criterion (DIC, saturated) ....: -3566681.28
Effective number of parameters .....................: 150.85

Marginal log-Likelihood:  -12155.34
```

Regional model outputs: Density of focal species

Grouped species

```
Fixed effects:
                                        mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                             -5.609 0.383     -6.361   -5.610     -4.858 -5.610   0
Coast_dist                            -0.220 0.165     -0.548   -0.218      0.102 -0.216   0
Coast_dist2                           -0.417 0.143     -0.701   -0.415     -0.141 -0.412   0
depth1                                 0.299 0.052      0.196    0.299      0.401  0.299   0
depth2                                -0.158 0.022     -0.201   -0.158     -0.116 -0.158   0
Propn_Hard                             0.837 0.013      0.812    0.837      0.863  0.837   0
Propn_Mixed                            0.646 0.011      0.624    0.646      0.668  0.646   0
Years_since_imp_LongTerm_RegionCentral  0.388 0.069      0.253    0.388      0.523  0.388   0
Years_since_imp_LongTerm_RegionNorth   0.360 0.058      0.246    0.360      0.475  0.360   0
Years_since_imp_LongTerm_RegionSouth  -0.026 0.039     -0.104   -0.026      0.051 -0.026   0
LongTerm_RegionCentral_SurveyYear      0.132 0.008      0.117    0.132      0.147  0.132   0
LongTerm_RegionNorth_SurveyYear        0.124 0.009      0.107    0.124      0.141  0.124   0
LongTerm_RegionSouth_SurveyYear        0.095 0.004      0.088    0.095      0.103  0.095   0

Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
                                                         mean    sd 0.025quant 0.5quant 0.975quant  mode
size for the nbinomial observations (1/overdispersion) 0.336 0.005      0.327    0.336      0.344 0.337
Range for i                                            4.073 0.662      3.137    3.944      5.694 3.611
Stdev for i                                            3.417 0.276      2.972    3.380      4.051 3.271

Deviance Information Criterion (DIC) ...............: 125951.40
Deviance Information Criterion (DIC, saturated) ....: -3134633.49
Effective number of parameters .....................: 255.80

Marginal log-Likelihood:  -63552.47
```

California Sheephead

```
Fixed effects:
                  mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept       -7.250 0.303     -7.844   -7.250     -6.657 -7.250   0
Years_since_imp  0.308 0.063      0.184    0.308      0.433  0.308   0
SurveyYear       0.122 0.006      0.110    0.122      0.133  0.122   0
Coast_dist       2.594 0.343      1.924    2.593      3.269  2.591   0
Coast_dist2     -0.869 0.147     -1.158   -0.868     -0.582 -0.868   0
depth1          -1.349 0.081     -1.508   -1.348     -1.191 -1.348   0
depth2          -0.189 0.045     -0.277   -0.189     -0.103 -0.189   0
Propn_Hard       0.679 0.023      0.634    0.679      0.725  0.679   0
Propn_Mixed      0.540 0.024      0.494    0.540      0.587  0.540   0

Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
                                                         mean    sd 0.025quant 0.5quant 0.975quant  mode
size for the nbinomial observations (1/overdispersion) 0.269 0.013      0.243    0.269      0.293 0.271
Range for i                                            2.318 0.282      1.800    2.307      2.906 2.291
Stdev for i                                            1.553 0.198      1.227    1.530      2.002 1.473

Deviance Information Criterion (DIC) ...............: 25654.41
Deviance Information Criterion (DIC, saturated) ....: -2078509.86
Effective number of parameters .....................: 74.67

Marginal log-Likelihood:  -12966.28
```

Vermilion Rockfish

```
Fixed effects:
                                        mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                             -6.431 0.384     -7.184   -6.431     -5.678 -6.431   0
Coast_dist                             0.407 0.231     -0.057    0.410      0.849  0.418   0
Coast_dist2                           -0.822 0.189     -1.198   -0.820     -0.457 -0.816   0
depth1                                 0.401 0.073      0.258    0.401      0.544  0.401   0
depth2                                -0.277 0.035     -0.347   -0.277     -0.208 -0.276   0
Propn_Hard                             0.995 0.022      0.953    0.995      1.038  0.995   0
Propn_Mixed                            0.755 0.018      0.720    0.755      0.790  0.755   0
Years_since_imp_LongTerm_RegionCentral  0.375 0.110      0.161    0.375      0.592  0.374   0
Years_since_imp_LongTerm_RegionNorth   0.192 0.136     -0.074    0.192      0.458  0.192   0
Years_since_imp_LongTerm_RegionSouth  -0.084 0.055     -0.191   -0.084      0.023 -0.084   0
LongTerm_RegionCentral_SurveyYear      0.106 0.012      0.082    0.106      0.130  0.106   0
LongTerm_RegionNorth_SurveyYear        0.172 0.020      0.134    0.172      0.212  0.172   0
LongTerm_RegionSouth_SurveyYear        0.062 0.005      0.052    0.062      0.073  0.062   0
```

```
Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
                                                        mean    sd 0.025quant 0.5quant 0.975quant mode
size for the nbinomial observations (1/overdispersion) 0.181 0.005      0.173    0.181      0.191 0.18
Range for i                                            3.987 0.539      2.939    3.992      5.047 4.04
Stdev for i                                            2.645 0.204      2.240    2.649      3.037 2.67

Deviance Information Criterion (DIC) ...............: 57172.07
Deviance Information Criterion (DIC, saturated) ....: -3450909.70
Effective number of parameters .....................: 241.18

Marginal log-Likelihood:  -28924.53
```

Copper Rockfish

```
Fixed effects:
                                         mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                              -8.535 0.319     -9.162   -8.535     -7.909 -8.535   0
Coast_dist                             -0.202 0.228     -0.660   -0.198      0.234 -0.190   0
Coast_dist2                            -0.557 0.169     -0.894   -0.555     -0.232 -0.552   0
depth1                                  0.892 0.072      0.751    0.892      1.034  0.892   0
depth2                                 -0.315 0.038     -0.391   -0.314     -0.241 -0.314   0
Propn_Hard                              0.966 0.025      0.916    0.966      1.016  0.966   0
Propn_Mixed                             0.736 0.021      0.695    0.736      0.777  0.736   0
Years_since_imp_LongTerm_RegionCentral  0.437 0.202      0.042    0.436      0.834  0.435   0
Years_since_imp_LongTerm_RegionNorth    0.383 0.152      0.085    0.383      0.682  0.383   0
Years_since_imp_LongTerm_RegionSouth    0.332 0.069      0.197    0.332      0.466  0.331   0
LongTerm_RegionCentral_SurveyYear       0.161 0.026      0.111    0.161      0.213  0.161   0
LongTerm_RegionNorth_SurveyYear         0.088 0.023      0.042    0.088      0.134  0.087   0
LongTerm_RegionSouth_SurveyYear         0.111 0.006      0.098    0.111      0.123  0.111   0

Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
                                                        mean    sd 0.025quant 0.5quant 0.975quant  mode
size for the nbinomial observations (1/overdispersion) 0.371 0.017      0.337    0.371      0.405 0.371
Range for i                                            5.473 0.826      3.984    5.431      7.227 5.363
Stdev for i                                            1.811 0.175      1.527    1.790      2.207 1.730

Deviance Information Criterion (DIC) ...............: 32863.39
Deviance Information Criterion (DIC, saturated) ....: -3539941.56
Effective number of parameters .....................: 161.42

Marginal log-Likelihood:  -16641.61
```

Canary Rockfish

```
Fixed effects:
                                         mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                              -4.103 0.636     -5.351   -4.103     -2.855 -4.102   0
Coast_dist                             -0.083 0.566     -1.232   -0.070      0.992 -0.045   0
Coast_dist2                            -1.640 0.448     -2.550   -1.629     -0.792 -1.608   0
depth1                                  2.152 0.163      1.833    2.152      2.474  2.151   0
depth2                                 -0.766 0.065     -0.894   -0.765     -0.640 -0.764   0
Propn_Hard                              0.116 0.034      0.051    0.116      0.182  0.116   0
Propn_Mixed                             0.168 0.032      0.105    0.168      0.230  0.168   0
Years_since_imp_LongTerm_RegionCentral  0.225 0.164     -0.096    0.224      0.548  0.223   0
Years_since_imp_LongTerm_RegionNorth    0.422 0.100      0.226    0.422      0.618  0.422   0
LongTerm_RegionCentral_SurveyYear       0.041 0.019      0.003    0.041      0.080  0.041   0
LongTerm_RegionNorth_SurveyYear         0.078 0.015      0.048    0.078      0.108  0.078   0

Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
                                                        mean    sd 0.025quant 0.5quant 0.975quant  mode
size for the nbinomial observations (1/overdispersion) 0.092 0.003      0.086    0.092      0.098 0.092
Range for i                                            6.779 1.132      4.975    6.625      9.411 6.276
Stdev for i                                            3.872 0.517      3.026    3.810      5.048 3.661

Deviance Information Criterion (DIC) ...............: 25340.65
Deviance Information Criterion (DIC, saturated) ....: -1395030.63
Effective number of parameters .....................: 158.63

Marginal log-Likelihood:  -12897.05
```

Gopher Rockfish

```
Fixed effects:
                                       mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                            -8.766 0.333     -9.419   -8.767     -8.112 -8.767   0
Coast_dist                            0.530 0.295     -0.051    0.530      1.108  0.531   0
Coast_dist2                          -2.051 0.307     -2.671   -2.045     -1.466 -2.033   0
depth1                               -0.681 0.091     -0.861   -0.681     -0.504 -0.680   0
depth2                               -0.622 0.061     -0.743   -0.621     -0.503 -0.620   0
Propn_Hard                            1.373 0.038      1.299    1.373      1.449  1.372   0
Propn_Mixed                           0.888 0.033      0.824    0.888      0.954  0.887   0
Years_since_imp_LongTerm_RegionCentral 0.679 0.108     0.470    0.679      0.891  0.678   0
Years_since_imp_LongTerm_RegionNorth  0.160 0.227     -0.280    0.158      0.610  0.154   0
Years_since_imp_LongTerm_RegionSouth -0.063 0.087     -0.235   -0.063      0.108 -0.064   0
LongTerm_RegionCentral_SurveyYear     0.183 0.011      0.163    0.183      0.204  0.183   0
LongTerm_RegionNorth_SurveyYear       0.232 0.028      0.178    0.231      0.289  0.230   0
LongTerm_RegionSouth_SurveyYear       0.174 0.008      0.159    0.174      0.189  0.174   0

Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
            mean    sd 0.025quant 0.5quant 0.975quant mode
Range for i 2.51 0.421       1.71     2.50       3.35 2.51
Stdev for i 2.15 0.194       1.73     2.16       2.48 2.24

Deviance Information Criterion (DIC) ...............: 24075.76
Deviance Information Criterion (DIC, saturated) ....: -3566536.37
Effective number of parameters .....................: 164.66

Marginal log-Likelihood:  -12238.86
```

Quillback Rockfish

```
Fixed effects:
                  mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept       -4.331 0.647     -5.602   -4.331     -3.062 -4.331   0
Years_since_imp  0.307 0.108      0.094    0.307      0.520  0.307   0
SurveyYear       0.129 0.017      0.096    0.129      0.162  0.129   0
Coast_dist      -0.424 0.533     -1.466   -0.425      0.623 -0.427   0
Coast_dist2     -1.175 0.497     -2.164   -1.170     -0.212 -1.161   0
depth1           0.222 0.130     -0.034    0.222      0.477  0.223   0
depth2          -0.753 0.078     -0.908   -0.752     -0.603 -0.750   0
Propn_Hard       1.046 0.070      0.912    1.045      1.188  1.043   0
Propn_Mixed      0.622 0.058      0.510    0.621      0.736  0.620   0

Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
                                                         mean    sd 0.025quant 0.5quant 0.975quant  mode
size for the nbinomial observations (1/overdispersion)  4.02 1.966       1.68     3.54       9.14  2.81
Range for i                                            11.14 2.887       6.41    10.83      17.66 10.25
Stdev for i                                             1.89 0.291       1.35     1.88       2.49  1.87

Deviance Information Criterion (DIC) ...............: 8917.23
Deviance Information Criterion (DIC, saturated) ....: -788304.30
Effective number of parameters .....................: 62.61

Marginal log-Likelihood:  -4543.65
```

Yelloweye Rockfish

```
Fixed effects:
                                       mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                            -1.468 0.917     -3.270   -1.468      0.328 -1.466   0
Coast_dist                           -0.143 0.531     -1.305   -0.099      0.778 -0.005   0
Coast_dist2                          -1.590 0.417     -2.449   -1.576     -0.810 -1.548   0
depth1                                0.927 0.098      0.740    0.925      1.123  0.922   0
depth2                               -0.319 0.064     -0.448   -0.318     -0.195 -0.317   0
Propn_Hard                            1.392 0.093      1.216    1.390      1.583  1.384   0
Propn_Mixed                           0.744 0.077      0.597    0.743      0.899  0.740   0
Years_since_imp_LongTerm_RegionCentral 0.198 0.106    -0.005    0.197      0.410  0.194   0
Years_since_imp_LongTerm_RegionNorth  0.002 0.056     -0.107    0.002      0.112  0.002   0
LongTerm_RegionCentral_SurveyYear     0.116 0.034      0.051    0.115      0.184  0.114   0
LongTerm_RegionNorth_SurveyYear       0.116 0.016      0.086    0.116      0.147  0.116   0

Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
              mean     sd 0.025quant 0.5quant 0.975quant   mode
```

```
Range for i 293.55 71.655     179.50    284.52     458.80 267.19
Stdev for i    1.91  0.363      1.30      1.87       2.72   1.80

Deviance Information Criterion (DIC) ...............: 5830.59
Deviance Information Criterion (DIC, saturated) ....: -1460871.57
Effective number of parameters .....................: 36.97

Marginal log-Likelihood:  -2958.02
```

Lingcod

```
Fixed effects:
                                       mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                            -6.590 0.199     -6.982   -6.590     -6.199 -6.590   0
Coast_dist                           -1.155 0.147     -1.448   -1.153     -0.869 -1.151   0
Coast_dist2                          -0.302 0.099     -0.498   -0.301     -0.109 -0.300   0
depth1                                0.443 0.063      0.319    0.443      0.568  0.443   0
depth2                               -0.136 0.026     -0.187   -0.136     -0.087 -0.136   0
Propn_Hard                            0.426 0.020      0.387    0.426      0.465  0.426   0
Propn_Mixed                           0.269 0.018      0.232    0.269      0.305  0.269   0
Years_since_imp_LongTerm_RegionCentral  0.400 0.096      0.213    0.399      0.588  0.399   0
Years_since_imp_LongTerm_RegionNorth  0.239 0.073      0.095    0.239      0.382  0.239   0
Years_since_imp_LongTerm_RegionSouth  0.146 0.077     -0.005    0.146      0.297  0.146   0
LongTerm_RegionCentral_SurveyYear     0.042 0.011      0.021    0.042      0.063  0.042   0
LongTerm_RegionNorth_SurveyYear      -0.063 0.011     -0.085   -0.063     -0.042 -0.063   0
LongTerm_RegionSouth_SurveyYear       0.071 0.007      0.057    0.071      0.086  0.071   0

Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
                                                        mean    sd 0.025quant 0.5quant 0.975quant  mode
size for the nbinomial observations (1/overdispersion) 0.443 0.025      0.395    0.442      0.495 0.441
Range for i                                            2.988 0.699      1.676    2.987      4.350 3.013
Stdev for i                                            1.427 0.128      1.216    1.411      1.717 1.368

Deviance Information Criterion (DIC) ...............: 42384.77
Deviance Information Criterion (DIC, saturated) ....: -3503938.25
Effective number of parameters .....................: 208.19

Marginal log-Likelihood:  -21431.75
```

Kelp Greenling

```
Fixed effects:
                                       mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                            -5.218 0.190     -5.592   -5.218     -4.845 -5.218   0
Coast_dist                           -1.014 0.176     -1.360   -1.014     -0.670 -1.014   0
Coast_dist2                          -0.823 0.150     -1.118   -0.822     -0.529 -0.822   0
depth1                               -0.510 0.066     -0.640   -0.510     -0.380 -0.509   0
depth2                               -0.348 0.042     -0.431   -0.348     -0.267 -0.348   0
Propn_Hard                            0.467 0.031      0.407    0.467      0.528  0.466   0
Propn_Mixed                           0.350 0.026      0.298    0.349      0.401  0.349   0
Years_since_imp_LongTerm_RegionCentral  0.193 0.108     -0.017    0.193      0.405  0.192   0
Years_since_imp_LongTerm_RegionNorth  0.124 0.059      0.009    0.124      0.239  0.124   0
LongTerm_RegionCentral_SurveyYear    -0.024 0.014     -0.053   -0.024      0.004 -0.024   0
LongTerm_RegionNorth_SurveyYear      -0.011 0.009     -0.029   -0.011      0.007 -0.011   0

Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
                                                        mean    sd 0.025quant 0.5quant 0.975quant  mode
size for the nbinomial observations (1/overdispersion) 2.617 0.532      1.756     2.55      3.841 2.421
Range for i                                            5.147 0.988      3.518     5.04      7.396 4.814
Stdev for i                                            0.767 0.104      0.582     0.76      0.992 0.746

Deviance Information Criterion (DIC) ...............: 23848.91
Deviance Information Criterion (DIC, saturated) ....: -1384332.43
Effective number of parameters .....................: 92.04

Marginal log-Likelihood:  -12033.22
```

Brown Rockfish

```
Fixed effects:
                  mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept       -7.601 1.166     -9.893   -7.600     -5.315 -7.599   0
SurveyYear       0.177 0.025      0.128    0.177      0.228  0.177   0
Years_since_imp  0.575 0.188      0.206    0.574      0.945  0.574   0
depth1           2.620 0.243      2.146    2.619      3.099  2.618   0
depth2          -0.193 0.128     -0.447   -0.191      0.056 -0.189   0
Propn_Hard       0.766 0.055      0.659    0.766      0.876  0.765   0
Propn_Mixed      0.461 0.048      0.368    0.461      0.555  0.461   0
```

```
Random effects:
  Name        Model
    i SPDE2 model

Model hyperparameters:
                                                         mean    sd 0.025quant 0.5quant 0.975quant   mode
size for the nbinomial observations (1/overdispersion)  0.59 0.078      0.466     0.58      0.768  0.554
Range for i                                            15.13 2.871     10.663    14.71     21.898 13.785
Stdev for i                                             4.38 0.634      3.302     4.32      5.791  4.194

Deviance Information Criterion (DIC) ...............: 7321.15
Deviance Information Criterion (DIC, saturated) ....: -819523.36
Effective number of parameters .....................: 80.47

Marginal log-Likelihood:  -3753.75
```

*Note: the region defined for brown rockfish was from Año Nuevo in the south to Reading Rock in the north.

Statewide model outputs: Density of large focal species

Grouped species

```
Fixed effects:
                  mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept       -5.867 0.462     -6.774   -5.867     -4.960 -5.866   0
Coast_dist      -0.698 0.339     -1.364   -0.698     -0.032 -0.698   0
Coast_dist2     -0.584 0.314     -1.201   -0.584      0.031 -0.583   0
SurveyYear       0.088 0.007      0.075    0.088      0.101  0.088   0
Years_since_imp  0.247 0.061      0.127    0.247      0.367  0.246   0
depth1           0.389 0.064      0.264    0.389      0.514  0.389   0
depth2          -0.132 0.029     -0.191   -0.132     -0.075 -0.132   0
Propn_Hard       1.026 0.018      0.990    1.026      1.062  1.026   0
Propn_Mixed      0.708 0.015      0.679    0.708      0.738  0.708   0

Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
            mean    sd 0.025quant 0.5quant 0.975quant mode
Range for i 5.06 0.733       3.81     4.99       6.68 4.84
Stdev for i 2.92 0.300       2.39     2.90       3.57 2.84

Deviance Information Criterion (DIC) ...............: 53112.29
Deviance Information Criterion (DIC, saturated) ....: -2070519.28
Effective number of parameters .....................: 139.67

Marginal log-Likelihood:  -27047.13
```

Vermilion Rockfish

```
Fixed effects:
                  mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept       -7.417 0.211     -7.831   -7.417     -7.004 -7.417   0
Coast_dist       0.318 0.130      0.063    0.318      0.573  0.318   0
Coast_dist2     -0.195 0.129     -0.449   -0.195      0.056 -0.194   0
SurveyYear       0.096 0.009      0.079    0.096      0.112  0.096   0
Years_since_imp  0.275 0.078      0.121    0.275      0.429  0.275   0
depth1           0.327 0.069      0.192    0.327      0.462  0.326   0
depth2          -0.187 0.040     -0.268   -0.187     -0.109 -0.186   0
Propn_Hard       1.192 0.028      1.138    1.192      1.246  1.191   0
Propn_Mixed      0.809 0.022      0.766    0.809      0.852  0.809   0

Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
            mean    sd 0.025quant 0.5quant 0.975quant mode
Range for i 1.59 0.271       1.12     1.57       2.18 1.53
Stdev for i 1.96 0.173       1.66     1.95       2.34 1.91

Deviance Information Criterion (DIC) ...............: 28156.33
Deviance Information Criterion (DIC, saturated) ....: -2176093.73
Effective number of parameters .....................: 69.67

Marginal log-Likelihood:  -14410.39
```

Copper Rockfish

```
Fixed effects:
                  mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept       -8.348 0.292     -8.922   -8.348     -7.776 -8.347   0
Coast_dist      -0.036 0.196     -0.422   -0.036      0.347 -0.035   0
Coast_dist2     -0.424 0.189     -0.797   -0.424     -0.055 -0.422   0
SurveyYear       0.074 0.012      0.051    0.074      0.097  0.074   0
Years_since_imp  0.516 0.109      0.303    0.516      0.731  0.516   0
depth1           0.765 0.085      0.598    0.765      0.932  0.764   0
depth2          -0.331 0.053     -0.437   -0.331     -0.229 -0.329   0
Propn_Hard       0.950 0.035      0.881    0.949      1.019  0.949   0
Propn_Mixed      0.694 0.028      0.640    0.694      0.748  0.693   0

Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
            mean    sd 0.025quant 0.5quant 0.975quant mode
Range for i 4.09 0.696       2.90     4.03       5.62 3.90
Stdev for i 1.46 0.140       1.19     1.46       1.74 1.46

Deviance Information Criterion (DIC) ...............: 15823.03
Deviance Information Criterion (DIC, saturated) ....: -2217083.85
```

