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

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Executive Summary

National initiative scoring and AFSC research priorities suggest a high priority for conducting an ecosystem and socioeconomic profile (ESP) for Alaska sablefish. Annual guidelines for the AFSC support research that improves our understanding of environmental and climate forcing of ecosystem processes with a focus on variables that can provide direct input into or improve stock assessment and management. The sablefish ESP follows the new standardized framework for evaluating ecosystem and socioeconomic considerations for sablefish and may be considered a proving ground for potential use in the main stock assessment.

We use information from a variety of data streams available for the sablefish stock in Alaska and present results of applying the ESP process through a metric and subsequent indicator assessment. Analysis of the ecosystem and socioeconomic processes for sablefish by life history stage along with information from the literature identified a suite of indicators for testing and continued monitoring within the ESP. Results of the metric and indicator assessment are summarized below as ecosystem and socioeconomic considerations that can be used for evaluating concerns in the main stock assessment.

Ecosystem Considerations

- Consistent slope bottom temperatures may provide a helpful buffer for sablefish egg development and subsequent larval hatch during heatwave years
- Non-discriminating prey selection and rapid growth of larval and YOY sablefish provide an advantage in warm years to monopolize on available plankton prey
- Overwinter and nearshore conditions have recently been favorable for juvenile sablefish based on high growth of YOY sablefish observed in seabird diets and large CPUE of juveniles in nearshore surveys
- Body condition of juveniles that are caught in offshore adult habitat has been below average since 2014 and poor for the 2014 and 2016 year-classes
- Mean age of spawners and age evenness have decreased recently suggesting higher contribution of the recent large 2014 year-class to the adult spawning biomass
- Condition of the 2014 year-class is poor when compared to the relatively good condition of age-4 fish in previously high recruitment years and this is accompanied by a drop of 2014 year class recruitment strength in the most recent model recruitment estimates
- Spatial overlap between sablefish migrating to adult slope habitat and the arrowtooth flounder population may have increased, based on recent large increases in incidental catch in the arrowtooth flounder fishery and may imply potentially higher competition and predation
- Condition of the overall population on slope habitat has been decreasing since 2015 and may impact young sablefish arriving in already poor condition
- Overall, physical, YOY, and early juvenile indicators were generally good for sablefish while juvenile and adult indicators were generally average to poor.

Socioeconomic Considerations

- Fishery CPUE indicators are showing contrasting trends by gear type and differ from trends in exploitable biomass suggesting potential temporal or spatial fluctuations in gear selectivity
- Catch of sablefish in non-sablefish targeted fisheries has recently been increasing in both the GOA and BSAI, which may imply shifting distribution of sablefish into non-preferred habitat
- Large, adult female sablefish condition in the GOA and BSAI fisheries appear to be in somewhat opposing trends during the year prior to large year-class events.
- Ex-vessel value of the fishery has remained relatively stable since 2013, but prices of small fish have declined dramatically in recent years

Introduction

Ecosystem-based science is becoming a component of effective marine conservation and resource management; however, the gap remains between conducting ecosystem research and integrating it with the stock assessment. A consistent approach has been lacking for deciding when and how to incorporate ecosystem and socioeconomic information into a stock assessment and how to test the reliability of this information for identifying future change. A new standardized framework termed the ecosystem and socioeconomic profile (ESP) has recently been developed to serve as a proving ground for testing ecosystem and socioeconomic linkages within the stock assessment process (Shotwell et al., *In Review*). The ESP uses data collected from a variety of national initiatives, literature, process studies, and laboratory analyses in a four-step process to generate a set of standardized products that culminate in a focused, succinct, and meaningful communication of potential drivers on a given stock. The ESP process and products are supported in several strategic documents (Sigler et al., 2017; Dorn et al., 2018; Lynch et al., 2018) and recommended by the North Pacific Fishery Management Council's (NPFMC) groundfish and crab Plan Teams and the Scientific and Statistical Committee (SSC).

This ESP for Alaska sablefish (*Anoplopoma fimbria*) follows the template for ESPs (Shotwell et al., *In Review*) and replaces the previous ecosystem considerations section in the main sablefish stock assessment and fishery evaluation (SAFE) report. Information from the original ecosystem considerations section may be found in Hanselman et al. (2017).

The ESP process consists of the following four steps:

1.) Evaluate national initiative and stock assessment classification scores (Lynch et al., 2018) along with regional research priorities to assess the priority and goals for conducting an ESP.
2.) Perform a metric assessment to identify potential vulnerabilities and bottlenecks throughout the life history of the stock and provide mechanisms to refine indicator selection.
3.) Select a suite of indicators that represent the critical processes identified in the metric assessment and monitor the indicators using statistical tests appropriate for the data availability of the stock.
4.) Generate the standardized ESP report following the guideline template and report ecosystem and socioeconomic considerations, data gaps, caveats, and future research priorities.

Justification

The national initiative prioritization scores for Alaska sablefish are overall high due to the high commercial importance of this stock and early life history habitat requirements (Hollowed et al., 2016; McConnaughey et al., 2017). The vulnerability scores were in the moderate to high range of all groundfish scores based on productivity, susceptibility (Ormseth and Spencer, 2011), and sensitivity to future climate exposure (Spencer et al., 2019). The new data classification scores for Alaska sablefish suggest a data-rich stock with high quality data for catch, size/age composition, abundance, life history and ecosystem linkage categories (Lynch et al., 2018). These initiative scores and data classification levels suggest a high priority for conducting an ecosystem and socioeconomic profile (ESP) for Alaska sablefish particularly given the high level of life history information and current application of ecosystem linkages in the operational assessment. Additionally, AFSC research priorities support ecosystem research on understanding recent recruitment fluctuations of Alaska sablefish.

Data

Initial information on sablefish was gathered through a variety of national initiatives that were conducted by AFSC personnel in 2015 and 2016. These include (but were not limited to) stock assessment prioritization, habitat assessment prioritization, climate vulnerability analysis, and stock assessment classification. Data from an earlier productivity susceptibility analysis conducted for all groundfish stocks in Alaska were also included (Ormseth and Spencer, 2011). Data derived from this effort served as the initial starting point for developing the ESP metrics for stocks in the BSAI and GOA groundfish fishery management plans (FMP). Please see Shotwell et al., *In Review*, for more details.

Supplementary data were also collected from the literature and a variety of process studies, surveys, laboratory analyses, accounting systems, and regional reports (Appendix Table 3C.1). Information for the first year of life was derived from ecosystem surveys and laboratory analyses run by multiple programs and divisions at the AFSC (e.g., Ecosystems and Fisheries Oceanography Coordinated Investigations (EcoFOCI), Recruitment Processes Alliance (RPA), Resource Assessment and Conservation Engineering (RACE) Division, Resource Ecology and Fisheries Management (REFM) Division, Auke Bay Laboratory (ABL) Division, Marine Mammal Laboratory (MML) Division), Pacific Continuous Plankton Recorder (CPR, Batten 2019), and the GulfWatch Alaska (GWA) Program. Data for early stage juveniles (less than 400 mm) through adult (greater than 550 mm) were consistently available from the AFSC bottom trawl and longline surveys, the Alaska Department of Fish and Game's (ADF&G) large mesh survey, and the North Pacific Observer Program administered by the Fisheries Monitoring and Analysis (FMA) division.

Data from Ecosystem Status Report (ESR) contributions were provided through personal communication with the contact author of the contribution (e.g., Ressler et al., 2019). Essential fish habitat (EFH) model output and maps were provided by personal communication with the editors of the EFH update (e.g., Rooney et al., 2018). Remote sensing data were collected through coordination with CoastWatch personnel at the Southwest Fisheries Science Center and initial development of an AFSC-specific ERDDAP (Simons, 2019). High resolution regional ocean modeling system (ROMS) and nutrient-phytoplankton-zooplankton (NPZ) data were provided through personal communication with authors of various publications (e.g., Laman et al., 2017, Gibson et al., *In Press*) that use these data.

The majority of sablefish economic value data were compiled and provided by the Alaska Fisheries Information Network (AKFIN). Sablefish ex-vessel pricing data were derived from the NMFS Alaska Region Blend and Catch Accounting System, the NMFS Alaska Region At-sea Production Reports, and the ADFG Commercial Operators Annual Reports (COAR). Sablefish first-wholesale data were from NMFS Alaska Region At-sea and Shoreside Production Reports and ADFG Commercial Operators Annual Reports (COAR). Global catch statistics were found online at FAO Fisheries & Aquaculture Department of Statistics (http://www.fao.org/fishery/statistics/en), 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), and the U.S. Department of Agriculture (http://www.ers.usda.gov/data-products/agricultural-exchange-rate-data-set.aspx). Information regarding the community involvement and percent value was derived from reports of the Community Development Quota (CDQ) Program.

Metrics Assessment

We first provide the analysis of the national initiative data used to generate the baseline metrics for this second step of the ESP process and then provide more specific analyses on relevant ecosystem and/or socioeconomic processes. Metrics are quantitative stock-specific measures that identify vulnerability or resilience of the stock with respect to biological or socioeconomic processes. Where possible, evaluating these metrics by life history stage can highlight potential bottlenecks and improve mechanistic understanding of ecosystem or socioeconomic pressures on the stock.

National Metrics

The national initiative data were summarized into a metric panel (Appendix Figure 3C.1) that acts as a first pass ecosystem and socioeconomic synthesis. Metrics range from estimated values to qualitative scores of population dynamics, life history, or economic data for a given stock (see Shotwell et al., *In Review* for more details). To simplify interpretation, the metrics are rescaled by using a percentile rank for sablefish relative to all other stocks in the groundfish FMP. Additionally, some metrics are inverted so that all metrics can be compared on a low to high scale between all stocks in the FMP. These adjustments allow for initial identification of vulnerable (percentile rank value is high) and resilient (percentile rank value is low) traits for sablefish. Data quality estimates are also provided from the lead stock assessment author (0 or green shaded means no data to support answer, 4 or purple shaded means complete data), and if there are no data available for a particular metric then an "NA" will appear in the panel. Sablefish did not have any data gaps for the metric panel and the data quality was rated as good to complete for nearly all metrics. The metric panel gives context for how sablefish relate to other groundfish stocks in the FMP and highlights the potential vulnerabilities for the sablefish stock.

The 80th and 90th percentile rank areas are provided to highlight metrics indicating a high level of vulnerability for sablefish (Appendix Figure 3C.1, yellow and red shaded area, respectively). For ecosystem metrics, recruitment variability for sablefish fell within the 90th percentile rank of vulnerability. Length at 50% maturity, maximum length and predation stressors fell within the 80th percentile rank when compared to other stocks in the groundfish FMP. For socioeconomic metrics, commercial value fell within the 90th percentile rank and constituent demand fell within the 80th percentile rank. Sablefish were relatively resilient for adult growth rate, range in latitude, range in depth, fecundity, breeding strategy, adult mobility, habitat dependence, and prey specificity.

Recruitment variability (standard deviation of log recruitment) for the sablefish stock is above the value of 0.9 which is considered very high recruitment variability (Lynch et al., 2018) and one of the highest among the Alaska groundfish stocks. Additionally, the relatively lower natural mortality, the larger size at 50% maturity, and the larger maximum length are characteristics of lower productivity stocks (Patrick et al., 2010). Predation pressures on adult sablefish are also high due to the recent increases in whale depredation (Hanselman et al., 2017). Sablefish is one of the most highly valued Alaska groundfish stocks relative to other Alaska groundfish stocks. The high value also explains the high constituent demand for excellence in the stock assessment. These initial results suggest that additional evaluation of ecosystem and socioeconomic processes would be valuable for sablefish with particular attention to understanding the extreme recruitment variability and economic performance to assist with subsequent indicator development.

Ecosystem Processes

Data evaluated over ontogenetic shifts (e.g., egg, larvae, juvenile, adult) may be helpful for identifying specific bottlenecks in productivity and relevant indicators for monitoring. We evaluate the life history stages of sablefish along four organizational categories of 1) distribution, 2) timing, 3) condition, and 4) trophic interactions to gain mechanistic understanding of influential ecosystem processes. We include a detailed life history synthesis (Appendix Table 3C.2a), an associated summary of relevant ecosystem processes (Appendix Table 3C.2b), a conceptual model summarizing the life history and ecosystem processes tables (Appendix Figure 3C.2), four life history graphics along the organizational categories (Appendix Figure 3C.3-6, updated from Shotwell et al., *In Review*), and provide supportive information from the literature, surveys, process studies, laboratory analyses, and modeling applications.

A suite of habitat variables can be used to predict the distribution of the stock by life history stage and determine the preferred properties of suitable habitat. The recent EFH update for Alaska groundfish included models and maps of habitat suitability distributions by stage and species (Rooney et al., 2018; Pirtle et al., *In Press*). We collected model output on the depth ranges, percent contribution of predictor variables, sign of directional deviation from the mean predictor value, and associated maps for the larval, early juvenile (<400 mm), late juvenile (>=400 mm & < 550 mm), and adult stages (>=550 mm) of sablefish (Appendix Figure 3C.3). Highly suitable larval habitat was characterized by bottom depth (250-850 m, 38% contribution), low surface temperature (33%), and low ocean color (a measure of primary productivity, 12%). However, the sampling for the larval stage was not synoptic for the GOA and large gaps exist between survey grids. Recent surveys in the eastern GOA show higher abundance and larval size relative to those captured in western GOA surveys during the same season suggesting different population pressures in the eastern survey areas (Siddon et al., *In Press*). Early juvenile suitable habitat was less reliant on depth (10-260 m, 10% contribution) with low tidal current (30%), low bottom temperature (21%), and low sponge presence (11%), characterizing the early juvenile habitat as colder, low-lying areas (e.g., channels, gullies, and flats) with little biogenic structure and less current. Depth becomes more important and deeper for the late juvenile stage (135-590 m, 37% contribution), with continued low bottom temperature (23%), low tidal current (12%), and low-lying areas (8%). Finally, depth is the primary predictor for adults (180-770 m, 89% contribution) with minor contribution (<5%) from other predictor variables. A clear ontogenetic habitat shift occurs between the early juvenile and later juvenile to adult stages with progression from nearshore bays and inlets to the colder continental shelf and slope (Appendix Figure 3C.2 b-d).

Sablefish are highly fecund, early spring, deep-water spawners with an extended spring through summer neustonic (extreme surface) pelagic phase that culminates in nearshore settlement in the early fall of their first year (Doyle and Mier 2016). At some point following the first overwinter, sablefish juveniles begin movement to their adult habitat arriving between 4 to 5 years later and starting to mature within 3 to 6 years (Hanselman et al., 2017). The timing or phenology of the pre-adult life stages (Appendix Figure 3C.2a) can be examined seasonally to understand match or mismatch with both physical and biological properties of the ecosystem (Appendix Figure 3C.4). We synthesized data on the egg, larval, early juvenile and late juvenile life stages (Appendix Table 3C.2a) and restricted to the core sampling area (western GOA only) for consistency across years for the egg and larval data. Data from the early and late juvenile stages were derived from bottom trawl and longline surveys. Physical and biological seasonal climatologies were derived from ROMS/NPZ model output used in an individual based model and the EFH update (Laman et al., 2017; Rooney et al., 2018, Gibson et al., *In Press*). Sablefish eggs caught in 600 mm bongos are in the water column from February to April when there is lower bottom temperature, lower indication of mesoscale variability as measured by current variability (e.g., eddies), and higher potential transport to the nearshore. Pelagic eggs in deep water over the slope and basin may provide a relatively stable environment for embryonic development as cold temperatures during winter favor slow development. Relatively large size at hatching (~6 mm) and rapid growth of larvae with good swimming ability likely confers an advantage in terms of larval feeding at the sea surface. Larvae are most abundant in neuston samples and are caught in shelf and slope waters, so larval abundance was provided for neuston samples only. Peak abundance of larvae (May–Jun) coincides with advanced development of the spring peak in zooplankton production following the onset of stratification (measured by a shallowing of the mixed layer) which likely means a plentiful supply of larval prey. Sablefish larvae are characterized by early development of large pectoral fins to assist with swimming ability but have delayed bone-development in their jaws potentially resulting in non-discriminating prey selection (Matarese et al. 2003; Deary et al., *In Press*). With the lack of overall ossification of the skeleton, pre-flexion sablefish larvae lack the rigidity in their jaw elements to quickly open and expand their mouths to suck in prey. Sablefish in this pre-flexion larval stage are only able to pick prey from the water and are thus restricted to prey that is small and prevalent. The clear match with the onset of the zooplankton bloom supports this need to be at the highest peak of productivity due to their vulnerability for non-discriminating prey selection. Although juveniles are captured in all months of the survey (June through August), there are more early juveniles (<400 mm) present at the start of summer when there are lower current speeds, which may assist with transition to the adult habitat. Juveniles are ubiquitous in the epipelagic zone of shelf, slope, and basin waters in the eastern and western GOA in summer and fall, which corresponds to the onset of the fall bloom but prior to the peak of bottom temperature which has a delayed onset from surface warming (Appendix Figure 3C.4).

Information on body composition, percent lipid and percent protein by size, can be used to understand shifts in energy allocation through the different life history stages (Appendix Figure 3C.5). Throughout the first year, larvae and age-0 fish grow very rapidly up until settlement in the nearshore environment (Sigler et al. 2001). Fish from 0 to 400 mm (Appendix Figure 3C.5, pre-settlement and settlement phases), have a fairly stable lipid and protein content. These fish are putting energy toward growth and not toward lipid energy storage. A potential bottleneck may occur pre-settlement as overwintering during the first year of life may incur an energetic cost that results in a change in body condition with reduced lipid content at about 200 mm that appears to be maintained until the late juvenile stage at about 400 mm (R. Heintz, *pers. commun.*). At lengths greater than 400 mm where fish are maturing (i.e., a portion of fish are mature) and at lengths were fish are all presumably adult (>650 mm), the percent lipid is much higher than at lengths less than 400 mm. This is likely because mature fish have a higher lipid content than immature fish. These data show that there is an ontogenetic shift that is related to how sablefish store energy and may be related to the size at which fish migrate from nearshore to offshore waters. The variability in lipid content at lengths greater than 400 mm could be attributed to some fish being mature and some being immature or skip spawning. For example, relative condition (body weight relative to length) and relative liver size (liver weight related to total weight), are higher in fish that will spawn than in skip spawning and immature female sablefish (Rodgveller, *In Review*). Variability could also be an effect of sex, sampling date, sampling area, and year. However, these data show a strong shift in lipid accumulation as fish grow and enter the late juvenile to adult stage.

