Sablefish − *Anoplopoma fimbria*

Overall Vulnerability Rank = Moderate

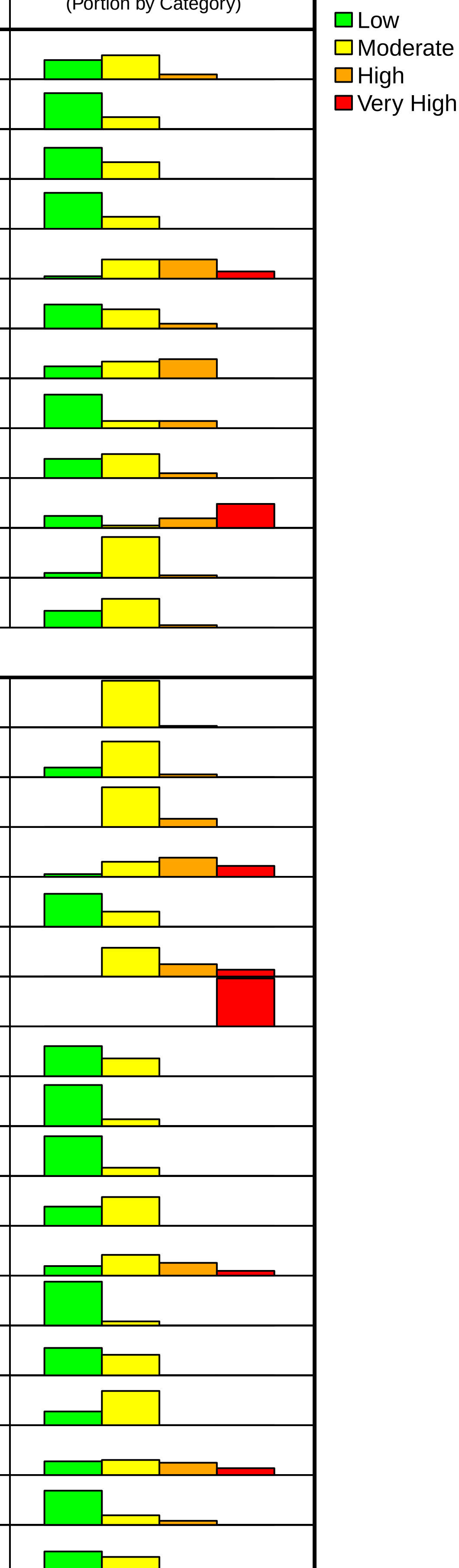
Biological Sensitivity = Moderate

Climate Exposure = Moderate

Sensitivity Data Quality = 50% of scores ≥ 2

Exposure Data Quality = 56% of scores ≥ 2

	Anoplopoma fimbria	Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Sensitivity attributes	Habitat Specificity	1.7	1.4	
	Prey Specificity	1.2	2.0	
	Adult Mobility	1.4	2.2	
	Dispersal of Early Life Stages	1.2	2.0	
	Early Life History Survival and Settlement Requirements	2.6	1.5	
	Complexity in Reproductive Strategy	1.6	1.8	
	Spawning Cycle	2.1	1.8	
	Sensitivity to Temperature	1.4	2.4	
	Sensitivity to Ocean Acidification	1.7	1.7	
	Population Growth Rate	3.0	2.9	
	Stock Size/Status	1.9	2.9	
	Other Stressors	1.7	1.9	
	Sensitivity Score	Moderate		
Exposure factors	Sea Surface Temperature	2.0	2.0	
	Sea Surface Temperature (variance)	1.9	2.0	
	Bottom Temperature	2.2	2.0	
	Bottom Temperature (variance)	2.8	2.0	
	Salinity	1.3	2.0	
	Salinity (variance)	2.5	2.0	
	Ocean Acidification	4.0	2.0	
	Ocean Acidification (variance)	1.4	2.0	
	Phytoplankton Biomass	1.1	1.2	
	Phytoplankton Biomass (variance)	1.2	1.2	
	Plankton Bloom Timing	1.6	1.0	
	Plankton Bloom Timing (variance)	2.3	1.0	
	Large Zooplankton Biomass	1.1	1.0	
	Large Zooplanton Biomass (variance)	1.4	1.0	
	Mixed Layer Depth	1.7	1.0	
	Mixed Layer Depth (variance)	2.3	1.0	
	Currents	1.4	2.0	
	Currents (variance)	1.7	2.0	
	Air Temperature	NA	NA	
	Air Temperature (variance)	NA	NA	
	Precipitation	NA	NA	
	Precipitation (variance)	NA	NA	
	Sea Surface Height	NA	NA	
	Sea Surface Height (variance)	NA	NA	
	Exposure Score	Moderate		
Overall Vulnerability Rank		Moderate		



