NORTHWEST FISHERIES SCIENCE CENTER INFORMATIONAL REPORT
TO THE PACIFIC FISHERY MANAGEMENT COUNCIL:
BACKGROUND INFORMATION RELEVANT TO DATA MODERATE ASSESSMENTS AND TO COMMENTS OR QUESTIONS RAISED DURING THE SEPTEMBER AND NOVEMBER 2023 COUNCIL MEETINGS REGARDING THE 2021 ASSESSMENT FOR QUILLBACK ROCKFISH

1. Background information on data-moderate assessment methodology

Assessment capacity and data to support assessments of West Coast groundfish

The Pacific Fishery Management Council (PFMC) Fishery Management Plan (FMP) for groundfish species off the U.S. West Coast includes 90+ stocks. The stocks within the FMP experience a wide range of high to low exploitation levels from commercial and recreational fishing. To date, only 41 species (some with multiple stocks) within the groundfish FMP have received some level of assessment to estimate abundance, status, and overfishing levels (OFLs) to set annual catch limits (ACLs) with all other species being managed under OFLs determined based on historical catches, biology, and an assumed relative stock status. The ability to assess additional species managed under the groundfish FMP is limited due to both data availability and assessment capacity.

Assessment capacity is limited due to the number of federal staff available to conduct assessments, reviews, conduct biological research to inform maturity and fecundity, and age reading within the biennial schedule. At present, depending upon the number of stocks and/or model areas, the assessment capacity within each biennium generally provides for benchmark assessments for between 3-8 species, 1-2 assessment updates, as well as several catch-only projections (note that, in addition, an international assessment for Pacific hake is mandated every winter). This limited capacity has led to challenges in ensuring that assessments used for management are conducted every 10-years or less, leading to a number of species where the most recent assessment was conducted up to 14 years ago (e.g., greenstriped rockfish and splitnose rockfish). For 16 species, the time since the most-recent assessment currently exceeds the target assessment frequency calculated as part of the stock assessment prioritization (SAP) analysis ranging between 2-10 years.

The second challenge to conducting assessments for all groundfish stocks is the availability of data. This limits the ability to assess a large number of particular stocks, outside of the issue of assessment capacity. The majority of stocks that are yet to be formally assessed lack sufficient length and/or age data from either fisheries or surveys. These data limitations are often most pronounced for nearshore stocks, particularly for those off California, where there may be little to no age data available from fisheries along with limited surveys collecting information on relative abundance and biological composition over time.

The evolution of the data moderate assessments for PFMC groundfish

The challenges posed due to assessment capacity and data limitation led to work by assessment scientists to identify assessment methods that can utilize more limited data and that may be less labor-intensive to conduct and review for West Coast groundfish stocks, thereby increasing both the number of stocks that have the potential to be assessed and assessment throughput. Initial research efforts focused on incorporating available relative indices of abundance along with assumptions around biology, stock status, and productivity resulting in the development of Extended Depletion Based Stock Reduction Analysis and Extended Simple Stock Synthesis (PFMC Methodology Review, 2012; Wetzel and Punt, 2015). These index-only data-moderate assessment methods were then applied in 2013 to assess nine groundfish species (Cope et al., 2015). A stock assessment review (STAR) panel determined that models for seven species (brown rockfish, China rockfish, copper rockfish, sharpchin rockfish, yellowtail rockfish north of 40° 10′ N. Lat, rex sole, and English sole) adequately estimated abundance and stock status and could be used for management (i.e., assessments for vermilion/sunset rockfish and yellowtail rockfish south of 40° 10′ N. Lat were withdrawn by the assessment authors and the model for stripetail rockfish was too uncertain for use by management). The Groundfish Subcommittee (GFSC) to the Scientific and Statistical Committee (SSC) and the full SSC reviewed and recommended the assessments as Best Scientific Information Available (BSIA) to determine stock status and OFLs.

Many of the data limited species with the groundfish FMP include data types that would be excluded within an index-only data-moderate assessment (e.g., length compositions) but which could be informative within an assessment. Additionally, many species without routine age collection for fisheries (or a survey) might never be considered for a benchmark assessment, and for those a data-moderate assessment approach might be the best that could be delivered without new data-collection initiatives. This led to new research led by the Northwest Fisheries Science Center (NWFSC) to develop a methodology for including index of abundance and length compositions under the data-moderate assessment framework (Rudd et al., 2021). This new method was termed length-based data-moderate (LB-DM) but has also been referred to as Stock Synthesis-Catch and Length (SS-CL). Rudd et al. (2021) conducted both a simulation study and systemic data reductions for existing benchmark assessments to evaluate model performance that was presented to the GFSC by the NWFSC at an assessment methodology workshop in the spring of 2020 (Agenda Item D.4, Attachment 2, September 2020). The simulation work examined the performance of length-based models across a variety of different life-history and data-availability assumptions. Existing benchmark assessments were also compared to versions retaining only catch and length data for 10 species. For each case, four different durations of length data retained were examined, ranging from all years to just the single most-recent year of length data. Comparison plots are shown in Figure 1 for the eight species where the base models included more than trivial amounts of age data. In some cases, models using only catch and at least 20 years of length data produced relative spawning biomass/output time series that were very close to the base models, and in a couple of cases, there was a divergence between base case and the most length-rich scenarios.

The performance of LB-DM assessments was further reviewed by the GFSC on October 23, 2020 and then reviewed by the full SSC, which endorsed the use of this methodology (Agenda Item G.5.a, Supplemental SSC Report 1, November 2020). The SSC noted that this approach could

provide an assessment pathway for species managed at that time under category 3 analyses and that are also highly attained relative to their OFL or ABC (or their OFL/ABC contributions to the totals for a complex; equivalently rated as highly vulnerable from productivity-susceptibility (PSA) analysis) and have adequate length data and life-history information. This approach could also be used for species stocks with dated category 1 assessments that have low attainment relative to existing OFLs and ABCs, and for any species where the ageing process is particularly time consuming and/or have high ageing error.

Subsequently, the GFSC proposed revisions to the groundfish stock assessment terms of reference to include guidance on how to conduct LB-DM (Agenda Item G.5.a, SSC Groundfish Subcommittee Report 1, November 2020). Based on endorsement by the SSC for LB-DM assessments, the Council adopted their use as well as an associated Terms of Reference, and identified three species—copper, quillback, and squarespot rockfishes—for which 2021 assessments would utilize this new approach.

As for the use of LB-DM assessments to inform stock status, there is no apparent reason why they should not be used to describe status. All of our assessments exist on a continuum of data availability and informational content of the data that are available. The SSC has, on occasion in the past, recommended that an assessment not be used to inform either status, if the confidence interval around the depletion estimate is unreasonably large, or setting an OFL, if the scale of the modeled population is highly sensitive to a reasonable range of parameter uncertainty. It is important to note that LB-DM assessments have essentially been conducted historically for species where no reliable ageing methodology exists (e.g., shortspine thornyhead, longspine thornyhead, and Pacific spiny dogfish). Additionally, across groundfish assessments length data are often the most abundant data source within assessments and are often highly influential in informing estimates of abundance, stock status, and OFLs. For example, 2023 benchmark assessments of copper rockfish in California waters that included catch, index, length, and age data resulted in relatively similar estimates of abundance, stock status and OFLs for the stock compared to the LB-DM assessments conducted in 2021 that used catch, length, and limited index data (Supplemental Informational Report 9, November 2023).

At both the September and November 2023 meetings there were discussions around whether data-moderate assessments should be used to determine stock status in opposition to the SSC's multiple recommendations since 2013 that had deemed the majority of data-moderate assessments were appropriate to determine stock status and inform OFLs, including this June 2021 SSC report (Agenda Item G.5.a, Suplemental SSC Report 1, June 2021; page 7, first bullet). The consequences of not using any data-moderate assessments to inform status would relegate all of them to category 3, for purposes of determining the scientific uncertainty buffer. That would have the effect of doubling the size of the buffer for calculating Acceptable Biological Catches (ABCs) for most of the 2021 and 2023 LB-DMs assessments (2021: copper rockfish in Oregon and Washington (California was reassessed in 2023), quillback rockfish in Oregon and California (Washington was already assigned as category 3), squarespot rockfish; 2023: rex sole and shortspine thornyhead), and those species assessed in 2013 that are yet to be re-assessed. Additionally, it would call into question whether assessments that are basically LB-DM such as the 2013 longspine thornyhead and 2021 Pacific spiny dogfish assessment should receive a category 3 assignment doubling the scientific uncertainty buffer.