```
Effective number of parameters .....................: 137.27

Marginal log-Likelihood:  -8029.41
```

Lingcod

```
Fixed effects:
                  mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept       -6.963 0.311     -7.574   -6.963     -6.354 -6.963   0
Coast_dist      -0.821 0.230     -1.276   -0.819     -0.373 -0.817   0
Coast_dist2     -0.737 0.209     -1.150   -0.736     -0.330 -0.734   0
SurveyYear      -0.077 0.013     -0.102   -0.077     -0.052 -0.077   0
Years_since_imp  0.320 0.101      0.122    0.319      0.517  0.319   0
depth1           0.069 0.095     -0.117    0.069      0.256  0.069   0
depth2          -0.212 0.046     -0.304   -0.212     -0.124 -0.211   0
Propn_Hard       0.696 0.040      0.619    0.696      0.774  0.695   0
Propn_Mixed      0.376 0.035      0.307    0.376      0.446  0.376   0

Random effects:
  Name        Model
    i SPDE2 model

Model hyperparameters:
            mean    sd 0.025quant 0.5quant 0.975quant mode
Range for i 4.40 0.868       2.92     4.32       6.33 4.17
Stdev for i 1.71 0.209       1.34     1.69       2.17 1.65

Deviance Information Criterion (DIC) ...............: 13833.40
Deviance Information Criterion (DIC, saturated) ....: -2226977.58
Effective number of parameters .....................: 155.58

Marginal log-Likelihood:  -7044.73
```

Regional model outputs: Density of large focal species

Grouped species

```
Fixed effects:
                                        mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                             -5.814 0.354     -6.510   -5.814     -5.118 -5.814   0
Coast_dist                            -0.570 0.215     -1.002   -0.567     -0.156 -0.560   0
Coast_dist2                           -0.643 0.205     -1.055   -0.639     -0.252 -0.631   0
depth1                                 0.367 0.063      0.244    0.367      0.490  0.367   0
depth2                                -0.140 0.030     -0.199   -0.140     -0.082 -0.139   0
Propn_Hard                             1.023 0.018      0.987    1.023      1.059  1.022   0
Propn_Mixed                            0.707 0.015      0.678    0.707      0.736  0.707   0
Years_since_imp_LongTerm_RegionCentral 0.681 0.211      0.268    0.681      1.094  0.682   0
Years_since_imp_LongTerm_RegionNorth   0.274 0.083      0.112    0.274      0.437  0.274   0
Years_since_imp_LongTerm_RegionSouth   0.234 0.106      0.027    0.233      0.442  0.232   0
LongTerm_RegionCentral_SurveyYear      0.086 0.018      0.050    0.086      0.122  0.086   0
LongTerm_RegionNorth_SurveyYear        0.080 0.012      0.056    0.080      0.103  0.080   0
LongTerm_RegionSouth_SurveyYear        0.087 0.009      0.070    0.087      0.105  0.087   0

Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
            mean    sd 0.025quant 0.5quant 0.975quant mode
Range for i 3.88 0.639       2.77     3.83       5.28 3.74
Stdev for i 2.53 0.256       2.06     2.51       3.07 2.48

Deviance Information Criterion (DIC) ...............: 53086.87
Deviance Information Criterion (DIC, saturated) ....: -2070544.70
Effective number of parameters .....................: 144.98

Marginal log-Likelihood:  -27040.85
```

Vermilion Rockfish

```
Fixed effects:
                                        mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                             -7.209 0.236     -7.672   -7.209     -6.747 -7.209   0
Coast_dist                             0.281 0.147     -0.010    0.282      0.568  0.283   0
Coast_dist2                           -0.359 0.146     -0.648   -0.358     -0.076 -0.357   0
depth1                                 0.295 0.072      0.154    0.295      0.436  0.295   0
depth2                                -0.221 0.043     -0.306   -0.221     -0.138 -0.220   0
Propn_Hard                             1.181 0.027      1.127    1.181      1.235  1.181   0
Propn_Mixed                            0.802 0.022      0.759    0.802      0.845  0.802   0
Years_since_imp_LongTerm_RegionCentral 0.271 0.175     -0.072    0.271      0.613  0.271   0
Years_since_imp_LongTerm_RegionNorth   0.167 0.153     -0.132    0.167      0.467  0.167   0
Years_since_imp_LongTerm_RegionSouth   0.252 0.107      0.044    0.252      0.462  0.251   0
LongTerm_RegionCentral_SurveyYear      0.142 0.023      0.098    0.142      0.187  0.142   0
LongTerm_RegionNorth_SurveyYear        0.130 0.024      0.085    0.130      0.177  0.130   0
LongTerm_RegionSouth_SurveyYear        0.084 0.010      0.063    0.084      0.104  0.084   0

Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
            mean    sd 0.025quant 0.5quant 0.975quant mode
Range for i 1.95 0.342       1.39     1.92       2.73 1.83
Stdev for i 1.94 0.155       1.67     1.93       2.28 1.90

Deviance Information Criterion (DIC) ...............: 28134.02
Deviance Information Criterion (DIC, saturated) ....: -2176116.05
Effective number of parameters .....................: 76.05

Marginal log-Likelihood:  -14432.66
```

Copper Rockfish

```
Fixed effects:
                                        mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                             -7.799 0.288     -8.364   -7.799     -7.234 -7.798   0
Coast_dist                            -0.203 0.205     -0.610   -0.201      0.194 -0.198   0
Coast_dist2                           -0.691 0.191     -1.070   -0.689     -0.320 -0.686   0
depth1                                 0.743 0.082      0.582    0.743      0.905  0.743   0
depth2                                -0.337 0.052     -0.442   -0.337     -0.236 -0.335   0
Propn_Hard                             0.944 0.035      0.876    0.944      1.012  0.943   0
Propn_Mixed                            0.690 0.028      0.636    0.690      0.745  0.690   0
Years_since_imp_LongTerm_RegionCentral 0.190 0.221     -0.244    0.190      0.624  0.190   0
Years_since_imp_LongTerm_RegionNorth   0.383 0.178      0.033    0.383      0.733  0.382   0
Years_since_imp_LongTerm_RegionSouth   0.600 0.147      0.312    0.599      0.890  0.598   0
LongTerm_RegionCentral_SurveyYear      0.101 0.037      0.030    0.101      0.174  0.101   0
LongTerm_RegionNorth_SurveyYear        0.059 0.029      0.003    0.059      0.116  0.059   0
LongTerm_RegionSouth_SurveyYear        0.073 0.014      0.045    0.073      0.100  0.073   0
```

```
Random effects:
  Name        Model
    i SPDE2 model

Model hyperparameters:
            mean    sd 0.025quant 0.5quant 0.975quant mode
Range for i 4.53 0.836       3.10     4.45       6.37 4.31
Stdev for i 1.40 0.135       1.16     1.39       1.68 1.37

Deviance Information Criterion (DIC) ...............: 15832.34
Deviance Information Criterion (DIC, saturated) ....: -2217074.54
Effective number of parameters .....................: 133.72

Marginal log-Likelihood:  -8055.33
```

Canary Rockfish

```
Fixed effects:
                                    mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                         -6.288 0.367     -7.009   -6.289     -5.568 -6.289   0
Coast_dist                         0.166 0.279     -0.384    0.166      0.713  0.166   0
Coast_dist2                       -0.845 0.227     -1.302   -0.840     -0.410 -0.832   0
depth1                             1.554 0.169      1.223    1.553      1.888  1.551   0
depth2                            -0.466 0.072     -0.611   -0.465     -0.327 -0.463   0
Propn_Hard                         0.430 0.043      0.347    0.429      0.514  0.429   0
Propn_Mixed                        0.302 0.039      0.225    0.302      0.380  0.302   0
Years_since_imp_LongTerm_RegionCentral  0.193 0.278     -0.353    0.193      0.739  0.193   0
Years_since_imp_LongTerm_RegionNorth  -0.003 0.135     -0.269   -0.003      0.261 -0.003   0
LongTerm_RegionCentral_SurveyYear -0.039 0.034     -0.106   -0.039      0.028 -0.039   0
LongTerm_RegionNorth_SurveyYear    0.093 0.022      0.050    0.093      0.137  0.092   0

Random effects:
  Name        Model
    i SPDE2 model

Model hyperparameters:
            mean    sd 0.025quant 0.5quant 0.975quant mode
Range for i 2.84 0.597       1.95     2.75       4.27 2.54
Stdev for i 2.42 0.269       1.97     2.40       3.02 2.33

Deviance Information Criterion (DIC) ...............: 9542.32
Deviance Information Criterion (DIC, saturated) ....: -1109963.73
Effective number of parameters .....................: 83.04

Marginal log-Likelihood:  -4965.33
```

Gopher Rockfish

```
Fixed effects:
                                    mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                         -5.736 0.691     -7.096   -5.736     -4.382 -5.734   0
Coast_dist                        -0.706 0.634     -1.985   -0.693      0.505 -0.669   0
Coast_dist2                       -2.439 0.490     -3.426   -2.430     -1.503 -2.412   0
depth1                            -0.559 0.233     -1.028   -0.555     -0.113 -0.546   0
depth2                            -0.968 0.197     -1.367   -0.963     -0.592 -0.955   0
Propn_Hard                         1.194 0.115      0.978    1.190      1.428  1.184   0
Propn_Mixed                        0.614 0.111      0.403    0.612      0.839  0.607   0
Years_since_imp_LongTerm_RegionCentral  0.037 0.443     -0.832    0.036      0.906  0.036   0
Years_since_imp_LongTerm_RegionSouth  -0.984 0.394     -1.762   -0.983     -0.214 -0.980   0
LongTerm_RegionCentral_SurveyYear  0.326 0.059      0.213    0.325      0.446  0.322   0
LongTerm_RegionSouth_SurveyYear    0.182 0.040      0.105    0.181      0.260  0.181   0

Random effects:
  Name        Model
    i SPDE2 model

Model hyperparameters:
             mean    sd 0.025quant 0.5quant 0.975quant  mode
Range for i 14.11 5.532       7.13    12.83      28.24 10.71
Stdev for i  2.98 0.651       1.96     2.90       4.50  2.71

Deviance Information Criterion (DIC) ...............: 2716.49
Deviance Information Criterion (DIC, saturated) ....: -1529291.35
Effective number of parameters .....................: 96.83

Marginal log-Likelihood:  -1400.70
```

Quillback Rockfish

```
Fixed effects:
                  mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept       -3.267 0.766     -4.771   -3.267     -1.766 -3.267   0
Years_since_imp  0.335 0.161      0.019    0.335      0.652  0.335   0
SurveyYear       0.042 0.025     -0.007    0.042      0.092  0.041   0
Coast_dist      -0.480 0.625     -1.698   -0.483      0.756 -0.490   0
```

```
Coast_dist2     -1.414 0.575     -2.564   -1.407      -0.305 -1.393   0
depth1           0.002 0.190     -0.373    0.002       0.374  0.003   0
depth2          -0.853 0.120     -1.094   -0.851      -0.622 -0.848   0
Propn_Hard       1.165 0.115      0.948    1.162       1.402  1.155   0
Propn_Mixed      0.626 0.091      0.452    0.624       0.809  0.621   0

Random effects:
  Name         Model
    i SPDE2 model

Model hyperparameters:
             mean    sd 0.025quant 0.5quant 0.975quant  mode
Range for i 13.17 3.784       7.05    12.75      21.79 11.95
Stdev for i  2.69 0.565       1.71     2.65       3.92  2.58

Deviance Information Criterion (DIC) ...............: 4386.16
Deviance Information Criterion (DIC, saturated) ....: -720823.94
Effective number of parameters .....................: 57.26