Young-of-the-year (YOY) sablefish prey mostly on euphausiids (Sigler et al. 2001) and copepods (Grover and Olla 1990), while juvenile and adult sablefish are opportunistic feeders (Appendix Figure 3C.6c,d). Since juvenile and adult sablefish feed opportunistically, diets differ throughout their range. In general, sablefish < 600 mm consume more euphausiids, shrimp, and cephalopods, while sablefish > 600 mm consume more fish (Yang and Nelson 2000). In the GOA, fish constituted 3/4 of the stomach content weight of adult sablefish with the remainder being invertebrates (Yang and Nelson 2000). Of the fish found in the diets of adult sablefish, pollock were the most abundant item while eulachon, capelin, Pacific herring, Pacific cod, Pacific sand lance, and flatfish also were found. Squid were the most important invertebrate and euphausiids and jellyfish were also present. In southeast Alaska, juvenile sablefish also consume juvenile salmon at least during the summer months (Sturdevant et al. 2009, Coutre, 2014). Off the coast of Oregon and California, fish made up 76 percent of the diet (Laidig et al. 1997), while euphausiids dominated the diet off the southwest coast of Vancouver Island (Tanasichuk 1997). Off Vancouver Island, herring and other fish were increasingly important as sablefish size increased; however, the most important prey item was euphausiids. Given that YOY and early juveniles sablefish predominantly feed on euphausiids (Appendix Figure 3C.6c,d), the availability and abundance of euphausiids may have an impact on YOY and early juveniles survival. Juvenile sablefish (< 600 mm FL) prey items overlap with the diet of small arrowtooth flounder. On the continental shelf of the GOA, both species consumed euphausiids and shrimp predominantly; these prey items are prominent in the diet of many other groundfish species as well. The diet overlap may cause competition for resources between small sablefish and other groundfish species. It is unlikely that juvenile and adult sablefish are affected by availability and abundance of individual prey species because they are opportunistic feeders. However, potential shifts in prey quality (e.g., for vital proteins or energy density) and system level changes in ecosystem productivity could impact the growth or survival of juvenile and adult sablefish.

The main predators of YOY sablefish during their pelagic stage are adult coho and chinook salmon and a variety of seabirds, although other predators such as pomfret have been increasing in recently years likely due to their increase in the GOA during warmer years (Strasburger, *pers. commun.*). Sablefish were the fourth most commonly reported prey species in the salmon troll logbook program from 1977 to 1984 (Wing 1985), however the effect of salmon predation on sablefish survival is unknown. YOY sablefish make up a variable percentage of the diet for piscivorous seabirds such as rhinoceros auklets and black-legged kittiwakes (Hatch et al., 2019). The only other fish species reported to prey on YOY sablefish in the GOA is Pacific halibut; however, sablefish comprised less than 1% of their stomach contents (M. Yang, October 14, 1999, NOAA, pers. comm.). Analyses of diet data taken from early surveys on the bottom trawl survey (pre-2001) suggest late juvenile and adult sablefish may not have been a prominent prey item (Appendix Figure 3C.6b). This is possibly due to either their historically low and sporadic abundance or their early development of swimming structures that allow them to evade predators. However, during their return trip from nearshore to adult habitat, young sablefish share residence on the continental shelf with potential predators such as arrowtooth flounder, halibut, Pacific cod, bigmouth sculpin, big skate, and Bering skate, which are the main piscivorous groundfishes in the GOA (Yang et al. 2006). It seems possible that during high recruitment years such as we are presently observing, predation on sablefish by other fish may increase due to shifts in spatial overlap on the continental shelf from an expanding population. Recent increases in incidental catch of small sablefish in multiple fisheries in both the GOA and BSAI suggest potential for increases in predation and competition. Sperm whales are likely a major predator of adult sablefish. Fish are an important part of sperm whale diet in some parts of the world, including the northeastern Pacific Ocean (Kawakami 1980). Fish have appeared in the diets of sperm whales in the eastern AI and GOA. Although fish species were not identified in sperm whale diets in Alaska, sablefish were found in 8.3% of sperm whale stomachs off of California (Kawakami 1980).

Socioeconomic Processes

Sablefish are primarily harvested by catcher vessels in the GOA, which typically account for upwards of 90% of the annual catch. Most sablefish are caught using the hook-and-line gear type. Starting in 2017 directed fishing for sablefish using pot gear was allowed in the GOA to mitigate whale depredation. As a valuable premium high-priced whitefish, sablefish is an important source of revenues for GOA catcher vessels and catches are at or near the TAC. Since the mid-2000s, decreasing biomass has ratcheted down the TAC and catch, a trend that continued up to 2016. In 2017 and 2018 the TACs increased as a result of a strong 2014 year-class. Alaska-wide total catches increased 18% to 15.3 thousand t and retained catches increased 7% to 12.3 thousand t (Appendix Table 3C.3a). The retention rate (ratio of total catch to retained catch), typically above 90%, dropped to 80% in 2018. This is in part related to the higher prohibited species catch of juvenile sablefish by Bering Sea trawlers targeting other species.

Revenues decreased 22.5% to $92.4 million in 2018 as ex-vessel prices fell 30% to $3.50/lb (Appendix Table 3C.3a). The decrease in the ex-vessel price was a reflection of a commensurate decrease in first-wholesale price to $6.28/lb (Appendix Table 3C.3b). First-wholesale value decreased to $100 million in 2018. Most sablefish is sold as headed-and-gutted at the first-wholesale level of production. Because of the minimal amount of value added by head-and-gut production and the size of the catcher vessel sector, the ex-vessel price is closely linked to the wholesale price. Persistent declines in catch may have been disruptive to revenue growth in the sablefish fishery through the mid-2000s to 2016, although strong prices maintained value in the fishery as catches declined. The 2017 price was the highest seen since prices peaked in 2011 at $8.71/lb. The 2018 price decrease is the result of smaller average fish size as the 2014 year-class has not fully grown to a higher marketable price. The increased abundance and supply of smaller fish puts downward pressure on price of small fish, increases the price margin between small and large fish, and lowers the average price. Export prices through June 2019 (which are typically a strong indicator of first-wholesale prices) show a 10% decrease.

The U.S. accounts for roughly 90% of global sablefish catch and Alaska accounts for roughly 75% of the U.S. catch. Canada catches roughly 10% of the global supply and a small amount is also caught by Russia. As the primary global producer of sablefish the significant supply changes in Alaska have market impact that influence wholesale and export prices. Most sablefish caught and produced are exported, though the domestic market has grown in recent years. Japan is the primary export market, but its share of export value has decreased from 79% in 2009-2013 to 63% in 2018 (Appendix Table 3C.3c). In recent years industry reports and U.S. import-export figures indicate that the strong demand for sablefish in the U.S. and foreign demand outside of Japan, including Europe, China and Southeast Asia. U.S. exports as a share of U.S. production has declined over time indicating increased domestic consumption. China's share of export value has also been increasing (Appendix Table 3C.3c). The US-Japanese exchange rate has remained relatively stable since 2016. The strength of the US dollar puts downward pressure on the price of exported goods as it further increases prices for foreign importers.

Twenty percent of the BSAI sablefish total allowable catch (TAC) allocated to vessels using hook-and-line or pot gear and 7.5% of the sablefish TAC allocated to trawl gear are reserved for use in the Community Development Quota (CDQ) program, which was implemented in 1995. The Sablefish IFQ program includes a cost recovery provision. Cost recovery has ranged from $0.75 million to $2.30 million and 1.0% to 3% of the ex-vessel value of the fishery, with 2015 being the first year the fishery reached the 3% limit. The majority of revenue from landings of sablefish as part of the CDQ program (Appendix

Figure 3C.7a) are from catcher vessels (CV) but there is a smaller percentage from catch processors (CP). Overall revenue for the program has declined slightly by 4% in 2017 relative to the baseline, but contribution from CV landings have increased by 5% while contribution from CP landings has declined by 60%. CPs land on average 12% of the total landings, but the CP share has ranged from 19.9% in 1995 to 5.0% in 2016 and the CP share of the total landings has generally been declining since 2012.

In order to identify the dominant communities engaged in commercial sablefish fisheries, the Regional Quotient was calculated from baseline (1992-1994) until the most recent available data (2013). The regional quotient is a measure of the importance of the community relative to all Alaska fisheries in terms of pounds landed or revenue generated from Alaska FMP groundfish fisheries. It is calculated as the landings or revenue attributable to a community divided by the total landings or revenue from all communities and community groupings (Fissel et al., 2018). The four communities most highly engaged with the sablefish fishery: Seward, Kodiak, Sitka, and Homer account for almost 48% of the regional value landed (Appendix Figure 3C.7b). In comparison, the community Local Quotient metric shows a decline in both pounds and regional value landed in all four of the highly engaged communities. The community Local Quotient, which measures the percentage of sablefish IFQ landed within a community out of the total amount of all species landed within that community, illustrates substantial declines in all highly engaged communities (S. Wise, *pers. commun.*).

Indicators Assessment

We first provide information on how we selected the indicators for the third step of the ESP process and then provide results on the indicators analysis. In this indicator assessment a time-series suite is first created that represent the critical processes identified by the metric assessment. These indicators must be useful for stock assessment in that they are regularly updated, reliable, consistent, and long-term. The indicator suite is then monitored in a series of stages that are statistical tests that gradually increase in complexity depending on the data availability of the stock (Shotwell et al., *In Review*).

Indicator Suite

Studies into the survival of early life stages of sablefish have identified important processes and subsequent indicators representing temperature, transport, and stratification have been related to recruitment fluctuations of sablefish (Coffin and Mueter, 2014; Shotwell et al., 2014; Gibson et al., *In Press*). Young-of-the-year (YOY) sablefish exhibit some thermal intolerance to very cold water (Sogard and Spencer 2004) and laboratory studies have shown a narrow optimal thermal range and a shift with size in thermal performance (Sogard and Olla 2001, Krieger et al., 2019). Transport to the nearshore during the first year of life is thought to relieve potential vulnerability if conditions are poor (Doyle and Mier 2016). The larval match to the onset of stratification and height of zooplankton production may provide a potential buffer against high predation in the epipelagic zone if thermal conditions were sufficient to allow sablefish to monopolize on their very high growth potential (Krieger et al., 2019). Larval sablefish abundance has been linked to copepod abundance and YOY abundance may be similarly affected by euphausiid abundance because of their apparent dependence on a single species (McFarlane and Beamish 1992). The dependence of larval and YOY sablefish on a single prey species may be the cause of the observed wide variation in annual sablefish recruitment. During the nearshore and settlement period, research on nearshore conditions and interactions with other surface foragers show positive relationships with sablefish recruitment (Yasumiishi et al. 2017; Arimitsu and Hatch, 2019). A fish with a good food supply and positive environmental conditions may have good overall condition and higher overwinter survival. The ADF&G large mesh bottom trawl survey (Appendix Figure 3C.8) has recently observed larger catches of smaller sablefish (age-1 through age-4) in the 2015 through 2019 surveys. These catches corroborate the large 2014 year-class, the return to average recruitment in 2015 and another potential large year class in 2016. This survey may be useful as an early signal of overwinter and nearshore residency success for the early to late juvenile stage. Estimates of pelagic and benthic foragers as well as apex predator biomass provide information on the relative fluctuations of these guilds (BSAI

ESR, 2017). When evaluated together, the fluctuations of these guilds may represent the health of the shelf habitat for groundfish. Abundance fluctuations for the slope habitat could be evaluated in a similar fashion to investigate the quality of the primary habitat for sablefish.

The clear increase in lipids as fish enter the later juvenile stage suggests that condition may impact the ability of these fish to mature and potentially contribute to the spawning population. Data to calculate the relative condition of sablefish, residuals from a length-weight relationship (Boldt et al., 2018), are available from the AFSC longline survey and the FMA observer database since 1996. These data can be used as an indicator of health and productivity in a time-series of the relative condition of fish for both juvenile and adult females. Annual condition differences should be evaluated for each life stage separately because energy storage strategies differ (Appendix Figure 3C.4). Because measures of body condition are related to spawning status, condition measures may be useful for predicting the maturity of sablefish on the longline survey and could provide annual estimates of the age-at-maturity (Rodgveller, *In Review*).

Longevity of marine fishes is often considered to be a life history strategy to be able to weather long periods of poor conditions and capitalize when conditions are good for reproductive success (Longhusrt 1998). Sablefish clearly fit this strategy with extended periods of low recruitment and episodic large recruitment events. Different measures of female spawning age composition over time from the current stock assessment model may assist with understanding how well the population is prepared to buffer against poor environmental conditions or take advantage of good conditions when they arise. The mean age of the population and how much the population may be concentrated into different cohorts (described here as evenness) may be two options for developing indicators to assess population stability associated with a long-lived strategy for sablefish.

The evaluation of economic performance suggests some areas for continued monitoring with regard to catch and value of small fish in the fishery. A recent discussion paper on sablefish discard allowance (Armstrong et al., 2018) provides information on biological and economic impacts for introducing minimum size regulations for sablefish. In 2018, there was a marked increase in sablefish landings for small (1-3 pound) sablefish in the BSAI fisheries, most notably the midwater pollock fishery, and an associated large decrease in value for these same sized fish (Armstrong et al., 2018). This size range is the likely age for the 2014 to 2016 year-classes (age 2-4). Estimates of sablefish incidental catch in the BSAI fisheries and associated value of small sized fish in this area may be useful to monitor as an early signal for potential shifts in economic yield during large year classes as this area represents the northern edge of the sablefish population distribution.

We generated a suite of ecosystem and socioeconomic indicators using the mechanisms and tested relationships listed above from previous studies and the relevant ecosystem processes identified in the metric assessment (Appendix Table 3C.2b, Appendix Figure 3C.2). The following list of indicators is organized by trophic level similarly to the ecosystem status reports (Zador and Yasumiishi, 2018) and by sablefish life history stage. Indicator title and a brief description are provided in Appendix Table 3C.4a for ecosystem indicators and Appendix Table 3C.4b for socioeconomic indicators with references, where possible, for more information.

Ecosystem Indicators:

1. Physical Indicators (Appendix Figure 3C.9a.a-f)
    - Annual marine heatwave index is calculated from daily sea surface temperatures for 1981 through August 2019 from the NOAA High-resolution Blended Analysis Data for the central GOA (< 300 m). Daily mean sea surface temperature data were processed to obtain the marine heatwave cumulative intensity (MHWCI) (Hobday et al., 2016) value where we defined a heat wave as 5 days or more with daily mean sea surface temperatures greater than the 90th percentile of the January 1983 through December 2012 time series (Zador and Yasumiishi, 2018).

- Summer temperature profiles were recorded during the annual longline survey along the continental slope using an SBE39 (Seabird Electronics) attached to the groundline approximately one-third of the way in from the shallow portion of a station (Malecha et al., 2019). In the GOA, 13 stations had complete temperature profiles for the entire time-series (2005–2019). Annual anomalies from the 15-year mean can be calculated by station at discrete depths, and an index for each year can be represented by the mean of these anomalies at a chosen depth. Interpolation between actual depth recordings in a profile was conducted using weighted parabolic interpolation (Reiniger and Ross, 1968). The 250 m isobath was selected to represent deeper water at the shelf-slope break where adult sablefish are typically sampled.
- Late spring (May-June) sea surface temperatures (SST) for the eastern GOA and southeastern Bering Sea were obtained from the monthly gridded 4 km Advanced Very High Resolution Radiometer (AVHRR) Pathfinder v5.3 dataset (Casey et al., 2010). These data were provided by Group for High Resolution SST (GHRSST) and the NOAA National Centers for Environmental Information (NCEI). This project was supported in part by a grant from the NOAA Climate Data Record (CDR) Program for satellites. The data were downloaded from NOAA CoastWatch-West Coast Regional Node and Southwest Fisheries Science Center's Environment Research Division.
- Derived chlorophyll *a* concentration data during spring seasonal peak (May) in the eastern GOA and southeastern Bering Sea were obtained from the 4km Ocean Colour Climate Change Initiative (OC-CCI) version 4.0 monthly gridded dataset, European Space Agency available online at http://www.esa-oceancolour-cci.org. The data were downloaded from NOAA CoastWatch-West Coast Regional Node and Southwest Fisheries Science Center's Environment Research Division.

2. Zooplankton Indicators (Appendix Figure 3C.9a.g-i)
    - Abundance of large copepods from the continuous plankton recorder (CPR) for the shelf and offshore waters of the central and eastern GOA (Batten, 2019).
    - Summer euphausiid abundance is represented as the acoustic backscatter per unit area (sA at 120 kHz, m2 nmi-2) classified as euphausiids and integrated over the water column and then across the surveyed area to produce an annual estimate of acoustic abundance (sA * area, proportional to the total abundance of euphausiids). The index is for the Kodiak core survey area available for variable years historically and biennially since 2013 (Ressler et al., 2019).
3. Larvae and Young-of-the-Year Indicators (Appendix Figure 3C.9a.j)
    - An age-0 sablefish growth is calculated as the coefficient for the regression of length (mm) by Julian day for each year and effectively tracks the nearshore age-0 growth rate of sablefish. Data have been collected since 1978 by the Institute for Seabird Research and Conservation and analyzed by the U.S. Geological Service. (Arimitsu and Hatch, 2019).
4. Juvenile Indicators (Appendix Figure 3C.9a.k-m)
    - The ADF&G large mesh bottom trawl survey of crab and groundfish has been conducted annually from 1988 to present and samples on a fixed grid in the Kodiak to eastern Aleutian area. Sablefish catch-per-unit-effort and lengths were summarized for the survey region. Sablefish lengths generally consist of fish between ages 2-4 and can be considered an index of sablefish juveniles in the nearshore prior to returning to adult habitat (Spalinger, 2015).
    - Catch-per-unit-of-effort of juvenile sablefish (<400 mm, likely age-1) collected on summer bottom-trawl surveys.
    - Summer sablefish condition for juvenile (designated as immature) female sablefish. Body condition was estimated using a length-weight regression (Boldt et al., 2017) from data

collected randomly for otoliths in the annual GOA longline survey (legs 3-7) from 1996 to present.

5. Adult Indicators (Appendix Figure 3C.9a.n-t)
    - Mean age of sablefish female spawning stock biomass from the most recent sablefish stock assessment model.
    - Measure of evenness or concentration of age composition by cohort of female sablefish from the most recent sablefish stock assessment model.
    - Summer sablefish condition for age-4, mature female sablefish. Body condition was estimated using a length-weight regression (Boldt et al., 2017) from data collected randomly for otoliths in the annual GOA longline survey (legs 3-7) from 1996 to present (Shotwell and Rodgveller, *pers. commun.*).
    - Arrowtooth flounder total biomass (metric tons) from the most recent stock assessment model (Spies et al., 2017).
    - Incidental catch of sablefish in the GOA arrowtooth flounder fishery (Shotwell, *pers. commun.*)
    - Averaged anomalies of the relative population weights for primary sampled species (giant grenadier, arrowtooth flounder, rougheye rockfish, shortraker rockfish, and shortspine thornyhead) on the GOA longline survey (Shotwell, *pers. commun.*).
    - Summer sablefish condition for large adult (>=750 mm) female sablefish. Body condition was estimated using a length-weight regression (Boldt et al., 2017) from data collected randomly for otoliths in the annual GOA longline survey (legs 3-7) from 1996 to present.

<u>Socioeconomic Indicators:</u>

1. Fishery Performance Indicators (Appendix Figure 3C.9b.a-d)
    - Catch-per-unit-of-effort of sablefish in tons estimated from fishery observer data from the longline fisheries in the GOA (Hanselman, *pers. commun.*).
    - Catch per unit of effort of sablefish in tons estimated from fishery observer data from the pot fisheries in the eastern Bering Sea (Hanselman, *pers. commun.*).
    - Incidental catch estimates of sablefish in the Bering Sea fisheries excluding the sablefish fishery. Data available from Alaska Fisheries Information Network (AKFIN) (Shotwell, *pers. commun.*).
    - Incidental catch of sablefish in the GOA fisheries excluding the sablefish fishery. Data available from Alaska Fisheries Information Network (AKFIN) (Shotwell, *pers. commun.*).
2. Economic Indicators (Appendix Figure 3C.9a.e-h)
    - Sablefish condition for large (>= 750 mm) female sablefish. Body condition was estimated using a length-weight regression (Boldt et al., 2017) from data collected randomly by observers for otoliths in the GOA and BSAI fisheries from 1999 to present (Shotwell and Rodgveller, *pers. commun.*).
    - Annual estimated real ex-vessel value measured in millions of dollars and inflation adjusted to 2018 USD (Fissel et al., 2019).
    - Average price per pound of small sablefish in BSAI fixed gear fisheries (Armstrong et al., 2018).

