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DRAFT Status of Sablefish (*Anoplopoma fimbria*) along the US West coast in 2021

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Stock

This update assessment reports the status of sablefish (*Anoplopoma fimbria*) off the US West coast using data through 2020. The resource is modeled as a single stock; however, sablefish disperse to and from offshore seamounts, along the coastal waters of the US West Coast, Canada, and Alaska, and across the Aleutian Islands to the western Pacific. Their movement is not explicitly accounted for in this analysis.

Catches

For the 2019 benchmark assessment, a variety of sources were used to reconstruct state-specific historical sablefish landings (i.e., fish brought to market), creating a series of landings from 1890 to present. In general, these reconstructions are more reliable than those for many other groundfish species because of the consistent identification of sablefish to the species level. Historical-landings reconstructions for sablefish have been completed for California, Oregon, and Washington, extending landings to the beginning of the US West Coast sablefish fishery (Figures 1 and 2). Fishery discard rates and weights were fit within the assessment model, i.e., simultaneous estimation of total catches and other model parameters. This internal estimation can result in model estimates of total mortality that differ between stock assessments, even when the input landings remain unchanged, due to changes in fixed and estimated parameter values, priors, or parameterizations. Model estimates of fishery discards in this update assessment resulted in model estimated total dead catches that were an average of 1.84% larger than the landings input into the stock assessment model over the last decade.

Historically, sablefish landings were just below recent landings (<4,000 mt) until the end of the 1960s and were primarily harvested by fixed gear (Figure 1). Large catches (24,395 mt) by foreign vessels fishing pot gear in 1976 resulted in the largest landings reported in a single year. A rapid rise in domestic pot and trawl landings followed this peak removal, such that, on average, nearly 8,400 mt of sablefish were landed per year between 1976 and 1990. Subsequently, annual landings have remained below 9,000 mt and, during the most recent decade, have been divided approximately 67%/33% between fixed and trawl gears, respectively. An Individual Fishing Quota (IFQ) program, referred to as "catch shares", was implemented for the U.S. West Coast trawl fleet beginning in 2011. Gear switching is allowed within the program such that fixed gear can be used to catch sablefish under trawl IFQ. This has resulted in changes in fleet behavior, the distribution of fishing effort, and discarding rates for both fisheries. Complete observer coverage on all vessels fishing IFQ quota became mandatory at the start of the program, while coverage in the other sectors remained stratified by port. The lack of historical observer coverage, and consequently information on total catch and age and length compositions, contributes to uncertainty regarding selectivity and retention during the historical period.

Table i: Recent landings by fleet, total landings summed across fleets, and the total mortality including discards.

Year	Fixed-gear	Trawl	Total Landings	Model-Estimated Total Dead Catch
2011	4,420.85	1,728.40	6,149.25	6,253.97
2012	3,670.22	1,514.58	5,184.80	5,283.60
2013	2,585.07	1,402.13	3,987.20	4,050.48
2014	2,924.26	1,292.20	4,216.46	4,294.90
2015	3,554.94	1,470.29	5,025.23	5,105.52
2016	3,829.86	1,475.95	5,305.81	5,401.39
2017	3,680.67	1,669.97	5,350.64	5,465.76
2018	3,648.68	1,478.26	5,126.94	5,220.22
2019	3,568.27	1,625.44	5,193.71	5,372.81
2020	2,660.03	1,102.72	3,762.75	3,882.69

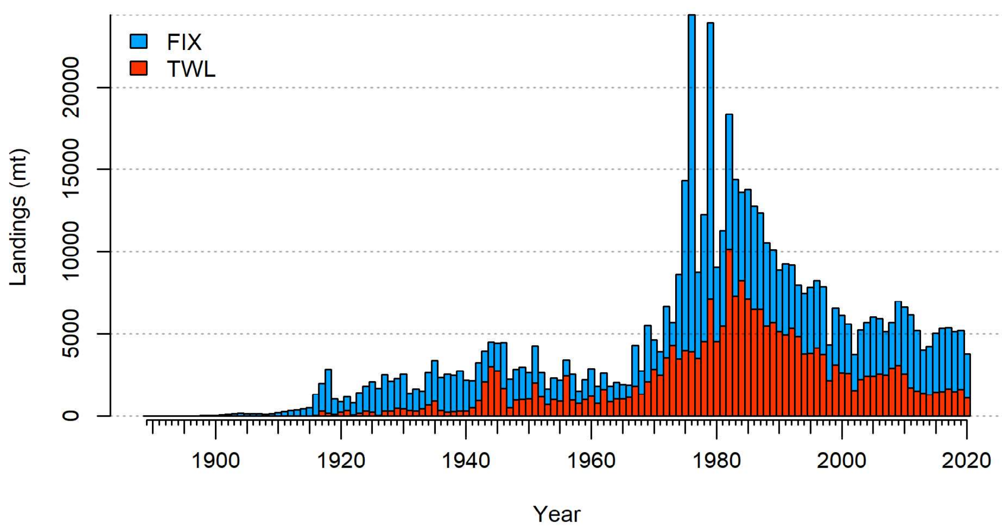


Figure i: Sablefish landings from 1890–2020 summarized by the gear types included in the base model, fixed-gear and trawl. Landings include those from foreign fleets, which are largely responsible for the peaks in 1976 and 1979.

Data and Assessment

The last benchmark stock assessment for sablefish took place during 2019 (Haltuch et al. (2019)), preceded by an update assessment during 2015 (Johnson et al. (2016)). The present (2021) update assessment used the most recent version of the Stock Synthesis modeling platform (3.30), and bridged between the sub-version used in the benchmark (v3.30.09, released 2019-03-09) and the latest release (v3.30.16, released 2020-09-03). Primary data sources include landings and age-composition data from the retained catch (Figure 3). For recent years, data on the discarded portion of commercial catch are available, including discard lengths, rates, and mean observed individual body weight of the discarded catch. The relative index of abundance estimated from the National Marine Fisheries Service (NMFS) Northwest Fisheries Science Center (NWFSC) West Coast Groundfish Bottom Trawl (WCGBT) Survey, which includes depths from 55 - 1,280 m, represents the primary source of information on the stock's trend and was updated and re-analyzed to include the most recent data, covering the period 2003-2019 (Figure 4); the updated index was consistent with the previous (Figures 5 and 12). Note that the WCGBT Survey does not access the closed Cowcod Conservation areas in southern California, and was not performed in 2020 due to the global SARS-CoV-2 pandemic. Other, discontinued, survey indices contribute information on trend and sablefish demographics: (a) NWFSC Slope Survey conducted from 1998-2002, (b) Alaska Fisheries Science Center (AFSC) Slope Survey (1997-2001), and (c) AFSC/NWFSC Triennial Shelf Survey (1980-2004). Additionally, an environmental time-series of sea level was used as a survey index of recruitment in the base model; this time-series was updated and re-analyzed using the latest tide gauge data (Figures 13 and 14).