2. Application of LB-DM methods to quillback rockfish

History of concerns around harvest levels of quillback rockfish

In the late 1990s and early 2000s nine West Coast groundfish stocks were declared overfished. The general pattern across these assessments was that stocks began to decline precipitously, generally starting in the 1970s, due to overexploitation. As of 2023, eight of the stocks declared overfished between 1999-2002 have been declared rebuilt due to management actions and positive environmental conditions (e.g., recent above average rockfish recruitment). Fishing mortality decreased from the levels observed during the period of stock declines for a wide range of species in the groundfish FMP due to a range of management measures aimed at rebuilding overfished stocks. Across nearshore and shelf species that have been assessed in the last 15-years a common pattern has been observed of population declines in the 1980s and 1990s, often below the relative biomass target reference point or even the minimum stock size threshold (MSST), and then increasing abundance from low levels starting in the early 2000s.

In 2010, the Groundfish Management Team (GMT) provided a report examining the vulnerability of species in the groundfish FMP using a productivity and susceptibility analysis (PSA; Agenda Item E.2.b, GMT Report, March 2010). This analysis identified China rockfish, copper rockfish, and quillback rockfish as three of the five most vulnerable stocks off the West Coast due to low productivity and high vulnerability to the fishery. Recently conducted category 1 and 2 assessments for China and copper rockfishes support the PSA analysis in that these assessments have estimated that portions of these species off the West Coast were below 40 percent at the time of assessment. The 2015 benchmark assessment of China rockfish off the West Coast estimated that the area south of 40° 10′ N. Lat. was 27.9 percent of unfished, well below the target reference point of 40 percent (Dick et al., 2016). The 2023 benchmark assessment of copper rockfish south of 34° 27′ N. Lat. estimated the population south of Point Conception in California waters to be at 16 percent of unfished spawning output with the California wide stock area at 36.6 percent of unfished (Wetzel et al., 2023).

Subsequent work to estimate OFLs for 50 data-limited, category 3, stocks in the groundfish FMP was conducted in 2010 (Dick and MacCall, 2010). This analysis used coastwide catches and assumptions around biology and the relative stock status in 2010 to estimate a coastwide OFL for quillback rockfish. Dick and MacCall (2010) noted for that the 2008-2009 average catch for three stocks (one of which was quillback rockfish) exceeded the estimated OFLs:

> "A comparison of recent catch levels (average catch, 2008-2009) and projected OFLs in 2010 suggests that if catch levels remain near recent levels, a number of species could be subject to overfishing (Table 63). Specifically, rougheye rockfish, quillback rockfish, and China rockfish have a greater than 50% chance of experiencing overfishing if 2010 catch is equal to average catch over the past two years."

The **coastwide** category-3 OFL for quillback rockfish was 15.0 mt (median value from Table 62 in Dick and MacCall, 2010). Examining historical coastwide catches between 1980-1999, coastwide catches exceeded the newly estimated 15.0 mt coastwide OFL for quillback rockfish in

17 out of 20 years, with catch exceeding the OFL in 7 out of 9 years between 2000-2009. It is important to note that quillback rockfish is currently managed in the nearshore complex, split north and south of 40° 10′ N. Lat. where overfishing is tracked at the complex level rather than at the species-specific OFL contribution.

In 2016, the NWFSC conducted the first formal stock assessment prioritization (SAP) process to identify species most in need of assessment based on a range of fishery and biological factors norting that SAP is conducted at the species level where information is aggregated at the coastwide level. The 2016 SAP identified that average attainment between 2012-2014 for quillback rockfish was 108 percent of the average OFL for that period. Subsequent SAPs conducted in 2018, 2020, and 2022 identified that average catches continued to be near or well above the coastwide OFL for quillback rockfish (2014-2016: 88 percent, 2016-2018: 163 percent, 2018-2020: 212 percent).

In summary, while a category-2 assessment of quillback rockfish was not available until 2021, there were numerous pieces of information indicating that catches continued to remain near or above the catches observed between 1981-2000, a period where other rockfish assessments have estimated that catches were often exceeding exploitation targets. Additionally, catches in recent years of quillback rockfish were known to be exceeding the category 3 species-specific OFL at the coastwide level.

Data workshops and scientific reviews for 2021 data-moderate assessments

In preparation for the 2021 length-based data-moderate assessment, a pre-assessment workshop was held on October 26, 2020. Available data, proposed model-areas, and modeling assumptions were presented for quillback, copper, and squarespot rockfishes. For quillback rockfish three separate model areas corresponding to state-areas were proposed, due to differences in historical exploitation and management. Landed catch of quillback rockfish in historical reconstructions for recreational and commercial fisheries was greatest in California waters, representing 63 percent of coastwide landings. At the time of the pre-assessment data-workshop it was noted that no otoliths collected from California recreational or commercial fisheries were available for ageing, with limited numbers of ages available in Oregon (921 samples) and Washington (240 samples). Given the limited number of ages across all areas, the estimation of a coastwide growth curve would be required.

All three length-based data-moderate assessments were reviewed by the Groundfish Sub-committee (GFSC) of the Scientific and Statistical Committee (SSC) at the beginning of the June 2021 Council meeting. All model-areas for the three species (e.g., four model areas for copper rockfish, three for quillback rockfish, and one area for squarespot rockfish) were endorsed by the SSC as BSIA for use by management. The Council, in its discussion of that agenda item, requested that the SSC and GFSC take an additional look at the quillback rockfish assessment (note that the Pacific spiny dogfish, squarespot rockfish, and two California models for copper rockfish were also included in the Council request). Subsequently, the quillback rockfish assessment author responded to five further requests from the GFSC, and that work was reviewed by the GFSC in two separate meetings held on August 17th and September 29th of 2021. The SSC considered the GFSC's report from those meetings in September and November, and reiterated its endorsement

of the assessment as BSIA and appropriate for use in management and status determination (Agenda Item C.6.a, Supplemental SSC Report 1, September 2021; Agenda Item E.2.a, Supplemental SSC Report 1, November 2021). The Council adopted the assessments for all three species at the November 2021 council meeting.

Subsequent to the November 2021 Council meeting, the National Marine Fisheries Service (NMFS) determined that a rebuilding plan, though already conducted and reviewed, was not needed at that time because a separate California quillback rockfish stock was not defined in the Groundfish FMP. At the June 2023 meeting, the Council adopted state-level stock units for quillback rockfish as part of Amendment 31 to establish stock definitions for species that were assessed in 2021 and being assessed in 2023. Given the definition of a California quillback stock and the 2021 assessment that estimated the stock to be below the MSST, an updated rebuilding plan was provided by the NWFSC, reviewed by the GFSC and SSC, and endorsed by the SSC as BSIA at the November 2023 Council meeting (Agenda item E.2.a, Supplemental SSC Report 1, November 2023). On December 14, 2023 NMFS declared quillback rockfish off California overfished and in need of rebuilding.

3. Responses to Council questions on the 2021 assessment of quillback rockfish in California waters

At the September and November 2023 Council meetings, considerable criticism was voiced regarding the 2021 quillback rockfish assessment despite past endorsement by the SSC and Council at the November 2021 Council meeting, and little if any objection during the intervening two years. The NWFSC was asked to provide an informational report to address concerns with the assessment. The Science Center was later provided with a set of topic areas by Executive Director Burden, which are summarized below, each briefly in a single sentence, followed by the full text in brackets:

- The relationship between estimated stock biomass and fishing mortality. [The relationship between total biomass and fishing mortality. Several Council members have indicated they think the amount of catch coming in over the last two to three years could not be possible if the biomass is as small as the assessment says it is.]
- Changes in the estimated population age structure over time. [Is it possible to develop a plot of population-level age structure over time? If that's not changing, then First Principles tells us we're probably dealing with a stable stock that's not being overharvested.]
- Reconciling a declining stock with a stable average length of fishery catch. [Why the assessment indicates the stock is going down, while the length data over time does not appear to reflect a declining size/age (logic being, if a stock is being overfished then the average size should be dropping). Examining the commercial length data would indicate the stock is stable]
- The assessment model's sensitivity to natural mortality and the degree of confidence we have in the value used in the base model. [The range of possible Natural Mortalities in the assessment and the confidence around the estimate that was eventually used. The assessment is highly sensitive to this parameter and some Council members have expressed

curiosity about how that number in the model was derived and how confident we are about it. Additionally, if this parameter is related to maximum age, then how confident are we in the maximum age for the stock off California (knowing that some studies/books have indicated quillback reaches 95 years of age off BC)]