Indicator Monitoring Analysis

We provide the list and time-series of indicators (Appendix Table 3C.4, Appendix Figure 3C.9) and then monitor the indicators using three stages of statistical tests that gradually increase in complexity depending on the stability of the indicator for monitoring the ecosystem or socioeconomic process and the data availability for the stock (Shotwell et al., *In Review*). At this time, we report the initial results of the first and second stage statistical tests of the indicator monitoring analysis for sablefish. The third stage will require more indicator development and review of the ESP modeling applications.

Stage 1, Traffic Light Test:

The first stage of the indicator analysis is a simple assessment of the most recent year relative value and a traffic-light evaluation of the current year where available (Appendix Table 3C.4). Both measures are based on one standard deviation from the long-term mean (log-transformed) of the time series. A symbol is provided if the most recent year of the time series is greater than (+), less than (-), or within (•) one standard deviation of the long-term mean for the time series. If the most recent year is also the current year then a color fill is provided for the traffic-light ranking based on whether the relative value creates conditions that are good (blue), average (white), or poor (red) for sablefish (Caddy et al., 2015). The blue or red coloring does not always correspond to a greater than (+) or less than (-) relative value. In some cases the current year data were not available. This identifies data gaps for evaluating ecosystem and socioeconomic data for sablefish and highlights potential future research priorities.

The sablefish population is currently experiencing a series of unusually large year-classes which are concurrent with large shifts in the physical environment (Appendix Figure 3C.9a.a-f). There have been increased sea surface warming in the GOA and BSAI ecosystems and the presence of a series of major heatwaves from 2014-2016 and potentially again in 2019 (Appendix Figure 3C.9a.a,c-d). This warming is also evident in bottom temperatures taken on the AFSC bottom trawl surveys and the International Pacific Halibut Commission (IPHC) surveys in hotspots throughout the continental shelf region. However, the warming was not particularly present over much of the slope environment, which may provide a buffer during spawning and egg deposition. Specifically, the 250-m slope temperature index from the longline survey which is in prime sablefish habitat, has not deviated greatly from the 15-year mean (Appendix Figure 3C.9a.b). However, this index has remained positive for the last three years, a deviation from the historical fluctuations around the mean, suggesting these deeper waters may remain somewhat warmer than average (~0.1°C) from 2017-2019. Late spring sea surface temperatures near the edges of the Alaska sablefish population in the eastern GOA (EGOA) and southeast Bering Sea (SEBS) were very high in 2015-2016 and again in 2019 during the peak sablefish larval time period (Appendix Figure 3C.9a.c-d). Primary production during the peak spring bloom time period in Alaska (May) has steadily been decreasing in these two areas with a peak only in 2014 in the EGOA (Appendix Figure 3C.9a.e-f). In contrast, the mesozooplankton biomass in the central and eastern GOA has been fairly high since 2014 on the shelf and high to average offshore except for 2018 (Appendix Figure 3C.9a.g-h). This most recent decline was largely due to a drop in large copepods which may have to do with the recent declines in the phytoplankton community (Batten, 2019). The euphausiid abundance index in the central GOA region has been steadily decreasing since 2011 but has returned to near average conditions in 2019 (Appendix Figure 3C.9a.i). The mixed physical and lower trophic level indices suggest that the warming has diverse regional impacts on the plankton community but that a variety of prey options are available for larval and YOY sablefish. During exceptionally warm years these conditions may provide an advantage for larval and YOY sablefish due to their non-discriminating prey selection and potential for rapid growth.

The high growth during warm years is reflected in the samples of young-of-the-year (YOY) and juvenile sablefish. Growth of YOY sablefish from rhinoceros auklet diet samples on Middleton Island show an increasing trend in growth since a low in 2012 (Appendix Figure 3C.9a.j). Peak growth occurred in 2014-2016 and again with a very high anomaly in 2019. Age-1 sablefish were also captured in high numbers in the ADF&G large mesh in 2015, 2017, and somewhat in 2019 (Appendix Figure 3C.8b) and in the bottom trawl survey in 2015 and 2017 (Appendix Figure 3C.9a.l). The ADF&G survey has also shown an increasing trend for sablefish catch-per-unit-of-effort (CPUE) overall since 2015 with the exception of 2017 (Appendix Figure 3C.8a). 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 (Appendix Figure 3C.9a.k). However, when combined with the length frequencies this survey is useful for identifying continued survival of sablefish throughout their residency on the shelf before transiting to the slope adult environment. Body condition of sablefish female juveniles captured on the longline survey (generally around age 3) can be used to measure the health of fish arriving at the adult habitat. This index has been at or below average since 2014 and the condition of age-3 juveniles in 2017 and 2019 (which would be the 2014 and 2016 year-class) was fairly poor (Appendix Figure 3C.9a.m). This implies that there may be additional factors contributing to the strength of the year-class following the overwinter survival and nearshore residency.

Mean age of spawners as estimated by the current stock assessment model has declined rapidly since 2017 implying a larger contribution of younger fish to the spawning stock biomass as the 2014 year-class begin to mature (Appendix Figure 3C.9a.n). Age evenness has severely declined in recent years and is far less even than the low point in the 1980s after the large 1977 year-class suggesting that the age composition of the population is made up of very few cohorts and potentially less resilient to future shifts in environmental conditions (Appendix Figure 3C.9a.o). Additionally, skip spawning was found to be more prevalent at younger ages (Rodgveller et al. 2018), therefore, the contribution of the 2014 year-class (and subsequent large year-classes) to future recruitment may be more variable than older year classes. The summer condition of age-4 female mature fish on the longline survey has been poor since 2015 (Appendix Figure 3C.9a.p). Specifically, the condition of age-4 in 2018 (or the 2014 year-class) is poor when compared to the relatively good condition of age-4 fish in previously high recruitment years (2001, 2002, and 2004, for the 1997, 1998, and 2000 year-classes). This age-4 bottleneck was also confirmed in the drop of the 2014 year-class recruitment estimate in the most recent sablefish stock assessment model to around the strength of the 1977 year-class.

Given non-specific dietary requirements at the maturing-to-adult stages, it is likely less useful to explore prey requirements than it is to interpret changes in predation. It, therefore, may be useful to consider impacts of potential predator biomass on sablefish transitioning to the offshore slope environment. Arrowtooth flounder has been considered a primary predator of young sablefish; however, the most recent biomass estimates from the stock assessment indicate a recent decline in total biomass (Appendix Figure 3C.9a.q). Conversely, the incidental catch estimates of sablefish in the GOA arrowtooth flounder fishery have increased dramatically since 2016 suggesting potentially higher levels of spatial overlap between the arrowtooth and sablefish populations (Appendix Figure 3C.9a.r). This may mean that young sablefish returning to adult slope habitat have a higher level of competition and predation resulting in the measured poor body condition (Appendix Figure 3C.9a.p). The relative health of the slope habitat has also been on a decreasing trend since 2015 as measured by the relative population weights (RPW) of major non-sablefish species on the longline survey (Appendix Figure 3C.9a.s). The cause of this decreasing trend is unknown but may also impact sablefish arriving in poor condition to their adult slope habitat and cause them to incur higher stress levels. Condition of large adult female sablefish from the longline survey is moderately positively correlated to the slope habitat relative health indicator and the recent declining trend in condition up until 2017 may also be reflective of this decreasing trend in slope habitat relative health. The condition indicator of large adult females is also highly variable over time (Appendix Figure 3C.9a.t) and is somewhat concerning given the increasing reliance on the 2014 cohort contribution to the sablefish population.

With regard to fishery performance, the CPUE of sablefish in the GOA longline fishery has been below average since 2011 and on a steadily decreasing trend to the lowest of the time series in 2019 (Appendix Figure 3C.9b.a). This is contrasted by the CPUE of the pot fishery in the eastern Bering Sea which was below average from 2009-2016 and recently increased to near record high in 2018 (Appendix Figure 3C.9b.b). These contrasting trends are concerning as they do not track the estimated exploitable biomass from the current stock assessment model and there may be temporal fluctuations in gear selectivity that are not accounted for in the current model configuration. Sablefish catch has been increasing recently in the non-sablefish target fisheries for both the GOA and BSAI fisheries (Appendix Figure 3C.9b.c-d). This is primarily due to increases of catch in the rockfish and arrowtooth flounder fisheries in the GOA and the

Greenland turbot and midwater pollock fisheries in the BSAI. Rapid changes of catch may imply shifting distribution of the sablefish population into non-preferred habitat and may increase competition and predation for sablefish. For economic trends, large adult female sablefish condition in the GOA and BSAI fisheries appear to be in somewhat opposing trends during the year prior to large year-class events (Appendix Figure 3C.9b.e-f). This may reflect pre-spawning condition, which appeared low in the BSAI and high in the GOA prior to the 2000 year-class, but very high in the BSAI and very low in the GOA prior to the 2014 year-class. The relative condition by region of the large female spawners may provide some insight on the habitat quality by region and the subsequent value of these fish considering the clear increase in lipids as these fish increase in size (Appendix Figure 3C.4). Overall, the ex-vessel value of the fishery has remained relatively stable since 2013; however, prices for small sablefish decreased dramatically in 2018 likely due to increases in catch of small fish as the 2014 year-class entered the fishery (Appendix Figure 3C.9b.g-h).

For the indicators available in the current year, the traffic light analysis shows an approximately even mix of good, stable, and poor conditions across all indicators. Physical, YOY, and early juvenile indicators were generally good, while juvenile and adult indicators were generally average to poor (Appendix Table 3C.4a). Socioeconomic indicators were also a mix but the majority of the indicators were not available for the most recent year (Appendix Table 3C.4b). In the future, a more quantitative summary measure across all indicators could be produced to generate an overall traffic light score for the ecosystem and socioeconomic indicators, respectively.

Stage 2, Regression Test:

Bayesian adaptive sampling (BAS) was used for the second stage statistical test to quantify the association between hypothesized predictors and sablefish recruitment and to assess the strength of support for each hypothesis. BAS explores model space, or the full range of candidate combinations of predictor variables, to calculate marginal inclusion probabilities for each predictor, model weights for each combination of predictors, and generate Bayesian model averaged predictions for outcomes (Clyde et al., 2011). In this second test, the full set of indicators is first winnowed to the predictors that could directly relate to recruitment and highly correlated covariates are removed (Appendix Figure 3C.10a). We further restrict potential covariates to those that can provide the longest model run and through the most recent estimate of recruitment that is well estimated in the current operational stock assessment model. This results in a model run from 1990 through the 2016 estimate of 2 year-olds or the 2014 year-class. We then provide the mean relationship between each predictor variable and log sablefish recruitment over time (Appendix Figure 3C.10b, left side), with error bars describing the uncertainty (1 standard deviation) in each estimated effect and the marginal inclusion probabilities for each predictor variable (Appendix Figure 3C.10b, right side). A higher probability indicates that the variable is a better candidate predictor of sablefish recruitment. The highest ranked predictor variables (inclusion probability > 0.5) based on this process were the summer juvenile sablefish CPUE from the ADF&G survey, the summer juvenile sablefish condition from the longline survey, and the catch from the arrowtooth flounder fishery in the GOA (Appendix Figure 3C.10).

The BAS method requires observations of all predictor variables in order to fit a given data point. This method estimates the inclusion probability for each predictor, generally by looking at the relative likelihood of all model combinations (subsets of predictors). If the value of one predictor is missing in a given year, all likelihood comparisons cannot be computed. When the model is run, only the subset of observations with complete predictor and response time series are fit. It is possible to effectively “trick” the model into fitting all years by specifying a 0 (the long-term average in z-score space) for missing predictor values. However, this may bias inclusion probabilities for time series that have more zeros and result in those time series exhibiting low inclusion probability, independent of the strength of the true relationship. Due to this consideration of bias, we only fit years with complete observations for each covariate at the longest possible time frame. This resulted in a smaller final subset of covariates. We plan to explore alternate model runs (e.g., biennial) to potentially include more covariates in the future.

Stage 3, Modeling 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 new spatially-explicit life cycle model (SILC) is in development for sablefish that pairs output from an individual based model (IBM) with the spatial statistical catch-at-age assessment model. The overall objective is to parse the movement and survival of sablefish in their first year using influences of environmental and predation processes from the subsequent traditional spatial and biological processes estimated for juveniles and adults. Increasing the resolution of our assessment of these processes will benefit the ability for the ESP to link with regional environmental and socioeconomic processes.

Once the SILC model is more 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 condition indicator and heatwave index could help explain the variability in recruitment deviations and predict pending recruitment events (e.g., Shotwell et al., 2014). The juvenile ADF&G index could be used directly in the model as a survey for age-1 plus sablefish and be updated on an annual basis. Utilizing indicators as indices directly inside the model would have the desirable property of influencing ABC recommendations in a neutral way.

Recommendations

The sablefish ESP follows the standardized framework for evaluating the various ecosystem and socioeconomic considerations for this stock (Shotwell et al., *In Review*). Given the metric and indicator assessment we provide the following set of considerations:

Ecosystem Considerations

- Consistent slope bottom temperatures may provide a buffer for sablefish egg development and subsequent larval hatch during heatwave years
- Non discriminating prey selection and rapid growth of larval and YOY sablefish provide an advantage in warm years to monopolize on available plankton prey
- Overwinter and nearshore conditions have recently been favorable for juvenile sablefish based on high growth of YOY sablefish observed in seabird diets and large CPUE of juveniles in nearshore surveys
- Body condition of juveniles that are caught in offshore adult habitat has been below average since 2014 and poor for the 2014 and 2016 year-classes
- Mean age of spawners and age evenness have decreased recently suggesting higher contribution of the recent large 2014 year-class to the adult spawning biomass
- Condition of the 2014 year-class is poor when compared to the relatively good condition of age-4 fish in previously high recruitment years and this is accompanied by a drop of 2014 year class recruitment strength in the most recent model recruitment estimates
- Spatial overlap between sablefish migrating to adult slope habitat and the arrowtooth flounder population may have increased based on recent large increases in incidental catch in the arrowtooth flounder fishery and may imply potentially higher competition and predation
- Body condition of the overall population on slope habitat has been decreasing since 2015 and may impact young sablefish arriving in already poor condition
- Overall, physical, YOY, and early juvenile indicators were generally good for sablefish while juvenile and adult indicators were generally average to poor.

Socioeconomic Considerations

- Fishery CPUE indicators are showing contrasting trends by gear type and differ from trends in exploitable biomass suggesting potential temporal or spatial fluctuations in gear selectivity
- Catch of sablefish in non-sablefish targeted fisheries has recently been increasing in both the GOA and BSAI which may imply shifting distribution of sablefish into non-preferred habitat

- Large adult female sablefish condition in the GOA and BSAI fisheries appear to be in somewhat opposing trends during the year prior to large year-class events.
- Ex-vessel value of the fishery has remained relatively stable since 2013, but prices of small fish have declined dramatically in recent years

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. Several indicators do not have a current year update and this may cause issues with generating a summary score for the ecosystem or socioeconomic considerations. Development of high-resolution remote sensing (e.g., regional surface temperature, transport estimates, primary production estimates) or climate model indicators (e.g., bottom temperature, NPZ variables) may assist with the current year data gap for several indicators if they sufficiently capture the main trends of the survey data and are consistently and reliably available. Some of the indicators collected for sablefish do not cover the full spatial distribution of the sablefish stock, particularly the zooplankton surveys. Potentially a large-scale zooplankton indicator that combines multiple data sources to determine a relative trend by region could be developed to more adequately capture the habitat that sablefish encounter during their first year of life.

It is important to consider the causal mechanisms for shifting condition of pre-spawning sablefish in both the survey and the fishery and the potential impact on spawning potential. There are many years of diet data collected for sablefish and many other groundfish that have not yet been incorporated into the ecopath model that initially estimated predation and consumption rates for sablefish. Once this model was updated, a more detailed synthesis on gut content could be developed to better evaluate the condition indices (which is a weight-at-length regression), potentially to generate time-series indicators of stomach fullness or energy content per individual sablefish biomass. These would help illuminate inference about competition and predation if other species were also updated in the ecopath model. It may also be useful to consider morphometric or physiological impacts on condition in pre- versus post-spawning individuals and individuals that skip spawn to measure energetic costs of spawning.

Evaluating condition and energy density of juvenile and adult sablefish samples throughout the whole population may be useful for understanding the impacts of shifting spatial distribution. Spatiotemporal comparison of condition may be useful to evaluate whether there are any regional impacts on sablefish condition during spawning. This would be highly dependent on sample size from observers for otolith fish. An evaluation of the spatial and temporal overlap between different fisheries may also provide insight on the potential new predation or competition pressures on the sablefish population. Since sablefish recruitment clearly has a weak relationship with spawning stock biomass, some of these factors may help explain and predict recruitment by determining the quality instead of the quantity of the annual spawning stock.

The monitoring analyses could also use refinement. An agreed upon target or range of the total number of indicators by category to be included in the indicator suite would help standardize any future potential scores or metrics resulting from the traffic light test. Exploration of alternatives for dealing with missing data would be very useful for updating the BAS model. One option may be to explore different types of models such as biennial or shorter time series ranges. Another may be to include a random-number as a covariate and test the inclusion probability (or perhaps many replicates) and use that inclusion probability (or its average across replicates) as a significance threshold for inclusion probability of other variables (J. Thorson, *pers. commun.*). Additional refinement on the SILC model might also allow for regional estimates of recruitment and an evaluation of a stock-recruitment relationship by region may provide insight into a selection of relevant indicators by region for future analyses.

As indicators are improved or updated, they may replace those in the current set of indicators to allow for refinement of the BAS model and potential evaluation of performance and risk within the operational stock assessment model. This could be accomplished in the next full ESP assessment and the timing of that will depend on how the ESP process matures. In the future, a partial ESP may be requested as an update to the full ESP report provided here when no new information except indicator updates are available. We plan to create a simplified template for evaluating the ESP considerations during a partial update year.

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Literature Cited

Alderdice, D.F., Jensen, F.P., and Velsen, J. 1982. Incubation of sablefish (*Anoplopama fimbria*) in a system designed for culture of fragile marine teleost eggs. Aquaculture. 71(3): 271-283. Appendix Table 3C.2a reference #22.

Arimitsu M. and S. Hatch. 2019. Arimitsu (USGS) and Hatch (ISRC), Gulf Watch Alaska Long-term Monitoring Program.

Armstrong, J. and S. Cunningham. 2018. Discussion Paper: Sablefish Discard Allowance. Report to North Pacific Fisheries Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501. 32 p.

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.

Batten, S., 2019. Continuous plankton recorder data from the northeast Pacific: lower trophic levels in 2018. *In*: S. Zador and E. Yasumiishi (Ed.), Ecosystem Considerations for 2019, Stock Assessment and Fishery Evaluation Report. Technical report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Blackburn, J.E., and Jackson, P.B. 1982. Seasonal composition and abundance of juvenile and adult marine finfish and crab species in the nearshore zone of Kodiak Island's eastside during April 1978 through March 1979; (in) Outer Continental Shelf Environmental Assessment Program, Final Reports of Principal Investigators 54:377-570 RU 0552. Appendix Table 3C.2a reference #4.