All externally estimated model parameters, (a) weight-length relationship, (b) maturity schedule, and (c) fecundity relationships remained unchanged from the 2019 benchmark assessment. As in previous assessments, growth and natural mortality were estimated using sex-specific relationships. Uncertainty in recruitment was included by estimating a full time-series of deviations from the stock-recruitment curve. The 'one-way-trip' nature of the time-series does not facilitate estimation of the steepness parameter (h) of the stock-recruitment relationship. Therefore, h was fixed at 0.7, similar to values used on other groundfish stock assessments, and was explored via sensitivity analysis in 2019; we explore information regarding h via likelihood profiles. During the 2019 assessment, a vast number of historical management actions were evaluated and condensed to a subset that were most likely to have had a direct influence on fishery behavior (either sorting and retention, selectivity, or both). These time periods were used to define time blocks to reduce the complexity of selectivity and retention parameterizations. The 2019 benchmark assessment utilized the same general structure as the 2011 assessment, with the addition of full retention for the trawl fishery after the implementation of the IFQ program in 2011.

During the exploration of recent data for this update assessment, modelers identified increased discarding in the trawl fleet, for which the discard ratio nearly quadrupled between 2018 and 2019 (Figure 64). In the first iteration of this update model, retention curve parameters were fixed, as discard length compositions were not included due to conflicts between the age and length data found in the 2019 benchmark assessment. Absent the data or structural flexibility to account for increased discarding, a model that conformed to the Terms of Reference (TOR) for an update assessment was unable to satisfactorily fit to the age composition data from the trawl fleets (Figure 17) nor the WCGBT survey length composition data (Figure 18), and greatly overestimated the 2019 index (Figure 19). Because the TOR model estimates retention for both fisheries in a single timeblock from 2011 onward, the discard data forced the model to generate many small fish, thus overestimating the model-expected index of abundance, the frequency of young and/or small individuals, and distorting the recruitment pattern (Figure 20).

We rectify the lack of fit to the data found in the TOR model by re-introducing the discard length compositions and time-blocking the retention curve to include a new block for the final two years of the model period (2019-2020; the benchmark model's terminal period for retention selectivity ran from 2011-2017). This adjustment resolved the aforementioned model fit issues (Figures 21-28), and is herein presented as the "base model".

Aging error, both precision and accuracy, was extensively investigated during the 2011 assessment but remains unresolved given the lack of an age validation study for sablefish. The age error analysis for this assessment used the same software and methods as the 2019 assessment, and the 2015 update and 2011 assessment before it. The larger number of between-lab reads from the AFSC and the NWFSC available for the 2019 assessment showed a small amount of variability between laboratories. Therefore, the analysis used the between-lab reads as well as the double reads from the NWFSC, treating them both as unbiased but potentially non-linearly variable. The age imprecision was such that by age 50 observed ages could differ from true ages by up to 16-17 years. The potential for underestimating or overestimating the age of the oldest fish still remains, and thus, the potential for aging bias remains a source of uncertainty.

Stock Biomass and Dynamics

During the first half of the 20th century it is estimated that sablefish were exploited at relatively modest levels. Modest catches continued until the 1960s, along with a higher frequency of above average, but uncertain, estimates of recruitment through the 1970s. The spawning stock biomass increased during the mid-1950s to mid-1970s. Subsequently, biomass is estimated to have declined between the mid-1970s and the early 2010s, with the largest harvests occurring during the 1970s followed by harvests that were, on average, higher than pre-1970s harvest through the 2000s. Despite estimates of harvest rates that were right around the target in the 1980s and 1990s and largely below overfishing rates from the 1990s forward coupled with a few high recruitments from the 1980s forward, the spawning biomass has only recently begun to increase. A period of low recruitment from 2001-2012 corresponds to with the decrease in harvest rates, restricting the rate of recovery. This stock assessment does suggest spawner per recruitment rates higher than the target during some years from the 1990s (as well as back to the 1970s) forward for two reasons. First, there have been many years with lower than expected recruitment. Second, stock assessment estimates of unfished spawning biomass have been steadily declining in each subsequent assessment prior to this update since 2007. Estimates of unfished biomass scale catch advice.

Although the relative trend in spawning biomass is robust to uncertainty in the leading model parameters, the productivity of the stock is uncertain due to confounding of natural mortality, absolute stock size, and productivity. The estimates of uncertainty around the point estimate of unfished stock size are large, suggesting that the unfished spawning biomass could range from just under 108,000 mt to 230,000 mt. The point estimate of 2021 spawning biomass from the base model is 97,801.9, however, the 95% interval ranges broadly from 40,802–154,801 mt. The point estimate of 2021 spawning biomass relative to an unfished state (i.e., depletion) from the base model is 57.9% of unexploited levels (95% interval: 38.4%-77.5%).

Table ii: Estimated recent trend in spawning biomass and the fraction unfished and the 95 percent intervals.

Year	Spawning Biomass (mt)	Lower Interval	Upper Interval	Fraction Unfished	Lower Interval	Upper Interval
2011	80,351.5	32,648.1	128,054.9	0.48	0.32	0.63
2012	79,223.0	31,838.5	126,607.5	0.47	0.31	0.63
2013	79,605.1	32,059.9	127,150.3	0.47	0.31	0.63
2014	80,187.9	32,563.5	127,812.3	0.47	0.31	0.64
2015	79,676.1	32,447.4	126,904.8	0.47	0.31	0.63
2016	78,633.2	31,824.6	125,441.8	0.47	0.31	0.62
2017	79,326.7	31,973.0	126,680.6	0.47	0.31	0.63
2018	80,687.2	32,503.6	128,870.8	0.48	0.31	0.64
2019	83,925.1	33,936.0	133,914.2	0.50	0.33	0.67
2020	90,756.5	37,136.0	144,377.0	0.54	0.35	0.72
2021	97,801.9	40,802.4	154,801.4	0.58	0.38	0.77

Recruitment

Sablefish recruitment is estimated to be quite variable with large amounts of uncertainty in individual recruitment events. A period with generally higher frequencies of strong recruitments spans from the early 1950s through the 1970s, followed by a lower frequency of large recruitments during 1980 forward, contributing to stock declines, with some recent larger recuritments pushing the population higher in the past few years. The period with a higher frequency of high recruitments contributed to a large increase in stock biomass that subsequently declined throughout much of the 1970s forward. Less frequent large recruitments during the mid-1980s through 1990 slowed the rate of stock decline, with another series of large recruitments during 1999 and 2000 leading to a leveling off in the stock decline. The above-average cohorts from 2008, 2010, 2013, and 2016 are contributing to an increasing spawning stock size.