- The impact of fishing-area restrictions on the representativeness of data used in the assessment. [The representativeness of input data to the actual population given the amount of area off limits to fishing. Given the high site fidelity of quillback, and the amount of area that is restricted to fishing, doesn't the data being used in the model indicate what is happening at several localized areas rather than an entire coast.]
- Use of data or parameters from areas other than California in the California model. [The biological input data into the CA assessment appears to come from information at various locations up and down the west coast. While data from other areas of the coast may be the only data point available in some cases, this doesn't necessarily mean it is representative of a population off of California. When combined with the high level of sensitivity the stock assessment has to biological parameters, assuming that biological data from other regions is representative of California is concerning]

The relationship between estimated stock biomass and fishing mortality

Concern was voiced in the September 2023 Council meeting about the relative proportion of quillback rockfish catch mortality in California compared to the estimated biomass from the model. In response, the relationship between fishing mortality and exploitable biomass for a number of other species whose low stock status levels have necessitated rebuilding were examined. A summary of those findings is provided in Table 1. The values for quillback rockfish indicate that catch represented a higher percentage of age 3+ biomass in the 1990s, when the stock was first depleted, than in the final years of the assessed period. Although not shown in the table, catches in 2021 and 2022 would likely fall into the 20-30 percent range of 3+ biomass, which would be more comparable to many of the years in the 1992-1998 period.

Also shown on the first page of Table 1 are comparable values for cowcod, drawn from the most recent 2019 assessment. Catches removed 10-20 percent of the estimated cowcod summary biomass in six consecutive years, beginning in 1976, a period which was followed by seven more years in which catch represented 20-40 percent of summary biomass. On the second page of Table 1 are time series from two different canary rockfish assessments: the one conducted this year and the 2005 assessment. Please note that the reported summary biomass amounts in these assessments include different age ranges. Both assessments indicate that catch began exceeding 10 percent of the summary biomass by 1980, continuing through the late 1990s, with this metric approaching 26 percent in some years in the 1990s. Similarly for copper rockfish in the area south of Pt. Conception, catch began exceeding 10 percent of estimated age 3+ biomass in 1979 and remained there through 2000, with the exception of two years. Copper rockfish also had four years in which catch represented more than 20 percent of summary biomass: three in the mid-1980s and in 1996. The last page of Table 1 reports values for bocaccio and yelloweye rockfish. Catches for bocaccio first topped 10 percent of age 1+ biomass in 1967, which continued in 1973, for 20 of the next 21 years (ending in 1995). Finally for yelloweye rockfish, catch rose above 10 percent of age 8+

biomass in 1989, which continued for 8 of the next 10 years (ending in 2000). These cases illustrate that the high rates of exploitation for quillback rockfish in recent and earlier periods are similar to rates calculated from assessments for other species-areas where spawning output has been depleted to less than 25 percent of the unfished level.

Conclusion: The relationship between stock biomass and the amount of catch for quillback rockfish is consistent with other species with low stock status levels.

Changes in the estimated population age structure over time

The age-composition of the quillback rockfish stock off California is estimated to have changed dramatically since the 1970s. Population structure was stable from the 1950s through the early 1970s, with fish over 50 years of age comprising 9 percent of the total biomass, and those over 15 years of age accounting for 65 percent, as illustrated in the upper panel of Figure 2, which depicts the age-group shares of total biomass from 1950 through 2021. Catches started increasing in 1983 and then peaked in the early 1990s. As a result, the estimated fraction of unfished spawning output fell from 55 percent in 1980 to 10 percent in 1998, which severely truncated the age composition of the stock. The contribution of fish older than 15 years fell to just 3 percent by 1999. The lower panels of Figure 2 show the fraction of unfished spawning output and total fishing mortality for the same time period.

Conclusion: The population age structure for quillback rockfish has changed over time.

Reconciling a declining stock with a stable average length of fishery catch

As shown in Figure 3, there have been trends over time in the average length of quillback rockfish caught in the recreational and commercial fisheries off California. Furthermore, those trends are broadly consistent with the pattern of depletion estimated by the base model, particularly the near-complete removal of fish older than 15 by the end of the 1990s. Increases in average length in the last decade are consistent with a growing share of the stock composed of age 11-25 fish, as well as recent expansions of the area available to fishing. Figure 4 overlays the average length time series over the asymptotic portion of the coastwide growth curve used in the assessment. A long period of negative recruitment deviations for nearly all years since 2000 also contributes toward an increasing trend in average catch lengths due to smaller sized fish not contributing as much to the population as during periods of above average recruitment.

Conclusion: The patterns in average length are consistent with model estimates of biomass and recruitment patterns.

Sensitivity to natural mortality

Natural mortality is a critical value in stock assessments, and the assessment for quillback rockfish is no exception. Estimating natural mortality was a sensitivity that resulted in some of the largest change in model results, and natural mortality was selected as the primary axis of uncertainty for

decision tables. However, natural mortality is difficult to estimate biologically. The assessment described the rationale for the choice of natural mortality value as based on literature values for longevity. Using literature values for model parameters is an accepted and common approach for West Coast assessments. The formula for determining the median of the prior around natural mortality is determined by dividing 5.4 by the maximum age (Hamel and Cope, 2022). Longevity estimates in the literature for quillback rockfish along the U.S. West Coast come from samples collected in waters off Washington or farther north. The value for maximum age used in the 2021 quillback rockfish assessment was 95 years (Yamanaka and Lacko, 2001). Although this study is based on data from southern Canada, it is widely cited in recent applications across the U.S. West Coast as the maximum age for quillback rockfish (e.g., Love et al., 2002; Palsson et al., 2009). A later study with an updated dataset from the one used in Yamanaka and Lacko (2001) shows that the next oldest age from southern Canada is 80 years (COSEWIC, 2009). The maximum age given from other recent studies include 73 years among samples in Puget Sound (Palsson et al., 2009), and 90 years among samples in southeast Alaska (Munk, 2001). It should be noted that longevity values between 73-95 all correspond to natural mortality estimates below the value used for the high state of nature, which also estimates that quillback rockfish are below the minimum stock size threshold of 25 percent. A number of older studies provide values for maximum age ranging from 15-73, but age-validation studies support higher values (Kerr et al., 2005), as do data collected and used within the 2021 quillback rockfish assessments (three fish sampled off Washington were aged at or greater than 69 years), despite the history of exploitation which would be expected to result in a lower maximum observed age relative to longevity. In the absence of information specific to California, there is limited justification to assume a greatly different value for longevity (and therefore natural mortality) for California from that used in the other 2021 assessments.

Conclusion: In the absence of California-specific literature studies, there is limited justification to assume a greatly different value for longevity (and therefore natural mortality) for California compared to Oregon and Washington.

The impact of fishing-area restrictions on the representativeness of data used in the assessment

Assessment models use the data available to them. Fishing-area restrictions limit collection of data from some areas. Despite the improved data availability and analysis in the quillback rockfish stock assessment, assessors were unable to fully account for potential biomass within geographic areas closed to fishing for quillback rockfish due to a lack of available monitoring data in closed areas, an ongoing issue for all nearshore rockfish stocks off the coast of California and Oregon. Selectivity blocks that corresponded to major changes in fishing restrictions were used within sensitivity runs for the 2021 assessment to explore in part how changes to fishing-area restrictions would affect model results. Some sampling programs sample within closed areas (e.g., CCFRP, CDFW ROV) and these data are planned to be incorporated in future assessments where such data are able to be used under the PFMC Terms of Reference. However, sensitivities within the 2023 copper rockfish stock assessments showed these data had limited impact on model results compared to other survey data sources for both the northern and southern California models (Figure 91 in Monk et al., 2023, and Figure 112 in Wetzel et al., 2023).

Conclusion: Limited data in areas closed to fishing is a common issue for assessments. This remains an area for future research.

Use of data or parameters from areas other than California in the California model

The current assessment was based on data from recreational and commercial fisheries that were specific to California along with coastwide or regional scientific research studies where California-specific data were unavailable or insufficient to estimate parameters on their own. Sharing data across adjoining areas is common for assessments, especially for species with limited enough data to warrant an LB-DM assessment. Increased sampling by the state of California would help reduce the need to use data from other regions in future assessments. The biggest concern in comments at the September 2023 Council meeting with the use of data from other areas for the California quillback assessment seemed to be related to growth estimation, to which the assessment model was found to be sensitive. Growth data were extensively reviewed by the GFSC and SSC during the August and September 2021 reviews. The reviews supported the conclusion by the STAT that California age and length data were insufficient to estimate a California-specific growth curve. Details of these analyses are extensively described in the reports from these meetings. Less concern was voiced for other biological relationships (though see response to natural mortality above).