Boldt, J., C. Rooper, and J. Hoff. 2017. Gulf of Alaska groundfish condition. *In* Zador, S., and Yasumiishi, E., 2018. Ecosystem Status Report 2018: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Caddy, J.F. 2015. The traffic light procedure for decision making: its rapid extension from fisheries to other sectors of the economy. Glob. J. of Sci. Front. Res: 1 Mar. Sci. 15(1), 30 pp.

Carlson, H.R., Haight, R.E., and Krieger, K.J. 1982. Species composition and relative abundance of demersal marine life in waters of southeastern Alaska, 1969-81. U.S. Department of Commerce, Juneau, AK. Appendix Table 3C.2a reference #3.

Casey, K.S., T.B. Brandon, P. Cornillon, and R. Evans. 2010. The Past, Present and Future of the

AVHRR Pathfinder SST Program, in Oceanography from Space: Revisited, eds. V. Barale, J.F.R. Gower, and L. Alberotanza, Springer. DOI: 10.1007/978-90-481-8681-5_16.

Clyde, M. A., J. Ghosh, and M. L. Littman. 2011. Bayesian Adaptive Sampling for Variable Selection and Model Averaging. Journal of Computational and Graphical Statistics 20:80-101.

Coffin, B., and F. Mueter. 2015. Environmental covariates of sablefish (*Anoplopoma fimbria*) and Pacific ocean perch (*Sebastes alutus*) recruitment in the Gulf of Alaska. Deep Sea Res. II. Special Issue.

Coutre, K.M. 2014. Feeding ecology and movement patterns of juvenile sablefish in coastal Southeast Alaska. Masters thesis. University of Alaska Fairbanks. 74 pp. Appendix Table 3C.2a reference #30.

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

Dorn, M. W., C. J. Cunningham, M. T. Dalton, B. S. Fadely, B. L. Gerke, A. B. Hollowed, K. K. Holsman, J. H. Moss, O. A. Ormseth, W. A. Palsson, P. A. Ressler, L. A. Rogers, M. A. Sigler, P. J. Stabeno, and M. Szymkowiak. 2018. A climate science regional action plan for the Gulf of Alaska. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-376, 58 p.

Doyle, M.J., Rugen, W.C., and Brodeur, R.D. 1995. Neustonic ichthyoplankton in the western Gulf of Alaska during spring. Fishery Bulletin 93(2): 231-253. Appendix Table 3C.2a reference #7.

Doyle, M.J., and Mier, K.L. 2012. A new conceptual model framework for evaluating the early ontogeny phase of recruitment processes among marine fish species. Canadian Journal of Fisheries and Aquatic Sciences 69: 2112-2129. Appendix Table 3C.2a reference #17.

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., and Mier, K.L. *Accepted*. Pelagic early life history exposure profiles of selected commercially important fish species in the Gulf of Alaska. Deep-Sea Res. II (special issue). Appendix Table 3C.2a reference #19.

Echave, K.B., Hanselman, D.H., Adkison, M.D., Sigler, M.F. 2012. Inter-decadal changes in sablefish, *Anoplopoma fimbria*, growth in the northeast Pacific Ocean. Fish. Bull. 210: 361-374. Appendix Table 3C.2a reference #28.

Fissel, B., M. Dalton, R. Felthoven, B. Garber-Yonts, A. Haynie, S. Kasperski, J. Lee, D. Lew, A. Santos, C. Seung, and K. Sparks. 2019. Economic status of the groundfish fisheries off Alaska, 2018. 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.

Fissel, B., M. Dalton, R. Felthoven, B. Garber-Yonts, A. Haynie, S. Kasperski, J. Lee, D. Lew, A. Santos, C. Seung, and K. Sparks. 2017. Economic status of the groundfish fisheries off Alaska, 2016. 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.O. Coyle, S. Hinckley, C. Parada, A. Hermann, M. Doyle, C. Ladd. *In Press*. An individual-based model for sablefish: Exploring the connectivity between potential spawning and nursery grounds in the Gulf of Alaska. Deep-Sea Res. II. Gulf of Alaska Integrated Ecosystem Research Program. Special Issue.

Grover, J.J. and Olla, B.L. 1990. Food habits of larval sablefish *Anoplopoma fimbria* from the Bering Sea. Fish. Bull. 88: 811-814. Appendix Table 3C.2a reference #29.

Haight, R.E., Reid, G.M., and Weemes, N. 2006. Distribution and habitats of marine fish and invertebrates in Katlian Bay, southeastern Alaska, 1967 and 1968. U.S. Department of Commerce, Juneau, AK. Appendix Table 3C.2a reference #6.

Hanselman, D.H., Lunsford, C.R., and Rodgveller, C.J. 2014. Assessment of the sablefish stock in

Alaska. *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. pp. 283-424. Appendix Table 3C.2a reference #18.

Hanselman, D.H., C.J., Rodgveller, C.R., Lunsford, and K.H. Fenske. 2017. Assessment of the sablefish stock in Alaska. 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.

Hobday, A. J., Alexander, L.V., Perkins, S. E., Smale, D. A., Straub, S. C., Oliver, E. C., Benthuysen, J. A., Burrows, M. T., Donat, M. G., and Feng, M. 2016. A hierarchical approach to defining marine heatwaves. Progress in Oceanography 141:227–238.

Hollowed, A.B., K. Aydin, K. Blackhart, M. Dorn, D. Hanselman, J. Heifetz, S. Kasperski, S. Lowe, and K. Shotwell. 2016. Discussion Paper Stock Assessment Prioritization for the North Pacific Fishery Management Council: Methods and Scenarios. Report to North Pacific Fisheries Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501. 17 pp.

Kendall, A.W., and Matarese, A.C. 1987. Biology of eggs, larvae, and epipelagic juveniles of sablefish, *Anoplopoma fimbria*, in relation to their potential use in management. Marine Fisheries Review 49(1): 1-13. Appendix Table 3C.2a reference #1.

Krieger, J.R., A. Sreenivasan, and R. Heintz 2019. Temperature-dependent growth and consumption of young-of-the-year sablefish Anoplopoma fimbria: Too hot, too cold or just right? Fisheries Research. 209: 32-39.

Laman, E. A., C. N. Rooper, S. C. Rooney, K. A. Turner, D. W. Cooper, and M. Zimmermann. 2017. Model-based essential fish habitat definitions for Bering Sea groundfish species. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-357, 265 p

Low, L.L., and Marasco, R. 1979. Preliminary report on bio-economic considerations of harvesting sablefish by longline and trawl gear in the Gulf of Alaska. U.S. Department of Commerce, Seattle, WA. Appendix Table 3C.2a reference #5.

Lunsford, C., C. Rodgveller, and P. Malecha. 2018. The 2017 longline survey of the Gulf of Alaska and eastern Bering Sea on the FV Ocean Prowler: Cruise Report OP-17-01. AFSC Processed Rep. 2018-01, 30 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 17109 Lena Point Loop Road, Juneau, AK 99801.

Lynch, P. D., R. D. Methot, and J. S. Link (eds.). 2018. Implementing a Next Generation Stock Assessment Enterprise. An Update to the NOAA Fisheries Stock Assessment Improvement Plan. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-183, 127 p. doi: 10.7755/TMSPO.183

Malecha, P., C. Rodgveller, C. Lunsford, and K. Siwicke. 2019. The 2018 longline survey of the Gulf of Alaska and eastern Aleutian Islands on the FV Alaskan Leader: Cruise Report AL-18-01. AFS Processed Rep. 2019-02, 30 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115

Mason, J.C., Beamish, R. J., and McFarlane, G.A. 1983. Sexual maturity, fecundity, spawning, and early life history of sablefish (Anoplopoma fimbria) off the Pacific coast of Canada. Can. J. Fish.Aquat. Sci. 40: 2126-2134. Appendix Table 3C.2a reference #26.

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.

McConnaughey, R. A., K. E. Blackhart , M. P. Eagleton , and J. Marsh. 2017. Habitat assessment prioritization for Alaska stocks: Report of the Alaska Regional Habitat Assessment Prioritization Coordination Team. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-361, 102 p.

McFarlane, G.A., and Beamish, R.J. 1992. Climatic influence linking copepod production with strong year-classes in sablefish, Anoplopoma fimbria. Canadian Journal of Fisheries and Aquatic Sciences 49(4): 743-753. Appendix Table 3C.2a reference #11.

Methot, R.D. Jr., and C.R. Wetzel. 2013. Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. Fisheries Research 142:86–99, http://dx.doi.org/10.1016/j.fishres.2012.10.012

Morrison, W.E., M. W. Nelson, J. F. Howard, E. J. Teeters, J. A. Hare, R. B. Griffis, J.D. Scott, and M.A. Alexander. 2015. Methodology for Assessing the Vulnerability of Marine Fish and Shellfish Species to a Changing Climate. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-OSF-3, 48 p.

Murphy, M.L., Johnson, S.W., and Csepp, D.J. 2000. A comparison of fish assemblages in eelgrass and adjacent subtidal habitats near Craig, Alaska. Alaska Fishery Research Bulletin 7: 11-21. Appendix Table 3C.2a reference #15.

Ormseth, O.A. and P.D., Spencer. 2011. An assessment of vulnerability in Alaska groundfish. Fish. Res.112:127–133.

Patrick, W.S., P. Spencer, J. Link, J. Cope, J. Field, D. Kobayashi, P. Lawson, T. Gedamke, E. Cortés, O.A. Ormseth, K. Bigelow, W. Overholtz. 2010. Using productivity and susceptibility indices to assess the vulnerability of United States fish stocks to overfishing. Fish. Bull., 108: 305–322.

Pirtle, J.L., S.K. Shotwell, M. Zimmermann, J.A. Reid, and N. Golden. *In Press*. Habitat suitability models for groundfish in the Gulf of Alaska. Deep-Sea Res. Pt. II. https://doi:10.1016/j.dsr2.2017.12.005.

Reiniger, R., and C. Ross. 1968. A method of interpolation with application to oceanographic data. Deep Sea Res., 15:185–193. doi:10.1016/0011-7471(68)90040-5.

Ressler, P.H. 2019. Gulf of Alaska Euphausiids. *In*: S. Zador and E. Yasumiishi (Ed.), Ecosystem Considerations for 2019, Stock Assessment and Fishery Evaluation Report. Technical report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

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. *In Review*. The utility of length, age, liver condition, and body condtion for predicting maturity and fecundity of female sablefish. Fish. Res.

Rooney, S., C.N., Rooper, E., Laman, K., Turner, D., Cooper, and M. Zimmermann. 2018. Model-based essential fish habitat definitions for Gulf of Alaska groundfish species. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-373, 380 p

Rugen, W.C. 1990. Spatial and temporal distribution of larval fish in the western Gulf of Alaska, with emphasis on the period of peak abundance of walleye pollock (*Theragra chalcogramma*) larvae. U.S. Department of Commerce, Seattle, WA. Appendix Table 3C.2a reference #16.

Rutecki, T.L. and Varosi, E.R. 1997. Distribution, age, and growth of juvenile sablefish, *Anoplopoma fimbria*, in Southeast Alaska. In M. Saunders and M. Wilkins (eds.). Proceedings of the International Symposium on the Biology and Management of Sablefish. pp 45-54. NOAA Tech.Rep. 130.26. Appendix Table 3C.2a reference #25.

Shotwell, S.K., K., Blackhart, D., Hanselman, P., Lynch, S., Zador, B., Fissel, P., Spencer, and K., Aydin. *In Prep*. Introducing a national framework for including stock-specific ecosystem and socioeconomic considerations within next generation stock assessments.

Shotwell, S.K., A. Deary, M. Doyle, J. Duffy-Anderson, K. Fenske, G.A. Gibson, E. Goldstein, D.H. Hanselman, J. Moss, F.J. Mueter, J.L. Pirtle, C. Rooper, W. Stockhausen, W. Strasburger, R. Suryan, J.J. Vollenweider, E. Yasumiishi, and S. Zador. *In Review*. Investigating a recruitment gauntlet to create specialized ontogenetic profiles and relevant indicators that identify life history bottlenecks for use in next generation stock assessments. Final Report GOA Synthesis. North Pacific Research Board. 97 p.

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. Appendix Table 3C.2a reference #20.

Siddon, E.C., De Forest, L.G., Blood, D.M., Doyle, M.J., and Matarese, A.C. *In Press*. Early life history ecology for five commercially and ecologically important fish species in the eastern and western Gulf of Alaska. Deep Sea Res. II. https://doi.org/10.1016/j.dsr2.2016.06.022

Siddon, S., and S. Zador. 2017. Ecosystem Considerations 2017: Status of the eastern Bering sea marine ecosystem. *In* Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501. 231 p.

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. Appendix Table 3C.2a reference #10.

Sigler, M. F., M. P. Eagleton, T. E. Helser, J. V. Olson, J. L. Pirtle, C. N. Rooper, S. C. Simpson, and R. P. Stone. 2017. Alaska Essential Fish Habitat Research Plan: A Research Plan for the National Marine Fisheries Service's Alaska Fisheries Science Center and Alaska Regional Office. AFSC Processed Rep. 2015-05, 22 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.

Sogard, S.M., and Olla, B.L. 2001. Growth and behavioral responses to elevated temperatures by juvenile sablefish *Anoplopoma fimbria* and the interactive role of food availability. Marine Ecology Progress Series 217: 121-134. Appendix Table 3C.2a reference #9.

Sogard, S.M. and Spencer, M.L. 2004. Energy allocation in juvenile sablefish: effects of temperature, ration and body size. Journal of Fish Biology 64: 726-738. Appendix Table 3C.2a reference #23.

Sogard, S.M. and Olla, B.L. 2003. Contrasts in the capacity and underlying mechanisms for compensatory growth in two pelagic marine fishes. Marine ecology progress series. 243: 165-177. Appendix Table 3C.2a reference #24.

Spalinger, K. 2015. Operational plan: Large-mesh bottom trawl survey of crab and groundfish: Kodiak, Chignik, South Peninsula, and Eastern Aleutian management districts–standard protocol 2015–2019. Alaska Department of Fish and Game, Regional Operational Plan ROP.CF.4K.2015.20, Kodiak.

Spies, I., and Palsson, W. 2018. Chapter 7 : Assessment of the arrowtooth flounder stock in the Gulf of Alaska. *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.

Strasburger, W., J. Moss, and E. Yasumiishi. 2017. Spatial and temporal trends in the abundance and distribution of YOY groundfish in pelagic waters of the eastern Gulf of Alaska during summer, 2010-2017. *In* S. Zador (Ed.), Ecosystem Considerations for 2017: Appendix C of the BSAI/GOA Stock Assessment and Fishery Evaluation Report. Technical report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Sturdevant, M.V., Sigler, M.F., and Orsi, J.A. 2009. Sablefish predation on juvenile Pacific salmon in the coastal marine waters of Southeast Alaska in 1999. Transactions of the American Fisheries Society 138(3): 675-691. Appendix Table 3C.2a reference #14.

Sullivan, K.M. and Smith Jr., K.L. 1982. Energetics of sablefish, *Anoplopoma fimbria*, under laboratory conditions. Can. J. Fish. Aquat. Sci. 39: 1012-1020. Appendix Table 3C.2a reference #21.

Wespestad, V.G., Thorson, K., and Mizroch, S. 1978. Movement of sablefish (Anoplopoma fimbria) in the northeastern Pacific Ocean as determined by tagging experiments (1971 - 1977). U.S. Department of Commerce, Seattle, WA. Appendix Table 3C.2a reference #8.

Wing, B.L. 1985. Salmon stomach contents from the Alaska Troll Logbook Program, 1977-84. NOAA Tech. Memo. NMFS F/NWC-91. 41 p. Appendix Table 3C.2a reference #31.

Wing, B.L., and Kamikawa, D.J. 1995. Distribution of neustonic sablefish larvae and associated ichthyoplankton in the eastern Gulf of Alaska, May 1990. U.S. Department of Commerce, Seattle, WA. Appendix Table 3C.2a reference #2.

Wing, B.L. 1997. Distribution of sablefish, *Anoplopoma fimbria*, larvae in the Eastern Gulf of Alaska. *In* M. Saunders and M. Wilkins (eds.). Proceedings of the International Symposium on the Biology and Management of Sablefish. pp 13-26. NOAA Tech. Rep. 130. Appendix Table 3C.2a reference #27.

Yang, M.S., and Nelson, M.W. 2000. Food habits of the commercially important groundfishes in the Gulf of Alaska in 1990, 1993, and 1996. U.S. Department of Commerce, Seattle, WA. Appendix Table 3C.2a reference #12.

Yang, M.S., Dodd, K.A., Hibpshman, R., and Whitehouse, A. 2006. Food habits of groundfishes in the Gulf of Alaska in 1999 and 2001. U.S. Department of Commerce, Seattle, WA. Appendix Table 3C.2a reference #13.

Yasumiishi, E.M., S.K. Shotwell, D.H. Hanselman, and E.A. Fergusson. 2017. Southeast coastal monitoring survey indices and the recruitment of Gulf of Alaska sablefish. 2017. *In* S. Zador (Ed.), Ecosystem Considerations for 2017: Appendix C of the BSAI/GOA Stock Assessment and Fishery Evaluation Report. Technical report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Zador, S., and E., Yasumiishi. 2018. Ecosystem Considerations 2018: Status of the Gulf of Alaska marine ecosystem. *In* Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501. 215 p.

Tables

Appendix Table 3C.1: List of data sources used in the ESP evaluation. Please see the main sablefish SAFE document, the Ecosystem Considerations Report (Zador and Yasumiishi, 2019) and the Economic Status Report (Fissel et al., 2019) for more details.

Title	Description	Years	Extent
EcoFOCI Spring Survey	Shelf larval survey in May-early June in Kodiak to Unimak Pass using oblique 60 cm bongo tows, fixed-station grid, catch per unit effort in numbers per 10 m^2	1978 – present	Western GOA annual, biennial
EMA Summer Survey	Shelf and slope age-0 survey during June and July using Nordic and CanTrawl surface trawls	2010-2017	Eastern GOA
ADF&G Large Mesh Survey	Bottom trawl survey of crab and groundfish on fixed-grid station design using eastern otter trawl	1988-2018	Western GOA to Aleutian Islands
RACE Bottom Trawl Survey	Bottom trawl survey of groundfish in June through August, Gulf of Alaska using Poly Nor'Eastern trawl on stratified random sample grid, catch per unit of effort in metric tons	1984 – present	GOA tri-, biennial
ABL Longline Survey	Longline survey of groundfish on stratified stations set 20-30 km apart using standard groundline	1987-2018	GOA annual
MACE Acoustic Survey	Mid-water acoustic survey in March in Shelikof Strait for pre-spawning pollock and again in summer for age 1 pollock	1981 – present	GOA annual, biennial
Seabird Surveys	Ecological monitoring for status and trend of suite of seabird species conducted by Institute for Seabird Research and Conservation and GulfWatch Alaska	1978 – present	Middleton Island, GOA
RECA Energetics Database	Compositional data and associated analyses by the Recruitment Energetics and Coastal Assessment (RECA) Program, AFSC on multiple platforms	1997 – present	Alaska variable
REEM Diet Database	Food habits data and associated analyses collected by the Resource Ecology and Ecosystem Modeling (REEM) Program, AFSC on multiple platforms	1990 – present	GOA biennial
AVHRR Pathfinder	4 km Advanced Very High Resolution Radiometer (AVHRR) version 5.3 monthly gridded sea surface temperature (SST) dataset (Group for High Resolution SST, GHRSST)	1981 – present	Global

Appendix Table 3C.1 (cont.): List of data sources used in the ESP evaluation. Please see the main sablefish SAFE document, the Ecosystem Considerations Report (Zador and Yasumiishi, 2018) and the Economic Status Report (Fissel et al., 2019) for more details.

