Development and Use of California Remotely Operated Vehicle (ROV) Data in Groundfish Stock Assessments

The California Department of Fish and Wildlife (CDFW) provides the following report in response to comments from the Scientific and Statistical Committee (SSC) following its review of Agenda Item H.4.a CDFW Report 1, March 2025. CDFW appreciates the SSC's endorsement of use of ROV surveys in stock assessments (Agenda Item H.4.a Supplemental SSC Report 1 March 2025) and understands decisions regarding use and application will be made on a species-by-species basis and are ultimately up to the stock assessment teams (STAT).

This report includes the following appendices:

- Appendix A addresses requests from the December 2024 Groundfish Subcommittee of the SSC (GFSC) review and informal comments from the SSC in March 2025.
- Appendix B provides a summary of reports related to California ROV data and products to date for easy access.
- Appendix C discusses recommended next steps for future ROV workshops and summarizes ongoing work to continue ROV sampling and improve ROV survey design off California.
- Appendix D consists of sections CDFW provided to the quillback rockfish STAT regarding application of indices of abundance and design-based estimates of abundance.

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CDFW recommends additional future workshops on model-based methods to estimate biomass from ROV data, which would further advance this important work building upon what has already been done. The indices of abundance and design-based estimates of abundance have been reviewed for use in management between the 2020 workshop, December 2024 GFSC review and March 2025 SSC meeting review. Development and review of additional approaches to apply and use ROV data in west coast stock assessments should continue to be a priority, acknowledging the value of this multi-year, non-lethal and fishery-independent data source.

In recognition of more than 20 years of large-scale Rockfish Conservation Area closures combined with California's Marine Protected Area (MPA) Network, CDFW has been working on incorporating ROV data collected inside and outside closed areas into stock assessments since 2018. The integration of ROV data to develop indices of relative abundance using Generalized Linear Mixed Models (GLMM) and estimates of absolute abundance using design-based and model-based methods in combination with seafloor mapping are a testament to the advancement of fishery population assessment modeling work that directly considers large-closed areas in a realistic and objective way.

CDFW appreciates the Pacific Fishery Management Council's support with hosting public review meetings and workshops and looks forward to continued collaboration with STAT science partners. The immediate goal of integrating this work into the full benchmark assessment for quillback rockfish remains a priority, while recognizing the application of these methods may be just as important for other groundfish species assessed in future cycles. Further analyses comparing the scale from design-based and model-based assessments to stock assessments for recently assessed species to which the biomass estimates from ROVs can be compared might be an additional focal point of future workshops.

Appendix A: Analyses Conducted in Response to Requests from the SSC at the March 2024 Council Meeting.

The following requests regarding indices of abundance and design-based estimates of abundance were made informally by the SSC at the March Council meeting after reviewing the ROV materials provided by CDFW (Agenda Item H.4.a, Supplemental CDFW Report 1, March 2025).

Request 1: A high priority issue is to justify the use of super years by examining differences among the constituent years before pooling those data. This is challenging because the same places were not sampled in the same years but could focus on places where there was spatiotemporal overlap in the survey.

Response 1: To provide some context, though a super year may contain sampling conducted over three calendar years, the duration was shorter with sampling taking place between 09/12/2014 - 10/13/2016 for a total of 25 months during the 2015 super year and between 08/03/2019 – 11/17/2021 in the 2020 super year for a total of 27 months, both of which are closer to two years rather than three. Thus, there is less time for deviation of conditions etc. between sampled years than may be presumed had the duration of sampling extended to a full 36 months as one might perceive on hearing the sampling took place across three calendar years.

The following analyses were undertaken to evaluate the potential for significant differences among years in each super year. The data set was split into two data sets based on super year and the cross product of super year removed from the model, while retaining all other variables from the proposed model. Then the subsequent separate analysis of all available data for each super year subject to the proposed GLMM and in a separate analysis, only sites with repeated sampling of transects in two years were retained in the data set to allow analysis of repeated observations within a super year. The survey years were treated as a continuous variable and as a categorical variable. The survey year was not significant for either data set or treatment of survey year as continuous evaluating trend or categorical variables testing between all years to identify significant differences between them with either the full data set or the reduced data set with only sites sampled twice in each super year (Table A-1). From this we can conclude that there is not significant difference by year in each super year and that combining them in the index within a year will be acceptable in further evaluation between super years.

Table A-1. P-value from analysis of full and reduced data sets with survey_year treated as a continuous and categorical variable.

Model	**2015**	**2020**
Full Data, Continuous	0.7781	0.80320
Full Data, Categorical	0.5379 (2015), 0.8574 (2016)	0.7554 (2015), 0.8574 (2020)
Reduced Data, Continuous	0.8404	0.86170
Reduced Data, Categorical	0.8404*	0.7534 (2015), 0.9551 (2020)

Request 2: Look at whether the DHARMa residuals were conditional or unconditional on the random effects and understand how to do this properly with random effects.

Response 2: In lme4 (R package), the default residuals returned by lmer are conditional, meaning they are calculated based on the fitted fixed and random effects. They represent the difference between the observed and predicted values, taking into account both fixed and random effects. Given the need to account for fixed and random effects, the conditional residuals are the preferred values and are used in the default settings used in this analysis. The unconditional or marginal residuals were not run as they do not account for the random effects invoked in the preferred model.

Request 3: Plot the predictions and residuals spatially and figure out where the high predictions are and where the residuals are positive or negative.

Response 3: The preferred model from the March Council meeting review with residual patterns found to be related to latitude is provided in Figure A-1 below. While the fit in the QQ plot was close to the one to one line, no outliers, the KS Test was negative indicating negative binomial to be a reasoned error distribution and dispersion was very low though significant as seen in Figure A-2, residual patterns persisted overall (Figure A-3) and with latitude (Figure A-4) though no significant residual patterns were observed with other variables. Plotting these residuals values on a chart with a jitter to make patterns more apparent in Figure A-5 did not indicate a clear pattern in the geographic distribution of residuals. The plot of residuals with latitude in Figure A-6 provides additional perspective on the geographic distribution of residuals, with comparable residual patterns distributed equally above and below the zero line north of Point Arena, with more variability to the south of Point Arena, where the species reaches the southern extent of its primary range by Point Sur approximately 100 miles to the south. There does appear to be some clustering of results of low residual values to the south that may be the result of increasing zero values and lower estimates with a few less frequent high observations as the abundance of the species decreases at the edge of the range.