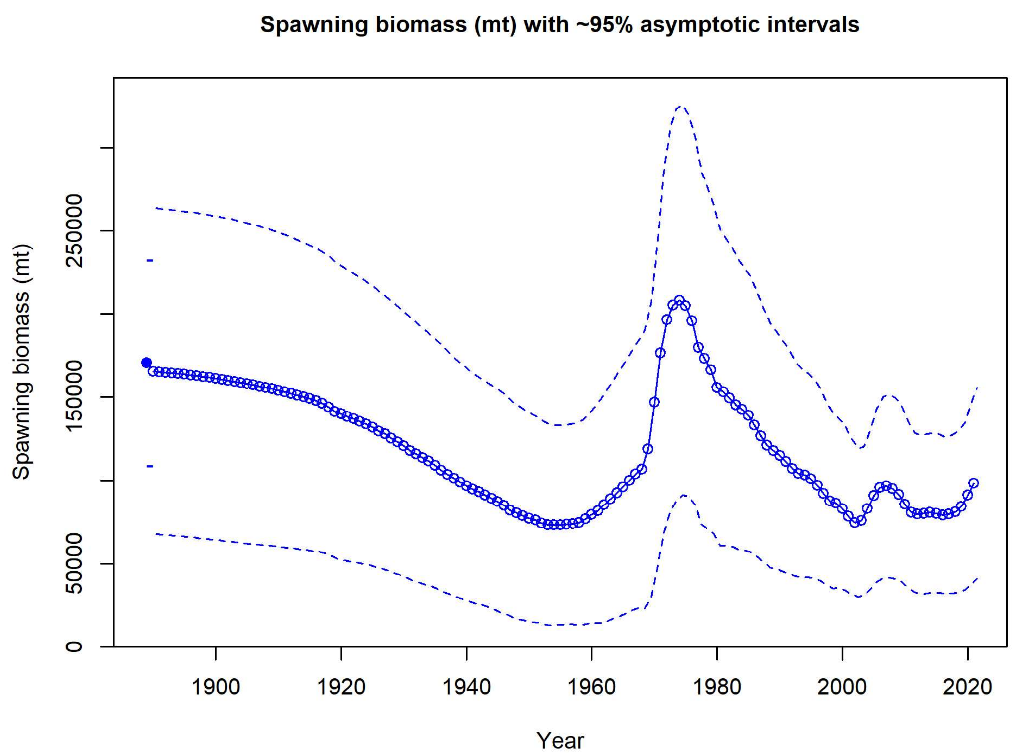
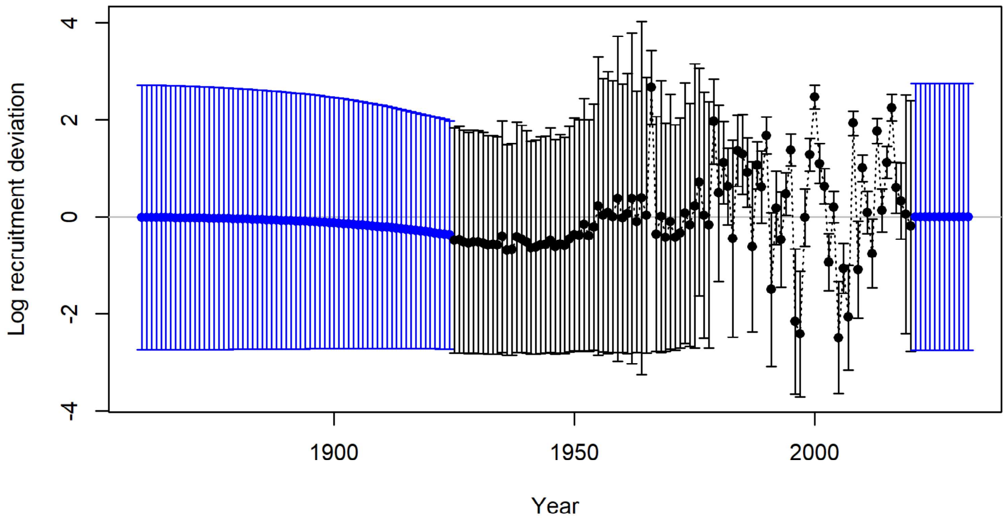


Figure ii: Time series of estimated sablefish spawning biomass (mt) from the base model (circles) with 95% intervals (dashedlines).



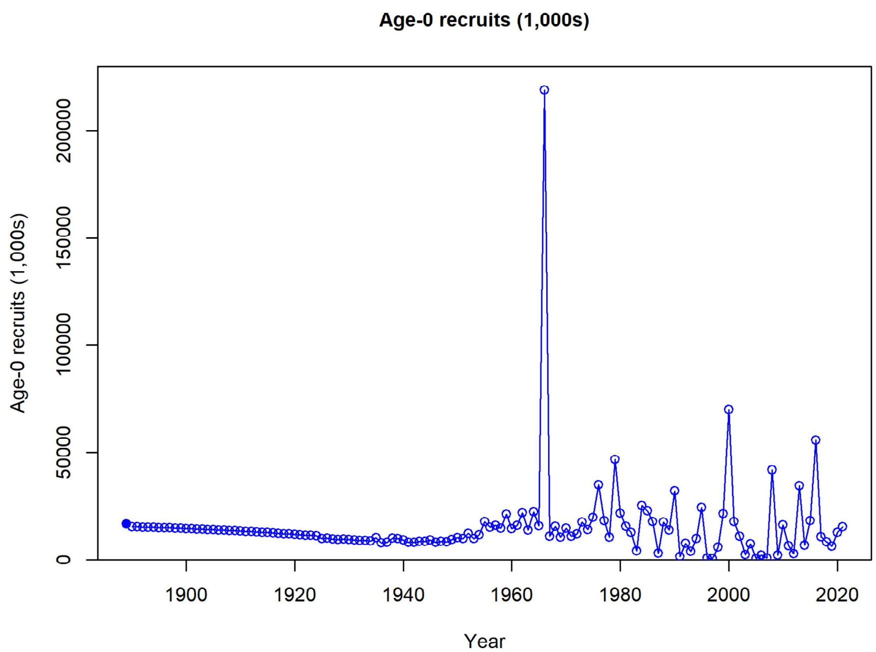


Figure iii: Time series of estimated recruitment deviations from the base model (solid line) with 95% intervals (vertical lines; upper panel) and recruitment without intervals (lower panel).