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Sablefish (*Anoplopoma fimbria*)

Overall Climate Vulnerability Rank: **Moderate**. (78% certainty from bootstrap analysis).

Climate Exposure: **Moderate**. Exposure to ocean acidification (4.0) was ranked as “very high”, and exposure to variability in bottom temperature (2.8) and variability in salinity (2.5) were ranked as “moderate”.

Biological Sensitivity: **Moderate**. Population growth rate (3.0) and early life history survival (2.7) were ranked as “moderate” sensitivity.

Potential for distribution change: **High** (89% certainty from bootstrap analysis). Adult mobility and dispersal of early life stages were ranked as “very high”, and habitat specificity was ranked as “high”.

Directional Effect in the Eastern Bering Sea: Projected climate change in the eastern Bering Sea is expected to have a negative effect on sablefish, with 72% certainty in expert scores.

Data Quality: 50% of the sensitivity attributes, and 56% of the exposure factors, had average data quality scores of 2 or greater (indicating at least “moderate” data quality).

Climate Effects on Abundance and Distribution:

Sablefish have are highly mobile and have highly variable recruitment that is more related to environmental variability than spawning biomass. They also exhibit some sensitivities to cold temperatures, and larval development and growth appears to be enhanced at higher temperatures. Juvenile and adults are opportunistic generalist predators but require a great deal of prey to grow at their usual prolific rates, so if prey is diminished under climate change this would negatively affect sablefish. Predators of sablefish at larval and juvenile stages are birds and other fishes, but known predators exist throughout the sablefish range. If climate change changes the density of predators this could affect the survival of young sablefish. Few predators exist for adult sablefish, but whale depredation induces mortality on adult sablefish. Given the similar high mobility of whales, these predators could move in conjunction with shifts in sablefish distributions. Northern expansion of sablefish into the EBS from the GOA might be hindered if there are inadequate bays and gullies for juveniles and deep slope habitat for adults.

Life History Synopsis:

Sablefish (*Anoplopoma fimbria*) inhabit the northeastern Pacific Ocean from northern Mexico to the Gulf of Alaska (GOA), westward to the Aleutian Islands (AI), and into the Bering Sea (BS) (Wolotira et al. 1993). Adult sablefish occur along the continental slope, shelf gullies, and in deep fjords, generally at depths greater than 200 m. Sablefish observed from a manned submersible were found on or within 1 m of the bottom (Krieger 1997). In contrast to the adult distribution, juvenile sablefish spend their first two to three years on the continental shelf of the GOA, and occasionally on the shelf of the southeast BS. The BS shelf is utilized significantly in some years and seldom used during other years (Shotwell et al. 2014).

Sablefish have traditionally been thought to form two populations based on differences in growth rate, size at maturity, and tagging studies (McDevitt 1990, Saunders et al. 1996, Kimura et al. 1998). The northern population inhabits Alaska and northern British Columbia waters and the southern population inhabits southern British Columbia, Washington, Oregon, and California waters, with mixing of the two populations occurring off southwest Vancouver Island and northwest Washington. However, recent genetic work by Jasonowicz et al. (2017) found no population sub-structure throughout their range along the US West Coast to Alaska, and suggested that observed differences in growth and maturation rates may be due to phenotypic plasticity or are environmentally driven. Significant stock structure among the federal Alaska population is unlikely given extremely high movement rates throughout their lives (Hanselman et al. 2015, Heifetz and Fujioka 1991, Maloney and Heifetz 1997, Kimura et al. 1998).