When latitude squared was added to the model (Figure A-7), the residual pattern was eliminated for the 25th percentile and reduced for the 50th and 75th percentiles (Figure A-8) though still indicated as significant. While some residual pattern may still exist, it appears reduced by the addition of latitude squared and are relatively minor. Residual patterns were still observed by the spline with latitude squared (Figure A-9) and latitude (Figure A-10), though splines are known to overfit and patterns in the data are not readily apparent to the eye except for the upper right, corresponding to more southerly latitudes. Only minor changes were observed in the residuals plotted with latitude when latitude squared was added in Figure A-11. No significant correlations were observed in analysis of residuals with other variables. The addition of latitude squared resulted in a decrease in the AIC value from 2214.1 to 2198.9, which is an appreciable reduction (ΔAIC >2) thus latitude squared was retained in the final model. Additional analyses considered included removing the area south of the Farallon Islands as being marginal habitat at the edge of the range, but an index representing the full distribution north of Point Conception was desired. A two-area model is a potential direction for future research, as is the use of a GAM to more closely fit the residual patterns. That said, no clear strong residual patterns are observed with the addition of latitude squared and the fit of the overall model is improved.

```
Formula: 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
  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                      1.742170.25290   6.889 5.63e-12 ***
avg_depth                    0.628840.10348   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 A-1. Results of a GLMM for preferred model with latitude.

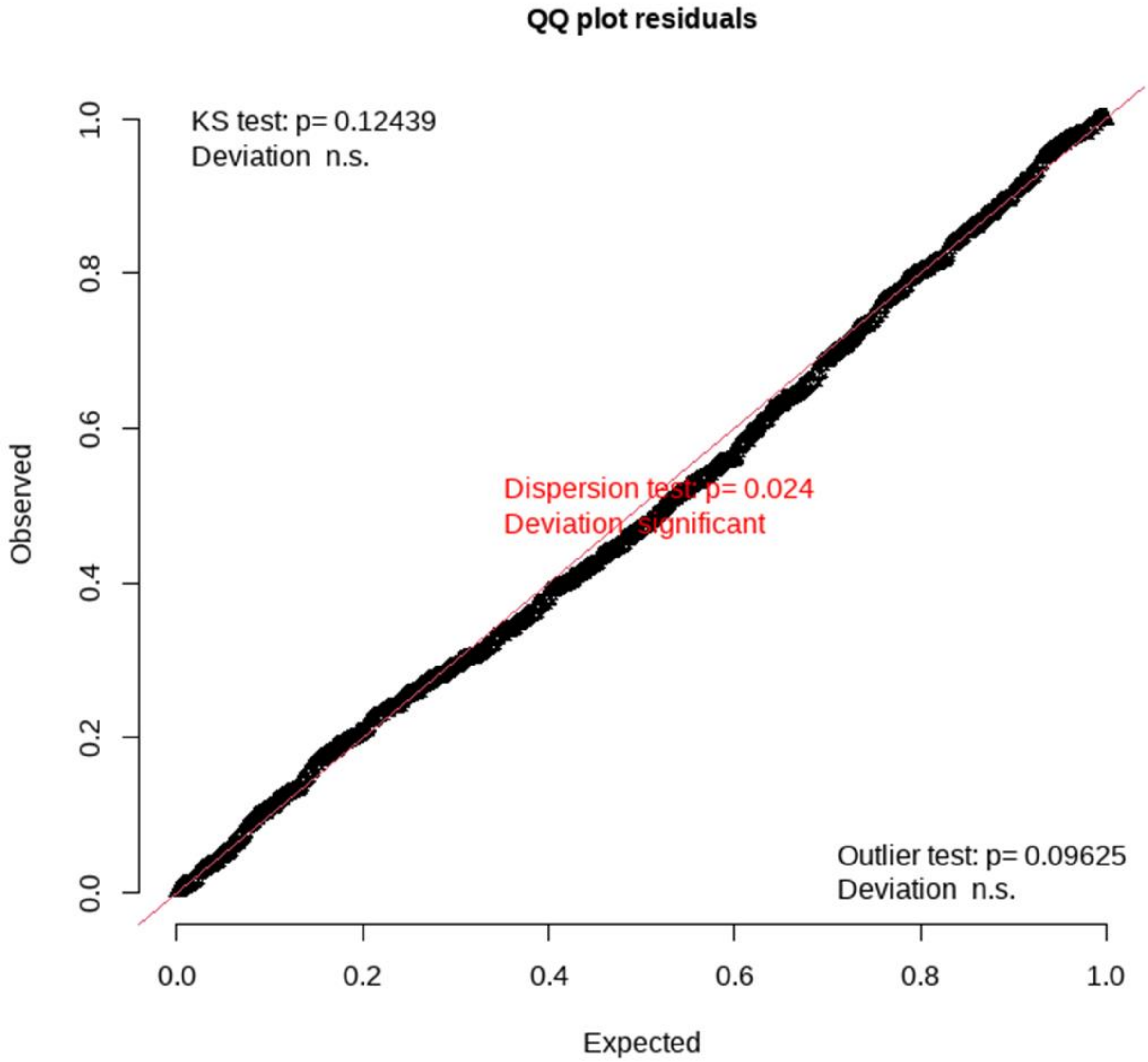

Figure A-2. QQ Plot from Dharma using the negative binomial distribution employed in the model, showing results of KS test, dispersion test and outlier test.

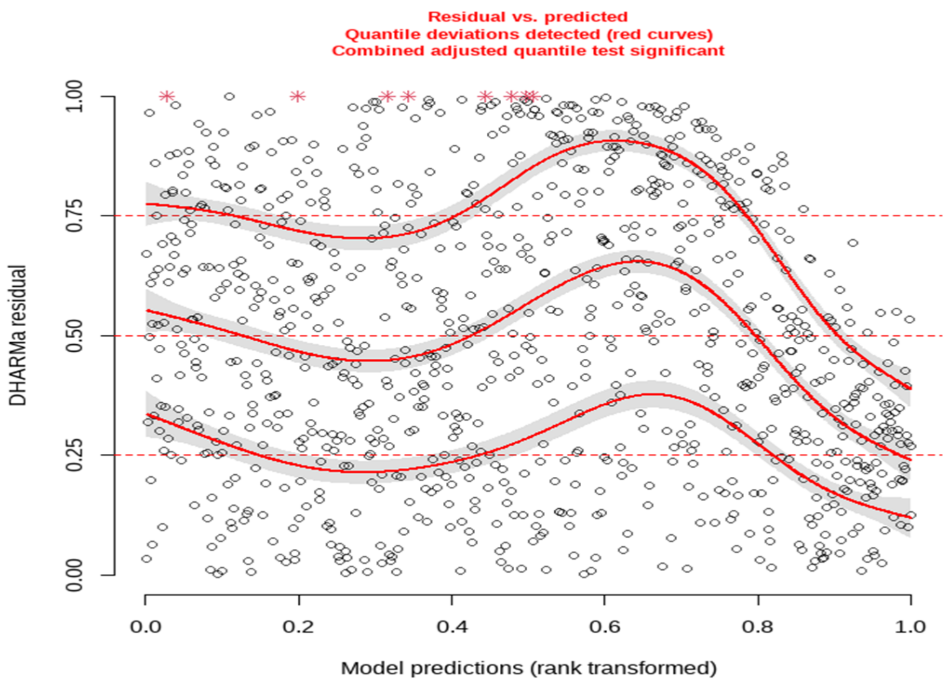

Figure A-3. Residuals with model predictions for the model without depth squared.

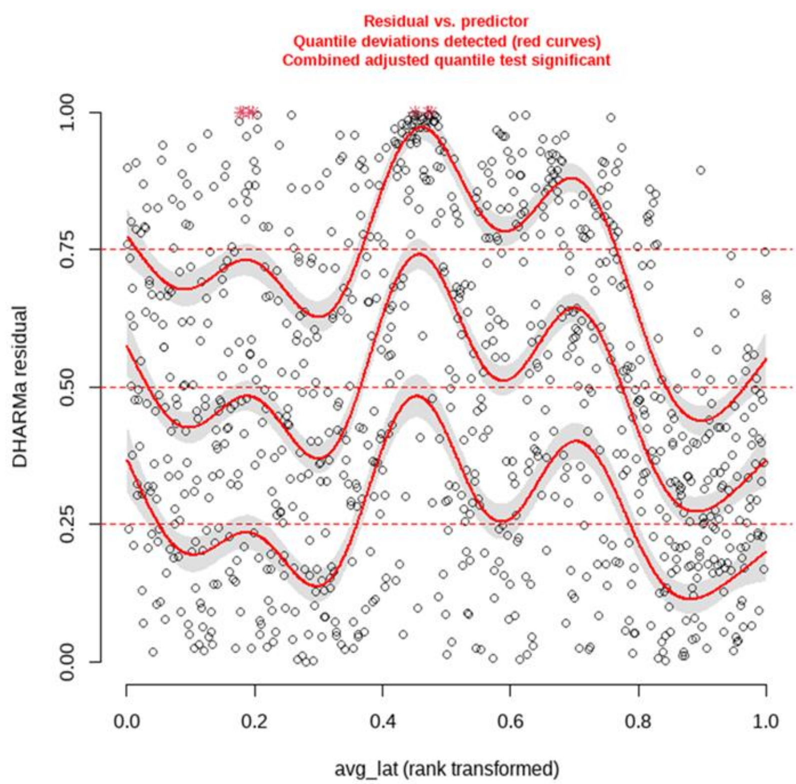

Figure A-4. Residuals with average latitude predictions for the model without depth squared.

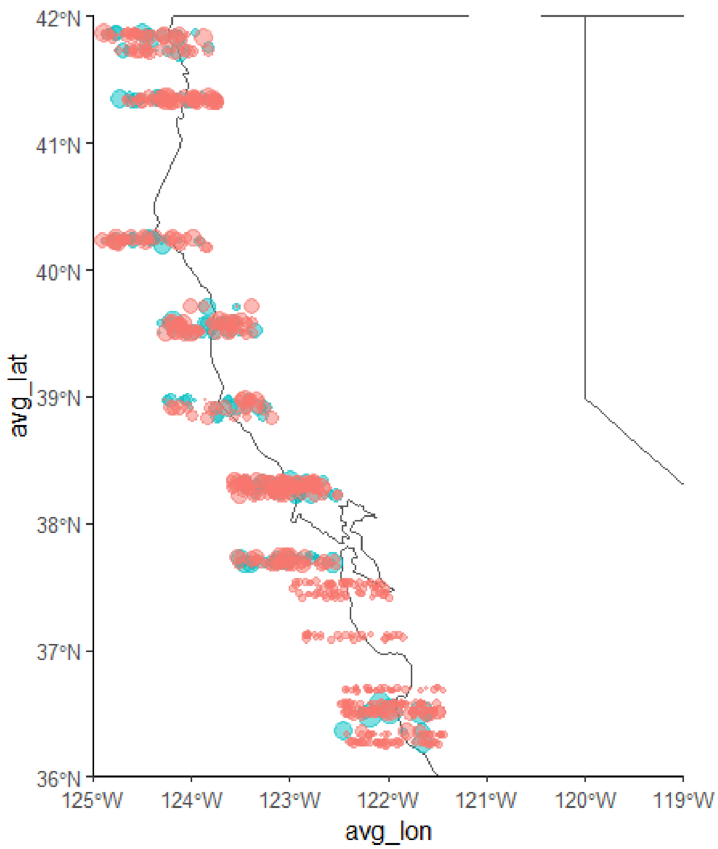

Figure A-5. Residuals plotted latitudinally with a jitter on the x axis to make them more easily visible.

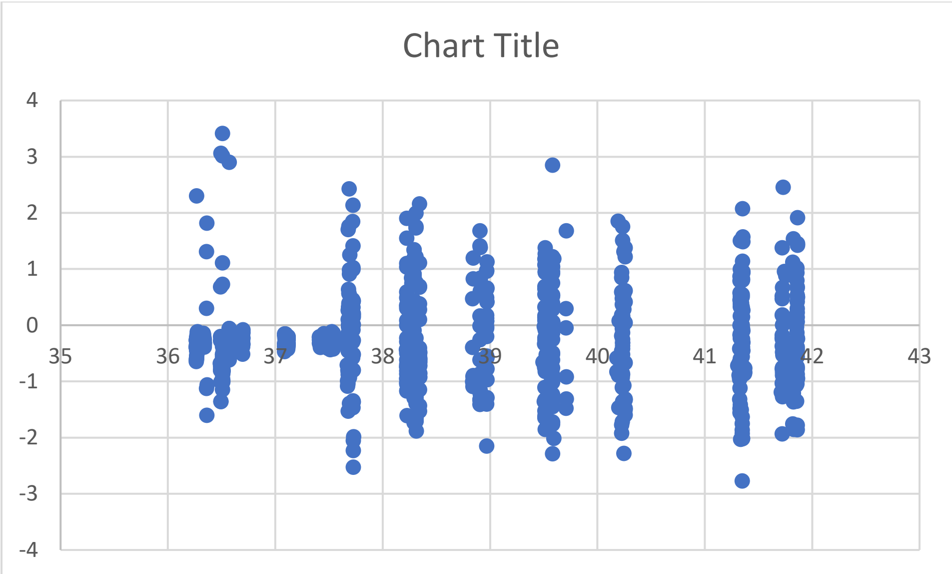

Figure A-6. Residuals with latitude without latitude squared.

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

```
  Data: sc.dat
 Offset: log(usable_area_fish)
    AIC      BIC   logLik deviance df.resid
  2198.9   2250.9  -1088.5   2176.9      820
Scaled residuals:
   Min      1Q  Median      3Q     Max
-1.3883 -0.5514 -0.2154  0.1049 11.2391

Random effects:
 Groups Name        Variance Std.Dev.
 site   (Intercept) 1.199    1.095
Number of obs: 831, groups:  site, 50