Exploitation Status

Although the estimated productivity and absolute scale of the stock are poorly informed by the available data and are, therefore, sensitive to changes in model structure and treatment of data, all sensitivity or alternate models evaluated showed a declining trend in biomass since the 1970s followed by a recent increase in biomass (Figures 33 and 34). The spawner potential ratio (SPR) relative to the fishing mortality target or overfishing level ($SPR_{45\%}$) that stabilizes the stock at the target (reported as $(1 - SPR)/[1 - SPR_{45\%}]$), was greater than 1 (thus exceeding the target rate) during nearly half of the years from 1976 through 2000, has been below the target since, and was between 0.62 and 0.76 from 2015-2019, descending to 0.40 in 2020. 'Relative 1-SPR' in Table 4 refers to $(1-SPR)/[1-SPR_{45\%}]$; where 1 is the target exploitation rate, and values over 1 indicate overexploitation relative to this proxy. While highly uncertain, the absolute equilibrium yield at the estimated fishing mortality that leads to the maximum sustainable yield (F_{MSY}) is 9,024 mt (4,242-13,807, ~95% interval), while the proxy SPR rate of 0.45 leads to a proxy MSY of 8,350 mt (3,924 - 12,777, 95% interval).

Table iii: Estimates of total dead catch (mt), relative 1-spawning potential ratio (SPR; 1-SPR/1-SPRTarget=0.45%), and exploitation rate (catch/biomass of age-4+) from the base model. Approximate 95% intervals follow in parentheses.

Year	Model-Estimated Total Dead Catch	Rel 1-SPR	Interval	Exploitation Rate	Interval
2011	6,253.97	0.97	0.60–1.34	0.0316	0.0138–0.0494
2012	5,283.60	0.75	0.41–1.09	0.0240	0.0106–0.0375
2013	4,050.48	0.61	0.31–0.92	0.0192	0.0084–0.0300
2014	4,294.90	0.61	0.30–0.92	0.0200	0.0088–0.0311
2015	5,105.52	0.71	0.37–1.05	0.0243	0.0108–0.0379
2016	5,401.39	0.76	0.41–1.10	0.0270	0.0119–0.0421
2017	5,465.76	0.68	0.36–1.01	0.0250	0.0110–0.0389
2018	5,220.22	0.66	0.34–0.98	0.0243	0.0107–0.0379
2019	5,372.81	0.62	0.31–0.92	0.0244	0.0107–0.0381
2020	3,882.69	0.40	0.18–0.63	0.0149	0.0066–0.0231

Ecosystem Considerations

The National Oceanic and Atmospheric Administration (NOAA) document titled 'Implementing a Next Generation Stock Assessment Enterprise, An update to the NOAA Fisheries Stock Assessment Improvement Plan' (Lynch, Methot, and Link (2018)) calls for bringing an ecosystem perspective into the assessment process. Moreover, introducing this perspective to the assessment process is a key component of the NOAA Fisheries Ecosystem-Based Fisheries Management (EBFM) Policy (NOAA National Oceanic and Atmospheric Administration (2016)), which calls for incorporation of ecosystem considerations into the management of living marine resources. Uptake of EBFM principles and tools into the assessment process can be accomplished through including ecosystem information in assessments, harvest control rules, and management decisions that are coordinated across species-specific

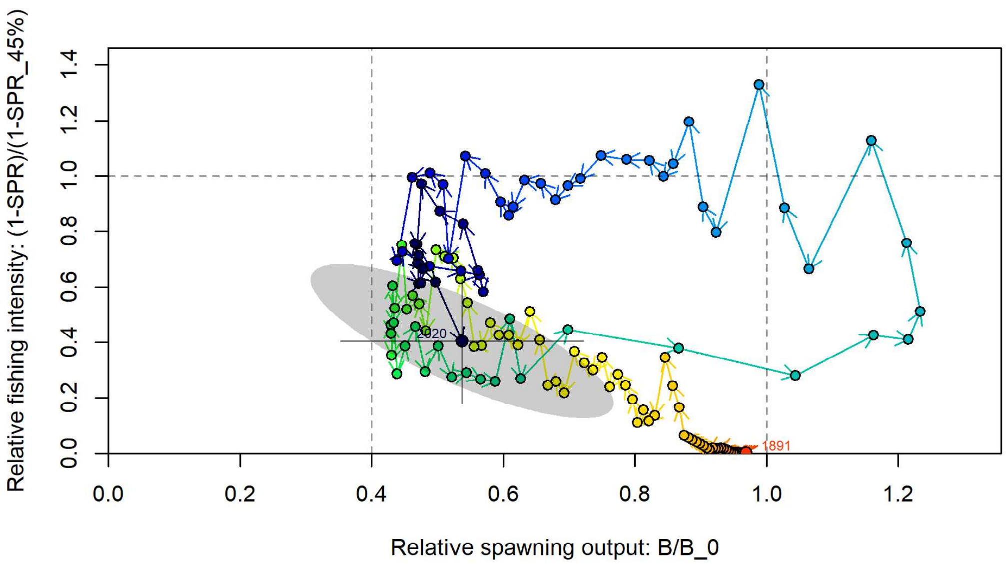


Figure iv: Estimated relative spawning potential ratio ($1 - SPR/1 - SPR_{Target=0.45\%}$) vs. estimated spawning biomass relative to the proxy 40% level from the base model. Higher spawning output occurs on the right side of the x-axis, higher exploitation rates occur on the upper side of the y-axis. The dark blue circle indicates the last year of available data, 2020, and the grey lines indicate the 95% confidence interval. Plot is based on maximum likelihood estimation results.