Marginal log-Likelihood:  -2260.25
```

Yelloweye Rockfish

```
Fixed effects:
                                         mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                              -1.726 0.921     -3.535   -1.726      0.079 -1.725   0
Coast_dist                             -0.789 0.507     -1.706   -0.817      0.286 -0.875   0
Coast_dist2                            -2.330 0.409     -3.182   -2.313     -1.576 -2.278   0
depth1                                  0.368 0.120      0.139    0.365      0.610  0.361   0
depth2                                 -0.088 0.096     -0.283   -0.086      0.095 -0.082   0
Propn_Hard                              1.327 0.146      1.057    1.321      1.631  1.309   0
Propn_Mixed                             0.721 0.122      0.490    0.717      0.969  0.711   0
Years_since_imp_LongTerm_RegionCentral  0.207 0.136     -0.052    0.204      0.483  0.198   0
Years_since_imp_LongTerm_RegionNorth    0.151 0.088     -0.019    0.151      0.325  0.150   0
LongTerm_RegionCentral_SurveyYear      -0.059 0.068     -0.192   -0.059      0.074 -0.059   0
LongTerm_RegionNorth_SurveyYear         0.084 0.027      0.031    0.084      0.137  0.083   0

Random effects:
  Name         Model
    i SPDE2 model

Model hyperparameters:
              mean     sd 0.025quant 0.5quant 0.975quant   mode
Range for i 314.19 79.662     179.04   307.71     488.97 295.48
Stdev for i   1.77  0.379       1.19     1.71       2.67   1.59

Deviance Information Criterion (DIC) ...............: 2629.88
Deviance Information Criterion (DIC, saturated) ....: -1130399.81
Effective number of parameters .....................: 32.30

Marginal log-Likelihood:  -1349.11
```

Lingcod

```
Fixed effects:
                                         mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                              -6.079 0.342     -6.751   -6.079     -5.408 -6.078   0
Coast_dist                             -0.196 0.250     -0.697   -0.191      0.283 -0.183   0
Coast_dist2                            -0.804 0.224     -1.251   -0.802     -0.372 -0.797   0
depth1                                 -0.066 0.102     -0.267   -0.066      0.135 -0.066   0
depth2                                 -0.245 0.048     -0.340   -0.245     -0.152 -0.244   0
Propn_Hard                              0.664 0.040      0.587    0.664      0.742  0.663   0
Propn_Mixed                             0.372 0.035      0.303    0.372      0.442  0.371   0
Years_since_imp_LongTerm_RegionCentral  0.381 0.242     -0.093    0.380      0.855  0.380   0
Years_since_imp_LongTerm_RegionNorth    0.082 0.136     -0.185    0.082      0.349  0.081   0
Years_since_imp_LongTerm_RegionSouth   -0.531 0.240     -1.004   -0.530     -0.060 -0.529   0
LongTerm_RegionCentral_SurveyYear      -0.174 0.027     -0.227   -0.174     -0.122 -0.174   0
LongTerm_RegionNorth_SurveyYear         0.055 0.020      0.015    0.055      0.095  0.054   0
LongTerm_RegionSouth_SurveyYear        -0.158 0.024     -0.206   -0.158     -0.111 -0.157   0

Random effects:
  Name         Model
    i SPDE2 model

Model hyperparameters:
            mean    sd 0.025quant 0.5quant 0.975quant mode
Range for i 4.41 1.025       2.84     4.26       6.83 3.94
Stdev for i 1.95 0.241       1.53     1.93       2.47 1.88

Deviance Information Criterion (DIC) ...............: 13695.92
Deviance Information Criterion (DIC, saturated) ....: -2227115.05
Effective number of parameters .....................: 176.58

Marginal log-Likelihood:  -6997.22
```

Kelp Greenling

```
Fixed effects:
                                      mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                           -5.656 0.142     -5.934   -5.656     -5.378 -5.656   0
Coast_dist                          -0.476 0.111     -0.694   -0.475     -0.260 -0.475   0
Coast_dist2                         -0.474 0.094     -0.661   -0.473     -0.291 -0.471   0
depth1                              -0.633 0.068     -0.768   -0.633     -0.502 -0.632   0
depth2                              -0.356 0.051     -0.458   -0.356     -0.257 -0.355   0
Propn_Hard                           0.554 0.046      0.466    0.554      0.646  0.553   0
Propn_Mixed                          0.405 0.040      0.328    0.405      0.483  0.404   0
Years_since_imp_LongTerm_RegionCentral  0.037 0.107     -0.172    0.037      0.247  0.037   0
Years_since_imp_LongTerm_RegionNorth  0.039 0.073     -0.105    0.039      0.183  0.039   0
LongTerm_RegionCentral_SurveyYear   -0.152 0.025     -0.201   -0.152     -0.104 -0.152   0
LongTerm_RegionNorth_SurveyYear     -0.069 0.013     -0.094   -0.069     -0.044 -0.069   0

Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
             mean    sd 0.025quant 0.5quant 0.975quant  mode
Range for i 6.085 2.308       2.81    5.674     11.722 4.946
Stdev for i 0.455 0.081       0.32    0.446      0.636 0.429

Deviance Information Criterion (DIC) ...............: 12250.12
Deviance Information Criterion (DIC, saturated) ....: -1092861.30
Effective number of parameters .....................: 52.85

Marginal log-Likelihood:  -6190.31
```

Brown Rockfish

```
Fixed effects:
                  mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept       -1.964 0.915     -3.761   -1.964     -0.170 -1.964   0
SurveyYear       0.151 0.036      0.082    0.150      0.222  0.149   0
Years_since_imp  0.450 0.265     -0.068    0.450      0.973  0.448   0
depth1           2.209 0.304      1.615    2.208      2.809  2.205   0
depth2          -0.185 0.170     -0.524   -0.182      0.143 -0.178   0
Propn_Hard       1.096 0.096      0.913    1.094      1.290  1.090   0
Propn_Mixed      0.666 0.080      0.513    0.665      0.826  0.663   0

Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
             mean    sd 0.025quant 0.5quant 0.975quant  mode
Range for i 16.94 3.184      11.56    16.64      24.02 16.06
Stdev for i  6.46 0.878       4.90     6.40       8.35  6.29

Deviance Information Criterion (DIC) ...............: 3920.86
Deviance Information Criterion (DIC, saturated) ....: -835801.65
Effective number of parameters .....................: 239.28

Marginal log-Likelihood:  -1885.00
```

*Note: the region defined for brown rockfish was from Año Nuevo in the south to Reading Rock in the north.

Individual MPA model outputs

Grouped species

```
Fixed effects:
                                            mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                                 -5.718 0.562     -6.821   -5.718     -4.616 -5.718   0
Coast_dist                                -0.513 0.435     -1.368   -0.513      0.341 -0.513   0
Coast_dist2                               -0.640 0.303     -1.235   -0.640     -0.047 -0.639   0
depth1                                     0.281 0.054      0.175    0.281      0.388  0.281   0
depth2                                    -0.157 0.023     -0.201   -0.157     -0.112 -0.156   0
Propn_Hard                                 0.834 0.013      0.809    0.834      0.860  0.834   0
Propn_Mixed                                0.646 0.011      0.624    0.646      0.668  0.646   0
Years_since_imp_MPAGroupAnacapa_Island    -0.304 0.067     -0.436   -0.304     -0.172 -0.304   0
Years_since_imp_MPAGroupAno_Nuevo          0.649 0.500     -0.322    0.646      1.639  0.639   0
Years_since_imp_MPAGroupBodega_Bay         0.876 0.089      0.703    0.875      1.051  0.874   0
Years_since_imp_MPAGroupCampus_Point       -0.280 0.199     -0.665   -0.282      0.116 -0.286   0
Years_since_imp_MPAGroupCarrington_Point   -0.336 0.078     -0.489   -0.336     -0.183 -0.337   0
Years_since_imp_MPAGroupFarnsworth         -0.188 0.150     -0.482   -0.189      0.108 -0.190   0
Years_since_imp_MPAGroupGull_Island         0.099 0.063     -0.024    0.099      0.222  0.099   0
Years_since_imp_MPAGroupHarris_Point        0.062 0.059     -0.054    0.062      0.178  0.062   0
Years_since_imp_MPAGroupMontara_Pillar_Point -0.528 0.189   -0.899   -0.529     -0.157 -0.529   0
Years_since_imp_MPAGroupPoint_Arena         0.734 0.126      0.490    0.732      0.984  0.730   0
Years_since_imp_MPAGroupPoint_Buchon        0.216 0.101      0.020    0.216      0.415  0.215   0
Years_since_imp_MPAGroupPoint_Conception   -0.271 0.198     -0.660   -0.271      0.117 -0.271   0
Years_since_imp_MPAGroupPoint_Lobos         0.527 0.087      0.359    0.527      0.699  0.525   0
Years_since_imp_MPAGroupPoint_St._George   -0.185 0.104     -0.390   -0.185      0.019 -0.185   0
Years_since_imp_MPAGroupPoint_Sur           0.617 0.128      0.369    0.616      0.872  0.613   0
Years_since_imp_MPAGroupPortuguese_Ledge   -2.438 0.528     -3.477   -2.438     -1.404 -2.436   0
Years_since_imp_MPAGroupReading_Rock        0.348 0.139      0.079    0.347      0.624  0.345   0
Years_since_imp_MPAGroupSE_Farallon_Islands 0.299 0.112      0.082    0.299      0.520  0.298   0
Years_since_imp_MPAGroupSea_Lion_Gulch      0.066 0.145     -0.216    0.066      0.352  0.065   0
Years_since_imp_MPAGroupSouth_La_Jolla      0.468 0.228      0.035    0.463      0.929  0.453   0
Years_since_imp_MPAGroupSouth_Point         0.182 0.068      0.049    0.182      0.315  0.181   0
Years_since_imp_MPAGroupSwamis              0.400 0.194      0.023    0.399      0.785  0.396   0
Years_since_imp_MPAGroupTen_Mile           -0.077 0.117     -0.307   -0.077      0.154 -0.077   0
SurveyYear_LongTerm_RegionCentral           0.137 0.008      0.121    0.137      0.152  0.137   0
SurveyYear_LongTerm_RegionNorth             0.117 0.009      0.100    0.117      0.134  0.117   0
SurveyYear_LongTerm_RegionSouth             0.095 0.004      0.087    0.095      0.103  0.095   0

Random effects:
  Name        Model
    i SPDE2 model

Model hyperparameters:
                                                         mean    sd 0.025quant 0.5quant 0.975quant  mode
size for the nbinomial observations (1/overdispersion) 0.336 0.005      0.326    0.336      0.347 0.335
Range for i                                            4.997 0.603      4.057    4.908      6.397 4.672
Stdev for i                                            3.932 0.257      3.438    3.929      4.449 3.930

Deviance Information Criterion (DIC) ...............: 125732.41
Deviance Information Criterion (DIC, saturated) ....: -3134852.48
Effective number of parameters .....................: 293.25