Fixed effects:
                         Estimate Std. Error z value Pr(>|z|)
(Intercept)              -6.62132    0.35878 -18.455  < 2e-16 ***
SuperYear2020             0.24369    0.13995   1.741  0.08164 .
Protection1              -0.33152    0.39346  -0.843  0.39946
PropHardMixed             0.62073    0.07106   8.735  < 2e-16 ***
avg_lat                   1.47585    0.23162   6.372 1.87e-10 ***
avg_latSquared           -0.54676    0.21556  -2.536  0.01120 *
avg_depth                 0.60985    0.10310   5.915 3.32e-09 ***
DepthSquared             -0.59888    0.07756  -7.721 1.15e-14 ***
SuperYear2020:Protection1  0.58084    0.18685   3.109  0.00188 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) SpY2020 Prtct1 PrpHrM avg_lt avg_lS avg_dp DpthSq
SuperYr2020 -0.233
Protection1 -0.593  0.204
PropHardMxd -0.036 -0.090  -0.006
avg_lat      0.0
25  0.065   0.185  0.012
avg_latSqrd -0.566  0.026   0.063 -0.029 -0.497
avg_depth    0.016 -0.012  -0.017  0.490  0.020 -0.063
DepthSquard -0.195  0.031   0.052  0.124  0.082 -0.038  0.152
SprY2020:P1  0.172 -0.746  -0.298  0.057 -0.039 -0.023  0.020 -0.003
```
Figure A-7. Results of a GLMM for preferred model with latitude and latitude squared.

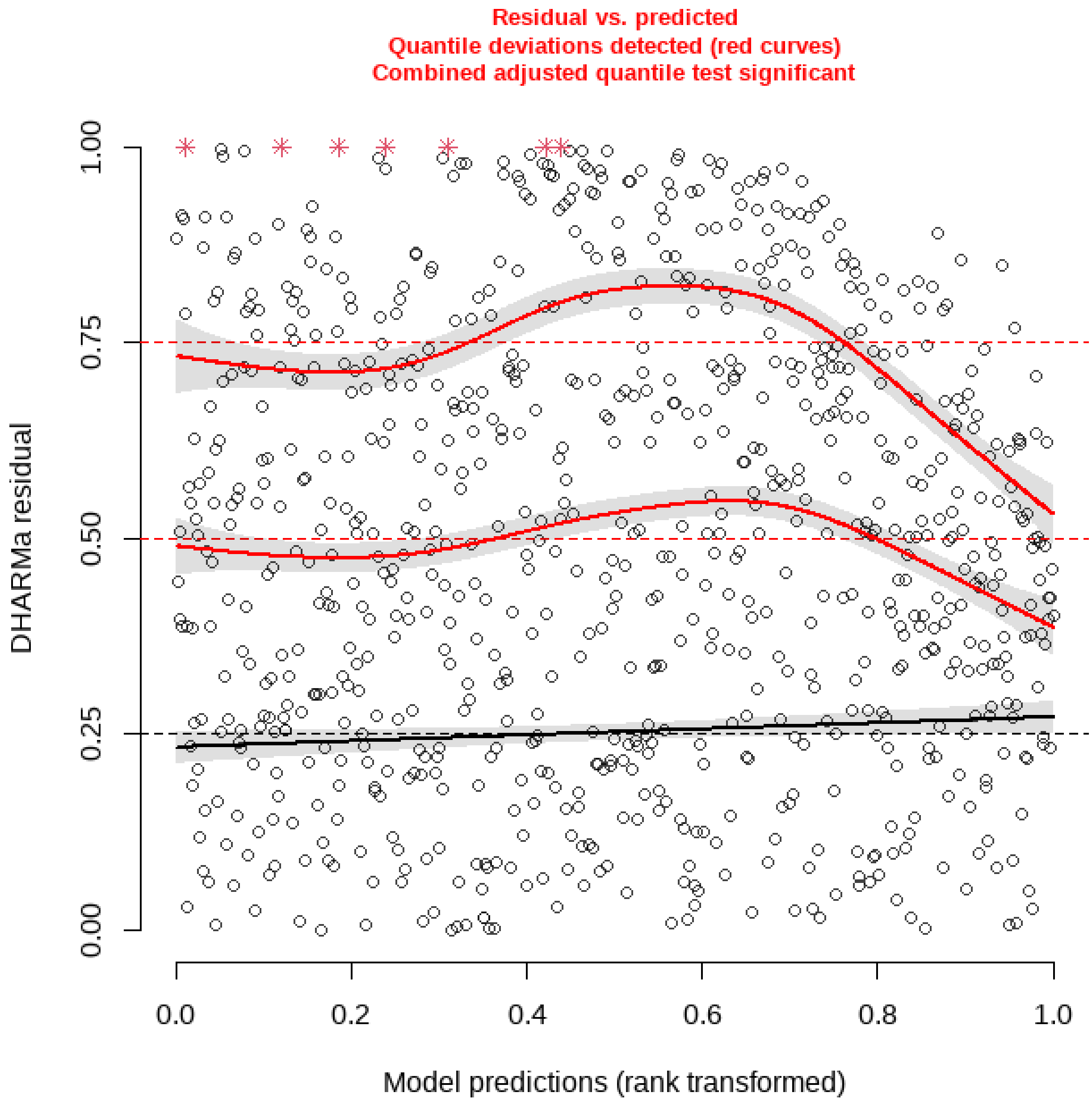

Figure A-8. Residuals with model predictions for the model with latitude squared.

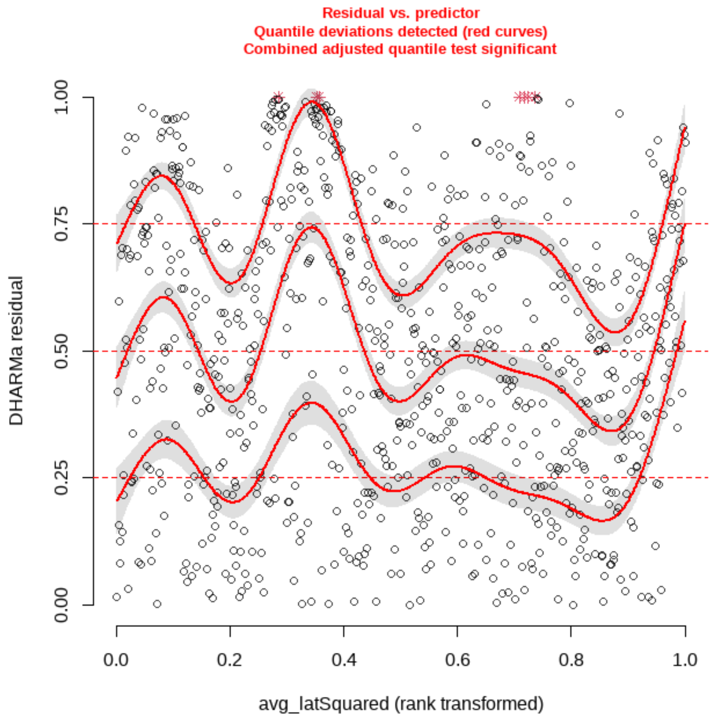

Figure A-9. Residuals with average latitude squared.

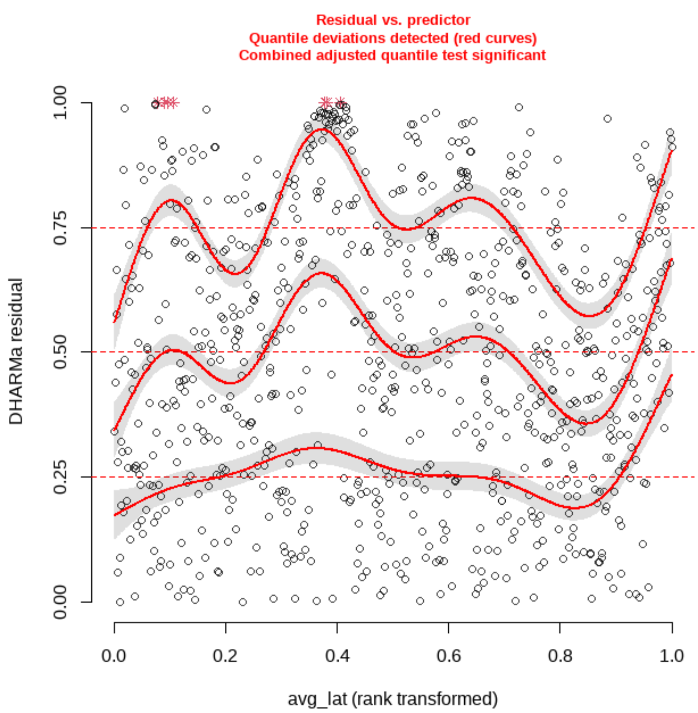

Figure A-10. Residuals with average latitude once latitude squared was included.

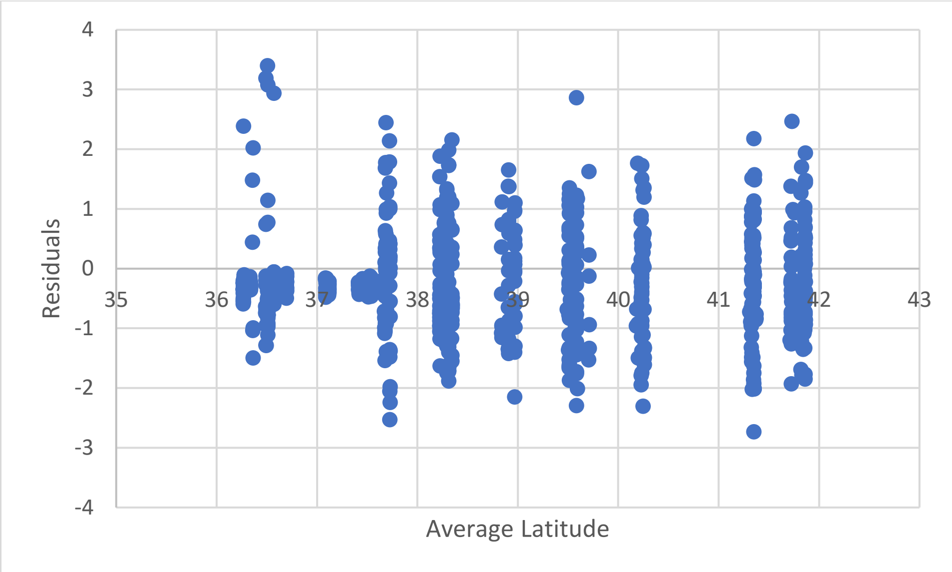

Figure A-11. Residuals with latitude with the addition of depth squared to the model.

Request 4: Even the absolute indices of abundance should be treated as relative indices for reasons such as (1) site selection is non-random because MPAs are not located randomly; (2) there are differences in the depth of reefs surveyed and the depth of reefs expanded to and depth-based stratification requires use of proxy data from other strata given limited sample size.

Response 4.a: From feedback above "(1) site selection is non-random because MPAs are not located randomly";

While the ROV sampling design is not randomly stratified across all rocky habitat or depth due to its primary objective of sampling inside and outside of MPAs, that does not mean the data it is not representative of California coastal habitats in general or the predominant habitat types for a species being examined. While there are portions of the California coast where the ROV sampling design may be more or less representative of the habitat types for a given area, the ROV data is robust and a good representation of the rocky reef habitat along the 1,100 miles of Californias coast since the MPA network (which the ROV survey is designed to sample) was designed to encompass these marine ecosystems throughout California. The MPA network was designed by regional stakeholder groups including commercial and recreational anglers, tribal and government representatives, educators, researchers, and conservationists. Once the MPA proposals were completed, they underwent scientific and policy review (Overview of Alternative Marine Protected Area Proposals (PDF)).

The California Collaborative Fisheries Research Program (CCFRP) is another survey designed to sample California's network of MPAs in order to evaluate their effectiveness as a tool for conservation and fisheries management. The sampling design of CCFRP is similar to that of the

ROV survey with sampling occurring inside MPAs and associated reference sites outside of MPAs. Data from CCFRP along with abundance indices have been utilized in stock assessments (gopher/black and yellow, China, vermilion, and copper rockfishes as well as cabezon). If a similar survey designed to sample MPAs is sufficient for utilization in stock assessments, there should be no issue with the utilization of ROV data to create a design-based estimates of abundance as a relative index of abundance as well.

While the ROV data may be biased for some species that are primarily distributed beyond the depth distribution sampled, it is reasonable to conclude that estimates from ROV data may be biased low or biased high dependent on species range and depth distribution relative to the ROV transects. If bias is a concern researchers or stock assessors could choose to utilize a randomized subset of the ROV data. However, CDFW does not feel this is warranted for most species but could be considered if data users feel it is appropriate. Comparison of the proportion of transects sampled over rocky reef by depth vs. proportion of habitat by depth from seafloor data within latitudinal strata resulted in probability distributions for the proportion at depth that had 54% to 83% overlap depending on the region, with an overlap of 83% overall. This would indicate relatively proportional sampling. In addition, the ROV sampling is random in that the deepest transect is randomly selected and an interval of depths for remaining transects selected, which results in random placement of transects within a site.

Any potential bias in the ROV dataset should be considered on a species-by-species basis vs. a default assertion that because the ROV sampling design is not random it is not representative. The question should be asked, is ROV data the best scientific information available (BSIA)? If so, ROV data should be utilized to its full extent to inform stock assessments or other research. A clear diagnostic for a threshold for acceptable deviation from representative depth distribution of habitat has not been established, though the current degree of overlap may be sufficient. Rather than presuming any deviation to be unacceptable, simulation studies evaluating the magnitude of effect of deviation could be pursued to better understand the implications of deviations for the estimates of abundance that result to establish a minimal overlap needed to provide a representative estimate of abundance.

When utilizing the ROV dataset and ROV derived products it is pertinent for STATs (or other data users) to look at a species range, depth distribution and habitat preferences to explore the question, if they were to develop a random or stratified random sampling design for a given species would it encompass a significantly different suite of sampling sites other than those currently sampled by the ROV survey? If not, a STAT should feel emboldened to utilize the ROV data to the fullest extent possible. If the STAT feels a species range, depth distribution and habitat preferences are not reasonably well encapsulated by the current ROV survey they may be more cautious in their utilization of ROV data and ROV derived products. CDFW provides the following ROV Transects and Habitat map to help the STAT (or other data users) with the evaluation of ROV data for quillback rockfish and other species.