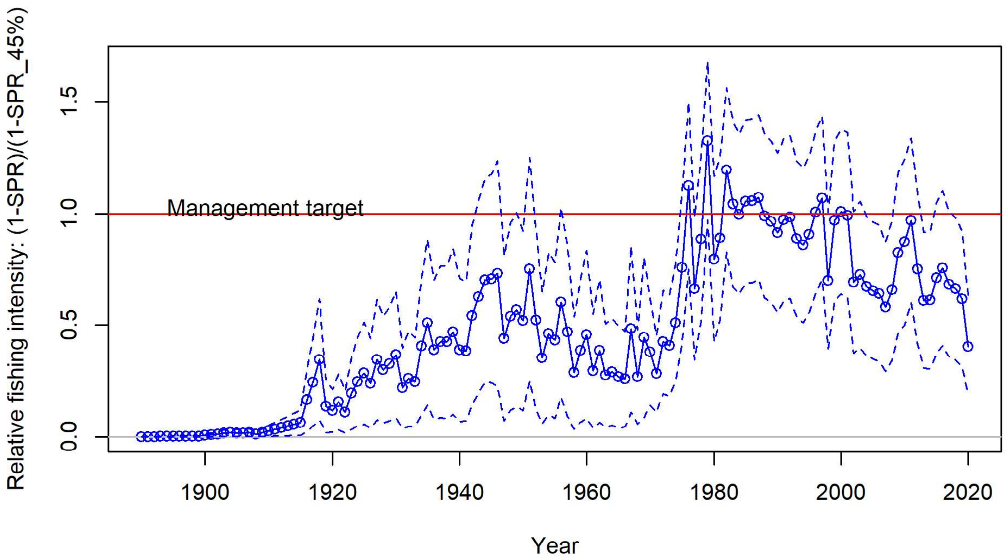


Figure v: Time series of estimated relative spawning potential ratio (1-SPR/1-SPRTarget=0.45%) from the base model (points) with 95% intervals (dashed lines). Values above 1.0 (red, horizontal line) reflect harvest rates in excess of the current overfishing proxy.

management plans and account for diverse trade-offs (NOAA National Oceanic and Atmospheric Administration (2016), Lynch, Methot, and Link (2018)). Guidelines for incorporating ecosystem considerations into fisheries management advice form the core of Guiding Principle 5 for implementing the NOAA EBFM Policy.

This assessment includes ecological factors based on the idea that research focused on the linkages within a social-ecological system (SES) and how they increase or decrease sustainability can help inform the management of natural resources (Ostrom (2009)). The SES framework requires consideration of extractive goals and human activities at a level that allows for ecological sustainability while also considering human well-being. Thus, the SES framework facilitates the consideration of environmental and human impacts on sablefish as well as sablefish impacts on the ecosystem and humans (e.g., Levin et al. (2016)).

The sablefish CVA McClure and Haltuch (n.d.)} suggests that processes affecting recruitment are sensitive to climatic and, therefore, oceanic drivers. Given high climate vulnerability, changes in the abundance, productivity, and spatial distribution of sablefish are likely, and these changes are likely to impact fishing fleets and communities because of the high value of this fishery. The CVA also suggests that sablefish are likely to shift their distribution in response to climate variability. Strong coast-wide recruitment appears to be associated with good recruitment north of Cape Mendocino ($\sim 40°$N). Modeling work shows that strong recruitment is correlated with transport and temperature in the northern portion ($40° - 48°$N) of the U.S. West Coast, specifically with the northern transport of yolk-sac larvae (Tolimieri et al. (2018)). A re-analysis of the relationship between sea level and recruitment found that variation around the stock-recruitment curve was negatively correlated with sea level north of Cape Mendocino. Reliable sea-level data are available back to 1925; the ability to produce an environment-recruitment index with this time series may allow for both hindcasting to better represent stock dynamics during data-poor time periods and nowcasting of recruitment with robust estimates of uncertainty.

The sablefish stock has experienced latitudinal shifts in the center of the distribution of stock biomass along the US West Coast, which has affected fishing opportunities to individual ports (Selden et al. (n.d.)). The population centroid shifted to the north from 1980 to 1992 then south by 2013. More recently, the distribution of stock biomass shifted north, illustrated by an increase in trawl survey biomass in the north, but not as far north as in the 1990s.

Whale entanglements with pot gear has the potential to limit effort in the pot-gear sectors due to protections for marine mammals. The estimated fleet-wide entanglements were consistently above the 5-year running average threshold during 2002 to 2017 in the combined Limited Entry sablefish and Open Access Fixed Gear pot sectors (Hanson et al. (2019)). This result was largely due to the Open Access Fixed Gear pot sector, which had entanglements consistently above the 5-year running average threshold, while entanglements in the Limited Entry sablefish pot sector were consistently below the threshold.

A detailed description of social-ecological system (SES) analyses, the Climate Vulnerability Assessment, and environmental drivers of sablefish recruitment is available in the 2019 Benchmark Assessment report (Haltuch et al. (2019)), and truncated from this update document.

Reference Points

Unfished spawning biomass was estimated to be 168,875 mt (107,749–230,001 ~95% interval). The abundance of sablefish was estimated to have declined to near the target during the period 1980-2000. The estimate of the target spawning biomass was 67,550 (43,099-92,001, ~95% interval). The stock was estimated to be above the target stock size in the beginning of 2021 at 97,802 mt (40,801-154,802, ~95% interval). The stock was estimated to be above the depletion level that would lead to maximum yield (0.4) (Figures 31 and 32). The estimate of the stock's current 2021 level of depletion was 0.579.

Table iv: Summary of reference points and management quantities, including estimates of the 95 percent intervals.

