Development of Indices of Abundance and Absolute Estimates of Abundance using Design-based Methods for Quillback Rockfish from California ROV Surveys

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A. Overview

The California Department of Fish and Wildlife (CDFW) in collaboration with Marine Applied Research and Exploration (MARE) have been conducting Remotely Operated Vehicle (ROV) surveys off the California coast to monitor changes in density (fish/square meter) and size of fish and invertebrate species inside marine protected areas (MPAs) closed to fishing and representative reference sites open to fishing for comparison of changes since the implementation of MPAs. In addition, this data has been applied to developing indices of relative abundance using Generalized Linear Mixed Models (GLMM) and estimates absolute abundance using design-based and model-based methods in combination with seafloor mapping data.

The habitat data are available from the California Seafloor Mapping Program (CSMP) providing high resolution mapping for state waters and Coastal and Marine Ecological Classification Standard (CMECS) produced by NMFS providing more comprehensive mapping of the nearshore habitat (<300 ft) in state and federal waters at various resolutions from contributing data sources. Estimates of absolute abundance in numbers resulting from expansions can be converted to metric tons using the lengths of fish observed using stereo-camera systems extracted using digital processing software, that are then converted to weight using existing length-weight relationships from the most recent assessment. The relative abundance indices and estimates of absolute abundance also referred to as biomass can be used as indices of abundance in integrated stock assessments, while biomass can also be compared to the results from the assessment as a check on the scale from the assessment based on catch history.

The analyses provided herein are intended to facilitate further development and inclusion of indices and biomass estimates in the 2025 quillback rockfish stock assessment. Garnering input on the methods at the accepted practices meeting December 2-3rd, 2024 will help hone the methods and familiarize assessment staff with the data and methods employed. The table of contents provides an outline of the contents of the document. The Department appreciates the time and effort of reviewers in providing feedback and guidance on the use of the methods for inclusion in the accepted practices document to inform future stock assessors.

B. Analysis of California Remotely Operated Vehicle Survey Data Providing an Index of Abundance for Quillback Rockfish for use in the 2025 Stock Assessment

Introduction

The California Department of Fish and Wildlife (CDFW) in collaboration with Marine Applied Research and Exploration (MARE) have been conducting Remotely Operated Vehicle (ROV) surveys along the California coast in Marine Protected Areas (MPAs) and reference sites adjacent to them since 2004 for the purposes of long-term monitoring of changes in length and density (fish/square meter) of fish and invertebrate species along the California coast. The use of these data in stock assessments to provide an index of abundance or absolute abundance estimates using seafloor mapping as the basis for expansion to rocky reef habitat was approved by the SSC for use in stock assessments after a methodology review conducted in 2019. This document provides analyses, an evaluation of indices of abundance, length data and design-based estimates of abundance for use in 2025 stock assessments, with particular focus on application of ROV data in the upcoming stock assessment for quillback rockfish.

Surveys of the entire coast (Figure B1) have now been undertaken twice, each taking three years to complete and each resulting in data combined into super years of 2015 (2014-2016) and 2020 (2019-2021) available for analysis to examine the changes over five years. The 500 m strip survey transects in each rocky reef sample site were selected by first randomly selecting the deepest transect at a given site, then selecting transects on a constant interval into shallower depths (Figure B2). Transects were designed to be oriented parallel to general depth contours, though they were carried out using a fixed bearing that crossed depths in some cases. Species encountered by the ROV along the transect were identified to species or lowest taxonomic grouping possible and stereo cameras along with analytical software were used to determine the length of individuals in a suitable orientation for estimation.

The seafloor was characterized along the course of the transect in 1 second micro frames of observation assembled into classifications of rock, mixed and soft bottom habitat. Frames taken when the ROV was off course due to pulling of the tether to the vessel or looking into open water at the top of high relief habitat were removed. The transects can either be analyzed in their entirety or broken into 10 m segments to allow evaluation of density of fish with variables such as depth, habitat type and latitude. The number of transects conducted in each Marine Protected Area (MPA) group, composed of MPA sites and reference sites, is provided in Figure B1. Length data and complete statewide coverages began in 2014, and are the focal period of this study.

Multibeam and side scan sonar data from the California Seafloor Mapping Program (CSMP) provides seafloor classification to soft and hard habitat and provided depth data within three miles of shore (Figure B2). In shallower water 2x2 m resolution depth data is available, while 3x3 or 5x5 grids are available in deeper depths from the CSMP. Lower resolution data for additional habitat is available from NMFS efforts to map rocky reef to identify Essential Fish Habitat lead by Joe Bizzaro referred to as the Coastal and Marine Ecological Classification Standard (CMECS) habitat data. The seafloor data from multiple sources including CSMP can be combined to provide estimates of rocky reef habitat, depth data and latitude to provide a basis for expansion to estimate abundance in numbers of fish.

Length data from the ROV stereo-camera estimates provide composition data representing the observed fish sampled among MPAs and reference sites that can be paired with the indices or abundance estimates as a research fleet in Stock Synthesis. In addition, the lengths can be converted to average weight using relationships derived from other sampling programs collecting both length and weight to inform conversion of estimates of abundance in numbers to biomass.

Additional details on sampling methods, data processing, index derivation and absolute abundance estimation principles and methods can be found in the report from the methodology review. The analyses provided in this document provide a starting point for further analysis of transect level data to provide indices of abundance for the 2025 quillback rockfish stock assessment. The resulting indices may be considered for use in assessments, or the assessment authors may use the provided data sets, R scripts, methodological descriptions and data user manual to provide their own preferred index.

Figure B1. Sample locations for the California ROV sampling project.

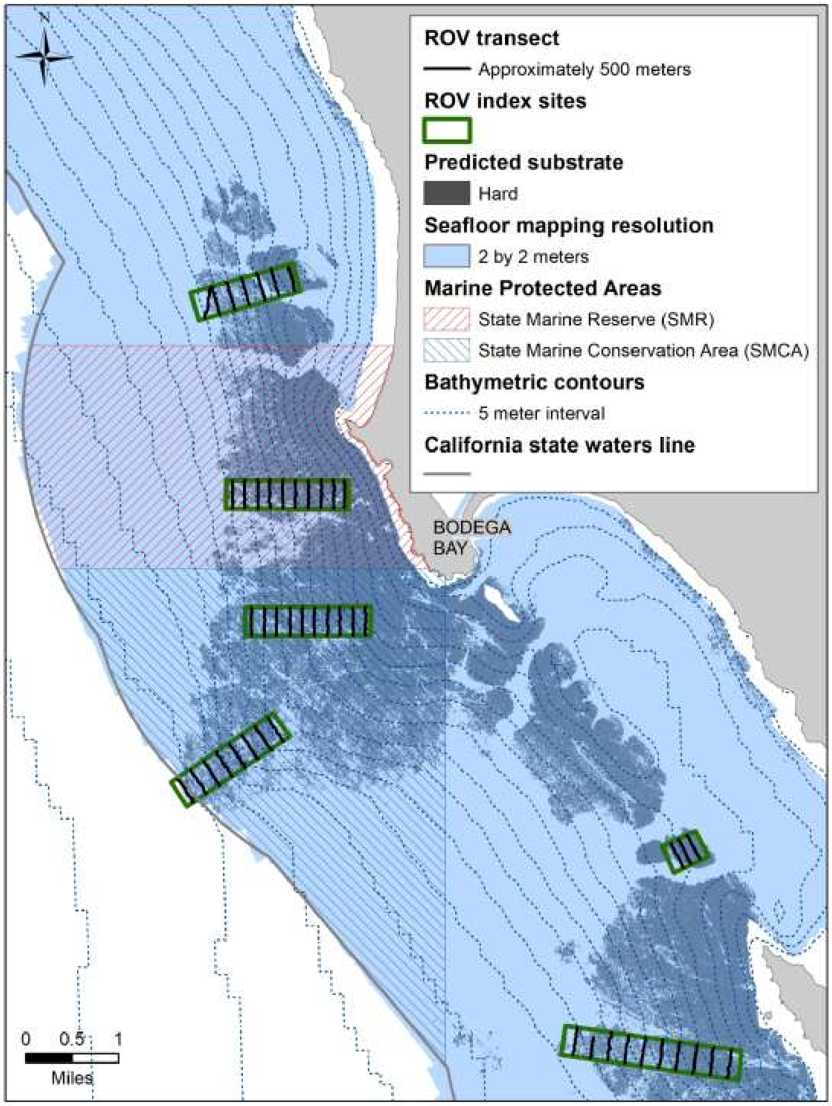

Figure B2. Depiction of the sampling design showing the boxes that identify sampling locations over hard substrate and the 500 m transect lines oriented to align with the bathymetry contours and other features pertinent to the study superimposed on CSMP seafloor characterization.

Table B1. List of MPA groups included in analysis (highlighted yellow) containing sites used in analysis and number of transects sampled in each year.

Region	MPA Group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total Transects	Total Series Replicates
North	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
	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
Central	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
	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
South	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
	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

Advancements since the ROV Methodology Review

The following efforts have been undertaken since the methodology review to address areas identified for further consideration.

- Incorporation of another temporal replicate (2020 super year data) extending the ROV time series to include data from 2014 to 2021, providing two complete coverages of the state centered on super years 2015 and 2020 allowing comparisons of trends over the intervening five-year period.
- Investigation of spatial autocorrelation in the integrated nested Laplace approximation (INLA) package of R. Modeling with a GLM with a negative binomial distribution using all available variables was conducted with variable selection using AIC, deviance and pseudo r-square measures with stepwise removal and evaluation of qq norm plots. The results indicate spatial autocorrelation on a scale of 8-12 km (Perkins 2023).
- Site or MPA Group variables were evaluated to address the uneven number of sampling events between locations and capturing regional variation.

- Investigation of 10 m resolution data and transect level analysis to investigate the effect of scale: A 10 m resolution was selected for further exploration of a higher resolution of data with the potential for application with terrain attributes derived from the California Seafloor Mapping Program at the native 2x2 m resolution at which the data is collected as a opposed to averaging across a more aggregated resolution with the 20 m resolution data used in the previous methodology review. The 10 m resolution data also allows a higher resolution analysis of depth as the transects are run on a bearing approximating the depth contour on paper rather than following a fixed depth. This also allows for a higher resolution analysis with seafloor composition of aggregated soft, mixed or hard substrate categories or alternatively mud, sand, gravel, cobble, boulders or rocky reef categorizations for correlation with individual fish positions using methods described further in the methodology review document. Investigation of the 10 m resolution is also consistent with the home range of many demersal *Sebastes* and was undertaken for evaluation of MPA effects (Perkins 2023).
- Spatial autocorrelation was evaluated in the INLA package and found to have low to moderate spatial autocorrelation Rho on a scale of 8 to 12 km in this study (Perkins 2023).
- A transect level GLMM analysis provided herein was conducted along the 500 m transects excluding unusable data from backsides of high relief structure looking into open water or “pull stops” from the vessel pulling the ROV off its set transect bearing.
- Length data from stereo-camera measurements were used to inform length composition in stock assessments since they are more reliable for use in stock assessment given apparent bias in paired laser approximations.

Methods

In discussions with NMFS in 2022 regarding the ROV data and its use in constructing indices of abundance, a strong preference was expressed for analysis at the transect level. In addition, a preference was expressed to include a sample site variable, which was treated as a random effect since sites selected for analysis are a subset of the seafloor that could potentially be sampled and the transect lines in each vary depending on the starting depth used each time the site is sampled. Alternative models for further exploration are discussed below. A generalized linear mixed model was fit by maximum likelihood (Laplace Approximation) ['glmerMod'] using a Negative Binomial error distribution with a log link and an Offset of log(Usable_Area_Fish) to provide the denominator in the density used as the dependent variable analyzed for correlation with variables described in Table B2.

The continuous variables were scaled prior to analysis by centering on the mean and dividing by their standard deviations to make coefficient estimates for covariates with very different scales (e.g. latitude versus proportion habitat) more interpretable. Also, scaling facilitates estimation of index values, as the model intercept represents expected values with covariates at their means rather than at zero. The Super Year (SuperYear) and variable describing whether a site is open to fishing or in a no take Marine Protected Area (Protection) were converted to factors to allow estimation of separate index values for them.

Indices of abundance providing density (fish/square meter) for each super year, both inside and outside of MPAs, were calculated using the ‘general linear hypothesis testing’ (glht) function from the multcomp package in R. This package allows the calculations of means and confidence intervals from linear combinations of beta coefficients. The estimated means and confidence intervals were back transformed to the response scale (density) by exponentiating the resultant means and upper and lower 95% confidence intervals. From the model output:

- The intercept represents the mean density in reference areas in 2015
- The intercept + the estimate for super year 2020 represents the mean density for reference areas in 2020
- The intercept + the estimate for protection represents the mean density for MPAs in 2015
- The intercept + the estimate for super year 2020 + the estimate for protection represents the mean density for MPAs in 2020

This assumes that all other covariates (e.g., depth, proportion hard etc.) were held constant at a value of zero in linear predictor (log) space. Zero values for the remaining covariates represent the mean value for each covariate in the data set as these were scaled prior to analysis. Therefore, index estimates are at the mean values of all remaining covariates across the modeled data.

An initial evaluation of spatial autocorrelation was conducted in the INLA package and found to be low to moderate (Autocorrelation Rho Spatial SD = 0.36) on a scale of 8 to 12 km with the model specified below. However, the spatial autocorrelation will be dependent on the model structure specified, and so further exploration was not conducted until the current approaches have been reviewed and a final model structure decided upon.

Table B2. Description of variables available for use in the ROV GLMM index analysis.

Variable	Description
SurveyYear	Year in which the actual survey occurred.
SuperYear	Survey coverages are completed over three years resulting in compilation to 2015 (2014-2016) and 2020 (2019-2021). Treated as a categorical factor.
MPAGroup	MPA name that identifies records from MPA sites and associated reference areas.
Site	CDFW/MARE historical site code. A site generally designates a 500 meter wide rectangle with varying length and depth range. May be preferable to use MPA Group given spatial proximate of sites within a group and scale of spatial autocorrelation. Number of transects may not be equal between sites.
Avg_X	Average of longitudinal positions within a segment expressed in UTM Zone 10N coordinates which are meters. Combine with Avg_Y to get geographic coordinates of centroid of segment. More amenable to analysis of longitude as a continuous scale as opposed to Avg Lat in decimal degrees.
Avg_Y	Average of latitudinal positions within a segment expressed in UTM Zone 10N coordinates which are meters. Combine with Avg_X to get geographic coordinates of centroid of segment. More amenable to analysis of latitude as a continuous scale as opposed to Avg Lat in decimal degrees.
Avg_Depth	Average depth in meters recorded within a segment. The values for segments were the averaged across the transect.
Avg_Depth^2	Average depth squared was calculated by squaring the AvgOfAvg_Depth values after scaling so that these values were also centered on the mean.
PropHard	The proportion of hard usable habitat along a transect.
PropMixed	The proportion of mixed usable habitat along a transect.
PropHardMixed	The proportion of hard or mixed usable habitat along a transect.
Protection	Whether the segment in question is in a no take closed Marine Protected Area (1) or open to fishing (0). Treated as a categorical factor.
ProtectionYrs	The number of years the site has been protected since implementation in the survey year.
portdistanceM	Distance in meters from nearest port to the centroid coordinates of the sub-unit. Derived from port distance raster layer provided by Becky Miller (SWFSC).
Quillback Rockfish	Total number of quillback rockfish individuals counted within sub-unit. Numerator of the dependent variable of density.
Usable_Area_Fish	Summed two dimensional area (m^2) of all microframes (one second of ROV area swept) within a sub-unit determined by multiplying Total_XYdist with estimated width at horizontal center of video frame for each microframe, where video parameters are within useable parameters. Denominator of the dependent variable of density implemented as an offset.

Results

The analysis started with the full GLMM model using a negative binomial distribution including all the variables of interest (see Model B1) results for which are provided in Figure B3. Examination of the correlations between variables indicated that as expected, a number of other variables were strongly correlated (Figure B4). Of the correlated variables, those showing the most significant correlation with density were selected for further examination. For example, proportion hard may have been significant in the absence of proportion hard or mixed, but the latter was selected for quillback rockfish. Though depth and depth squared were correlated in the matrix seen in Figure B4, they are orthogonal once rescaled prior to running the GLMM, thus both were included to capture the rise and fall in abundance with depth through inclusion of the quadratic form in squared depth. Further examination of the reduced model identified that backsides indicative of pinnacles, average temperature, proportion hard bottom and distance from port were non-significant and removed from the model. The reduced model (Model B2) included site as a random effect and super year, protection proportion hard or mixed substrate, average latitude, average depth and depth squared.

The correlation between super year and protection of -0.608 seen in Figure B5 was further evaluated through an interaction term added in Model B3, and compared to the reduced model without it in Model B2. While protection in MPAs was not significant on its own, the interaction term was, and thus both were retained. Results for Model B2 provided in Figure B5, with an AIC value of 2220.8 for Model B2 as compared to 2214.1 in Figure B8 providing results for Model B3 with the interaction term for protection and super year, indicating the latter to be a better fit. To evaluate the implications of not accounting for protection inside and outside MPAs at all, an additional model was analyzed excluding protection level in Model B4. The resulting AIC value for model B4 was 2219.3 indicating it is less well fit than Model B3 accounting for the interaction term.

The indices and confidence limits resulting from the varied models are provided in Figures B7, B10 and B13 for Models B2, B3 and B4, respectively. The respective quantile-quantile (Q-Q) plots from these models comparing predicted to observed values were similar in their deviation from the one-to-one line seen in Figures B6, B9, and B12. The indices (fish/square meter) and 95% confidence limits resulting from each of the models are provided in Tables 3, 4 and 5. A comparison of the indices weighting for the proportion of rocky reef habitat inside and outside MPAs, with 80% outside MPAs and 20% protected in MPAs for Model B2 without an interaction term and Model B3 with an interaction term and no adjustment for Model B4 without accounting for protection, are provided in Table B6, resulting in an 79.1%, 48.9% and 79.3% increase in abundance, respectively. The indices may overestimate the change in abundance without an interaction term for Protection and Super Year to account for potential differences in response over time as observed in Model B2, or with the complete omission of protection from MPAs in producing an index as in Model B3.

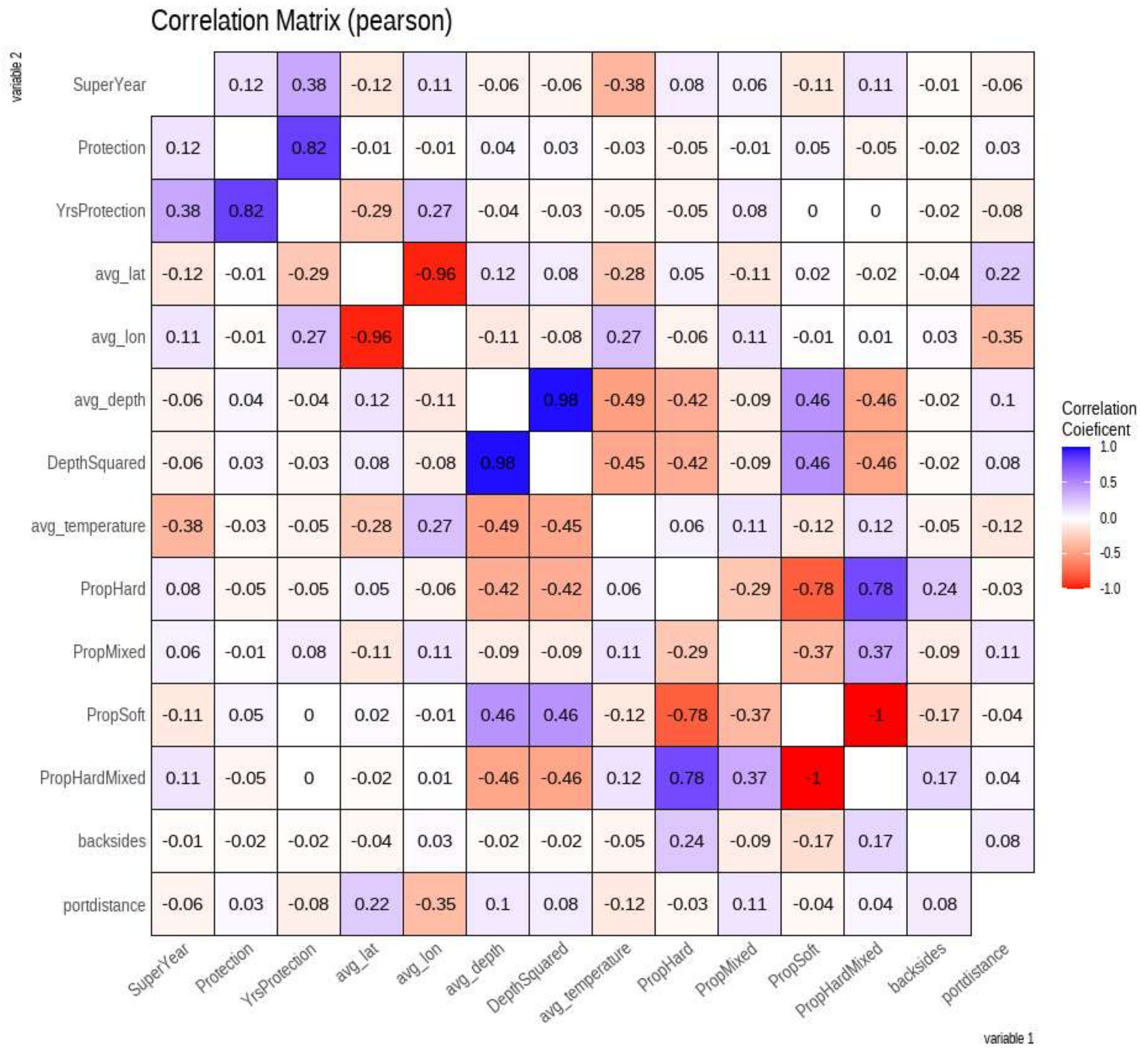

Figure B3. Correlations among variables evaluated for use.

Model B1. Full model for quillback rockfish treating site as a random effect including all analyzed variables (AIC = 1583).

Quillback.Rockfish ~ (1 | site) + SuperYear + Protection + PropHard + PropHardMixed + avg_lat + avg_depth + DepthSquared + portdistance + avg_temperature

```
     AIC      BIC   logLik deviance df.resid 
  2222.0   2280.1  -1099.0   2198.0      923 

Scaled residuals: 
    Min      1Q  Median      3Q     Max 
-1.3735 -0.4989 -0.1625 -0.0315 11.9623 

Random effects:
 Groups Name        Variance Std.Dev.
 site   (Intercept) 1.733    1.317   
Number of obs: 935, groups:  site, 60

Fixed effects:
                 Estimate Std. Error z value Pr(>|z|)    
(Intercept)     -8.159809   0.349199 -23.367  < 2e-16 ***
SuperYear2020    0.644395   0.138559   4.651 3.31e-06 ***
Protection1      0.285792   0.426389   0.670   0.5027    
PropHard         0.003938   0.080703   0.049   0.9611    
PropHardMixed    0.599710   0.100712   5.955 2.61e-09 ***
avg_lat          1.680492   0.243801   6.893 5.47e-12 ***
avg_depth        0.635008   0.110961   5.723 1.05e-08 ***
DepthSquared    -0.597317   0.078369  -7.622 2.50e-14 ***
portdistance     0.417703   0.193175   2.162   0.0306 *  
avg_temperature  0.051038   0.085024   0.600   0.5483    
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) SY2020 Prtct1 PrpHrd PrpHrM avg_lt avg_dp DpthSq prtdst
SuperYr2020 -0.195                                                        
Protection1 -0.635 -0.030                                                 
PropHard     0.003  0.141 -0.015                                          
PropHardMxd -0.054 -0.153  0.022 -0.696                                   
avg_lat     -0.394  0.121  0.213 -0.048  0.039                            
avg_depth   -0.059  0.255 -0.011  0.113  0.240  0.039                     
DepthSquard -0.183 -0.057  0.036  0.053  0.061  0.020  0.067              
portdistanc -0.194  0.054  0.017  0.013 -0.034 -0.064 -0.075 -0.081       
avg_temprtr -0.128  0.728 -0.013  0.103 -0.098  0.131  0.338 -0.131  0.072
```

Figure B4. Results of a GLMM for Model B1 including all variables.

Model B2. Reduced model without interaction term of super year and protection.

Quillback.Rockfish ~ (1 | site) + SuperYear + Protection + PropHardMixed + avg_lat + avg_depth + DepthSquared, data = sc.dat, offset = log(usable_area_fish)

```
    AIC      BIC   logLik deviance df.resid
 2220.8   2264.4  -1101.4   2202.8      926

Scaled residuals:
    Min      1Q  Median      3Q     Max
-1.3672 -0.5012 -0.1668 -0.0325 11.3166

Random effects:
 Groups Name        Variance Std.Dev.
 site   (Intercept) 1.931    1.389
Number of obs: 935, groups:  site, 60

Fixed effects:
              Estimate Std. Error z value Pr(>|z|)
(Intercept)   -8.08698    0.35420 -22.831  < 2e-16 ***
SuperYear2020  0.58266    0.09475   6.149 7.79e-10 ***
Protection1    0.29412    0.44553   0.660    0.509
PropHardMixed  0.61118    0.07257   8.422  < 2e-16 ***
avg_lat        1.77166    0.25236   7.020 2.21e-12 ***
avg_depth      0.63415    0.10426   6.082 1.19e-09 ***
DepthSquared  -0.58194    0.07733  -7.525 5.27e-14 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) SY2020 Prtct1 PrpHrM avg_lt avg_dp
SuperYr2020 -0.151
Protection1 -0.653 -0.025
PropHardMxd -0.072 -0.071  0.013
avg_lat     -0.400  0.044  0.218  0.000
avg_depth   -0.021  0.007 -0.009  0.488 -0.025
DepthSquard -0.206  0.051  0.033  0.132  0.027  0.110
```

Figure B5. Results of a GLMM for Model B2 without interaction term of super year and protection.

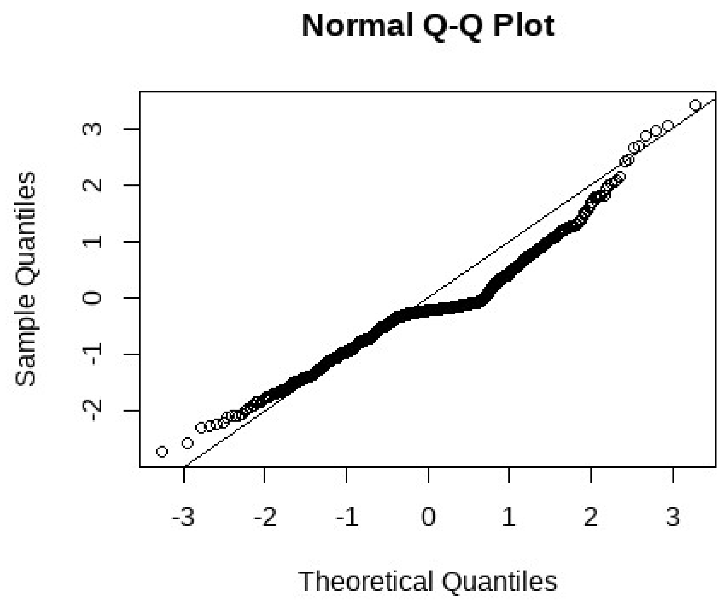

Figure B6. Q-Q Plot comparing model predicted and sample values to a one-to-one line for equivalence for Model B2 without an interaction term for super year and protection.

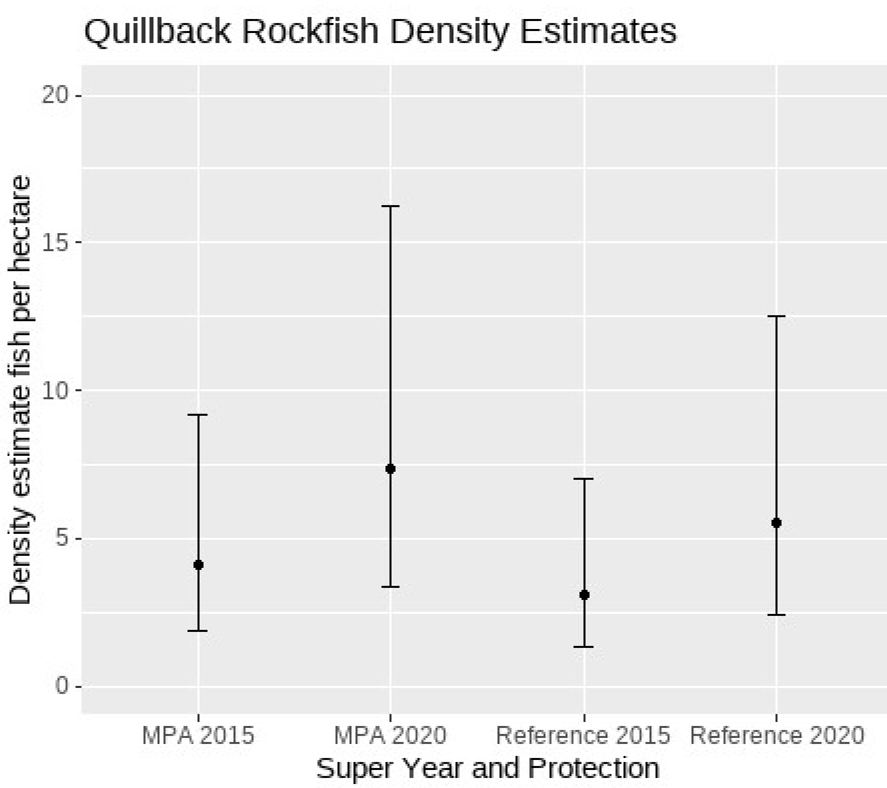

Figure B7. Index and confidence limit estimates for GLMM Model B2 without an interaction term of super year and protection.

Table B3. Index (fish/hectare) and upper and lower confidence limits for Model B2 without an interaction term of super year and protection.

Time/Area	Estimate	Lower CL	Upper CL
2015 Reference Site	3.08	1.35	7.01
2020 Reference Site	5.51	2.42	12.51
2015 MPA	4.13	1.86	9.17
2015 MPA	7.39	3.36	16.24

Model B3. Reduced model with interaction term of super year and protection.

Quillback.Rockfish ~ (1 | site) + SuperYear * Protection + PropHardMixed + avg_lat + avg_depth + DepthSquared

```
    AIC      BIC   logLik deviance df.resid 
  2214.1   2262.5  -1097.0   2194.1      925 

Scaled residuals: 
    Min      1Q  Median      3Q     Max 
-1.4038 -0.4996 -0.1692 -0.0318 11.1463 

Random effects:
 Groups Name        Variance Std.Dev.
 site   (Intercept) 1.947    1.395   
Number of obs: 935, groups:  site, 60

Fixed effects:
                          Estimate Std. Error z value Pr(>|z|)    
(Intercept)               -7.91685    0.35878 -22.066  < 2e-16 ***
SuperYear2020              0.26365    0.14069   1.874  0.06093 .  
Protection1               -0.04960    0.46153  -0.107  0.91442    
PropHardMixed              0.61822    0.07174   8.617  < 2e-16 ***
avg_lat                    1.74217    0.25290   6.889 5.63e-12 ***
avg_depth                  0.62884    0.10348   6.077 1.22e-09 ***
DepthSquared              -0.58254    0.07689  -7.576 3.56e-14 ***
SuperYear2020:Protection1  0.55911    0.18748   2.982  0.00286 ** 
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) SpY2020 Prtct1 PrpHrM avg_lt avg_dp DpthSq
SuperYr2020 -0.204                                          
Protection1 -0.663  0.165                                   
PropHardMxd -0.062 -0.087  -0.001                            
avg_lat     -0.400  0.050   0.220 -0.004                     
avg_depth   -0.016 -0.004  -0.010  0.489 -0.030              
DepthSquard -0.199  0.035   0.033  0.133  0.023  0.113       
SprY2020:P1  0.149 -0.747  -0.249  0.054 -0.032  0.012 -0.006
```

Figure B8. Results of a GLMM for Model B3 with interaction term of super year and protection.