The areas which are the least represented in the ROV surveys are deeper depths in Federal waters, where data indicates that quillback rockfish increase in density to 60-70 m and increase in size with depth (Figure C1-1 & C1-6, California ROV Indices and Design-based Estimates of Abundance-11-22-2024_Final). For quillback rockfish, the lack of sampling in deeper depths within quillback rockfish known distribution has the potential to bias the estimates low as ROV abundance indexes and estimates are applying length data primarily derived from smaller quillback rockfish in shallower depths to deeper areas where quillback rockfish are larger due to ontogenetic migration to deeper depths. Conversely, the lack of high-resolution habitat mapping in area seaward of the three miles from shore delineating state waters within which high resolution seafloor mapping data is available from the CSMP, results in a potential overestimation of habitat in deeper depths as the variable resolution of data can result in areas circumscribed as rocky reef containing soft bottom habitat in the CMECS data set. This potential bias may also make the proportion of habitat in deeper depth appear greater than in reality, making the proportion of habitat sampled in transects vs. proportion of a total habitat to appear more different than they are. This can be visualized in the ROV Transects and Habitat map by comparing the ROV transects to the overall rocky reef habitat. The ROV transects are minimally a robust sampling of quillback rockfish populations inside MPAs and the corresponding ROV reference sites outside MPA's are a good representation of rocky reef habitat in the shallower portion of quillback rockfishes range and depth distribution as illustrated in the orange "Core Quillback Habitat (20m - 90m)" in the ROV Transects and Habitat map.

CDFW's asserts that ROV data is the best scientific information available to account for species populations within large-closed areas such as Marine Protected Areas, and in part the Rockfish Conservation Area off California. If ROV data is not utilized to account for a species population in closed areas the STAT should clearly articulate what information was used in place of ROV derived data as the best scientific information available to directly inform scale/trends, and why that information source/ methodology should be considered BSIA over the ROV data. This will help constituents, agencies and the scientific communities understand when and where ROV data is BSIA and when another dataset or methodology to estimate population size should be used instead of ROV data. In the absence of more robust information, the ROV data set, abundance indices and estimates could be considered BSIA and should be utilized to their full extent in stock assessments or other research.

Response 4.b: From feedback above "(2) there are differences in the depth of reefs surveyed and the depth of reefs expanded to and depth-based stratification requires use of proxy data from other strata given limited sample size. CDFW investigated the differences in the proportion of transects surveyed by depth and that of reefs used in the expansion from seafloor data. Due to the wide variety of reef habitat across the California coast, these differences vary spatially and are addressed through the stratification schemes used in the expansion.

When comparing all reefs and transects from Pt. Sur to the Oregon border (Figure A-12), there is an 81% and 83% overlap of ROV transect depths with CSMP and CMECS data respectively.

Given the lower resolution in deeper depths, the proportion of transects sampled by depth may be closer to the proportion of habitat in reality than reflected by the CMECS data set in deeper depths. There is under sampling in shallower depths (20-40 m) and oversampling in mid-depths (40-80 m). This is primarily driven by the area North of Pt. Arena as seen in Figure A-13 and Figure A-14.

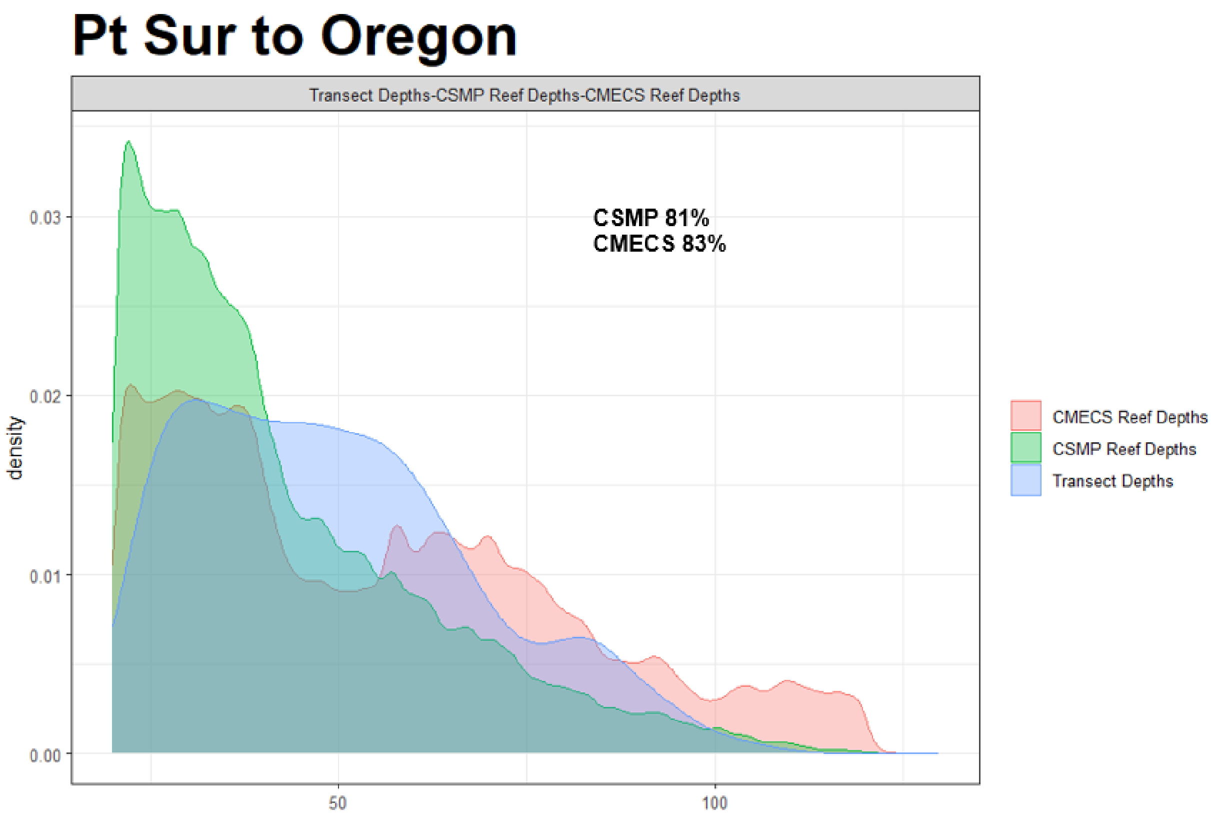

Figure A-12. Comparison of the probability distribution of reefs mapped in the California Seafloor Mapping Project data, reefs mapped in the Coastal and Marine Ecological Classification Standard (CMECS) data, and the average depths of ROV transects with depth. All reefs and transects from Pt Sur, California to the Oregon Border were considered. Numbers indicate the % overlap of each data source with the depths of the ROV transects.

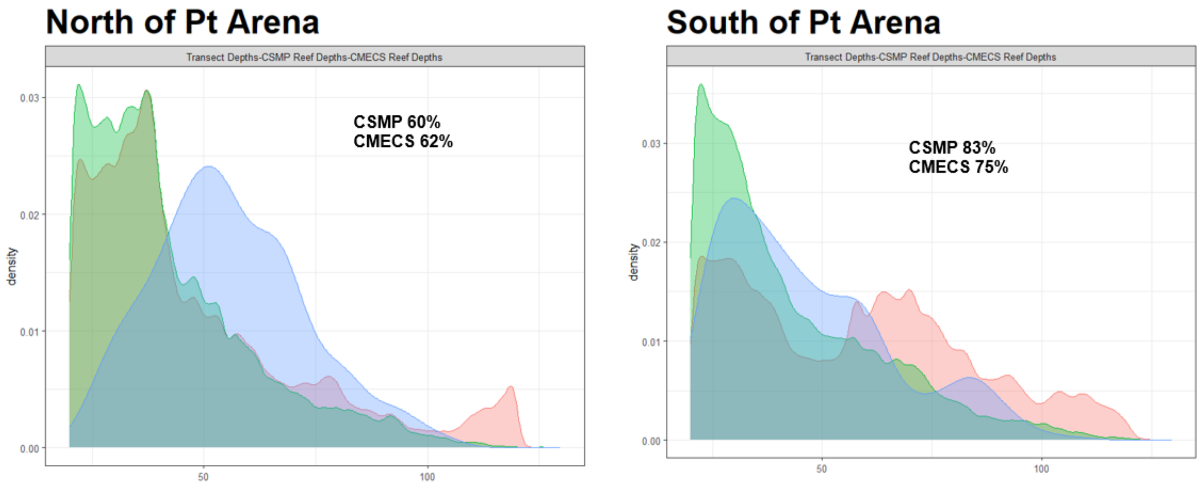

Figure A-13. Comparison of the probability distribution of reefs mapped in the California Seafloor Mapping Project data, reefs mapped in the Coastal and Marine Ecological Classification Standard (CMECS) data, and the average depths of ROV transects. The data north of Pt. Sur is stratified North and South of Pt. Arena. Numbers indicate the % overlap of each data source with the depths of the ROV transects.

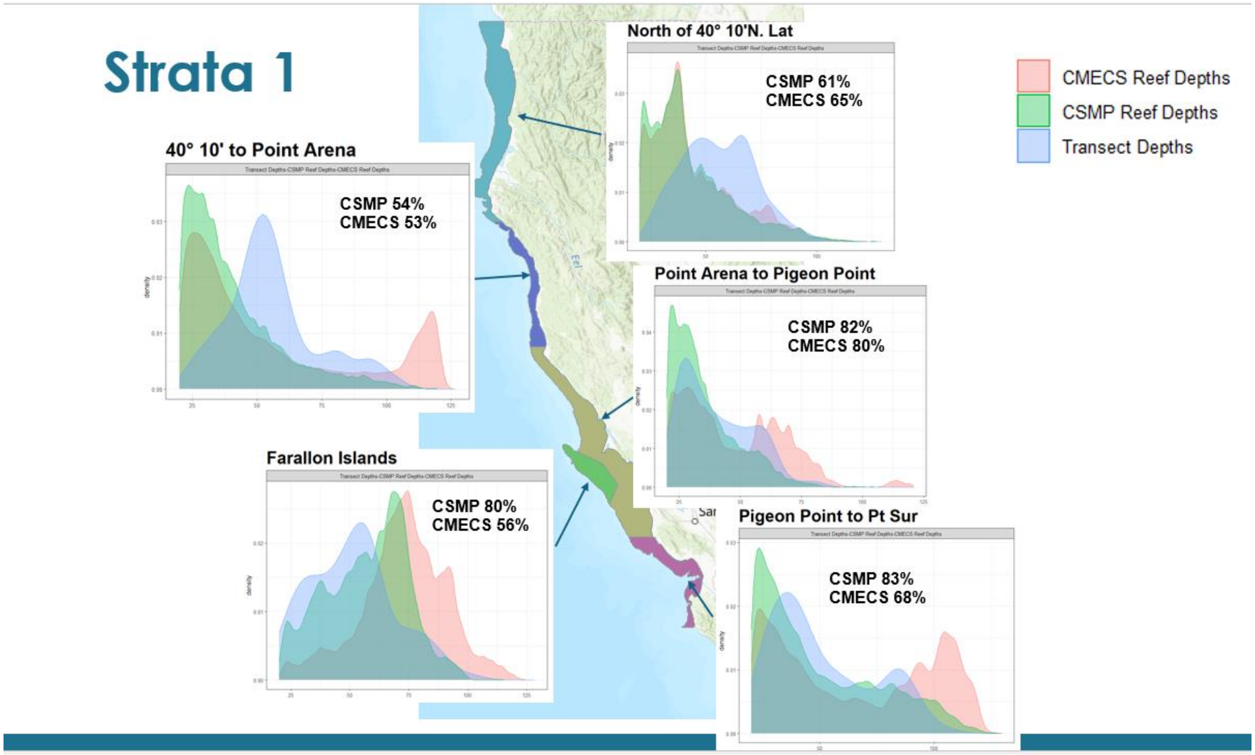

Figure A-14. Comparison of the probability distribution of reefs mapped in the California Seafloor Mapping Project data, reefs mapped in the Coastal and Marine Ecological Classification Standard (CMECS) data, and the average depths of ROV transects. The data north of Pt. Sur is stratified at 40°10' N. Lat., Pt. Arena, Pigeon Pt., and around the Farallon Islands. Numbers indicate the % overlap of each data source with the depths of the ROV transects.

Request D.6.iv.: Develop absolute abundance and associated uncertainty estimates for another stock/species for which we have a more robust stock assessment for comparison, such as copper, gopher or China rockfishes.

Response D.6.iv.: Design-based ROV Estimates of Abundance for Copper Rockfish

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 develop estimates of absolute abundance using design-based and model-based methods in combination with seafloor mapping data. Habitat data are available from the California Seafloor Mapping Program (CSMP) providing high resolution mapping for state waters and layers produced using the Coastal and Marine Ecological Classification Standard (CMECS) generated by National Marine Fisheries Service (NMFS) providing more comprehensive mapping of the nearshore habitat (<300 ft) in state waters from CSMP and federal waters at various resolutions from contributing data sources.

Estimates of absolute abundance in numbers of fish resulting from expansions can be converted to metric tons utilizing the lengths of fish observed from stereo-camera systems extracted by digital processing software, that are then converted to weight using existing length-weight relationships from the most recent stock assessment.

Surveys of the California coast (Figure A-15) have now been undertaken twice, 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, with each super year taking a little more than 2 years with 25 months in the 2015 super year and 27 months for the 2020 super year. The 500 m strip survey transects in each rocky reef sample site were selected by randomly selecting the deepest transect at a given site, then selecting transects on a constant interval into shallower depths (Figure A-16). 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. The number of transects sampled in various locations included for analysis are found in Table A-2. The filters applied to the data set include excluding sample sites south of Point Conception, California to facilitate comparison to stock assessment results stratified to the north and south of Point Conception, depth exceeding the primary distribution of copper rockfish in waters shallower than 100 m, excluding surveys prior to 2014 lacking statewide coverage and removing transects completely over soft bottom according to GIS layers for rocky reef from the NMFS compiled according to the CMECS habitat data (Table A-3).