Conclusion: This issue has been extensively discussed during reviews in 2021. Increased sampling by California would help reduce the need to use data from other regions in future assessments.

4. Data collection needs to support assessments

Lack of age data from California continues to be a serious challenge

The lack of ongoing random otolith collections from commercial and recreational fisheries in California poses serious challenges to assessments and is not isolated to only quillback rockfish. Comparing the number of available read ages across the modeled areas in the recent assessments of black rockfish and vermilion and sunset rockfish from the commercial and recreational fisheries highlight the severity of the issue. Since 2010, there were 0 commercial and recreational ages available for the two California assessments of vermilion and sunset rockfish, compared to 1,469 and 623 ages available from Oregon and Washington, respectively. Yet 97 percent of the coastwide spawning output for vermilion and sunset rockfish is estimated to occur in waters off California. The assessments of black rockfish in California had a total of 1,720 ages associated with commercial or recreational fisheries since 2010 compared to 22,956 ages available in Oregon and 19,498 in Washington for the same time period. The ages available in California for black rockfish comprise only 3 percent of the total ages coastwide, far below the Coastwide proportion of estimated black rockfish spawning output estimated to occur in California (e.g., 33 percent in California, 41 percent in Oregon, and 26 percent in Washington). The lack of otoliths collected from fisheries in California has also impacted other assessments. The 2015 assessment of China rockfish in California (Dick et al., 2016), the 2017 assessment of California scorpionfish (Monk et al., 2017), and the 2019 assessment of gopher and black and yellow rockfish (Monk and He,

2019) all have 0 ages associating with fishing fleets in the model. Each of the above assessments in California relied heavily on ages collected by surveys (e.g., CCFRP, NWFSC Hook & Line, NWFSC West Coast Groundfish Bottom Trawl [WCGBT]) when available, various historical research projects (e.g., Jeff Abrams, Bob Lea, 1976-79 CDFW Research Survey), or historical fishery collections. In California, up until 2022 there was no mandatory sampling of the commercial fisheries and challenges remain in obtaining any age structure sampling from the live-fish fishery.

Starting in 2022 a cooperative otolith collection program led by scientists at the Southwest Fisheries Science Center (SWFSC) with onboard Charter-Party Fishing Vessels (CPFV) has attempted to fill the otolith collection void to support nearshore assessments in California. Each of the participating CPFVs has agreed to set aside time from their regular operations to follow random sampling protocols and to send samples to the SWFSC. The SWFSC-CPFV cooperative collection program collected over 700 otoliths in 2022 alone that supported the 2023 assessments of copper rockfish in California. In 2022 and 2023, this collection program began collecting data for quillback rockfish with at least 154 otoliths collected by mid-December of 2023. This data collection program has been a success to-date due to the willingness of CPFV owners and operators to volunteer their time and effort to support assessment science. However, these efforts should not be considered an adequate replacement for ongoing sustained random collections from commercial and recreational fisheries particularly since they depend upon ongoing volunteer participation.

The lack of available otoliths across species within California fisheries often requires assessments to heavily rely on otoliths from historical research projects or ad-hoc CDFW collections, which presents at least two issues for assessments. First, any age data used within an assessment from these sources can only be used to estimate growth within the model. In contrast, randomly collected age data from fishery sources and surveys can provide information not only on growth but also on population age-structure and the strength or weakness of recruitment events. Hence, relying only on ad-hoc collections hinders robust population estimates in assessments. The second issue is that California lacks a cataloged inventory of unread nearshore otolith structures. Prior to a species being selected for assessment, it can be challenging to know what otoliths are truly available for age reading before a search is conducted. This greatly hinders the ability to understand the age data available but also limits the ability to conduct age reading on the tight timeline for assessments. To be considered "available to assessors" in a useful way, structures must be 1) physically located, 2) linked with meta-data containing fish length and other descriptors, and 3) transported to an agreed-upon ageing lab for reading within the time. It is also important to note that California is the only state that does not currently have a state-run ageing lab.

Age data available for the 2021 assessment for quillback rockfish and ongoing collection to support a future assessment of quillback rockfish

At the November Council meeting, Agenda Item E.2.a, Supplemental CDFW Report 2, November 2023, states that "...123 otoliths collected in California remain unread from previous collections that were available to assessors for the last assessment that were not prioritized for use." This statement is incorrect. First, all California quillback samples that were identified prior to the initial data deadline for the assessment review were prioritized and read in time to be included in the external growth estimation used within the California model. Following the June 2021 Council

meeting, additional samples were identified, and those were aged (i.e., to bring the total to 143 ages) as rapidly as possible so that they could be included in follow-up assessment exploration that occurred over the summer. The additional samples that were collected as part of the Jeff Abrams research were not identified and transferred to the Newport Ageing Lab in time to be read for inclusion during additional model review in September 2021. However, they were read later that fall, and are included in the ageing summary table above. The only age structures that were from available cataloged collections, linked to complete meta-data, and sent to the ageing lab from California waters prior to the data deadline for the original June 2021 review were the 21 otoliths collected by the NWFSC West Coast Groundfish Bottom Trawl (WCGBT) survey. As noted above, the lack of known available age-structures in California was discussed at the pre-assessment data workshop held in October of 2020. Only after the June 2021 Council meeting, which occurred after the initial June review of the assessment, with the Council requesting that the assessment be reconsidered by the SSC to review growth and modeling choices, was a concerted effort made by staff at the SWFSC to locate samples with data and ship them to the Newport Ageing Lab, where they were aged expeditiously in order to support additional analyses that were reviewed in August and September.

As of January 2024, the Newport Ageing Lab has aged 578 quillback rockfish and has 206 additional structures on hand to be aged (e.g., 154 collected by SWFSC-CPFV cooperative collection and 52 collected by California Recreational Fisheries Survey [CRFS]), and other collections are anticipated to be sent later in 2024 (Table 2). Roughly 80 percent of the structures that have been aged were collected north of Cape Mendocino, and fewer than 8 percent are from fish that were smaller than 30 cm. So, at present, not only are there relatively few total ages available from California, but they are not drawn in a balanced manner from throughout the California extent of the stock, nor do they provide a reliable basis for estimating the lower end of the growth curve. There are plans underway by the SWFSC that will hopefully enhance available ages, but those data may not be available until well into 2024.

With regard to otoliths that have been collected since the fall of 2021, we have been in touch with individuals holding those samples and they have recently been shipped to Newport to be aged or have stated intentions to ship them early in 2024. Secondly, we must emphasize that assembling a set of ages (and corresponding lengths) that is sufficient for estimating a reliable growth curve is not solely a matter of numbers. Having sufficient samples from small fish is essential to reliably estimating the shape of the growth curve for very young fish. Given the form of the von Bertalanffy equation, the shape of the curve in the region of the youngest ages can also impact the estimated length at age of somewhat older fish. Additionally, the severe truncation of the California stock's age structure that occurred by 2000, prior to the imposition of depth restrictions, suggests that even if samples were collected from the depths that have been closed for two decades, they are very unlikely to provide adequate information about the older end of the age-length relationship. Consequently, it should not be taken for granted that simply increasing the number of structures available for ageing, by 100 or 200, will automatically resolve the challenge of estimating a reliable California-specific growth curve.

Another consideration, with respect to the prospect of developing a benchmark assessment for quillback rockfish in 2025, is that all of the current collection of otoliths from California fisheries is being conducted as special projects. There is no standardized collection of otoliths that would

permit existing fishery ages to be used to directly characterize the age-distribution of fishery removals. The ACLs associated with the alternative rebuilding strategies for quillback rockfish starting in 2025 will present real challenges to collecting age data in the future. Other groundfish species managed under rebuilding plans have experienced similar data challenges but the future limitations for quillback rockfish may be one of the most constraining situations off the West Coast. The limited random collections from the commercial and recreational fisheries following the 2021 assessment, aside from the SWFSC led cooperative sampling program, represents a missed opportunity to better understand the population of quillback rockfish in California waters and to inform future assessments given the expected future constraints to catch of quillback rockfish.

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Tables

Table 1. Time series of catch and summary/exploitable biomass, for selected species estimated to be overfished.