Title	Description	Years	Extent
Ocean Colour CCI	4km Ocean Colour Climate Change Initiative (OC-CCI) version 4.0 monthly gridded derived chlorophyll dataset, European Space Agency, (http://www.esa-oceancolour-cci.org)	1998 – 2018	Global
Pacific CPR	Continuous Plankton Recorder (CPR) near surface plankton net (7m) towed behind vessels of opportunity, identify and count zooplankton and hard shelled phytoplankton	2000-present	North Pacific
Climate Model Output	Daily sea surface temperatures from the NOAA High-resolution Blended Analysis Data	1977 – present	Central GOA
ROMS/NPZ Model Output	Coupled hydrographic Regional Ocean Modeling System and lower tropic Nutrient-Phytoplankton-Zooplankton dynamics model	1996 – 2013	Alaska variable
Essential Fish Habitat Models	Habitat suitability MaxEnt models for describing essential fish habitat of groundfish and crab in Alaska, EFH 2016 Update	1970 – 2016	Alaska
FMA Observer Database	Observer sample database maintained by Fisheries Monitoring and Analysis Division	1988 – present	Alaska annual
NMFS Alaska Regional Office	Catch, economics, and social values for fishing industry, data processed and provided by Alaska Fisheries Information Network	1992 – 2018	Alaska annual
Reports & Online	ADFG Commercial Operators Annual Reports, AKRO At-sea Production Reports, Shoreside Production Reports, FAO Fisheries & Aquaculture Department of Statistics	2011 – 2018	Alaska, U.S., Global annual

Appendix Table 3C.2a: Ecological information by life history stage for sablefish.

Stage		Habitat & Distribution	Phenology	Age, Length, Growth	Energetics	Diet	Predators/Competitors
Adult	**Recruit**	Shelf edge, slope, gullies (>200 m), GOA to Bering, benthic(18)	First recruit to survey and fishery age 2, high movement (10-88%)(18)	Max: 73yrs(18,19,28), 134♀/138♂ cm Average: 12 yrs L_inf=80♀/68♂ cm, K= 0.22♀/0.29♂	Low conversion efficiency, low metabolic rate(21)	Opportunistic, euphausiids, pol/cod, capelin, herring, squid, jelly(12,18,REEM)	P: Sperm whales, orca, fisheries, C: slope groundfish(18)
	Spawning	Shelf break(1), deep water pelagic	Winter-spring, batch spawner, peak March, 25 wks, high production(1,26,17)	1st mature: 5.5 yr, 50%: 6.6 yr/65cm ♀, 5 yr/57 cm ♂(17,18), females > males	Oviparous, high fecundity (120-$1000 \cdot 10^3$) eggs, Skip-spawning(1,17,18)	Opportunistic, euphausiids, pol/cod, capelin, herring, squid, jelly(12,18,REEM)	P: Sperm whales, orca, fisheries, C: slope groundfish(18)
Offshore to Nearshore Pelagic	**Egg**	Slope (>200-400 m), sink to deeper depths, negatively buoyant(1)	Late winter to early spring, 10 wks peak egg to peak larvae (17)	Egg size: 1.8-2.2 mm, large egg size(17,RACE)	Max survival to hatch, 34-35ppt, 4-6.6°C (lab)(22)	Yolk (RACE)	
	Larvae	Slope (>200-600 m) (hatch to yolk-sac), epipelagic over shelf and slope, 160 km offshore(1,2,7,17)	Late spring and summer, peak end May, 12 wks, epipelagic(7,16,17,19)	10-80 mm SL (1,7,16), 1.2 mm/day, develop as obligate neuston(7,10,16)	Growth threshold 22°C, optimum 12-16°C (lab)(9)	copepod nauplii, nauplii, small copepods, small and large copepods(1,29)	C: larval cottids, hexagrammids, wrymouths, non-obligate neustonic taxa(7)
	YOY	Shelf(1), neuston and near surface (upper 10-20 cm of water column)(1,10,17)	No marked transition time to stage, move to nearshore(1,19)	60-230 mm FL (120 mm avg, neustonic), rapid growth, 1.2 mm/day(10)	Upper thermal limit near upper limit survival(9), absence lipid regulation(23)	Euphausiids, pelagic tunicates, other crustaceans, larval fish(1,10)	P: Coho and chinook salmon(31), seabirds, C: active inshore migration(1)
Nearshore Settlement	**Juvenile**	Nearshore (6-214 m), inlet, bay, fjord, strait, mixed mud, soft, proximity to rock(3,4,6)	Late summer-fall, diel pelagic feeding excursions(4,30)	300-400 mm after second summer, age 2+ yrs(25)		Herring, smelts, salmon remains, jellies(30)	P: Salmon, halibut (12,31), seabirds, C: macroalgae, sponge, anemone, whip, basket star, eelgrass, shelf groundfish(3, 12,15)
	Pre-Recruit	Nearshore, shelf (10-207 m), inlet, bay, fjord, strait, mixed mud, soft, proximity to rock(3,4,6,8)	Offshore movement begins after 2nd summer(25)	<600 mm FL(5), age 2+ yrs(10)		Euphausiids, shrimp, pollock, other fish, other crustaceans, cephalopods, jellies, salmon (12,13,14)	P: Salmon, halibut (12,31), seabirds, C: sponge, whip, sea pen, coral, basket star, anemone, shelf groundfish(3,12)

Appendix Table 3C.2b. Key processes affecting survival by life history stage for sablefish.

Stage		Processes Affecting Survival	Relationship to Sablefish
Adult	**Recruit**	1. Abundance of predators/competitors in preferred slope habitat 2. Bottom temperature	Increases in main predators of sablefish would be negative but minor predators or competitors may indicate sablefish biomass increase. Increases in bottom temperature may impact spawning habitat.
	Spawning	1. Large-scale offshore thermal environment winter before spawning(20) 2. Condition, age of female spawners	Stability of offshore thermal environment may be necessary for spawning and provide buffer. Poor body condition or earlier age of female spawners may result in lowered productivity, more variable spawn timing or skip spawning, and mismatch with spring bloom.
Offshore to Nearshore Pelagic	**Egg**	1. Bottom temperatures 2. Advection/retention 3. Oxygen minimum zone	Increases in bottom temperature and advection would be negative for egg stage resulting in early hatching or dispersal from preferred habitat. Shoaling of the oxygen minimum zone may also adversely impact survival to hatch.
	Larvae	1. Surface temperature in neuston 2. Match with spring bloom(17), abundant prey 3. Currents that facilitate nearshore transport(1)	Increases in temperature and zooplankton prey may be positive for sablefish that can utilize multiple prey types and have a high growth potential at warmer temperatures. Increases in nearshore transport to preferred habitat would be positive for sablefish during settlement transition.
	YOY	1. Surface temperature in neuston 2. Spring/summer abundance of zooplankton prey(11) 3. Currents that transport onto shelf(1) 4. Predation	Increases in temperature and zooplankton prey may be positive for sablefish similar to the larval stage. Increases in nearshore transport would assist with settlement to preferred habitat and increases in predation would be negative for sablefish although this is not an abundant species and not a common prey item.
Nearshore Settlement	**Juvenile**	1. Summer/fall abundance of zooplankton prey (11) 2. Bottom temperature in nearshore 3. Predation	Increases in preferred zooplankton prey would be positive for sablefish condition as they prepare to overwinter in the nearshore and higher bottom temperatures may assist with energetic costs of settlement. Predation would be negative for sablefish, although sablefish is not a primary prey item for most stocks.
	Pre-Recruit	1. Abundance of predators/competitors during transition from nearshore to offshore habitat 2. Top-down predation increase on age 2+	Increases in encounter of main competitors and predators of juvenile sablefish would be negative but minor predators or competitors may indicate sablefish biomass increase. Increases in main predator of sablefish would be negative but minor predators such as seabirds may indicate sablefish biomass increase.

Appendix Table 3C.3a. 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 vessels, and the proportion of vessels that are catcher vessels, 2009-2013 average and 2014-2018.

	2009-2013 Average	2014	2015	2016	2017	2018
Total Catch K mt	14.0	12.3	11.7	10.9	13.0	15.3
Retained Catch K mt	13.3	11.6	10.8	9.9	11.5	12.3
Value M US$	$113.5	$94.6	$94.1	$92.9	$119.1	$92.4
Price/lb US$	$3.98	$3.82	$3.97	$4.38	$4.99	$3.50
% value GOA	90%	93%	95%	96%	97%	95%
Vessels #	337	298	290	288	281	290
Proportion CV	87%	89%	90%	88%	85%	84%

Appendix Table 3C.3b. 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, 2009-2013 average and 2014-2018.

	2009-2013 Average	2014	2015	2016	2017	2018
Quantity K mt	7.66	6.70	6.06	5.86	6.59	7.22
Value M US$	$112.8	$99.1	$91.0	$102.1	$123.8	$99.9
Price/lb US$	$6.68	$6.71	$6.81	$7.90	$8.52	$6.28
H&G share	95%	97%	98%	97%	97%	97%

Appendix Table 3C.3c. 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, 2009-2013 average and 2014-2019.

	2009-2013 Average	2014	2015	2016	2017	2018	2019 (thru June)
Global catch K mt	20.9	17.8	18.7	17.2	19.1	-	-
U.S.Share of global	89%	90%	86%	89%	90%	-	-
AK share of global	64%	65%	58%	57%	60%	-	-
Export Volume K mt	10.16	6.67	6.66	5.58	5.73	6.57	2.48
Export value M $	$ 94.91	$ 81.58	$ 82.26	$ 80.82	$ 86.48	$ 84.73	$ 28.80
Export Price/lb US$	$ 4.24	$ 5.55	$ 5.60	$ 6.57	$ 6.84	$ 5.85	$ 5.27
Japan value share	79%	73%	63%	59%	66%	63%	63%
China value share	10%	10%	17%	21%	18%	20%	20%
Exchange rate, Yen/Dollar	87.7	105.9	121.0	108.8	112.2	110.4	110.5

Note: Exports include production from outside Alaska fisheries.

Source: NMFS Alaska Region Blend and Catch-accounting System estimates; 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). FAO Fisheries & Aquaculture Dept. Statistics http://www.fao.org/fishery/statistics/en. NMFS Alaska Region Blend and Catch-accounting System estimates. 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.

Appendix Table 3C.4a. First stage ecosystem indicator analysis for sablefish including indicator title and short description. The most recent year relative value (greater than (+), less than (-) or within 1 standard deviation (•) of long-term mean) of the time series is provided. Fill color is based on a traffic light evaluation for sablefish of the current year conditions relative to 1 standard deviation of the long-term mean (white = average, blue = good, red = poor, no fill = no current year data).

Title	Description	Recent
Heatwave GOA	Regional daily mean sea surface temperatures from NOAA climate model processed following Hobday et al., 2016 to obtain marine heatwave cumulative intensity (Barbeaux, 2019)	+
Summer 250 Temperature GOA Slope	Anomalies of summer slope temperature (°C) at 250 m over all hauls of the ABL Longline survey (Siwicke, *pers. commun.*).	●
Spring Sea Surface Temperature EGOA	Eastern GOA late spring (May-June) sea surface temperature from Pathfinder v5.3 gridded monthly dataset (Casey et al., 2010, GHRSST, CoastWatch)	+
Spring Sea Surface Temperature SEBS	Southeast Bering Sea late spring (May-June) sea surface temperature from Pathfinder v5.3 gridded monthly dataset (Casey et al., 2010, GHRSST, CoastWatch)	+
Spring Peak Phytoplankton Production EGOA	Eastern GOA peak (May) derived chlorophyll *a* from Ocean Colour CCI v4.0 gridded monthly dataset (Jackson et at., 2017, European Space Agency, CoastWatch)	-
Spring Peak Phytoplankton Production SEBS	Southeast Bering Sea peak (May) derived chlorophyll *a* from Ocean Colour CCI v4.0 gridded monthly dataset (Jackson et at., 2017, European Space Agency, CoastWatch)	-
Large Copepod Abundance GOA Shelf CPR	Abundance of large copepods from the continuous plankton recorder over GOA shelf waters (Batten, 2019)	●
Large Copepod Abundance GOA Offshore CPR	Abundance of large copepods from the continuous plankton recorder over GOA offshore waters (Batten, 2019)	-
Summer Euphausiid Abundance Kodiak	Acoustic backscatter per unit area classified as euphausiids and integrated over the water column and across Kodiak core survey area from MACE summer survey (Ressler et al., 2019)	●
Sablefish Growth YOY Middleton Auklets	Anomalies from growth index of sablefish sampled in rhinoceros auklet diet (Arimitsu and Hatch, 2019)	+

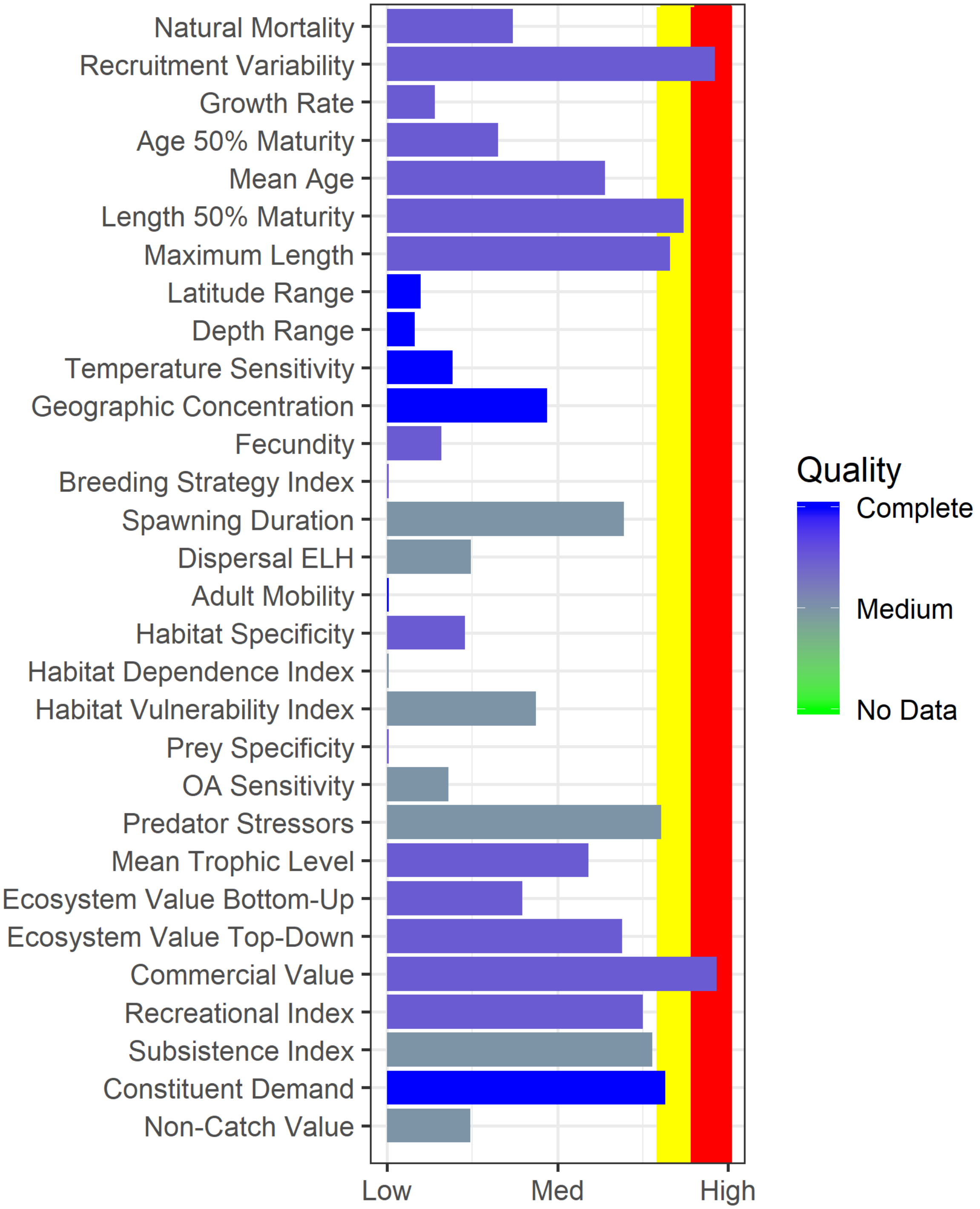
Appendix Table 3C.4a (cont.). First stage ecosystem indicator analysis for sablefish including indicator title and short description. The most recent year relative value (greater than (+), less than (-) or within 1 standard deviation (•) of long-term mean) of the time series is provided. Fill color is based on a traffic light evaluation for sablefish of the current year conditions relative to 1 standard deviation of the long-term mean (white = average, blue = good, red = poor, no fill = no current year data).