The following were considered when developing expansions in the interest of minimizing bias and uncertainty to avoid overexpansion.

1. Depth of Expansion: While the depth range of copper rockfish according to fish base is 10 m to 183 m, they were observed to 100 m in the ROV data, despite having sampled multiple transects within 120 m, though few additional transects were sampled deeper than 120 m. The primary depth range of copper rockfish observed by the ROV survey was between 10 m to 100 m given the counts, transects sampled and densities in Table A-4. The depths included in the seafloor area estimate were selected to encompass the primary depth distribution between 10 m and 100 m as opposed to extremes of the entire range. Three depth strata were imposed from 10-40 m, 40-70 m and 70-100 m to account for variability in density and length of observed fish with depth.
2. Latitude of Expansion: The latitudinal boundaries of the expansion area were limited to the primary distribution from the Oregon/California border to Point Conception, though the reported range of copper rockfish extends south to Mexico. The counts, transects sampled and density within each degree of latitude is provided in Table A-5. The area to the north of Point Conception provided a more complete representation of seafloor coverage to inform expansion and our estimates and comparisons were relegated to north of Point Conception as a result.
3. Delineation and Characterization of Seafloor Habitat: Expansions were made with the NMFS CMECS product using multiple resolutions to inform habitat in waters deeper than the high resolution CSMP data set used to represent the shallower depths given the higher resolution of data available there. Table A-6 provides the number of observed copper rockfish by depth and latitude informing the extent of area and depth to which expansions were made.

4. Latitudinal Stratification of Expansion Areas: Stratification at Point Arena was applied to reflect differences in density and average weight with latitude, discussed further below.
5. Nature of Density Estimates: The density estimates included all habitat types observed during the course of the ROV survey observed over the course of a transect rather than focusing on habitat identified as "rock" alone over a portion of the transect. This decision was made in recognition of the design of the survey to cover rocky reef generally, and including all bottom types observed over the transect reduces the density, relative to using only observations over rock, making the density estimate conservatively biased low. There are interstitial spaces of soft habitat between rocky habitat in the CSMP/CMECS characterizations of seafloor and these inclusions are even greater for CMECS in deeper depths where there is lower resolution to separate characterizations into rock and soft bottom at fine resolution limiting error. The general density estimate for all observed seafloor within the transects conducted over "rocky reef" including some soft and mixed bottom may compensate to some degree for the lack of resolution in seafloor mapping to distinguish between rock and interspersed soft bottom in deeper depths than sampled by the CSMP, represented by several compiled layers in the CMECS data set where lower resolution data was available.

The stratification scheme for design-based estimates of abundance for copper rockfish were developed using an analysis of the density (fish per square meter, Figure A-17) and length (Figure A-18) by depth and latitudinal strata of observed individuals used to inform latitudinal stratification at Point Arena and 40° 10' N. Lat., resulting in three strata from the Oregon Border to 40° 10' N. Lat., 40° 10' N. Lat. to Point Arena and Point Arena to Pigeon Point. The final data sets included sites sampled in data from each super year period and sites sampled in only one of the two super years, providing a sample size of 1105 transects informing density (fish per square meter).

Of 1257 copper rockfish observed, 485 stereo-lengths were available from fish in orientations facilitating measurement usable to inform average weight. Density data (fish per square meter) collected by the ROV were stratified consistently with the seafloor area estimates 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 = 0.0000111*Length^3.15) from measured and weighed fish reported in the 2021 Copper Rockfish stock assessment (Monk et al. 2024). 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. 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 value was then calculated to get point estimates of each stratum, which were then combined to provide a total.

Generalized Equations A-1 and A-2 below were used to derive stratum specific estimates of abundance in numbers and weight, respectively. The estimates and bootstrapped variance were then summed across latitudinal strata north and south of Point Arena and protection (inside or outside an MPA) to provide an aggregate estimate.

Equation A-1: Numbers of Fish = fish/square meter *square miles/square meter* square miles rocky reef habitat

Equation A-2: Stratum Biomass = fish/square meter *square miles/square meter* square miles rocky reef habitat * average weight

For each of the estimates, rocky reef habitat area estimates for each strata inside and outside of MPAs were estimated from the CMECS seafloor data as the basis for habitat area expansion. Lengths of fish observed and measured with stereo-camera techniques were converted to weights using established length-weight relationships from the 2024 assessment (Monk et al. 2024) in Equation A-3. Weights within each strata were multiplied by habitat area inside and outside of MPAs to provide corresponding estimates in each stratum, which were then summed to provide an aggregate estimate for the full distribution north of Point Conception. Estimates were provided for each super year inside and outside of MPAs in each stratum. For each parameter, we calculated the 2.5th and 97.5th percentiles of the bootstrapped distributions to obtain 95% confidence intervals and estimated the CV from the confidence interval using Equation A-4. These results were aggregated for both point estimates and associated uncertainty for each combination of latitudinal strata, depth strata, protection status, and super year.

Equation A-3: Weight = 0.0000111*Length^3.15

Equation A-4: CV=Upper CI - Lower CI) / (2*Point Estimate)

Results

Estimates of abundance in numbers of fish, lower and upper confidence intervals and coefficient of variation for each super year are provided in Table A-7 and depicted in Figure A-19, showing an increasing trend in abundance over time, also observed both inside and outside of MPAs (Table A-8 and Figure A-20). The abundance in numbers increased by 46.7% from 733,471 fish in 2015 to 1,076,279 fish in 2020, with a 111.5% increase in number of fish inside MPAs and 28.7% outside MPAs. Estimates of abundance in metric tons, lower and upper confidence intervals and coefficient of variation for each super year are provided in Table A-9 and depicted in Figure A-21, showing a 25.8% increase in metric tons of fish between super years from 985 mt in 2015 to 1328 mt in 2020. Estimates of abundance in metric tons, lower and upper confidence intervals and coefficient of variation for each super year and protection are provided in Table A-10 and depicted in Figure A-22, with an 31.8% increase outside MPAs and a 45.2% increase inside MPAs.