Sablefish have the highest known movement rates of any demersal fish. A model that analyses the extensive tag-recapture time-series for sablefish estimates high aannual movement probabilities ranging from 10-88% depending between major management areas (e.g., EBS to Western GOA). Overall, movement probabilities were very different between areas of occupancy and moderately different between size groups. Estimated annual movement of small sablefish from the central Gulf of Alaska had the reverse pattern of a previous study, with 29% moving westward and 39% moving eastward. Movement probabilities also varied annually with decreasing movement until the late 1990s and increasing movement until 2009 (Hanselman et al. 2015). Because of this high mobility, sablefish should be resilient to a changing environment and their estimated movement patterns could be change and alter their distribution.

Sablefish are thought to exhibit some thermal intolerance to very cold water (Sogard and Olla 1998) and their upper thermal limit is near their upper limit of survival (Sogard and Olla 2001). Preliminary results from an age-0 and age-1 juvenile energetics experiment suggest that their optimal thermal environment for growth is around 16 °C (A. Sreenivasan pers. comm.). Also, transport to the nearshore environment during the first year of life is thought to relieve potential vulnerability if conditions are poor (Doyle and Mier 2016). Above average recruitment was associated with a more northerly winter current direction and warmer sea surface temperatures (Sigler et al. 2001). A recent hierarchal cluster analysis of multiple environmental indices on age-0 and age-1 sablefish suggested that sablefish recruitment was positively related to July upwelling favorable winds and negatively related to spring freshwater discharge in the eastern GOA (Coffin and Mueter 2014). Colder than average wintertime sea surface temperatures in the central North Pacific along the North Pacific Polar Front were hypothesized to setup downstream oceanic conditions that create positive recruitment events for sablefish during their early life history (Shotwell et al. 2014). At first this may seem conflicting with the sablefish warm temperature requirements; however, the colder wintertime temperature index may represent a shifting of the polar front spatially rather than any true temperature signal. This sort of mechanism can be seen in a sea surface temperature heat map (Shotwell et al. 2014, Figure 2), during the 1976/77 regime shift and again in the 2000s. This would imply that large ocean scale events that translate temperature signals across domains, such as recently seen with the Warm Blob event being translated from the west coast U.S. to Alaska in 2013 to 2014 (Bond et al. 2015), may create these conditions that sablefish are finely tuned to exploit. The potential vulnerability in their extended pelagic phase may be limiting under average conditions, but may also be a strength under anomalous conditions where their astounding growth capacity and early swimming ability allows widespread exploitation of available resources. Also, under average conditions, enhanced transport to the nearshore environment may be critical for maintaining a base to average level of recruitment. A simple individual based model recently developed for sablefish suggested that overall connectivity to the nearshore nursery areas was highly related to sablefish recruitment over the 1996 - 2011 time period when there were very few high recruitment events (Gibson et al. 2018).

Spawning is pelagic at depths of 300-500 m near the edges of the continental slope (Mason et al. 1983, McFarlane and Nagata 1988), with eggs developing at depth and larvae developing near the surface as far offshore as 180 miles (Wing 1997). Along the Canadian coast (Mason et al. 1983) and off Southeast Alaska (Jennifer Stahl, February, 2010, ADF&G, pers. comm.) sablefish spawn from January-April with a peak in February. In a survey near Kodiak Island in December, 2011 that targeted sablefish preparing to spawn, spawning appeared to be imminent, but spent fish were not found. It is likely that they would spawn in January or February (Katy Echave, October, 2012, AFSC, pers. comm.). Farther down the coast off of central California sablefish spawn earlier, from October-February (Hunter et al. 1989). An analysis of larval otoliths showed that spawning in the Gulf of Alaska may occur a month later than southern sablefish (Sigler et al. 2001). Sablefish in spawning condition were also noted as far west as Kamchatka in November and December (Orlov and Biryukov 2005).