	Estimate	Lower Interval	Upper Interval
Unfished Spawning Biomass (mt)	168,875	107,749	230,001

Table iv: Summary of reference points and management quantities, including estimates of the 95 percent intervals. *(continued)*

	Estimate	Lower Interval	Upper Interval
Unfished Age 4+ Biomass (mt)	393,647	242,084	545,210
Unfished Recruitment (R0)	16,392	6,586	26,198
Spawning Biomass (mt) (2021)	97,802	40,802	154,801
Fraction Unfished (2021)	0.579	0.384	0.775
Proxy Spawning Biomass (mt) SB40 Percent	67,550	43,100	92,000
SPR Resulting in SB40 Percent	0.464		
Exploitation Rate Resulting in SB40 Percent	0.043	0.035	0.051
Yield with SPR Based On SB40 Percent (mt)	8,209	3,857	12,562
Proxy Spawning Biomass (mt) (SPR45)	64,848	41,376	88,320
Exploitation Rate Corresponding to SPR45	0.045	0.037	0.053
Yield with SPR45 at SB SPR (mt)	8,350	3,924	12,777
Spawning Biomass (mt) at MSY (SB MSY)	41,702	26,527	56,876
SPR MSY	0.328	0.324	0.331
Exploitation Rate Corresponding to SPR MSY	0.070	0.057	0.083
MSY (mt)	9,024	4,242	13,807

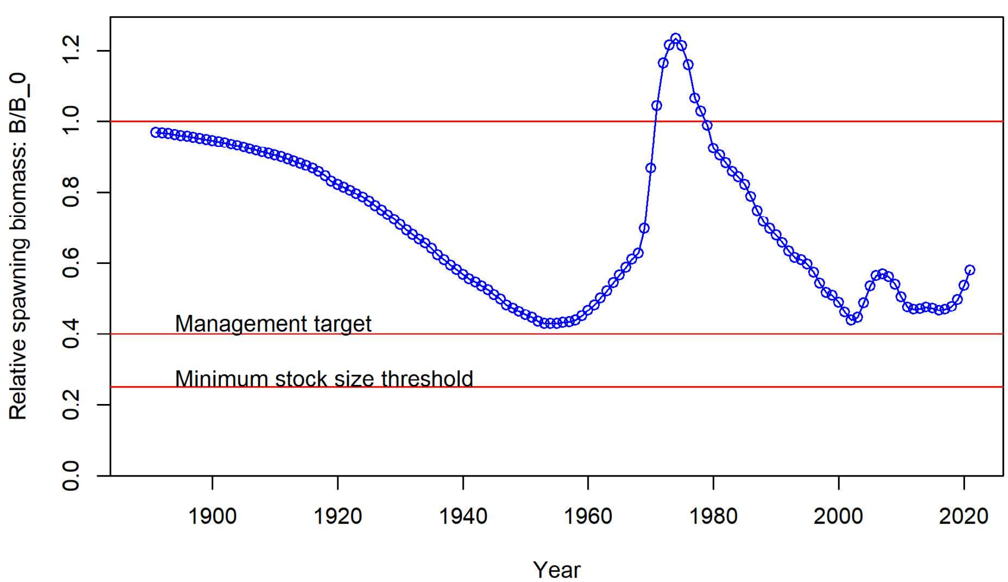


Figure vi: Time series of estimated depletion (i.e., spawning biomass relative to unfished spawning biomass) from the base model (circles) with 95% intervals (dashed lines).

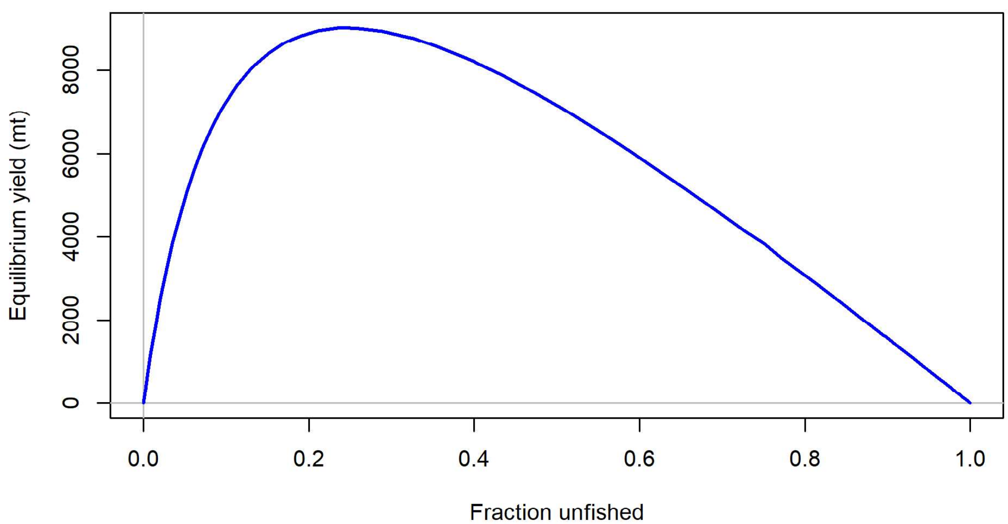


Figure vii: Equilibrium yield curve (total dead catch) for the base model.

Management Performance

Sablefish management includes a rich history of seasons, size-limits, trip-limits, and a complex permit system. Managers divide coast-wide yield targets among the fleets, fishery sectors (including both limited entry and open access), as well as north and south of 36°N latitude. Peak catches occurred during the late 1970s just prior to the imposition of the first catch limits. Over the last decade, the total estimated dead catch has been 55% of the sum of the overfishing limits and 65% of the annual catch limits.

Table v: Recent trend in the overfishing limits (OFL), the annual catch limits (ACLs), the total landings, and model-estimated total dead catch ("total mortality", mt). Note that the Acceptable Biological Catches (ABCs) and ACLs are equal because the stock is estimated to be above 40% of the unfished spawning biomass, and the PFMC has not seen fit to lower the ACLs for other reasons.

Year	OFL	ACL	Landings	Total Mortality
2011	8,808	6,813	6,149.25	6,253.97
2012	8,623	6,605	5,184.80	5,283.59
2013	6,621	5,451	3,987.20	4,050.48
2014	7,158	5,909	4,216.46	4,294.90
2015	7,857	6,512	5,025.23	5,105.53
2016	8,526	7,121	5,305.81	5,401.39
2017	8,050	7,117	5,350.64	5,465.75
2018	8,239	7,419	5,126.94	5,220.23
2019	8,489	7,750	5,193.71	5,372.81
2020	8,648	7,896	3,762.75	3,882.70
2021	9,402	8,791	-	-
2022	9,005	8,375	-	-

Unresolved Problems and Major Uncertainties

The data available for sablefish off the U.S. West Coast are not informative with respect to absolute stock size and productivity. This is, in part, due to the one-way-trip nature of the historical series (i.e., a slow and steady decline in spawning biomass), which can be consistent with a larger less productive stock, a smaller more productive stock, or many combinations in between. While the historical catches provide some information about the minimum stock size necessary to remove the catches from the population, there is limited information in the data regarding the upper limit of the stock size. The above factors are also confounded by movement of sablefish between the region included in this assessment and regions to the north primarily, which is ignored in the stock assessment. Likelihood profiles, parameter estimates, and general model behavior illustrate that small changes in any of a suite of parameters can result in different management reference points. However, because leading model parameters, such as natural mortality, selectivity, and historical recruitments, are estimated within the stock assessment model, the uncertainty about these estimates remains large and uncertainty intervals typically overlapped among the investigated models. The uncertainty will remain high until a more informative time-series, better quality demographic and biological information are accumulated, or a range-wide analysis is completed for sablefish.

