Appendix 3C. Ecosystem and Socioeconomic Profile of the Sablefish stock in Alaska - Report Card

S. Kalei Shotwell (Editor)

Katy Echave, Bridget Ferriss, Dan Goethel, Chris Lunsford, Krista Oke, Elizabeth Siddon, Kevin Siwicke, Jane Sullivan, Marysia Szymkowiak, and Ben Williams (Team)

November 2023

With Contributions from:

Anna Ableman, Mayumi Arimitsu, Steve Barbeaux, Matt Callahan, Curry Cunningham, Brian Garber-Yonts, Dana Hanselman, Jean Lee, Jens Nielsen, Clare Ostle, Patrick Ressler, Cara Rodgveller, Kalei Shotwell, Kevin Siwicke, Kally Spalinger, Jane Sullivan

Current Year Update

The ecosystem and socioeconomic profile, or ESP, is a standardized framework for compiling and evaluating relevant stock-specific ecosystem and socioeconomic indicators and communicating linkages and potential drivers of the stock within the stock assessment process (Shotwell et al., *Accepted*). The ESP process creates a traceable pathway from the initial development of indicators to management advice and serves as an on-ramp for developing ecosystem-linked stock assessments.

Please refer to the last full ESP and partial ESP documents (Shotwell et al., 2019 Appendix 3C, pp. 157-202, Shotwell et al., 2020 Appendix 3C, pp. 190-218) which are available within the Alaska sablefish stock assessment and fishery evaluation or SAFE reports for further information regarding the ecosystem and socioeconomic linkages for this stock.

Management Considerations

The following are the summary considerations from current updates to the ecosystem and socioeconomic indicators evaluated for sablefish:

- Marine heatwave events were below average, surface temperatures in the Gulf of Alaska (GOA) and southeastern Bering Sea (SEBS) were below average, and bottom temperatures on the slope in the GOA decreased but still above average similar to 2021.
- Chlorophyll *a* biomass was low in the GOA and lowest of the time series in the SEBS, while the spring bloom timing was high (late) in the GOA and average in the SEBS.
- Zooplankton community size in the eastern GOA was below average and low in the western GOA in 2022, implying a smaller sized community.
- Growth of YOY sablefish was slightly below average, but mean length was low in 2023.
- Nearshore survey sablefish CPUE has declined since the time series peak in 2020, but remain above average and age-1 sablefish from the bottom trawl survey were above average.
- Condition of the 2018 year-class (2022 data) was low suggesting insufficient resources just prior to maturing, while condition of adult females in the longline survey was high in 2023, relative to low in 2022.
- Arrowtooth flounder total biomass remains low and spatial overlap between sablefish migrating to adult slope habitat and the arrowtooth flounder population decreased to average.
- Standardized fishery CPUE indicators demonstrate similar trends, with the combined fishery indicator increasing to high and the pot fishery index at an all-time high for the time series.
- Incidental catch of sablefish in non-sablefish targeted fisheries in 2023 decreased to low in the GOA but remains high in the BSAI.
- Condition of adult female sablefish in the GOA fisheries increased from low in 2022 to slightly below average in 2023, but sample sizes were small compared to previous years.
- Real ex-vessel value increased to slightly above average and average price per pound remains low in 2022, in part due to continued small average fish size from recent large year classes and high quotas coastwide in recent years.

The sablefish fishery has undergone dramatic changes in response to multiple large year classes and increased quotas. Incidental fisheries have seen dramatic increases in catch of small sablefish and all fisheries have seen an unprecedented market collapse. Further, the directed fishery has experienced exceptional catch rates in recent years but these catches are dominated by small fish with low market value. The existing fishery performance and economic indicators presented in this report card do not capture these drastic changes well. Indicators for these factors need further examination and refinement as these fishery and market shifts should be captured in this analysis.

Modeling Considerations

The following are the summary results from the intermediate and advanced stage monitoring analyses for sablefish:

- The highest ranked predictor variables of sablefish recruitment based on the importance methods in the intermediate stage indicator analysis were the summer juvenile sablefish CPUE from the ADF&G large mesh survey and the spring SST in the SEBS (inclusion probability > 0.5).
- A spatially explicit life cycle model and a temperature linked projection model are under development to understand ecosystem drivers of movement and improve recruitment projections.

Assessment

Ecosystem and Socioeconomic Processes

We summarize important processes that may be helpful for identifying productivity bottlenecks and dominant pressures on the stock in conceptual models detailing ecosystem processes by life history stage (Figure 3C.1) and economic performance (Table 3C.1). Please refer to the last full ESP document (Shotwell et al., 2019) for more details.

An analysis of commercial processing and harvesting data may be conducted to examine sustained participation for those communities substantially engaged in a commercial fishery. The Annual Community Engagement and Participation Overview (ACEPO) report evaluates engagement at the community level and focuses on providing an overview of harvesting and processing sectors of identified highly engaged communities for groundfish and crab fisheries in Alaska (Wise et al., 2022). Please refer to this report for information on community engagement in the sablefish fishery.

Indicator Suite

The list of ESP indicators is organized by categories, three for ecosystem indicators (physical, lower trophic, and upper trophic) and three for socioeconomic indicators (fishery performance, economic, and community). For sablefish socioeconomic categories, only fishery performance and economic indicators are available at this time. A short description and contact name for the indicator contributor are provided. For ecosystem indicators, we also include the anticipated sign of the proposed relationship between the indicator and the stock population dynamics where relevant, and specify the lag applied if the indicator was tested in the intermediate stage indicator analysis (see section below for more details). Please refer to the full ESP document for detailed information regarding the ecosystem and socioeconomic indicator descriptions and proposed mechanistic linkages for this stock (Shotwell et al., 2019). Time series of the ecosystem and socioeconomic indicators are provided in Figure 3C.2a and Figure 3C.2b, respectively.

ESP indicators are evaluated during a full ESP. Report card years maintain those indicators but minor modifications may be needed annually to ensure product delivery. Modifications to ecosystem indicators in 2023 include: 1) chlorophyll *a* concentration and peak timing of the spring bloom derived from MODIS satellite measurements have been replaced with a European Space Agency (ESA) GlobColour blended satellite product because the satellites that hold the MODIS instruments will soon be retired due to changes in orbits, 2) mean age and age evenness from the sablefish stock assessment model are no longer included because this information is now an operational output in the main SAFE analysis, and 3) condition of large females from the BSAI fisheries is no longer included due to limited sample sizes that are likely to continue into the future. These modifications will preclude direct comparison to indicator timeseries in previous ESP documents.

Ecosystem Indicators:

Physical Indicators (Figure 3C.2a.a-d)

a.) Annual **marine heatwave cumulative index** over the central GOA (contact: S. Barbeaux). Proposed sign of the relationship to recruitment is positive.
b.) Late **spring** (May-June) daily **sea surface temperatures** (SST) for the GOA from the NOAA Coral Reef Watch Program (contact: M. Callahan). Proposed sign of the relationship to recruitment is positive.
c.) Late **spring** (May-June) **daily sea surface temperatures** (SST) for the southeastern Bering Sea from the NOAA Coral Reef Watch Program (contact: M. Callahan). Proposed sign of the relationship to recruitment is positive and the time series is not lagged for the intermediate stage indicator analysis.
d.) **Summer temperature anomalies at 250 m** isobath during the AFSC annual longline survey (contact: K. Siwicke). Proposed sign of the relationship to recruitment is negative.

Lower Trophic Indicators (Figure 3C.2a.e-l)

e.) Derived **chlorophyll *a* concentration** during spring seasonal peak (May) in the **GOA** calculated from ESA GlobColour blended satellite product (contact: M. Callahan). Proposed sign of the relationship to recruitment is positive.
f.) Derived **chlorophyll *a* concentration** during spring seasonal peak (May) in the **southeastern Bering Sea** calculated from ESA GlobColour blended satellite product (contact: M. Callahan). Proposed sign of the relationship to recruitment is positive.
g.) **Peak timing of the spring bloom** averaged across individual ADF&G statistical areas in the **GOA** region calculated from ESA GlobColour blended satellite product (contact M. Callahan). Proposed sign of the relationship to recruitment is negative.
h.) **Peak timing of the spring bloom** averaged across individual ADF&G statistical areas in the **southeastern Bering Sea** calculated from ESA GlobColour blended satellite product (contact: J. Nielsen). Proposed sign of the relationship to recruitment is negative.
i.) Abundance of **copepod community size** from the continuous plankton recorder (CPR) for the offshore **eastern GOA** (contact: C. Ostle). Proposed sign of the relationship to recruitment is positive.
j.) Abundance of **copepod community size** from the continuous plankton recorder (CPR) for the offshore **western GOA** (contact: C. Ostle). Proposed sign of the relationship to recruitment is positive.
k.) **Summer euphausiid abundance** from the AFSC acoustic survey for the Kodiak core survey area (contact: P. Ressler). Proposed sign of the relationship to recruitment is positive.
l.) **Age-0 sablefish growth rate from auklet diets** in Middleton Island (contact: M. Arimitsu). Proposed sign of the relationship to recruitment is positive and the time series is not lagged for the intermediate stage indicator analysis.

Upper Trophic Indicators (Figure 3C.2a.m-t)

m.) **Sablefish catch-per-unit-effort** (CPUE) and lengths from the ADF&G large mesh bottom trawl survey of crab and groundfish (contact: K. Spalinger). Proposed sign of the relationship to recruitment is positive and the time series is lagged three years for the intermediate stage indicator analysis.
n.) **Summer** length compositions extrapolated to the population of **juvenile sablefish** (<350 mm, likely age-1) collected on AFSC bottom-trawl surveys (contact: K. Shotwell). Proposed sign of the relationship to recruitment is positive.
o.) **Summer sablefish condition for age-4**, maturing female sablefish from the GOA AFSC longline survey (contact: J. Sullivan). Proposed sign of the relationship to recruitment is positive.
p.) **Arrowtooth flounder total biomass** from the previous year stock assessment model (contact: K. Shotwell). Proposed sign of the relationship to recruitment is negative and the time series is lagged three years for the intermediate stage indicator analysis.

q.) **Incidental catch of sablefish** in the **GOA arrowtooth flounder fishery** (contact: K. Shotwell). Proposed sign of the relationship to recruitment is negative and the time series is lagged three years for the intermediate stage indicator analysis.
r.) **Summer sablefish condition** for large **adult** (>=750 mm) **female sablefish** from the GOA AFSC longline survey (contact: J. Sullivan). Proposed sign of the relationship to recruitment is positive and the time series is not lagged for the intermediate stage indicator analysis.

Socioeconomic Indicators:

Fishery Performance Indicators (Figure 3C.2b.a-f)

a.) **Catch-per-unit-effort of sablefish** from the **combined** longline and pot fisheries in Alaska (contact: M. Cheng).
b.) **Catch-per-unit-effort of sablefish** estimated from the **pot** fisheries in Alaska (contact: M. Cheng).
c.) **Incidental catch estimates of sablefish** in the **GOA** fisheries excluding the sablefish fishery (contact: K. Shotwell).
d.) **Incidental catch estimates of sablefish** in the **Bering Sea** fisheries excluding the sablefish fishery (contact: K. Shotwell).
e.) **Sablefish condition** for large (>= 750 mm) **female sablefish** from data collected randomly by observers in the GOA fisheries (contact: J. Sullivan).

Economic Indicators (Figure 3C.2b.g-h)

f.) Annual estimated **real ex-vessel value** of sablefish (contact: J. Lee).
g.) Average real **ex-vessel price per pound** of sablefish from fish ticket information (contact: J. Lee).

Indicator Monitoring Analysis

There are up to three stages (beginning, intermediate, and advanced) of statistical analyses for monitoring the indicator suite listed in the previous section. The beginning stage is a relatively simple evaluation by traffic light scoring. This evaluates the current year trends relative to the mean of the whole time series, and provides a historical perspective on the utility of the whole indicator suite. The intermediate stage uses importance methods related to a stock assessment variable of interest (e.g., recruitment, growth, catchability). These regression techniques provide a simple predictive performance for the variable of interest and are run separate from the stock assessment model. They provide the direction, magnitude, uncertainty of the effect, and an estimate of inclusion probability. The advanced stage is used for providing visibility on current research ecosystem models and may be used for testing a research ecosystem linked stock assessment model where output can be compared with the current operational stock assessment model to understand information on retrospective patterns, prediction performance, and comparisons to model outputs.