The estimates of abundance could be utilized directly in a future copper rockfish assessment model along with the associated length data. These values can be considered in a relative sense like indices of abundance, to provide support for sensitivities on parameters affecting scale, or be applied in direct adjustments to catchability in the assessment. While these estimates were also intended to be used as standalone estimates of abundance to which proxy values for F_{MSY} could be applied to provide an overfishing limit (OFL) buffered by a category 2 or three buffer to provide an acceptable biological catch (ABC), the lack of exact proportionality of sampling vs rocky reef depth distribution was identified as a consideration by the Scientific and Statistical Committee (SSC). Additional efforts to consider the factors that result in large discrepancies between the scale of the estimates from the 2023 assessment and design-based estimates from the ROV, may provide further perspective on the viability of either method in producing accurate estimates of abundance and help reconcile the difference through sensitivity analyses.

Biomass Compared to 2021 Copper Rockfish Stock Assessment

The scale of ROV design-based estimates of abundance north of Point Conception in 10 to 100 m of water was 985 mt in 2015 and 1328 mt in 2020 is substantially lower than the 2575.68 mt in 2015 and 2620.84 mt in 2020 from the 2024 copper rockfish full assessment (Monk et al. 2024). The estimates from the stock assessment and ROV present an unprecedented opportunity to examine differences between methods among assessed species with expanded estimates of biomass from ROV data. Previously, no other data source has offered the ability to produce an independent estimate of biomass to confirm scale. Better understanding the nature of the discrepancy may also lead to methods to directly incorporate estimates of biomass from the ROV survey directly in future assessments. The discrepancy in biomass may be explained by the following:

- The resolution of the area of expansion for the ROV estimate.
- Differences in the depth or latitudinal distribution of fishing effort or ROV sampling compared to habitat resulting in deviations.
- Species that tend to aggregate may result in catch estimates that are disproportionately higher than those that are more evenly disbursed on the seascape.
- Misspecification of parameters affecting scale in the assessment ie selectivity, R0 natural mortality or steepness.
- Catchability is misspecified in the assessment resulting in deviation of biomass from the assessment and ROV.
- Potential overestimation of biomass for more aggressive or abundant species in non-trawl dominant assessments due to hook saturation or exclusion resulting in underestimation for less aggressive non-schooling species.

A meta-analysis can be conducted comparing ROV-based estimates of abundance from design-based estimates and model-based estimates methods to the results of stock assessments for copper, quillback, China, vermilion and gopher/black and yellow rockfish and additional analyses conducted to test these working hypotheses.

Comparison of Results of the Copper and Quillback Rockfish Estimates of Abundance to Stock Assessments.

Comparisons of the same ROV transects resulted in sampling of 1257 copper rockfish and 1535 quillback rockfish north of Point Conception, expanded to 1328 mt and 971 mt, respectively in 2020, indicating more comparable biomass estimates between species than the assessments would suggest. Contrary to this result, the assessments indicated the current biomass between the species at 2620.84 mt for copper rockfish and 77.53 mt for quillback rockfish in 2020, indicating a substantial difference in the perception of relative scale between the two species compared to the values from the ROV. If the ROV derived estimates are accurate, the difference in the perception of the relative scale between species would indicate that the assessment may be overestimating biomass for copper rockfish and underestimating that of quillback rockfish. Further examination of the factors contributing to the differences is needed to fully understand the discrepancy.

Figure A-15. Map displaying copper rockfish lengths were sampled by the ROV during the time period analyzed (2014 – 2021) with coloring to distinguish between latitudinal strata. Colored circles represent copper rockfish observations.

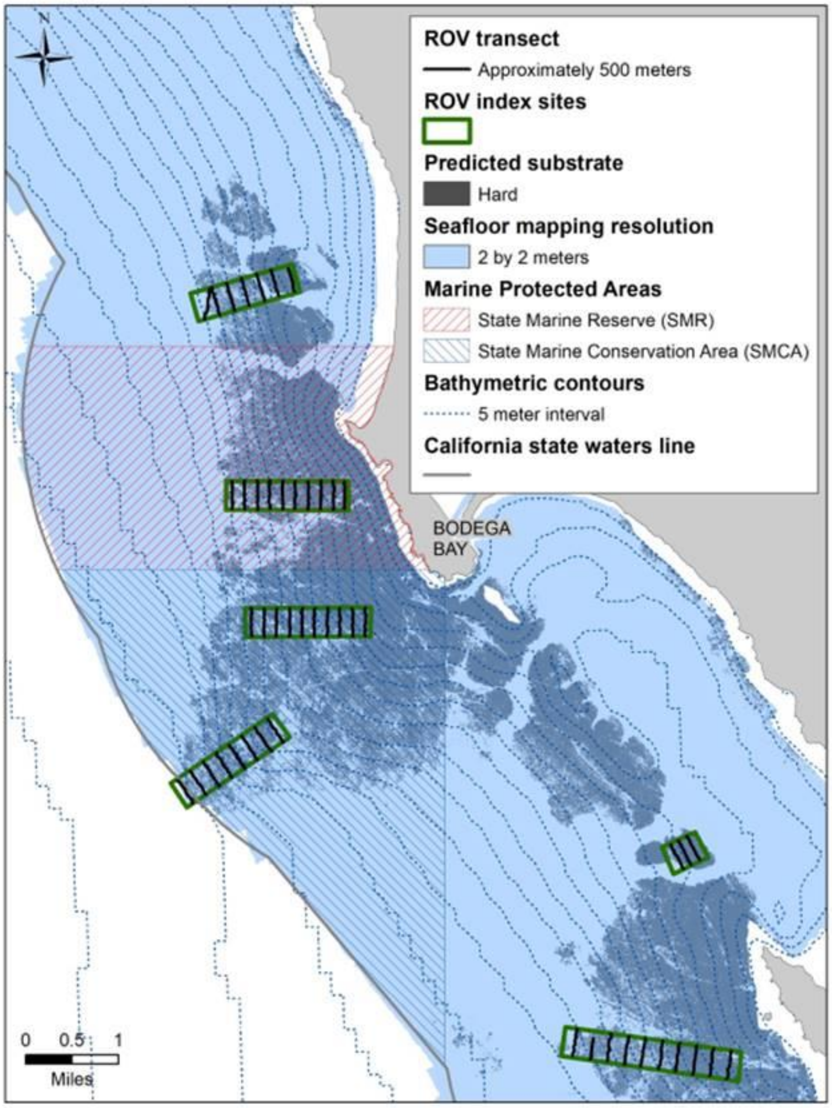

Figure A-16. Depiction of the sampling design showing the boxes that identify sampling locations over hard substrate and the 500 m transect lines oriented to align with the bathymetry contours and other features pertinent to the study superimposed on CSMP seafloor characterization.

Table A-2. List of sampled locations and number of transects sampled in each survey year.

Location	2014	2015	2016	2019	2020	2021	Total

Albion	10						10
Ano Nuevo		9		10		10	29
Asilomar			15				15
Big Creek			24		13		37
Big Flat	3						3
Bodega Bay		44		38	43		125
Cabrillo	7						7
Carmel Bay			8				8
Church Rock			4				4
Crescent City	4						4
Cypress Point			8	10		14	32
Duxbury Point		3					3
Fort Ross		1					1
Half Moon Bay		8			16	7	31
MacKerricher	12						12
Mattole Canyon	16	13					29
Montara		12			11	10	33
Morro Bay			30				30
N Farallon Islands					10		10
Noyo	3						3
Pacific Grove			8				8
Piedras Blancas			8		15		23
Pillar Point		4			4	4	12
Point Arena		17			14	11	42
Point Buchon			15	14		15	44
Point Lobos			16	13		20	49
Point St. George	28	12			19	12	71
Point Sur			23	22		21	66
Portuguese Ledge			12	12		10	34
Reading Rock	22	15			20	14	71
San Gregorio Reef		6					6
Saunders Reef		8					8
SE Farallon Islands		27		23	23		73
Sea Lion Gulch	15	6			18	20	59
South Cape Mendocino	14						14
Stewarts Point		3					3
Ten Mile	21	16			20	18	75
Tolo Bank	18						18
Tomales Point		3					3
Total	173	207	171	142	226	186	1105

Table A-3. The beginning number of transects removed and copper rockfish sampled statewide, the number of each remaining after each filtering was completed.

Data Set	Transects	Copper Rockfish	Positive
Full	3273	5771	1468
S. of Conception	1769	4434	982
Prior to 2014	359	80	55
Depth Range	12	0	0
Soft Bottom GIS	27	0	0
Final	1105	1257	430

Table A-4. The number of fish and density of fish (fish/transect) observed by the ROV in each 10-meter depth bin.

Depth (m)	Transects	Copper Rockfish	Density (Fish/Transect)
0-10	0	0	0.0000
10-20	11	1	0.0909
20-30	179	90	0.5028
30-40	213	193	0.9061
40-50	195	264	1.3538
50-60	200	305	1.5250
60-70	147	178	1.2109
70-80	59	80	1.3559
80-90	73	105	1.4384
90-100	20	41	2.0500
100-110	8	0	0.0000
110-120	1	0	0.0000
Total	1105	1257	1.1365

Table A-5. The number of fish and density of fish (fish/square meter) observed by the ROV in each one-degree latitude bin north to south.

Latitude (Degrees)	Transects	Copper Rockfish	Density (Fish/Transect)

35-36	113	127	1.1239
36-37	237	408	1.7215
37-38	197	133	0.6751
38-39	182	230	1.2637
39-40	125	157	1.2560
40-41	106	80	0.7547
41-42	146	122	0.8356
Total	1105	1257	1.1365