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). 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 (A. Deary pers. comm.). Throughout the first year, larvae and age-0 fish grow very rapidly up until settlement in the nearshore environment (Shenker and Olla 1986; Sigler et al. 2001). Suitable nearshore habitat is described as low-lying areas such as channels, gullies, and flats with fine grain-size sediment, little biogenic structure, and reduced rock presence (Pirtle et al. 2019). Settlement incurs an energetic cost that results in a change in body condition with reduced lipid content that appears to be maintained until the late juvenile stage (R. Heintz pers. comm). At some point following the first overwinter, sablefish juveniles begin movement to their adult habitat arriving between 4 to 5 years later and becoming mature generally within 3 to 6 years (Hanselman et al. 2016). The long duration and widespread exposure to variable surface conditions during their first year represents a vulnerability in their life history. However, their widespread exploitation of available pelagic prey and robust larvae with good swimming ability may also allow some resilience to fluctuating conditions (Doyle et al. *In Review*).

Larval sablefish sampled by neuston nets in the eastern Bering Sea fed primarily on copepod nauplii and adult copepods (Grover and Olla 1990). In gill nets set at night for several years on the AFSC longline survey, most young-of-the-year sablefish were caught in the central and eastern GOA (Sigler et al. 2001). Near the end of the first summer, pelagic juveniles less than 20 cm move inshore and spend the winter and following summer in inshore waters where they exhibit rapid growth, reaching 30-40 cm by the end of their second summer (Rutecki and Varosi 1997). Gao et al. (2004) studied stable isotopes in otoliths of juvenile sablefish from Oregon and Washington and found that as the fish increased in size they shifted from midwater prey to more benthic prey. In nearshore southeast Alaska, juvenile sablefish (20-45 cm) diets included fish such as Pacific herring and smelts and invertebrates such as krill, amphipods and polychaete worms (Coutré et al. 2015). In late summer, juvenile sablefish also consumed post-spawning pacific salmon carcass remnants in high volume, revealing opportunistic scavenging (Coutré et al. 2015). After their second summer, they begin moving offshore to deeper water, typically reaching their adult habitat, the upper continental slope, at 4 to 5 years. This corresponds to the age range when sablefish start becoming reproductively viable (Mason et al. 1983).

Recruitment variability in sablefish is extremely high and likely related to environmental variability. A preliminary energetics profile based on body composition (wet mass) for percent lipid and percent protein by size shows obvious shifts in body composition and energy allocation through the different life history stages (Heintz and Vollenweider, pers. comm.). Age-0 sablefish increase in lipid content dramatically during the pelagic phase prior to settlement. Lipid levels decline when fish reach around 200 mm indicating a clear cost for settlement. Protein synthesis remains constant throughout this time period as the fish grow rapidly. Body composition then remains relatively consistent until the fish reach 400 mm (age 2-3), which is the time period in their life history when fish begin to move toward adult habitat. After this point, lipids begin to increase fairly constantly as they get larger with age. The 400 mm length is also the designated maximum body size for the early stage juvenile habitat suitability models and the point where we start to see this size fish and larger in the primary assessment surveys (Pirtle et al. 2019, Hanselman et al. 2016). The high variability of percent lipid in the age-0 pelagic phase just prior to settlement suggests a potential bottleneck in the life history (Heintz and Vollenweider, pers. comm.). A fish with a higher percent lipid composition may have a higher chance for overwinter survival than a fish with a lower percent lipid composition, particularly given the cost of settlement that this fish seems to incur.

Another bottleneck may occur as the fish move from the post-settlement juvenile stage in nearshore habitat to the adult slope habitat. During this time, the percent lipid stays low and constant until about 400 mm where it begins to increase (almost linearly) with size, while the percent protein decreases slightly. This suggests that the fish in the nearshore are still growing quickly with an associated high energetic cost, but as they move offshore the fish have relatively low energetic demands and can begin to allocate surplus lipid to storage with age as they grow (Heintz and Vollenweider, pers. comm.). The juvenile nearshore stage appears to continue to be an energetically-demanding period as all surplus energy is allocated toward growth (protein). Another explanation for this is that food is limited and not a lot of surplus energy is consumed. Later during the early offshore residence for juveniles, the energetic constraints are relieved and fish obtain surplus energy that is stored as lipid. In addition to reducing the pressure for rapid growth, the extreme increase in lipid storage may represent considerably better feeding grounds, and/or life history constraints to increase lipid content as the fish move into the deeper depths of the adult habitat as they age. Juvenile fish that can put on weight faster may have a higher chance for survival than fish experiencing suboptimal conditions. Future investigations should consider comparing composition data in a given year from a regional distribution of samples representing these different life stages of sablefish.