Beginning Stage: Traffic Light Test

We use a simple scoring calculation for this beginning stage traffic light evaluation on the indicators listed in the Indicator Suite section. Indicator status is evaluated based on being greater than ("high"), less than ("low"), or within ("neutral") one standard deviation of the long-term mean. A sign based on the anticipated relationship between the ecosystem indicator and the stock (generally shown in Figure 3C.1 and specifically by indicator in the Indicator Suite, Ecosystem Indicators section) is also assigned to the indicator where possible. If a high value of an indicator generates good conditions for the stock and is also greater than one standard deviation above the mean, then that value receives a "+1" score. If a high value generates poor conditions for the stock and is greater than one standard deviation above the mean, then that value receives a "-1" score. All values less than or equal to one standard deviation from the long-term mean are average and receive a "0" score. The scores are summed by the three organizational categories within the ecosystem (physical, lower trophic, and upper trophic) or socioeconomic (fishery performance, economic, and community) indicators and divided by the total number of indicators available in that category for a given year. The scores over time allow for comparison of the indicator performance and the history of stock productivity (Figure 3C.3). We note, per December 2023 SSC suggestion, that the socioeconomic indicators can provide a combination of performance and context and the overall scores by category should only include indicators that reflect performance. In this way higher scores should reflect "good" conditions and would not be influenced by indicators that are included for context (e.g., composition of product form, or market share). We also provide five year indicator status tables with a color (ecosystem indicators only) for the relationship with the stock (Tables 3C.2a,b), and evaluate each year's status in the historical indicator time series graphic (Figures 3C.2a,b) for each ecosystem and socioeconomic indicator.

We evaluate the status and trends of the ecosystem and socioeconomic indicators to understand the pressures on the sablefish stock regarding recruitment, stock productivity, and stock health. We start with the physical indicators and proceed through the increasing trophic levels, then evaluate the socioeconomic indicators as listed above. Here, we concentrate on updates since the last ESP report card (Shotwell et al., 2022). We use the following nomenclature when describing these indicators:

- If the value in the time series is at the long-term mean of the time series (or the mean), we use the term "average" (dotted green line in Figure 3C.2)
- If the value is above/below the mean but below/above 1 standard deviation of the mean (solid green line in Figure 3C.2) we us the terms "above average" or "below average"
- Any value within 1 standard deviation of the mean is considered "neutral" in Table 3C.2
- If the value is above/below 1 standard deviation of the mean (solid green line in Figure 3C.2) we us the term "high" or "low"

Overall, the physical indicators scored average, the lower trophic indicators were below average, and the upper trophic indicators were above average. The fishery performance indicators were average for 2023 and above average for 2022, while the economic indicators remain below average for 2022 (Figure 3C.3). Compared to last year, this is an increase from below average for the physical indicators, a continued decrease from below average for the lower trophic indicators, and an increase from below average for the upper trophic indicators. For the fishery performance indicators this is a decrease from above average last year and the year before and the economic indicators have been below average since 2018. We note caution when comparing scores between odd to even years as there are two indicators (one lower and one upper trophic) missing in even years due to the off-cycle year surveys in the GOA. Also, there have been other cancellations due to COVID-19 and continuing issues with staffing of NOAA white ships since 2020 that have resulted in delayed or canceled surveys, reductions in survey sampling coverage and resolution, increased uncertainty in survey results, and increased costs/reduced efficiency for surveys. This has limited production and delivery timing of several indicators. Some fishery performance and all economic indicators are lagged by at least one year due to timing of the availability of the current year information and the production of this report.

In terms of physical indicators (Figure 3C.2a.a-d), all four were neutral this year (Table 3C.2a). The sablefish population is currently experiencing a series of unusually large year-classes, which are concurrent with large shifts in the physical environment. This year, large marine heatwave events were less frequent than last year, and below average for the time series. Sea surface temperature (SST) in the GOA and the southeastern Bering Sea (SEBS) both decreased to below average. Bottom temperatures along the slope environment decreased but were still above average this year and similar to 2021. The 250-m slope temperature index is in prime sablefish habitat and the magnitude of interannual differences is small compared to surface water temperature fluctuations. However, this index has remained positive for the last seven years, a deviation from the historical fluctuations around the mean, suggesting these deeper waters continue to be warmer than average (~0.15°C) since 2017. Subsurface waters below mixed layers can absorb and store heat. These changes do not occur at the same timescales as changes in surface water temperatures, often showing delayed responses by a year or more. These temperature changes are also very small compared to surface waters. The warmer that subsurface waters become, the less cooling capacity they have to absorb heat from surface waters. Implications of changes in subsurface temperatures are not well known, but could impact biology, species distributions, or prey presence, quality and abundance (Siwicke 2022).

For lower trophic indicators (Figure 3C.2a.e-l), two of eight indicators were neutral, two were low, and one was high, two are lagged by one year and were neutral and low, and one did not have data available (Table 3C.2a). Estimates of chlorophyll *a* concentration in the GOA and SEBS (Figure 3C.2a.e-f) were low and in the GOA was the lowest in the time series (Figure 3C.2a.e), similar to values at the onset of the marine heatwave. Peak timing of the spring bloom was high in the GOA and average in the SEBS (Figure 3C.2a.g-h). Continuous plankton recorder data were updated for 2021 for the oceanic GOA on the eastern and western sides (Figure 3C.2a.i-j), and the community size anomalies in the eastern GOA remained below average and similar to 2021, while in the western GOA decreased to low. With a couple exceptions, the copepod community size anomaly was mostly negative in both regions since 2015. In warm conditions smaller species tend to be more abundant and the copepod community size index reflects this throughout the marine heat wave periods of 2014-2016, and 2018-2020. The large diatom abundance was positive in 2022 in the shelf and western regions, however in the eastern GOA regions there is a lower than average diatom anomaly (Ostle and Batten, 2023). There were no updates for the euphausiid abundance index due to an issue with recurring radiated noise on the survey but a data processing solution is being implemented and there may be updates in the future.

The age-0 growth index was slightly below the long-term average, but size of age-0 sablefish was much lower than usual in 2023 (Figure 3C.2a.l, Figure 3C.4). When 2023 data were added to this year's model, we found that the interaction between Julian Day and year explains the majority of variability in age-0 sablefish length (OLS: $F = 26.78$, $p < 0.001$, $R^2 = 0.86$). In 2023 age-0 sablefish growth (1.7 mm/day) and the growth index anomaly (-0.17 mm/day) was slightly below average. Additionally, the predicted length (79 mm) was well below average (-21 mm) on the median sampling date (Jul 24). 2023 indices are based on measurements of 22 fish sampled by a slightly lower than average number of diet samples (n = 169, average = 179) because rhinoceros auklets had unusually low productivity in 2023 so fewer meals could be collected overall. Size of age-0 sablefish at the end of July is important because frequency of occurrence of age-0 sablefish in seabird diets is positively related to predicted fish length ($p < 0.001$). It is likely that the seabirds avoid age-0 sablefish that are too small, either because they cannot sense them as easily or because they are passing them up for higher energy food, resulting in a lower provisioning rates than would be if the fish were larger in size during the chick rearing stage. Age-0 sablefish are not well sampled by other survey methods, and so time series of age-0 sablefish growth derived from seabird diet monitoring at Middleton Island are among the longest available from any Alaska location. Growth (or size) of age-0 sablefish may provide an early indication of recruitment because these indices may be related to survival of the cohort. Growth index values were high during the marine heatwave years (2014-2016, 2019), and low during the cool stanza prior to the heatwave (2008-2013). If growth or size of age-0 sablefish is related to recruitment, it may be important to consider how size selectivity influences sampling by seabirds at Middleton Island.

For upper trophic indicators (Figure 3C.2a.m-r), three of six indicators were neutral, one was high, one was updated for 2022 and was low, and one was not updated (Table 3C.2a). Sablefish CPUE (kg per km towed) on the nearshore ADF&G large-mesh bottom trawl survey remained at relatively low levels from 1989 until 2015 when it began increasing to a peak in 2020 (Figure 3C.2a.m). Sablefish CPUE continued to decline in 2023, but remains above average (Figure 3C.2a.m). Overall, this survey likely contains a mix of different aged sablefish from age-1 through age-3 or age-4, and so the CPUE index is an index of cohort strength across the previous 3-4 years (Figure 3C.5, top graph). The high CPUE for 2020-2021 were largely driven by catches in the Kodiak area, while high CPUE in 2018, 2019 was up in all areas of the survey. There was also an increase in catches in the eastern Aleutians in 2021 (Figure 3C.5, top graph). In 2022, CPUE in Kodiak decreased while CPUE in all other areas increased and in 2023 CPUE in all areas decreased. This is consistent with the main assessment and AFSC longline survey that imply most of the recent population growth is in the western areas of the GOA. When combined with the length frequencies, this survey is useful for identifying continued survival of sablefish throughout their residency in the nearshore before transitioning to the slope adult environment. Length frequencies from 2020 are similar to those in 2015 suggesting a strong 2019 year-class similar to 2014. The length frequencies from 2021 through 2023 match the growth of the 2019 cohort to age-2, -3, and -4, but do not show any new cohorts at age-1 (Figure 3C.5, bottom graph). Age-1 sablefish (measured by population extrapolated length frequencies of <35 cm fish) in the AFSC bottom trawl survey were above average this year similar to 2001 (2000 year class) and could represent a stronger 2022 year class than average (Figure 3C.2a.n).

Body condition of female sablefish captured on the longline survey can be used to measure the health of fish arriving at the adult habitat. The summer relative condition of age-4 immature female fish on the AFSC longline survey is lagged by one year because it relies on age data, which take longer to provide. The age-4 condition indicator was low in 2022, similar to 2019, suggesting the 2018 year class did not have sufficient resources just prior to when a portion of the population will be maturing (Figure 3C.2a.o). Factors influencing the condition could include poor environmental conditions, reduced prey availability or quality, or increased inter- or intra-specific competition and could translate into slower maturation and somatic growth, or reduced survival rates. Condition of large adult female sablefish from the AFSC longline survey increased to high in 2023 from low in 2022 (Figure 3C.2a.r), and could translate into a lower likelihood of skip spawning, increased somatic growth rates, or increased survival rates relative to 2022. Arrowtooth flounder has been considered a primary predator of young sablefish, but this stock has been declining over the past decade (Figure 3C.2a.p., Shotwell et al., 2021). The arrowtooth flounder stock assessment model was not updated in 2022 as it was an off-cycle year but estimates from the 2023 bottom trawl survey were 5% greater than in 2021 (but still below the long term mean). Additionally, the incidental catch estimates of sablefish in the GOA arrowtooth flounder fishery have decreased since the high of the time series in 2018 and were average in 2023, suggesting lower levels of spatial overlap between the arrowtooth flounder and sablefish populations (Figure 3C.2a.q). This suggests that the large sablefish year classes of 2014-2016 have moved off the continental shelf into adult sablefish habitat on the slope and are no longer competing with or experiencing predation by arrowtooth flounder. Thus, the large 2019 year class of sablefish may not have as much overlap with GOA arrowtooth flounder.

For fishery performance indicators (Figure 3C.2b.a-f), one of five was neutral, three were high, and one was low in 2022, while one was neutral, one was high, and one was low in 2023 (Table 3C.2b). The standardized index of abundance for the combined index in 2022 increased dramatically relative to 2021, reflecting an increase of 37.7%, and represents the second largest value throughout the time series (Figure 3C.2b.a). The standardized index of abundance for the pot fishery in the BSAI region is at a time series high in 2022 (Figure 3C.2b.b). Compared to 2021, there was a 34.2% increase. Increases in standardized indices of abundance are attributed to a variety of factors, but are notably a result of high recruitment events in recent years. Trends indicate that large year classes from previous years are becoming increasingly available to both the hook-and-line and pot fishery across management areas.