Table A-6. The number of fish and density of fish (fish/transect) observed by the ROV in each 10 m depth bin and one-degree latitude bin.

Depth (m)	35-36	36-37	37-38	38-39	39-40	40-41	41-42	Total Fish	Transects	Density (Fish/Transect)
0-10										
10-20				1				1	11	0.09091
20-30	3	20	27	31		9		90	179	0.50279
30-40	15	48	6	76	12	33	3	193	213	0.90610
40-50	37	46	14	57	52	20	38	264	195	1.35385
50-60	28	62	50	44	72	12	37	305	200	1.52500
60-70	9	86	5	21	13	1	43	178	147	1.21088
70-80	15	34	20		5	5	1	80	59	1.35593
80-90	18	74	10		3			105	73	1.43836
90-100	2	38	1					41	20	2.05000
100-110									8	0.00000
110-120									1	0.00000

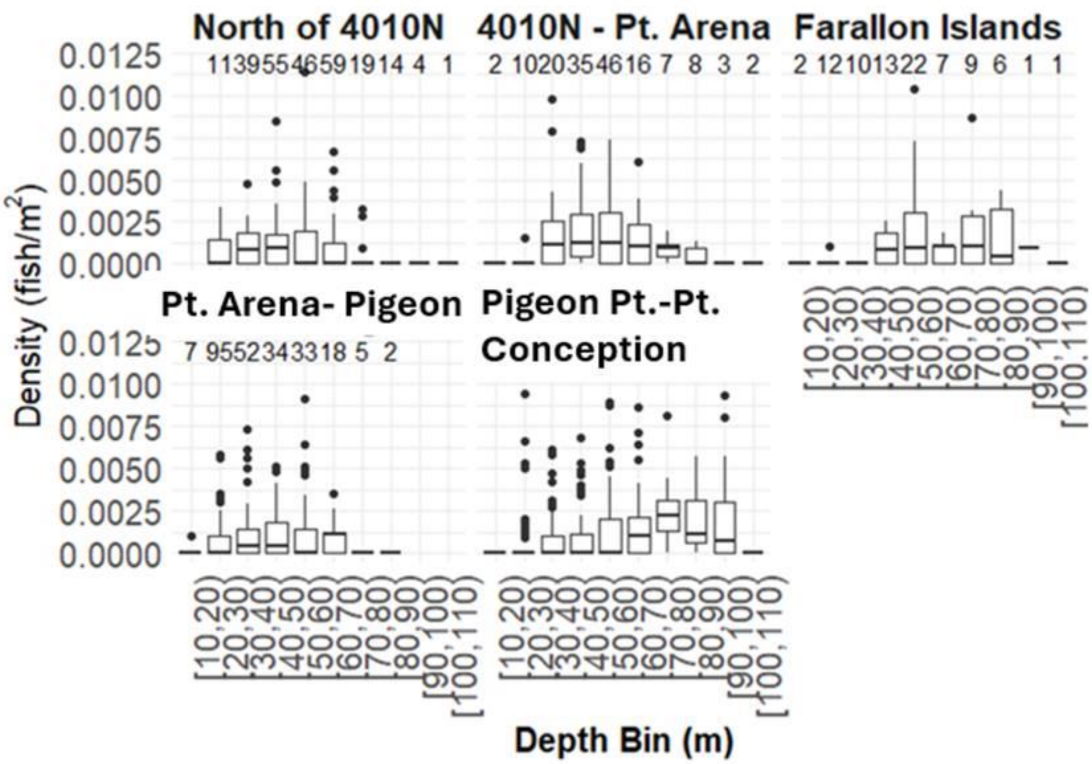

Figure A-17. Copper rockfish ROV transect-level density boxplots separated by 10-meter depth strata in each latitudinal stratum.

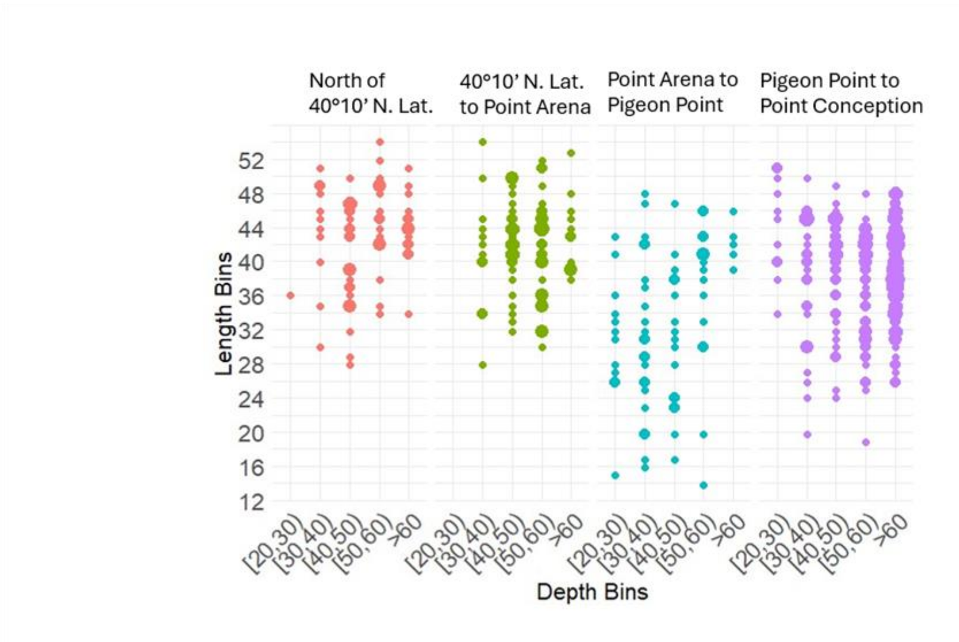

Figure A-18. Copper rockfish length frequency distribution bubble charts by latitudinal strata and 10-meter depth bins. Different colors are used to distinguish latitudinal strata. Farallon Islands and coastal sites from Pt. Arena – Pigeon Pt. Strata are separated in this figure.

Table A-7. Estimates of abundance in numbers of fish, lower and upper confidence intervals and coefficient of variation for each super year.

Super Year	Point Estimate	Lower 95% CI	Upper 95% CI	CV
2015	733471	613235	859587	0.168
2020	1076279	925625	1241382	0.147

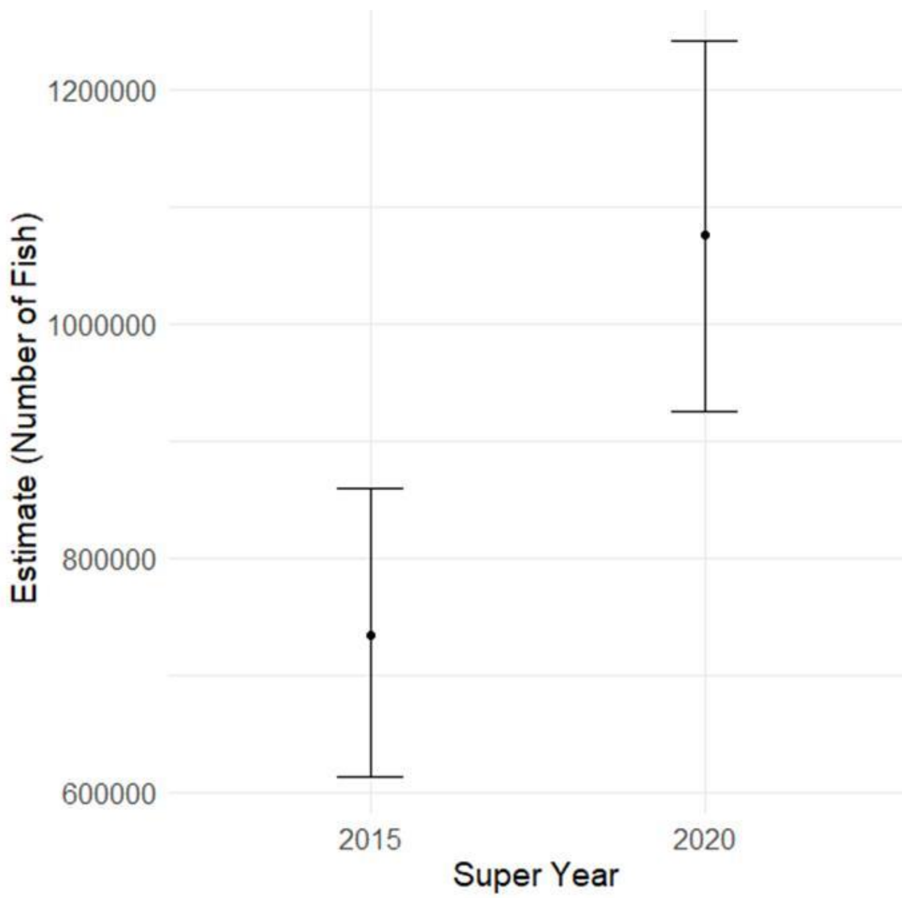

Figure A-19. Estimates of abundance in numbers of fish, lower and upper confidence intervals for each super year without depth stratification.

Table A-8. Estimates of abundance in numbers of fish, lower and upper confidence intervals and coefficient of variation for each super year and protection (0 outside MPA, 1 inside MPA).

Super Year	Protection	Point Estimate	Lower 95% CI	Upper 95% CI	CV
2015	0	589036	472612	713922	0.205
2015	1	144223	114421	178042	0.221
2020	0	769777	627891	924299	0.193
2020	1	305006	262334	348958	0.142

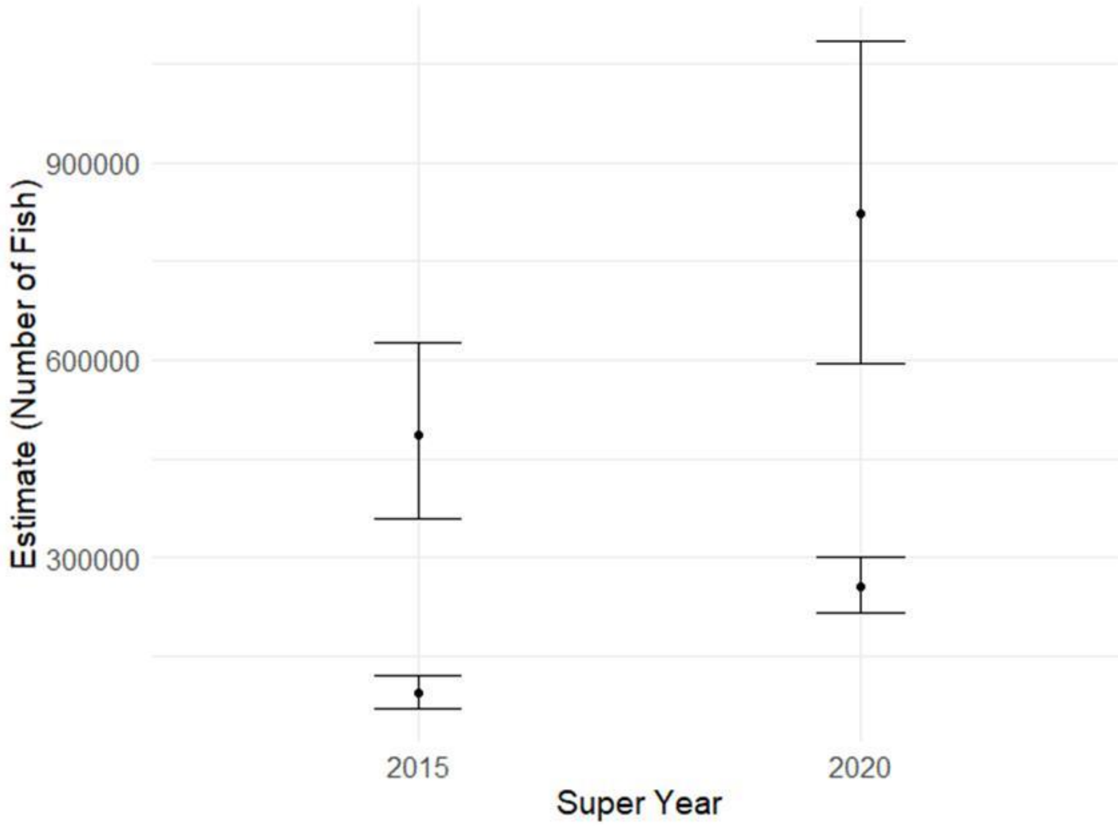

Figure A-20. Estimates of abundance in numbers of fish, lower and upper confidence intervals for each super year and protection (outside MPAs area upper, inside MPAs lower).

Table A-9. Estimates of abundance in metric tons, lower and upper confidence intervals and coefficient of variation for each super year.

Super Year	Point Estimate	Lower 95% CI	Upper 95% CI	CV
2015	985	822	1163	0.173
2020	1328	1122	1561	0.165

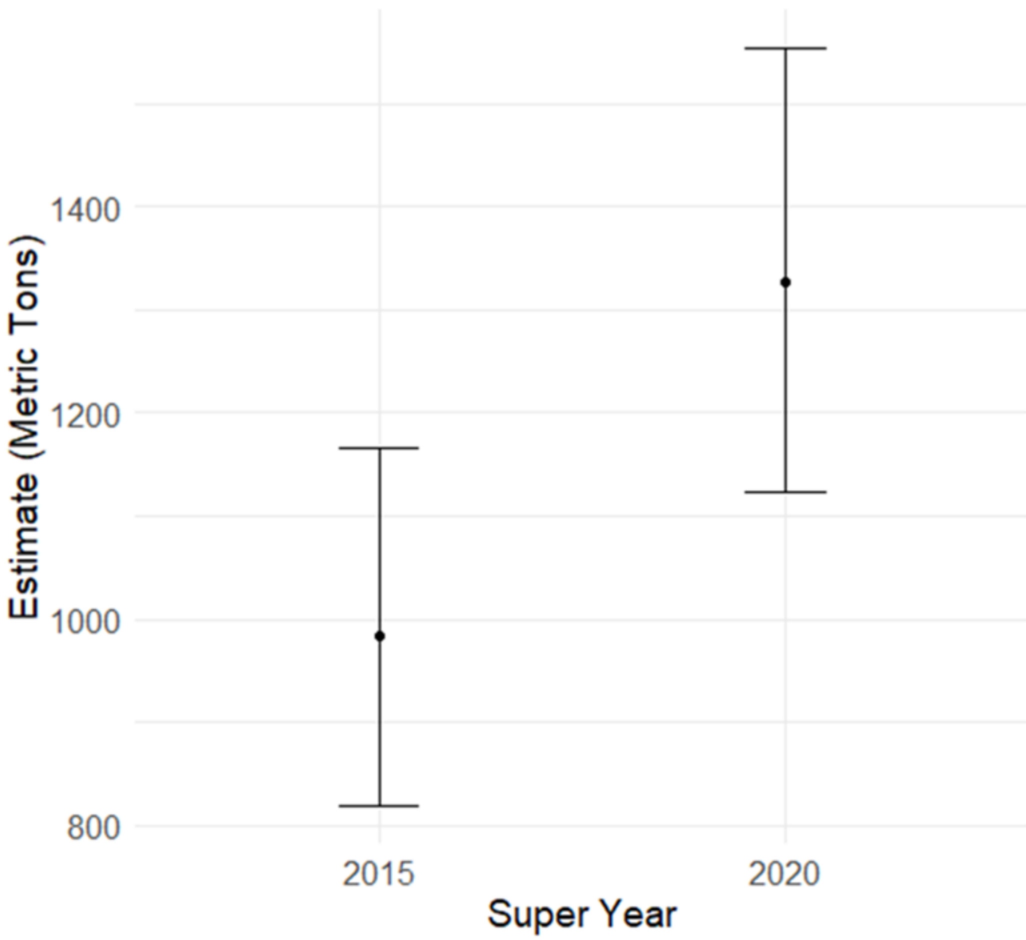

Figure A-21. Estimates of abundance in metric tons, lower and upper confidence intervals for each super year.

Table A-10. Estimates of abundance in numbers of fish, lower and upper confidence intervals and coefficient of variation for each super year and protection (0 outside MPA, 1 inside MPA).

Super Year	Protection	Point Estimate	Lower 95% CI	Upper 95% CI	CV
2015	0	767	613	938	0.212
2015	1	217	168	273	0.242
2020	0	1011	815	1231	0.206
2020	1	315	268	366	0.156

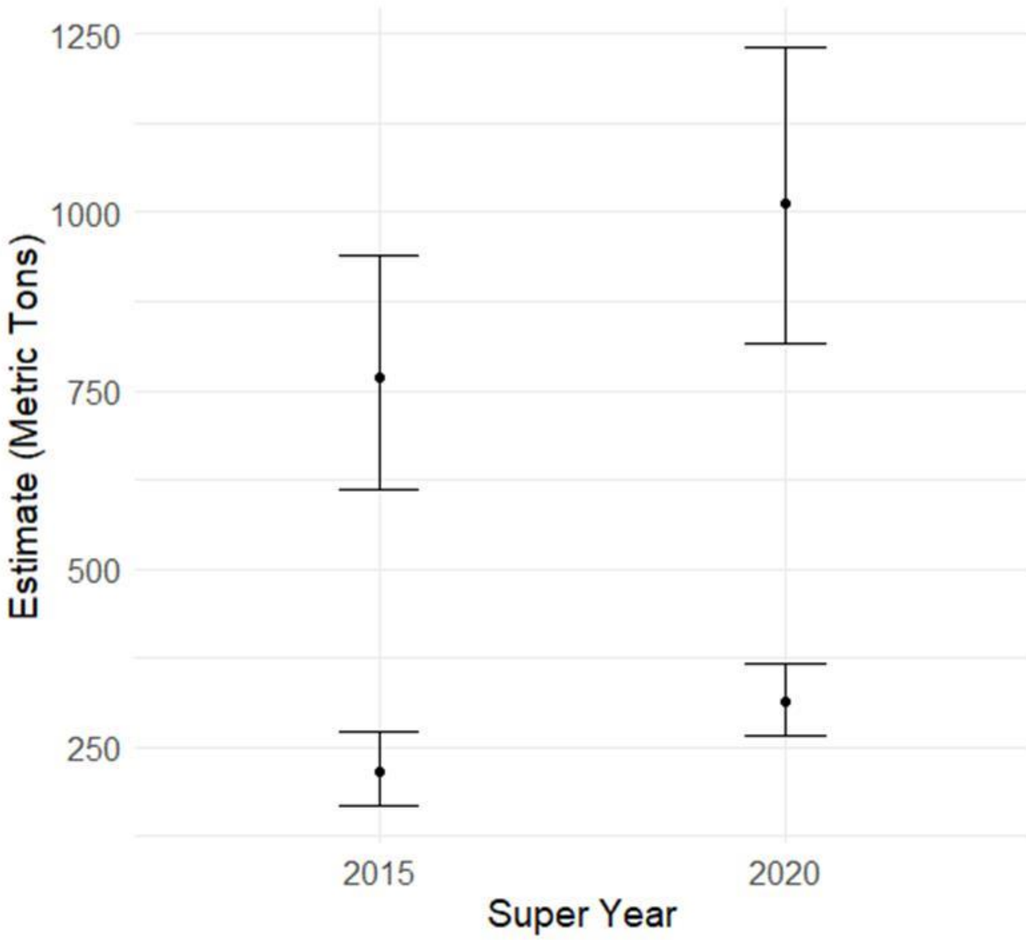

Figure A-22. Estimates of abundance in metric tons, lower and upper confidence intervals for each super year and protection (outside MPAs area upper, inside MPAs lower).

References

Monk, M.H., C.R. Wetzel, J. Coates. 2024. Status of copper rockfish (*Sebastes caurinus*) along the U.S. California coast north of Point Conception in 2023. Pacific Fishery Management Council, Portland, Oregon. 286 p

Appendix B. Summary of California ROV Reports to Date

Documentation of ROV Related Reports to Date

- Original 2020 California ROV Methodology Review. Methods for using remotely operated vehicle survey data in assessment of nearshore groundfish stocks along the California coast.
- September 2020 Methodology report from the SSC on original ROV workshop with comments.
- December 2024, PFMC workshop, California ROV Indices and Design-based Estimates of Abundance-11-22-2024_Final
- March 2025, SSC GFSC report on December 2024 workshop. Agenda Item H.4.a, SSC Groundfish Subcommittee Report 2, March 2025
- March 2025, CDFW report with answers to some questions raised from March 2025 SSC report.
- March 2025, SSC Report on Final assessment Methodologies. The report contains some guidance and blesses ROV work products utilization in stock assessments at STATs discretion.

Appendix C. ROV Next Steps for Future Workshops

Future Surveys and Current Funding off California

- Third super year: Funding to conduct a third super year of ROV transect work in California's MPAs was recently funded by California Sea Grant.
- California ROV Design discussion/revamp: In October of 2024 an expert panel provided Recommendations to Inform Monitoring Strategies for Mid-Depth Rocky Reef Habitats in California. CDFW and the California Ocean Protection Council are continuing to evaluate sampling design considerations for all MPA monitoring groups that focus on subtidal rocky reef habitats and will likely pursue funding of projects to specifically explore sampling gaps and design considerations in the next MPA monitoring funding cycle (2027-2029).
- Additional funding and sampling efforts are needed to expand side scan sonar south of Point Conception and seaward of state waters to provide more complete coverage at higher resolution to better inform expanded estimates of biomass.

Workshop Topics/Long-Term Recommendations from SSC and Proponents:

1. Analyzing the data using alternative transect lengths (longer than 10 m, but shorter than 500 m full transects).

2. Consider a hierarchical bootstrap where transects are nested within sites. The current bootstrap procedure might be positively biased if the estimate of variance does not account for clustering.

3. CDFW proposes a meta-analysis comparing estimates of biomass from multiple stock assessments to the results of biomass estimates from design-based and model-based estimates of abundance. Test the working hypothesis that catch-based scale from assessments will overestimate the biomass of more aggressive species ie copper and vermilion rockfish and underestimate biomass for less aggressive species ie quillback rockfish, copper rockfish and gopher/black and yellow rockfish relative to the ROV estimates based on density observations and habitat area expansions.

4. CDFW proposes simulation studies evaluating the magnitude of effect of deviation of proportion of habitat by depth sampled and proportion of transects by depth could be pursued to better understand the implications of the magnitude of deviations for the estimates of abundance that result to establish a minimal overlap needed to provide a representative estimate of abundance.

5. Explore other model-based approaches for abundance estimation, such as a negative binomial model with the following categorical covariates (number of factor levels in parentheses):

a) Super year (2)

b) Region (5; same as before, with Farallon Islands separate)

c) Depth (4; e.g., <30, 30-50, 50-70, >70)

d) Protection status (2)

e) Interaction between super year and protection status

f) Site as random effect

g) Test other 2-way interactions, if possible

ii. Use model selection to identify important sources of variability.

iii. Use model predictions of density with habitat areas to produce estimates of numerical abundance

iv. Use estimates of numerical abundance by stratum to expand length composition data. Derive mean weights from those expansions and derive biomass estimates from the expanded length compositions.