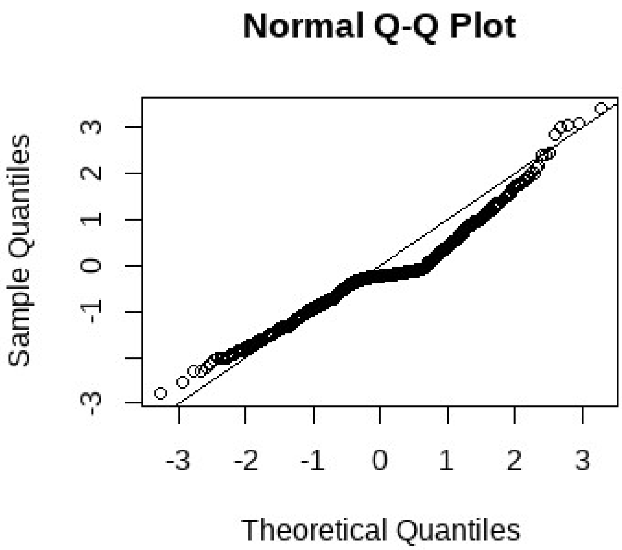

Figure B9. Q-Q Plot for Model B3 comparing model predicted and sample values to a one-to-one line for equivalence.

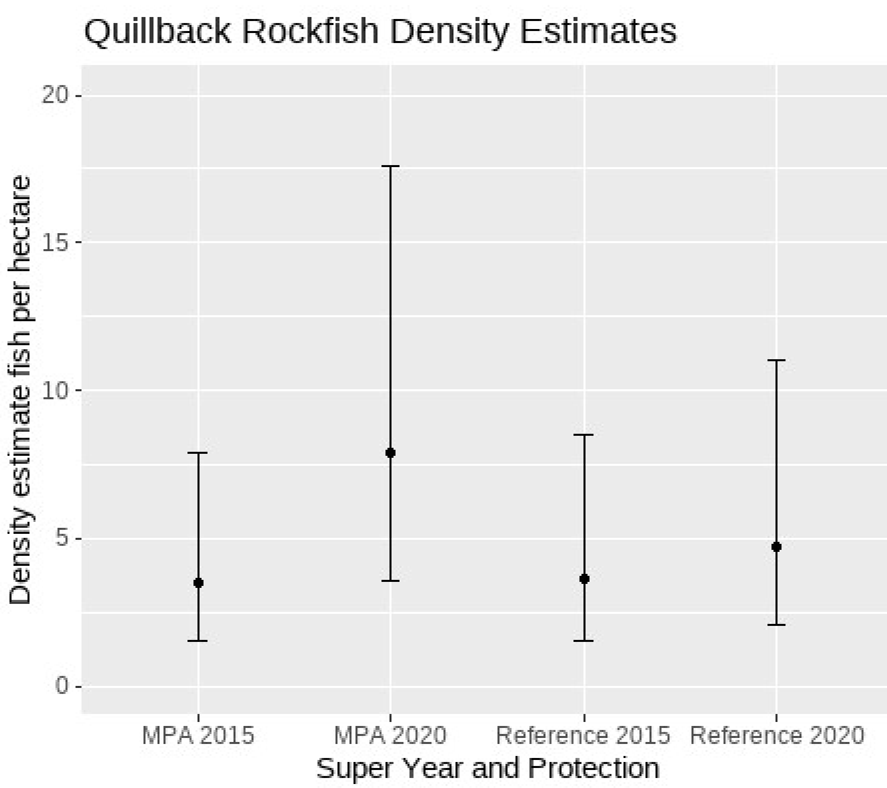

Figure B10. Index and confidence limit estimates for GLMM Model B2 with an interaction term of super year and protection.

Table B4. Index (fish/hectare) and upper and lower confidence limits for Model B3.

Time/Area	Estimate	Lower CL	Upper CL
2015 Reference Site	3.65	1.56	8.50
2020 Reference Site	4.75	2.04	11.04
2015 MPA	3.47	1.52	7.92
2015 MPA	7.90	3.54	17.62

Model B4. Reduced model without protection.

Quillback.Rockfish ~ (1 | site) + SuperYear + PropHardMixed + avg_lat + avg_depth + DepthSquared, data = sc.dat, offset = log(usable_area_fish)

```
   AIC      BIC   logLik deviance df.resid
  2219.3   2258.0  -1101.6   2203.3      927

Scaled residuals:
    Min      1Q  Median      3Q     Max
-1.3681 -0.5029 -0.1665 -0.0340 11.4230

Random effects:
 Groups Name        Variance Std.Dev.
 site   (Intercept) 1.938    1.392
Number of obs: 935, groups:  site, 60

Fixed effects:
              Estimate Std. Error z value Pr(>|z|)
(Intercept)   -7.94263    0.26896 -29.531  < 2e-16 ***
SuperYear2020  0.58414    0.09476   6.164 7.08e-10 ***
PropHardMixed  0.61062    0.07259   8.412  < 2e-16 ***
avg_lat        1.74274    0.24639   7.073 1.51e-12 ***
avg_depth      0.63437    0.10434   6.080 1.20e-09 ***
DepthSquared  -0.58391    0.07736  -7.547 4.44e-14 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) SY2020 PrpHrM avg_lt avg_dp
SuperYr2020 -0.218
PropHardMxd -0.085 -0.071
avg_lat     -0.348  0.049 -0.002
avg_depth   -0.035  0.007  0.488 -0.024
DepthSquard -0.246  0.052  0.131  0.022  0.111
```

Figure B11. Results of a GLMM Model B4 not accounting for protection or interaction between Super Year and Protection

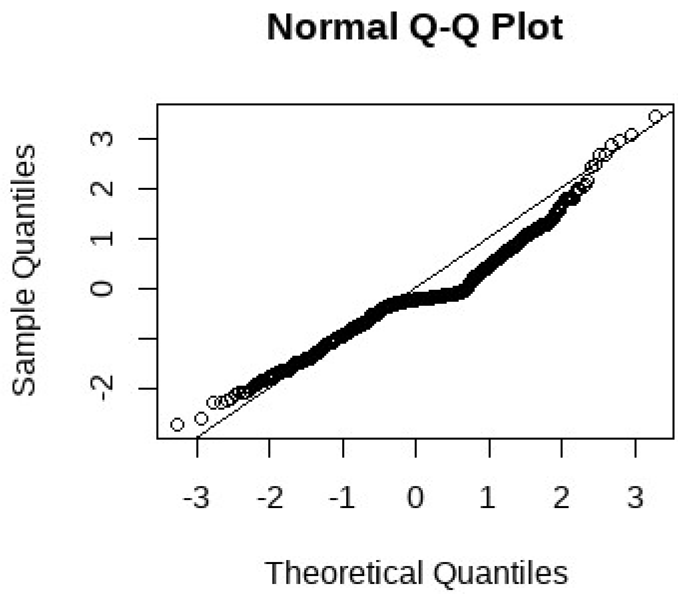

Figure B12. Q-Q Plot for Model B4 comparing model predicted and sample values with a one-to-one line for equivalence.

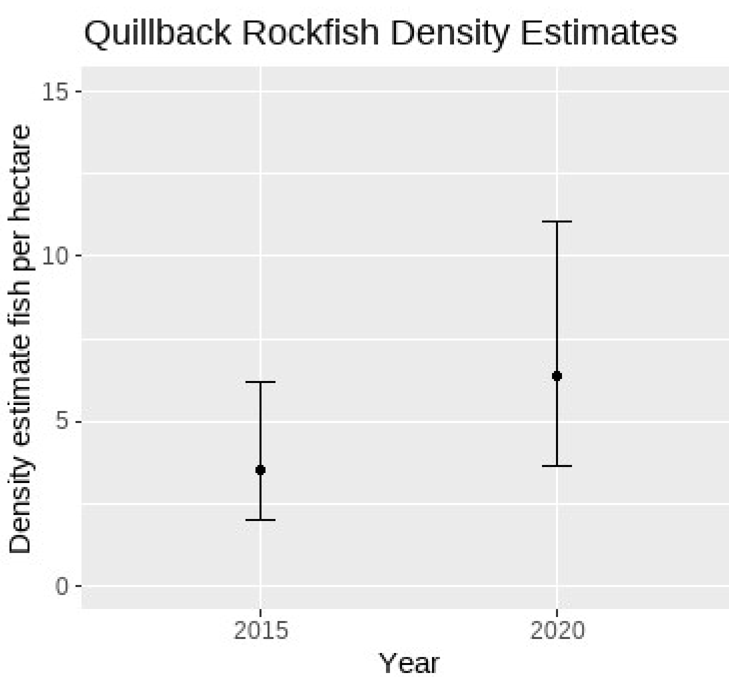

Figure B13. Index and confidence limits for GLMM Model B4 not accounting for protection or interaction between Super Year and Protection.

Table B5. Point estimate of the index (fish/hectare) and upper and lower confidence limits for Model B4.

Time/Area	Estimate	Lower CL	Upper CL
2015	3.55	2.03	6.22
2020	6.37	3.67	11.06

Table B6. Comparison of indices (fish/hectare) from models evaluated for quillback rockfish.

Model	2015				2020				Percent Change
2	Area	Index	Weight	Index* Weight	Area	Index	Weight	Index*Weight	
	Open	3.08	0.8	2.46	Open	5.51	0.8	4.41	
	MPA	4.13	0.2	0.83	MPA	7.39	0.2	1.48	
			Sum	**3.29**			Sum	**5.88**	**79.07%**
3	Area	Index	Weight	Index* Weight	Area	Index	Weight	Index*Weight	
	Open	3.65	0.8	2.92	Open	4.75	0.8	3.80	
	MPA	3.47	0.2	0.69	MPA	7.90	0.2	1.58	
			Sum	**3.61**			Sum	**5.38**	**48.91%**
4	Total	**3.55**		**3.55**		**6.37**		**6.37**	**79.34%**

Analysis of Alternative Distributions to the Negative Binomial Distribution

The R package DHARMa was used to evaluate the degree of overdispersion in models comparing the negative binomial distribution, Poisson, quasi-Poisson, zero-inflated Poisson, binomial and Tweedie for the transect level data set. A Delta-Lognormal model was also analyzed with a lognormal density component and binomial presence absence component to the model since this was the model considered by NMFS stock assessors for the 2023 stock assessment. Only the Poisson and negative binomial models could be run with a random effect for site, thus all models were run for the reduced model without the random site effect, with common significant variables, while omitting the random site effect. The AIC, overdispersion, Q-Q plots were examined to further evaluate the prospective distributions.

Comparison of Poisson and Negative Binomial Models with Random Effect for Site

A direct comparison of a Poisson model (Model B5) with a random effect for site equivalent to Model B3 with the negative binomial distribution was conducted to compare the resulting correlations, indices and measures of fit. The AIC, overdispersion and Q-Q plots were conducted to further evaluate the prospective distributions and further examine model parameterization.

The same variables were found to be significant as the negative binomial distribution in Model B3 and the Poisson distribution in Model B5 with the same random site effect and variables (Figure B14).The negative binomial distribution Model B3 showed lower AIC, BIC and log-likelihood as well as reduced overdispersion indicating an improvement over the Poisson distribution (Model B5) shown in Table B7. The index values resulting from Model B5 with the Poisson distribution accounting for weighting of results inside and outside of MPAs results in a similar trend between 2015 and 2020 of increasing abundance inside and outside MPAs with a greater increase outside (Figure B15), though the increase in not as great as with the negative binomial (Table B8). The Q-Q plots showed a similar form and divergence from the one-to-one line seen in Figure B16.

Model B5. Poisson Model with Random Effect for Site

Quillback.Rockfish ~ (1 | site) + SuperYear * Protection + PropHardMixed + avg_lat + avg_depth + DepthSquared, Data: sc.dat, Family: poisson(log), Offset: log(usable_area_fish)

```
AIC      BIC   logLik deviance df.resid
  2341.1   2384.7  -1161.6   2323.1      926

Scaled residuals:
    Min      1Q  Median      3Q     Max
-2.7034 -0.5898 -0.1689 -0.0397 14.7051

Random effects:
 Groups Name        Variance Std.Dev.
 site   (Intercept) 2.107    1.452
Number of obs: 935, groups:  site, 60

Fixed effects:
                         Estimate Std. Error z value Pr(>|z|)
(Intercept)              -7.87480    0.36020 -21.862  < 2e-16 ***
SuperYear2020             0.16387    0.09738   1.683   0.0924 .
Protection1              -0.06188    0.46538  -0.133   0.8942
PropHardMixed             0.53444    0.04916  10.872  < 2e-16 ***
avg_lat                   1.76218    0.26041   6.767 1.31e-11 ***
avg_depth                 0.40548    0.07388   5.489 4.05e-08 ***
DepthSquared             -0.59992    0.06085  -9.859  < 2e-16 ***
SuperYear2020:Protection1  0.62301    0.12881   4.837 1.32e-06 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) SpY2020 Prtct1 PrpHrM avg_lt avg_dp DpthSq
SuperYr2020 -0.135
Protection1 -0.667  0.114
PropHardMxd -0.041 -0.073  -0.004
avg_lat     -0.407  0.029   0.227 -0.030
avg_depth    0.010 -0.007  -0.008  0.481 -0.060
DepthSquard -0.140  0.028   0.030  0.166  0.003  0.201
SprY2020:P1  0.103 -0.757  -0.175  0.069 -0.022  0.007 -0.014
```

Figure B14. Results of Model B5 applying the Poisson distribution to the Model B3 structure for comparison.

Table B7. Comparison of diagnostics between the Poisson and negative binomial models including site as a random variable.

Model	AIC	BIC	Log Likliehood	Deviance	Dispersion
Negative Binomial	2214.1	2262.5	-1101.6	2203.3	0.927
Poisson	2341.1	2384.7	-1161.6	2323.1	1.498

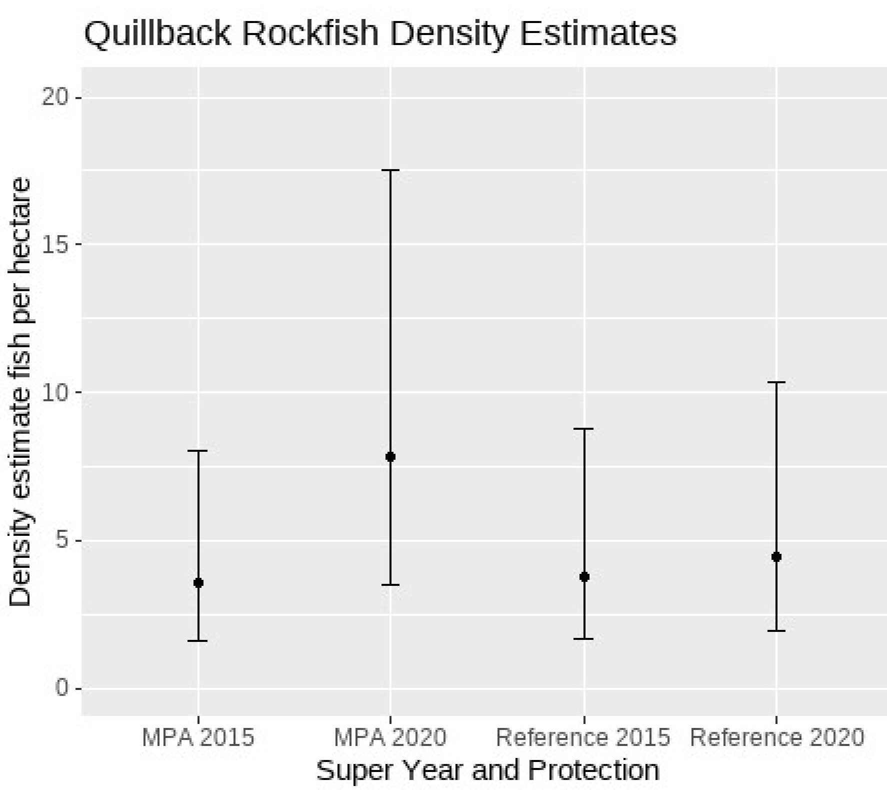

Figure B15. Index and confidence limits for GLMM Model B5.

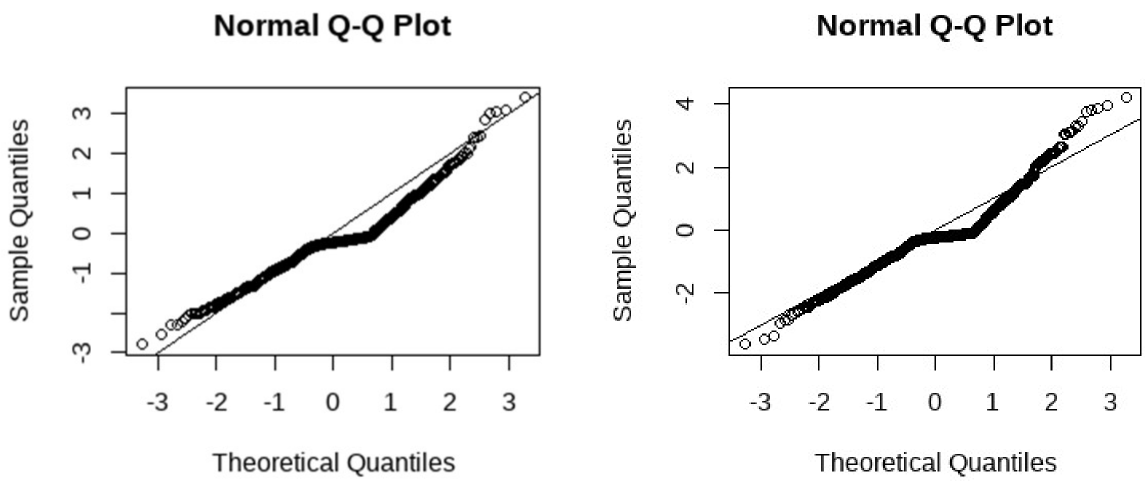

Figure 16. QQ norm plot of Model B3 Negative Binomial distribution (left) and Model B5 Poisson distribution with the same variables and model structure (right).

Table B8. Comparison of percent change in area weighted index values between 2015 and 2020 for Negative Binomial distribution (Model B3) and the Poisson distribution (Model B5), weighted by the proportion of habitat inside and outside MPAs.

Model	2015				2020				Percent Change
Negative Binomial (Model 3)	Area	Index	Weight	Index* Weight	Area	Index	Weight	Index*Weight	
	Open	3.65	0.8	2.92	Open	4.75	0.8	3.80	
	MPA	3.47	0.2	0.69	MPA	7.90	0.2	1.58	
			Sum	**3.61**			Sum	**5.38**	**48.91%**
Poisson (Model 5)	Area	Index	Weight	Index* Weight	Area	Index	Weight	Index*Weight	
	Open	3.80	0.8	3.04	Open	4.48	0.8	3.58	
	MPA	3.57	0.2	0.71	MPA	7.85	0.2	1.57	
			Sum	**3.76**			Sum	**5.15**	**37.19%**

Reduced Model Comparison of Alternative Distributions

The correlations for alternative distributions were similar to those observed with the negative binomial distribution for simplified models without the random effects for site, otherwise with the same variables (Model B6) allowing comparison (Table B9). The AIC values were higher for the Poisson model, indicating a degraded fit compared to the negative binomial (Table B9). The binomial model examining presence absence alone resulted in a much lower AIC value and the interaction term between Protection and Super Year was not significant or nearly so as for other distributions analyzed. The Tweedie and Delta-Lognormal models examined with the same model structure resulted in Dispersion of 1.62 and 2.12, respectively. The Q-Q plots for each distribution are presented in Figure B17.

The Poisson distribution was subject to overdispersion with dispersion greater than 1 even when zero inflated methods were employed, and the quasi-poison did not fit well to the one-to-one line in addition to still being subject to overdispersion. The negative binomial remains the best-behaved model relative to dispersion being nearer to under dispersed than over dispersed and the fit to the one-to-one line is better than many of the other distributions. The binomial presence/absence model fit well to the one-to-one line and may not be an unreasonable basis for an index for a primarily solitary species like quillback rockfish, though over the course of a transect, more than one individual may be observed regularly making a model with a count preferable to presence/absence. That said, the 10 m segment data set may be amenable to a binomial model. The Q-Q plot for the Delta-Lognormal model did not fit well to the one-to-one line and was subject to overdispersion. The negative-binomial model remains the preferred model for further exploration. Though the Tweedie model also fit well to the one-to-one line, it was subject to greater overdispersion.

Model B6. Simplified model without random site variable to facilitate comparison of model distributions.
Quillback.Rockfish ~ SuperYear * Protection + PropHardMixed + avg_lat + avg_depth + DepthSquared, family = X, data = sc.dat, offset = log(sc.dat$usable_area_fish))

Table B9. Comparison of results of various distributions using the structure and variables in Model B5.

Variable	Poisson	Quasi-Poisson	Zero - Inflated Poisson	Zero-Inflated Quasi-Poisson	Negative Binomial	Zero-Inflated Negative Binomial	Binomial
AIC	3455.6	NA	NA	NA	2869.4	NA	938.5
Dispersion	3.18	3.12	1.42	1.42	0.96	1.42	0.96
Intercept	***	***	***	***	***	***	***
Super Year	***	**	***	***	***	***	***
Protection							
Proportion Hard or Mixed	***	***	**	**	***	**	***
Average Latitude	***	***	**	**	***	**	***
Average Depth	***	***	*	*	***	*	***
Depth Squared	***	***	***	***	***	***	***
Super Year *Protection	***	*	.	.	.	.	

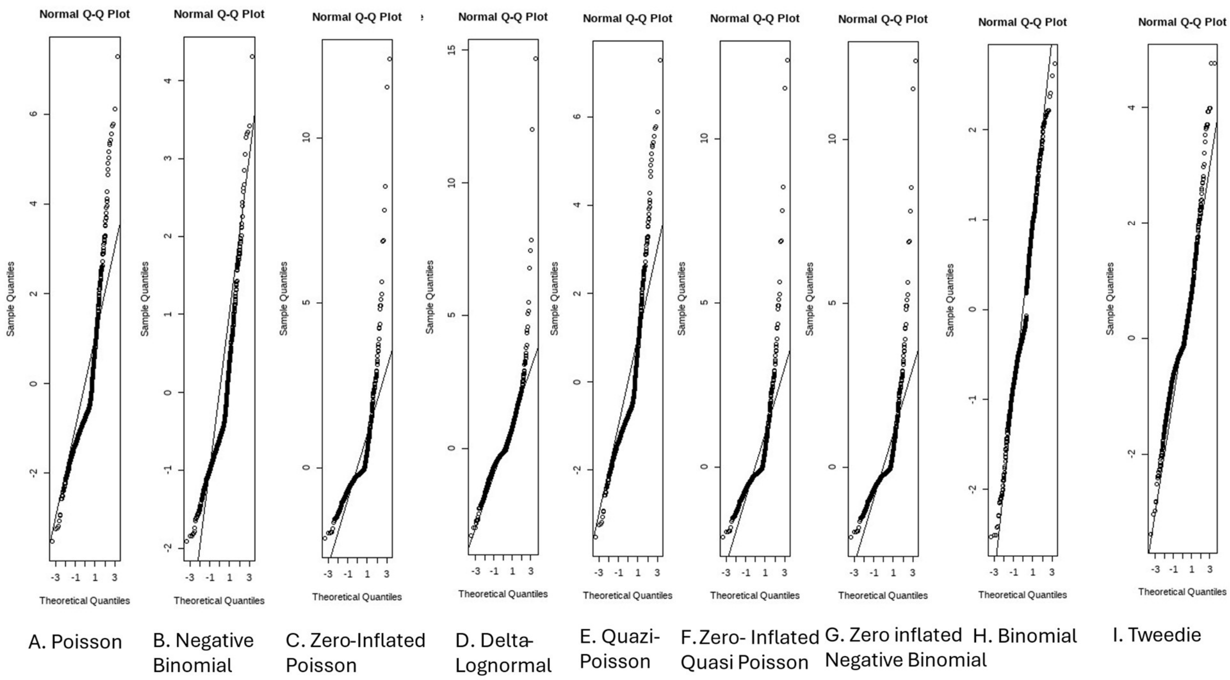

Figure B17. Q-Q plots for each of the distributions examined with Model B5, providing theoretical and sample quantiles and the one-to-one line for comparison.

10 m Segment Data Set

In addition to the transect level analysis, a higher resolution analysis with 10 m segments of transects was conducted for comparisons. This spatial resolution of analysis allows for finer habitat analysis facilitating evaluation of correlation with seafloor characterization from direct observations for habitat type (rock, mixed, soft) or backsides indicative of pinnacles or other high relief habitat or extracted terrain attributes from the California Seafloor mapping georeferenced to each segment in GIS. Concerns have been expressed about the potential for spatial autocorrelation to be an issue for variance estimates due to a lack of independence of the segments given their spatial proximity relative to the potential degree of movement of rockfish within their home range. Arguments can also be made that the smaller segments may allow for a higher resolution of inference relative to variables of interest defined for the smaller segment to better evaluate correlations with seafloor characteristics such as the percent rock or mixed seafloor, which is less clearly associated with the density or presence of fish at the resolution of a 500 m transect. The degree of overdispersion and Q-Q plots were examined for 10 m segments and compared to the results for the transect level analysis.

The correlation between variables provided in Figure B18 below is similar to that observed for the transect level data set in Figure B3, with correlations between variables in the same direction and magnitude at the 10 m segment resolution. Of the variables explored in Model B3 with the transect level data set identified as the preferred model, all variables but average depth were still significant with the 10 m segment data set (Figure B19). When average depth was removed, the AIC scores increased slightly, going from 10543.1 to 10544.8. Despite the expectation of greater potential for overdispersion with the 10 m segment data given the higher prevalence of zero values, the actual dispersion for the negative binomial at 0.78 was very similar to what was observed for the transect level data at 0.92, which would be considered under dispersed. The same was the case for the Poisson distribution at 0.89, as compared to the transect level value which showed slight overdispersion at 1.29.

Examination of the Q-Q plots showed much greater deviation from the one-to-one line in models with and without average depth for the negative binomial, Poisson and delta-lognormal models (Figure B20). The Tweedie distribution provided a better fit to the one-to-one line and resulted in a dispersion of 1.13, which is only slightly overdispersed relative to the ideal value of 1. While the Tweedie distribution provided a more reasonable fit than other distributions, it was unable to incorporate the site level variable as a random effect and was not evaluated further.

The indices resulting from the 10 m data set for the negative binomial distribution were very similar in terms of the observed trend, though the scale of the increase in MPAs was higher than for the transect level data for the equivalent model form and variables as Model B3 using the negative binomial distribution (Figure B21). The indices and confidence limits resulting from the negative binomial distribution are provided in Table 10. The indices resulting from weighting indices by the proportion of habitat inside and outside of MPAs provided in Table 11 shows a 51.8% increase in relative abundance between 2015 and 2020 super years, consistent with the magnitudes observed with the transect data of 48.91% with the negative binomial distribution and 37.19% for the Poisson distribution.

The underlying concerns regarding application of the 10 m data set remain in terms of potential for spatial autocorrelation and pseudo-samples due to lack of independence along a transect. The data is also more susceptible to an excess of zero values given the small fragment size. In addition, terrain attributes or other variables that may prove beneficial in further explaining variance in the density of quillback rockfish were not employed, limiting the potential benefits of the 10 m resolution analysis. Even if terrain attributes were available, they were found to account for a relatively low proportion of the total variance in analyses conducted for the 2020 methodology review. This may be in part due to the potential spatial error when deriving them from the CSMP data set and aligning them with the transects or not having captured terrain attributes at the spatial scale meaningful to the species in question. Thus, the transect level data set is preferred at present and should be explored further in deriving an index for the 2025 quillback rockfish stock assessment.

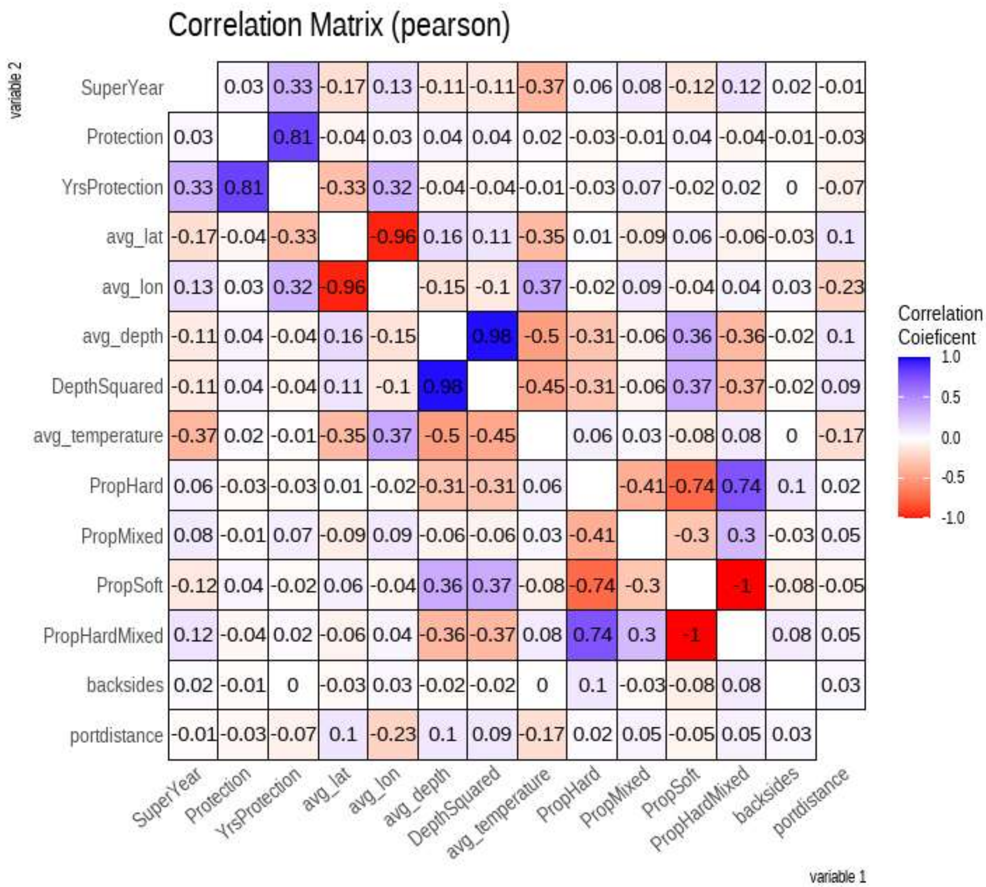

Figure B18. Correlations between variables used in the 10 m segment analysis.

```
 AIC      BIC   logLik deviance df.resid
 10544.8  10623.7  -5263.4  10526.8    47455
Scaled residuals:
   Min     1Q Median     3Q    Max
-0.390 -0.185 -0.103 -0.024 42.587

Random effects:
 Groups Name        Variance Std.Dev.
 site   (Intercept) 2.57     1.603
Number of obs: 47464, groups:  site, 59

Fixed effects:
                          Estimate Std. Error z value Pr(>|z|)
(Intercept)               -7.73411    0.38969 -19.847  < 2e-16 ***
SuperYear2020              0.29067    0.10672   2.724 0.006455 **
Protection1               -0.09709    0.51964  -0.187 0.851785
PropHardMixed              0.19075    0.03692   5.166 2.39e-07 ***
avg_lat                    1.87562    0.29183   6.427 1.30e-10 ***
DepthSquared              -0.67173    0.06284 -10.690  < 2e-16 ***
SuperYear2020:Protection1  0.54935    0.14170   3.877 0.000106 ***
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) SpY2020 Prtct1 PrpHrM avg_lt DpthSq
SuperYr2020 -0.140
Protection1 -0.665  0.114
PropHardMxd -0.027 -0.085   0.002
avg_lat     -0.372  0.031   0.243 -0.004
DepthSquard -0.142  0.044   0.029  0.083  0.013
SprY2020:P1  0.103 -0.750  -0.176  0.041 -0.022 -0.013
```

Figure B19. Results of applying the negative binomial distribution with Model B3 structure to the 10 m data set.