2021 Quillback (All CA)						2019 Cowcod (S. of Pt. Conception)				
Year	Total catch	Age-3+ biomass (mt)	**Catch/ 3+ Biomass**	Fraction of Unfished		Year	Total catch	Summary biomass (mt)	**Catch/ Summary Biomass**	Fraction of Unfished
1981	5.5	231.6	2.4%	0.52		1966	76.6	2,489	3.1%	68%
1982	5.6	228.1	2.5%	0.51		1967	102.4	2,462	4.2%	67%
1983	40.6	224.8	**18.0%**	0.50		1968	105.0	2,412	4.4%	66%
1984	13.6	187.6	7.2%	0.41		1969	125.1	2,359	5.3%	64%
1985	12.3	177.8	6.9%	0.39		1970	95.9	2,288	4.2%	62%
1986	13.3	170.3	7.8%	0.37		1971	106.1	2,246	4.7%	61%
1987	5.7	163.4	3.5%	0.35		1972	152.6	2,196	7.0%	60%
1988	2.1	166.1	1.3%	0.35		1973	171.8	2,104	8.2%	57%
1989	11.6	173.2	6.7%	0.36		1974	183.7	1,996	9.2%	54%
1990	17.6	178.9	9.8%	0.35		1975	182.6	1,880	9.7%	51%
1991	73.9	177.0	**41.8%**	0.34		1976	189.4	1,767	**10.7%**	48%
1992	35.4	121.5	**29.1%**	0.22		1977	191.2	1,651	**11.6%**	44%
1993	40.7	101.2	**40.2%**	0.18		1978	203.2	1,536	**13.2%**	41%
1994	23.9	76.2	**31.4%**	0.13		1979	262.2	1,414	**18.5%**	38%
1995	12.7	68.2	**18.6%**	0.11		1980	223.6	1,244	**18.0%**	33%
1996	15.6	70.7	**22.0%**	0.11		1981	216.0	1,113	**19.4%**	29%
1997	23.0	73.2	**31.4%**	0.11		1982	327.5	990	**33.1%**	26%
1998	15.0	66.9	**22.4%**	0.10		1983	177.1	779	**22.7%**	20%
1999	13.8	74.0	**18.7%**	0.10		1984	227.9	699	**32.6%**	17%
2000	13.3	78.2	**17.0%**	0.11		1985	208.1	582	**35.8%**	14%
2001	16.1	81.3	**19.8%**	0.12		1986	194.4	490	**39.7%**	12%
2002	6.0	90.7	6.6%	0.13		1987	105.8	415	**25.5%**	10%
2003	13.9	104.3	**13.4%**	0.16		1988	100.5	411	**24.4%**	9%
2004	5.6	108.2	5.2%	0.18		1989	38.7	412	9.4%	9%
2005	10.6	117.6	9.0%	0.21		1990	30.5	465	6.6%	10%
2006	14.6	120.1	**12.1%**	0.23		1991	26.4	525	5.0%	12%
2007	19.3	116.8	**16.5%**	0.23		1992	35.8	587	6.1%	13%
2008	11.1	107.6	**10.3%**	0.22		1993	24.5	637	3.8%	15%
2009	6.9	104.7	6.6%	0.21		1994	39.6	693	5.7%	16%
2010	3.6	104.4	3.4%	0.21		1995	25.1	731	3.4%	17%
2011	5.5	106.4	5.1%	0.22		1996	29.9	774	3.9%	19%
2012	8.0	105.9	7.5%	0.22		1997	9.2	807	1.1%	20%
2013	3.6	102.7	3.5%	0.22		1998	4.0	856	0.5%	21%
2014	3.0	106.0	2.8%	0.22		1999	7.2	908	0.8%	23%
2015	8.6	109.6	7.8%	0.22		2000	4.9	959	0.5%	25%
2016	9.5	107.3	8.8%	0.22						
2017	12.5	103.4	**12.1%**	0.21		2020	12.3	76.3	**16.2%**	0.16
2018	12.8	95.9	**13.4%**	0.20		*2021*	*15.6*	*69.4*	***22.4%***	
2019	16.0	87.6	**18.3%**	0.18		*2022*	*18.1*	*62.1*	***29.2%***	

Table 1 (cont.). Time series of catch and summary/exploitable biomass, for selected species estimated to be overfished.

2005 Canary (Coastwide)

Year	Total catch	Age-3+ biomass (mt)	**Catch/ 3+ Biomass**	Fraction of Unfished
1971	1,521	46,801	3.2%	0.51
1972	1,604	46,135	3.5%	0.50
1973	2,482	45,351	5.5%	0.49
1974	1,863	43,723	4.3%	0.47
1975	1,862	42,742	4.4%	0.46
1976	1,460	41,826	3.5%	0.45
1977	2,048	41,390	4.9%	0.44
1978	3,074	40,455	7.6%	0.43
1979	3,461	38,577	9.0%	0.41
1980	4,132	36,401	**11.4%**	0.38
1981	3,372	33,593	**10.0%**	0.35
1982	5,374	31,484	**17.1%**	0.33
1983	4,858	27,471	**17.7%**	0.29
1984	2,396	24,033	10.0%	0.25
1985	2,731	22,912	**11.9%**	0.24
1986	2,244	21,414	**10.5%**	0.23
1987	3,147	20,374	**15.4%**	0.22
1988	2,767	18,401	**15.0%**	0.19
1989	3,270	16,747	**19.5%**	0.18
1990	2,751	14,571	**18.9%**	0.15
1991	3,170	12,869	**24.6%**	0.13
1992	2,822	10,761	**26.2%**	0.11
1993	2,187	8,967	**24.4%**	0.09
1994	1,205	7,761	**15.5%**	0.07
1995	1,190	7,382	**16.1%**	0.07
1996	1,531	6,933	**22.1%**	0.07
1997	1,441	6,087	**23.7%**	0.06
1998	1,513	5,258	**28.8%**	0.05
1999	856	4,287	**20.0%**	0.04
2000	181	3,889	4.6%	0.04
2001	123	4,118	3.0%	0.04
2002	104	4,368	2.4%	0.05
2003	48	4,601	1.0%	0.05
2004	38	4,847	0.8%	0.05

Canary 2023 (Coastwide)

Year	Total catch	Age-5+ biomass (mt)	**Catch/ 5+ Biomass**	Fraction of Unfished
1971	2,016	45,052	4.5%	0.04
1972	1,924	44,892	4.3%	0.04
1973	2,782	45,320	6.1%	0.06
1974	2,317	44,392	5.2%	0.05
1975	2,045	43,554	4.7%	0.05
1976	1,763	42,837	4.1%	0.04
1977	1,855	42,633	4.4%	0.04
1978	4,346	42,624	**10.2%**	0.10
1979	2,921	39,790	7.3%	0.07
1980	4,574	38,429	**11.9%**	0.12
1981	3,580	35,745	**10.0%**	0.10
1982	5,702	33,666	**16.9%**	0.17
1983	5,297	29,800	**17.8%**	0.18
1984	2,811	26,369	**10.7%**	0.11
1985	3,053	24,951	**12.2%**	0.12
1986	2,698	23,760	**11.4%**	0.11
1987	3,435	22,769	**15.1%**	0.15
1988	3,474	20,830	**16.7%**	0.17
1989	3,674	19,043	**19.3%**	0.19
1990	3,265	17,032	**19.2%**	0.19
1991	3,915	15,303	**25.6%**	0.26
1992	3,302	13,015	**25.4%**	0.25
1993	2,900	11,325	**25.6%**	0.26
1994	1,429	10,208	**14.0%**	0.14
1995	1,332	10,465	**12.7%**	0.13
1996	1,591	10,671	**14.9%**	0.15
1997	1,487	10,669	**13.9%**	0.14
1998	1,498	10,462	**14.3%**	0.14
1999	901	10,244	8.8%	0.09
2000	205	10,649	1.9%	0.02
2001	123	11,738	1.0%	0.01
2002	97	12,722	0.8%	0.01
2003	69	13,686	0.5%	0.01
2004	47	14,558	0.3%	0.01

Table 1 (cont.). Time series of catch and summary/exploitable biomass, for selected species estimated to be overfished.