Sablefish catch in the non-sablefish target fisheries for the GOA decreased to low in 2023 from above average in 2022 (Figure 3C.2b.c) but only decreased slightly in the BSAI non-sablefish target fisheries (Figure 3C.2b.d). These catches are primarily from the rockfish, halibut, and arrowtooth flounder trip targets in the GOA and the rockfish and Kamchatka flounder trip targets in the BSAI. This represents a shift from the higher incidental catches from the BSAI midwater pollock trip targets in 2019-2021 (K. Siwicke and K. Echave, Appendix 3D). Rapid changes of incidental catch may imply shifting distribution of the sablefish population into non-preferred habitat, which could increase competition and predation for sablefish, particularly with the influx of the recent large year classes. Relative condition of adult females, based on the length-weight relationship, in the GOA fisheries improved from low in 2022 to slightly below average in 2023 (Figure 3C.2b.e), but sample sizes of adult females severely declined from 2019 - 2022, potentially due to the increase in electronic monitoring and reduced fishing effort due to low prices, small fish, and COVID-19. The relative condition of females that are of the size and age to spawn by region may provide insight into regional productivity. Condition of these larger females, may be related to maturity, where fish may be mature or could be skip spawning. Condition can also be an indication of habitat quality. Heavier fish for their length will also have a higher value per pound.

Sablefish ex-vessel value in 2022 recovered from historically low levels observed in 2019-2021, increasing to slightly above average (Figure 3C.2b.f, Table 3C.1a). However, with 2022 ex-vessel price remaining low similar to 2021 (Figure 3C.2b.g), aggregate ex-vessel value in 2022 was remarkably low in contrast to the marked increase in production volume, with 2022 retained catch more than twice the average value observed from 2013-2017 (Table 3C.1a). The price decrease since 2017 was, in part, the result of smaller average fish size as the large cohorts of younger year classes had not fully grown to a higher marketable price. The increased abundance and supply of smaller fish put downward pressure on the price of small fish, increased the price margin between small and large fish, and lowered the average price. Other factors (e.g., global supply, foreign competition) also play a role in the decreasing prices and a more thorough economic analysis is warranted but not available at this time. Japan is the primary export market, but its share of export value has fluctuated since 2018 (Table 3C.1c). China's share of export value has also been generally increasing (Table 3C.1c). Additionally, increased global supply, media reports of inventory buildup in Japan, and the small size of fish have put downward pressure on sablefish prices (Fissel et al., 2020).

The sablefish fishery has undergone dramatic changes in response to multiple large year classes and increased quotas. Incidental fisheries have seen dramatic increases in catch of small sablefish and all fisheries have seen an unprecedented market collapse. Further, the directed fishery has experienced exceptional catch rates in recent years but these catches are dominated by small fish with low market value. The existing fishery performance and economic indicators presented in this report card do not capture these drastic changes well. Indicators for these factors need further examination and refinement as these fishery and market shifts. We provide some areas for improvement in the Data Gaps and Future Research Priorities section.

Intermediate Stage: Importance Test

Bayesian adaptive sampling (BAS) was used for the intermediate stage statistical test to quantify the association between hypothesized predictors and sablefish recruitment, and to assess the strength of support for each hypothesis. In this stage, the full set of indicators is first evaluated for normality and transformed as needed or removed if the indicators cannot be transformed for this analysis. The remaining set of indicators is winnowed to the predictors that could directly relate to recruitment and highly correlated covariates (>0.6) are removed. We explored recruitment here as it was initially identified for this importance test within the full ESP (Shotwell et al., 2019). Other time-varying stock assessment parameters of interest could be evaluated should they become priorities for exploring ecosystem linkages in the future. Covariates with the strongest links to recruitment are retained and then z-scored. We further restrict potential covariates to those that can provide the longest model run (e.g., indicators from biennial surveys or gappy time series would be removed) and through the most recent estimate of recruitment that is well estimated (not just average recruitment) in the current operational stock assessment model. This results in a model run from 1996 through the 2019 year-class. We provide the relationship between the observed and predicted estimates (Figure 3C.6, top panel, left side) and the fit over time (Figure 3C.6, top panel, right side) for reference. We then provide the mean relationship between each predictor variable and log sablefish recruitment over time (Figure 3C.6, left side), with error bars describing the uncertainty

(95% confidence intervals) in each estimated effect and the marginal inclusion probabilities for each predictor variable (Figure 3C.6, right side). A higher probability indicates that the variable is a better candidate predictor of sablefish recruitment. This year the highest ranked predictor variables (inclusion probability > 0.5) based on this process are the summer juvenile sablefish CPUE from the ADF&G large mesh survey and the spring SST in the SEBS (Figure 3C.6).

Many indicators were removed from the BAS analysis due to limitations around missing data, collinearity, and short time series. Incorporating additional importance methods in this intermediate stage indicator analysis may be useful for evaluating the full suite of indicators and may allow for identifying more robust indicators for potential use in the operational stock assessment model. A new study uses the sablefish ESP indicator suite (Shotwell et al., 2022) and sablefish recruitment from the operational stock assessment model (Goethel, et al., 2022) to investigate the strengths and weaknesses of multiple statistical approaches for evaluating indicators (Oke et al., *In prep*.). Along with BAS, this study also evaluates generalized additive models (GAM), boosted regression trees (BRT), and dynamic factor analysis (DFA) paired with state-space regression. The non-BAS methods also identified SST and several juvenile abundance indicators as being strongly correlated with sablefish recruitment (Oke et al., *In prep*) and provide support for evaluating these strong candidate indicators within an ecosystem linked research model.

Advanced Stage: Research Model Test

In the future, highly ranked predictor variables could be evaluated in the third stage statistical test, which is a modeling application that analyzes predictor performance and estimates risk probabilities within the operational stock assessment model. A Spatially Integrated Life Cycle (SILC) model is in development for sablefish that pairs output from an individual based model (IBM) with a spatial statistical catch-at-age assessment model. The overall objective is to parse the movement and survival of sablefish in their first year and incorporating the impact of spatially explicit environmental and predation processes on juveniles and adults. Increasing the resolution of our assessment of these processes will benefit the ability of the ESP to link with regional environmental processes. The sablefish IBM has been updated to include temperature relationships in the early life stages (Gibson et al., 2023) as part of an exploration of the impact of seamounts on connectivity to the nearshore settlement environment. Information on connectivity from spawning to nursery areas will likely be used in the SILC model configuration. Once the SILC model is developed and published, regional estimates of recruitment could be generated and linked with appropriate indicators to explain spatial shifts in the sablefish population and tested as an alternative environmentally-linked assessment. The juvenile ADF&G index continues to have a high inclusion probability in the stage 2 test and could be used directly in the model as a survey for age-1 plus sablefish (or a range of ages). Utilizing indicators as indices directly inside the model would have the desirable property of influencing ABC recommendations in a neutral way by reducing uncertainty in the model, whereas risk tables and other adjustments can only reduce ABC.

Another way that the ESP may be used to forward an advanced research model is to include environmental forcing or ecosystem information in future projections. Previous work (Shotwell et al., 2014) had identified SST as a potential driver of recruitment and demonstrated the potential benefits of including these in short-term projections (1-5 years). A new generic projection model has been developed for NPFMC stocks that has been applied using SST for sablefish (M. Veron, *pers. commun*.). The most recent BAS results identified SST in the SEBS as being highly related to recruitment. This index is currently generated from satellite data but could be replaced in the future by SST from the Bering 10K ROMS-NPZ model (Kearney et al., 2020) that has been validated for the SEBS with bottom trawl survey temperatures. The SST hindcast and forecast from the ROMS-NPZ model could be used as a covariate on the recruitment deviations in an ecosystem model run and compared to the operational projections to evaluate the impact of temperature on the stock 1-5 years into the future. Projections from the ROMS-

NPZ model could also be evaluated at various intervals into the future under high and low emission scenarios to gain an understanding of stock fluctuations in a changing climate.

Data Gaps and Future Research Priorities

While the metric and indicator assessments provide a relevant set of proxy indicators for evaluation at this time, there are certainly areas for improvement. The list below summarizes the data gaps and future research priorities for this ESP by ecosystem and socioeconomic category. Please reference the full ESP (Shotwell et al., 2019, 2020) and past report cards (Shotwell et al., 2021, 2022) for more details.

Ecosystem Priorities

- Development of high-resolution remote sensing (e.g., regional surface temperature, transport estimates, mesoscale eddy activity, primary production estimates) or climate model indicators (e.g., bottom temperature, nutrient-phytoplankton-zooplankton variables) to assist with the current year data gap for several indicators.
- Refinement to current indicators (e.g., heatwave, chlorophyll *a*) that were only partially specialized for sablefish such as more specific phytoplankton indicators tuned to the spatial and temporal distribution of sablefish larvae as well as phytoplankton community structure information (e.g., hyperspectral information for size fractionation).
- Development of large-scale indicators from multiple data sources (e.g., zooplankton surveys) to determine a relative trend by region.
- Information from laboratory studies to help refine the current indicators or identify thresholds (e.g., time to starvation in first feeding larvae).
- Increased sampling of weights and analysis of diet data on surveys to improve condition indicators. This would help:
  - Identify causal mechanisms for shifting condition of pre-spawning sablefish in both the survey and the fishery and the potential impact on spawning potential,
  - Increase understanding of the relationships between condition and spawning by region and identify the link between body condition and productivity,
  - Update the Ecopath model (Aydin et al., 2007) that initially estimated predation and consumption rates for sablefish and other groundfish
  - Allow for a more detailed synthesis of gut contents to generate time series indicators of stomach fullness or energy content per individual sablefish,
  - Provide inference about competition and predation if other species were also updated in the Ecopath model.
  - Allow for considering morphometric or physiological impacts on condition in pre- versus post-spawning individuals and individuals that exhibit skipped spawning to measure energetic costs of spawning.
  - Increase understanding on the impacts of shifting spatial distribution and evaluate whether there are any regional impacts on sablefish condition during spawning
- Evaluation of the spatial and temporal overlap between different fisheries to provide insight on predation or competition pressures and determine the quality of the annual spawning stock.
- Updated sablefish IBM (Gibson et al., 2023) could be used to spatially tune physical and lower trophic indicators to more accurately reflect sablefish early life history distributions.
- Refinement of the SILC model to create regional estimates of recruitment to provide insight into a selection of relevant indicators by region for future analyses
- Summary indicators of tagging data or output from the research spatial model would be helpful for understanding movement dynamics and shifts in the spatial distribution of the stock.

Socioeconomic Priorities

- Reorganization of indicators by scale, structure, and dependence per December 2022 SSC request that may result in a transition of indicators currently reported and a potential shift in focus
- Re-evaluation of fishery performance indicators to potentially include:
    - CPUE measures (e.g., proportion of the catch by gear, level of effort by gear)
    - Fleet characteristics (e.g., number of active vessels, number of processors)
    - Spatial distribution measures (e.g., center of gravity, area occupied)
- Re-evaluation of economic indicators to potentially include:
    - Percentage of total allowable catch (TAC) harvested by active vessels
    - Measures by size grade (e.g., proportion landed, price per pound)
    - Revenue per unit effort by area or gear type
- Evaluation of additional sources of socioeconomic information to determine what indicators could be provided in the ESP that are not redundant with indicators already provided in the Economic SAFE and the ACEPO report
- Consideration of the timing of indicators that are delayed by 1 to several years depending on the data source from the annual stock assessment cycle and when updates can be available.
- Consideration on how to include local knowledge, traditional knowledge, and subsistence information to understand recent fluctuations in stock health, shifts in stock distributions, or changes in size or condition of species in the fishery per SSC recommendation.
- Information on the historical use of sablefish by coastal communities per SSC recommendation.

As indicators are improved or updated, they may replace those in the current set of ecosystem or socioeconomic indicators to allow for refinement of the indicator analyses and potential evaluation of performance and risk. Incorporating additional importance methods in the intermediate stage indicator analysis may also be useful for evaluating the full suite of indicators and may allow for identifying robust indicators for potential use in the operational stock assessment model. The annual request for information (RFI) for the sablefish ESP will include these data gaps and research priorities that could be developed for the next full ESP assessment.