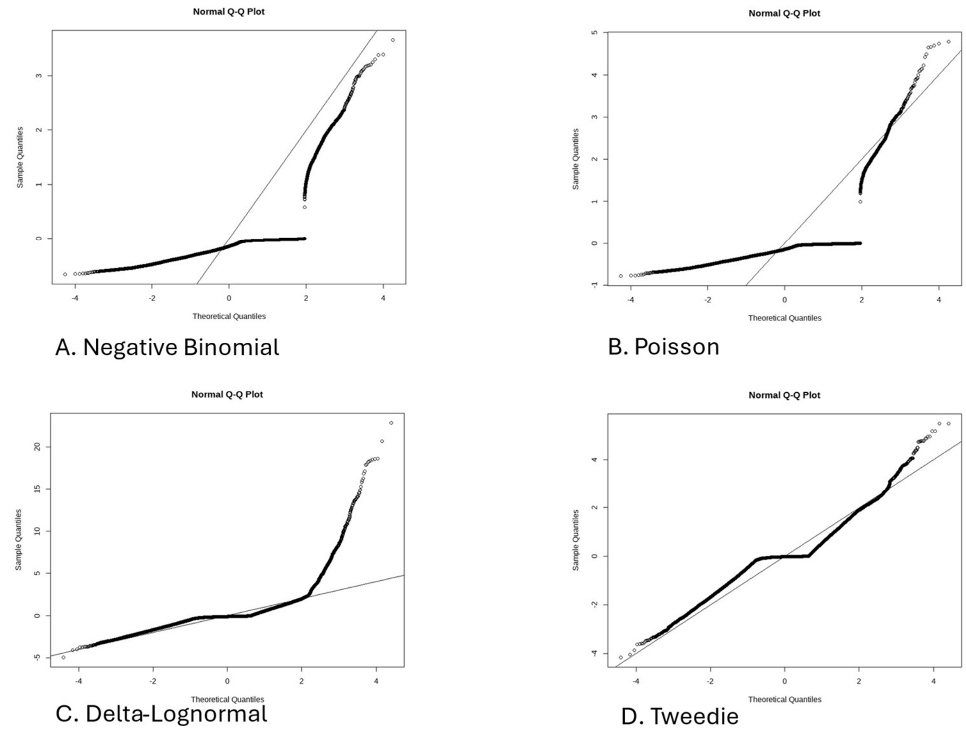

Figure B20. Q-Q plots for each of the distributions examined with Model B5, providing theoretical and sample quantiles and the one-to-one line for comparison.

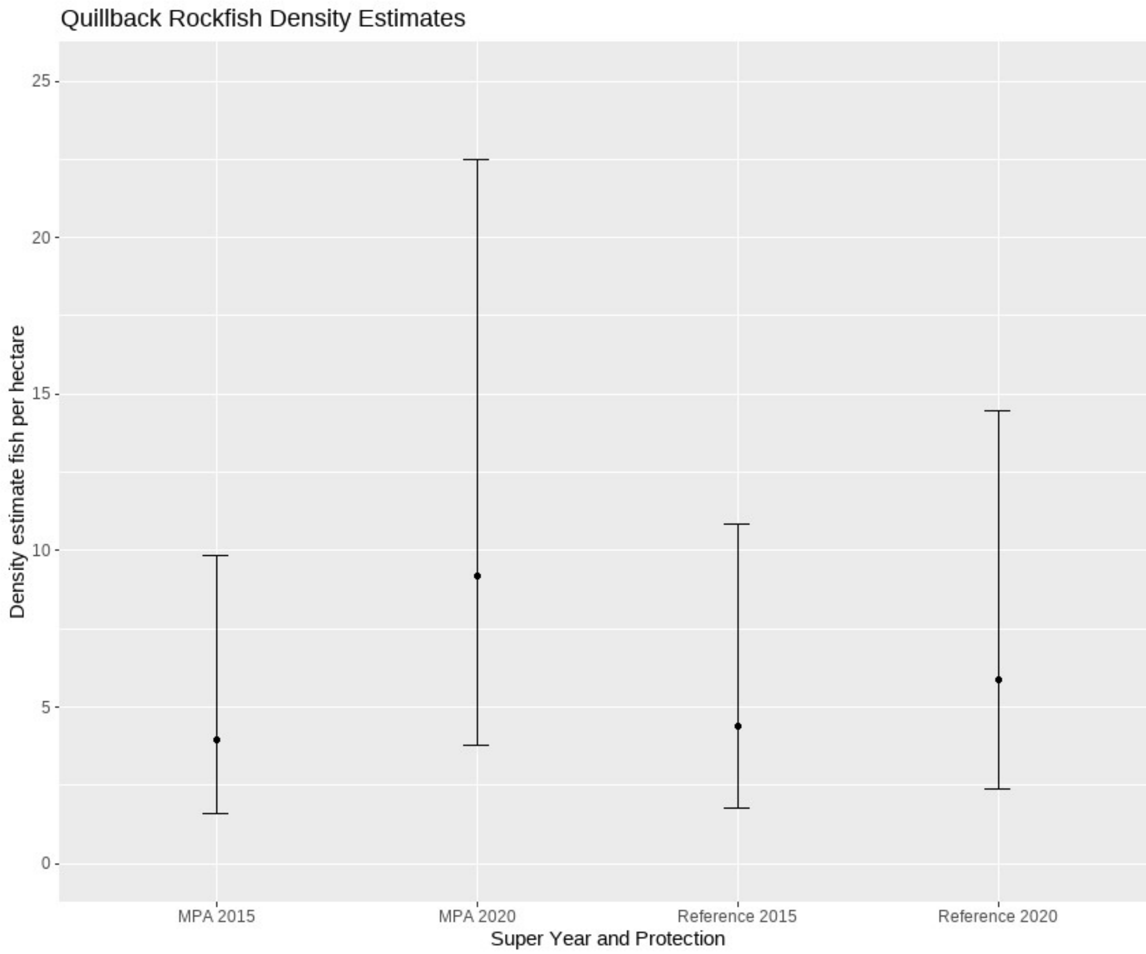

Figure B21. Index and confidence limits for the 10 m data set using a GLMM with the negative binomial distribution.

Table B10. Index (fish per hectare) and confidence limits inside and outside of MPAs for the 10 m data set using a GLMM with the negative binomial distribution.

Time/Area	Estimate	Lower CL	Upper CL
2015 Reference Site	4.38	1.77	10.84
2020 Reference Site	5.85	2.37	14.48
2015 MPA	3.97	1.60	9.86
2015 MPA	9.20	3.76	22.51

Table B11. Index (fish/hectare) and confidence limits for the 10 m data set using a GLMM with the negative binomial distribution weighted by the percentage of rocky reef habitat inside and outside MPAs.

2015				2020				Percent Change
Area	Index	Weight	Index* Weight	Area	Index	Weight	Index*Weight	
Open	4.38	0.8	3.50	Open	5.85	0.8	4.68	
MPA	3.97	0.2	0.79	MPA	9.20	0.2	1.84	**51.84%**
		Sum	**4.30**			Sum	**6.52**	

C. Absolute Abundance Estimation Using Design-based Methods and Seafloor Mapping

Estimating the number and biomass of quillback rockfish off the coast of California using design-based methods involves a multi-step process. To identify depth and latitudinal strata over which to estimate absolute abundance should be produced, the density (fish/square meter) and length were analyzed in each groundfish management area along the coast to test for discontinuities. Once strata were identified, estimates of density and average weight derived from observed lengths were produced for each strata. Estimates of absolute abundance, variance and confidence intervals inside and outside MPAs were produced in state waters within three miles of shore through expansions using seafloor habitat data from the CSMP as well as in state and federal waters using CMECS data sets The individual steps are described further below. The resulting estimates of abundance were compared to the biomass estimates from the 2023 quillback rockfish stock assessment informed by catch history.

C1. Stratification Analysis of Quillback Rockfish Length Data from Remotely Operated Vehicle Surveys

Introduction

This analysis uses the length data of quillback rockfish off the coast of California Marine Applied Research and Exploration (MARE) Remotely Operated Vehicle (ROV) length data set. ROV stereo cameras along with analytical software were used to determine the length of individuals in a suitable orientation for estimation. The main goal of this analysis is to identify possible differences in quillback rockfish length distributions between various latitudinal and depth strata to inform stratification for design-based methods of estimates of abundance. To confirm visual differences seen in figures, Kolmogorov-Smirnov (K-S) tests were conducted on the different combinations of stratum to determine whether the differences seen are statistically significant. For validation purposes, the MARE ROV length data is compared to California Recreational Fisheries Survey (CRFS) data.

Methods

Data QAQC, Processing, Visualization, and Statistical Testing Tools

All data preprocessing and manipulation was performed using R Studio (v. 2023.12.1). Visualization was performed using the R package ggplot2 (v. 3.5.0). Two-sided K-S tests were conducted using the ks.test() function from the stats (v. 4.3.2) package.

The following corrections were made to the length data set:

- Two observations of quillback rockfish which were observed at the Channel Islands were removed due to previously being identified as misidentification errors by CDFW staff.
- The observation with ID 3583 in the length data contained an error and was corrected to the numerical value 20.
- Five observations of quillback rockfish observations missing latitude and longitude coordinates and depths were removed for any stratification of the data.

ROV Latitudinal Analysis

The ROV strata selected include North of 40°10’ N Latitude, 40°10’ N Latitude to Point Arena, Point Arena to Pigeon Point, Pigeon Point to Point Conception, and the Farallon Islands. The North of 40°10’ N Latitude stratum extends from the Oregon border to 40°10’ N Latitude. Since no quillback rockfish were observed in ROV data south of Point Conception after final QAQC, this area was not analyzed. These strata are based on current fishery management regimes within California. The specific latitudes for Point Arena, Pigeon Point, and Point Conception are 38° 57.5' N., 37° 11' N, and 34° 27' N, respectively. All degrees and decimal minute formats were converted to decimal degrees by dividing the minutes by 60 (e.g., 34° 27' N becomes 34.45°) to ensure consistency with the ROV length dataset. If no differences were detected between the selected strata, a plan was in place to combine them for testing differences at a broader scale. Figure C1-1 provides a visual representation of the selected strata along with quillback rockfish observations and ROV transects as identified from the ROV length dataset. After appropriately grouping the data by strata, the length data was visualized using various types of length frequency distribution (LFD) plots and inspected. Following visual inspection, two-sided K-S tests were performed between all different combinations of strata.

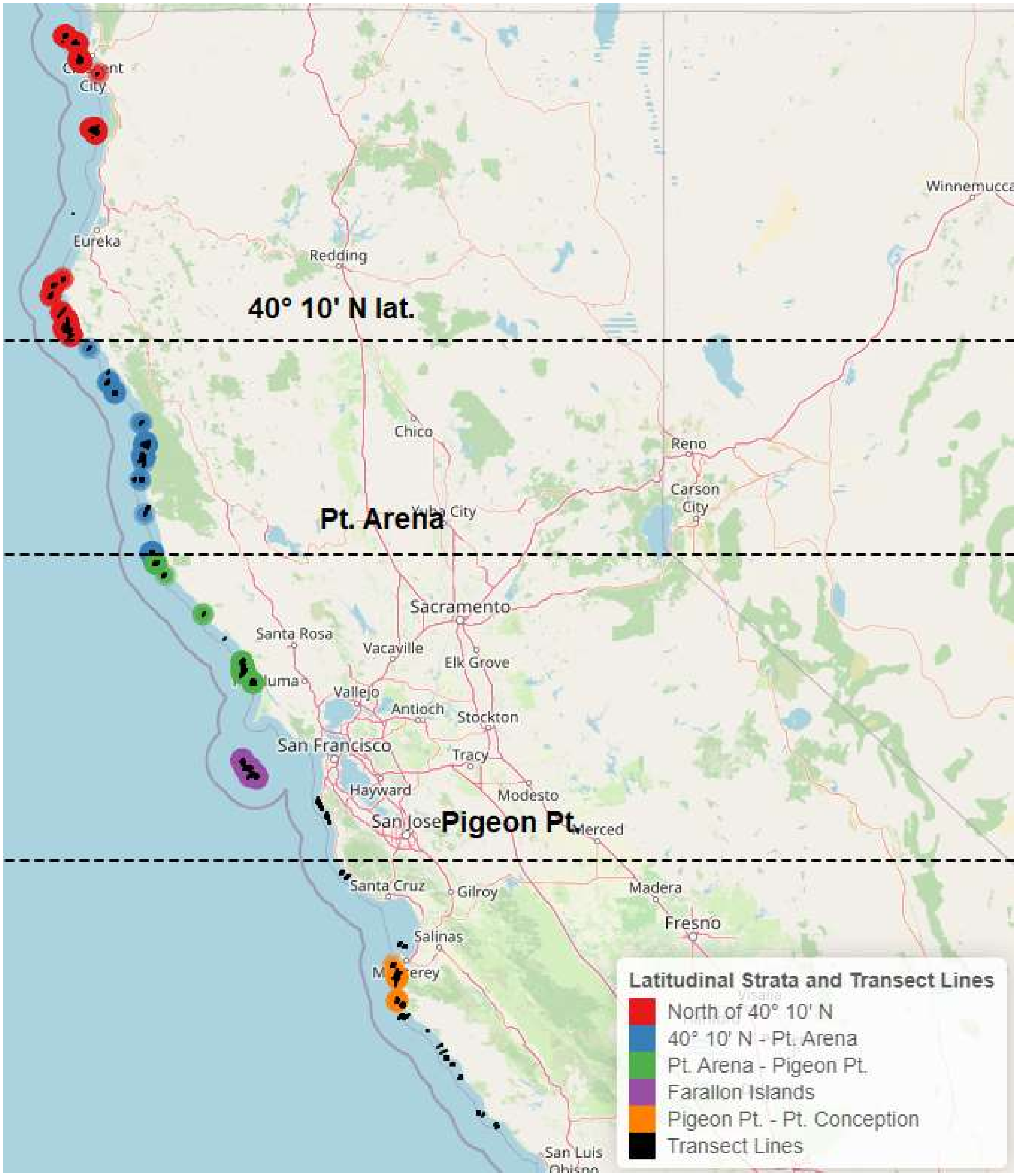

Figure C1-1. Map displaying quillback rockfish lengths were sampled by the ROV during the time period analyzed (2014 – 2021) with coloring to distinguish between latitudinal strata. Colored circles represent quillback rockfish observations. Small black lines represent individual ROV transect lines as identified from the length data set. The frequency of quillback rockfish is not to scale, as some observations overlap.

ROV Depth Analysis
Following the latitudinal length analysis, an analysis of possible differences in LFDs stratified by depth was performed. First, depth bins of 10 and 20 meters were created for analysis. Then within their respective 10 or 20 meter binning group, LFDs were compared visually and using KS tests, both coastwide and within each latitudinal strata. The small sample sizes observed deeper than 80 meters (n = 15, coastwide) led to binning all fish deeper than 60 meters together.

Results for the coastwide K-S tests are displayed in Table C1-3 and Table C1-4. However, due to the size of the tables of the K-S test results of LFDs stratified by latitude and depth, statistically significant differences are simply identified within the LFD figures - Figure C1-6 and Figure C1-7.

CRFS Comparison
Latitudinally stratified LFDs of the ROV and CRFS length data for quillback rockfish were compared by plotting the data and visually examining the distributions. K-S tests were not conducted as they would not serve the main purpose of this analysis and were considered unnecessary. The ROV strata were matched to corresponding CRFS areas which can be seen in Table C1-1. CRFS data was obtained from the publicly available dataset at www.recfin.org and filtered to include quillback rockfish in California from 2014 to 2021 to align with the ROV dataset. The ROV latitudinal strata, Farallon Islands and Point Arena – Pigeon Point, were both combined and separated when visually comparing to the CRFS Bay Area. This is because the publicly available CRFS Bay Area data includes coastal data as well as data from the Farallon Islands with no currently available method to separate the two.

Table C1-1. CRFS areas and their respective ROV strata.

CRFS	ROV
Redwood	North of 40° 10’ N
Wine	40° 10’ N Latitude – Pt. Arena
Bay Area	Pt. Arena – Pigeon Pt. (Farallon Islands Included)
Central	Pigeon Pt. – Pt. Conception

Results

ROV Latitudinal Analysis
Figure C1-2 displays the quillback length frequency distribution by stratum using ROV data. The bottom most LFD is for the Farallon islands. The LFD above that is the Pigeon Point to Point Conception strata where a small sample size is observed indicating the southern range of

quillback rockfish. When examining the next three LFDs from south to north a pattern of smaller to larger fish is observed. The Point Arena – Pigeon Point stratum (Farallon Islands excluded) contains a majority of smaller fish less than 25 centimeters, 40° 10' N Latitude – Point Arena contains a mix of large and small fish, and North of 40° 10' N Latitude contains mainly larger fish greater than 25 centimeters. The boxplots in Figure C1-3 provide another method of observing the pattern of big to small fish from north to south (left to right in the figure) from the Oregon/California border to Pigeon Point.

In addition to the visual differences, the Kolmogorov-Smirnov test results indicate most of the LFDs for each stratum are significantly different with a few exceptions. No significant difference was observed in 2 of the 4 combinations involving the Pigeon Point – Point Conception strata. This is not surprising due to the low sample size (n = 13) observed in that strata. Outside of those two exceptions, statistically significant differences (P-value < 0.05) were observed between all other combinations of strata (Table C1-2).

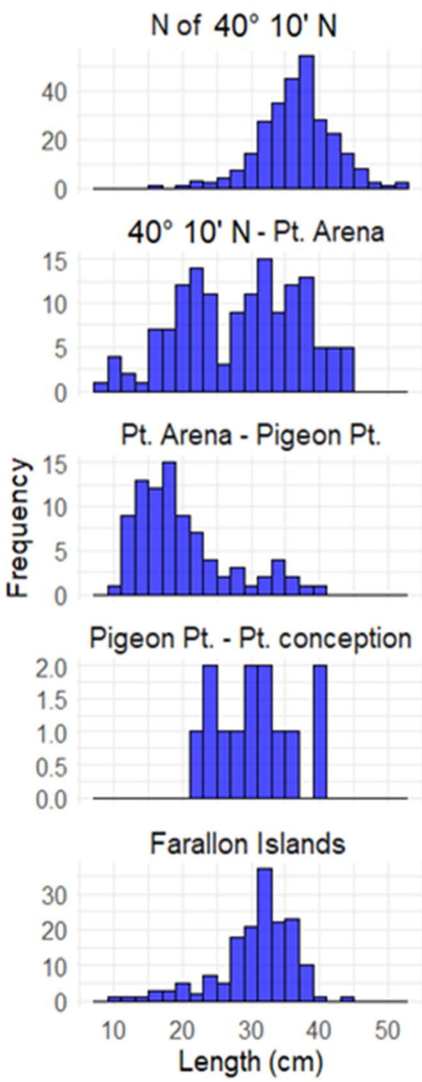

Figure C1-2. Quillback Length Frequency Distributions by latitudinal stratum. Only ROV data (years 2014-2021) is included.

Table C1-2. Results of the Kolmogorov-Smirnov tests conducted between all combinations of latitudinal strata including p-value and sample sizes. Only ROV data (years 2014-2021) is included.

Location 1	Location 2	p - value	n (Location 1)	n (Location 2)
Pt. Arena – Pigeon Pt.	Farallon Islands	<0.01	86	163
Pt. Arena – Pigeon Pt.	Pigeon Pt. – Pt. Conception	<0.01	86	13
Pt. Arena – Pigeon Pt.	40° 10’ N– Pt. Arena	<0.01	86	146
Pt. Arena – Pigeon Pt.	N of 40° 10’ N	<0.01	86	270
Farallon Islands	Pigeon Pt. – Pt. Conception	0.56	163	13
Farallon Islands	40° 10’ N – Pt. Arena	<0.01	163	146
Farallon Islands	N of 40° 10’ N	<0.01	163	270
Pigeon Pt. – Pt. Conception	40.10 – Pt. Arena	0.16	13	146
Pigeon Pt. – Pt. Conception	N of 40° 10’ N	<0.01	13	270
40° 10’ N – Pt. Arena	N of 40° 10’ N	<0.01	146	270

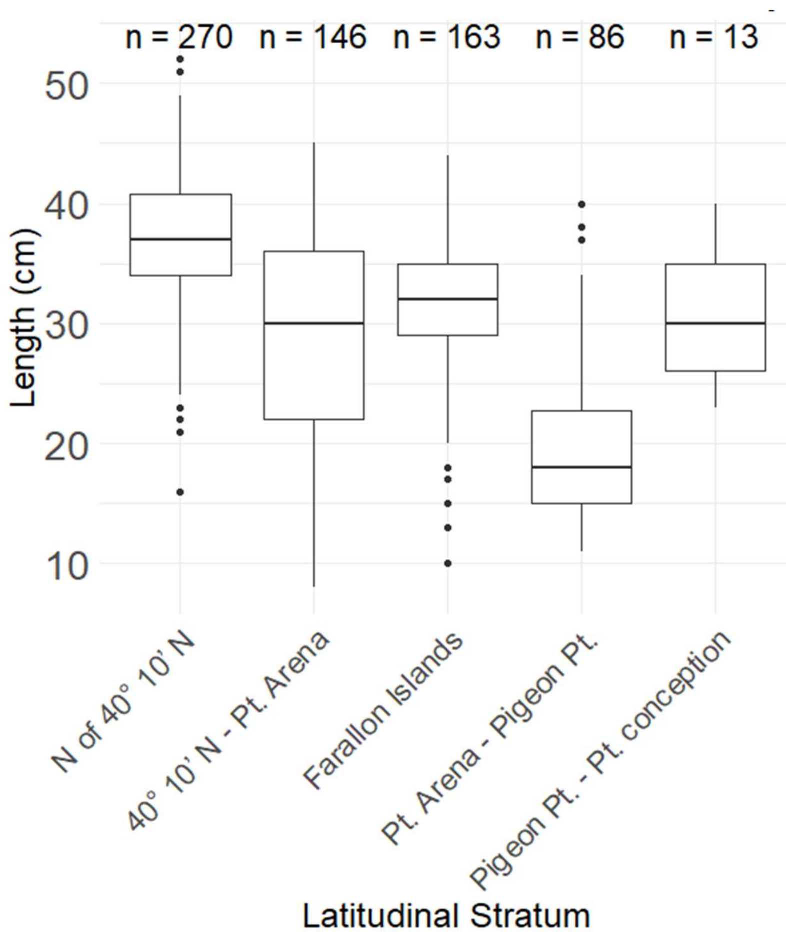

Figure C1-3. Box and whisker plots with sample sizes of quillback rockfish length separated by stratum. Only ROV data (years 2014-2021) is included.

ROV Depth Analysis

Relevant Summary Statistics

The shallowest quillback rockfish was observed at 20.5 meters (11.2 fm). The deepest quillback rockfish was observed at 93.8 meters. There were only 15 observations of fish deeper than 80 meters, and 53 observations of fish deeper than 70 meters. Figure C1-4 displays the average depth of all ROV transects within each latitudinal stratum.

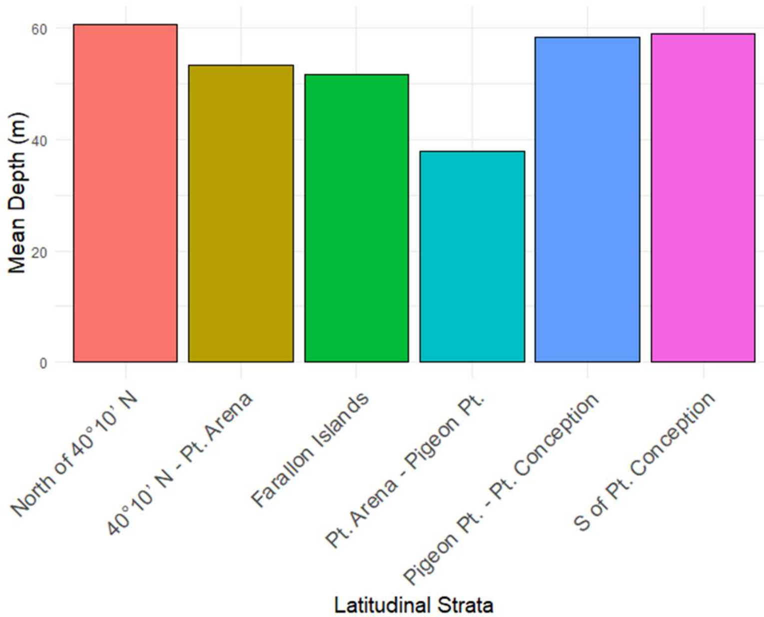

Figure C1-4. Average depth of all ROV transects within each latitudinal stratum.

Coastwide

Figure C1-5 and Figure C1-6 show the length distributions of quillback rockfish coastwide, grouped by 10- and 20-meter depth bins separately in each figure, respectively. Deeper than 40-meters, both figures show a pattern of larger fish in deeper water. However, shallower than 40-meters, the pattern is unclear.

Table C1-3 displays the K-S tests for the coastwide 10-meter depth bin stratification for all combinations of depths. The results show that all LFD combinations of stratum deeper than 40 meters are significantly different. Results were mixed for combinations containing stratum shallower than 40 meters.

Table C1-4 displays the coastwide K-S test results for the 20-meter depth bin stratification. The LFD of greater than 60-meter depth bin is observed to be significantly different from the 20-40 and 40-60 m depth bins.

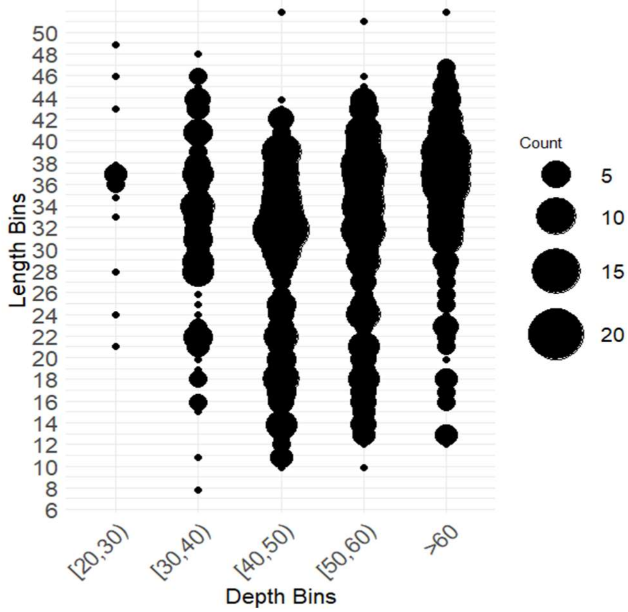

Figure C1-5. Quillback rockfish bubble chart length frequency distributions coastwide in California separated by 10-meter depth bins. No quillback rockfish were observed < 20 meters. Only ROV data (years 2014-2021) is included.

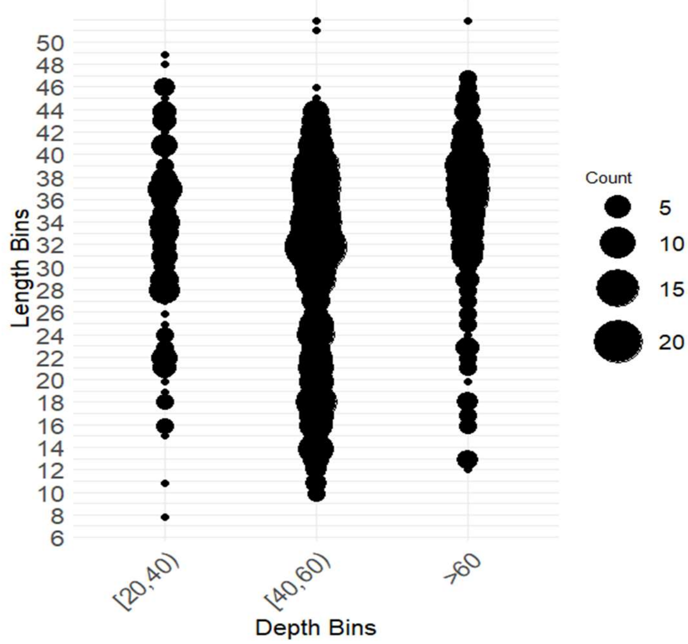

Figure C1-6. Quillback rockfish LFDs stratified by 20-meter depth bins coastwide in California. No quillback rockfish were observed < 20 meters. Only ROV data (years 2014-2021) is included.

Table C1-3. K-S test results of coastwide 10-meter depth stratifications for quillback rockfish ROV length data in decreasing p-value order.

Depth Bin1	Depth Bin 2	p-value	n (Depth Bin 1)	n (Depth Bin 2)
>60	[20,30)	0.92307202	175	14
[30,40)	[50,60)	0.90819457	95	200
[40,50)	[30,40)	0.17659121	194	95
[50,60)	[20,30)	0.12091806	200	14
[30,40)	[20,30)	0.0803457	95	14
[40,50)	[50,60)	0.02364934	194	200
[40,50)	[20,30)	0.00490045	194	14
[30,40)	>60	0.00131597	95	175
>60	[50,60)	0.00092254	175	200
[40,50)	>60	3.3405E-10	194	175

Table C1-4. K-S test results of quillback rockfish LFDs stratified by 20-meter depth bins coastwide. Only ROV data (years 2014-2021) is included.