2023 Copper rockfish (south of Pt Conception)

Year	Total catch	Age-3+ biomass (mt)	**Catch/ 3+ Biomass**	Fraction of Unfished
1970	69.5	1,812	3.8%	0.89
1971	66.8	1,785	3.7%	0.86
1972	92.2	1,763	5.2%	0.84
1973	111.5	1,710	6.5%	0.82
1974	138.1	1,629	8.5%	0.79
1975	142.1	1,518	9.4%	0.74
1976	116.9	1,405	8.3%	0.69
1977	109.0	1,314	8.3%	0.64
1978	108.0	1,229	8.8%	0.60
1979	151.7	1,143	**13.3%**	0.56
1980	147.9	1,014	**14.6%**	0.50
1981	85.6	888	9.6%	0.44
1982	156.7	824	**19.0%**	0.40
1983	82.0	684	**12.0%**	0.34
1984	91.4	620	**14.7%**	0.30
1985	115.7	547	**21.2%**	0.27
1986	101.2	448	**22.6%**	0.22
1987	78.3	368	**21.3%**	0.18
1988	52.2	324	**16.1%**	0.15
1989	53.4	314	**17.0%**	0.13
1990	60.0	307	**19.6%**	0.12
1991	52.6	295	**17.8%**	0.11
1992	33.8	290	**11.6%**	0.11
1993	20.0	310	6.5%	0.11
1994	62.5	350	**17.8%**	0.13
1995	51.2	345	**14.8%**	0.13
1996	97.1	343	**28.3%**	0.13
1997	42.8	286	**15.0%**	0.11
1998	54.8	281	**19.5%**	0.11
1999	49.8	258	**19.3%**	0.10

Continued

Year	Total catch	Age-3+ biomass (mt)	**Catch/ 3+ Biomass**	Fraction of Unfished
2000	27.5	234	**11.8%**	0.10
2001	20.5	230	8.9%	0.10
2002	14.4	247	5.8%	0.10
2003	17.5	268	6.5%	0.10
2004	16.8	282	6.0%	0.11
2005	29.8	299	10.0%	0.12
2006	13.7	311	4.4%	0.12
2007	32.3	333	9.7%	0.13
2008	26.9	339	7.9%	0.14
2009	24.9	339	7.3%	0.14
2010	23.4	351	6.7%	0.15
2011	44.8	369	**12.1%**	0.15
2012	51.0	406	**12.6%**	0.15
2013	79.5	467	**17.0%**	0.15
2014	61.7	489	**12.6%**	0.16
2015	82.2	530	**15.5%**	0.17
2016	99.0	573	**17.3%**	0.19
2017	86.9	565	**15.4%**	0.19
2018	101.3	540	**18.8%**	0.20
2019	80.7	486	**16.6%**	0.20
2020	70.3	433	**16.2%**	0.19
2021	50.7	379	**13.4%**	0.18
2022	19.5	338	5.8%	0.16

Table 1 (cont.). Time series of catch and summary/exploitable biomass, for selected species estimated to be overfished.

2015 Bocaccio (US S. of Cape Blanco, OR)

Year	Total catch	Age 1+ biomass (mt)	**Catch/ Summary Biomass**	Fraction of Unfished
1962	1,743	24,898	7.0%	0.48
1963	2,021	27,374	7.4%	0.52
1964	1,533	29,816	5.1%	0.57
1965	1,753	32,876	5.3%	0.63
1966	3,428	40,400	8.5%	0.70
1967	5,336	46,818	**11.4%**	0.78
1968	3,410	50,478	6.8%	0.93
1969	2,359	54,368	4.3%	1.08
1970	2,858	58,217	4.9%	1.18
1971	2,519	60,940	4.1%	1.24
1972	3,661	62,554	5.9%	1.30
1973	7,207	62,232	**11.6%**	1.33
1974	9,005	58,460	**15.4%**	1.24
1975	6,411	53,121	**12.1%**	1.11
1976	6,186	50,005	**12.4%**	1.06
1977	4,865	45,606	**10.7%**	1.01
1978	4,382	44,778	9.8%	0.95
1979	6,172	46,677	**13.2%**	0.90
1980	5,543	46,562	**11.9%**	0.91
1981	5,812	45,449	**12.8%**	0.95
1982	6,772	41,823	**16.2%**	0.93
1983	5,770	35,154	**16.4%**	0.82
1984	4,491	28,328	**15.9%**	0.68
1985	2,811	24,073	**11.7%**	0.55
1986	3,168	22,218	**14.3%**	0.48
1987	2,693	20,193	**13.3%**	0.44
1988	2,346	18,476	**12.7%**	0.42
1989	2,808	17,663	**15.9%**	0.38
1990	2,699	16,332	**16.5%**	0.34
1991	1,739	14,964	**11.6%**	0.32
1992	1,857	14,375	**12.9%**	0.31
1993	1,635	13,402	**12.2%**	0.29
1994	1,341	12,378	**10.8%**	0.27
1995	768	11,458	6.7%	0.26
1996	578	10,938	5.3%	0.25

2017 yelloweye (Coastwide)

Year	Total catch	Age 8+ Biomass (mt)	**Catch/ 8+ Biomass**	Fraction of Unfished
1980	253.6	6,123	4.1%	0.59
1981	340.9	5,958	5.7%	0.57
1982	551.7	5,708	9.7%	0.54
1983	511.8	5,277	9.7%	0.49
1984	329.8	4,883	6.8%	0.45
1985	447.3	4,668	9.6%	0.43
1986	297.2	4,330	6.9%	0.39
1987	342.4	4,145	8.3%	0.38
1988	321.5	3,928	8.2%	0.35
1989	385.8	3,755	**10.3%**	0.33
1990	307.6	3,550	8.7%	0.31
1991	440.9	3,401	**13.0%**	0.29
1992	412.0	3,135	**13.1%**	0.26
1993	389.0	2,875	**13.5%**	0.23
1994	266.6	2,620	**10.2%**	0.21
1995	270.6	2,478	**10.9%**	0.20
1996	291.0	2,323	**12.5%**	0.18
1997	305.0	2,138	**14.3%**	0.17
1998	154.2	1,928	8.0%	0.15
1999	194.8	1,854	**10.5%**	0.15
2000	62.7	1,741	3.6%	0.14
2001	67.1	1,791	3.7%	0.15
2002	14.5	1,823	0.8%	0.15
2003	12.7	1,885	0.7%	0.15
2004	10.2	1,945	0.5%	0.16
2005	10.8	2,009	0.5%	0.17
2006	7.5	2,084	0.4%	0.18
2007	12.8	2,199	0.6%	0.18
2008	9.3	2,278	0.4%	0.19
2009	11.7	2,372	0.5%	0.20
2010	6.7	2,548	0.3%	0.21
2011	8.3	2,680	0.3%	0.22
2012	11.2	2,782	0.4%	0.23
2013	10.4	2,887	0.4%	0.24
2014	8.8	3,001	0.3%	0.25

Table 2. California quillback rockfish otoliths that have been provided to the Newport Ageing Lab by source, fish length, and ageing status. There are an additional 141 otoliths collected in 2021, 2022, and 2023 from California recreational fisheries that are not shown in the below table because they have not yet been received by the Newport Ageing Lab.

	Lower bound of 2-cm length bin																		As of 12/2023		
	10	14	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	Aged	Unaged	Total
CDFW																					
Commercial							1	2	7	6	10	34	54	30	19	4	3	1	**171**		**171**
Recreational							1	4	0	1	5	10	2	5	9	0	1		**38**		**38**
Abrams Research			1		2	2	1	7	12	14	31	18	12	9	7	2	1		**119**		**119**
Other				1			1	5	7	8	3	2							**27**		**27**
CCFRP				2	10	8	12	11	9	10	9	10	10	6	2	1			**48**	**52**	**100**
SWFSC-CPFV Coop			1	13	11	9	13	9	46	25	17	7		2	1					**154**	**154**
NWFSC WCGBT Survey	1	1								2	3	5	5	3	1				**21**		**21**
Total	**1**	**1**	**2**	**16**	**23**	**19**	**29**	**38**	**81**	**66**	**78**	**86**	**83**	**55**	**39**	**7**	**5**	**1**	**578**	**206**	**784**