Literature Cited

Arimitsu, M. L. and Hatch, S. A., 2023, Age-0 Sablefish size and growth indices from seabird diets at Middleton Island, Alaska: U.S. Geological Survey data release, https://doi.org/10.5066/P94KVH9X

Arimitsu, M. L. and B. Hatch. 2023. Age-0 Sablefish size and growth indices from seabird diets at Middleton Island, Gulf of Alaska. USGS Open-File Report 2023-1049, 4 p. https://doi.org/10.3133/ofr20231049

Aydin, K., S. Gaichas, I. Ortiz, D. Kinzey, and N. Friday. 2007. A comparison of the Bering Sea, Gulf of Alaska, and Aleutian Islands large marine ecosystems through food web modeling. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-178, 298 p.

Cheng, M.L.H., Rodgveller, C.J., Langan, J.A., and Cunningham, C.J. 2023. Standardizing fishery-dependent catch-rate information across gears and data collection programs for Alaska sablefish (Anoplopoma fimbria). ICES Journal of Marine Science: fsad037. doi:10.1093/icesjms/fsad037.

Deary, A.L., Porter, S.M., Dougherty, A.B., and Duffy-Anderson, J.T. 2019. Preliminary observations of the skeletal development in pre-flexion Sablefish, Anoplopoma fimbria, larvae. Ichthyological Research. DOI 10.1007/s10228-018-0657-0

Doyle, M.J., and K.L. Mier. 2016. Early life history pelagic exposure profiles of selected commercially important fish species in the Gulf of Alaska. Deep-Sea Res II. 132: 162-193.

Doyle, M.J., S.L. Strom, K.O. Coyle, A.J. Hermann, C. Ladd, A.C. Matarese, S.K. Shotwell, R.R. Hoperoft 2019. Early life history phenology among Gulf of Alaska fish species: Strategies, synchronies, and sensitivities. Deep. Res. PART II-TOPICAL Stud. Oceanogr., 165 (2019), pp. 41-73, 10.1016/j.dsr2.2019.06.005.

Fissel, B., M. Dalton, R. Felthoven, B. Garber-Yonts, A. Haynie, S. Kasperski, J. Lee, D. Lew, A. Santos, C. Seung, and K. Sparks. 2021. Economic status of the groundfish fisheries off Alaska, 2020. In Stock assessment and fishery evaluation report for the groundfish resources of the GOA and BS/AI. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Gibson, G.A., W.T. Stockhausen, K. Shotwell, A.L. Deary, J.L. Pirtle, K.O. Coyle, A.J. Hermann. 2023. Can seamounts in the Gulf of Alaska be a spawning ground for sablefish settling in coastal nursery grounds? Fisheries Research. 261: 106625. DOI: https://doi.org/10.1016/j.fishres.2023.106625

Hanselman, D.H., J. Heifetz, K.B. Echave, and S.C. Dressel. 2015. Move it or lose it: Movement and mortality of sablefish tagged in Alaska. Canadian Journal of Fish and Aquatic Sciences. http://www.nrcresearchpress.com/doi/abs/10.1139/cjfas-2014-0251.

Hanselman, D.H., C.J. Rodgveller, K.H. Fenske, S.K. Shotwell, K.B. Echave, P.W. Malecha, and C.R. Lunsford. 2019. Assessment of the Sablefish stock in Alaska. Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea Aleutian Islands and Gulf of Alaska. North Pacific Fishery Management Council, 1007 W 3rd Ave, Suite 400 Anchorage, AK 99501.

Heifetz, J. and J. T. Fujioka. 1991. Movement dynamics of tagged sablefish in the northeastern Pacific Ocean. Fish. Res., 11: 355-374

Kearney, K., A. Hermann, W. Cheng, I. Ortiz, and K. Aydin. 2020. A coupled pelagic–benthic–sympagic biogeochemical model for the Bering Sea: documentation and validation of the BESTNPZ model (v2019.08.23) within a high-resolution regional ocean model. Geoscientific Model Development

13(2): 597-650. https://doi.org/10.5194/gmd-13-597-2020. (Source code available at https://github.com/beringnpz/roms-bering-sea, Additional information at https://beringnpz.github.io/roms-bering-sea/).

Kimura, D. K., A. M. Shimada, and F. R. Shaw. 1998. Stock structure and movement of tagged sablefish, *Anoplopoma fimbria*, in offshore northeast Pacific waters and the effects of El Niño-Southern Oscillation on migration and growth. Fish. Bull. 96: 462-481.

Matarese, A.C., Blood, D.M., Picquelle, S.J., and Benson, J.L. 2003. Atlas of abundance and distribution patterns of ichthyoplankton from the northeast Pacific Ocean and Bering Sea ecosystems based on research conducted by the Alaska Fisheries Science Center (1972-1996). U.S. Dep. Commer., NOAA Prof. Paper NMFS 1, 281 pp.

McDevitt, S. A. 1990. Growth analysis of sablefish from mark-recapture data from the northeast Pacific. M.S. University of Washington. 87 p.

Ostle, C. and S. Batten. 2021a. Continuous Plankton Recorder Data from the Northeast Pacific, 2000-2020. *In* Ferriss, B., and Zador, S., 2021. Ecosystem Status Report 2021: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501.

Ostle, C., and S. Batten. 2021b. Continuous Plankton Recorder Data from the Eastern Bering Sea. *In* Siddon, E.C., 2021. Ecosystem Status Report 2021: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501.

Ostle, C., and Batten, S. 2023. Continuous Plankton Recorder Data from the Gulf of Alaska: Lower Trophic Levels in 2022. *In* Ferriss, B., and Zador, S., 2023. Ecosystem Status Report 2021: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501.

Rodgveller, C. J. 2018. A comparison of methods for classifying female sablefish maturity and skip spawning outside of the spawning season. Marine and Coastal Fisheries. 10(6):563-576. doi:10.1002/mcf2.10053.

Rodgveller, C. J., K. B. Echave, P-J. F. Hulson, and K. M. Coutré. 2018. Age-at-maturity and fecundity of female sablefish sampled in December of 2011 and 2015 in the Gulf of Alaska. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-371, 31 p.

Rodgveller, C. J. 2019. The utility of length, age, liver condition, and body condtion for predicting maturity and fecundity of female sablefish. Fish. Res. 216:18-28.

Rutecki, T. L., C. J. Rodgveller, C. R. Lunsford. 2016. National Marine Fisheries Service longline survey data report and survey history, 1990-2014. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-324, 329 p.

Saunders, M. W., B. M. Leaman, V. Haist, R. Hilborn, and G. A. McFarlane. 1996. Sablefish stock assessment for 1996 and recommended yield options for 1997. Unpublished report available Department of Fisheries and Oceans, Biological Sciences Branch, Pacific Biological Station, Nanaimo, British Columbia, V9R 5K6.

Shotwell, S.K., K., Blackhart, C. Cunningham, E. Fedewa, D., Hanselman, K., Aydin, M., Doyle, B., Fissel, P., Lynch, O. Ormseth, P., Spencer, S., Zador. *In Review*. Introducing the Ecosystem and Socioeconomic Profile, a proving ground for next generation stock assessments.

Shotwell, S.K., B. Fissel, and D. Hanselman. 2019. Ecosystem and socioeconomic profile of the Sablefish stock in Alaska. Appendix 3C In Hanselman, D.H., C.J. Rodgveller, K.H. Fenske, S.K. Shotwell, K.B. Echave, P.W. Malecha, and C.R. Lunsford. 2019. Assessment of the Sablefish stock in

Alaska. Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea Aleutian Islands and Gulf of Alaska. North Pacific Fishery Management Council, 1007 W 3rd Ave, Suite 400 Anchorage, AK 99501. Pp. 157-202.

Shotwell, S.K., D. Goethel, A. Deary, K. Echave, K. Fenske, B. Fissel, D. Hanselman, C. Lunsford, K. Siwicke, and J. Sullivan. 2020. Ecosystem and socioeconomic profile of the Sablefish stock in Alaska. Appendix 3C In D.R. Goethel, D.H., Hanselman, C.J. Rodgveller, K.H. Fenske, S.K. Shotwell, K.B. Echave, P.W. Malecha, K.A. Siwicke, and C.R. Lunsford. 2020. Assessment of the Sablefish stock in Alaska. Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea Aleutian Islands and Gulf of Alaska. North Pacific Fishery Management Council, 1007 W 3rd Ave, Suite 400 Anchorage, AK 99501. Pp. 190-218.

Shotwell, S.K., D. Goethel, A. Deary, K. Echave, B. Fissel, D. Hanselman, C. Lunsford, K. Siwicke, and J. Sullivan, M. Szymkowiak, A. Tyrell, B. Williams, and S. Zador. 2021. Ecosystem and socioeconomic profile of the Sablefish stock in Alaska. Appendix 3C In D.R. Goethel, D.H., Hanselman, C.J. Rodgveller, K.B. Echave, B.C. Williams, S.K. Shotwell, J.S. Sullivan, P.F. Hulson, P.W. Malecha, K.A. Siwicke, and C.R. Lunsford. 2021. Assessment of the Sablefish stock in Alaska. Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea Aleutian Islands and Gulf of Alaska. North Pacific Fishery Management Council, 1007 W 3rd Ave, Suite 400 Anchorage, AK 99501. Pp. 198-223.

Shotwell, S.K., D. Goethel, A. Deary, B. Ferriss, K. Echave, C. Lunsford, K. Siwicke, E. Siddon, J. Sullivan, M. Szymkowiak, and B. Williams. 2022. Ecosystem and socioeconomic profile of the Sablefish stock in Alaska. Appendix 3C *In* D.R. Goethel, C.J. Rodgveller, K.B. Echave, S.K. Shotwell, K.A. Siwicke, D.H., Hanselman, P.W. Malecha, M. Cheng, M. Williams, K. Omori, and C.R. Lunsford. 2022. Assessment of the Sablefish stock in Alaska. Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea Aleutian Islands and Gulf of Alaska. North Pacific Fishery Management Council, 1007 W 3rd Ave, Suite 400 Anchorage, AK 99501. Pp. 110-139.

Shotwell, S.K., Hanselman, D.H., and Belkin, I.M. 2014. Toward biophysical synergy: Investigating advection along the Polar Front to identify factors influencing Alaska sablefish recruitment. Deep-Sea Res. II, 107: 40-53. http://dx.doi.org/10.1016/j.dsr2.2012.08.024.

Shotwell, K., I. Spies, J.N. Ianelli, K. Aydin, D.H Hanselman, W. Palsson, K. Siwicke, and E. Yasumiishi. 2021. Assessment of the arrowtooth flounder stock in the Gulf of Alaska. In Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska. North Pacific Fishery Mngt. Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Shotwell, S.K., W. Stockhausen, G.A. Gibson, J. Pirtle, A. Deary, and C. Rooper. *In Prep.* Developing a novel approach to estimate habitat-related survival rates for early life history stages using individual-based models.

Sigler, M.F., Rutecki, T.L., Courtney, D.L., Karinen, J.F., and Yang, M.S. 2001. Young of the year sablefish abundance, growth, and diet in the Gulf of Alaska. Alaska Fishery Research Bulletin 8(1): 57-70.

Siwicke, K. 2022. Summary of temperature and depth recorder data from the Alaska Fisheries Science Center's longline survey (2005–2021). U.S. Dep. Commer., NOAA Tech. Memo. NMFSAFSC-437, 74 p. DOI: https://doi.org/10.25923/9ckj-0665

Wolotira, R. J. J., T. M. Sample, S. F. Noel, and C. R. Iten. 1993. Geographic and bathymetric distributions for many commercially important fishes and shellfishes off the west coast of North America, based on research survey and commercial catch data, 1912-1984. NOAA Tech. Memo. NMFS-AFSC-6. 184 pp.

Wise, S., S. Kasperski, A. Abelman, J. Lee, M. Parks, and J. Reynolds. 2022. Annual Community Engagement and Participation Overview. Report from the Economic and Social Sciences Program of the Alaska Fisheries Science Center. 98 pp.

Tables

Table 3C.1a. Sablefish ex-vessel data from Alaska Fisheries. Total catch (federal and state) (thousand metric tons), catch in federal fisheries (thousand metric tons), ex-vessel value (million US$), price (US$ per pound), number of vessel, and the proportion of vessels that are catcher vessels, average and most recent 5 years.