Depth_Bin1	Depth_Bin2	p_value	n (Depth_Bin1)	n (Depth_Bin2)
[40,60)	[20,40)	0.333714	394	109
[20,40)	>60	0.008868	109	175
[40,60)	>60	2.15E-08	394	175

By Depth and Latitudinal Strata

Figure C1-7 and Figure C1-8 display the LFDs for each depth bin within each latitudinal strata using 10- and 20-meter depth bins respectively. Matching letters indicate a statistically significant difference between two LFDs. Seven combinations were observed to be significantly different by K-S tests using the 10-meter bins and 3 combinations when using the 20-meter bins. The patterns observed in the coastwide figures (Figure C1-5 and Figure C1-6) are also observed when separated by latitudinal strata (Figure C1-7 and Figure C1-8) although they appear more dispersed due to sample sizes being split even further. Additionally, the larger quillback rockfish observed shallower than 40 meters are seen to reside mainly in the “North of 40° 10’ N” stratum.

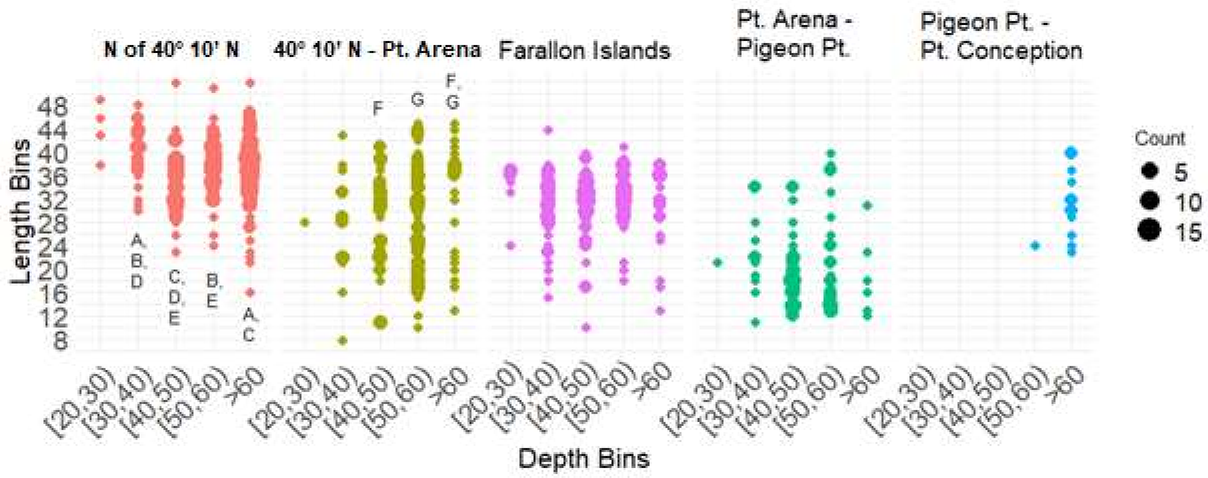

Figure C1-7. Quillback rockfish length frequency distribution bubble charts by latitudinal strata and 10-meter depth bins. Different colors are used to distinguish latitudinal strata. Matching letters indicate K-S test results that are significantly different (p-value <0.05). Only ROV data (years 2014-2021) is included.

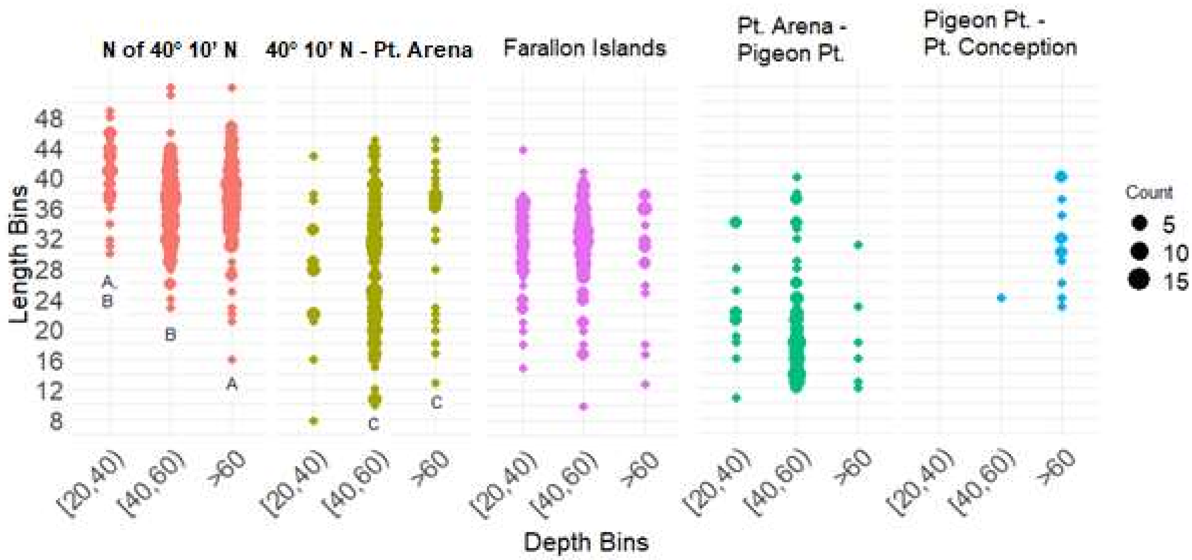

Figure C1-8. Quillback rockfish length frequency distribution bubble charts by strata and 20-meter depth bins. Different colors are used to distinguish latitudinal strata. Matching letters indicate K-S test results that are significantly different (p-value <0.05). Only ROV data (years 2014-2021) is included.

Habitat Analysis

Figure C1-9 was created to identify if small quillback rockfish (< 25 cm) had a different preference for bottom type than large (> 25 cm) quillback rockfish. The figures appear similar, so no further analysis was done.

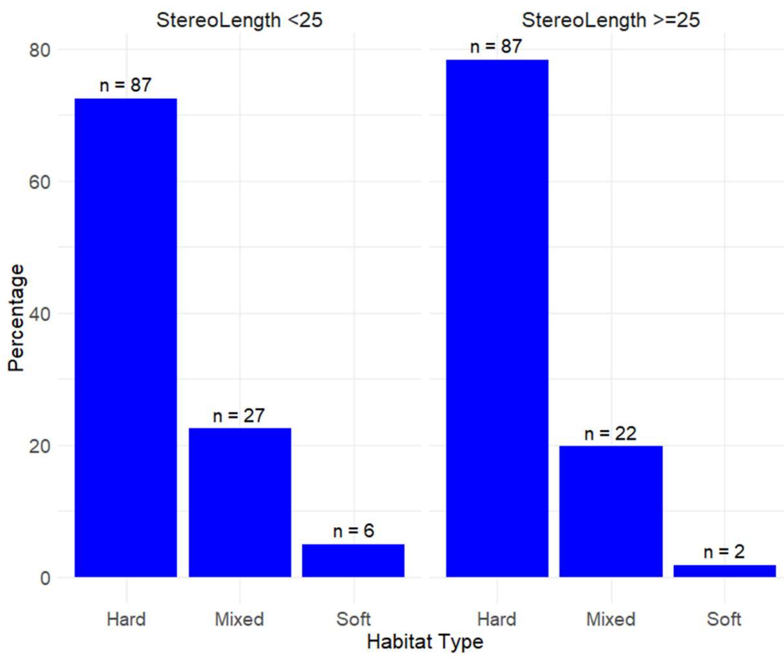

Figure C1-9. The percentage of small (<25 cm) and large (>= 25 cm) quillback rockfish by habitat type. Only ROV data (years 2014-2021) is included.

ROV and CRFS Comparison

Figure C1-10, Figure C1-11, Figure C1-12, and Figure C1-13 display the LFDs of quillback rockfish from both ROV and CRFS data for comparison/validation. The figures are displayed in order from north to south. In all figures, the ROV is able to observe much smaller fish than are observed in the CRFS data set which is consistent with prior research (Caselle & Cabral, n.d.). Very few fish less than 25 centimeters were observed in the CRFS dataset which is likely due to gear selectivity (Alós, Cerdà, Deudero, & Grau, 2008; Cortez-Zaragoza, Dalzell, & Pauly, 1989; Erzini, Gonçalves, Bentes, Lino, & Cruz, n.d.).

In Figure C1-10 “Redwood (CRFS) & North of 40° 10’ N Latitude (ROV)” the LFDs appear similar in shape, however the ROV data is shifted slightly to the left indicating observations of smaller fish on average in comparison to CRFS. This difference is likely due to the gear selectivity and fisher preference for larger fish that occurs in fishery dependent data, especially recreational hook & line data, like the CRFS data for quillback rockfish (Alós, Cerdà, Deudero, & Grau, 2008; Cardinale & Hjelm, 2012; Cortez-Zaragoza, Dalzell, & Pauly, 1989; Erzini, Gonçalves, Bentes, Lino, & Cruz, n.d.).

The LFDs seen in Figure C1-11 “Wine (CRFS) & 40° 10’ N Latitude – Pt. Arena (ROV)” appear somewhat similar in shape when looking at fish greater than 25 cm. However, since the ROV is able to detect much smaller quillback rockfish than are observed in the CRFS data set, a major difference in distribution is seen in the proportion of fish below 25 centimeters.

Similar to Figure C1-11 , the ROV LFD in Figure C1-12, panel A “Bay Area (CRFS) and Pt. Arena – Pigeon Pt. (Farallon Islands included) (ROV)”, contains a larger proportion of fish less than 25 centimeters than the CRFS data set. The ROV data in Figure C1-12, panel A, is a combination of the Farallon Islands and the Pt. Arena - Pigeon Pt. strata. Figure C1-12, panel B “Bay Area (CRFS) and Farallon Islands (ROV)”, shows that the Farallon Islands LFD more closely aligns with the Bay Area CRFS LFD than the combined Pt. Arena - Pigeon Pt. and Farallon Islands strata. Figure C1-12, panel C “Bay Area (CRFS) and Pt. Arena – Pigeon Pt. (Coastal)”, shows how the ROV data of the coastal region in this latitudinal stratum mainly contains smaller fish especially when compared to the CRFS Bay Area data.

In Figure C1-13 “Central (CRFS) and the Pigeon Pt. – Pt. Conception (ROV)”, despite the small sample sizes seen from both the ROV and CRFS data sets, the distributions appear surprisingly similar.

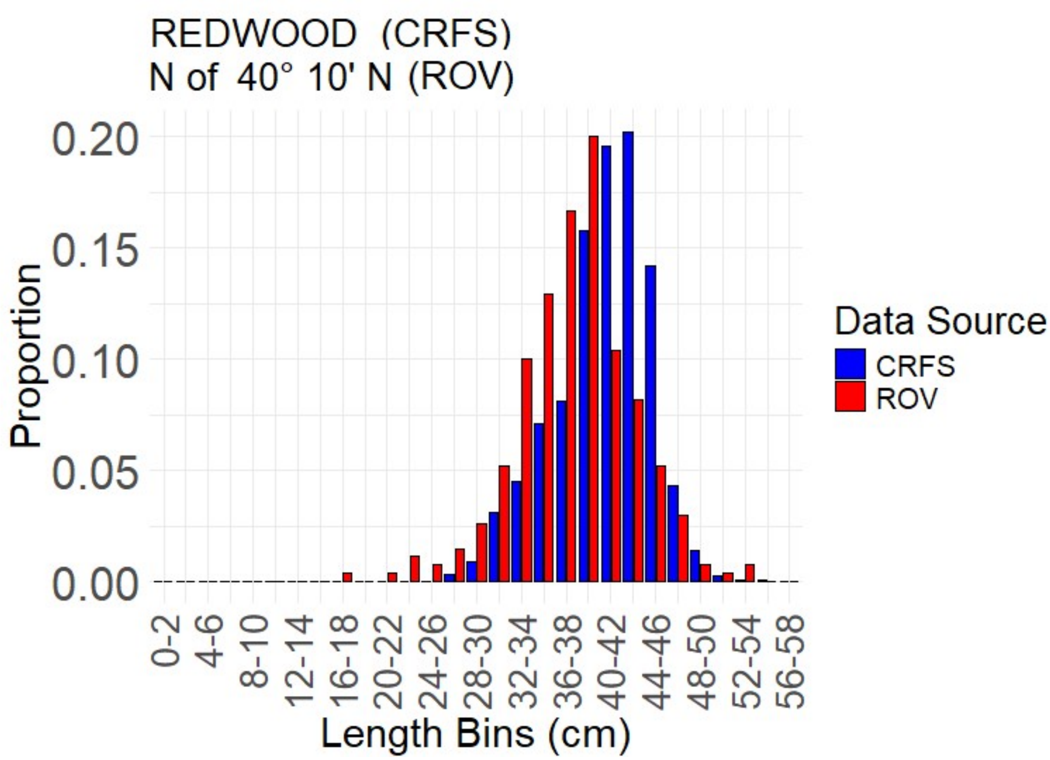

Figure C1-10. Length frequency distributions of quillback rockfish for the Redwood (CRFS) and the North of 40° 10’ N Latitude (ROV) strata. All available ROV years included (2014 – 2021) with matching CRFS years.

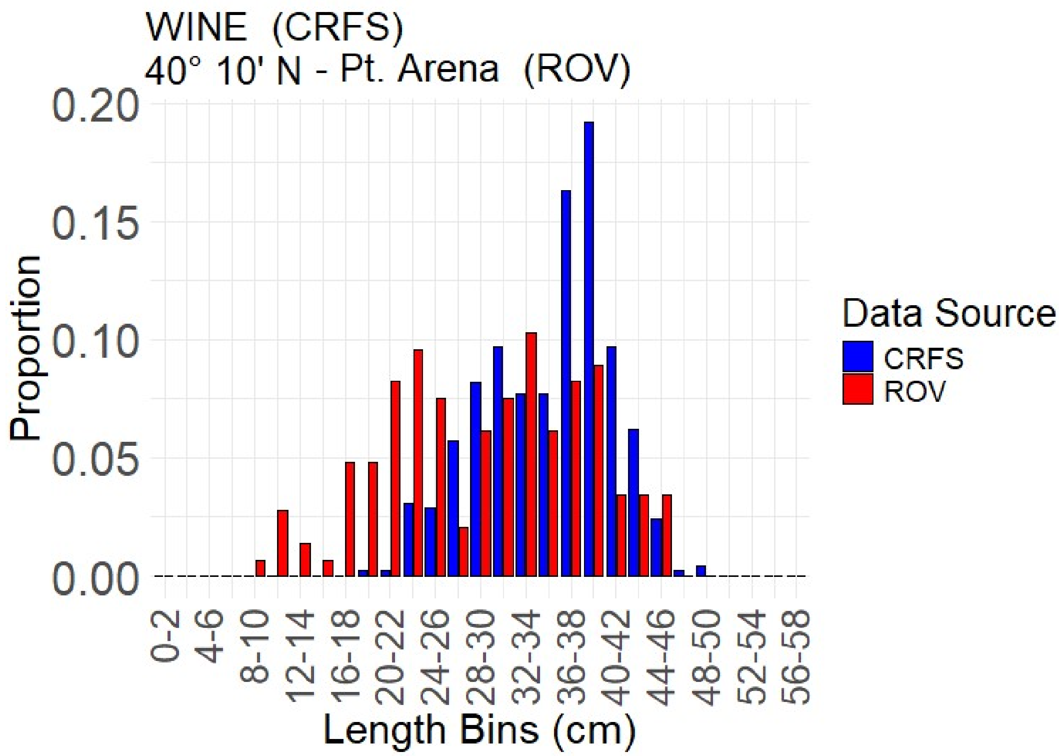

Figure C1-11. Length frequency distributions of quillback rockfish for the Wine (CRFS) and 40°10’ N Latitude – Pt. Arena (ROV) strata. All available ROV years included (2014 – 2021) with matching CRFS years.

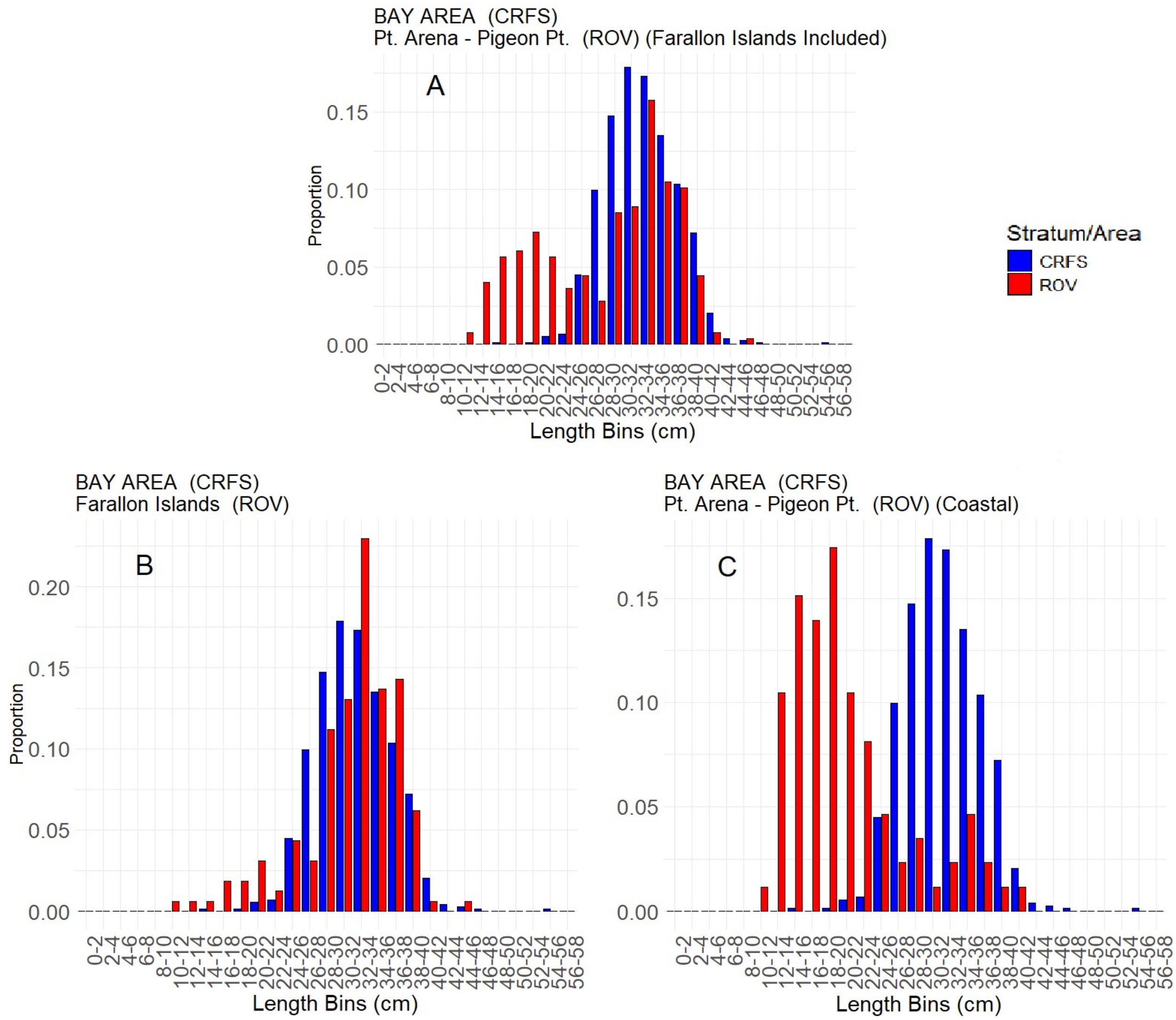

Figure C1-12. Length frequency distributions of quillback rockfish for the A) Bay Area (CRFS) and Pt. Arena – Pigeon Pt. (Farallon Islands included) (ROV) strata; B) Bay Area (CRFS) and Farallon Islands (ROV); and C) Bay Area (CRFS) and Pt. Arena – Pigeon Pt. (Coastal). All available ROV years are included (2014 – 2021) with matching CRFS years.

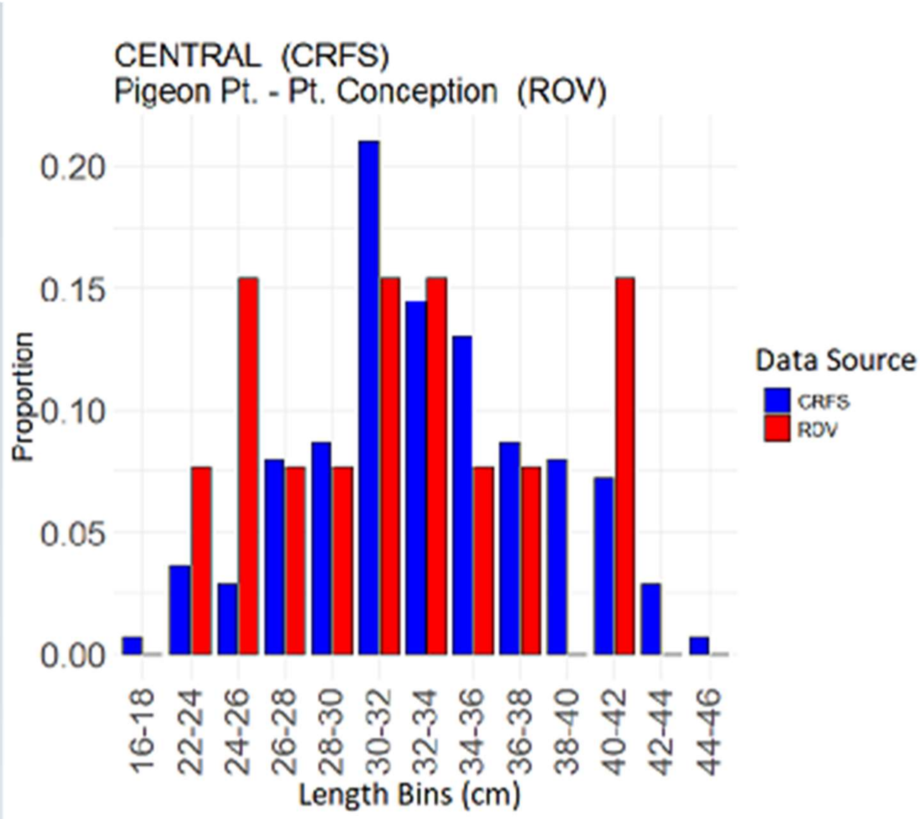

Figure C1-13. Length frequency distributions of quillback rockfish for the Central (CRFS) and the Pigeon Pt. – Pt. Conception (ROV) strata. All available ROV years included (2014 – 2021) with matching CRFS years.

Discussion

Latitudinal Analysis

Some possible explanations of the pattern of small to larger fish from south to north seen in Figure 2 include:

1. Nursery Ground Hypothesis: The coastal Point Arena – Pigeon Point stratum (Farallon Islands excluded) is a nursery ground for quillback rockfish and these fish migrate north and to the Farallon islands as they mature. The proportion of smaller fish diminishing the further north data is collected is evidence of this. Additionally, 85% of the fish observed in the Point Arena – Pigeon Point strata were observed in the 2020 super year (which is the second of the two super years). This indicates that small fish are not consistently present in this stratum, but rather they appear there with a recruitment event. Further analyses should be performed to provide further evidence for this hypothesis.
2. ROV Sampling: As seen in Figure C1-4, the average depth of ROV transects in the Point Arena – Pigeon Point stratum (Farallon Islands excluded) was approximately 10-20 meters shallower than the other strata. In combination with the relationship between

depth and length seen for this species, this could explain the absence of large fish in the ROV data for this stratum.

3. High Fishing Pressure: High fishing pressure in the Point Arena – Pigeon Point strata (Farallon Islands excluded) may have reduced the number of large fish. This may be confounded with having sampled shallower depths in the ROV survey. Being able to identify the exact fishing locations of the quillback rockfish sampled in the CRFS data set could help resolve this hypothesis. In other words, if large fish are mainly being caught at the Farallon Islands as opposed to coastal, then this hypothesis would be strengthened. Conversely, additionally ROV sampling could also help resolve this hypothesis.

Despite the inability to decipher the biological reasons for the observed data, the visually observed and statistical differences seen between the distributions may warrant separation in design-based estimates of abundance.

Depth Analysis

It was expected that larger fish would be seen in deeper water compared to shallower water, so the pattern seen in water deeper than 40 meters was not surprising, as similar patterns have been observed elsewhere in the Sebastes (Love et al., 2002). However, the larger fish observed in water shallower than 40 meters was unexpected. Figure C1-7 shows these larger fish were mainly sampled in the North of 40° 10’ N stratum. Since the coastwide sample sizes of the depth stratum shallower than 40 meters were smaller in comparison to the deeper strata (14 observations in the 20-30 meter bin, 95 in the 30-40 meter bin, 194 in the 40-50 meter bin, 200 in the 50-60 meter bin, and 175 observations for depths greater than 60 meters), this could indicate that fish are moving to shallow water for specific behavioral reasons and the patterns observed deeper than 40 meters are the species’ typical depth distributions. Further analysis would be required to resolve this question.

ROV and CRFS Comparison

The comparison between CRFS and ROV data generally provides validation of the ROV data set. Regarding Figure C1-12, if the CRFS data set is spatially resolved to separate the Farallon Islands, and the resulting distributions match their respective ROV counterparts (ignoring small fish observed by the ROV since the ROV is generally able to detect smaller fish) then the ROV data set will be further validated. However, if large fish are observed nearshore in the Bay Area (CRFS) data set, further investigations will be required to resolve the potential difference.

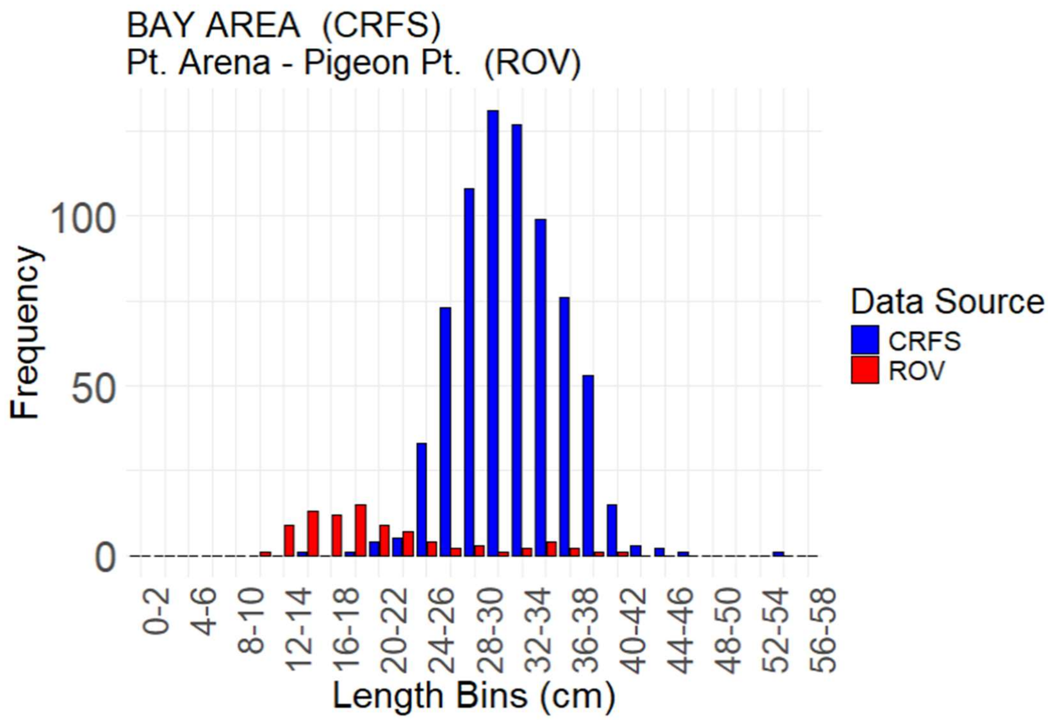

Figure C1-14. Frequency representation of Figure C1-11, Panel C.

Additionally, looking to Figure C1-14, which displays Figure C1-12, panel C with regards to frequency instead of proportion, one can better observe that although the distributions are vastly different, the ROV data is not observing the same number of fish as seen in the CRFS data, as Figure C1-12 might suggest. CRFS samples can originate from anywhere within the latitudinal constraints of this stratum (and within the constraints of fishing regulations), including the Farallon Islands and deeper reefs, and from any time period. ROV transects in comparison cover a very small area, primarily occurring in Marine Protected Areas where anglers cannot fish and occur over relatively short periods of time. Figure C1-15 shows a heat map of quillback rockfish Catch Per Unit Angler (CPUA) from CRFS data between Pt. Arena and Pigeon Pt. While Figure C1-1 illustrates the majority of ROV quillback rockfish observations with associated lengths along the coast between Pt. Arena and Pigeon Pt. are observed north of Bodega Bay, Figure C1-15 illustrates a large number of coastal quillback interactions, as seen in CRFS data, occur south of Bodega Bay. This provides an explanation of the differences observed in the distributions of quillback rockfish lengths between CRFS and ROV while also highlighting the need for more extensive ROV sampling.

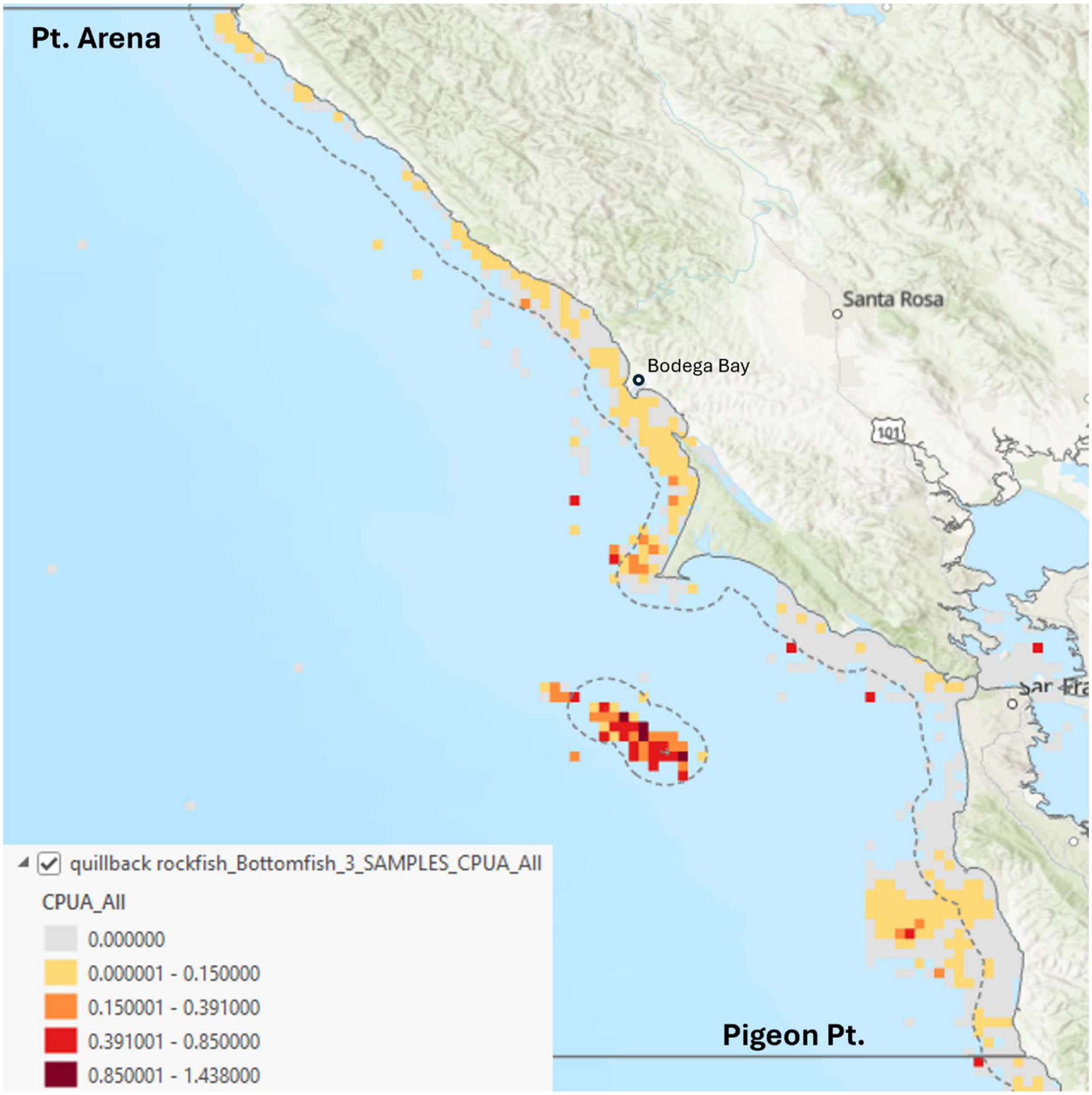

Figure C1-15. Quillback Rockfish CPUA between Pt. Arena and Pigeon Pt. CRFS data are summarized for anglers targeting bottomfish, which include species other than rockfish. Gray cells represent where there was bottomfish effort but no quillback rockfish were caught. Not all CRFS data has location data reported so this figure is not comprehensive of all quillback rockfish, especially in 2020 and 2021 when CRFS sampling was impacted by the Covid-19 pandemic.