There is no age validation for sablefish. Validation is complicated by the fact that most known-age fish from Alaska are aged at less than 20 years while there are very few ages from the US West Coast, particularly in recent decades. Uncertainty in the current aging methods (both bias and imprecision), as well as relatively sparse fishery sampling, result in age data that potentially variable. Furthermore, because sablefish grow rapidly, nearing asymptotic length in their first decade of life, length data is not particularly informative about historical patterns in recruitment. The patterns observed in historical sablefish recruitment suggest that the stock trajectory (via shifts in recruitment strength) is closely linked to productivity regimes in the US West Coast. Uncertainty in future environmental conditions, changes in the timing, dynamics, and productivity of the California Current ecosystem via climate change or cycles similar to the historical period should be considered a significant source of uncertainty in all projections of stock status. The ongoing WCGBT Survey is a fairly precise relative index of abundance over a broad demo- graphic component of the stock, but it does not survey the entire stock as sablefish reside in waters deeper than 1280 m, the survey depth limit, and to the north of the Washington/British Columbia border. To the modelers' knowledge there is no information from the Pacific coast of Mexico. Therefore, a portion of the stock is unobserved. This index has the potential to inform future stock assessments about the scale of the population relative to catches being removed, however such information will require contrast in the observed survey trend.

Decision Table and Harvest Projections

Decision Table

The decision table reports 12-year projections for alternate states of nature (columns) and management options (rows). The results of this table are conditioned on the Groundfish Management Team specified catches for 2021 and 2022, which are below the already-specified annual catch limits approved by the Pacific Fisheries Management Council.

Uncertainty in management quantities for the decision table was characterized using the asymptotic standard deviation for the 2021 spawning biomass from the base model. Specifically, the 2021 spawning biomass for the high and low states of nature are given by the base model mean $\pm 1.15 \cdot$ standard deviation (i.e., the 12.5th and 87.5th percentiles). A search across fixed values of R_0 was used to attain the 2021 spawning biomass values for the high and low states of nature. The base catch streams were based on the 40-10 harvest control rule and a $P^* = 0.45$ buffer vector. This is presented as the bottom row of the decision table as it represents the highest exploitation level among the three catch streams. To replicate a request of the Groundfish Management Team representative at the 2019 STAR panel, the additional catch streams were set using the Category 1 values of $P^* = 0.35$ and $P^* = 0.40$; these are presented as the first and second rows of the decision table, respectively.

Spawning stock biomass in 2021 ranges across the three states of nature from 64,916 to 131,513 mt, with corresponding stock status ranging from 51% to 63% of the unfished stock size. The decision table suggests that all catch scenarios under across all states of nature result in decreases in stock size. Under both the base and high states of nature and across all catch scenarios, the stock remains either at or above the target stock size at the end of the projection period. The reason that depletion does not decline as substaintally as suspected in the base case at the 12-year time horizon is the emergence of recent, large recruitment events into the fishery; this is reflected in a disproportionate increase in summary biomass (Figure 68). However, all catch scenarios under the low state of nature drive the stock into the precautionary zone by 2030, where it remains in 2032.

Table vi: Decision table of 12-year projections of spawning stock biomass (SSB) and % unfished (depletion) for alternative states of nature (columns) and management options (rows) beginning in 2021. Low and high states of nature are based on the 2021 SSB ± 1.15·base model SSB standard deviation and the resulting unfished recruitment was used for the projections. Results are conditioned on the 2021 and 2022 catches, provided by the Pacific Fisheries Management Council Groundfish Management Team (GMT), being achieved exactly. The alternative catch streams are based on the GMT's requested P* values of 0.35 and 0.40. Note that values for the agreed-upon buffer level of P* = 0.45 is presented as the third row of the decision table as it represents the highest exploitation level among the three catch streams. Catches are total dead biomass, i.e., dead discard plus catch.

	Year	Total	Low state (0.25)		Base (0.5)		High state (0.25)	
scenario		catch	SSB	Depletion	SSB	Depletion	SSB	Depletion
P*=0.35	2021	7,405	64,916	0.51	97,802	0.58	131,513	0.63
	2022	7,055	66,222	0.52	99,957	0.59	134,550	0.65
	2023	9,412	65,396	0.51	99,450	0.59	134,266	0.64
	2024	8,608	62,150	0.49	96,661	0.57	131,626	0.63
	2025	8,101	59,177	0.46	94,436	0.56	129,680	0.62
	2026	7,796	56,750	0.44	92,909	0.55	128,548	0.62
	2027	7,649	54,732	0.43	91,867	0.54	127,974	0.61
	2028	7,570	52,951	0.41	91,099	0.54	127,714	0.61
	2029	7,504	51,310	0.40	90,483	0.54	127,626	0.61
	2030	7,437	49,770	0.39	89,967	0.53	127,646	0.61
	2031	7,342	48,316	0.38	89,530	0.53	127,742	0.61
	2032	7,247	46,956	0.37	89,175	0.53	127,911	0.61
P*=0.40	2021	7,405	64,916	0.51	97,802	0.58	131,513	0.63
	2022	7,055	66,222	0.52	99,957	0.59	134,550	0.65
	2023	10,107	65,396	0.51	99,450	0.59	134,266	0.64
	2024	9,252	61,794	0.48	96,308	0.57	131,273	0.63
	2025	8,722	58,494	0.46	93,761	0.56	129,004	0.62
	2026	8,421	55,765	0.44	91,935	0.54	127,568	0.61
	2027	8,282	53,451	0.42	90,602	0.54	126,699	0.61
	2028	8,218	51,380	0.40	89,546	0.53	126,149	0.60
	2029	8,168	49,449	0.39	88,643	0.52	125,774	0.60
	2030	8,117	47,616	0.37	87,840	0.52	125,509	0.60
	2031	8,039	45,869	0.36	87,117	0.52	125,324	0.60
	2032	7,950	44,214	0.35	86,479	0.51	125,215	0.60
P*=0.45	2021	7,405	64,916	0.51	97,802	0.58	131,513	0.63
	2022	7,055	66,222	0.52	99,957	0.59	134,550	0.65
	2023	10,825	65,396	0.51	99,450	0.59	134,266	0.64
	2024	9,923	61,426	0.48	95,935	0.57	130,908	0.63
	2025	9,372	57,787	0.45	93,014	0.55	128,302	0.62
	2026	9,070	54,742	0.43	90,821	0.54	126,550	0.61
	2027	8,934	52,126	0.41	89,130	0.53	125,375	0.60
	2028	8,888	49,760	0.39	87,727	0.52	124,528	0.60
	2029	8,860	47,532	0.37	86,483	0.51	123,858	0.59
	2030	8,810	45,402	0.36	85,346	0.51	123,298	0.59
	2031	8,753	43,364	0.34	84,304	0.50	122,829	0.59
	2032	8,684	41,415	0.32	83,351	0.49	122,438	0.59