	2013-2017 Average	2018	2019	2020	2021	2022
Total catch K mt	12.46	15.2	17.5	20	22.2	28.1
Retained catch K mt	11.48	12.28	13.01	14.08	18.73	25.07
Value M US$	$98.07	$92.19	$73.3	$51.42	$82.98	$124.17
Price/lb US$	$4.01	$3.5	$2.6	$1.72	$2.09	$2.26
% value GOA	94.7%	95.16%	92.46%	88.64%	88.7%	83.65%
Vessels #	295.8	296	265	262	266	276
Proportion CV	88.1%	84.2%	87.16%	85.72%	84.78%	80.85%

Source: NMFS Alaska Region Blend and Catch-accounting System estimates; NMFS Alaska Region At-sea Production Reports; and ADF&G Commercial Operators Annual Reports (COAR). Data compiled and provided by the Alaska Fisheries Information Network (AKFIN).

Table 3C.1b. Sablefish first-wholesale data from Alaska Fisheries. Production (thousand metric tons), value (million US$), price (US$ per pound), and head and gut share of production, average and most recent 5 years.

	2013-2017 Average	2018	2019	2020	2021	2022
Quantity K mt	6.61	7.22	7.94	7.93	11.26	15.9
Value M US$	$102.45	$99.88	$86.18	$69.54	$110.66	$168.42
Price/lb US$	$7.03	$6.28	$4.93	$3.98	$4.46	$4.8
H&G share	97.35%	97.35%	93.7%	94.45%	93.23%	94.11%

Source: NMFS Alaska Region At-sea and Shoreside Production Reports; and ADF&G Commercial Operators Annual Reports (COAR). Data compiled and provided by the Alaska Fisheries Information Network (AKFIN).

Table 3C.1c. Sablefish global catch (thousand metric tons), U.S. and AK shares of global catch; WA & AK export volume (thousand metric tons), value (million US$), price (US$ per pound) and the share of export value from trade with Japan and China, average and most recent 5 years.

	2013-2017 Average	2018	2019	2020	2021	2022
U.S. Share of Global Catch	89%	88%	86%	88%	87%	-
AK share of global	61.92%	61.43%	60.84%	66.08%	69.17%	-
Export quantity K mt	6.66	6.57	6.21	6.69	8.11	12.28
Export value M US$	$85.34	$84.73	$68.01	$68.23	$86.36	$130.91
Export price/lb US$	$5.81	$5.85	$4.97	$4.63	$4.83	$4.83
Japan value export	67.41%	63.21%	64.68%	72.43%	72.99%	63.5%
China value share	15.25%	19.98%	18%	18.39%	18.05%	19.42%
Exchange rate, Yen/Dollar	109.11	110.42	109.01	106.77	109.76	131.497

Note: Exports include production from outside Alaska fisheries
Source: FAO Fisheries & Aquaculture Dept. Statistics http://www.fao.org/fishery/statistics/en (Canadian catch for 2018 from personal communication with DFO). NOAA Fisheries, Fisheries Statistics Division, Foreign Trade Division of the U.S. Census Bureau, http://www.st.nmfs.noaa.gov/commercial-fisheries/foreign-trade/index. U.S. Department of Agriculture http://www.ers.usda.gov/data-products/agricultural-exchange-rate-data-set.aspx.

Table 3C.2a. First stage ecosystem indicator analysis for sablefish, including indicator title and the indicator status of the last five years. The indicator status is designated with text, (greater than = “high”, less than = “low”, or within 1 standard deviation = “neutral” of long-term mean). Fill color of the cell is based on the sign of the anticipated relationship between the indicator and the stock (blue or italicized text = good conditions for the stock, red or bold text = poor conditions, white = average conditions). A gray fill and text = “NA” will appear if there were no data for that year.

Indicator category	Indicator	2019 Status	2020 Status	2021 Status	2022 Status	2023 Status
Physical	Annual Heatwave GOA Model	*high*	neutral	neutral	neutral	neutral
	Spring Temperature Surface GOA Satellite	*high*	*high*	neutral	neutral	neutral
	Spring Temperature Surface SEBS Satellite	*high*	*high*	neutral	neutral	neutral
	Summer Temperature 250m GOA Survey	**high**	neutral	neutral	**high**	neutral
Lower Trophic	Spring Chlorophyll a Biomass GOA Satellite	**low**	**low**	neutral	neutral	**low**
	Spring Chlorophyll a Biomass SEBS Satellite	neutral	neutral	neutral	neutral	**low**
	Spring Chlorophyll a Peak GOA Satellite	**high**	neutral	neutral	neutral	**high**
	Spring Chlorophyll a Peak SEBS Satellite	*low*	neutral	neutral	neutral	neutral
	Annual Copepod Community Size EGOA Survey	**low**	neutral	neutral	neutral	NA
	Annual Copepod Community Size WGOA Survey	*high*	neutral	neutral	**low**	NA
	Summer Euphausiid Abundance Kodiak Survey	neutral	NA	NA	NA	NA
	Annual Sablefish Growth YOY Middleton Survey	*high*	neutral	neutral	neutral	neutral
Upper Trophic	Summer Sablefish CPUE Juvenile Nearshore GOAAI Survey	*high*	*high*	*high*	*high*	neutral
	Summer Sablefish CPUE Juvenile GOA Survey	neutral	NA	neutral	NA	neutral

Indicator category	Indicator	2019 Status	2020 Status	2021 Status	2022 Status	2023 Status
	Summer Sablefish Condition Female Age4 GOA Survey	**low**	neutral	*high*	**low**	NA
	Annual Arrowtooth Biomass GOA Model	neutral	*low*	*low*	NA	NA
	Annual Sablefish Incidental Catch Arrowtooth Target GOA Fishery	**high**	neutral	neutral	neutral	neutral
	Summer Sablefish Condition Female Adult GOA Survey	neutral	neutral	neutral	**low**	*high*

Table 3C.2b. First stage socioeconomic indicator analysis for sablefish, including indicator title and the indicator status of the last five years. The indicator status is designated with text, (greater than = “high”, less than = “low”, or within 1 standard deviation = “neutral” of long-term mean). A gray fill and text = “NA” will appear if there were no data for that year.

Indicator category	**Indicator**	**2019 Status**	**2020 Status**	**2021 Status**	**2022 Status**	**2023 Status**
Fishery Performance	Annual Sablefish Combined CPUE Alaska Fishery	low	low	neutral	high	NA
	Annual Sablefish Pot CPUE Alaska Fishery	high	neutral	high	high	NA
	Annual Sablefish Incidental Catch GOA Fishery	high	high	neutral	neutral	low
	Annual Sablefish Incidental Catch BSAI Fishery	high	high	high	high	high
	Annual Sablefish Condition Female Adult GOA Fishery	neutral	high	neutral	low	neutral
Economic	Annual Sablefish Real Exvessel Value Fishery	low	low	low	neutral	NA
	Annual Sablefish Real Exvessel Price Fishery	neutral	low	low	low	NA

Figures

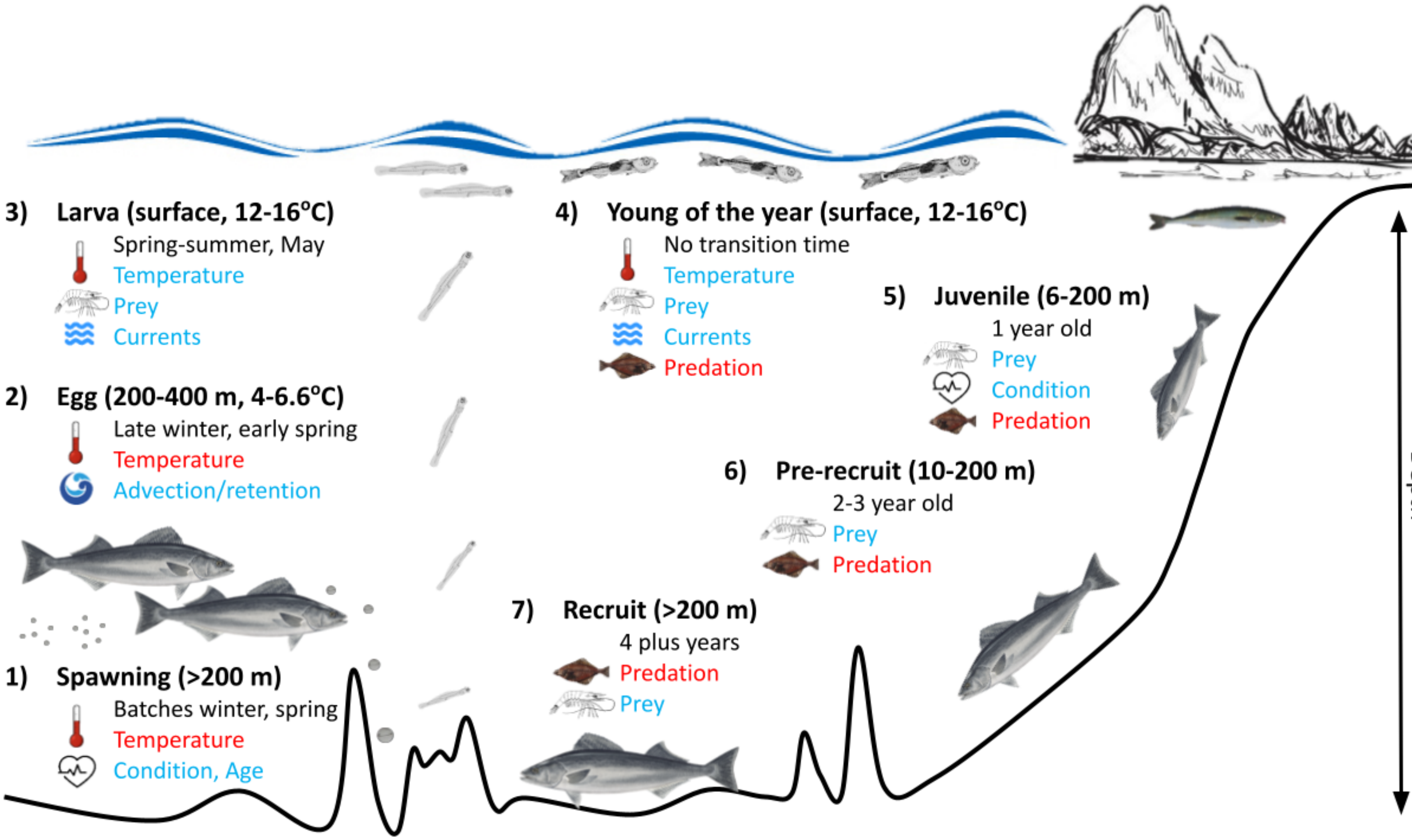


Figure 3C.1: Life history conceptual model for sablefish summarizing ecological information and key ecosystem processes affecting survival by life history stage. Red text indicates that increases in the process negatively affect survival of the stock, while blue text means that increases in the process positively affect survival.