Title	Description	Recent
Summer Sablefish CPUE Juvenile ADF&G Survey	Catch-per-unit-of-effort for juvenile sablefish in the ADF&G large-mesh survey (Spalinger, *pers. commun.*, 2019)	+
Summer Sablefish CPUE Juvenile GOA BTS Survey	Catch-per-unit-of-effort for age-1 sablefish in the GOA bottom trawl survey (Hanselman, *pers. commun.*)	●
Summer Sablefish Condition Juvenile GOA LL Survey	Length-weight regression of immature juvenile female sablefish sampled randomly for otoliths in the GOA Longline survey, legs 3-7 (Rodgveller, Shotwell, *pers. commun.*)	-
Sablefish Spawner Mean Age	Mean age of spawning sablefish from the most recent sablefish stock assessment model (Hanselman, *pers. commun,*)	-
Sablefish Spawner Age Evenness	Concentration of age composition by cohort (evenness) of female sablefish from the most recent sablefish stock assessment model (Hanselman, *pers. commun.*)	-
Summer Sablefish Condition Age 4 GOA LL Survey	Length-weight regression of age 4 female sablefish sampled randomly for otoliths in the GOA Longline survey, legs 3-7 (Shotwell, Rodgveller, *pers. commun.*)	●
Arrowtooth Biomass Assessment	Total biomass estimates from arrowtooth flounder stock assessment model output (Spies et al., 2017)	●
Sablefish Incidental Catch Arrowtooth Fishery	Incidental catch of sablefish in the GOA arrowtooth flounder fishery (Shotwell, *pers. commun.*)	+
Summer Benthic Abundance GOA LL Survey	Averaged anomalies of the relative population weights for primary sampled species on the GOA longline survey (Shotwell, *pers. commun.*)	-
Summer Sablefish Condition Adult GOA LL Survey	Length-weight regression of large (>=75 cm) female sablefish sampled randomly for otoliths in the GOA Longline survey, legs 3-7 (Shotwell, Rodgveller, *pers. commun.*)	●

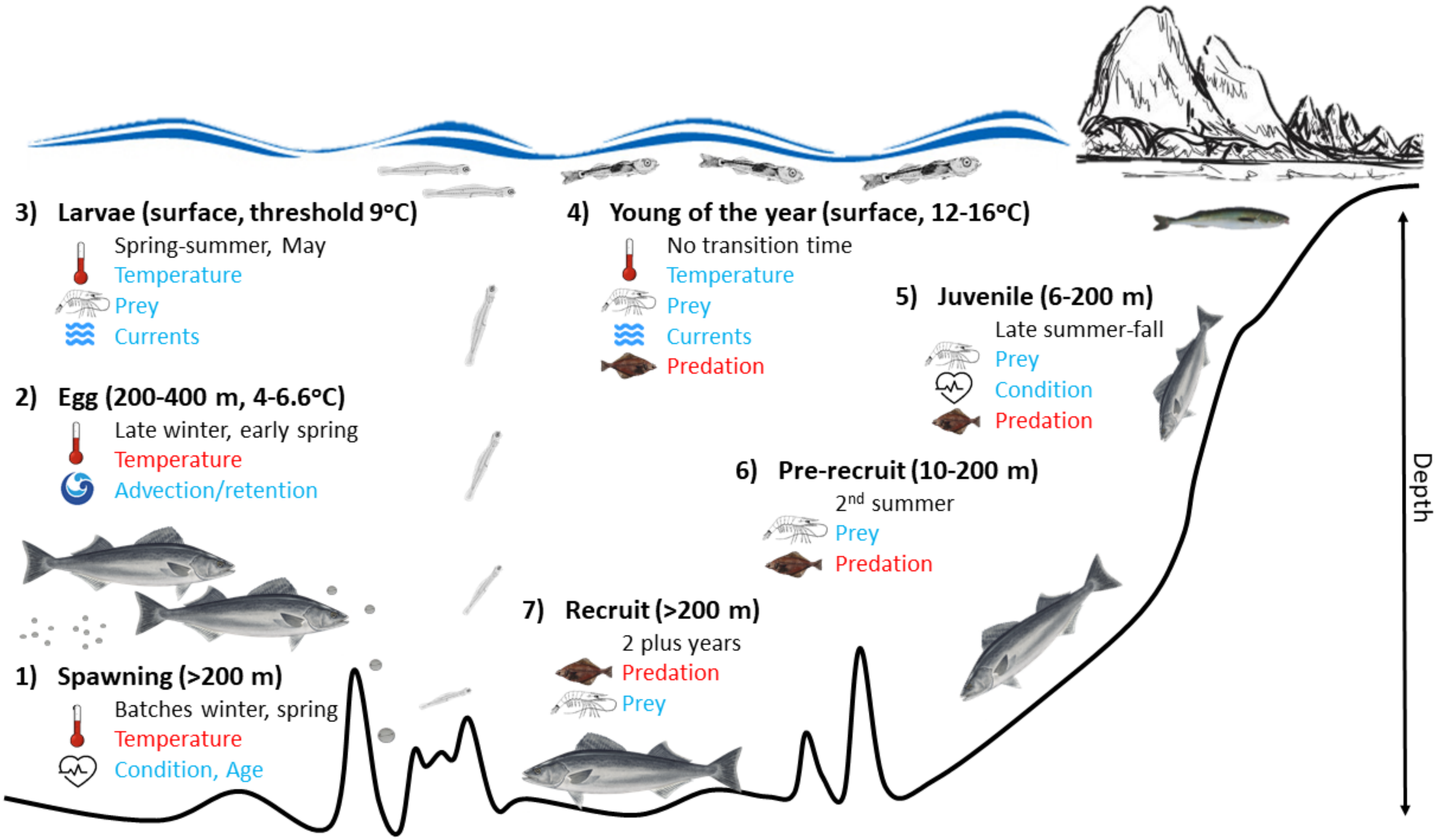
Appendix Table 3C.4b. First stage socioeconomic indicator analysis for sablefish including indicator title and short description. The most recent year relative value (greater than (+), less than (-) or within 1 standard deviation (•) of long-term mean) of the time series is provided. Fill color is based on a traffic light evaluation for sablefish of the current year conditions relative to 1 standard deviation of the long-term mean (yellow = average, blue = good, red = poor, no fill = no current year data).

Title	Description	Recent
Sablefish CPUE Longline Fishery GOA	Catch per unit of effort of sablefish from the longline fisheries in the GOA (Hanselman, *pers. commun.*)	🟥 -
Sablefish CPUE Pot Fishery EBS	Catch per unit of effort of sablefish from the pot fisheries in the eastern Bering Sea (Hanselman, *pers. commun.*)	+
Sablefish Incidental Catch BSAI Fisheries	Incidental catch of sablefish in the Bering Sea fisheries excluding the sablefish fishery (Shotwell, *pers. commun.*)	🟥 +
Sablefish Incidental Catch GOA Fisheries	Incidental catch of sablefish in the GOA fisheries excluding the sablefish fishery (Shotwell, *pers. commun.*)	●
Sablefish Condition Adult GOA Fishery	Length-weight regression of large (>=75 cm) female sablefish sampled by observers during in the GOA fisheries (Shotwell, Rodgveller, *pers. commun.*)	●
Sablefish Condition Adult BSAI Fishery	Length-weight regression of large (>=75 cm) female sablefish sampled by observers during in the BSAI fisheries (Shotwell, Rodgveller, *pers. commun.*)	🟦 +
Annual Sablefish Real Ex-vessel Value	Estimate of real ex-vessel value in millions inflation adjusted to 2018 USD (Fissel et al., 2019)	●
Small Sablefish Price	Average price per pound of small sablefish in BSAI fixed gear fisheries (Armstrong et al., 2018)	-

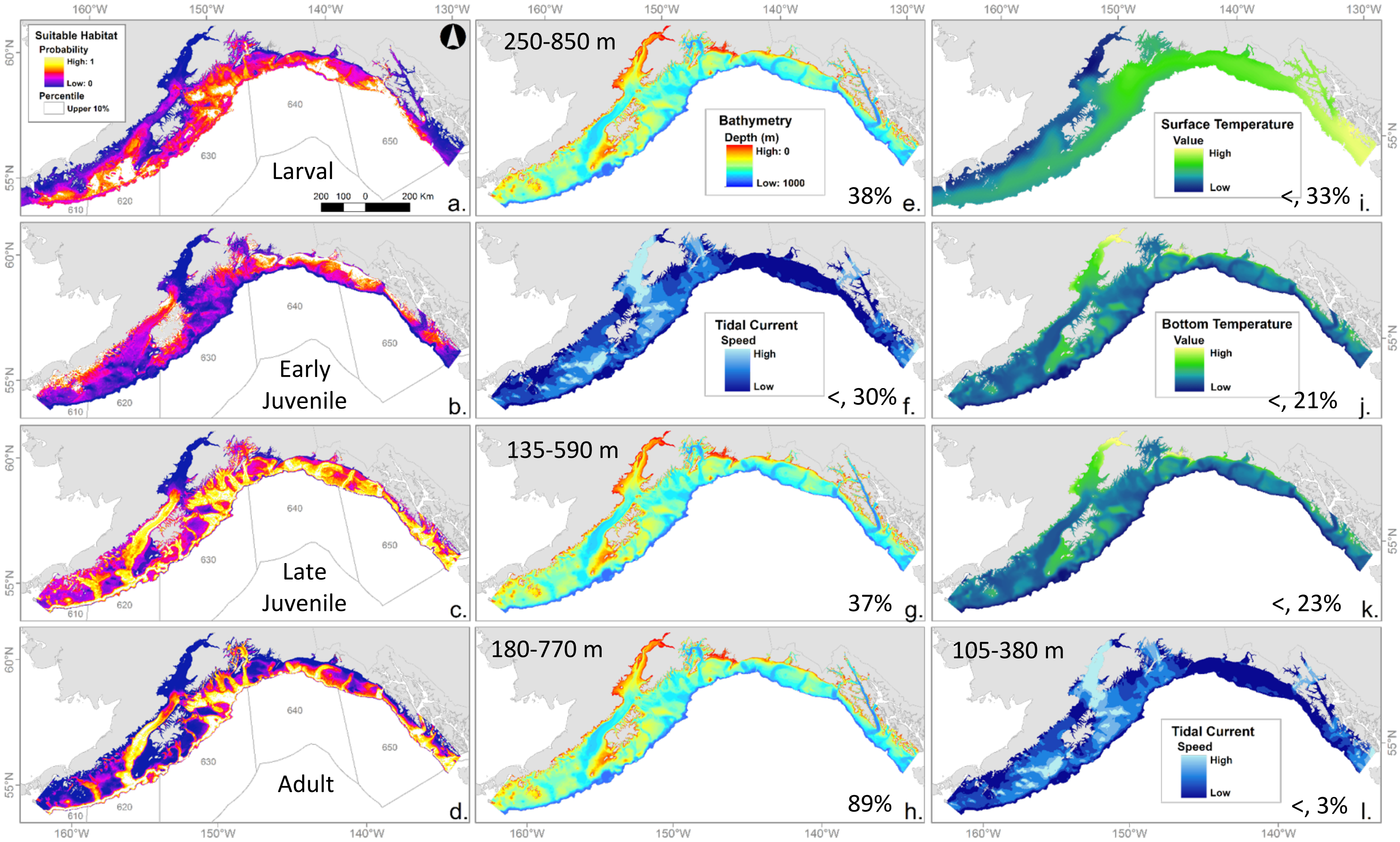
Figures



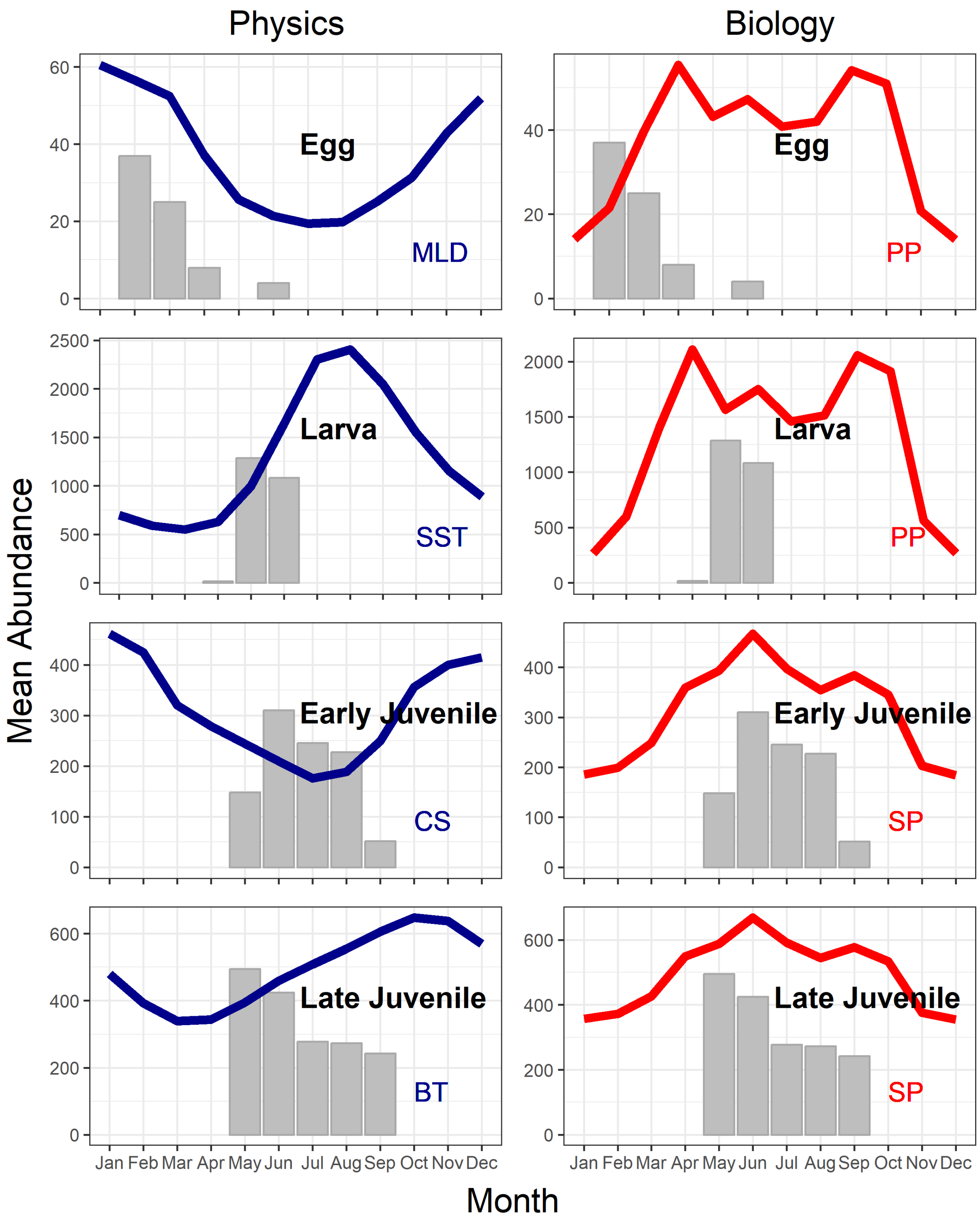
Appendix Figure 3C.1. Baseline metrics for sablefish graded as percentile rank over all groundfish in the FMP. Red bar indicates 90th percentile, yellow bar indicates 80th percentile. Higher rank values indicate a vulnerability and color of the horizontal bar describes data quality of the metric (see Shotwell et al., *In Review*, for more details on the metric definitions).



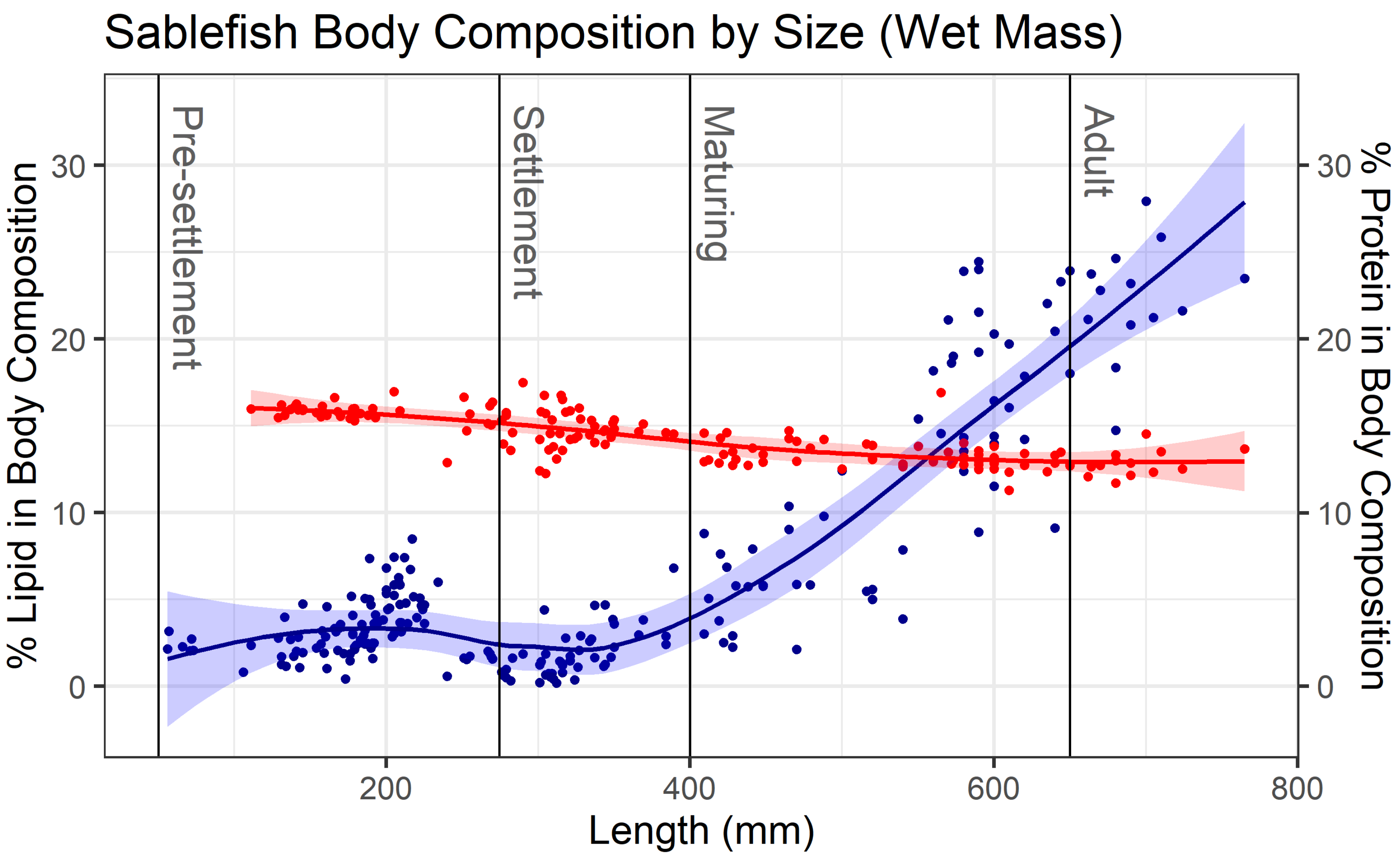
Appendix Figure 3C.2: Life history conceptual model for sablefish summarizing ecological information and key ecosystem processes affecting survival by life history stage. Red text means increases in process negatively affect survival, while blue text means increases in process positively affect survival.



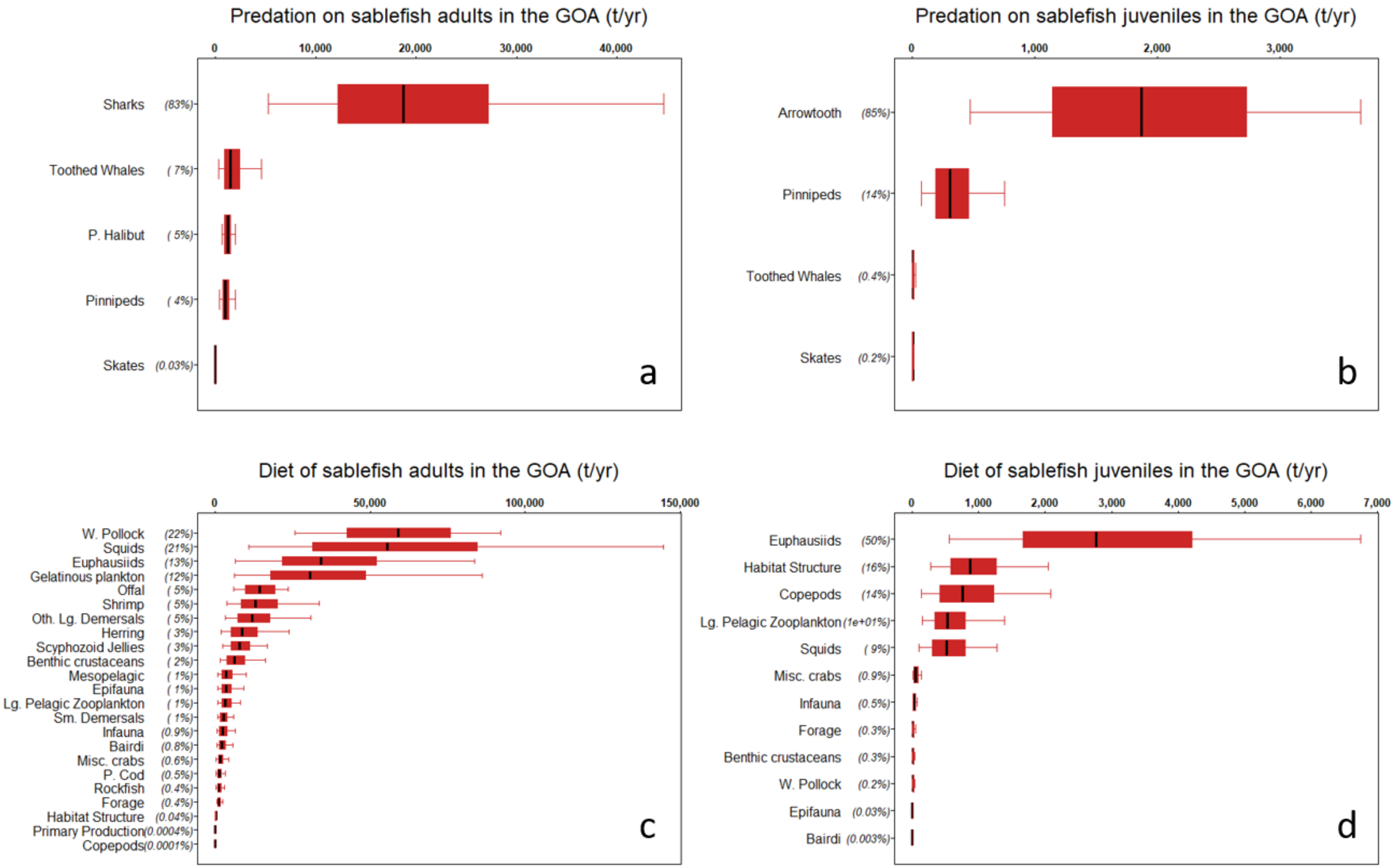
Appendix Figure 3C.3. Sablefish probability of suitable habitat by life stage (a=larval, b=early juvenile, c=late juvenile, and d=adult) with predictor habitat variables representing the highest (e=depth, f=tidal current speed, g=depth, h=depth) and second highest contribution (i=surface temperature, j=bottom temperature, k=bottom temperature, and l=tidal current speed). Upper 10 %-ile of suitable habitat is shown in white within the probability of suitable habitat range (yellow to purple). Sign (<, >, <>) of the deviation from mean direction and the percent of contribution to predict suitability provided for each non-depth variable. Range provided for depth. See Shotwell et al., *In Review* for more details.