Marginal log-Likelihood:  -63479.67
```

California Sheephead

```
Fixed effects:
                                          mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                               -6.267 0.490     -7.229   -6.267     -5.307 -6.267   0
SurveyYear                               0.120 0.006      0.108    0.120      0.132  0.120   0
Coast_dist                               2.254 0.572      1.131    2.254      3.377  2.253   0
Coast_dist2                             -0.902 0.244     -1.381   -0.902     -0.424 -0.902   0
depth1                                  -1.447 0.089     -1.622   -1.447     -1.274 -1.447   0
depth2                                  -0.186 0.046     -0.278   -0.186     -0.096 -0.186   0
Propn_Hard                               0.684 0.023      0.638    0.684      0.730  0.683   0
Propn_Mixed                              0.538 0.024      0.491    0.538      0.585  0.537   0
Years_since_imp_MPAGroupAnacapa_Island   0.789 0.089      0.614    0.789      0.965  0.788   0
Years_since_imp_MPAGroupCampus_Point    -0.186 0.671     -1.529   -0.177      1.106 -0.159   0
Years_since_imp_MPAGroupCarrington_Point -0.026 0.132    -0.283   -0.027      0.236 -0.029   0
Years_since_imp_MPAGroupFarnsworth      -0.039 0.207     -0.439   -0.041      0.372 -0.045   0
Years_since_imp_MPAGroupGull_Island      0.259 0.101      0.062    0.258      0.457  0.258   0
Years_since_imp_MPAGroupHarris_Point    -0.047 0.171     -0.378   -0.048      0.292 -0.051   0
Years_since_imp_MPAGroupPoint_Conception -0.982 0.793    -2.611   -0.957      0.503 -0.907   0
Years_since_imp_MPAGroupSouth_La_Jolla   0.570 0.292      0.016    0.563      1.162  0.549   0
Years_since_imp_MPAGroupSouth_Point     -0.092 0.110     -0.307   -0.092      0.125 -0.093   0
Years_since_imp_MPAGroupSwamis           0.503 0.431     -0.315    0.492      1.379  0.472   0

Random effects:
  Name        Model
    i SPDE2 model

Model hyperparameters:
```

	mean	sd	0.025quant	0.5quant	0.975quant	mode
size for the nbinomial observations (1/overdispersion)	0.279	0.014	0.254	0.279	0.308	0.277
Range for i	8.797	6.406	3.119	6.800	26.308	4.483
Stdev for i	2.068	0.341	1.458	2.049	2.795	2.017

```
Deviance Information Criterion (DIC) ...............: 25564.19
Deviance Information Criterion (DIC, saturated) ....: -2075282.77
Effective number of parameters .....................: 87.18

Marginal log-Likelihood:  -12932.62
```

Vermilion Rockfish

Fixed effects:

	mean	sd	0.025quant	0.5quant	0.975quant	mode	kld
intercept	-7.411	0.354	-8.107	-7.411	-6.716	-7.411	0
Coast_dist	0.857	0.262	0.342	0.857	1.372	0.857	0
Coast_dist2	-0.247	0.192	-0.625	-0.246	0.129	-0.245	0
depth1	0.440	0.071	0.300	0.440	0.580	0.439	0
depth2	-0.268	0.035	-0.337	-0.268	-0.201	-0.268	0
Propn_Hard	0.997	0.022	0.954	0.997	1.039	0.996	0
Propn_Mixed	0.755	0.018	0.720	0.755	0.790	0.755	0
Years_since_imp_MPAGroupAnacapa_Island	-0.457	0.101	-0.655	-0.457	-0.260	-0.457	0
Years_since_imp_MPAGroupAno_Nuevo	0.777	0.563	-0.321	0.774	1.887	0.769	0
Years_since_imp_MPAGroupBodega_Bay	0.740	0.205	0.348	0.737	1.152	0.731	0
Years_since_imp_MPAGroupCampus_Point	-0.643	0.256	-1.145	-0.644	-0.139	-0.645	0
Years_since_imp_MPAGroupCarrington_Point	-0.520	0.108	-0.732	-0.520	-0.308	-0.520	0
Years_since_imp_MPAGroupFarnsworth	0.079	0.201	-0.312	0.078	0.475	0.076	0
Years_since_imp_MPAGroupGull_Island	-0.081	0.086	-0.249	-0.081	0.087	-0.081	0
Years_since_imp_MPAGroupHarris_Point	0.138	0.081	-0.021	0.138	0.298	0.138	0
Years_since_imp_MPAGroupMontara_Pillar_Point	1.457	0.333	0.813	1.454	2.119	1.448	0
Years_since_imp_MPAGroupPoint_Arena	0.251	0.302	-0.316	0.242	0.871	0.223	0
Years_since_imp_MPAGroupPoint_Buchon	0.393	0.155	0.093	0.392	0.701	0.390	0
Years_since_imp_MPAGroupPoint_Conception	-0.272	0.247	-0.758	-0.271	0.211	-0.270	0
Years_since_imp_MPAGroupPoint_Lobos	0.258	0.136	-0.005	0.256	0.528	0.254	0
Years_since_imp_MPAGroupPoint_St._George	-0.642	0.270	-1.167	-0.643	-0.109	-0.645	0
Years_since_imp_MPAGroupPoint_Sur	0.411	0.182	0.060	0.409	0.774	0.405	0
Years_since_imp_MPAGroupPortuguese_Ledge	-0.516	0.584	-1.663	-0.516	0.628	-0.516	0
Years_since_imp_MPAGroupReading_Rock	0.468	0.385	-0.251	0.454	1.262	0.427	0
Years_since_imp_MPAGroupSE_Farallon_Islands	0.015	0.203	-0.377	0.012	0.418	0.008	0
Years_since_imp_MPAGroupSea_Lion_Gulch	-0.157	0.297	-0.730	-0.161	0.435	-0.168	0
Years_since_imp_MPAGroupSouth_La_Jolla	0.358	0.287	-0.190	0.353	0.938	0.342	0
Years_since_imp_MPAGroupSouth_Point	0.055	0.093	-0.126	0.055	0.237	0.055	0
Years_since_imp_MPAGroupSwamis	0.771	0.245	0.295	0.769	1.256	0.766	0
Years_since_imp_MPAGroupTen_Mile	0.023	0.313	-0.570	0.015	0.659	0.000	0
SurveyYear_LongTerm_RegionCentral	0.106	0.012	0.082	0.106	0.130	0.106	0
SurveyYear_LongTerm_RegionNorth	0.166	0.020	0.128	0.166	0.205	0.166	0
SurveyYear_LongTerm_RegionSouth	0.063	0.005	0.052	0.063	0.074	0.063	0

```
Random effects:
  Name          Model
    i SPDE2 model
```

Model hyperparameters:

	mean	sd	0.025quant	0.5quant	0.975quant	mode
size for the nbinomial observations (1/overdispersion)	0.183	0.005	0.175	0.182	0.194	0.18
Range for i	3.580	0.310	2.964	3.587	4.178	3.63
Stdev for i	2.385	0.200	2.019	2.375	2.805	2.35

```
Deviance Information Criterion (DIC) ...............: 57118.78
Deviance Information Criterion (DIC, saturated) ....: -3450962.99
Effective number of parameters .....................: 245.60

Marginal log-Likelihood:  -28903.44
```

Copper Rockfish

Fixed effects:

	mean	sd	0.025quant	0.5quant	0.975quant	mode	kld
intercept	-7.923	0.408	-8.724	-7.923	-7.123	-7.922	0
Coast_dist	-0.297	0.337	-0.961	-0.297	0.363	-0.296	0
Coast_dist2	-0.681	0.232	-1.138	-0.681	-0.227	-0.680	0
depth1	0.902	0.074	0.757	0.902	1.047	0.902	0
depth2	-0.336	0.039	-0.413	-0.335	-0.261	-0.335	0
Propn_Hard	0.970	0.025	0.920	0.970	1.020	0.970	0
Propn_Mixed	0.740	0.021	0.698	0.739	0.781	0.739	0
Years_since_imp_MPAGroupAnacapa_Island	0.003	0.109	-0.210	0.002	0.218	0.001	0
Years_since_imp_MPAGroupAno_Nuevo	0.098	0.616	-1.112	0.098	1.305	0.099	0
Years_since_imp_MPAGroupBodega_Bay	0.832	0.256	0.347	0.826	1.352	0.814	0
Years_since_imp_MPAGroupCampus_Point	0.129	0.338	-0.514	0.122	0.814	0.108	0
Years_since_imp_MPAGroupCarrington_Point	-0.076	0.120	-0.310	-0.077	0.161	-0.078	0
Years_since_imp_MPAGroupFarnsworth	-0.386	0.258	-0.888	-0.387	0.123	-0.390	0
Years_since_imp_MPAGroupGull_Island	0.821	0.113	0.601	0.820	1.044	0.818	0
Years_since_imp_MPAGroupHarris_Point	0.246	0.097	0.056	0.246	0.437	0.245	0
Years_since_imp_MPAGroupMontara_Pillar_Point	-0.174	0.522	-1.191	-0.177	0.856	-0.182	0
Years_since_imp_MPAGroupPoint_Arena	0.399	0.263	-0.102	0.393	0.930	0.383	0

```
Years_since_imp_MPAGroupPoint_Buchon            0.474 0.363     -0.214     0.465      1.211  0.449   0
Years_since_imp_MPAGroupPoint_Conception        0.192 0.276     -0.339     0.188      0.746  0.180   0
Years_since_imp_MPAGroupPoint_Lobos             0.768 0.263      0.270     0.761      1.302  0.749   0
Years_since_imp_MPAGroupPoint_St._George       -0.303 0.287     -0.866    -0.304      0.261 -0.305   0
Years_since_imp_MPAGroupPoint_Sur               0.512 0.300     -0.061     0.508      1.115  0.498   0
Years_since_imp_MPAGroupPortuguese_Ledge       -1.435 0.513     -2.443    -1.435     -0.428 -1.435   0
Years_since_imp_MPAGroupReading_Rock            0.430 0.354     -0.246     0.424      1.145  0.411   0
Years_since_imp_MPAGroupSE_Farallon_Islands     0.706 0.278      0.179     0.699      1.270  0.687   0
Years_since_imp_MPAGroupSea_Lion_Gulch         -0.150 0.485     -1.114    -0.146      0.790 -0.138   0
Years_since_imp_MPAGroupSouth_La_Jolla          0.221 0.560     -0.873     0.218      1.326  0.213   0
Years_since_imp_MPAGroupSouth_Point             0.710 0.122      0.473     0.709      0.952  0.707   0
Years_since_imp_MPAGroupSwamis                  0.825 0.539     -0.191     0.810      1.926  0.780   0
Years_since_imp_MPAGroupTen_Mile                0.184 0.259     -0.312     0.180      0.703  0.172   0
SurveyYear_LongTerm_RegionCentral               0.164 0.026      0.114     0.164      0.215  0.163   0
SurveyYear_LongTerm_RegionNorth                 0.078 0.023      0.033     0.078      0.124  0.077   0
SurveyYear_LongTerm_RegionSouth                 0.109 0.007      0.096     0.109      0.122  0.109   0

Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
                                                        mean    sd 0.025quant 0.5quant 0.975quant  mode
size for the nbinomial observations (1/overdispersion) 0.375 0.023      0.327    0.377      0.417 0.383
Range for i                                            7.552 1.264      5.329    7.466     10.285 7.310
Stdev for i                                            2.125 0.248      1.697    2.103      2.669 2.051

Deviance Information Criterion (DIC) ...............: 32775.99
Deviance Information Criterion (DIC, saturated) ....: -3540028.97
Effective number of parameters .....................: 175.73