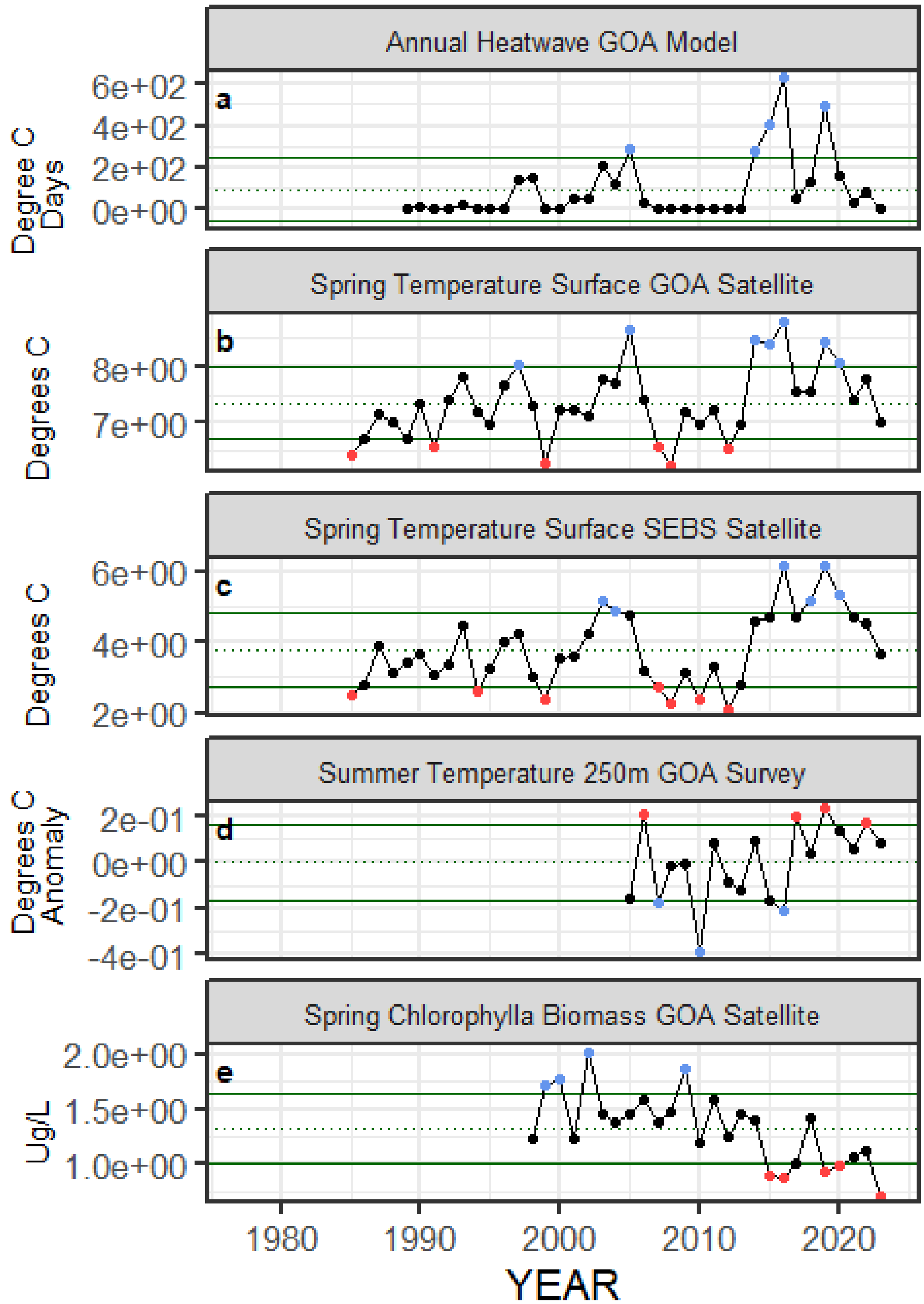


Figure 3C.2a. Selected ecosystem indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are colored if above or below 1 standard deviation of the time series mean and the color represents the proposed relationship for stock (blue for good conditions, red for poor conditions), black circle for neutral.

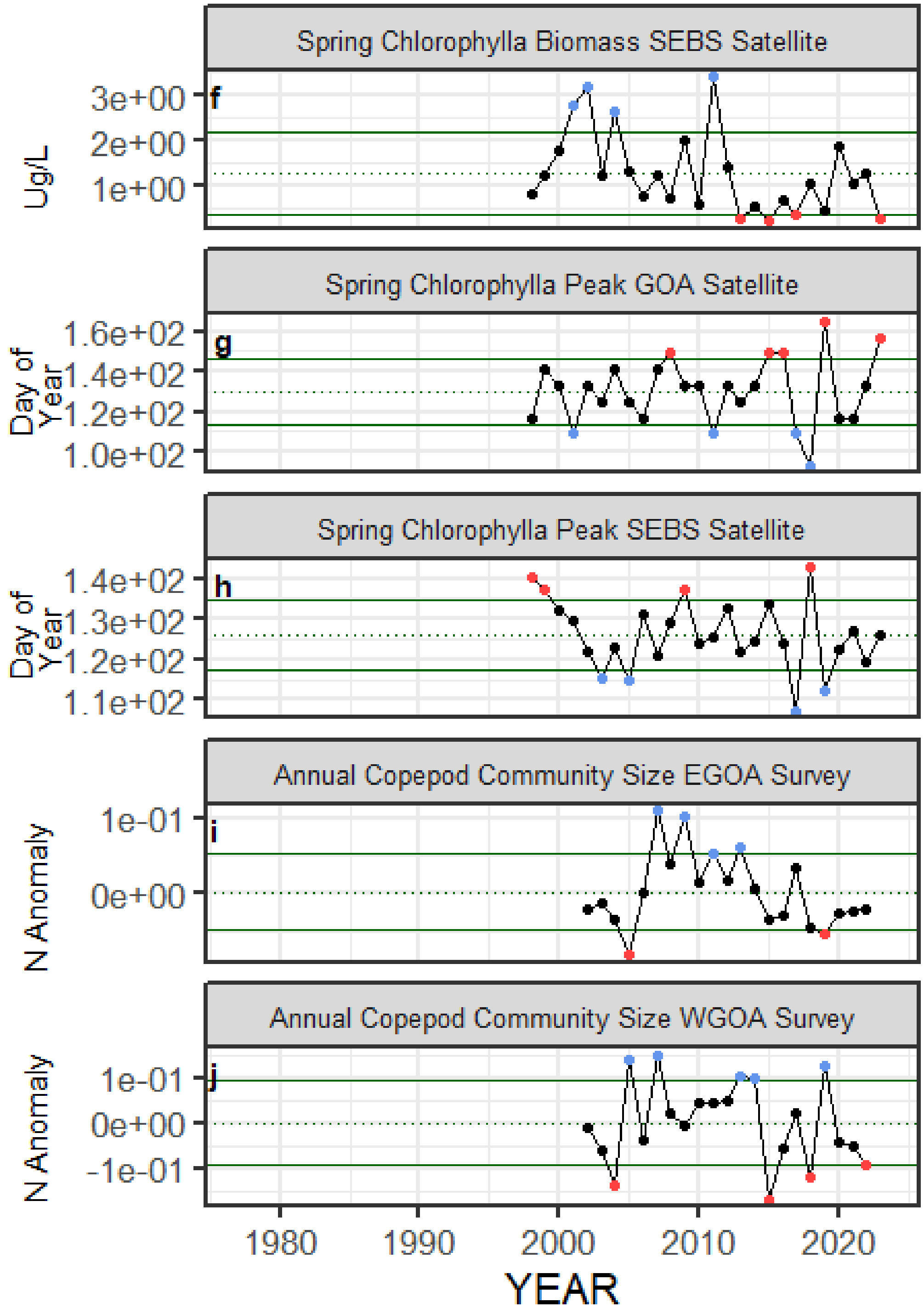


Figure 3C.2a (cont.). Selected ecosystem indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are colored if above or below 1 standard deviation of the time series mean and the color represents the proposed relationship for stock (blue for good conditions, red for poor conditions), black circle for neutral.

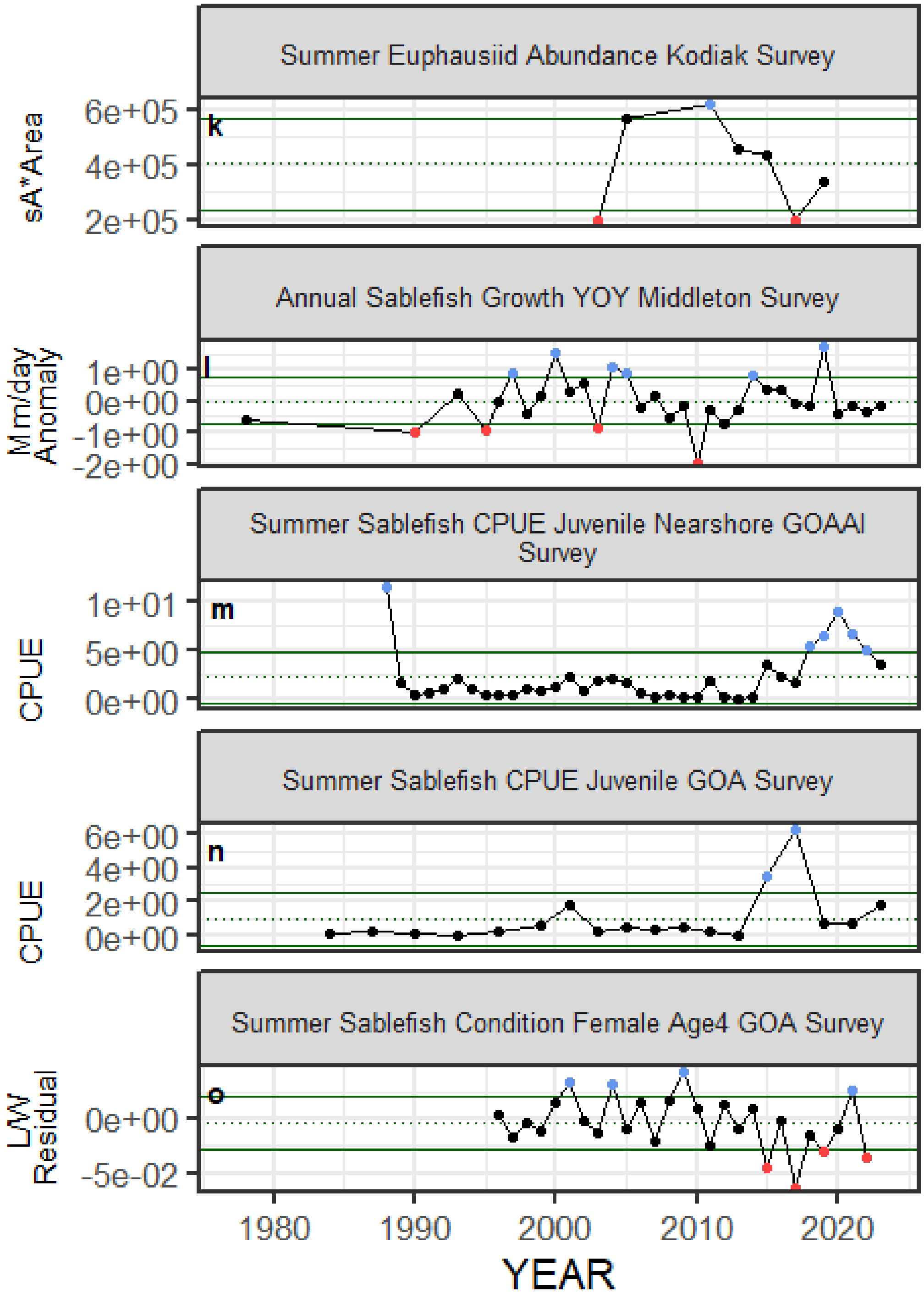


Figure 3C.2a (cont.). Selected ecosystem indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are colored if above or below 1 standard deviation of the time series mean and the color represents the proposed relationship for stock (blue for good conditions, red for poor conditions), black circle for neutral.