In addition to data validation, the ROV to CRFS comparison also displays the ability of ROVs to identify smaller fish than is possible with fishery dependent data, especially fishery dependent data from hook and line fisheries. This is valuable because ROV data may be able to identify recruitment events before they are observed in the fishery.

Furthermore, this comparison highlights the selectivity seen in recreational hook and line fisheries which create a bias in data sets (which are typically accounted for) used in stock assessments. ROV data could remove the need to account for gear selectivity and fisherman preference of larger fish, thus providing more accurate data in stock assessments.

C.2 Stratification by Density Analysis

Introduction

This analysis utilizes quillback rockfish count data collected off the coast of California from the Marine Applied Research and Exploration (MARE) Remotely Operated Vehicle (ROV) transect-level dataset. The primary goal is to use data visualization to identify potential differences in quillback rockfish densities across various latitudinal and depth strata, informing stratification for design-based abundance estimation methods.

Methods

MARE ROV transect-level count data for quillback rockfish was used to create figures that assist in identifying differences in densities across different latitudinal and depth strata in California. Densities were calculated by dividing the total count of fish in a transect by that transect's "usable area" for fish (an explanation of this variable can be found in the CDFW ROV Data User Manual). These densities were then visualized with boxplots. All data points are included in the density calculations, including transects with 0 quillback rockfish observations. All data manipulation and plotting were performed using R Studio (v. 2023.12.1) and the R package ggplot2 (v. 3.5.0).

Ten-meter depth bins were chosen for this analysis, although visualizations with 20-meter depth bins were also examined. The 10-meter bins provided more detail and better separation between strata, likely reflecting the quillback rockfish's affinity for specific depth ranges. The use of both 10- and 20-meter bins aligns with previous analyses for consistency.

QAQC and data processing

- Non-super-year survey years were removed to maintain more even sampling.
- Latitudinal and depth strata were created using the same methods as those for the quillback rockfish length analysis (see the quillback rockfish analysis for details regarding the strata). Notably, the Point Arena – Pigeon Point stratum does not contain data from the Farallon Islands unless otherwise stated.

Results

Figure C2-1, which displays quillback rockfish density by latitudinal strata, shows that the median quillback rockfish density is highest at the Farallon Islands, followed by the North of 40°10' N stratum, the 40°10' N - Pt. Arena stratum, the Pt. Arena - Pigeon Pt. stratum, and finally the Pigeon Pt. to Pt. Conception stratum.

Figure C2-2 is similar to Figure C2-1 except the Pt. Arena - Pigeon Pt. and the Farallon Islands stratum and the Pt. Arena - Pigeon Pt. stratum are combined into the Pt. Arena - Pigeon Pt. stratum. This combination highlights a trend of decreasing densities from north to south.

Figure C2-3 displays coastwide quillback rockfish densities by 10-meter depth strata. This figure shows that the highest densities are observed between 40 and 70 meters (21.9 to 38.3 fathoms).

Figure C2-4 displays quillback rockfish densities by 10-meter depth strata and latitudinal strata. The distributions of densities among depth bins display a large amount of variability between latitudinal strata.

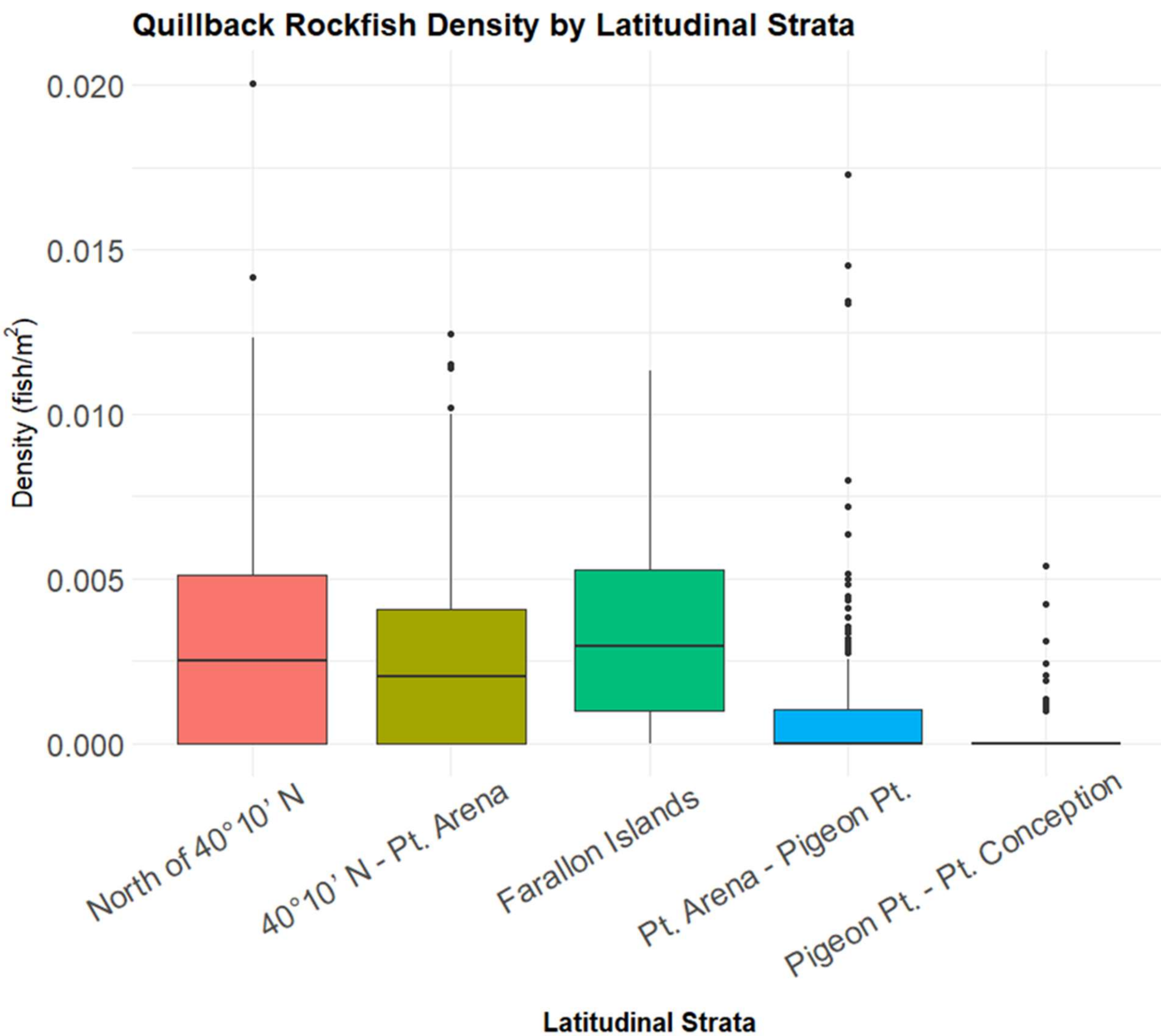

Figure C2-1. Quillback rockfish ROV transect-level density boxplots separated by latitudinal strata. Only ROV data (from 2014 to 2021) are included.

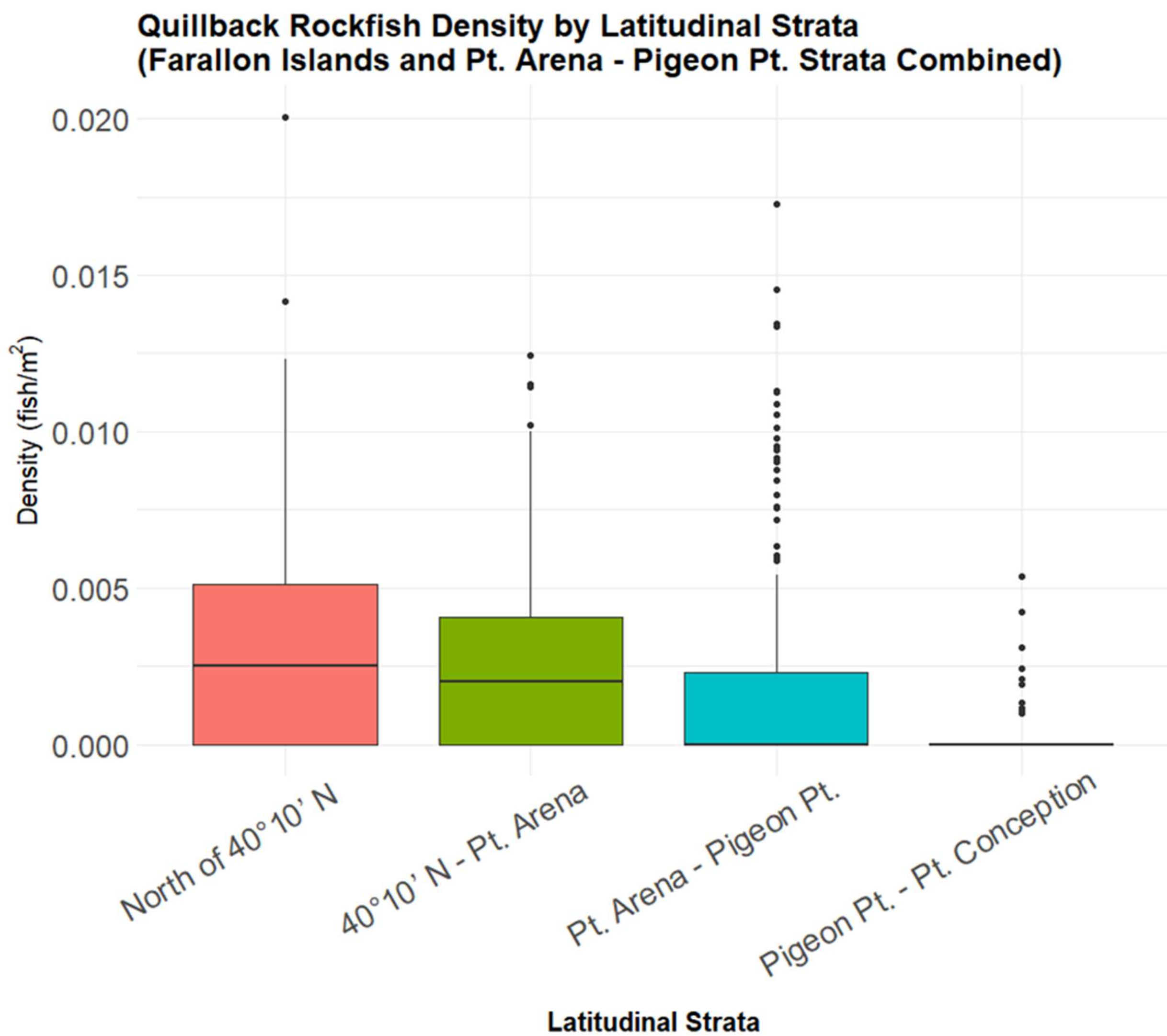

Figure C2-2. Quillback rockfish ROV transect-level density boxplots separated by latitudinal strata. Farallon Islands and Pt. Arena – Pigeon Pt. Strata are combined. Only ROV data (from 2014 to 2021) are included.

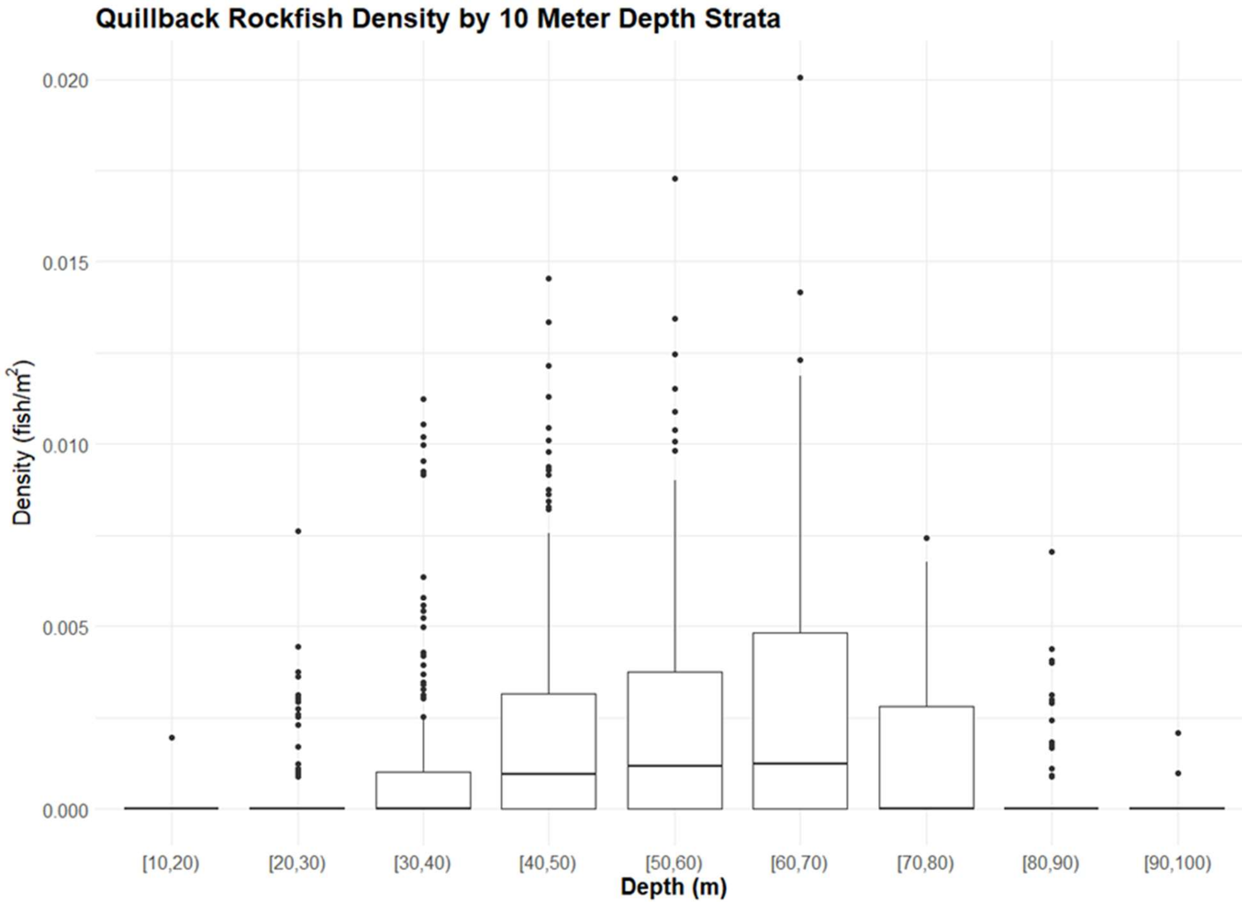

Figure C2-3. Quillback rockfish ROV transect-level density boxplots separated by 10-meter depth strata (coastwide). Only ROV data (from 2014 to 2021) are included.

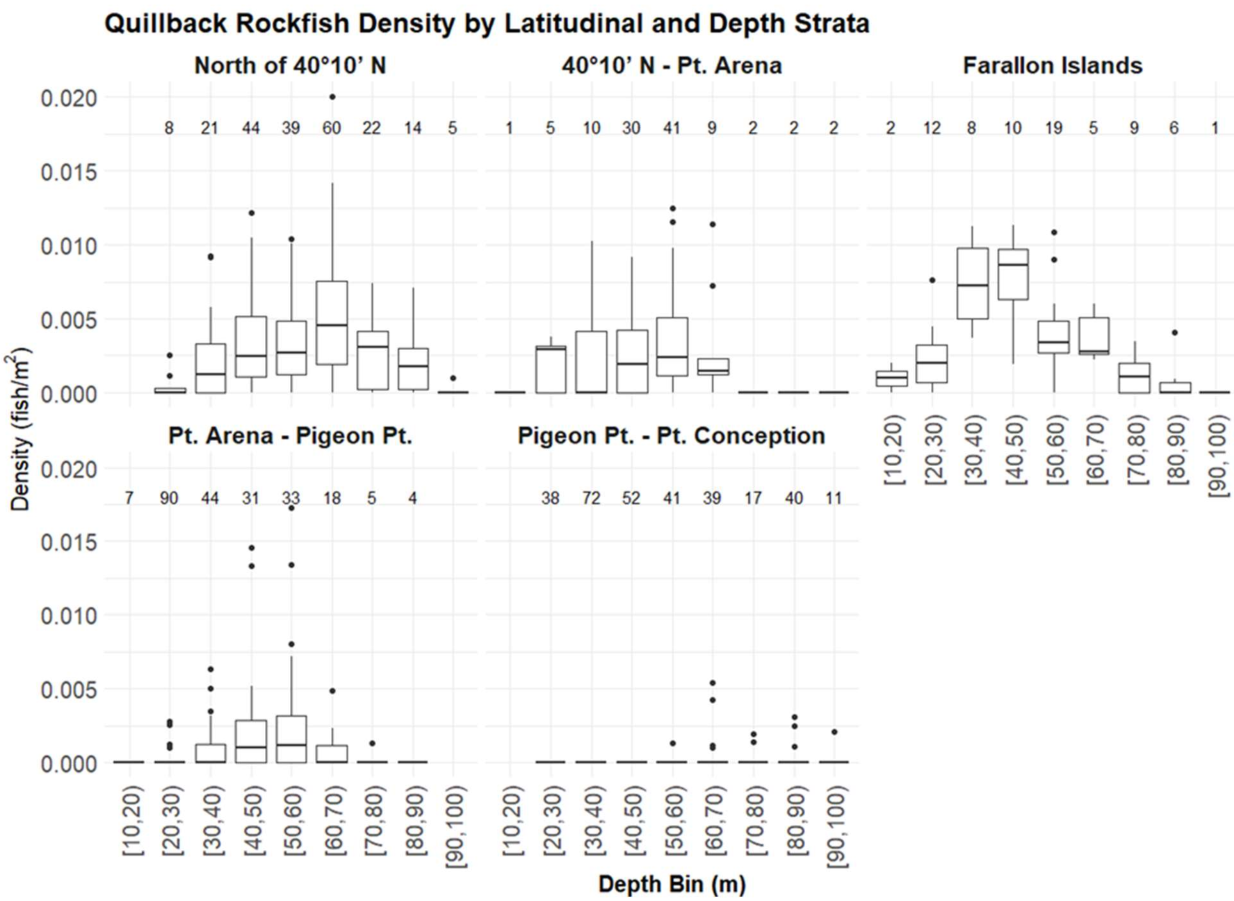

Figure C2-4. Quillback rockfish ROV transect-level density boxplots separated by 10-meter depth strata and latitudinal strata. Numbers above each boxplot represent the sample size for that boxplot. Only ROV data (from 2014 to 2021) are included.

Discussion

In regard to stratifying for design-based estimates, there are two takeaways from the different figures visualizing quillback rockfish densities using MARE ROV data.

1. The Farallon Islands' densities appear to be much different than those of its adjacent coastal region, Pt. Arena - Pigeon Pt. Additionally, as seen in Figure C2-4, sample sizes from the Pt. Arena - Pigeon Pt (coastal) stratum are greater than the Farallon Islands stratum, with a large number of transects with densities of zero in the Pt. Arena - Pigeon Pt. (Coastal) stratum. This sample size difference explains why when combining the Farallon Islands into the coastal Pt. Arena - Pigeon Pt. stratum (Figure C2-2) the resulting boxplot is more similar to the Pt. Arena - Pigeon Pt. stratum than the Farallon Islands stratum.
2. The Pt. Arena - Pigeon Pt. stratum contains a large number of samples (n = 90) in the [20,30) depth stratum compared to the next highest sample size (n = 44) in the [30,40) depth stratum. The [20,30) depth stratum also contains a large number of zeros (n =

83). This may be important when averaging densities since there is a large representation of this shallow depth where very few quillback rockfish are seen.

These two points can provide valuable insight into stratifying for design-based estimates and may enhance our understanding of the biology and fishery of quillback rockfish.

C.3 Analysis of Quillback Rockfish and Habitat Types

This section examines the relationship between quillback rockfish and various habitat types as determined by the 1-second MARE ROV dataset. Unlike the transect or ten-meter datasets, which only display the proportion of bottom type per transect or ten-meter square, the 1-second dataset assigns a specific habitat type to each fish.

Methods

Data Processing and Visualization

All data manipulation and plotting were conducted using R Studio (version 2023.12.1) along with the ggplot2 package (version 3.5.0). Depth bins and latitudinal strata were created in a manner consistent with the quillback rockfish length analysis.

In Figure C3-1, which illustrates coastwide quillback rockfish counts by habitat type, it is evident that hard habitats are the predominant bottom type where quillback rockfish are found, followed by mixed and soft habitats. This pattern is consistent across different latitudinal strata, as shown in Figure C2-2, and across depth strata in Figure C3-3.

Given the consistency observed within and between these figures, no further analyses were deemed necessary.

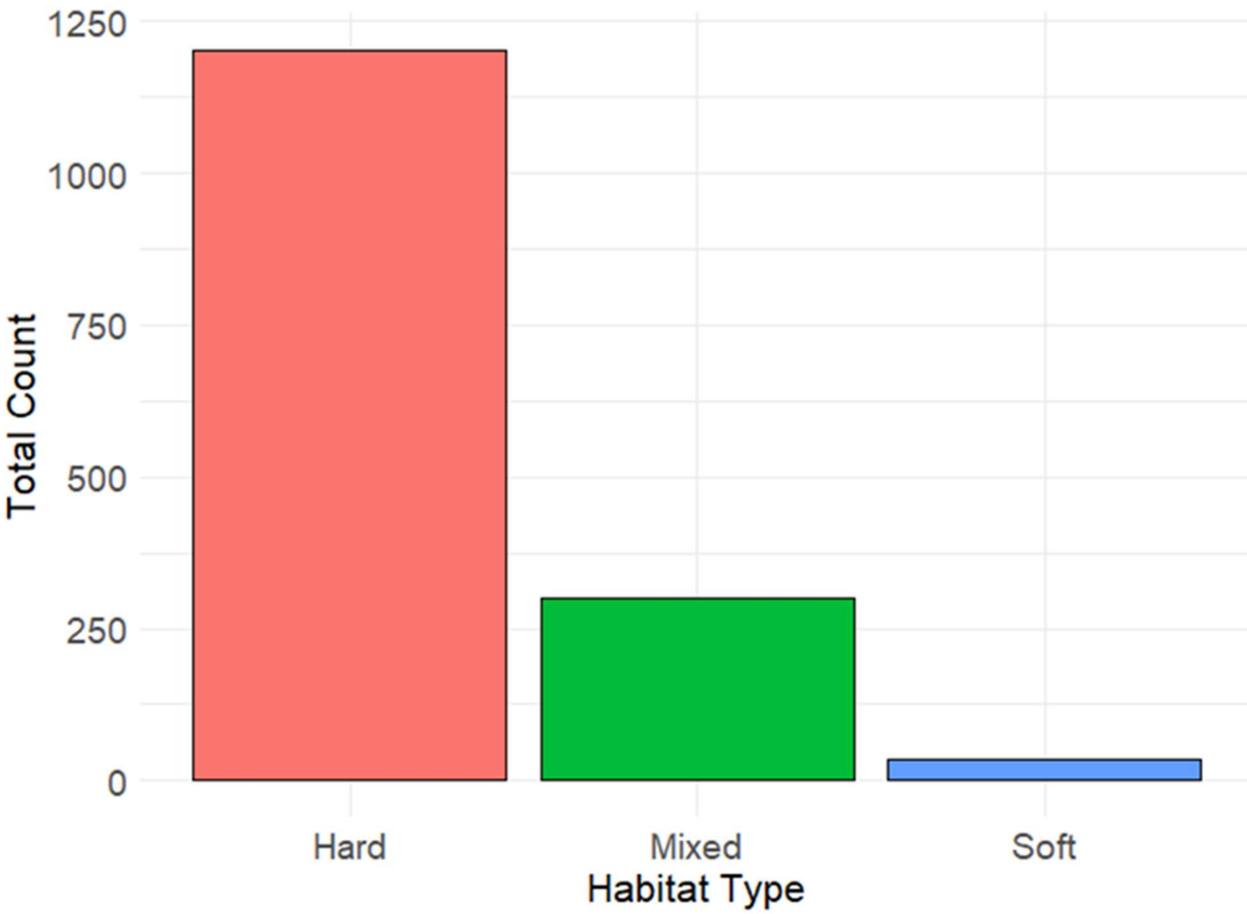

Figure C3-1. Coastwide Quillback rockfish counts by habitat type. Only ROV data (from 2014 to 2021) are included.

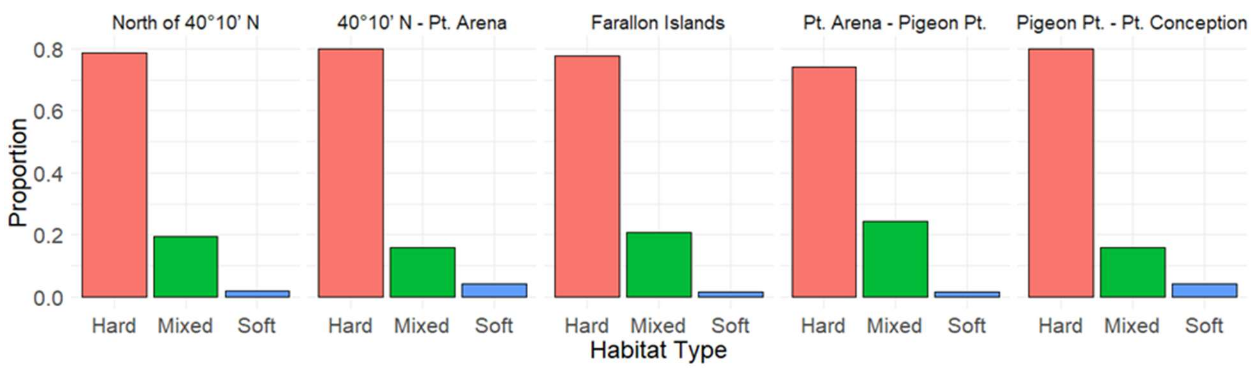

Figure C3-2. Quillback rockfish counts by habitat type and latitudinal strata. Only ROV data (from 2014 to 2021) are included.

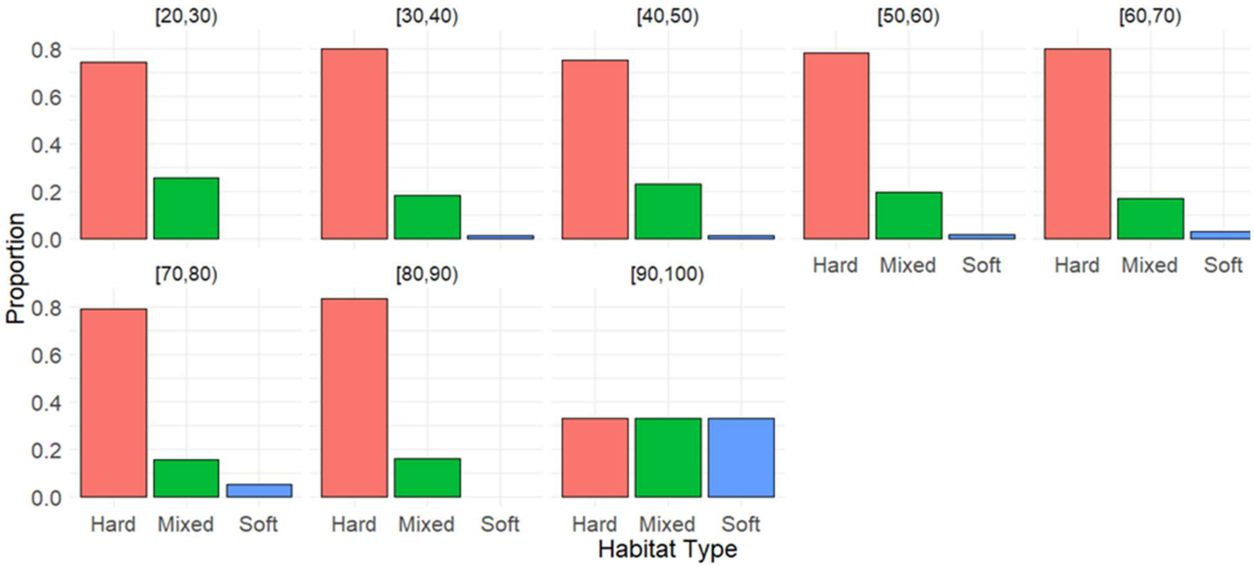

Figure C3-3. Coastwide Quillback rockfish counts by habitat type and depth strata. The [90,100) depth stratum can be explained by a small sample size (n = 3). Only ROV data (from 2014 to 2021) are included.

Estimates of Rocky Reef Habitat Informing Expansions

To estimate the amount of total reef within each strata, two datasets were investigated:

- California Seafloor Mapping Project (CSMP) Predicted Substrate
- West Coast USA Nearshore Coastal and Marine Ecological Classification Standard (CMECS) Substrate Habitat

California Seafloor Mapping Project Background

The California Seafloor Mapping Project (CSMP) was a systematic effort to collect bathymetric data for the state waters of California during the Marine Life Protection Act implementation. This effort resulted in 93% coverage of state waters north of Pt. Conception with high resolution bathymetric data. Due to project implementation funding, waters south of Pt. Conception have less comprehensive coverage. Resolution varied due to the depth collected. Generally, depths from 10m - 80m were measured at a 2m resolution, 85m - 200m depths at a 5m resolution and greater than 200m at a 10m resolution. Depths from 0 -10m were interpolated due to inaccessibility of the boat collecting the bathymetric data.

Table C3-1. Percentage coverage of state waters by resolution. Values in parenthesis represent areas in square kilometers.