Marginal log-Likelihood:  -16613.69
```

Canary Rockfish

```
Fixed effects:
                                               mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                                    -3.240 0.733     -4.679    -3.240     -1.802 -3.240   0
Coast_dist                                    0.138 0.706     -1.248     0.138      1.524  0.138   0
Coast_dist2                                  -1.865 0.592     -3.029    -1.865     -0.704 -1.864   0
depth1                                        2.053 0.167      1.727     2.052      2.382  2.051   0
depth2                                       -0.752 0.066     -0.884    -0.752     -0.624 -0.751   0
Propn_Hard                                    0.097 0.034      0.031     0.097      0.163  0.097   0
Propn_Mixed                                   0.167 0.032      0.104     0.167      0.230  0.167   0
Years_since_imp_MPAGroupAno_Nuevo             0.172 0.677     -1.156     0.171      1.501  0.170   0
Years_since_imp_MPAGroupBodega_Bay            1.022 0.151      0.729     1.021      1.321  1.020   0
Years_since_imp_MPAGroupMontara_Pillar_Point -0.606 0.336     -1.266    -0.606      0.053 -0.606   0
Years_since_imp_MPAGroupPoint_Arena           0.804 0.193      0.430     0.802      1.186  0.799   0
Years_since_imp_MPAGroupPoint_Buchon          0.086 0.261     -0.425     0.085      0.599  0.084   0
Years_since_imp_MPAGroupPoint_Lobos           0.555 0.197      0.176     0.552      0.948  0.548   0
Years_since_imp_MPAGroupPoint_St._George     -0.190 0.165     -0.515    -0.189      0.133 -0.189   0
Years_since_imp_MPAGroupPoint_Sur             0.111 0.463     -0.776     0.104      1.042  0.089   0
Years_since_imp_MPAGroupPortuguese_Ledge     -1.518 0.712     -2.919    -1.517     -0.125 -1.515   0
Years_since_imp_MPAGroupReading_Rock          0.378 0.261     -0.125     0.375      0.899  0.370   0
Years_since_imp_MPAGroupSE_Farallon_Islands   0.567 0.205      0.170     0.565      0.976  0.561   0
Years_since_imp_MPAGroupSea_Lion_Gulch       -0.111 0.259     -0.618    -0.112      0.399 -0.113   0
Years_since_imp_MPAGroupTen_Mile             -0.053 0.180     -0.408    -0.053      0.299 -0.053   0
SurveyYear_LongTerm_RegionCentral             0.044 0.019      0.006     0.044      0.082  0.044   0
SurveyYear_LongTerm_RegionNorth               0.072 0.015      0.042     0.072      0.101  0.072   0

Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
                                                        mean    sd 0.025quant 0.5quant 0.975quant  mode
size for the nbinomial observations (1/overdispersion) 0.093 0.004      0.087    0.093      0.101 0.092
Range for i                                            8.144 1.378      5.621    8.095     11.003 8.044
Stdev for i                                            4.370 0.556      3.333    4.355      5.520 4.342

Deviance Information Criterion (DIC) ...............: 25281.59
Deviance Information Criterion (DIC, saturated) ....: -1395089.65
Effective number of parameters .....................: 164.97

Marginal log-Likelihood:  -12875.90
```

Gopher Rockfish

```
Fixed effects:
                                               mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                                    -9.272 0.369     -9.994    -9.273     -8.545 -9.275   0
Coast_dist                                    0.733 0.336      0.069     0.734      1.389  0.736   0
Coast_dist2                                  -1.921 0.370     -2.676    -1.910     -1.225 -1.889   0
depth1                                       -0.661 0.092     -0.843    -0.661     -0.481 -0.660   0
depth2                                       -0.594 0.062     -0.717    -0.593     -0.474 -0.592   0
Propn_Hard                                    1.381 0.039      1.306     1.381      1.458  1.380   0
```

```
Propn_Mixed                                  0.895 0.033      0.830    0.894      0.961  0.894   0
Years_since_imp_MPAGroupAnacapa_Island      -0.777 0.197     -1.161   -0.778     -0.390 -0.780   0
Years_since_imp_MPAGroupAno_Nuevo            0.632 0.475     -0.292    0.630      1.570  0.625   0
Years_since_imp_MPAGroupBodega_Bay           0.449 0.284     -0.093    0.443      1.021  0.433   0
Years_since_imp_MPAGroupCampus_Point        -1.150 1.318     -4.095   -1.009      1.056 -0.700   0
Years_since_imp_MPAGroupCarrington_Point     0.088 0.203     -0.300    0.085      0.496  0.079   0
Years_since_imp_MPAGroupFarnsworth          -0.231 0.735     -1.718   -0.215      1.167 -0.184   0
Years_since_imp_MPAGroupGull_Island          0.122 0.148     -0.165    0.120      0.417  0.117   0
Years_since_imp_MPAGroupHarris_Point         0.079 0.111     -0.138    0.079      0.299  0.077   0
Years_since_imp_MPAGroupMontara_Pillar_Point 0.976 0.351      0.297    0.972      1.676  0.964   0
Years_since_imp_MPAGroupPoint_Arena          1.122 0.649     -0.116    1.110      2.433  1.085   0
Years_since_imp_MPAGroupPoint_Buchon         0.374 0.144      0.095    0.373      0.661  0.370   0
Years_since_imp_MPAGroupPoint_Conception    -2.179 1.179     -4.775   -2.072     -0.157 -1.844   0
Years_since_imp_MPAGroupPoint_Lobos          0.894 0.163      0.587    0.889      1.229  0.879   0
Years_since_imp_MPAGroupPoint_St._George    -0.007 1.993     -3.958    0.006      3.867  0.032   0
Years_since_imp_MPAGroupPoint_Sur            0.873 0.178      0.530    0.871      1.229  0.866   0
Years_since_imp_MPAGroupPortuguese_Ledge    -0.958 1.213     -3.707   -0.805      1.002 -0.457   0
Years_since_imp_MPAGroupReading_Rock        -0.154 1.861     -4.166   -0.021      3.139  0.252   0
Years_since_imp_MPAGroupSE_Farallon_Islands -0.569 0.324     -1.183   -0.576      0.088 -0.591   0
Years_since_imp_MPAGroupSea_Lion_Gulch      -0.688 1.471     -3.975   -0.530      1.773 -0.185   0
Years_since_imp_MPAGroupSouth_La_Jolla       0.429 0.681     -0.897    0.426      1.776  0.418   0
Years_since_imp_MPAGroupSouth_Point         -0.127 0.130     -0.379   -0.128      0.132 -0.130   0
Years_since_imp_MPAGroupSwamis              -0.793 1.396     -3.912   -0.643      1.543 -0.315   0
Years_since_imp_MPAGroupTen_Mile             0.270 0.943     -1.612    0.280      2.094  0.301   0
SurveyYear_LongTerm_RegionCentral            0.186 0.011      0.165    0.186      0.207  0.185   0
SurveyYear_LongTerm_RegionNorth              0.239 0.029      0.183    0.238      0.298  0.237   0
SurveyYear_LongTerm_RegionSouth              0.171 0.008      0.157    0.171      0.186  0.171   0

Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
            mean    sd 0.025quant 0.5quant 0.975quant mode
Range for i 2.70 0.322       2.14     2.68       3.40 2.62
Stdev for i 2.20 0.167       1.89     2.20       2.54 2.20

Deviance Information Criterion (DIC) ...............: 24304.88
Deviance Information Criterion (DIC, saturated) ....: -3566307.26
Effective number of parameters .....................: 301.37

Marginal log-Likelihood:  -12214.29
```

Quillback Rockfish

```
Fixed effects:
                                              mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                                   -3.820 0.705     -5.204   -3.820     -2.437 -3.819   0
SurveyYear                                   0.123 0.017      0.091    0.123      0.156  0.123   0
Coast_dist                                  -0.467 0.591     -1.628   -0.467      0.692 -0.468   0
Coast_dist2                                 -1.507 0.563     -2.612   -1.507     -0.403 -1.507   0
depth1                                       0.208 0.128     -0.043    0.209      0.459  0.209   0
depth2                                      -0.750 0.076     -0.902   -0.750     -0.604 -0.748   0
Propn_Hard                                   1.044 0.070      0.909    1.043      1.186  1.040   0
Propn_Mixed                                  0.619 0.058      0.508    0.619      0.734  0.617   0
Years_since_imp_MPAGroupBodega_Bay           0.868 0.236      0.424    0.861      1.352  0.846   0
Years_since_imp_MPAGroupPoint_Arena          1.041 0.289      0.501    1.031      1.638  1.010   0
Years_since_imp_MPAGroupPoint_St._George    -0.244 0.162     -0.560   -0.245      0.074 -0.246   0
Years_since_imp_MPAGroupReading_Rock         0.468 0.215      0.056    0.464      0.902  0.457   0
Years_since_imp_MPAGroupSE_Farallon_Islands  0.549 0.196      0.176    0.544      0.946  0.536   0
Years_since_imp_MPAGroupSea_Lion_Gulch      -0.119 0.206     -0.520   -0.120      0.289 -0.123   0
Years_since_imp_MPAGroupTen_Mile             0.074 0.229     -0.362    0.069      0.539  0.060   0

Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
                                                   mean    sd 0.025quant 0.5quant 0.975quant  mode
size for the nbinomial observations (1/overdispersion)  3.74 1.582       1.71     3.39       7.80  2.82
Range for i                                       16.36 5.736       8.53    15.21      30.75 13.21
Stdev for i                                        2.31 0.507       1.52     2.23       3.51  2.08

Deviance Information Criterion (DIC) ...............: 8887.21
Deviance Information Criterion (DIC, saturated) ....: -788334.32
Effective number of parameters .....................: 63.39