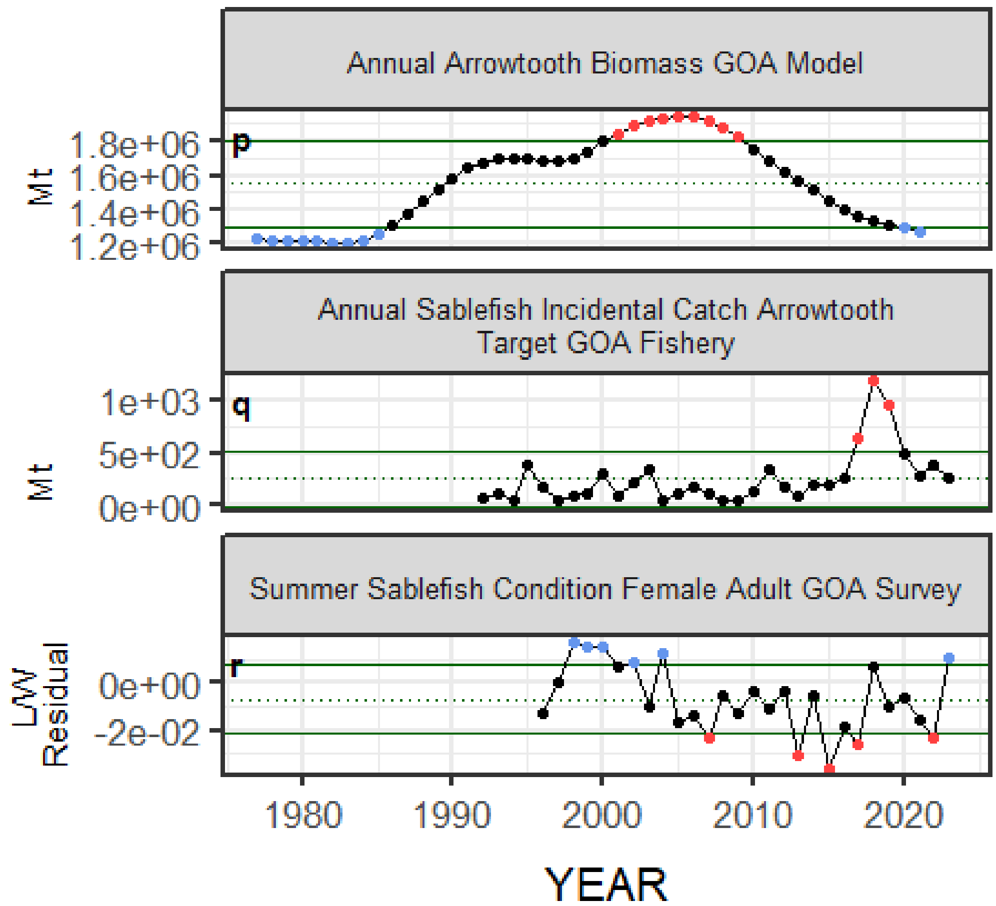


Figure 3C.2a (cont.). Selected ecosystem indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are colored if above or below 1 standard deviation of the time series mean and the color represents the proposed relationship for stock (blue for good conditions, red for poor conditions), black circle for neutral.

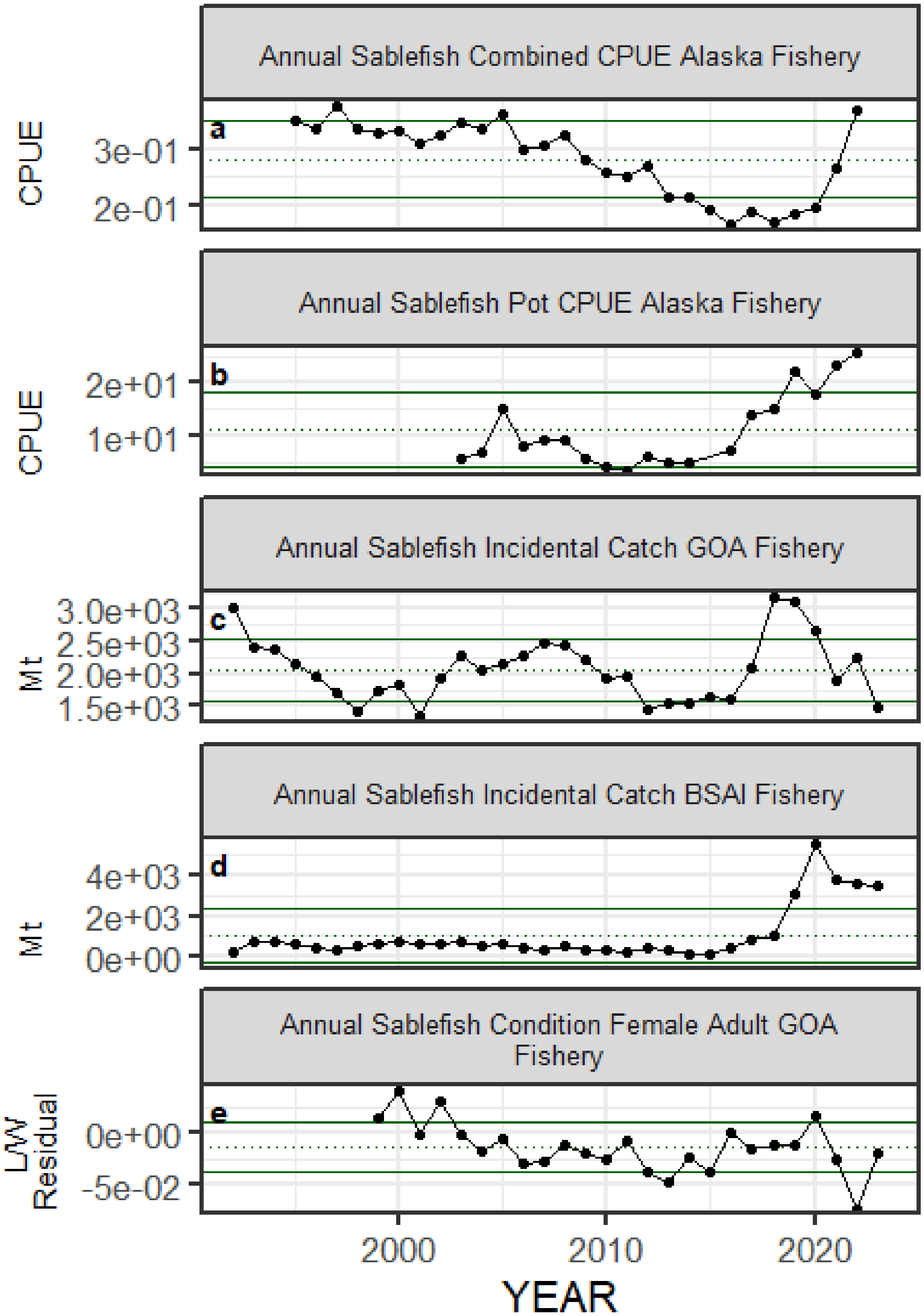


Figure 3C.2b. Selected ecosystem indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

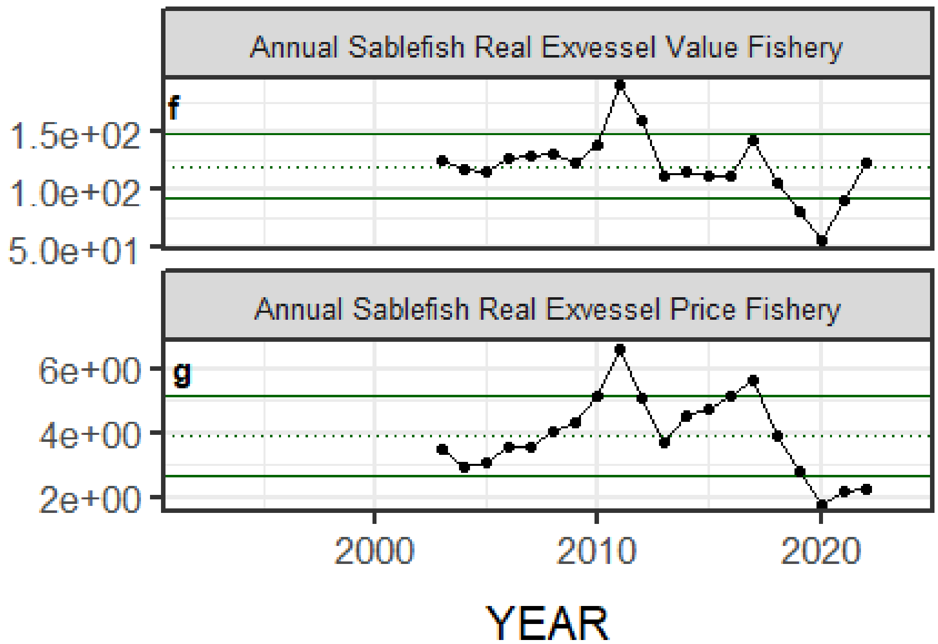


Figure 3C.2b (cont.). Selected ecosystem indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

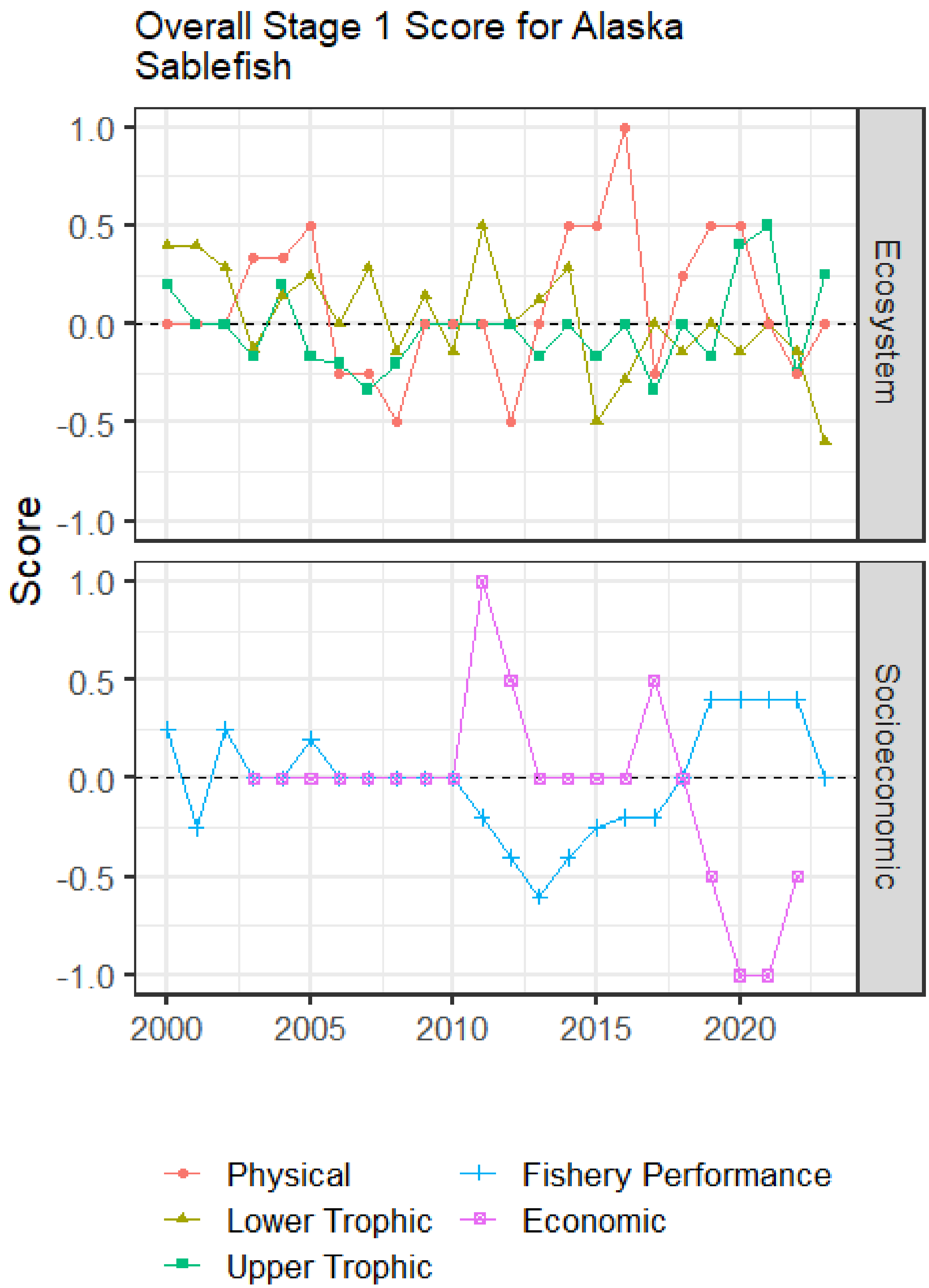


Figure 3C.3: Simple summary traffic light score by category for ecosystem and socioeconomic indicators from 2000 to present.