6. Responses to requests from the 2020 methodology review regarding model-based estimates of abundance not yet addressed. This cycle, the focus was on responses to requests from the 2020 methodology review and additional requests from the SSC regarding index and design-based abundance estimation methods. Those requests which directly pertained to indices of abundance and design-based estimates of abundance for the quillback rockfish stock assessment were prioritized. Additional requests for analyses of the model-based estimates of abundance outlined in the 2020 methodology review may be addressed at a workshop to address remaining requests posed to the CDFW and Oregon Department of Fish and Wildlife (ODFW) in 2026.

Appendix D. Information provided to the Quillback Rockfish Stock Assessment Team

Following the March 2025 PFMC meeting CDFW received informal comments from the SSC on the March 2025, CDFW ROV report. CDFW integrated feedback to the extent possible and revised methodology to improve upon the ROV derived index of abundance and designed based estimate of abundance for quillback rockfish. The results from each method along with the data, R code needed to generate the results and write ups were provided to the quillback rockfish STAT by the March data deadline. A high-level summary of the work and results for both methods is provided below.

CDFW looks forward to Stock Assessment Review (STAR) panel review of the ROV derived index of abundance and design-based estimate of abundance for their applicability in the quillback rockfish and other future stock assessments.

ROV Survey Index of Abundance for Quillback Rockfish

A generalized linear mixed model (GLMM) was fit in R 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. The GLMM analysis was conducted using the full 500 m transect length as the scale of inference. 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 and variable describing whether a site is open to fishing or in a no take Marine Protected Area were converted to categorical variables as factors to allow estimation of separate index values for them. In addition, site was included as a random effect. The final model was subjected to evaluation using various criteria from the package Dharma in R including overdispersion, outliers, Kolmogrov-Smirnov (KS) tests for error distribution fit, which were non-significant.

The indices and 95% confidence limits resulting from the final model is depicted in Figure D-1, and values provided in Table D-1. The result indicates the relative abundance has increased inside and outside of MPAs between 2015 and 2020 super years, but to a greater extent in MPAs. The resulting combined index reflecting weighting based on the proportion of rocky reef habitat inside (20%) and outside MPAs (80%), was 9.54 fish per hectare (95% CI= 5.11 - 17.81) in 2015 with a log standard error of 0.23 and 14.62 fish per hectare (CI=7.67 - 27.88) in 2020 with a log standard error of 0.24.

The weighted index indicated a 53.34% increase in relative abundance between the 2015 and 2020 super years. The length data indicated recent recruitment, reflected in the indices. The length compositions from the survey were weighted by the proportion of rocky habitat area inside and outside of MPAs, consistent with the index weighting.

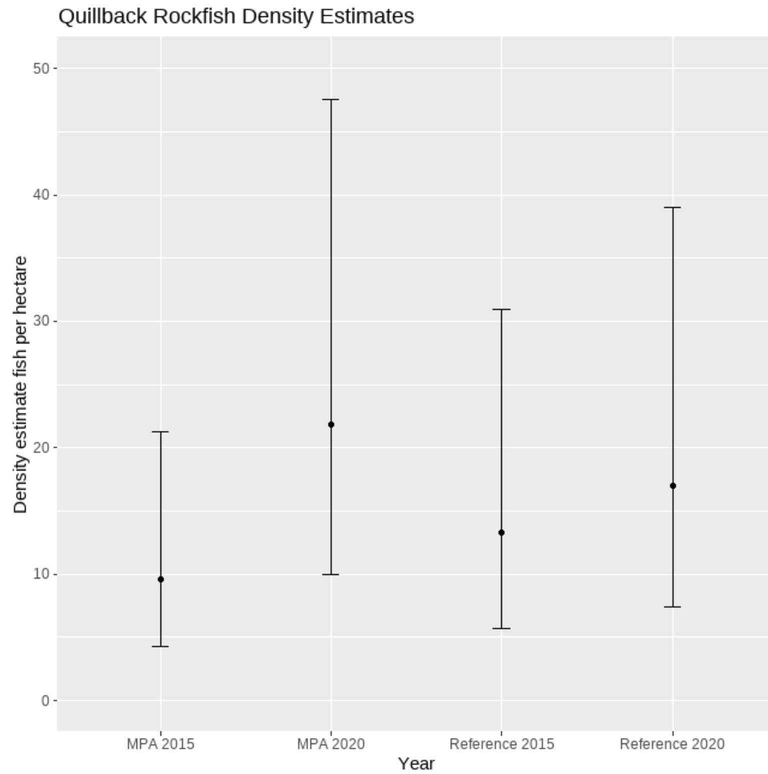

Figure D-1. Index and 95% confidence limit estimates for final GLMM Model inside and outside MPAs.

Table D-1. Index (fish/hectare) and upper and lower 95% confidence limits.

Index Value	Estimate	Lower 95% CL	Upper 95% CL
Outside MPA 2015	9.54	5.15	17.66
Outside MPA 2020	12.89	6.77	24.54
Inside MPA 2015	9.52	4.92	18.43
Inside MPA 2020	21.55	11.26	41.25

Table D-2. Indices of abundance (fish/hectare) weighting values in Table A4-1 based on percent of nearshore rocky reef inside MPAs (20%) and outside MPAs (80%) from seafloor mapping, as well as the upper and lower confidence limits, log standard error (SE) and percent change in abundance between the 2015 and 2020 super years.

Value	2015 Index	2015 log SE	2020 Index	2020 log SE	Percent Change
Estimate	9.54	0.2317	14.62	0.2405	53.34%
Lower 95% CL	5.11	-	7.67	-	50.21%
Upper 95% CL	17.81	-	27.88	-	56.51%

Design-based ROV Estimates of Abundance for Quillback Rockfish

The filters applied to the data set were selected to focus the expansion on the primary distribution of quillback in waters by removing sample sites south of Point Sur, California, depth shallower than 20 m and deeper than 90 m, excluding surveys prior to 2014 lacking statewide coverage and removing transects completely over soft bottom according to GIS layers for rocky reef from the NMFS compiled according to the CMECS habitat data. In addition, the entire transect including interstitial soft bottom along the distance surveyed was used to derive the density, but only expended to rocky reef habitat from the seafloor habitat characterization, which in combination with the filters are expected to result in a conservative (biased low estimate of biomass). The resolution of seafloor habitat in deeper depths may counter this to some degree as many reefs in deeper depths are roughly delineated by expert opinion rather than informed by side scan sonar as is the case for the CSMP data inside state waters available at higher resolutions. Stratification at Point Arena was applied to reflect differences in density and average weight with latitude, discussed further below.

Estimates of abundance in metric tons, lower and upper confidence intervals and coefficient of variation for each super year are provided in Table D3 and depicted in Figure D2, showing a

123% increase in metric tons of fish between super years from 435.45 mt in 2015 to 971.98 mt in 2020. The scale of design-based estimates of abundance in 2020 of 971.98 mt in 2020 is a great deal higher than the 77.53 mt estimate for 2020 from the [2021 quillback rockfish length-based data-moderate assessment].

Estimates of abundance in metric tons, lower and upper confidence intervals and coefficient of variation for each super year are provided in Table D4 and depicted in Figure D3 for results inside and outside of MPAs. The estimate of abundance increased both inside and outside of MPAs, with a 116% increase outside MPAs and a 159% increase inside MPAs.

Table D-3. Estimates of abundance in metric tons, lower and upper confidence intervals and coefficient of variation for each super year.

Super Year	Point Estimate	Lower_95_CI	Upper_95_CI	CV
2015	435.45	346.93	537.12	0.2184
2020	971.98	660.86	1363.19	0.3613

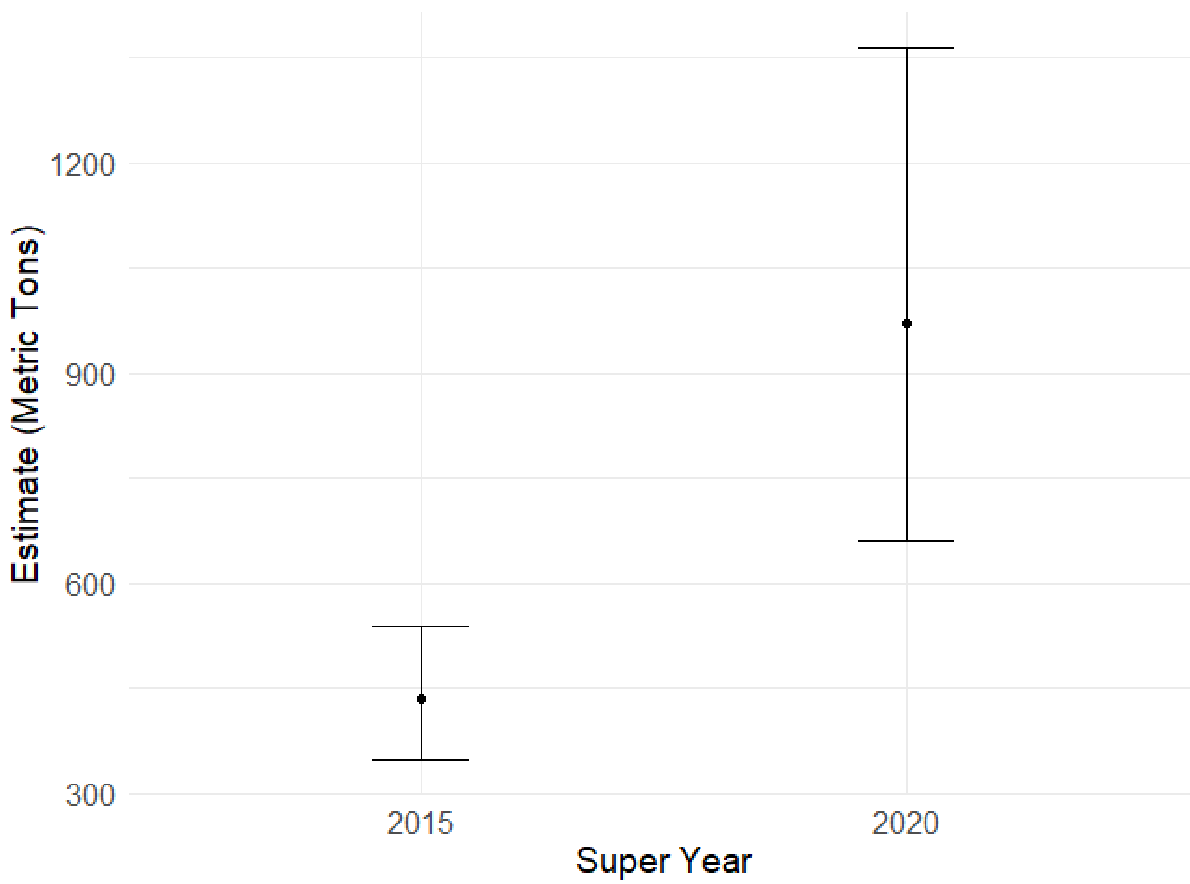

Figure D-2. Estimates of abundance in metric tons, lower and upper confidence intervals for each super year.

Table D-4. Estimates of abundance in metric tons, lower and upper confidence intervals and coefficient of variation for each super year and protection (0 outside MPA, 1 inside MPA).

Super Year	Protection	Point Estimate	Lower_95_CI	Upper_95_CI	CV
2015	0	369.30	281.00	472.38	0.2591
2015	1	66.48	50.21	84.81	0.2602
2020	0	798.71	481.72	1179.58	0.4369
2020	1	172.26	144.89	203.73	0.1708

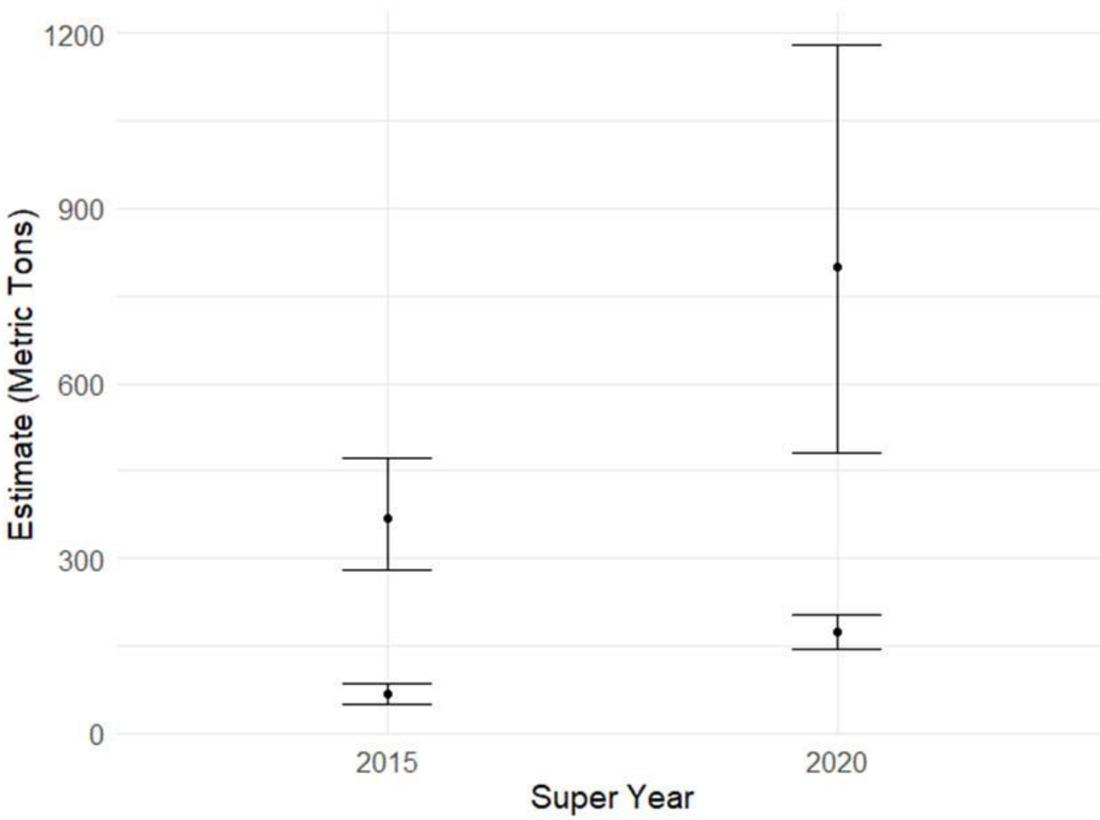

Figure D-3. Estimates of abundance in metric tons, lower and upper confidence intervals for each super year and protection (outside MPAs area upper, inside MPAs lower).