Marginal log-Likelihood:  -4531.01
```

Yelloweye Rockfish

```
Fixed effects:
                                              mean    sd 0.025quant 0.5quant 0.975quant   mode kld
```

intercept	-9.693	0.626	-10.927	-9.691	-8.469	-9.688	0
Coast_dist	-1.233	0.593	-2.432	-1.221	-0.103	-1.197	0
Coast_dist2	-0.318	0.477	-1.273	-0.312	0.601	-0.300	0
depth1	1.048	0.156	0.746	1.046	1.360	1.043	0
depth2	-0.375	0.081	-0.537	-0.374	-0.220	-0.372	0
Propn_Hard	1.364	0.098	1.179	1.361	1.563	1.356	0
Propn_Mixed	0.722	0.080	0.569	0.721	0.883	0.718	0
Years_since_imp_MPAGroupAno_Nuevo	-0.943	1.203	-3.667	-0.793	1.006	-0.453	0
Years_since_imp_MPAGroupBodega_Bay	0.011	0.388	-0.732	0.005	0.791	-0.008	0
Years_since_imp_MPAGroupMontara_Pillar_Point	0.445	0.669	-0.876	0.447	1.750	0.453	0
Years_since_imp_MPAGroupPoint_Arena	-0.310	0.713	-1.791	-0.282	1.012	-0.225	0
Years_since_imp_MPAGroupPoint_Buchon	-0.804	1.477	-4.087	-0.655	1.694	-0.333	0
Years_since_imp_MPAGroupPoint_Lobos	0.788	0.431	-0.024	0.776	1.669	0.753	0
Years_since_imp_MPAGroupPoint_St._George	-0.251	0.162	-0.569	-0.251	0.068	-0.252	0
Years_since_imp_MPAGroupPoint_Sur	0.266	0.578	-0.859	0.263	1.407	0.257	0
Years_since_imp_MPAGroupPortuguese_Ledge	-0.027	0.381	-0.776	-0.027	0.720	-0.027	0
Years_since_imp_MPAGroupReading_Rock	0.262	0.193	-0.114	0.260	0.645	0.257	0
Years_since_imp_MPAGroupSE_Farallon_Islands	-0.358	0.463	-1.274	-0.356	0.545	-0.352	0
Years_since_imp_MPAGroupSea_Lion_Gulch	0.161	0.159	-0.151	0.160	0.474	0.159	0
Years_since_imp_MPAGroupTen_Mile	0.911	0.539	-0.100	0.894	2.020	0.860	0
SurveyYear_LongTerm_RegionCentral	0.094	0.039	0.019	0.094	0.172	0.093	0
SurveyYear_LongTerm_RegionNorth	0.121	0.022	0.078	0.121	0.166	0.121	0

Random effects:
Name Model
i SPDE2 model

Model hyperparameters:

	mean	sd	0.025quant	0.5quant	0.975quant	mode
Range for i	16.69	6.124	7.262	15.90	30.88	14.23
Stdev for i	1.48	0.322	0.954	1.44	2.21	1.37

Deviance Information Criterion (DIC) ....: 5847.42
Deviance Information Criterion (DIC, saturated) ....: -1460854.73
Effective number of parameters ....: 85.62

Marginal log-Likelihood: -2965.96

Lingcod

Fixed effects:

	mean	sd	0.025quant	0.5quant	0.975quant	mode	kld
intercept	-5.822	0.290	-6.392	-5.822	-5.253	-5.822	0
Coast_dist	-1.176	0.229	-1.626	-1.176	-0.726	-1.175	0
Coast_dist2	-0.519	0.154	-0.822	-0.519	-0.218	-0.519	0
depth1	0.397	0.070	0.261	0.397	0.534	0.397	0
depth2	-0.145	0.027	-0.198	-0.145	-0.093	-0.144	0
Propn_Hard	0.416	0.020	0.377	0.416	0.456	0.416	0
Propn_Mixed	0.265	0.019	0.229	0.265	0.302	0.265	0
Years_since_imp_MPAGroupAnacapa_Island	-0.762	0.154	-1.066	-0.761	-0.462	-0.760	0
Years_since_imp_MPAGroupAno_Nuevo	-0.694	0.448	-1.574	-0.694	0.184	-0.694	0
Years_since_imp_MPAGroupBodega_Bay	0.506	0.112	0.288	0.506	0.727	0.504	0
Years_since_imp_MPAGroupCampus_Point	-1.040	0.290	-1.613	-1.039	-0.473	-1.037	0
Years_since_imp_MPAGroupCarrington_Point	0.278	0.183	-0.078	0.277	0.641	0.274	0
Years_since_imp_MPAGroupFarnsworth	-0.762	0.366	-1.493	-0.757	-0.056	-0.748	0
Years_since_imp_MPAGroupGull_Island	0.495	0.138	0.227	0.494	0.769	0.493	0
Years_since_imp_MPAGroupHarris_Point	0.694	0.130	0.441	0.694	0.953	0.692	0
Years_since_imp_MPAGroupMontara_Pillar_Point	0.041	0.224	-0.397	0.041	0.483	0.039	0
Years_since_imp_MPAGroupPoint_Arena	0.351	0.161	0.035	0.350	0.669	0.349	0
Years_since_imp_MPAGroupPoint_Buchon	0.202	0.156	-0.101	0.201	0.511	0.199	0
Years_since_imp_MPAGroupPoint_Conception	-0.701	0.305	-1.300	-0.701	-0.102	-0.701	0
Years_since_imp_MPAGroupPoint_Lobos	0.854	0.142	0.583	0.852	1.140	0.847	0
Years_since_imp_MPAGroupPoint_St._George	0.370	0.151	0.075	0.370	0.666	0.369	0
Years_since_imp_MPAGroupPoint_Sur	0.289	0.188	-0.075	0.287	0.664	0.283	0
Years_since_imp_MPAGroupPortuguese_Ledge	-1.283	0.351	-1.973	-1.283	-0.596	-1.282	0
Years_since_imp_MPAGroupReading_Rock	0.589	0.140	0.315	0.588	0.865	0.587	0
Years_since_imp_MPAGroupSE_Farallon_Islands	0.411	0.149	0.120	0.410	0.705	0.409	0
Years_since_imp_MPAGroupSea_Lion_Gulch	-0.163	0.248	-0.658	-0.161	0.318	-0.156	0
Years_since_imp_MPAGroupSouth_La_Jolla	-0.792	0.390	-1.562	-0.792	-0.029	-0.790	0
Years_since_imp_MPAGroupSouth_Point	0.737	0.129	0.487	0.736	0.992	0.735	0
Years_since_imp_MPAGroupSwamis	-0.814	0.650	-2.160	-0.790	0.394	-0.742	0
Years_since_imp_MPAGroupTen_Mile	-0.806	0.147	-1.098	-0.805	-0.519	-0.803	0
SurveyYear_LongTerm_RegionCentral	0.045	0.011	0.023	0.045	0.066	0.045	0
SurveyYear_LongTerm_RegionNorth	-0.068	0.011	-0.090	-0.068	-0.046	-0.068	0
SurveyYear_LongTerm_RegionSouth	0.057	0.008	0.042	0.057	0.071	0.057	0

Random effects:
Name Model
i SPDE2 model

Model hyperparameters:

	mean	sd	0.025quant	0.5quant	0.975quant	mode
size for the nbinomial observations (1/overdispersion)	0.473	0.034	0.412	0.47	0.546	0.463
Range for i	5.001	0.593	4.087	4.91	6.384	4.666
Stdev for i	1.828	0.127	1.606	1.82	2.102	1.790

```
Deviance Information Criterion (DIC) ...............: 42097.84
Deviance Information Criterion (DIC, saturated) ....: -3504225.19
Effective number of parameters .....................: 234.81

Marginal log-Likelihood:  -21328.33
```

Kelp Greenling

```
Fixed effects:
                                            mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                                 -4.601 0.327     -5.242   -4.601     -3.960 -4.600   0
Coast_dist                                -0.961 0.296     -1.541   -0.961     -0.381 -0.961   0
Coast_dist2                               -1.123 0.250     -1.614   -1.123     -0.634 -1.123   0
depth1                                    -0.518 0.074     -0.664   -0.518     -0.373 -0.517   0
depth2                                    -0.366 0.044     -0.453   -0.366     -0.281 -0.366   0
Propn_Hard                                 0.468 0.031      0.408    0.468      0.529  0.468   0
Propn_Mixed                                0.347 0.026      0.296    0.347      0.399  0.347   0
Years_since_imp_MPAGroupAno_Nuevo         -0.165 0.371     -0.894   -0.164      0.562 -0.164   0
Years_since_imp_MPAGroupBodega_Bay         0.187 0.078      0.035    0.186      0.339  0.186   0
Years_since_imp_MPAGroupMontara_Pillar_Point -1.002 0.211  -1.416   -1.002     -0.589 -1.001   0
Years_since_imp_MPAGroupPoint_Arena       -0.006 0.108     -0.218   -0.006      0.207 -0.006   0
Years_since_imp_MPAGroupPoint_Buchon      -0.157 0.207     -0.562   -0.157      0.250 -0.157   0
Years_since_imp_MPAGroupPoint_Lobos        0.868 0.168      0.547    0.865      1.206  0.859   0
Years_since_imp_MPAGroupPoint_St._George   0.366 0.158      0.059    0.365      0.678  0.364   0
Years_since_imp_MPAGroupPoint_Sur          0.391 0.223     -0.040    0.389      0.836  0.384   0
Years_since_imp_MPAGroupPortuguese_Ledge  -0.306 0.492     -1.316   -0.291      0.616 -0.260   0
Years_since_imp_MPAGroupReading_Rock       0.673 0.163      0.358    0.672      0.999  0.668   0
Years_since_imp_MPAGroupSE_Farallon_Islands 0.042 0.136    -0.224    0.042      0.311  0.041   0
Years_since_imp_MPAGroupSea_Lion_Gulch     0.056 0.168     -0.274    0.056      0.385  0.056   0
Years_since_imp_MPAGroupTen_Mile          -0.287 0.120     -0.522   -0.287     -0.051 -0.288   0
SurveyYear_LongTerm_RegionCentral         -0.015 0.015     -0.045   -0.015      0.014 -0.015   0
SurveyYear_LongTerm_RegionNorth           -0.010 0.009     -0.029   -0.010      0.008 -0.010   0

Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
                                                mean    sd 0.025quant 0.5quant 0.975quant mode
size for the nbinomial observations (1/overdispersion) 2.82 0.568 1.863  2.77       4.09 2.67
Range for i                                     8.92 1.607      6.145     8.79      12.43 8.55
Stdev for i                                     1.18 0.162      0.901     1.16       1.54 1.12

Deviance Information Criterion (DIC) ...............: 23739.36
Deviance Information Criterion (DIC, saturated) ....: -1384441.98
Effective number of parameters .....................: 102.32

Marginal log-Likelihood:  -12001.85
```

Brown Rockfish

```
Fixed effects:
                                            mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                                 -6.557 1.403     -9.314   -6.556     -3.806 -6.555   0
Coast_dist                                 1.269 1.182     -1.050    1.269      3.589  1.268   0
Coast_dist2                               -1.540 1.021     -3.546   -1.540      0.461 -1.539   0
depth1                                     2.655 0.250      2.167    2.654      3.149  2.653   0
depth2                                    -0.190 0.132     -0.453   -0.189      0.066 -0.187   0
Propn_Hard                                 0.779 0.055      0.672    0.779      0.889  0.778   0
Propn_Mixed                                0.462 0.048      0.370    0.462      0.556  0.462   0
Years_since_imp_MPAGroupAno_Nuevo          1.033 0.895     -0.707    1.028      2.805  1.016   0
Years_since_imp_MPAGroupBodega_Bay         0.980 0.240      0.513    0.978      1.456  0.974   0
Years_since_imp_MPAGroupMontara_Pillar_Point 0.746 0.564   -0.370    0.749      1.844  0.755   0
Years_since_imp_MPAGroupPoint_Arena        1.247 0.771     -0.113    1.191      2.915  1.074   0
Years_since_imp_MPAGroupReading_Rock       0.315 0.317     -0.287    0.308      0.958  0.294   0
Years_since_imp_MPAGroupSE_Farallon_Islands -0.152 0.936   -1.835   -0.207      1.840 -0.319   0
Years_since_imp_MPAGroupSea_Lion_Gulch    -0.760 1.439     -3.910   -0.638      1.730 -0.381   0
Years_since_imp_MPAGroupTen_Mile          -0.563 0.292     -1.124   -0.566      0.020 -0.574   0
SurveyYear_LongTerm_RegionCentral          0.153 0.057      0.043    0.152      0.267  0.150   0
SurveyYear_LongTerm_RegionNorth            0.165 0.028      0.110    0.165      0.222  0.164   0

Random effects:
  Name          Model
    i SPDE2 model

Model hyperparameters:
                                                  mean    sd 0.025quant 0.5quant 0.975quant   mode
size for the nbinomial observations (1/overdispersion)  0.595 0.072 0.465 0.591     0.746  0.585
Range for i                                     13.410 3.251      7.937   13.126     20.614 12.593
Stdev for i                                      4.305 0.875      2.735    4.266      6.148  4.212

Deviance Information Criterion (DIC) ...............: 7320.12
Deviance Information Criterion (DIC, saturated) ....: -816942.81
Effective number of parameters .....................: 97.02
```

```
Marginal log-Likelihood:  -3752.42
```

*Note: the region defined for brown rockfish was from Año Nuevo in the south to Reading Rock in the north.

Non-spatial, rugosity, and full spatial model comparison for vermilion rockfish in the Central region

Non-spatial model