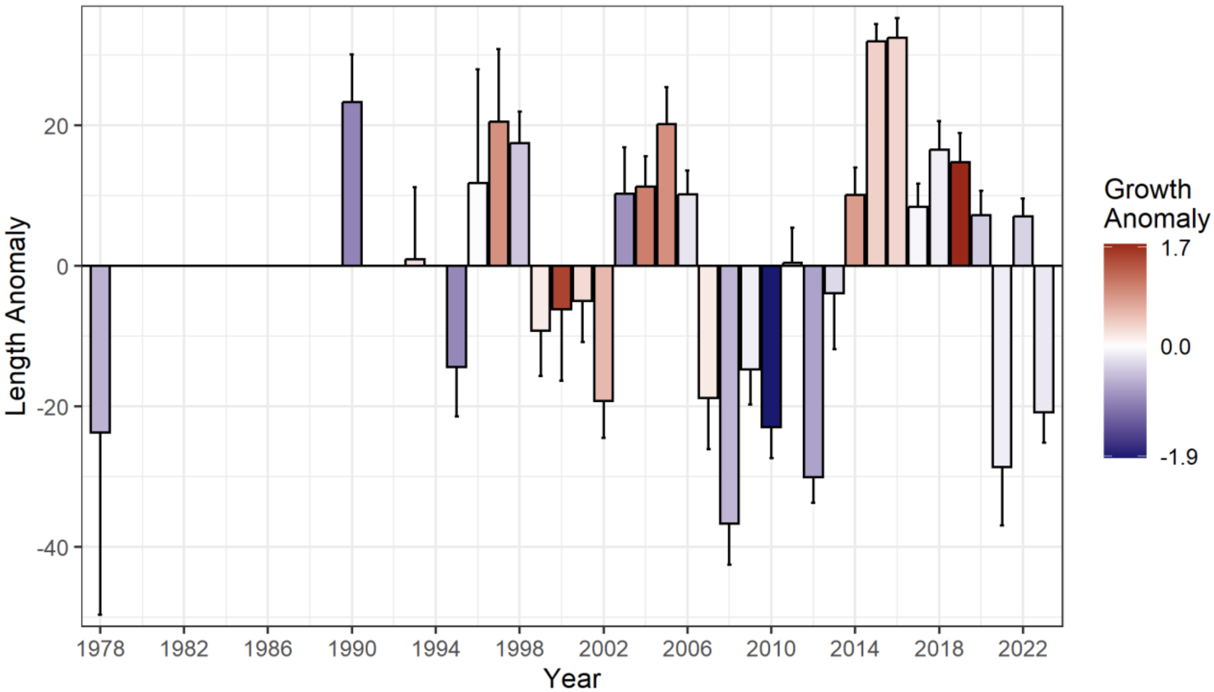
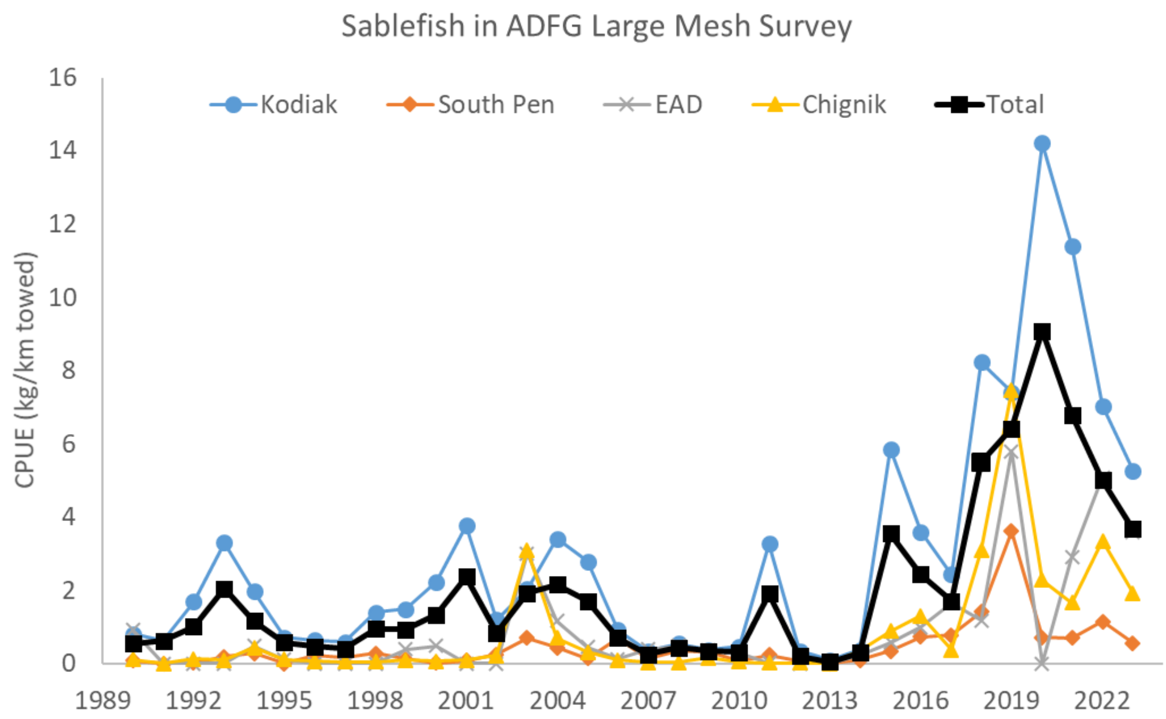


Figure 3C.4: Growth anomaly calculated from the relationship between mean fish length and Julian date and length anomaly predicted from the growth relationship on the median sampling date (July 24) for each year from Rhinoceros auklet diets at Middleton Island in the Gulf of Alaska.



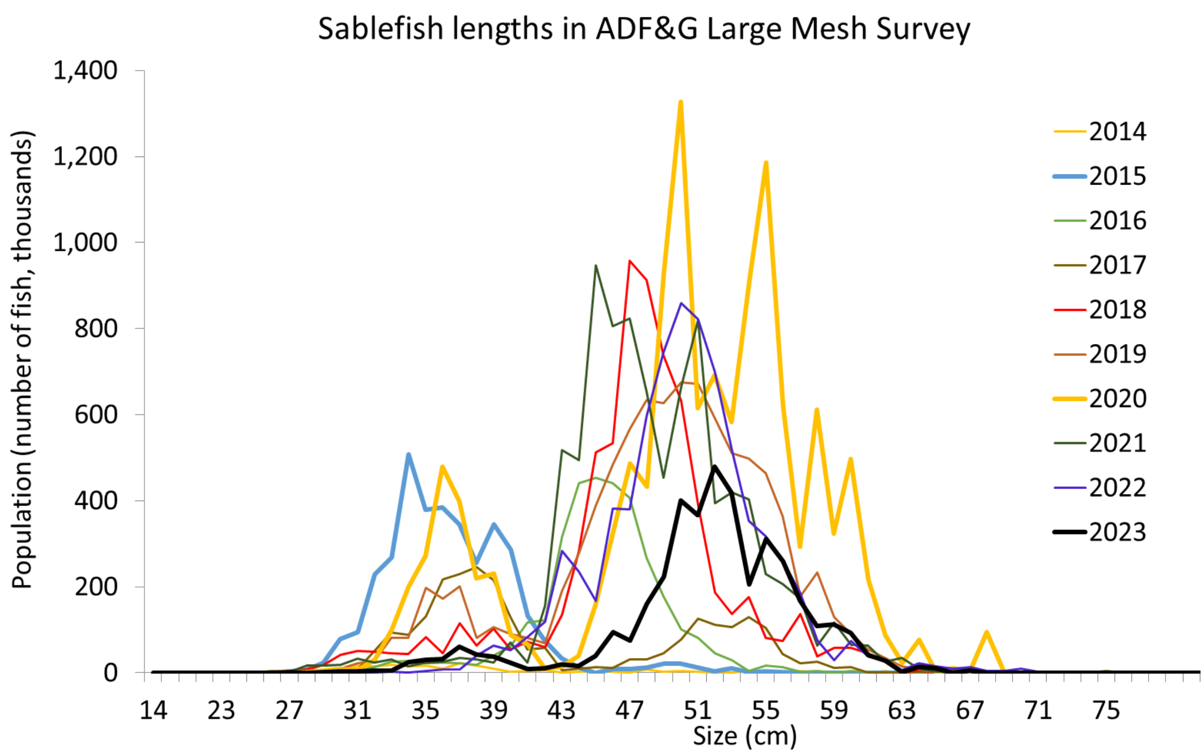


Figure 3C.5: Catch-per-unit-effort from 1990 to present (top graph) and length (cm) composition (bottom graph) from 2011 to present of sablefish in the nearshore ADF&G large-mesh survey (EAD = Eastern Aleutians District).

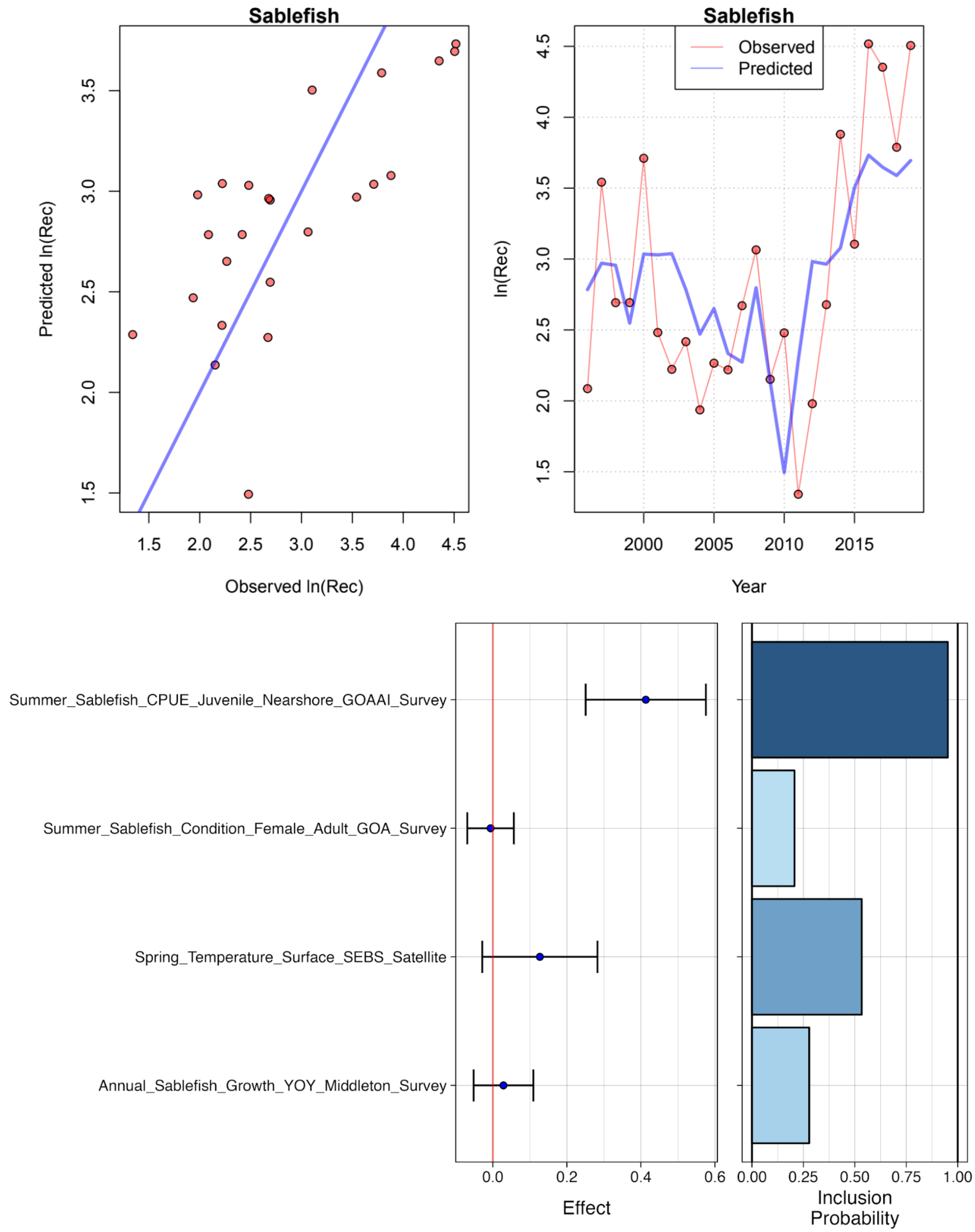


Figure 3C.6: Bayesian adaptive sampling output showing (top graph) observed and predicted model fit and (bottom graph) the mean relationship and uncertainty (95% confidence intervals) with log sablefish recruitment, in each estimated effect (left bottom graph), and marginal inclusion probabilities (right bottom graph) for each predictor variable of the subsetted covariate set.