Resolution	N of Conception	S of Conception	Total
Whitezone (30m)	6% (477)	NA	4% (477)
2m	77% (5,811)	22% (1,308)	52% (7,119)
5m	8% (634)	9% (538)	9% (1,172)
10m	2% (179)	9% (539)	5% (718)
>10m	7% (435)	60% (3,708)	30% (4,143)
Total Habitat	7536 sq km	6093 sq km	13,629 sq km

Using this bathymetric data, substrate habitat data was algorithmically derived using rugosity to classify each grid to either ‘hard’ or ‘soft’ habitat determinations. All CSMP habitat data was aggregated into a single habitat feature ‘Predicted Nearshore Benthic Substrates of California - R7 - CDFW [ds3091]’ that can be downloaded through CDFW’s MarineBIOS system.

Due to the CSMP only mapping California state waters (three miles offshore), there is less coverage of high-resolution bathymetric data in areas of interest that extend into federal waters. For Quillback depth ranges (up to 100m), this leads to a lack of coverage of bathymetric data in some areas. This is especially prevalent off of San Francisco Bay and the North Coast of California. To ameliorate this lack of data the West Coast USA Nearshore CMECS Substrate Habitat (CMECS) data was also investigated.

Table C3-2. Percentage coverage of CSMP data of potential quillback habitat ranges. Values in parenthesis represent areas in square kilometers.

Resolution	0 - 100m	18m - 100m
White zone (30m)	4% (477)	0.1% (22)
2m	47% (6078)	46% (5289)
5m	3% (402)	4% (402)
10m	0% (0.0003)	0% (0.0003)
>10m	**46% (5,892)**	50% (5,892)
Total Habitat	*12,842 sq km*	*11,569 sq km*

West Coast USA Nearshore CMECS Substrate Habitat Background

This data is an aggregated dataset of bathymetric and habitat data by the Pacific Marine and Estuarine Fish Habitat Partnership. This data was classified into the Substrate Component of the Coastal and Marine Ecological Classification Standard (CMECS). It is important to note that the CSMP data is included in this dataset.

The resolution of the underlying bathymetric data in the CMECS data is highly variable but spatial extent of the data covers all areas within our strata. There is a corresponding Data Quality layer that provides additional information about the resolution, ground truthing and metadata associated with the habitat data. The data can be viewed and downloaded here: West Coast USA Nearshore CMECS Substrate Habitat | Pacific Marine and Estuarine Fish Habitat Partnership

While the dataset compiles habitat into multiple levels of categories and sub-categories, the NOAA Habitat Area of Particular Concern (HAPC) field that classifies relevant habitat area ‘Rocky Reef HAPC’ were used. On visual inspection of CSMP ‘hard’ habitat versus CMEC’s ‘Rocky Reef’ habitat, there is general alignment and interchangeability. However, while reviewing CMECS data, there does appear to be some loss of resolution of the smaller interstitial spaces between ‘hard’ determinations . This leads to some overestimated reef classifications in the CMECS data.

Estimating Total Reef Habitat

Polygons representing the various strata were created in ArcGIS Pro. Depth stratifications utilized contours estimated using CSMP data when possible. When not possible, contours were created using NOAA's 30m bathymetric grid. The CMECS and CSMP habitat layers were each intersected with the strata and the total area of hard habitat for CSMP and rocky reef in CMEC was summed within each of the strata. This was repeated for habitat only within MPAs to find an estimate of the protected area for the expansions.

This process was repeated for each strata framework and data source. For CSMP data, the underlying resolution of the bathymetric data was included. Additionally, the area within each of the strata that did not have habitat coverage was provided. In many areas, this can be up to 50% of the area for CSMP data.

Table C3-3. Example strata habitat totals for CSMP data. Coverage and habitat by resolution is also provided.

Stratification Zone	Stratification Depth	Hard Area	Total MPA Hard	Total Area	Missing Coverage of Habitat Data	Hard (2m)	2m Coverage	Hard (5m)	5m Coverage	Hard (>10m)	>10m Coverage
Above 40 deg 10	0 - 120m	57.26	11.32	1423.73	55%	42.56	38%	2.14	2%	12.56	5%
Farallon	0 - 120m	12.76	5.03	464.7	75%	9.51	18%	0.77	3%	2.48	4%
Pigeon Point to Pt Arena - Coastal	0 - 120m	85.81	20.92	2028.95	67%	65.86	31%	0	0%	19.95	2%
Pt Arena to 40 deg 10	0 - 120m	42.83	6.22	503.99	27%	27.82	47%	0.98	20%	14.03	5%
Pt Conception to Pigeon Point	0 - 120m	127.67	34.23	1586.23	29%	87.42	54%	1.75	7%	38.49	9%

Discussion

The CSMP data estimates of hard habitat is the best possible data source for habitat expansions. However, there are key areas outside of state waters missing good resolution habitat data. The CMECS data source was investigated to fill in these data gaps. While the spatial extent of the CMECS data covers the entire strata area, the data quality and resolution is highly variable.

Therefore, the CSMP data is recommended as the best estimates of hard reef habitat. Due to the missing coverage in many areas in federal waters, expansions of total reef habitat using CSMP data are conservative estimates of total reef available in each strata. For example in the Farallon Islands strata, there are key data gaps of reef habitat around Cordell bank. Further investigation can be done to see how the 2 m, 5 m, and 10 m resolutions may affect total reef area estimates. Since we are aggregating to a large scale, mixed areas most likely 'even out' between cells that overestimate reef and other cells that underestimate reef. One possible analysis is to compare the ROV habitat determinations with the CSMP data. This is an ongoing area of research by CDFW staff.

More investigation needs to be done into the CMECS data sources in areas outside of the CSMP coverage, many of these areas are poor resolution reef delineations and therefore may be overestimates of total reef habitat within each strata.

C4. Design-based Estimates of Abundance

Introduction

The current stock assessments rely on catch history to help inform the scale of the assessment, but for some species that are less commonly encountered or are less desirable, they may never reach the dock or go unreported. They may also be inaccessible due to depth or other spatial regulatory constraints. The lack of historical reporting of encounters and low demand for quillback rockfish may have affected the scale of estimates and prompts the need for a fishery independent estimate of the scale of the population as compared to the scale observed in the assessment. Design-based estimates of abundance in numbers and weight using seafloor mapping, ROV density observations and average weights from lengths extracted from stereo-camera data have been developed to provide new independent fishery information to consider. The following considerations were taken into account when developing the framework for the expansions in the interest of minimizing bias and uncertainty to avoid overexpansion.

1. Depth of Expansion: The depths included in the area estimate were selected to encompass the primary depth distribution between 20 and 90 m as opposed to extremes.
2. Latitude of Expansion: The latitudinal boundaries of the expansion area were limited to the primary distribution from the Oregon/California border to Point Sur, though their reported range extends to the northern Channel Islands.
3. Delineation and Characterization of Seafloor Habitat: Expansions were made on both the high resolution CSMP data set within state waters and with the NMFS CMECS product using multiple resolutions in waters where CSMP did not cover.
4. Stratification of expansion areas: Multiple stratification schemes were evaluated based on the variation in lengths and densities across space, resulting in differing variance, data availability and limitations reflective of variation of abundance along the coast.
5. Nature of density estimates: The density estimates included all habitat types covered during the course of the survey rather than focusing on habitat identified as “rock” alone. This decision was made in recognition of the design of the survey to cover rocky reef generally, interstitial spaces between rock in the CSMP/CMECS characterizations of seafloor and the lack of resolution to separate observations in various habitat types in the transect level data. While efforts could be made to determine density only for rock or rock and mixed habitat in this decision was made to provide a conservative estimate given the nature of the sampling design to sample “rocky reef” and the lack of resolution is aspects of the seafloor data. The general density estimate for all observed seafloor within the rocky reef provides a reasonable value for estimation considering these factors.

Methods

Design-based estimates of abundance were developed for quillback rockfish using an analysis of the depth and latitudinal distribution of density and average weight of observed individuals used to inform stratification presented in prior sections of this report. Data from the CMECS seafloor mapping Essential Fish Habitat analyses provided by NMFS were used to provide the most comprehensive estimate of rocky reef seafloor, while data from the California Seafloor Mapping Program provided higher resolution estimate of habitat within 3 miles of shore in state waters. The CSMP data was available at a higher resolution of 2, 5 or 10 m squared depending on depth, with the 2 m data being most prevalent.

While quillback rockfish were observed to 120 m, their primary depth range was is 20 m to 90 m in the ROV data given the counts and densities in Table C4-1, the former of which is consistent with the California recreational fishery and the latter of which is consistent with the findings on fish base. The primary latitudinal range within California identified with ROV data is more limited than the extremes of its range, noted as the northern Channel Islands on fish base as shown by the counts and density in Table C4-2, with declining densities from north to south within California with an exception at the Farallon Islands where abundance is more elevated given the remoteness of the islands 26 miles from the nearest port. The number of fish and density of fish (fish/square meter) observed by the ROV in each 10-meter depth bin.

Table C4-1. The number of fish and density of fish (fish/square meter) observed by the ROV in each 10 meter depth bin.

Depth (m)	Fish	Density (Fish/Square Meter)	Transects Sampled
0-10	0	0	0
10-20	2	0.000196724	10
20-30	46	0.000338732	153
30-40	164	0.001122868	155
40-50	332	0.002180902	167
50-60	382	0.002450196	173
60-70	314	0.002834064	131
70-80	74	0.001417482	55
80-90	43	0.000618206	66
90-100	3	0.000161173	19
100-110	0	0	6
All Depths	1360	0.001613925	935

Table C4-2. The number of fish and density of fish (fish/square meter) observed by the ROV in each one-degree latitude bin.

Latitude (Degrees)	Fish	Density (Fish/Square Meter)	Transects Sampled
41-42	478	0.003689607	155
40-41	149	0.002456499	59
39-40	158	0.002166626	81
38-39	260	0.001799346	177
37-38	290	0.001528266	178
36-37	25	0.000127114	206
35-36	0	0	79
34-35	0	0	0
Oregon Border to Point Conception	1360	0.001613925	935

Density data (fish per square meter) collected by the ROV were stratified consistently with the seafloor to inform expansions estimating the number of fish in each stratum and weight data converted from stereo-camera length measurements. The lengths were converted to weight using the length/weight relationships (Weight = 0.00001963*Length^3.02) from measured and weighed fish reported in the 2023 Quillback Rockfish stock assessment. For each stratification scheme considered, estimates of density and average weight as well as the associated variance for each stratum were estimated within and outside of MPAs using 9999 non-parametric bootstrap draws and summed across all strata to produce a single estimate for each super year. Generalized Equations 1 and below were used to derive specific estimates of abundance in numbers and weight. The estimates and variance were then summed across strata to provide an aggregate estimate.

Equation 1. Numbers of Fish = fish/square meter *square miles/square meter* square miles rocky reef habitat

Equation 2. Stratum Biomass = fish/square meter *square miles/square meter* square miles rocky reef habitat * Average Weight

Expansion Strata

Five stratification scenarios were investigated to develop the design-based estimates of abundance. For each of the estimates, rocky reef habitat area estimates for each strata inside and outside of MPAs were estimated from the CMECS and CSMP data sets using GIS, as the basis for habitat area expansion. For each of the corresponding strata density and multiplied by the area estimate to provide estimates in numbers of fish. Lengths of fish observed and measured with stereo-camera techniques were converted to weights using established length-weight relationships. Weights within each strata were multiplied by habitat area inside and outside of MPAs to provide corresponding estimates in each strata, which were then summed to provide an aggregate estimate for the full distribution within California for each stratification scheme. Estimates were provided for each super year inside and outside of MPAs in each stratum. The following stratifications schemes were evaluated:

1.) Oregon/California Border to Point Sur.

2.) Oregon California to 40 deg 10 min N. Lat, 40 deg 10 min N. Lat to Point Arena, Farallon Islands, Point Arena to Pigeon Point, Pigeon Point to Point Sur.

3.) Oregon California to Point Arena, Point Arena to Point Sur, Farallon Islands.

4.) Oregon California to 40 deg 10 min N. Lat, 40 deg 10 min N. Lat to Point Arena, Point Arena to Point Sur.

5.) Oregon California to Point Arena, Point Arena to Point Sur.

Bootstrapping Variance and Confidence Intervals

A bootstrap resampling method to estimate fish abundance and biomass, for various strata within different protection levels and years. Iterating through each latitudinal strata, super year, and protection status, we extracted the density and weight data, which were subsequently resampled using the non-parametric bootstrap method. A total of 9,999 bootstrap resamples were generated for both density and weight. From these bootstrapped distributions, we estimated the number of fish by multiplying the bootstrapped density values by the area (converted to square meters), and biomass by multiplying the number of fish by the corresponding (pairwise for each 9999 resamples) bootstrapped weight. The mean and variance of each bootstrapped parameter was then calculated to get point estimates of each.

For each parameter, we calculated the 2.5th and 97.5th percentiles of the bootstrapped distributions to obtain 95% confidence intervals. These results were aggregated into a comprehensive dataset, which includes both point estimates and associated uncertainty for each combination of strata, protection status, and year.

Results and Discussion

Estimates of abundance for stratification schemes treating the Farallon Islands and the area south of Pigeon Point as a separate stratum in stratification scheme 2 and 3 resulted in a lack of samples to inform some strata. To inform average length and thus weight for 2015 at the Farallon Islands, values from 2020 for inside and outside of MPAs were used as a proxy. Densities for the area south of Pigeon Point in 2015 were informed using the densities inside MPAs in 2015 as a proxy in Table C4-3 for the CMECS habitat expansion and Table C4-9 for the CSMP habitat expansion for estimates in numbers of fish. Bootstrapped estimates of abundance in metric tons are found Table C4-4 for CMECS and Table C4-10 for CSMP in metric tons. The Farallon Islands and south of Point Sur were combined with the area between Point Arena to Pigeon Point to address the low sample size in these strata and evaluate the effect on the confidence interval of the estimate in scenarios 4 and 5 as well scenario 1 from the Oregon Border to Point Sur providing a statewide perspective.

Bootstrapped estimates of numbers of fish are in Tables C4-3 and in metric tons in Table C4-6 for the CMECS habitat data, and the equivalent tables are provided for the CMSP habitat expansion in Tables C4-9 and Table C4-12, respectively. The results from the bootstrap estimates were consistent with manual calculations validating the bootstrap results. All of the stratification scheme resulted in an increase in the number of fish over time both inside and outside of MPAs, and all but the statewide scenario 1 showed an increase in biomass between 2015 and 2020. The decrease in abundance metric tons over time in scenario 1 from 925 mt to 745 mt for the CMECS habitat expansion and 516 mt to 440 mt is attributable to the large number of young fish that recruited south of 40° 10' N. Lat in 2020. This resulted in a reduced average weight in aggregate statewide that is biased relative to the average weight north and south, resulting in a lower estimate to the north than is representative, which was also the case for CSMP expansions. All the remaining stratification scenarios accounting for the lower average weight to the south in 2020 result in increased estimates of biomass between 2015 and 2020 (CMEC Table C4-6 and CSMP Table C4-9).

The bootstrap estimates and their 95% confidence intervals are provided for the CMECS habitat data for numbers of fish in Table C4-4 and metric tons of fish in Table C4-7, and sample sizes, variance, standard deviation and standard error are provided in Table C4-5 and Table C4-8, respectively. The corresponding tables for the CSMP habitat data are provided in Table C4-11 for estimates and confidence intervals in numbers of fish and Table C4-13 for biomass in metric tons, while the corresponding measure of dispersion are provided in Table C4-11 for numbers of fish and Table C4-14 for biomass in metric tons.

The lack of lengths for 2015 at the Farallon Islands and observations south of Pigeon Point outside MPAs in 2015 prevented direct comparison of the aggregated variance for stratification schemes 2 and 3, but schemes 4 and 5 combining them into an Area south of Point Arena provide complete comparisons to the statewide stratification in scheme 1. Between scheme 1, 4 and 5, the statewide stratification scheme 1 showed higher dispersion, while the alternatives with greater strata decreased variance for schemes 4 and 5. Even missing strata, the dispersion was greater for option 2 than the other stratified options, likely the result of the sample sizes becoming more limited with greater stratification. Within a given habitat data expansion, the estimates from each of the stratified sampling schemes were fairly comparable, thus the performance relative to dispersion provides a better guide as to which is preferable.

The estimated number and metric tons of quillback rockfish from the Oregon Border to Point Sur from 20 to 90 m with their 95% confidence intervals for each of the stratification schemes for the CMECS habitat expansion (state and federal waters) and CSMP habitat expansion (state waters) are presented in Figure C4-1 and Figure C4-2, respectively. All stratification schemes showed an increasing number of fish and all but the statewide scheme 1 showed increasing biomass, the difference being the result of smaller fish from recent recruitment in the south in 2020 addressed by stratification in the remaining schemes, making the statewide result biased and unrepresentative. In addition, there was little difference in the width of the confidence intervals among stratification schemes apart from the 2015 results where scheme 1 reflects no stratification. Stratification schemes 2 and 3 separating the Farallon Islands and south of Pigeon Point from the rest of the area south of Point Arena resulted in the need to use proxy values, with not much apparent benefit in terms of reduction in the confidence intervals, though simpler stratification schemes combining them in schemes 4 and 5 may be preferable. Schemes 4 and 5 reflecting more intermediate sampling schemes in terms of degree of stratification did result in lower estimates of numbers and metric tons, while still showing an increasing trend over time while having slightly narrower confidence intervals compared to the first three schemes making them more reasonable candidates for future exploration.

The CMECS habitat area was more expansive, covering the entire primary depth distribution of quillback rockfish compared to the CSMP habitat area reflecting higher resolution mapping representing only state waters within three miles of shore. As a result, the CMECS estimates are between 594 mt and 1011 mt, while the CSMP estimates are between 440 mt and 642 mt for stratification schemes 2 through 5. The scale of these results are a great deal higher than the result 77.53 mt estimate for 2020 from the most recent 2023 assessment as seen in Table C4-15 and Figure C4-3.

The discrepancy in biomass between the 2023 stock assessment and the estimates herein may be explained to some degree by either the resolution of the area of expansion, and/or the data available to inform catch contributing to the scale of the assessment. Prior to the live-fish fishery in the nearshore, species like quillback rockfish and Cabezon were often discarded since the conversion rates for such species with large heads and small bodies was too low to justify processing. Since the mid-1980s, the demand for quillback rockfish has increased with the advent of the live fish fishery. The scale of the historical catch may be off as a result.

In addition, they are not encountered as often as many other more abundant species and do not grow to as great of size as many co-occurring species in the nearshore waters, thus recreational anglers may choose not to retain them and not know the name to be able to report them and instead the end up categorized as discards of unspecified rockfish genus. Outreach efforts in the last 15 to 20 years have improved identification over time and the proportion of rockfish genus reported has declined. As anglers are reporting more frequently as they learn to identify species more accurately in order to abide by prohibitions on retention, the apparent mortality increases, while the unaccounted historical encounters bias low the scale of the assessment. This leads to greater constraints, exacerbating the fishery management issue in an effort to keep more representative catch estimates from exceeding ACLs biased low by unreported encounters. Use of design-based estimates of abundance or model-based estimates of abundance may help better inform the scale as well as trend of the 2025 quillback rockfish assessment and future assessments of other nearshore rockfish species. Future efforts to compare the biomass estimates from the recent assessments assessment to estimates from the two available super years for design-based estimates may provide further information on the comparability among stocks. It is expected that biomass estimates for more common or desirable species informed by catch data in assessments will be comparable to estimates from ROV-based estimates. For species like quillback rockfish that are less common or desirable, the scale in stock assessments is hypothesized be underestimated by assessments reliant on catch estimates.

Table C4-3. Results of bootstrap estimation of abundance in numbers in each stratification scheme using the CMECS habitat data from NMFS encompassing the primary range of quillback rockfish. Bold values denote averages for densities and summations for a given stratification scheme.

Stratifi-cation Scheme	Area	Super Year	Mean Density Outside MPAs	Mean Density Inside MPAs	Meters Squared per Square Mile	Square Miles Outside MPAs	Square Miles Inside MPAs	Mean Fish Outside MPAs	Mean Fish Inside MPAs	Total Fish
1	**Oregon Border to Point Sur**	**2015**	**0.001674**	**0.001396**	**2589988**	**191.5**	**38.6**	**829711**	**139432**	**969143**
		2020	**0.001677**	**0.002866**	**2589988**	**191.5**	**38.6**	**831666**	**286512**	**1118179**
2	North of 40° 10' N. Lat	2015	0.002701	0.002548	2589988	45.1	10.9	314825	71836	386661
		2020	0.003761	0.004791	2589988	45.1	10.9	438472	135001	573473
	40° 10' to Point Arena	2015	0.001356	0.001609	2589988	18.0	2.6	63029	11039	74069
		2020	0.002359	0.005116	2589988	18.0	2.6	109641	35139	144779
	Farallon Islands	2015	0.003904	0.002959	2589988	29.2	3.8	296567	29535	326102
		2020	0.003685	0.004523	2589988	29.2	3.8	277936	45164	323100
	Point Arena to Pigeon Point	2015	0.000561	0.000301	2589988	77.1	15.5	111786	12107	123892
		2020	0.000777	0.001718	2589988	77.1	15.5	155582	69108	224690
	Pigeon Point to Point Sur	2015	0.000000	0.000289	2589988	22.1	5.7	0	4283	4283
		2020	0.000141	0.000168	2589988	22.1	5.7	8065	2447	10512
	Total	**2015**	**0.001699**	**0.001517**		**191**	**39**	**786207**	**128800**	**915006**
		2020	**0.002067**	**0.003197**		**191**	**39**	**989696**	**286858**	**1276554**
3	North of Point Arena	2015	0.002314	0.002235	2589988	63.0	13.5	378518	78542	457060
		2020	0.003364	0.004914	2589988	63.0	13.5	548449	172588	721037
	Farallon Islands	2015	0.003904	0.002959	2589988	29.2	3.8	294808	29482	324290
		2020	0.003685	0.004523	2589988	29.2	3.8	279398	45066	324464
	Point Arena to Point Sur	2015	0.000314	0.000297	2589988	99.2	21.2	80566	16361	96926
		2020	0.000472	0.001113	2589988	99.2	21.2	121247	61183	182430
	Total	**2015**	**0.002177**	**0.001830**		**191.5**	**38.6**	**753891**	**124385**	**878276**
		2020	**0.002507**	**0.003517**		**191.5**	**38.6**	**949094**	**278837**	**1227931**

Table C4-3 (Cont.). Results of bootstrap estimation of abundance in numbers in each stratification scheme using the CMECS habitat from NMFS encompassing the primary range of quillback rockfish. Bold values denote averages for densities and summations for a given stratification scheme.

Stratifi-cation Scheme	Area	Super Year	Mean Density Outside MPAs	Mean Density Inside MPAs	Meters Squared per Square Mile	Square Miles Outside MPAs	Square Miles Inside MPAs	Mean Fish Outside MPAs	Mean Fish Inside MPAs	Total Fish
4	North of 40° 10' N. Lat	2015	0.0027009	0.0025481	2589988	45.1	10.9	315004	71687	386691
		2020	0.0037613	0.0047913	2589988	45.1	10.9	440289	134934	575223
	40° 10' to Point Arena	2015	0.0013565	0.0016094	2589988	18.0	2.6	63455	11065	74520
		2020	0.0023588	0.0051163	2589988	18.0	2.6	109133	35110	144243
	Point Arena to Point Sur	2015	0.0009618	0.0006459	2589988	128.4	25.1	321153	41917	363071
		2020	0.0009087	0.0016892	2589988	128.4	25.1	302573	109701	412274
	Total	**2015**	**0.001673**	**0.001601**		**191.5**	**38.6**	**699612**	**124670**	**824282**
		2020	**0.002343**	**0.003866**		**191.5**	**38.6**	**851995**	**279745**	**1131740**
5	North of Point Arena	2015	0.0023144	0.0022352	2589988	63.0	13.5	377990	78386	456376
		2020	0.0033636	0.0049137	2589988	63.0	13.5	549955	172145	722100
	Point Arena to Point Sur	2015	0.0009618	0.0006459	2589988	99.2	21.2	247641	35491	283132
		2020	0.0009087	0.0016892	2589988	99.2	21.2	233089	92881	325970
	Total	**2015**	**0.001638**	**0.001441**		**162.2**	**34.8**	**625631**	**113877**	**739508**
		2020	**0.002136**	**0.003301**		**162.2**	**34.8**	**783044**	**265026**	**1048070**

Table C4-4. Estimates of numbers of fish with the associated lower and upper 95% confidence intervals, from bootstrap estimation in each stratification scheme using the CMECS habitat data from NMFS encompassing the primary range of quillback rockfish. Bold values denote summations for a given stratification scheme.

Stratification Scheme	Area	Super Year	Mean Fish Outside MPAs	Lower CI Fish Outside MPAs	Upper CI Fish Outside MPAs	Mean Fish Inside MPAs	Lower CI Fish Inside MPAs	Upper CI Fish Inside MPAs	Mean Fish Total	Lower CI Fish Total	Upper CI Fish Total
1	**Oregon Border to Point Sur**	**2015**	**829711**	**618368**	**1060163**	**139432**	**103297**	**177787**	**969419**	**753013**	**1209856**
		2020	**831666**	**661685**	**1008927**	**286512**	**240807**	**334418**	**1119769**	**946772**	**1300801**
2	North of 40° 10' N. Lat	2015	314825	214081	431012	71836	49583	96419	386744	284749	503814
		2020	438472	343034	541738	135001	110967	160074	573208	475336	675645
	40° 10' to Point Arena	2015	63029	35161	92878	11039	6316	16255	74523	46275	105564
		2020	109641	67859	155640	35139	26225	44276	144561	102005	191062
	Farallon Islands	2015	295074	154402	449449	29565	12095	49979	324927	182316	482351
		2020	277936	166338	405397	45164	34314	56495	323651	210897	448572
	Point Arena to Pigeon Point	2015	111786	47802	189769	12107	4691	21075	123052	60102	202387
		2020	155582	91948	227462	69108	40418	103657	224533	152884	303648
	Pigeon Point to Point Sur	2015	0	0	0	4283	0	12132	4316	0	12132
		2020	8065	1046	17241	2447	363	5581	10581	3108	20329
	Total	**2015**	**786468**	**598535**	**991327**	**128651**	**97680**	**161482**	**913562**	**717479**	**1121203**
		2020	**990795**	**823007**	**1167530**	**286634**	**244604**	**331375**	**1276535**	**1100990**	**1456042**
3	North of Point Arena	2015	378518	273055	501359	78542	58142	101553	455968	348597	579894
		2020	548449	440862	663295	172588	147389	198665	721741	610635	840315
	Farallon Islands	2015	295074	154402	449449	29565	12095	49979	324065	180942	477644
		2020	279398	169874	405934	45066	33984	56412	324592	210611	453486
	Point Arena to Point Sur	2015	80566	33220	141974	16361	6856	28839	96721	48289	158760
		2020	121247	74473	174760	61183	35185	91368	182523	128098	241728
	Total	**2015**	**752847**	**565885**	**958254**	**123975**	**94446**	**155665**	**876753**	**684684**	**1078641**
		2020	**950079**	**785784**	**1125540**	**278478**	**240557**	**319466**	**1228856**	**1056106**	**1412809**

Table C4-4 (Cont.). Estimates of numbers of fish with the associated lower and upper 95% confidence intervals from bootstrap estimation in each stratification scheme using the CMECS habitat data from NMFS encompassing the primary range of quillback rockfish. Bold values denote summations for a given stratification scheme.

Stratifi-cation Scheme	Area	Super Year	Mean Fish Outside MPAs	Lower CI Fish Outside MPAs	Upper CI Fish Outside MPAs	Mean Fish Inside MPAs	Lower CI Fish Inside MPAs	Upper CI Fish Inside MPAs	Mean Fish Total	Lower CI Fish Total	Upper CI Fish Total
4	North of 40° 10' N. Lat	2015	315004	216260	431401	71687	49501	96084	387606	285321	507812
		2020	440289	344877	540818	134934	110435	160052	575059	473953	679886
	40° 10' to Point Arena	2015	63455	35378	93073	11065	6141	16131	74035.5	44976.5	105223
		2020	109133	67076	154260	35110	26349	44176	144890	102788	191946
	Point Arena to Point Sur	2015	321153	167313	507837	41917	21069	67354	361099	205133	545780
		2020	302573	203367	420614	109701	78554	144865	411162	304514	531320
	Total	**2015**	**698415**	**503581**	**918968**	**124811**	**92998**	**160468**	**822740**	**625918**	**1038192**
		2020	**850628**	**705357**	**1008925**	**279353**	**238560**	**322298**	**1131110**	**979073**	**1294068**
5	North of Point Arena	2015	377990	274746	499272	78386	57988	100924	456020	348019	577331
		2020	549955	443510	662430	172145	146611	198601	721764	612523	834746
	Point Arena to Point Sur	2015	247641	128801	389182	35491	17653	57203	283157	161814	422976
		2020	233089	155787	324366	92881	66022	121986	326687	245500	420719
	Total	**2015**	**625518**	**463228**	**806832**	**114091**	**86070**	**145132**	**739178**	**575751**	**925254**
		2020	**782298**	**649307**	**923606**	**265264**	**228277**	**304230**	**1048451**	**909327**	**1194874**

Table C4-5. Sample sizes, variance, standard deviation and standard error from bootstrap estimation in numbers of fish in each stratification scheme using the CMECS habitat data from NMFS encompassing the primary range of quillback rockfish. Bold values denote summations for a given stratification scheme.