```
Fixed effects:
                                           mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                                -8.155 0.131     -8.415   -8.154     -7.903 -8.152   0
SurveyYear                                0.119 0.009      0.101    0.119      0.137  0.119   0
Coast_dist                               -0.060 0.057     -0.173   -0.060      0.051 -0.060   0
Coast_dist2                               0.914 0.075      0.768    0.914      1.063  0.913   0
depth1                                    0.606 0.069      0.472    0.605      0.741  0.605   0
depth2                                   -0.226 0.041     -0.308   -0.225     -0.146 -0.224   0
Propn_Hard                                0.792 0.060      0.677    0.792      0.911  0.791   0
Propn_Mixed                               0.551 0.049      0.455    0.550      0.648  0.550   0
Years_since_imp_MPAGroupAno_Nuevo         0.201 0.075      0.052    0.201      0.348  0.202   0
Years_since_imp_MPAGroupMontara_Pillar_Point -0.097 0.068 -0.231   -0.097      0.037 -0.097   0
Years_since_imp_MPAGroupPoint_Buchon     -0.006 0.061     -0.126   -0.006      0.113 -0.007   0
Years_since_imp_MPAGroupPoint_Lobos       0.304 0.061      0.184    0.304      0.424  0.304   0
Years_since_imp_MPAGroupPoint_Sur         0.341 0.066      0.211    0.340      0.470  0.340   0
Years_since_imp_MPAGroupPortuguese_Ledge  0.000 2.000     -3.927    0.000      3.923  0.000   0

Model hyperparameters:
                                                         mean    sd 0.025quant 0.5quant 0.975quant  mode
size for the nbinomial observations (1/overdispersion) 0.154 0.012      0.131    0.153      0.179 0.152

Deviance Information Criterion (DIC) ...............: 8549.36
Deviance Information Criterion (DIC, saturated) ....: -576338.32
Effective number of parameters .....................: 12.97

Marginal log-Likelihood:  -4341.57
```

Non-spatial model including rugosity

```
Fixed effects:
                                           mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                                -8.300 0.135     -8.568   -8.299     -8.039 -8.296   0
SurveyYear                                0.118 0.009      0.100    0.118      0.136  0.118   0
Coast_dist                               -0.127 0.059     -0.242   -0.127     -0.013 -0.127   0
Coast_dist2                               1.074 0.083      0.913    1.073      1.237  1.072   0
depth1                                    0.691 0.071      0.553    0.690      0.830  0.690   0
depth2                                   -0.251 0.042     -0.335   -0.251     -0.171 -0.250   0
Propn_Hard                                0.650 0.065      0.523    0.649      0.779  0.648   0
Propn_Mixed                               0.475 0.051      0.375    0.474      0.576  0.474   0
VRM20                                     0.292 0.061      0.173    0.292      0.413  0.292   0
Years_since_imp_MPAGroupAno_Nuevo         0.216 0.075      0.068    0.217      0.363  0.217   0
Years_since_imp_MPAGroupMontara_Pillar_Point -0.213 0.072 -0.354   -0.213     -0.071 -0.213   0
Years_since_imp_MPAGroupPoint_Buchon      0.028 0.061     -0.091    0.028      0.148  0.028   0
Years_since_imp_MPAGroupPoint_Lobos       0.275 0.061      0.155    0.275      0.396  0.275   0
Years_since_imp_MPAGroupPoint_Sur         0.418 0.068      0.285    0.418      0.552  0.418   0
Years_since_imp_MPAGroupPortuguese_Ledge  0.000 2.000     -3.927    0.000      3.923  0.000   0

Model hyperparameters:
                                                         mean    sd 0.025quant 0.5quant 0.975quant  mode
size for the nbinomial observations (1/overdispersion) 0.159 0.013      0.136    0.159      0.185 0.158

Deviance Information Criterion (DIC) ...............: 8524.09
Deviance Information Criterion (DIC, saturated) ....: -576362.72
Effective number of parameters .....................: 11.95

Marginal log-Likelihood:  -4333.39
```

Full spatial model

```
Fixed effects:
                                           mean    sd 0.025quant 0.5quant 0.975quant   mode kld
intercept                                -7.501 0.597     -8.674   -7.501     -6.330 -7.501   0
SurveyYear                                0.103 0.013      0.079    0.103      0.128  0.103   0
Coast_dist                               -0.160 0.448     -1.039   -0.160      0.718 -0.160   0
Coast_dist2                               0.450 0.427     -0.389    0.450      1.287  0.450   0
depth1                                    0.691 0.122      0.453    0.691      0.932  0.690   0
depth2                                   -0.245 0.058     -0.361   -0.244     -0.135 -0.241   0
Propn_Hard                                0.655 0.067      0.526    0.655      0.788  0.654   0
Propn_Mixed                               0.479 0.052      0.377    0.479      0.583  0.478   0
VRM20                                     0.336 0.068      0.203    0.336      0.470  0.335   0
Years_since_imp_MPAGroupAno_Nuevo         0.548 0.427     -0.288    0.547      1.386  0.546   0
Years_since_imp_MPAGroupMontara_Pillar_Point  1.014 0.313  0.406    1.011      1.635  1.007   0
Years_since_imp_MPAGroupPoint_Buchon      0.423 0.153      0.125    0.422      0.727  0.420   0
Years_since_imp_MPAGroupPoint_Lobos       0.250 0.134     -0.009    0.248      0.515  0.246   0
Years_since_imp_MPAGroupPoint_Sur         0.395 0.178      0.051    0.393      0.751  0.390   0
Years_since_imp_MPAGroupPortuguese_Ledge  0.000 2.000     -3.927    0.000      3.923  0.000   0

Random effects:
```

```
  Name        Model
    i SPDE2 model

Model hyperparameters:
                                                         mean    sd 0.025quant 0.5quant 0.975quant  mode
size for the nbinomial observations (1/overdispersion) 0.169 0.015      0.138     0.17      0.199 0.172
Range for i                                            8.287 3.119      3.817     7.75     15.868 6.777
Stdev for i                                            1.299 0.454      0.628     1.23      2.385 1.094

Deviance Information Criterion (DIC) ...............: 8456.27
Deviance Information Criterion (DIC, saturated) ....: -576429.52
Effective number of parameters .....................: 37.16

Marginal log-Likelihood:  -4319.22
```

Appendix C: Expected timelines of MPA responses

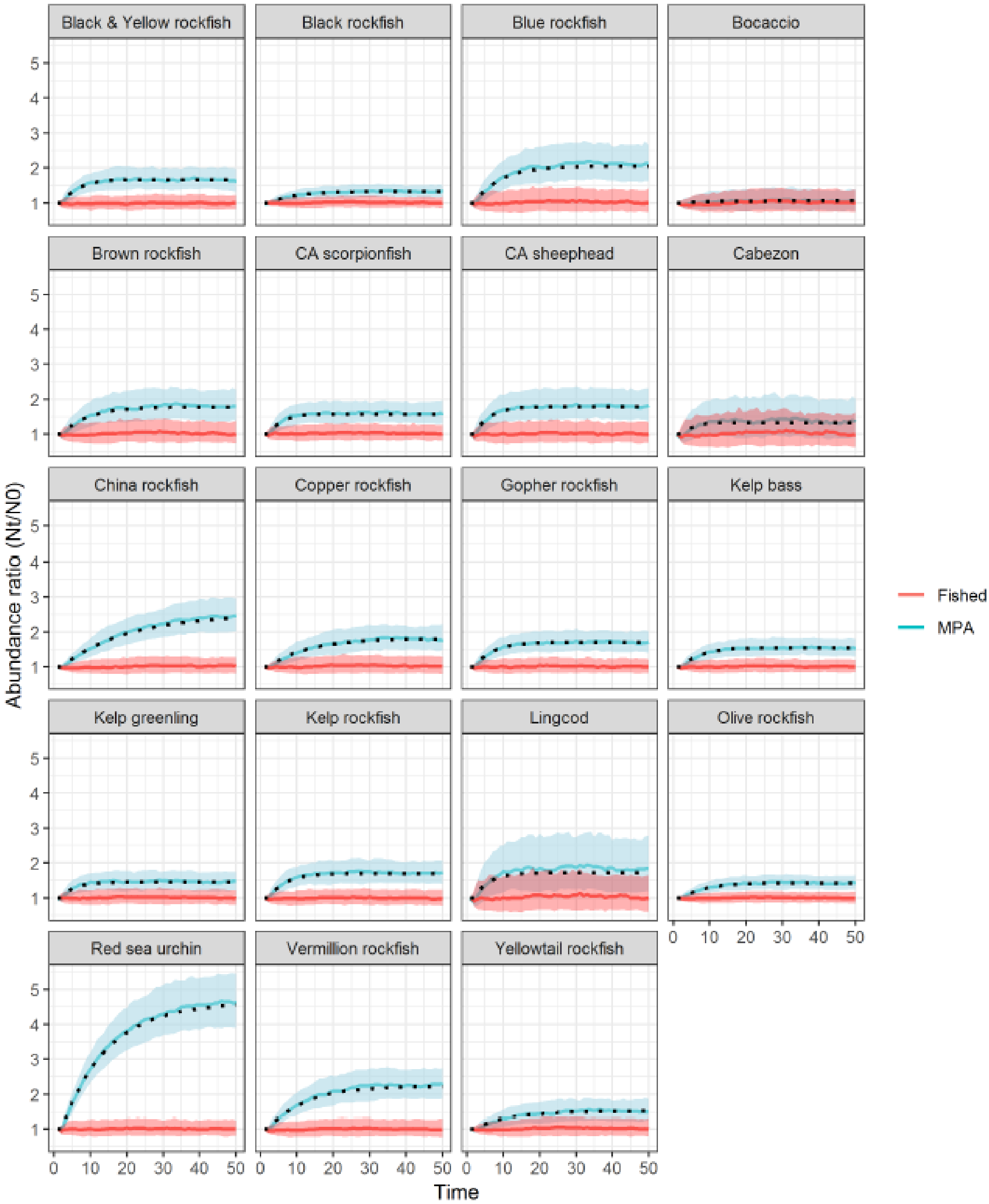

Figure AC-1. Trajectories of population abundance ratios over time, with (blue) and without (red) MPA establishment, given open population dynamics with stochastic recruitment. Banded intervals represent the lower quartile and upper quartile for 500 simulated runs, and solid-colored lines indicate median responses. Greater separation between the ranges of outcomes with versus without MPA establishment indicates greater ability to distinguish an MPA effect. Black dotted lines represent deterministic model projections inside an MPA. Figure and caption taken from Kaplan et al. (2019).

Table AC-1. Length of time in years to reach 95% of final equilibrium abundance (N ratio) or biomass ratio (B ratio) for deterministic open population models.

Species	*N* ratio time to equilibrium (y)	*B* ratio time to equilibrium (y)	Final *N* ratio (N_f/N_0)	Final *B* ratio (B_f/B_0)
Kelp rockfish	10	13	1.69	2.24
Blue rockfish	17	21	2.04	2.94
Black rockfish	12	14	1.32	1.45
Gopher rockfish	10	12	1.69	1.95
Lingcod	9	12	1.72	2.31
Copper rockfish	22	27	1.79	2.38
CA scorpionfish	8	10	1.57	1.92
Brown rockfish	15	18	1.76	2.47
Yellowtail rockfish	18	22	1.52	1.81
Vermillion rockfish	24	31	2.23	3.94
Bocaccio	1	4	1.06	1.08
Cabezon	6	7	1.33	1.45
China rockfish	40	41	2.45	2.62
Kelp greenling	6	8	1.44	1.60
CA sheephead	9	12	1.78	2.22
Red sea urchin	35	37	4.63	6.71
Kelp bass	11	16	1.55	2.12
Olive rockfish	12	14	1.42	1.64
Black & yellow rockfish	9	9	1.65	1.68

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