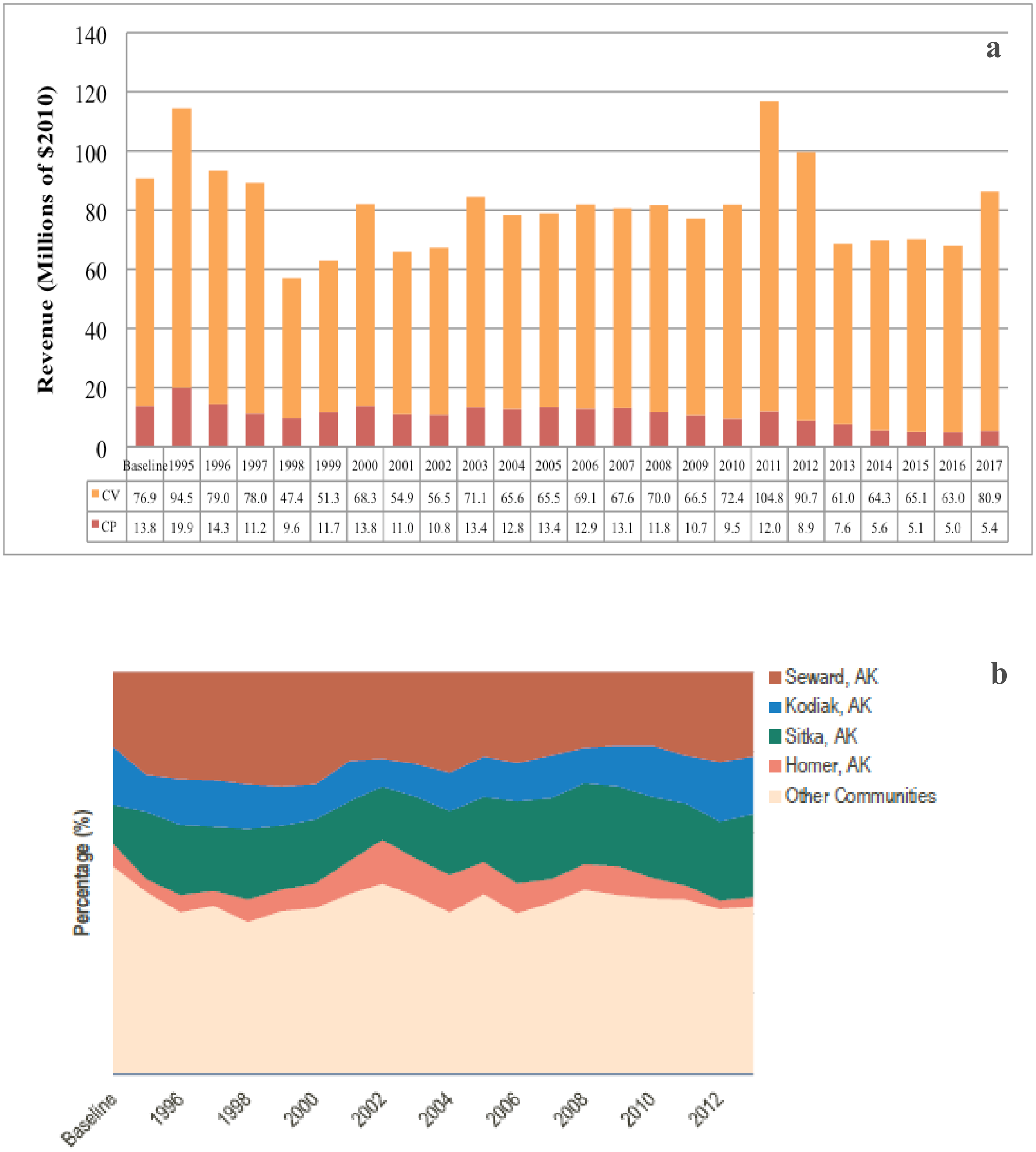
Appendix Figure 3C.4. Sablefish average abundance by month over all years available for the egg, larval, nearshore juvenile, and offshore juvenile stages available from EcoFOCI for egg and larvae stages, and AFSC bottom trawl and longline surveys for juvenile stage. Relevant climatologies from the hydrographic and plankton models provide physical and biological indices (MLD = mixed layer depth, SST = surface temperature, CS = current speed, BT = bottom temperature, PP = primary productivity, and SP = secondary productivity, see Laman et al., 2017, Gibson et al., *In Press*, for more details).



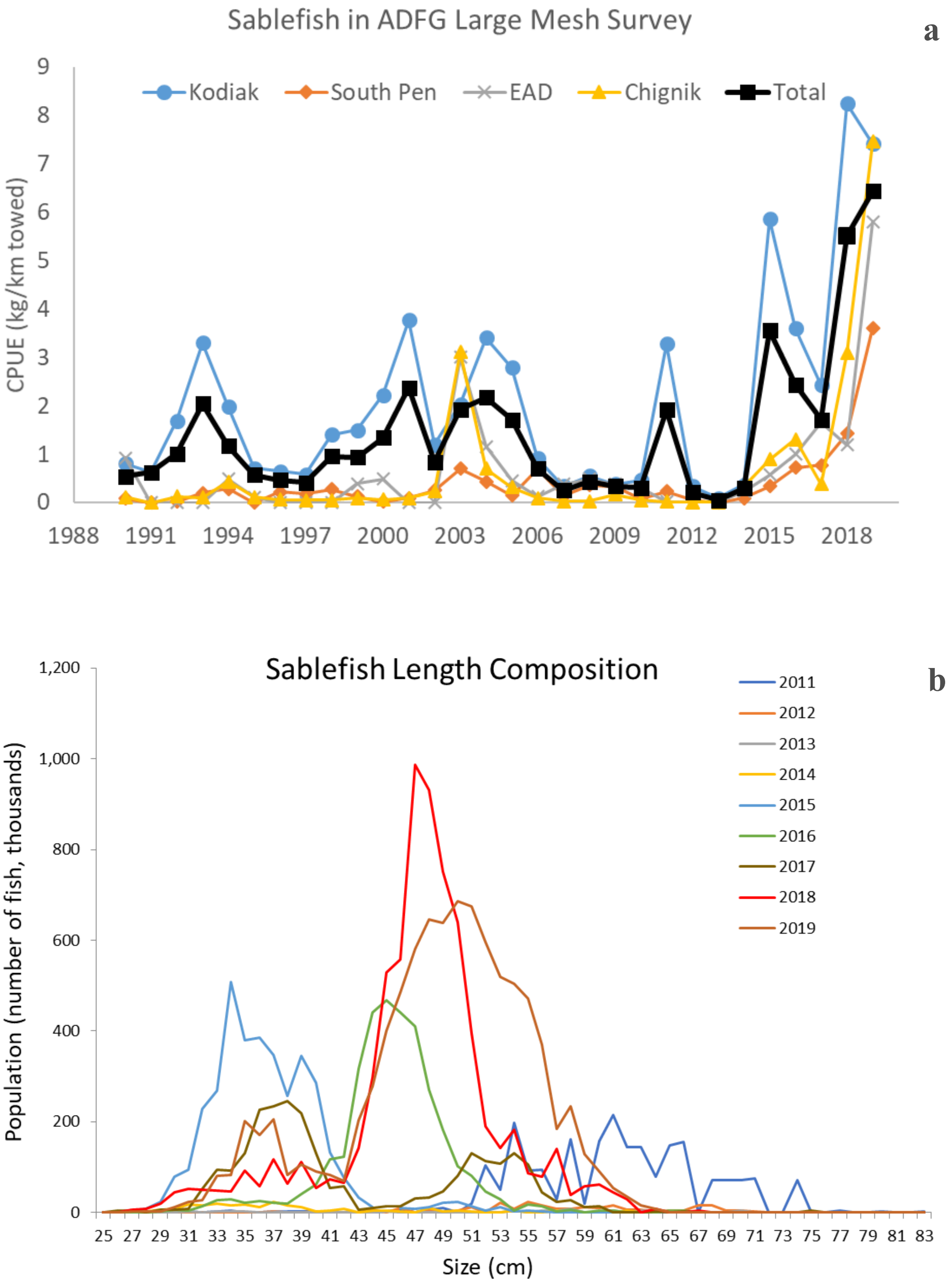
Appendix Figure 3C.5. Sablefish percent body composition by length (mm), blue dots are % lipid by size, red dots are % protein by size and lines represent smoother (loess) for trend visualization. Horizontal lines depict the average size at different life stage transitions and the adult transition is based on size at 50% female maturity.



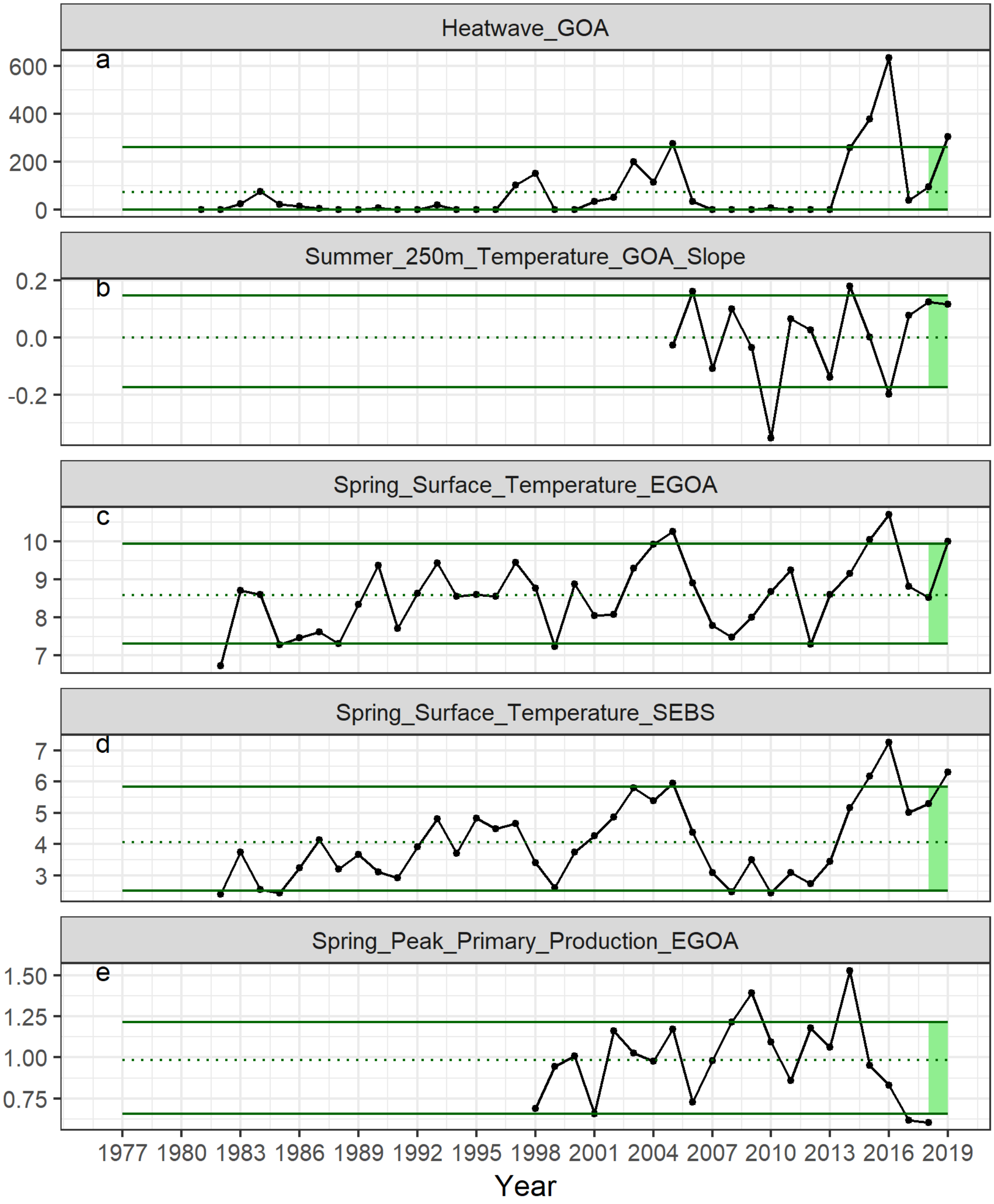
Appendix Figure 3C.6. Sources of predation mortality for (a) adult (>200 mm) and (b) juvenile sablefish (<=200 mm) in the GOA, and diet composition for (c) adult and (d) juvenile sablefish in the GOA (Aydin et al., 2007).



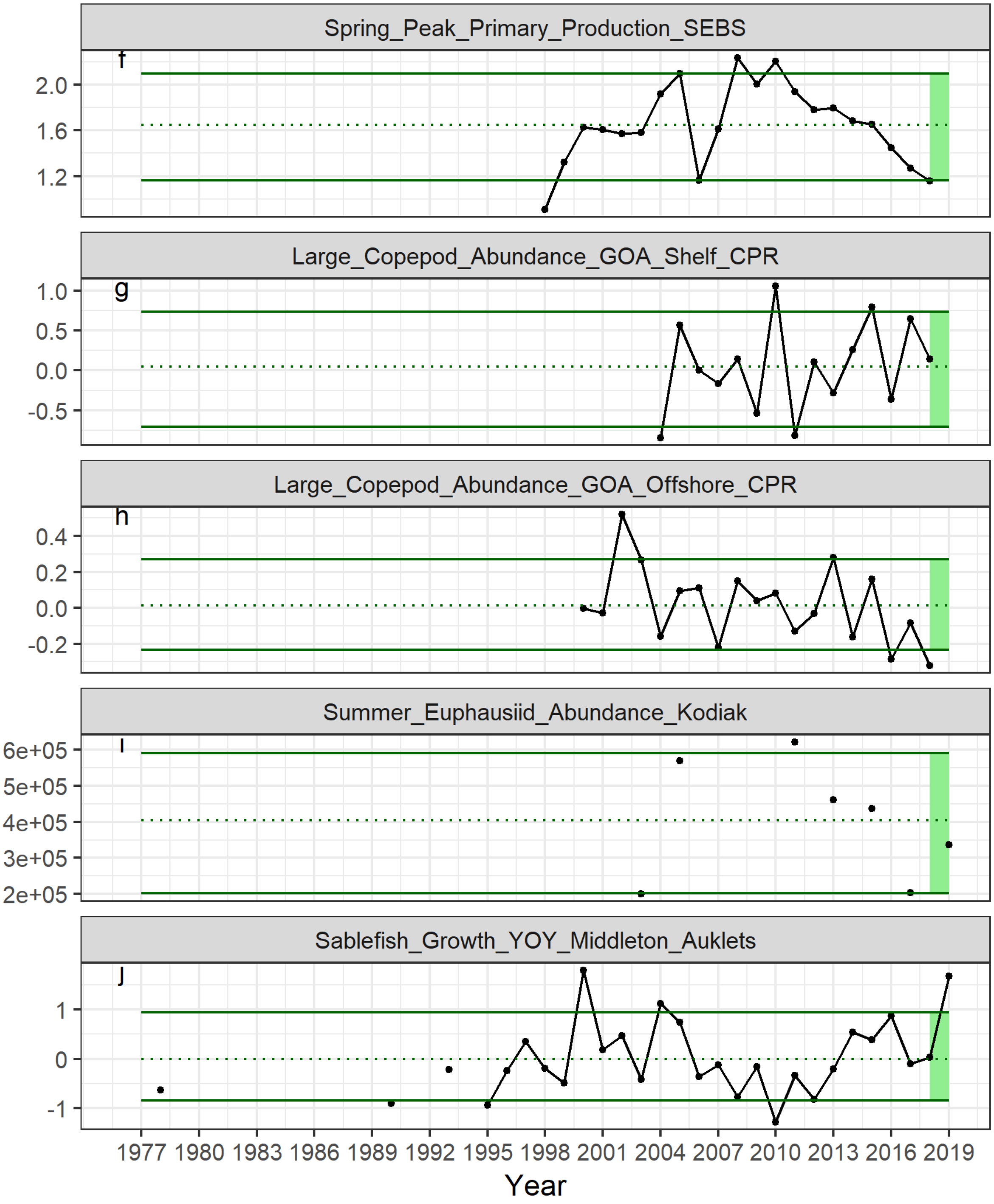
Appendix Figure 3C.7. Revenue in millions from landings of sablefish as part of the Community Development Quota (CDQ) program separated by catcher vessels (CV) and catcher processors (CP) (a) and Regional Quotient (expressed in percent) for communities highly engaged in the sablefish IFQ portion of the Alaska Halibut and Sablefish Individual Fishing Quota Program (b).