Stratification Scheme	Area	Super Year	Density Sample Size Outside MPAs	Density Sample Size Inside MPAs	Fish Var Outside MPAs	Fish Var Inside MPAs	Fish Var Total	Fish SD Outside MPAs	Fish SD Inside MPAs	Fish SD Total	Fish SE Outside MPAs	Fish SE Inside MPAs	Fish SE Total
1	**Oregon Border to Point Sur**	**2015**	**152**	**159**	**12586727112**	**354728559**	**12941455671**	**112191**	**18834**	**113761**	**9100**	**1494**	**6451**
		2020	**214**	**233**	**7735907082**	**554492786**	**8290399868**	**87954**	**23548**	**91052**	**6012**	**1543**	**4307**
2	North of 40° 10' N. Lat	2015	57	50	3106958294	143815878	3250774173	55740	11992	57016	7383	1696	5512
		2020	48	53	2539279119	157078870	2696357989	50391	12533	51926	7273	1722	5167
	40° 10' to Point Arena	2015	23	25	221155656	6507389	227663045	14871	2551	15089	3101	510	2178
		2020	19	32	500682179	21165658	521847836	22376	4601	22844	5133	813	3199
	Farallon Islands	2015	13	11	5741727333	94203475.52	5835930809	75774	9706	76393	21016	2926	15594
		2020	20	25	3732760882	32510766	3765271648	61096	5702	61362	13662	1140	9147
	Point Arena to Pigeon Point	2015	33	51	1343243055	17314937	1360557993	36650	4161	36886	6380	583	4025
		2020	66	75	1188036449	262875309	1450911758	34468	16213	38091	4243	1872	3208
	Pigeon Point to Point Sur	2015	26	22	0	12717930	12717930	0	3566	3566	0	760	515
		2020	61	48	17065858	2000372	19066230	4131	1414	4366	529	204	418
	Total	**2015**	**152**	**159**	**10413084339**	**104881361**	**10517965701**	**102045**	**10241**	**102557**	**8277**	**812**	**5815**
		2020	**214**	**233**	**7977824487**	**171687293**	**8149511780**	**89319**	**13103**	**90275**	**6106**	**858**	**4270**
3	North of Point Arena	2015	80	75	3307374490	121755115	3429129604	57510	11034	58559	6430	1274	4704
		2020	67	85	3189727034	170886570	3360613604	56478	13072	57971	6900	1418	4702
	Farallon Islands	2015	13	11	5741727333	94203475.52	5835930809	75774	9706	76393	21016	2926	15594
		2020	20	25	3722336720	32599718	3754936439	61011	5710	61278	13642	1142	9135
	Point Arena to Point Sur	2015	59	73	792176644	31314420	823491063	28146	5596	28697	3664	655	2498
		2020	127	123	657940929	204392525	862333453	25650	14297	29366	2276	1289	1857
	Total	**2015**	**152**	**159**	**9841278467**	**247273010**	**10088551477**	**99203**	**15725**	**100442**	**8046**	**1247**	**5696**
		2020	**214**	**233**	**7570004682**	**407878813**	**7977883496**	**87006**	**20196**	**89319**	**5948**	**1323**	**4225**

Table C4-5 (Cont.). Sample sizes, variance, standard deviation and standard error from bootstrap estimation in numbers of fish in each stratification scheme using the CMECS habitat data from NMFS encompassing the primary range of quillback rockfish. Bold values denote summations for a given stratification scheme

Stratifi-cation Scheme	Area	Super Year	Density Sample Size Outside MPAs	Density Sample Size Inside MPAs	Fish Var Outside MPAs	Fish Var Inside MPAs	Fish Var Total	Fish Count SD Outside MPAs	Fish Count SD Inside MPAs	Fish SD Total	Fish SE Outside MPAs	Fish SE Inside MPAs	Fish SE Total
4	North of 40° 10' N. Lat	2015	57	50	3031910092	139810955	3171721046	55063	11824	56318	7293	1672	5444
		2020	48	53	2492897810	160137251	2653035061	49929	12655	51508	7207	1738	5125
	40° 10' to Point Arena	2015	23	25	222068811	6549609	228618420	14902	2559	15120	3107	512	2182
		2020	19	32	494394155	20672492	515066646	22235	4547	22695	5101	804	3178
	Point Arena to Point Sur	2015	72	84	7640280847	140317403	7780598251	87409	11846	88208	10301	1292	7062
		2020	147	148	3051317957	284226608	3335544565	55239	16859	57754	4556	1386	3363
	Total	**2015**	**152**	**159**	**10894259750**	**286677967**	**11180937718**	**104376**	**16932**	**105740**	**8466**	**1343**	**5996**
		2020	**214**	**233**	**6038609921**	**465036351**	**6503646273**	**77708**	**21565**	**80645**	**5312**	**1413**	**3814**
5	North of Point Arena	2015	80	75	3326095920	120655904	3446751824	57672	10984	58709	6448	1268	4716
		2020	67	85	3151191841	175803984	3326995825	56135	13259	57680	6858	1438	4678
	Point Arena to Point Sur	2015	72	84	4444565966	102475399	4547041365	66668	10123	67432	7857	1105	5399
		2020	147	148	1846487075	203684372	2050171446	42971	14272	45279	3544	1173	2636
	Total	**2015**	**152**	**159**	**7770661886**	**223131304**	**7993793189**	**88151**	**14938**	**89408**	**7150**	**1185**	**5070**
		2020	**214**	**233**	**4997678915**	**379488355**	**5377167271**	**70694**	**19480**	**73329**	**4833**	**1276**	**3468**

Table C4-6. Results of bootstrap estimation of abundance in metric tons in each stratification scheme using the CMECS habitat data from NMFS encompassing the primary range of quillback rockfish. Bold values denote summations for a given stratification scheme.

Stratifi-cation Scheme	Area	Super Year	Total Fish	Mean Weight Outside MPAs	Mean Weight Inside MPAs	Mean Bootstrap Biomass Outside MPAs (kg)	Mean Bootstrap Biomass Inside MPAs (kg)	kg per metric ton	Mean Bootstrap Biomass Outside MPAs (mt)	Mean Bootstrap Biomass Inside MPAs (mt)	Total Bootstrap Biomass
1	**Oregon Border to Point Sur**	**2015**	**969143**	**1.17**	**0.84**	**971495**	**117486**	**1000**	**971**	**117**	**1089**
		2020	**1118179**	**0.80**	**0.68**	**666131**	**195686**	**1000**	**666**	**196**	**862**
2	North of 40° 10' N. Lat	2015	386661	1.33	1.17	419082	84296	1000	419	84	503
		2020	573473	1.13	1.01	496027	135612	1000	496	136	632
	40° 10' to Point Arena	2015	74069	0.89	0.65	56139	7143	1000	56	7	63
		2020	144779	0.61	0.56	66791	19585	1000	67	20	86
	Farallon Islands	2015	326102	0.675	0.7066	200158	20868	1000	200	21	221
		2020	323100	0.68	0.71	187539	31901	1000	188	32	219
	Point Arena to Pigeon Point	2015	123892	0.20	0.46	21767	5566	1000	22	6	27
		2020	224690	0.33	0.17	51508	11916	1000	52	12	63
	Pigeon Point to Point Sur	2015	4283	0.77	0.36	0	1564	1000	0	2	2
		2020	10512	0.77	0.80	6217	1955	1000	6	2	8
	Total	**2015**	**588905**	**0.84**	**0.70**	**697147**	**119437**	**1000**	**697**	**119**	**817**
		2020	**1276554**	**0.72**	**0.65**	**808083**	**200969**	**1000**	**808**	**201**	**1009**
3	North of Point Arena	2015	457060	1.21	0.93	458023	73085	1000	458	73	531
		2020	721037	0.99	0.82	543073	142236	1000	543	142	685
	Farallon Islands	2015	0	0.68	0.71	199091	20829	1000	199	21	220
		2020	324464	0.68	0.71	188631	31826	1000	189	32	220
	Point Arena to Point Sur	2015	96926	0.20	0.44	15708	7136	1000	16	7	23
		2020	182430	0.43	0.22	51904	13276	1000	52	13	65
	Total	**2015**	**553986**	**0.69**	**0.69**	**672822**	**101050**	**1000**	**673**	**101**	**774**
		2020	**1227931**	**0.70**	**0.58**	**783607**	**187338**	**1000**	**784**	**187**	**971**

Table C4-6. (Cont.). Results of bootstrap estimation for abundance in metric tons in each stratification scheme using the CMECS habitat from NMFS encompassing the primary range of quillback rockfish. Bold values denote summations for a given stratification scheme.

Stratifi-cation Scheme	Area	Super Year	Total Fish	Mean Weight Outside MPAs	Mean Weight Inside MPAs	Mean Bootstrap Biomass Outside MPAs (kg)	Mean Bootstrap Biomass Inside MPAs (kg)	kg per metric ton	Mean Bootstrap Biomass Outside MPAs (mt)	Mean Bootstrap Biomass Inside MPAs (mt)	Total Bootstrap Biomass
4	North of 40° 10' N. Lat	2015	386691	1.33	1.17	418840	84135	1000	419	84	503
		2020	575223	1.13	1.01	497580	135634	1000	498	136	633
	40° 10' to Point Arena	2015	74520	0.89	0.65	56589	7151	1000	57	7	64
		2020	144243	0.61	0.56	66542	19594	1000	67	20	86
	Point Arena to Point Sur	2015	363071	0.20	0.44	62591	18256	1000	63	18	81
		2020	412274	0.60	0.53	181036	58402	1000	181	58	239
	Total	**2015**	**824282**	**0.81**	**0.75**	**538020**	**109543**	**1000**	**538**	**110**	**648**
		2020	**1131740**	**0.78**	**0.70**	**745157**	**213629**	**1000**	**745**	**214**	**959**
5	North of Point Arena	2015	456376	1.21	0.93	457075	72807	1000	457	73	530
		2020	722100	0.99	0.82	545144	141750	1000	545	142	687
	Point Arena to Point Sur	2015	283132	0.20	0.44	48680	15511	1000	49	16	64
		2020	325970	0.60	0.53	139600	49450	1000	140	49	189
	Total	**2015**	**739508**	**0.70**	**0.68**	**505756**	**88319**	**1000**	**506**	**88**	**594**
		2020	**1048070**	**0.79**	**0.68**	**684744**	**191200**	**1000**	**685**	**191**	**876**

Table C4-7. Estimates of biomass in metric tons with the associated lower and upper 95% confidence intervals from bootstrap estimation in each stratification scheme using the CMECS habitat data from NMFS encompassing the primary range of quillback rockfish. Bold values denote summations for a given stratification scheme.

Stratification Scheme	Area	Super Year	Mean Bootstrap Biomass Outside MPAs	Lower CI Biomass Outside MPAs	Upper CI Biomass Outside MPAs	Mean Bootstrap Biomass Inside MPAs	Lower CI Biomass Inside MPAs	Upper CI Biomass Inside MPAs	Mean Bootstrap Biomass Total	Lower CI Biomass Total	Upper CI Biomass Total
1	**Oregon Border to Point Sur**	**2015**	**971**	**715**	**1253**	**117**	**83**	**157**	**1089**	**826**	**1385**
		2020	**666**	**520**	**821**	**196**	**162**	**232**	**863**	**719**	**1021**
2	North of 40° 10' N. Lat	2015	419	283	581	84	56	118	503	364	668
		2020	496	381	624	136	110	163	631	514	759
	40° 10' to Point Arena	2015	56	30	87	7	4	11	64	38	95
		2020	67	38	103	20	14	27	86	56	123
	Farallon Islands	2015	199	104	308	21	8	35	220	122	329
		2020	188	111	278	32	24	41	220	144	308
	Point Arena to Pigeon Point	2015	22	6	50	6	2	11	27	11	57
		2020	52	23	92	12	6	20	63	35	103
	Pigeon Point to Point Sur	2015	0	0	0	2	0	5	2	0	5
		2020	6	1	14	2	0	5	8	2	16
	Total	**2015**	**697**	**528**	**887**	**119**	**88**	**156**	**816**	**641**	**1011**
		2020	**809**	**661**	**969**	**201**	**172**	**232**	**1009**	**859**	**1166**
3	North of Point Arena	2015	458	328	614	73	52	99	530	397	683
		2020	543	427	673	142	119	168	686	566	818
	Farallon Islands	2015	199	104	308	21	8	35	220	123	327
		2020	189	113	275	32	24	41	221	142	311
	Point Arena to Point Sur	2015	16	4	37	7	3	13	23	10	44
		2020	52	27	85	13	7	22	65	39	99
	Total	**2015**	**671**	**505**	**860**	**100**	**74**	**130**	**772**	**600**	**957**
		2020	**785**	**641**	**943**	**187**	**161**	**215**	**972**	**824**	**1135**

Table C4-7 (Cont.). Estimates of biomass in metric tons with the associated lower and upper 95% confidence intervals from bootstrap estimation in each stratification scheme using the CMECS habitat data from NMFS encompassing the primary range of quillback rockfish. Bold values denote summations for a given stratification scheme.

Stratifi-cation Scheme	Area	Super Year	Mean Bootstrap Biomass Outside MPAs	Lower CI Biomass Outside MPAs	Upper CI Biomass Outside MPAs	Mean Bootstrap Biomass Inside MPAs	Lower CI Biomass Inside MPAs	Upper CI Biomass Inside MPAs	Mean Bootstrap Biomass Total	Lower CI Biomass Total	Upper CI Biomass Total
4	North of 40° 10' N. Lat	2015	419	284	578	84	56	118	505	366	669
		2020	498	383	621	136	110	163	634	513	765
	40° 10' to Point Arena	2015	57	31	87	7	4	11	63	37	94
		2020	67	37	102	20	14	27	87	57	123
	Point Arena to Point Sur	2015	63	20	139	18	8	32	81	36	154
		2020	181	119	256	58	41	78	239	173	315
	Total	**2015**	**539**	**388**	**711**	**110**	**79**	**147**	**649**	**495**	**826**
		2020	**744**	**610**	**892**	**213**	**181**	**247**	**959**	**817**	**1111**
5	North of Point Arena	2015	457	330	610	73	51	99	530	397	682
		2020	545	428	675	142	118	168	686	569	815
	Point Arena to Point Sur	2015	49	16	107	16	7	28	64	29	123
		2020	140	91	197	49	34	66	189	138	249
	Total	**2015**	**506**	**368**	**666**	**89**	**64**	**117**	**594**	**453**	**752**
		2020	**683**	**558**	**823**	**192**	**163**	**222**	**876**	**746**	**1013**

Table C4-8. Sample sizes, variance, standard deviation and standard error from bootstrap estimation abundance in metric tons in each stratification scheme using the CMECS habitat data from NMFS encompassing the primary range of quillback rockfish. Bold values denote summations for a given stratification scheme.

Stratification Scheme	Area	Super Year	Weight Sample Size Inside MPAs	Weight Sample Size Outside MPAs	Biomass Var Outside MPAs	Biomass Var Inside MPAs	Biomass Var Total	Biomass SD Outside MPAs	Biomass SD Inside MPAs	Biomass SD Total	Biomass SE Outside MPAs	Biomass SE Inside MPAs	Biomass SE Total
1	**Oregon Border to Point Sur**	**2015**	**68**	**102**	**19057**	**361**	**19418**	**138**	**19**	**139**	**13.7**	**2.3**	**10.7**
		2020	**325**	**180**	**5768**	**318**	**6086**	**76**	**18**	**94**	**5.7**	**1.0**	**4.2**
2	North of 40° 10' N. Lat	2015	30	71	5851	263	6114	76	16	93	9.1	3.0	9.2
		2020	100	68	3812	186	3997	62	14	75	7.5	1.4	5.8
	40° 10' to Point Arena	2015	26	27	209	4	213	14	2	16	2.8	0.4	2.3
		2020	68	25	276	11	287	17	3	20	3.3	0.4	2.1
	Farallon Islands	2015	101	60	2718.062932	48.01658334	2766	52	7	59	6.7	0.7	4.7
		2020	101	60	1804	18	1822	42	4	47	5.5	0.4	3.7
	Point Arena to Pigeon Point	2015	9	4	134	5	140	12	2	14	5.8	0.8	3.9
		2020	52	21	312	12	324	18	3	21	3.9	0.5	2.5
	Pigeon Point to Point Sur	2015	3	6	0	2	2	0	1	1	0.0	0.8	0.4
		2020	4	6	12	2	13	3	1	5	1.4	0.6	1.5
	Total	**2015**	**169**	**168**	**8912**	**322**	**9235**	**94**	**18**	**112**	**7.3**	**1.4**	**6.1**
		2020	**325**	**180**	**6215**	**228**	**6444**	**79**	**15**	**94**	**5.9**	**0.8**	**4.2**
3	North of Point Arena	2015	56	98	5172	147	5319	72	12	84	7.3	1.6	6.8
		2020	168	93	3999	160	4159	63	13	76	6.6	1.0	4.7
	Farallon Islands	2015	101	60	2718	48	2766	52	7	59	6.7	0.7	4.7
		2020	101	60	1778	18	1797	42	4	46	5.4	0.4	3.7
	Point Arena to Point Sur	2015	12	4	74	8	82	9	3	11	4.3	0.8	2.8
		2020	56	27	225	15	240	15	4	19	2.9	0.5	2.1
	Total	**2015**	**169**	**162**	**7965**	**202**	**8167**	**89**	**14**	**103**	**7.0**	**1.1**	**5.7**
		2020	**325**	**180**	**6003**	**194**	**6197**	**77**	**14**	**91**	**5.8**	**0.8**	**4.1**

Table C4-8 (Cont.). Sample sizes, variance, standard deviation and standard error from bootstrap estimation abundance in metric tons in each stratification scheme using the CMECS habitat data from NMFS encompassing the primary range of quillback rockfish. Bold values denote summations for a given stratification scheme.

Stratification Scheme	Area	Super Year	Weight Sample Size Inside MPAs	Weight Sample Size Outside MPAs	Biomass Var Outside MPAs	Biomass Var Inside MPAs	Biomass Var Total	Biomass SD Outside MPAs	Biomass SD Inside MPAs	Biomass SD Total	Biomass SE Outside MPAs	Biomass SE Inside MPAs	Biomass SE Total
4	North of 40° 10' N. Lat	2015	30	71	5603	256	5859	75	16	77	8.9	2.9	7.6
		2020	100	68	3735	187	3922	61	14	63	7.4	1.4	4.8
	40° 10' to Point Arena	2015	26	27	207	4	211	14	2	15	2.8	0.4	2.0
		2020	68	25	271	11	282	16	3	17	3.3	0.4	1.7
	Point Arena to Point Sur	2015	12	4	976	39	1015	31	6	32	15.6	1.8	8.0
		2020	157	87	1216	91	1308	35	10	36	3.7	0.8	2.3
	Total	**2015**	**68**	**102**	**6786**	**299**	**7085**	**82**	**17**	**84**	**8.2**	**2.1**	**6.5**
		2020	**325**	**180**	**5222**	**289**	**5511**	**72**	**17**	**74**	**5.4**	**0.9**	**3.3**
5	North of Point Arena	2015	56	98	5226	147	5373	72	12	73	7.3	1.6	5.9
		2020	168	93	3938	164	4102	63	13	64	6.5	1.0	4.0
	Point Arena to Point Sur	2015	12	4	587	29	616	24	5	25	12.1	1.6	6.2
		2020	157	87	731	67	797	27	8	28	2.9	0.7	1.8
	Total	**2015**	**68**	**102**	**5813**	**176**	**5989**	**76**	**13**	**77**	**7.5**	**1.6**	**5.9**
		2020	**325**	**180**	**4669**	**231**	**4900**	**68**	**15**	**70**	**5.1**	**0.8**	**3.1**

Table C4-9. Results of bootstrap estimation of abundance in numbers in each stratification scheme using the CSMP habitat data encompassing the primary range of quillback rockfish inside state waters within 3 miles of shore. Bold values denote averages for densities and summations for a given stratification scheme.

Stratifi-cation Scheme	Area	Super Year	Mean Density Outside MPAs	Mean Density Inside MPAs	Meters Squared per Square Mile	Square Miles Outside MPAs	Square Miles Inside MPAs	Mean Fish Outside MPAs	Mean Fish Inside MPAs	Total Fish
1	Oregon Border to Point Sur	**2015**	**0.0016737**	**0.0013955**	**2589988**	**101.6**	**31.3**	**440515**	**113237**	**553752**
		2020	**0.0016773**	**0.0028655**	**2589988**	**101.6**	**31.3**	**442063**	**232235**	**674298**
2	North of 40° 10' N. Lat	2015	0.0027009	0.0025481	2589988	29.1	8.1	203649	53707	257356
		2020	0.0037613	0.0047913	2589988	29.1	8.1	283700	100686	384386
	40° 10' to Point Arena	2015	0.0013565	0.0016094	2589988	19.6	2.7	69113	11103	80216
		2020	0.0023588	0.0051163	2589988	19.6	2.7	119797	35289	155085
	Farallon Islands	2015	0.0039039	0.0029589	2589988	7.6	4.0	76119	30542	106661
		2020	0.0036848	0.0045228	2589988	7.6	4.0	72234	46531	118765
	Point Arena to Pigeon Point	2015	0.0005606	0.0003007	2589988	30.6	11.7	44370	9050	53420
		2020	0.0007773	0.0017182	2589988	30.6	11.7	61595	51899	113493
	Pigeon Point to Point Sur	2015	0	0.0002895	2589988	14.7	4.9	0	3662	3662
		2020	0.0001407	0.0001681	2589988	14.7	4.9	5346	2121	7467
	Total	**2015**	**0.001488**	**0.001183**		**101.6**	**31.3**	**393251**	**108065**	**501316**
		2020	**0.001534**	**0.002136**		**101.6**	**31.3**	**542671**	**236525**	**779196**
3	North of Point Arena	2015	0.0023144	0.0022352	2589988	48.7	10.8	291607	62560	354167
		2020	0.0033636	0.0049137	2589988	48.7	10.8	424611	137344	561955
	Farallon Islands	2015	0.0039039	0.0029589	2589988	7.6	4.0	76119	30542	106661
		2020	0.0036848	0.0045228	2589988	7.6	4.0	72259	46639	118898
	Point Arena to Point Sur	2015	0.0003136	0.0002973	2589988	45.3	16.5	36932	12812	49744
		2020	0.0004716	0.0011133	2589988	45.3	16.5	55312	47745	103057
	Total	**2015**	**0.0021770**	**0.0018300**		**33.9**	**10.4**	**404658**	**105913**	**510571**
		2020	**0.0025070**	**0.0035170**		**33.9**	**10.4**	**552183**	**231727**	**783910**

Table C4-9 (Cont.). Results of bootstrap estimation for abundance in numbers in each stratification scheme using the CSMP habitat data encompassing the primary range of quillback rockfish inside state waters within 3 miles of shore. Bold values denote averages for densities and summations for a given stratification scheme.

Stratifi-cation Scheme	Area	Super Year	Mean Density Outside MPAs	Mean Density Inside MPAs	Meters Squared per Square Mile	Square Miles Outside MPAs	Square Miles Inside MPAs	Mean Fish Outside MPAs	Mean Fish Inside MPAs	Total Fish
4	North of 40° 10' N. Lat	2015	0.0027009	0.0025481	2589988	29.1	8.1	203714	53702	257415
		2020	0.0037613	0.0047913	2589988	29.1	8.1	283722	100939	384661
	40° 10' to Point Arena	2015	0.0013565	0.0016094	2589988	19.6	2.7	68966	11057	80022
		2020	0.0023588	0.0051163	2589988	19.6	2.7	119428	35233	154661
	Point Arena to Point Sur	2015	0.0009618	0.0006459	2589988	52.8	20.5	131148	34301	165449
		2020	0.0009087	0.0016892	2589988	52.8	20.5	124421	89916	214337
	Total	**2015**	**0.0016730**	**0.001601**		**101.6**	**31.3**	**403827**	**99059**	**502887**
		2020	**0.0023403**	**0.003866**		**101.6**	**31.3**	**527571**	**226087**	**753658**
5	North of Point Arena	2015	0.0023144	0.0022352	2589988	48.7	10.8	292972	62613	355585
		2020	0.0033636	0.0049137	2589988	48.7	10.8	424020	137377	561397
	Point Arena to Point Sur	2015	0.0009618	0.0006459	2589988	52.8	20.5	131406	34378	165784
		2020	0.0009087	0.0016892	2589988	52.8	20.5	124396	89746	214142
	Total	**2015**	**0.0016380**	**0.0014410**		**101.6**	**31.3**	**424378**	**96991**	**521369**
		2020	**0.0021360**	**0.0033010**		**101.6**	**31.3**	**548416**	**227123**	**775539**

Table C4-10. Estimates of numbers of fish with the associated lower and upper 95% confidence intervals, from bootstrap estimation in each stratification scheme using the CSMP habitat data encompassing the primary range of quillback rockfish in state waters within three miles of shore. Bold values denote summations for a given stratification scheme.

Stratifi-cation Scheme	Area	Super Year	Mean Fish Outside MPAs	Lower CI Fish Outside MPAs	Upper CI Fish Outside MPAs	Mean Fish Inside MPAs	Lower CI Fish Inside MPAs	Upper CI Fish Inside MPAs	Mean Fish Total	Lower CI Fish Total	Upper CI Fish Total
1	Oregon Border to Point Sur	**2015**	**440515**	**327252**	**564926**	**113237**	**85165**	**144569**	**552951**	**436980**	**681035**
		2020	**442063**	**355599**	**536304**	**232235**	**194849**	**271631**	**672314**	**578093**	**771092**
2	North of 40° 10' N. Lat	2015	203649	139696	277983	53707	37366	71587	257030	191809	333450
		2020	283700	222201	349082	100686	82770	119166	384665	320527	453690
	40° 10' to Point Arena	2015	69113	38439	102299	11103	6204	16397	79948	49233	112990
		2020	119797	75653	169074	35289	26406	44381	155711	109272	206742
	Farallon Islands	2015	76435	39915	117400	30575	12335	51587	107194	66132	151551
		2020	72234	43446	104676	46531	35284	58184	118779	87963	153142
	Point Arena to Pigeon Point	2015	44370	19456	76365	9050	3555	15531	53248	27397	85461
		2020	61595	36339	91137	51899	30166	78159	113358	78709	151351
	Pigeon Point to Point Sur	2015	0	0	0	3662	0	10425	3642	0	10425
		2020	5346	694	11260	2121	312	4802	7484	2370	13956
	Total	**2015**	**394426**	**310043**	**489322**	**108238**	**81501**	**137684**	**501063**	**409897**	**600919**
		2020	**541701**	**454305**	**632359**	**236631**	**204059**	**271896**	**779996**	**686825**	**876828**
3	North of Point Arena	2015	291607	208503	384898	62560	46192	80190	355201	273075	450237
		2020	424611	343490	511755	137344	116971	158100	561634	476175	651368
	Farallon Islands	2015	76435	39915	117400	30575	12335	51587	107065	66177	151935
		2020	72259	43272	105787	46639	35390	58401	118437	87320	152315
	Point Arena to Point Sur	2015	36932	15051	64352	12812	5264	22504	49275	25859	78726
		2020	55312	33983	79899	47745	27768	71201	102813	72299	136149
	Total	**2015**	**405854**	**310891**	**511466**	**105548**	**79148**	**134454**	**511541**	**413257**	**620387**
		2020	**552491**	**461443**	**648395**	**231854**	**200863**	**264675**	**782883**	**685940**	**884868**

Table C4-10. (Cont.). Estimates of numbers of fish with the associated lower and upper 95% confidence intervals from bootstrap estimation in each stratification scheme using the CSMP habitat data encompassing the primary range of quillback rockfish in state waters within three miles of shore. Bold values denote summations for a given stratification scheme.

Stratifi-cation Scheme	Area	Super Year	Mean Fish Outside MPAs	CI Lower Fish Outside MPAs	Upper CI Fish Outside MPAs	Mean Fish Inside MPAs	Lower CI Fish Inside MPAs	CI Upper Fish Inside MPAs	Mean Fish Total	Lower CI Fish Total	Upper CI Fish Total
4	North of 40° 10' N. Lat	**2015**	**203714**	**140890**	**279886**	**53702**	**36774**	**72162**	**257169**	**190810**	**335339**
		2020	**283722**	**222490**	**348635**	**100939**	**82589**	**119679**	**384406**	**320014**	**452618**
	40° 10' to Point Arena	2015	68966	38049	101802	11057	6304	16237	80167	48658	112792
		2020	119428	74425	169434	35233	26562	44441	155410	109322	207765
	Point Arena to Point Sur	2015	131148	68144	206264	34301	17196	54735	166238	100961	244458
		2020	124421	82958	171370	89916	64548	117381	213991	164285	269148
	Total	**2015**	**403961**	**307519**	**511982**	**99199**	**73712**	**127692**	**503574**	**403208**	**616551**
		2020	**527872**	**438575**	**619996**	**225718**	**192702**	**261281**	**753808**	**658788**	**854040**
5	North of Point Arena	2015	292972	212023	387519	62613	46213	80441	354369	271553	446768
		2020	424020	341511	510641	137377	117387	158355	562827	477281	651748
	Point Arena to Point Sur	2015	131406	67485	207466	34378	17097	55157	165361	99626	244902
		2020	124396	82814	172771	89746	64467	117582	214394	164061	269835
	Total	**2015**	**423435**	**318085**	**541748**	**96774**	**72083**	**123601**	**519730**	**409642**	**641320**
		2020	**549648**	**456739**	**649465**	**227113**	**193492**	**262314**	**777220**	**676918**	**881482**

Table C4-11. Sample sizes, variance, standard deviation and standard error from bootstrap estimation in numbers of fish in each stratification scheme using the CSMP habitat data encompassing the primary range of quillback rockfish the primary range of quillback rockfish in state waters within three miles of shore. Bold values denote summations for a given stratification scheme.

Stratification Scheme	Area	Super Year	Density Sample Size Outside MPAs	Density Sample Size Inside MPAs	Fish Var Outside MPAs	Fish Var Inside MPAs	Fish Var Total	Fish Count SD Outside MPAs	Fish Count SD Inside MPAs	Fish SD Total	Fish SE Outside MPAs	Fish SE Inside MPAs	Fish SE Total
1	Oregon Border to Point Sur	**2015**	**152**	**159**	**3669632778**	**231673190**	**3901305969**	**60577**	**15221**	**62460**	**4913**	**1207**	**3542**
		2020	**214**	**233**	**2139441969**	**382372019**	**2521813988**	**46254**	**19554**	**50218**	**3162**	**1281**	**2375**
2	North of 40° 10' N. Lat	2015	57	50	1259613909	77938201	1337552109	35491	8828	36573	4701	1249	3536
		2020	48	53	1058924863	86176906	1145101770	32541	9283	33839	4697	1275	3367
	40° 10' to Point Arena	2015	23	25	269352863	6634227	275987090	16412	2576	16613	3422	515	2398
		2020	19	32	573979794	20663491	594643285	23958	4546	24385	5496	804	3415
	Farallon Islands	2015	13	11	393569903.3	101709097.8	495279001	19839	10085	22255	5502	3041	4543
		2020	20	25	248092291	34575762	282668053	15751	5880	16813	3522	1176	2506
	Point Arena to Pigeon Point	2015	33	51	212862872	9513161	222376033	14590	3084	14912	2540	432	1627
		2020	66	75	193318264	151090692	344408956	13904	12292	18558	1711	1419	1563
	Pigeon Point to Point Sur	2015	26	22	0	9498808	9498808	0	3082	3082	0	657	445
		2020	61	48	7496194	1448712	8944906	2738	1204	2991	351	174	286
	Total	**2015**	**152**	**159**	**2135399547**	**205293495**	**2340693042**	**46210**	**14328**	**48381**	**3748**	**1136**	**2743**
		2020	**214**	**233**	**2081811406**	**293955563**	**2375766969**	**45627**	**17145**	**48742**	**3119**	**1123**	**2305**
3	North of Point Arena	2015	80	75	2020199085	76439289	2096638374	44947	8743	45789	5025	1010	3678
		2020	67	85	1851865407	108529974	1960395382	43033	10418	44276	5257	1130	3591
	Farallon Islands	2015	13	11	393569903.3	101709097.8	495279001	19839	10085	22255	5502	3041	4543
		2020	20	25	253226961	34653532	287880492	15913	5887	16967	3558	1177	2529
	Point Arena to Point Sur	2015	59	73	161234035	19649627	180883661	12698	4433	13449	1653	519	1171
		2020	127	123	135671581	121338242	257009823	11648	11015	16032	1034	993	1014
	Total	**2015**	**152**	**159**	**2575003023**	**197798014**	**2772801037**	**50744**	**14064**	**52657**	**4116**	**1115**	**2986**
		2020	**214**	**233**	**2240763949**	**264521748**	**2505285697**	**47337**	**16264**	**50053**	**3236**	**1065**	**2367**

Table C4-11(Cont.). Sample sizes, variance, standard deviation and standard error from bootstrap estimation in numbers of fish in each stratification scheme using the CSMP habitat data encompassing the primary range of quillback rockfish the primary range of quillback rockfish in state waters within three miles of shore. Bold values denote summations for a given stratification scheme.