Figures

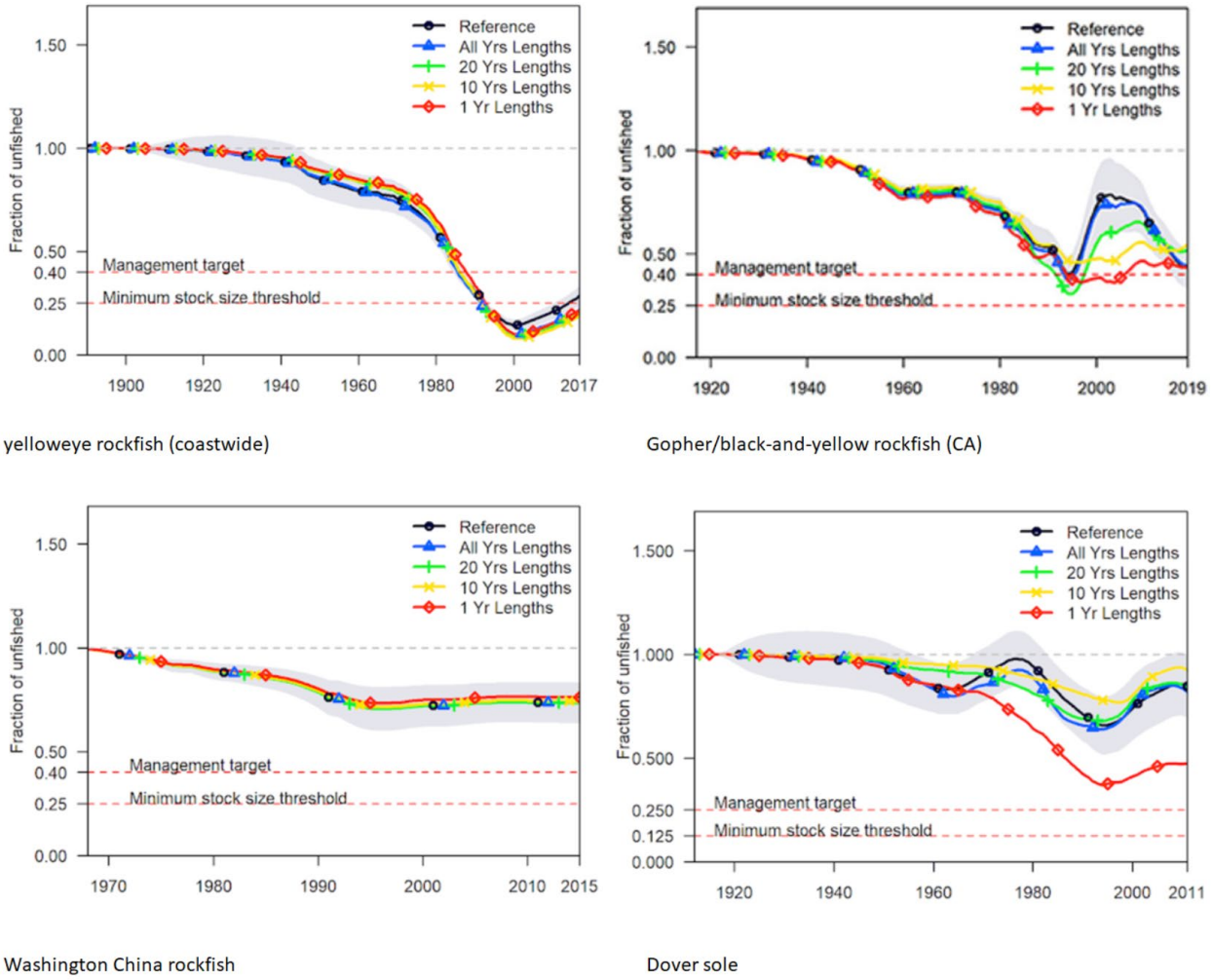
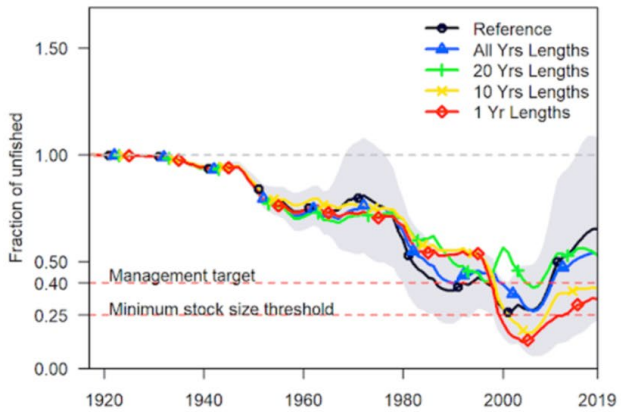
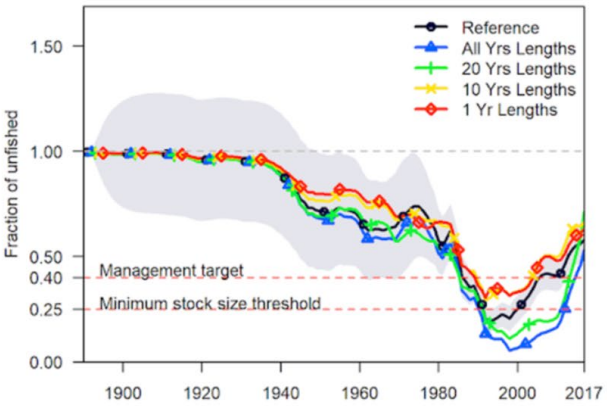


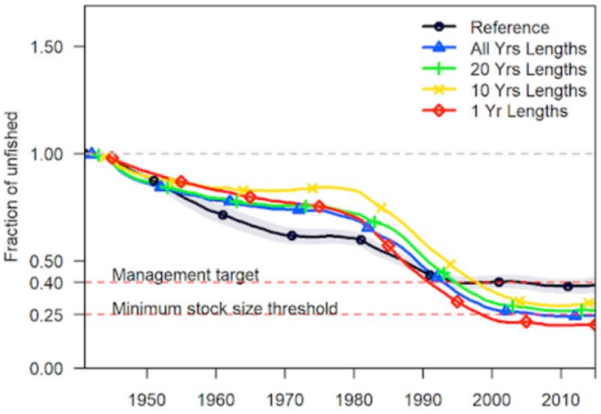
Figure 1. Comparison of estimates of relative spawning biomass between accepted benchmark base models and length-based, data-moderate models using varying durations of length data and no survey indices.



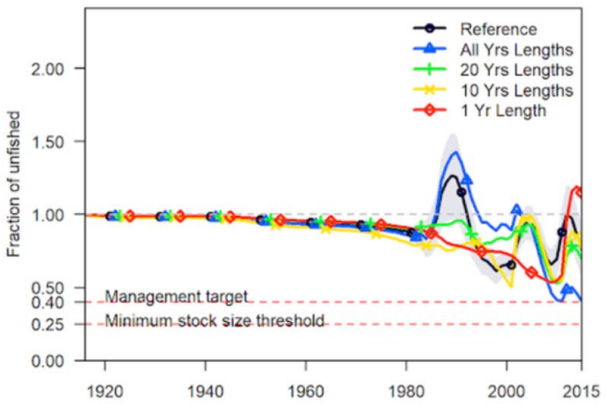
cabezon (Pt Conception to California-Oregon border)



Lingcod North of 40°10'



Washington black rockfish



Kelp greenling (Oregon)

Figure 1 (cont.). Comparison of estimates of relative spawning biomass between accepted benchmark base models and length-based, data-moderate models using varying durations of length data and no survey indices.