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. 2016; M. Arimitsu pers. comm.). Age-2 sablefish recruitment was modeled as a function of sea surface temperatures, nearshore production (chlorophyll *a*), and adult pink salmon returns (co-occurring in this environment). The best model described the stock assessment estimates of age-2 recruitment as a function of late August maximum chlorophyll *a* during the age-0 stage, late August maximum sea temperature during the age-0 stage, and pink salmon returns during the age-1 life stage of these sablefish (Yasumiishi et al. 2017). Another interaction can be seen through the use of seabirds as samplers of the marine environment. The proportion of biomass in rhinoceros auklets on Middleton Island seems to fluctuate in response to other more dominant species in the diet such as capelin and sand lance (Hatch et al. 2017). However, in the recent very warm years of 2014-2016, the proportion of other species such as sablefish has increased in the auklet diet. A more direct measure of the sablefish condition has been calculated from the samples taken in the auklet diet. This age-0 sablefish growth index, calculated as the coefficient for the regression of length (mm) by Julian day for each year (Arimitsu pers. comm.), effectively tracks the nearshore age-0 growth rate of sablefish and has a positive relationship with sablefish recruitment.

Juvenile and adult appear to be generalists and it is not likely that prey abundances have much influence on sablefish dynamics. However, killer and sperm whales are likely major predators of sablefish based on depredation rates estimated on the AFSC longline survey and in the fishery (Peterson and Hanselman 2017). One possibility of a changing climate could shift the sablefish distribution away from sperm whales in the southeast to areas with more killer whales in the EBS. However, these marine mammals are also very mobile and may merely change their distribution in order to continue to depredate on sablefish.

The recent update to the Essential Fish Habitat for Alaska groundfish included models and maps of species habitat suitability distribution (Pirtle et al. 2019, EFH 2017). Models and associated maps for each life history stage were provided and the more fully developed models resulting from model selection methods were provided to the lead assessment authors for review on the early juvenile settlement stage (<400 mm), late juvenile stage (>=400 mm & < 550 mm), and adult stage (>=550 mm). Clear progression from bathymetrically low-lying areas in nearshore bays and inlets to the gullies of the continental shelf and finally to the slope environment can be seen from the three stages. The models indicate that tidally-derived current speed and bottom temperature are important for the early and late juvenile stages, while depth is the primary predictor for the adult stage (Pirtle et al. 2019, EFH 2017). These results suggest that suitable habitat for juvenile sablefish is more influenced by non-static variables than just depth (as with adults). It is then possible that the amount of suitable habitat may vary from year to year and impact the selectivity of sampling gear to these life stages. This concept is somewhat supported in a preliminary analysis of the bottom trawl survey temperature data. We restricted the haul data to the depths predicted by the habitat models for the juvenile stages (approximated by strata less than 200 m and less than 100 m). Average bottom temperature varies both spatially and temporally with higher variability in the western GOA. We also considered the difference between the surface temperature and bottom temperature at each haul as a measure of mixing. This can be thought of as a proxy for the tidal movement habitat variable in that more tidal movement would promote mixing and less would promote stratification. The eastern GOA seems to be dominated by stratification as the difference between surface and bottom temperatures are high and do not fluctuate much over time. In contrast, the western GOA is highly variable with more stratification in the earliest and most recent surveys and more mixing in the 2000s. Based on recent results from a sablefish movement model, the western GOA is an area where small sablefish do not tend to stay, while the eastern GOA is considered more an area of residence (Hanselman et al. 2015). The habitat suitability model results for juvenile sablefish combined with the supportive data from the bottom trawl survey suggest that an indicator of the temporally varying aspects of suitable habitat for this life stage may be useful to monitor and may ultimately link to time-varying selectivity within the stock assessment model.

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