Stratification Scheme	Area	Super Year	Density Sample Size Outside MPAs	Density Sample Size Inside MPAs	Fish Var Outside MPAs	Fish Var Inside MPAs	Fish Var Total	Fish Count SD Outside MPAs	Fish Count SD Inside MPAs	Fish SD Total	Fish SE Outside MPAs	Fish SE Inside MPAs	Fish SE Total
4	North of 40° 10' N. Lat	2015	57	50	1275909627	82278948	1358188574	35720	9071	36854	4731	1283	3563
		2020	48	53	1053443739	89882352	1143326091	32457	9481	33813	4685	1302	3365
	40° 10' to Point Arena	2015	23	25	268041148	6589745	274630893	16372	2567	16572	3414	513	2392
		2020	19	32	585423791	21265438	606689228	24196	4611	24631	5551	815	3449
	Point Arena to Point Sur	2015	72	84	1241753209	93939630	1335692840	35239	9692	36547	4153	1058	2926
		2020	147	148	512079072	182023180	694102253	22629	13492	26346	1866	1109	1534
	Total	**2015**	**152**	**159**	**2785703984**	**182808323**	**2968512307**	**52780**	**13521**	**54484**	**4281**	**1072**	**3090**
		2020	**214**	**233**	**2150946602**	**293170970**	**2444117572**	**46378**	**17122**	**49438**	**3170**	**1122**	**2338**
5	North of Point Arena	2015	80	75	1970262775	76573239	2046836014	44388	8751	45242	4963	1010	3634
		2020	67	85	1851088169	109636167	1960724337	43024	10471	44280	5256	1136	3592
	Point Arena to Point Sur	2015	72	84	1285885880	96213286	1382099166	35859	9809	37177	4226	1070	2977
		2020	147	148	515781088	186338117	702119205	22711	13651	26498	1873	1122	1543
	Total	**2015**	**304**	**318**	**3256148655**	**172786526**	**3428935180**	**57063**	**13145**	**58557**	**3273**	**737**	**2348**
		2020	**428**	**466**	**2366869257**	**295974284**	**2662843541**	**48650**	**17204**	**51603**	**2352**	**797**	**1726**

Table C4-12. Results of bootstrap estimation of biomass in metric tons in each stratification scheme using the CSMP habitat data encompassing the primary range of quillback rockfish inside state waters within 3 miles of shore. Bold values denote summations for a given stratification scheme.

Stratification Scheme	Area	Super Year	Total Fish	Mean Weight Outside MPAs	Mean Weight Inside MPAs	Mean Bootstrap Biomass Outside MPAs (kg)	Mean Bootstrap Biomass Inside MPAs (kg)	kg per metric ton	Mean Bootstrap Biomass Outside MPAs (mt)	Mean Bootstrap Biomass Inside MPAs (mt)	Total Bootstrap Biomass
1	Oregon Border to Point Sur	**2015**	**553752**	**1.17**	**0.84**	**515549**	**95350**	**1000**	**516**	**95**	**611**
		2020	**674298**	**0.80**	**0.68**	**354144**	**158583**	**1000**	**354**	**159**	**513**
2	North of 40° 10' N. Lat	2015	257356	1.33	1.17	271115	63098	1000	271	63	334
		2020	384386	1.13	1.01	320955	101107	1000	321	101	422
	40° 10' to Point Arena	2015	80216	0.89	0.65	61544	7176	1000	62	7	69
		2020	155085	0.61	0.56	73107	19654	1000	73	20	93
	Farallon Islands	2015	0	0.675	0.7066	51387	21586	1000	51	22	73
		2020	118765	0.68	0.71	48782	32874	1000	49	33	82
	Point Arena to Pigeon Point	2015	53420	0.20	0.46	8650	4172	1000	9	4	13
		2020	113493	0.33	0.17	20349	8952	1000	20	9	29
	Pigeon Point to Point Sur	2015	3662	0.77	0.36	0	1335	1000	NA	1	1
		2020	7467	0.77	0.80	4121	1688	1000	4	2	6
	Total	**2015**	**394655**	**3.86**	**3.35**	**392696**	**97366**	**1000**	**393**	**97**	**490**
		2020	**779196**	**3.52**	**3.24**	**467314**	**164276**	**1000**	**467**	**164**	**632**
3	North of Point Arena	2015	354167	1.21	0.93	352696	58163	1000	353	58	411
		2020	561955	0.99	0.82	420548	113073	1000	421	113	534
	Farallon Islands	2015	0	0.68	0.71	51387	21586	1000	51	22	73
		2020	118898	0.68	0.71	48779	32935	1000	49	33	82
	Point Arena to Point Sur	2015	49744	0.20	0.44	7216	5596	1000	7	6	13
		2020	103057	0.43	0.22	23691	10382	1000	24	10	34
	Total	**2015**	**403910**	**0.69**	**0.69**	**411299**	**85344**	**1000**	**411**	**85**	**497**
		2020	**783910**	**0.70**	**0.58**	**493018**	**156390**	**1000**	**493**	**156**	**649**

Table C4-12 (Cont.). Results of bootstrap estimation of biomass in metric tons in each stratification scheme using the CSMP habitat data encompassing the primary range of quillback rockfish inside state waters within 3 miles of shore. Bold values denote summations for a given stratification scheme.

Stratifi-cation Scheme	Area	Super Year	Total Fish	Mean Weight Outside MPAs	Mean Weight Inside MPAs	Mean Bootstrap Biomass Outside MPAs (kg)	Mean Bootstrap Biomass Inside MPAs (kg)	kg per metric ton	Mean Bootstrap Biomass Outside MPAs (mt)	Mean Bootstrap Biomass Inside MPAs (mt)	Total Bootstrap Biomass
4	North of 40° 10' N. Lat	2015	257415	1.33	1.17	271165	63018	1000	271	63	334
		2020	384661	1.13	1.01	321020	101512	1000	321	102	423
	40° 10' to Point Arena	2015	80022	0.89	0.65	61478	7157	1000	61	7	69
		2020	154661	0.61	0.56	72863	19644	1000	73	20	93
	Point Arena to Point Sur	2015	165449	0.20	0.44	25732	14992	1000	26	15	41
		2020	214337	0.60	0.53	74405	47845	1000	74	48	122
	Total	**2015**	502887	**2.42**		**358375**	**85167**		**358**	**85**	**444**
		2020	753658	**2.34**		**468288**	**169001**		**468**	**169**	**637**
5	North of Point Arena	2015	355585	1.21	0.93	354387	58107	1000	354	58	412
		2020	561397	0.99	0.82	420376	113106	1000	420	113	533
	Point Arena to Point Sur	2015	165784	0.20	0.44	25506	14973	1000	26	15	40
		2020	214142	0.60	0.53	74460	47711	1000	74	48	122
	Total	**2015**	521369	**0.70**	**0.68**	**379893**	**73080**		**380**	**73**	**453**
		2020	775539	**0.79**	**0.68**	**494836**	**160817**		**495**	**161**	**656**

Table C4-13. Estimates of biomass with the associated lower and upper 95% confidence intervals from bootstrap estimation in each stratification scheme using the CSMP habitat data encompassing the primary range of quillback rockfish in state waters within three miles of shore. Bold values denote summations for a given stratification scheme.

Stratification Scheme	Area	Super Year	Mean Bootstrap Biomass Outside MPAs	Lower CI Biomass Outside MPAs	Upper CI Biomass Outside MPAs	Mean Bootstrap Biomass Inside MPAs	Lower CI Biomass Inside MPAs	Upper CI Biomass Inside MPAs	Mean Bootstrap Biomass Total	Lower CI Biomass Total	Upper CI Biomass Total
1	Oregon Border to Point Sur	**2015**	**516**	**376**	**667**	**95**	**68**	**127**	**610**	**470**	**770**
		2020	**354**	**280**	**438**	**159**	**131**	**188**	**511**	**432**	**598**
2	North of 40° 10' N. Lat	2015	271	185	374	63	42	88	334	245	439
		2020	321	246	403	101	82	122	422	346	506
	40° 10' to Point Arena	2015	62	33	94	7	4	11	69	40	102
		2020	73	42	112	20	14	27	93	61	134
	Farallon Islands	2015	52	27	80	22	9	37	73	45	105
		2020	49	29	71	33	25	42	82	60	106
	Point Arena to Pigeon Point	2015	9	2	20	4	1	8	1	0	4
		2020	20	9	37	9	5	15	6	2	11
	Pigeon Point to Point Sur	2015	0	0	0	1	0	4	13	6	25
		2020	4	1	9	2	0	4	29	17	46
	Total	**2015**	**394**	**299**	**504**	**97**	**71**	**128**	**490**	**389**	**605**
		2020	**467**	**381**	**557**	**164**	**141**	**188**	**632**	**544**	**728**
3	North of Point Arena	2015	353	249	469	58	41	78	412	309	533
		2020	421	332	519	113	94	133	534	442	634
	Farallon Islands	2015	52	27	80	22	9	37	73	45	104
		2020	49	29	72	33	25	42	81	60	105
	Point Arena to Point Sur	2015	7	2	17	6	2	11	13	6	23
		2020	24	12	38	10	5	17	34	21	50
	Total	**2015**	**413**	**306**	**537**	**85**	**63**	**110**	**498**	**390**	**622**
		2020	**493**	**399**	**597**	**156**	**135**	**179**	**649**	**553**	**752**

Table C4-13 (Cont.). Estimates of biomass with the associated lower and upper 95% confidence intervals from bootstrap estimation in each stratification scheme using the CSMP habitat data encompassing the primary range of quillback rockfish in state waters within three miles of shore. Bold values denote summations for a given stratification scheme.

Stratification Scheme	Area	Super Year	Mean Bootstrap Biomass Outside MPAs	Lower CI Biomass Outside MPAs	Upper CI Biomass Outside MPAs	Mean Bootstrap Biomass Inside MPAs	Lower CI Biomass Inside MPAs	Upper CI Biomass Inside MPAs	Mean Bootstrap Biomass Total	Lower CI Biomass Total	Upper CI Biomass Total
4	North of 40° 10' N. Lat	2015	271	185	377	63	41	89	334	242	439
		2020	321	247	403	102	82	122	422	345	506
	40° 10' to Point Arena	2015	61	33	95	7	4	11	69	40	101
		2020	73	41	112	20	14	27	93	60	134
	Point Arena to Point Sur	2015	26	8	55	15	7	27	41	20	73
		2020	74	49	104	48	34	64	122	91	156
	Total	**2015**	358	262	468	85	61	113	443	344	556
		2020	468	381	563	169	143	195	637	546	734
5	North of Point Arena	2015	354	254	474	58	41	78	411	309	529
		2020	420	332	517	113	94	134	535	442	636
	Point Arena to Point Sur	2015	26	8	55	15	7	26	41	20	72
		2020	74	49	105	48	34	64	122	92	157
	Total	**2015**	379	274	501	73	54	96	452	346	572
		2020	496	402	601	161	136	187	657	559	763

Table C4-14. Sample sizes, variance, standard deviation and standard error from bootstrap estimation in metric tons in each stratification scheme using the CSMP habitat data encompassing the primary range of quillback rockfish the primary range of quillback rockfish in state waters within three miles of shore. Bold values denote summations for a given stratification scheme.

Stratification Scheme	Area	Super Year	Weight Sample Size Inside MPAs	Weight Sample Size Outside MPAs	Biomass Var Outside MPAs	Biomass Var Inside MPAs	Biomass Var Total	Biomass SD Outside MPAs	Biomass SD Inside MPAs	Biomass SD Total	Biomass SE Outside MPAs	Biomass SE Inside MPAs	Biomass SE Total
1	Oregon Border to Point Sur	**2015**	**68**	**102**	**5542**	**232**	**5773**	**74**	**15**	76	**7.4**	**1.8**	**5.8**
		2020	**325**	**180**	**1614**	**213**	**1827**	**40**	**15**	43	**3.0**	**0.8**	**1.9**
2	North of 40° 10' N. Lat	2015	30	71	2351	142	2493	48	12	50	5.8	2.2	5.0
		2020	100	68	1619	101	1720	40	10	41	4.9	1.0	3.2
	40° 10' to Point Arena	2015	26	27	248	4	252	16	2	16	3.0	0.4	2.2
		2020	68	25	322	11	333	18	3	18	3.6	0.4	1.9
	Farallon Islands	2015	101	60	186	52	238	14	NA	15	1.8	NA	1.2
		2020	101	60	119	19	139	11	4	12	1.4	0.4	0.9
	Point Arena to Pigeon Point	2015	9	4	21	3	24	5	2	5	2.3	0.6	1.4
		2020	52	21	50	7	57	7	3	8	1.5	0.4	0.9
	Pigeon Point to Point Sur	2015	3	6	0	1	1	0	1	1	0.0	0.7	0.4
		2020	4	6	5	1	6	2	1	3	0.9	0.5	0.8
	Total	**2015**	**169**	**168**	**2806**	**202**	**3008**	**82**	**17**	**55**	**6.4**	**1.3**	**3.0**
		2020	**325**	**180**	**2115**	**139**	**2254**	**78**	**21**	**47**	**5.8**	**1.2**	**2.1**
3	North of Point Arena	2015	56	98	3153	93	3246	56	10	57	5.7	1.3	4.6
		2020	168	93	2301	100	2401	48	10	49	5.0	0.8	3.0
	Farallon Islands	2015	101	60	186	52	238	14	7	15	1.8	0.7	1.2
		2020	101	60	121	20	141	11	4	12	1.4	0.4	0.9
	Point Arena to Point Sur	2015	12	4	16	5	20	4	2	5	2.0	0.6	1.1
		2020	56	27	45	9	54	7	3	7	1.3	0.4	0.8
	Total	**2015**	**169**	**162**	**3354**	**149**	**3504**	**74**	**19**	**59**	**5.8**	**1.5**	**3.3**
		2020	**325**	**180**	**2467**	**129**	**2596**	**66**	**17**	**51**	**4.9**	**1.0**	**2.3**

Table C4-14 (Cont.). Sample sizes, variance, standard deviation and standard error from bootstrap estimation in metric tons in each stratification scheme using the CSMP habitat data encompassing the primary range of quillback rockfish the primary range of quillback rockfish in state waters within three miles of shore. Bold values summations for a given stratification scheme.

Stratifi-cation Scheme	Area	Super Year	Weight Sample Size Inside MPAs	Weight Sample Size Outside MPAs	Biomass Var Outside MPAs	Biomass Var Inside MPAs	Biomass Var Total	Biomass SD Outside MPAs	Biomass SD Inside MPAs	Biomass SD Total	Biomass SE Outside MPAs	Biomass SE Inside MPAs	Bioma ss SE Total
4	North of 40° 10' N. Lat	2015	30	71	2398	151	2549	49	12	50	5.8	2.2	5.0
		2020	100	68	1586	105	1690	40	10	41	4.8	1.0	3.2
	40° 10' to Point Arena	2015	26	27	252	4	255	16	2	16	3.1	0.4	2.2
		2020	68	25	330	11	342	18	3	18	3.6	0.4	1.9
	Point Arena to Point Sur	2015	12	4	160	26	186	13	5	14	6.3	1.5	3.4
		2020	157	87	204	59	263	14	8	16	1.5	0.6	1.0
	Total	**2015**	**68**	**102**	**2810**	**181**	**2991**	**53**	**13**	**55**	**5.2**	**1.6**	**4.2**
		2020	**325**	**180**	**2120**	**175**	**2295**	**46**	**13**	**48**	**3.4**	**0.7**	**2.1**
5	North of Point Arena	2015	56	98	3099	91	3190	56	10	56	5.6	1.3	4.6
		2020	168	93	2283	101	2383	48	10	49	5.0	0.8	3.0
	Point Arena to Point Sur	2015	12	4	158	26	183	13	5	14	6.3	1.5	3.4
		2020	157	87	206	60	266	14	8	16	1.5	0.6	1.0
	Total	**2015**	**68**	**102**	**3256**	**117**	**3373**	**57**	**11**	**58**	**5.7**	**1.3**	**4.5**
		2020	**325**	**180**	**2489**	**161**	**2649**	**50**	**13**	**51**	**3.7**	**0.7**	**2.3**

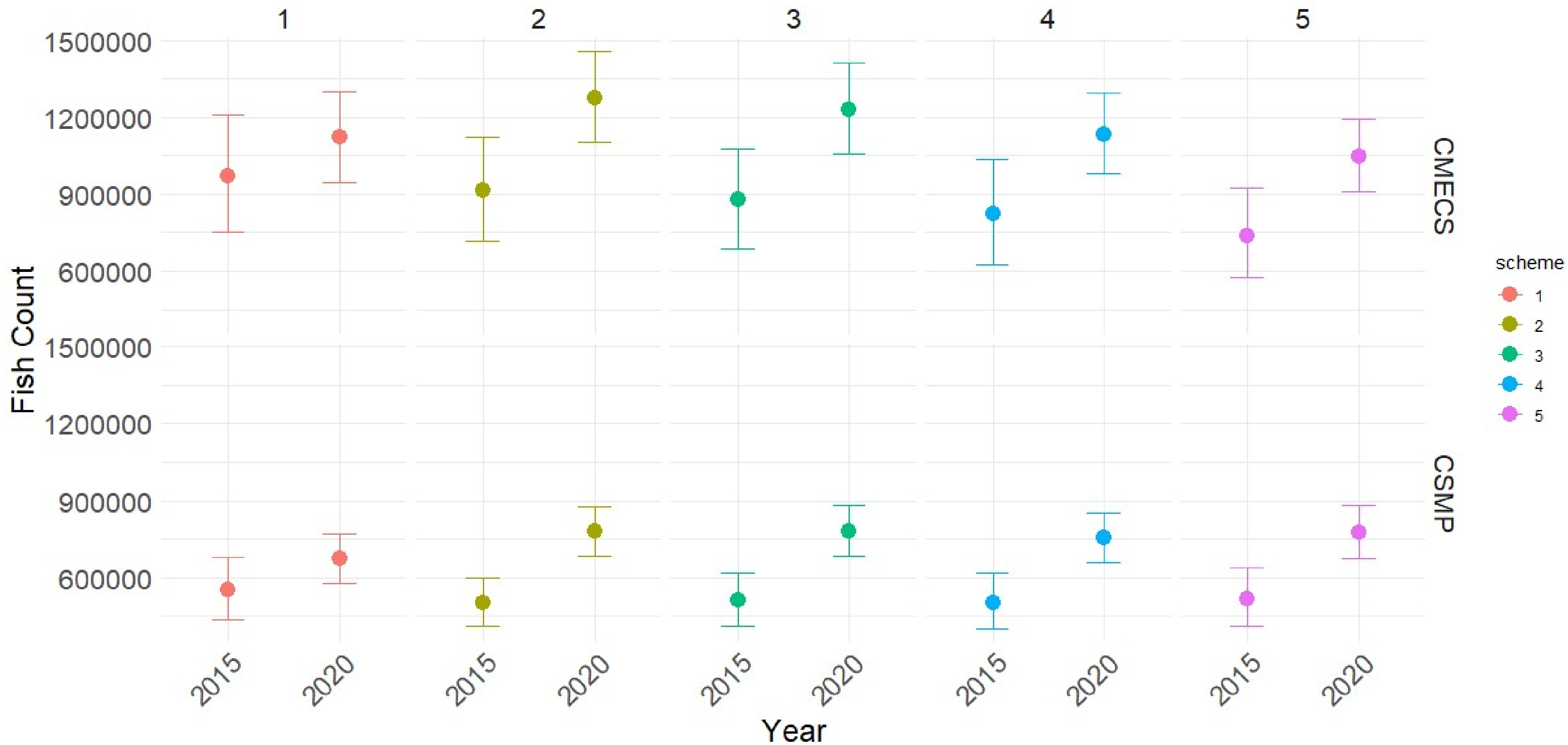

Figure C4-1. Number of quillback rockfish estimated using bootstrap methods in each super year from the Oregon Border to Point Sur from 20 to 90 m using each of the stratification schemes with the CMECS (state and federal waters) and CSMP (state waters) habitat expansions.

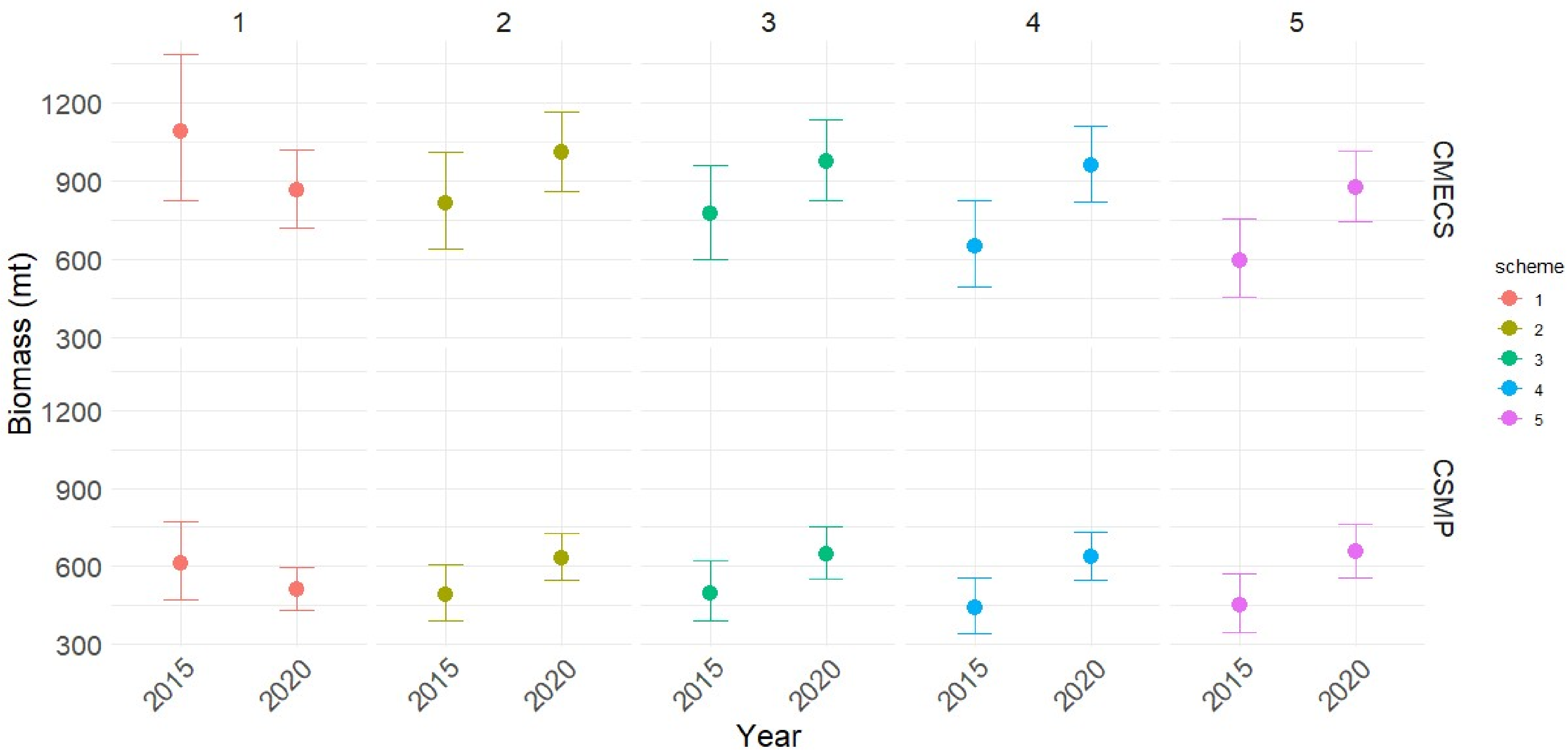

Figure C4-2. Metric Tons of quillback rockfish biomass estimated using bootstrap methods in each super year from the Oregon Border to Point Sur from 20 to 90 m using each of the stratification schemes with the CMECS (state and federal waters) and CSMP (state waters) habitat expansions.

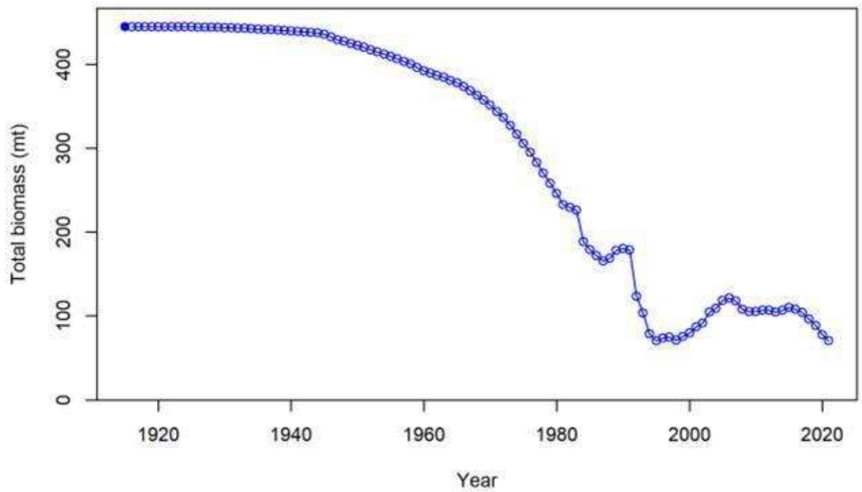

Figure 23: Estimated time series of total biomass.

Figure C4-3. Estimates of total biomass from the 2023 quillback rockfish stock assessment.

Table C4-15. Estimates of total biomass from the 2023 quillback rockfish stock assessment.

Year	Total Biomass (mt)	Spawning Output	Total Biomass 3+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	1-SPR	Exploitation Rate
1993	103.81	9.92	101.23	0.18	26.07	40.67	0.96	0.40
1994	78.69	7.12	76.20	0.13	42.59	23.90	0.93	0.31
1995	70.28	5.81	68.24	0.11	18.48	12.66	0.89	0.19
1996	73.59	5.85	70.74	0.11	70.50	15.56	0.91	0.22
1997	75.08	5.88	73.19	0.11	13.02	22.98	0.94	0.31
1998	71.18	5.29	66.93	0.10	13.66	14.98	0.91	0.22
1999	75.16	5.56	74.02	0.10	92.17	13.81	0.90	0.19
2000	80.00	6.02	78.15	0.11	10.68	13.31	0.88	0.17
2001	86.73	6.82	81.26	0.12	9.57	16.10	0.89	0.20
2002	91.47	7.39	90.73	0.13	8.86	5.96	0.70	0.07
2003	104.93	8.76	104.25	0.16	10.45	13.92	0.84	0.13
2004	108.84	9.75	108.18	0.18	14.50	5.64	0.60	0.05
2005	118.38	11.76	117.57	0.21	17.11	10.59	0.73	0.09
2006	121.11	12.85	120.05	0.23	10.06	14.55	0.79	0.12
2007	117.91	12.90	116.79	0.23	7.71	19.32	0.85	0.17
2008	108.25	11.93	107.56	0.22	7.25	11.05	0.75	0.10
2009	105.22	11.66	104.67	0.21	8.16	6.88	0.64	0.07
2010	104.97	11.80	104.42	0.21	12.50	3.56	0.46	0.03
2011	107.13	12.27	106.44	0.22	28.47	5.45	0.57	0.05
2012	106.95	12.39	105.87	0.22	15.17	7.99	0.68	0.08
2013	104.56	12.04	102.72	0.22	9.06	3.57	0.46	0.03
2014	106.98	12.13	105.99	0.22	6.86	2.97	0.41	0.03
2015	110.22	12.30	109.61	0.22	6.87	8.55	0.70	0.08
2016	107.80	12.00	107.30	0.22	9.00	9.46	0.73	0.09
2017	103.96	11.74	103.43	0.21	11.69	12.52	0.79	0.12
2018	96.59	11.06	95.90	0.20	17.10	12.84	0.81	0.13
2019	88.55	10.19	87.64	0.18	16.70	16.02	0.87	0.18
2020	77.52	8.78	76.30	0.16	15.78	12.34	0.85	0.16
2021	70.60	7.75	69.42	0.14	14.99	13.50	0.88	0.19
2022	63.18	6.61	62.06	0.12	13.97	13.50	0.90	0.22
2023	56.39	5.60	55.34	0.10	12.89	0.03	0.01	0.00
2024	63.27	6.29	62.28	0.11	13.65	0.34	0.12	0.01
2025	70.34	7.10	69.40	0.13	14.44	0.68	0.19	0.01
2026	77.37	7.98	76.38	0.14	15.18	1.03	0.25	0.01
2027	84.21	8.86	83.17	0.16	15.84	1.37	0.29	0.02
2028	90.82	9.70	89.72	0.18	16.40	1.69	0.31	0.02
2029	97.20	10.48	96.06	0.19	16.87	1.97	0.33	0.02
2030	103.37	11.23	102.19	0.20	17.28	2.23	0.35	0.02
2031	109.38	11.95	108.17	0.22	17.64	2.48	0.36	0.02

D. Data Gaps, Funding and Future Research Needs

Data used in these analyses were collected from ROV surveys designed to inform the performance of California's marine protected area (MPA) network including the evaluation of the response of density and biomass of fish species to the implementation of protection from take. The sampling design employed is described above and utilizes fixed index sites inside and outside of protected areas within California's territorial waters, therefore the design does not fully encompass all available rocky reef and depth strata into the sampling frame.

The typical range of depths surveyed have been limited to depths that are present within rocky reefs in MPAs and reference areas that were selected to match these depths and habitat. In 2014-2016 CDFW provided funding that augmented MPA surveys of more non-protected reefs specifically to better inform fisheries management including single species abundance indices and estimates. These expanded surveys also covered deeper depths in reefs where greater depth was available including some areas outside of California's territorial waters. In 2019-2021 MPA monitoring funding as well as some CDFW funding and matching funds from MARE allowed for replication of statewide coverage of most MPA and reference sites completed in 2014-2016 minus the extra rocky reef sites added previously (Table B1). A lapse of state funding for MPA monitoring in mid-depths by ROV occurred in 2022 and 2023. In 2024 the funding available for mid-depth (30-100m) MPA surveys was divided between ROV and BRUV surveys which significantly reduced the coverage of ROV surveys to a handful of sites in northern California. Also in 2024, the California Ocean Protection Council (OPC) and CDFW initiated a formal review of mid-depth monitoring methods, sampling design and analytical approaches. This review resulted in a report of findings and recommendations by an international panel of experts and a competitive request for proposals (RFP) that is currently open with proposals expected to be selected in February 2025. The RFP allows for a maximum of $1.2 million for surveys in 2024 and 2025 which is likely to be not sufficient to replicate the 2019-2021 statewide survey.

A component of the MPA RFP is for the examination and refinement of sampling designs moving towards sampling design stratified minimally by depth and habitat and exploring more spatially balanced distribution to allow for examination of other driving factors on MPA performance metrics. These efforts will be congruent with needs to more fully capture variation in single species abundance in rocky habitats to inform stock assessments and fisheries management. Data gaps will still exist as MPA monitoring funding will likely not be sufficient to achieve desired sampling effort for robust estimates for fishery needs. However, with modest augmented funding from fishery management sources a complimentary and robust MPA/Fishery survey approach could be achieved which is synergistic for more complete coverage for both management needs.

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