Harvest Projections

Previous sablefish stock assessments have been designated as Category 1 stock assessments. Projections and decision tables are based on P^*=0.45, the adopted value for the most recent management cycle, and the values of σ adopted by the Pacific Fisheries Management Council for stock projections. The time series of multiplicative buffer fractions that are a function of P^* and the time series of σs provide the multipliers on the overfishing limit; these values are all less than 1 for category 1 stocks. σ for sablefish is the time-varying category 1 value, which starts at 0.5 in the year after the (update) assessment and increases throughout the projection period. The uncertainty around the OFL value for the first forecast year (2022) is 0.319; the uncertainty around spawning output in that same year is 0.298, both less than 0.5. The multipliers are combined with OFLs to calculate the ABC values. The Council sets ACL values which cannot exceed (with limited exceptions) the ABCs as modified by the 40-10 rule. The total catches in 2021 and 2022 were set at the Pacific Fisheries Management Council Groundfish Management Team requested values, below the Pacific Fisheries Management Council annual catch limits for sablefish. The average ratio between GMT-specified 2021-2022 catches were used to distribute catches among the fisheries for forecasted years.

Projections are provided through 2032 (Table 7). Current medium-term projections from the base model under the Pacific Fisheries Management Council 40-10 harvest control rule estimate that the stock will remain above the target stock size of 40% of the estimated unfished spawning biomass during the projection period. Forecasts from the 2019 benchmark assessment projected the spawning biomass to increase by 28% from 2017 to 2021 given specified harvests, whereas the current assessment estimated the increase at 23%. The estimate of unexploited spawning biomass (in the year of each assessment) is 13% higher than that estimated in 2019 and 19% lower than the 2011 estimate. Relative unfished biomass in 2021 was estimated at 0.58, while the 2019 benchmark assessment forecasted it to be 0.46.

Table vii: Projections of potential OFLs (mt), ABCs (mt), estimated spawning biomass and fraction unfished. The total catches in 2021 and 2022 were set at the PFMC Groundfish Management Team requested values of 7,405 mt for 2021 and 7,055 mt for 2022 which are about 20% lower than the ACL = ABC for those years; see Table 6 for GMT-defined ACLs and OFLs in 2021 and 2022.

Year	Predicted OFL (mt)	*Catches* (2021-22) or ABCs (2023+) (mt)	Age 4+ Biomass (mt)	Spawning Biomass (mt)	Fraction Unfished
2021	-	*7,405.00*	265,655	97,801.9	0.58
2022	-	*7,055.00*	261,481	99,956.5	0.59
2023	11,577.1	10,824.6	253540	99,449.9	0.59
2024	10,669.8	9,922.9	246090	95,943.8	0.57
2025	10,120.6	9,371.7	241976	93,063.3	0.55
2026	9,837.4	9,070.1	238823	90,925.0	0.54
2027	9,742.3	8,933.7	236280	89,290.8	0.53
2028	9,735.2	8,888.3	234037	87,941.5	0.52
2029	9,747.2	8,860.2	231955	86,743.8	0.51

Table vii: Projections of potential OFLs (mt), ABCs (mt), estimated spawning biomass and fraction unfished. *(continued)*

Year	Predicted OFL (mt)	*Catches* (2021-22) or ABCs (2023+) (mt)	Age 4+ Biomass (mt)	Spawning Biomass (mt)	Fraction Unfished
2030	9,746.0	8,810.4	229993	85,644.5	0.51
2031	9,725.9	8,753.3	228162	84,634.2	0.50
2032	9,691.9	8,684.0	226462	83,707.8	0.50

Scientific Uncertainty

The time series of multiplicative buffer fractions that are a function of P^* and the time series of σs provide the multipliers on the overfishing limit; these values are all less than 1 for category 1 stocks. σ for sablefish is the time-varying category 1 value, which starts at 0.5 in the year after the (update) assessment and increases throughout the projection period. The uncertainty around the OFL value for the first forecast year (2022) is 0.319; the uncertainty around spawning output in that same year is 0.298, both less than 0.5.

Research and Data Needs

Most of the research needs listed below entail investigations that need to take place outside of the routine assessment cycle and require additional resources to be completed.

1. Not all of the available sablefish otoliths were aged for this stock assessment update because of time constraints resulting from Covid-19, exacerbated by the the federal government furlough in 2019, and, in some cases, the sample sizes of aged fish are lower than what would be ideal. Resources should be provided to age otolith samples from years with missing age data or small sample sizes.

2. A transboundary stock assessment and the management framework to support such assessments would be beneficial given the migratory nature and broad distribution of sablefish along the Pacific Rim. A transboundary assessment would likely improve the ability to estimate the scale of the population, particularly during the early modeled period.

3. Investigation of environmental covariates for recruitment on a stock-wide, northeast Pacific scale.

4. Continuation of the annual WCGBT Survey will provide information on stock trends and incoming recruitments. A longer survey time series may improve the precision of estimates of absolute stock size and productivity into the future.

5. Age validation is needed to verify the level of age bias present in the data, if any.

6. Investigate aging methods that could prove more precise and/or rapid than current break-and-burn methods. More accurate age data would facilitate tracking cohorts to older ages, improving estimates of historical year-class strengths.

7. Research on understanding the interactions between spatial patterns in sablefish growth, fishery size selectivity, and movement across the Northeast Pacific began during 2019 and are ongoing. The results of this research should be considered in future benchmark stock assessments.

8. Anecdotal information, such as the large 1947 recruitment reported by central California sport fisherman, along with historical records could be investigated to provide additional information on historical patterns of recruitment.