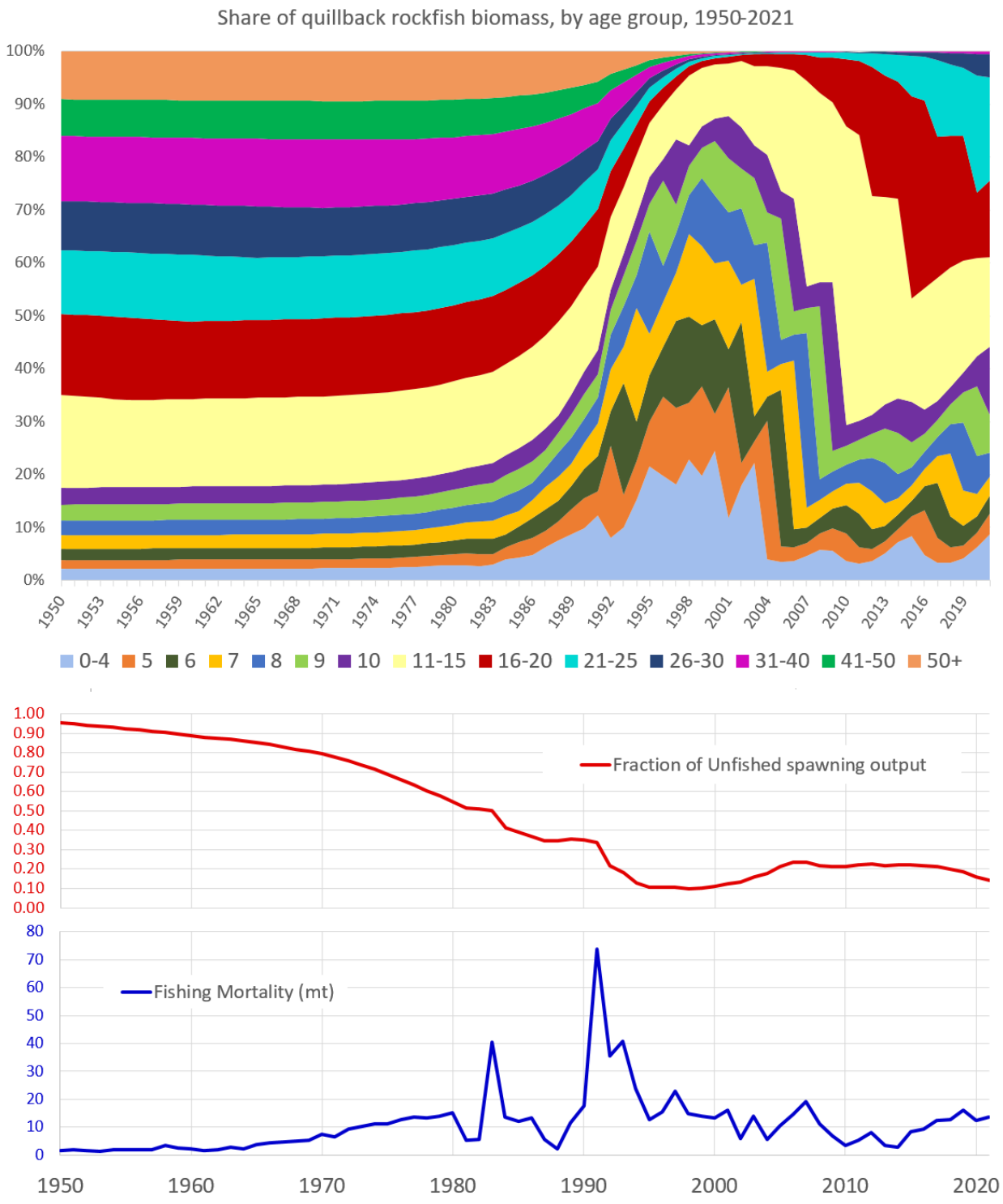


Figure 2. Proportion of the population by age between 1950 and 2019 (top panel). The estimated fraction of unfished spawning output and the relative fishing mortality between 1950 and 2019 (bottom panel).

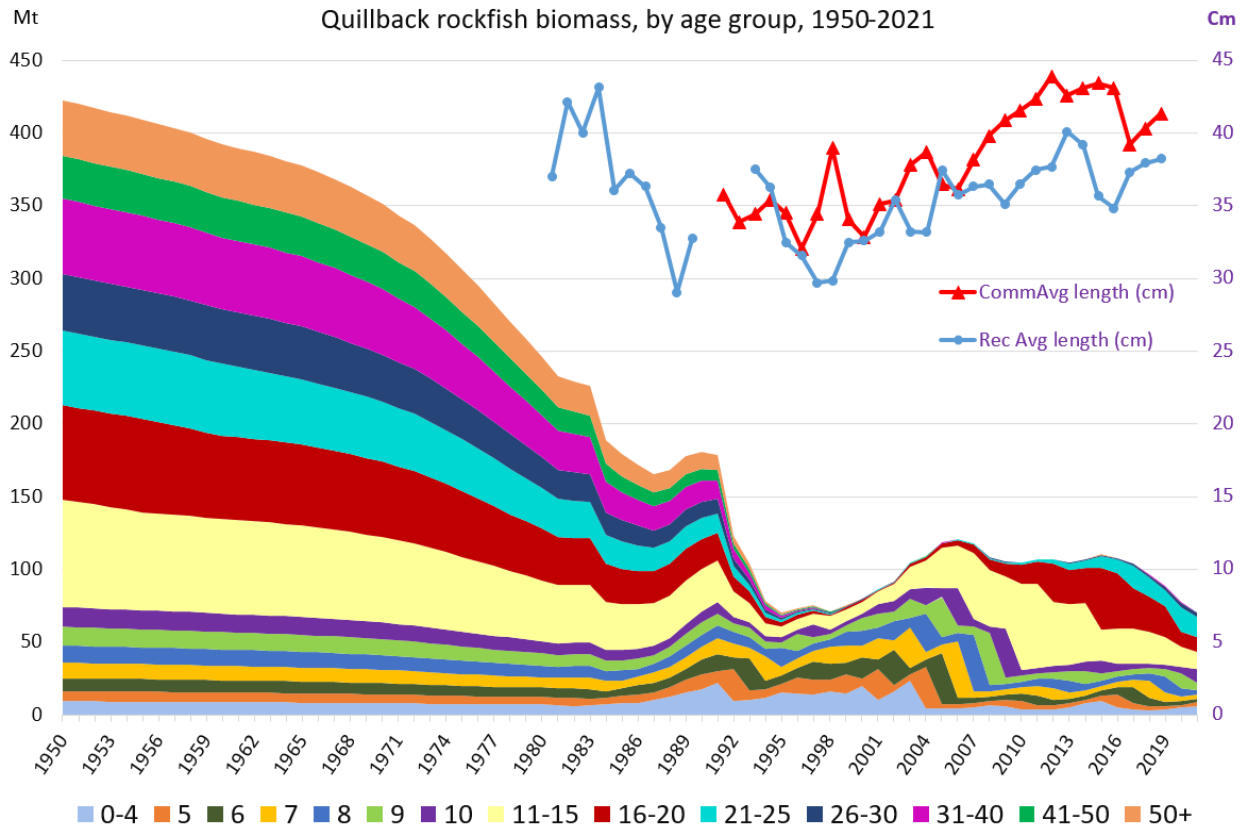


Figure 3. Biomass by age between 1950 and 2019 and trends in the average length in the fishery and recreational composition data.

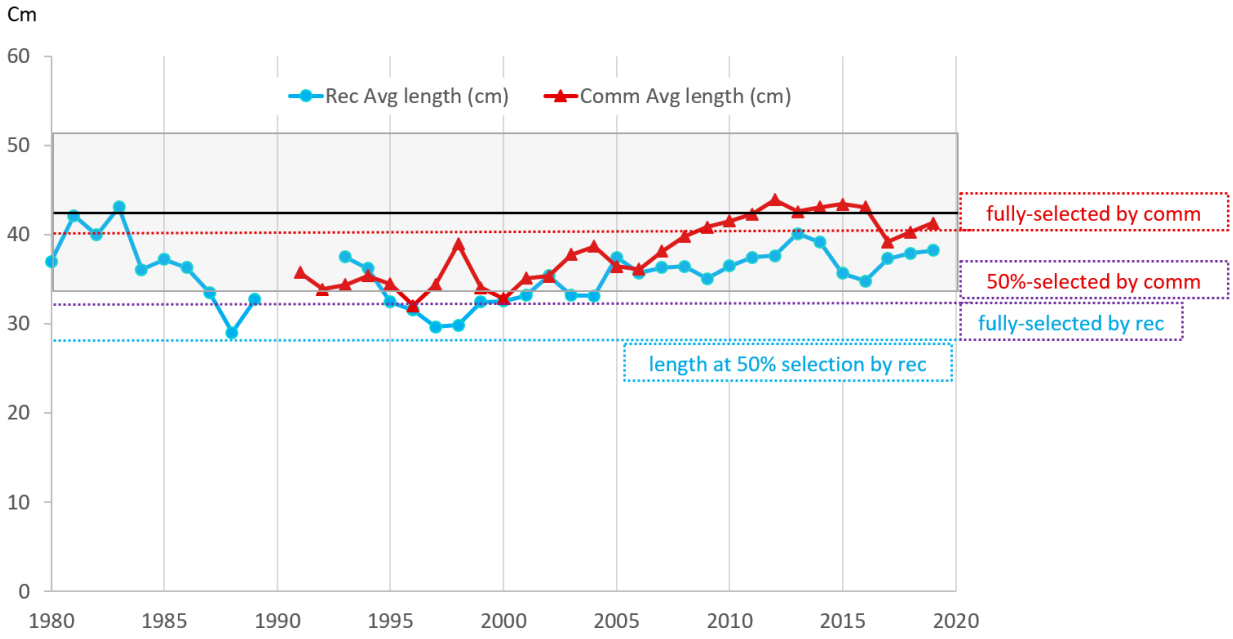


Figure 4. Average length (cm) of 50 percent and full selection by the commercial and recreational fleets.