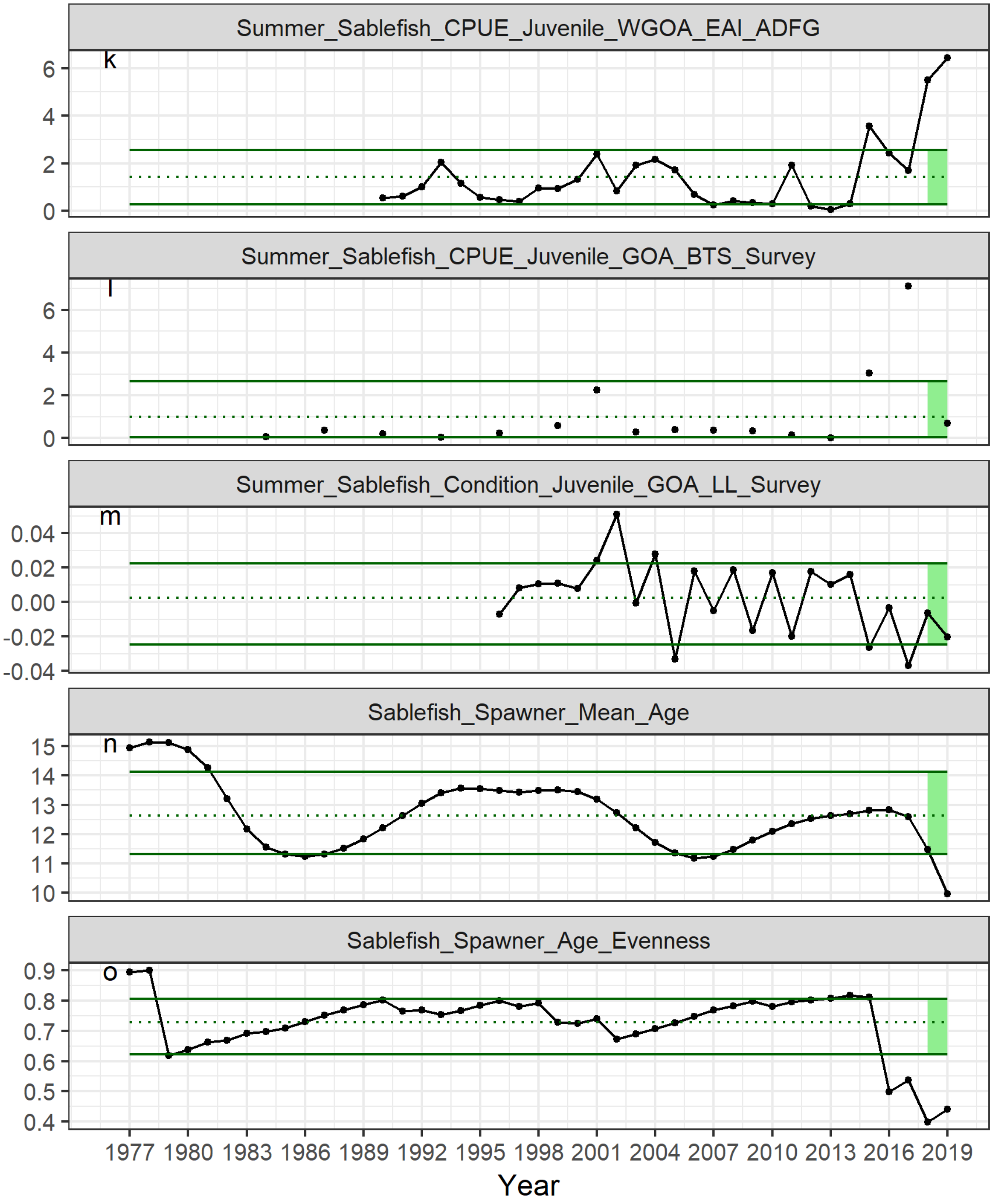
Appendix Figure 3C.8: Catch-per-unit-effort (top graph) from 1990 to present and length (cm) composition (bottom graph) from 2011 to present of sablefish in the ADF&G large-mesh survey.



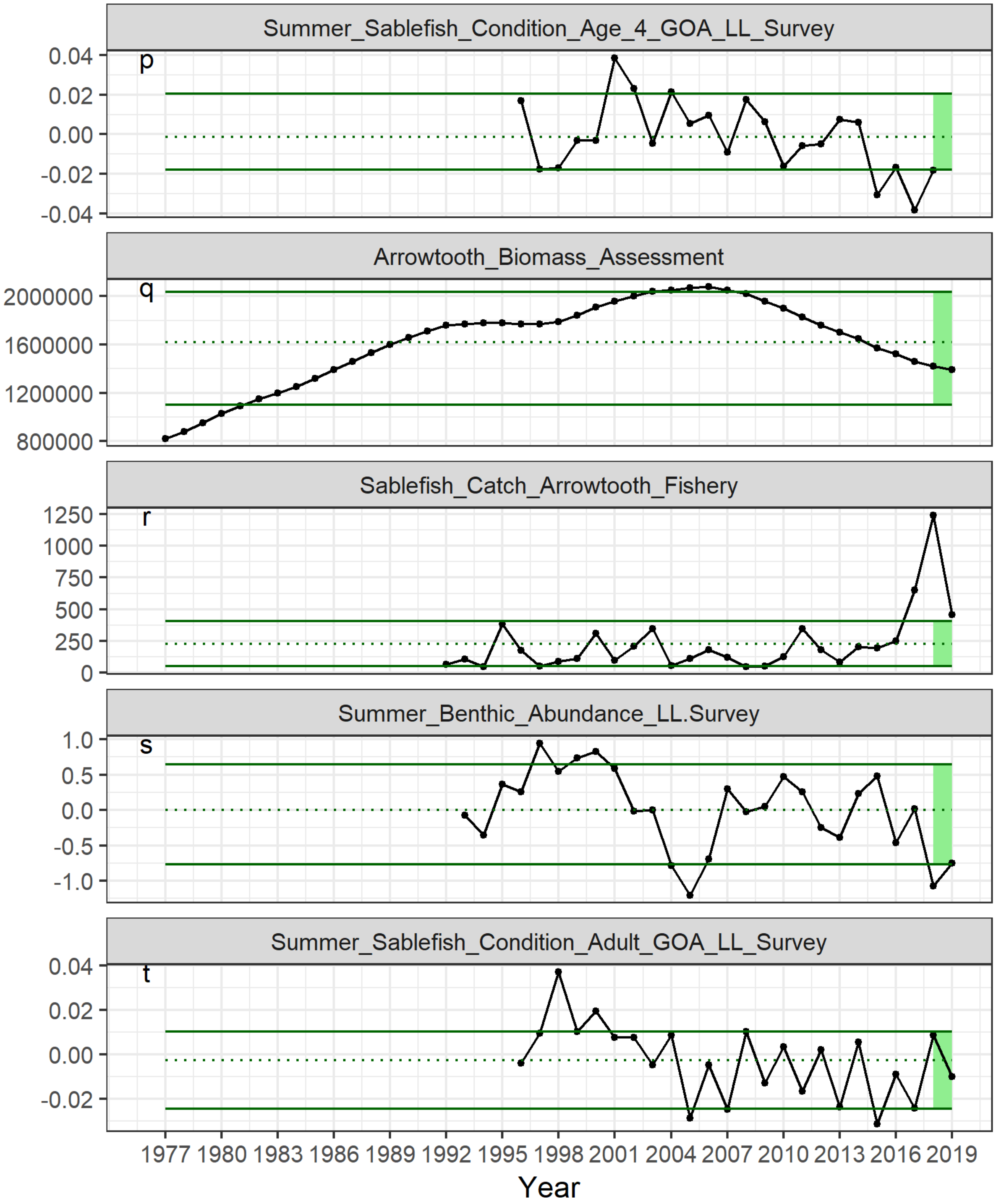
Appendix Figure 3C.9a. Selected ecosystem indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is mean of time series. Light green shaded area represents most recent year for traffic light analysis.



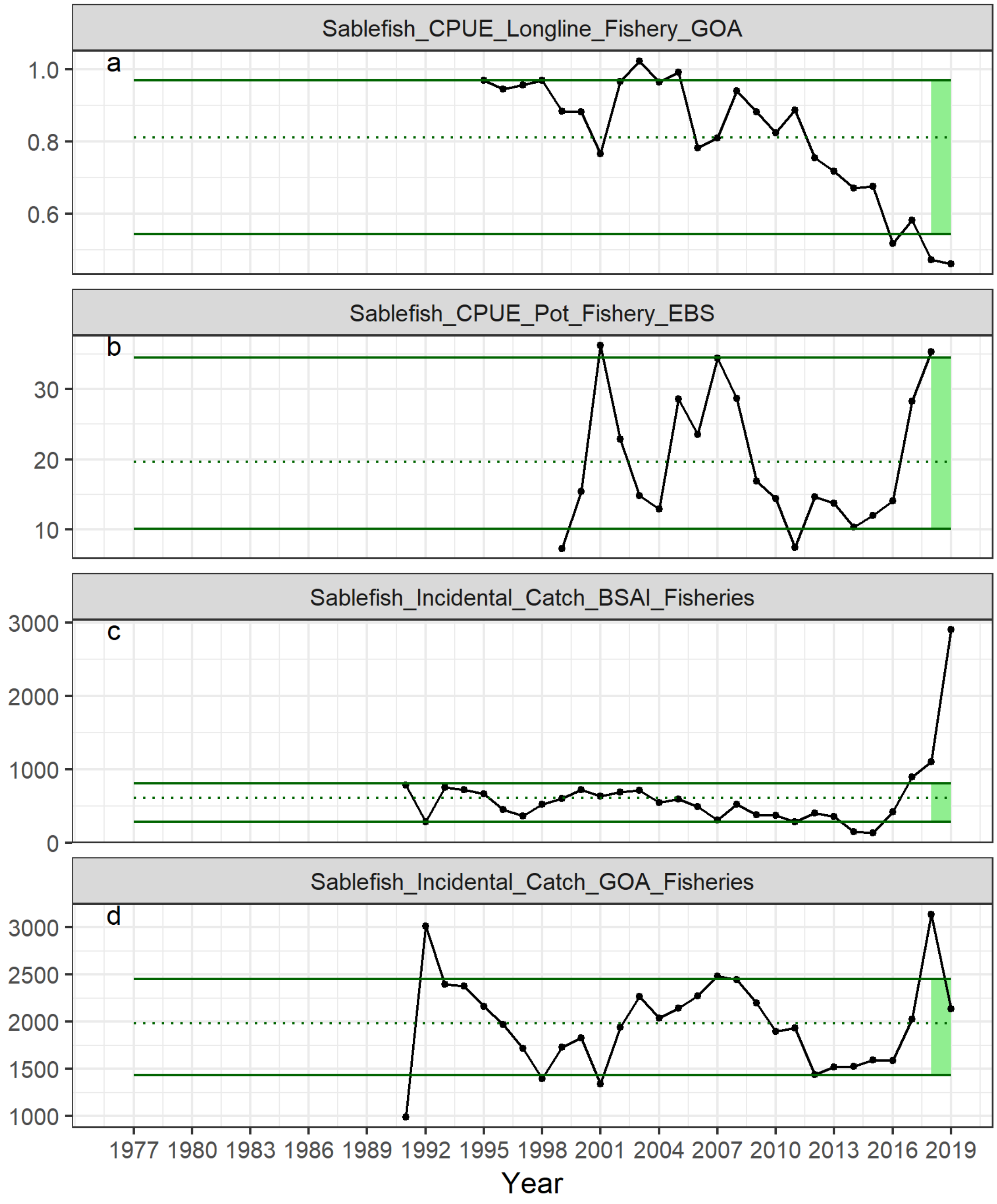
Appendix Figure 3C.9a (cont.). Selected ecosystem indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is mean of time series. Light green shaded area represents most recent year for traffic light analysis.



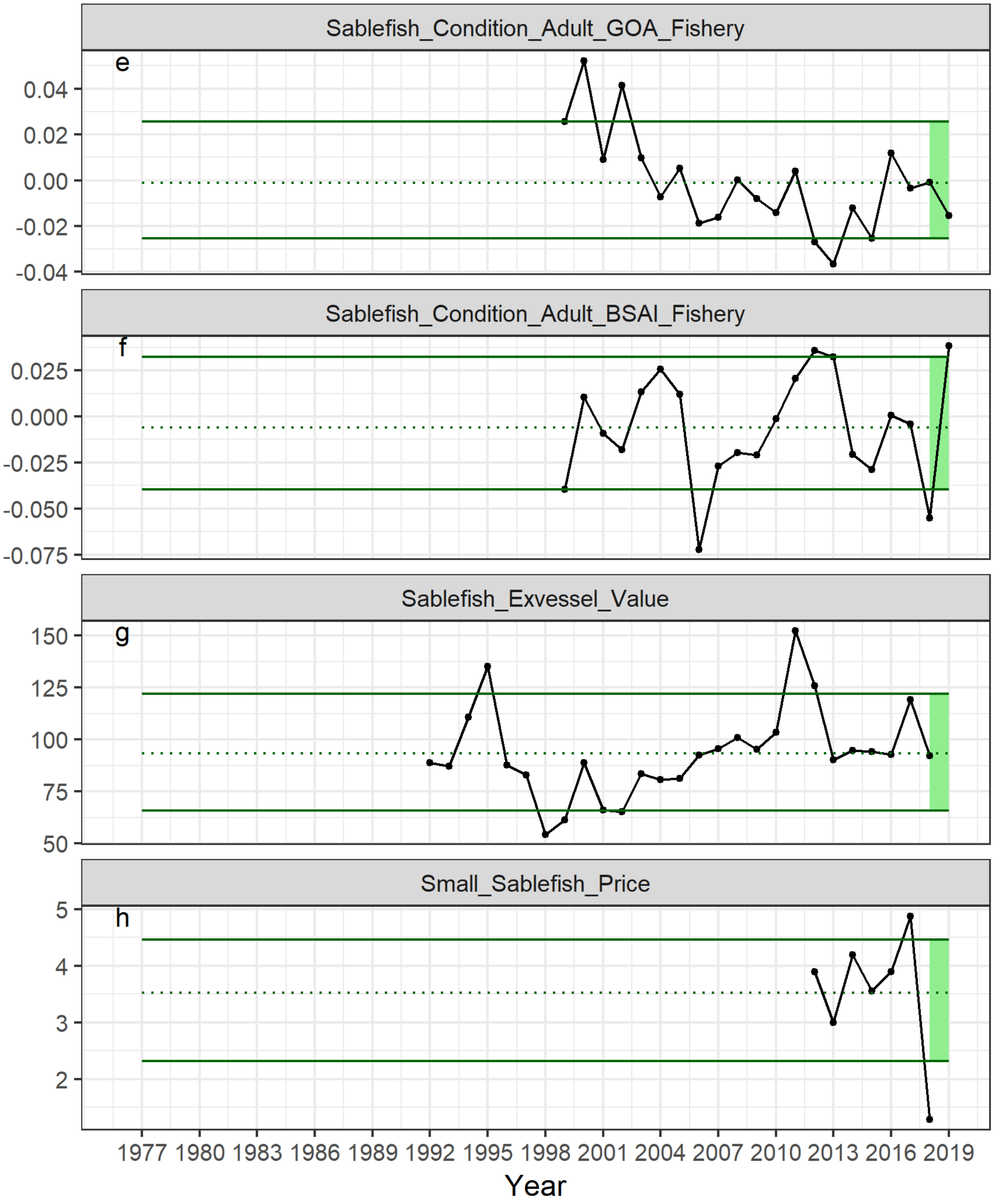
Appendix Figure 3C.9a (cont). Selected ecosystem indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is mean of time series. Light green shaded area represents most recent year for traffic light analysis.



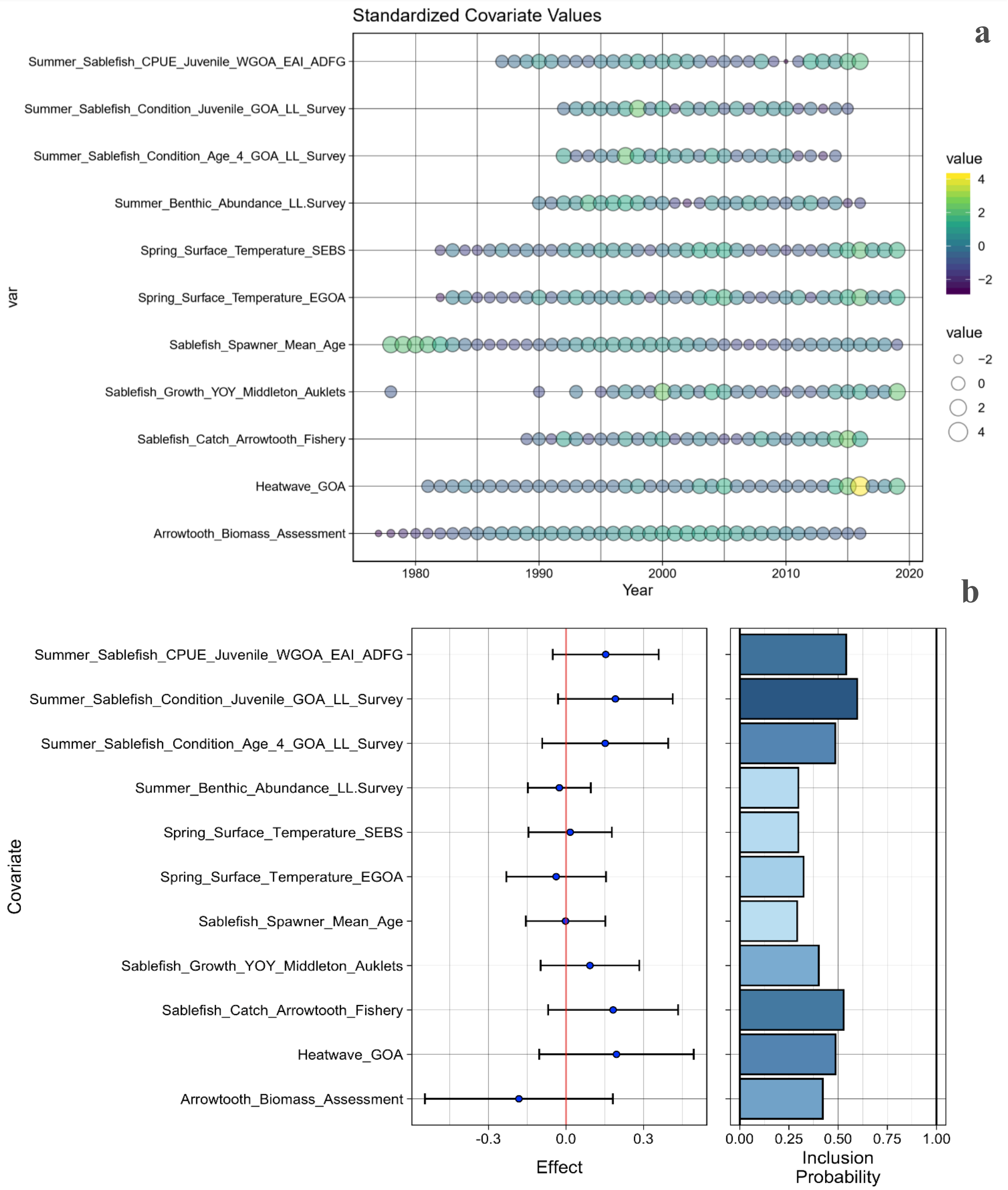
Appendix Figure 3C.9a (cont). Selected ecosystem indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is mean of time series. Light green shaded area represents most recent year for traffic light analysis.



Appendix Figure 3C.9b. Selected socioeconomic indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is mean of time series. Light green shaded area represents most recent year for traffic light analysis.



Appendix Figure 3C.9b. Selected socioeconomic indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is mean of time series. Light green shaded area represents most recent year for traffic light analysis.



Appendix Figure 3C.10: Bayesian adaptive sampling output showing (a) standardized covariates prior to subsetting and (b) the mean relationship and uncertainty (1 standard deviation) 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.