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Report on the 2018 International Sablefish Workshop

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M. A. Haltuch, D. H. Hanselman, M. Kapur, L. Lacko, C. Lunsford,
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U.S. DEPARTMENT OF COMMERCE
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Report on the 2018 International Sablefish Workshop

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Executive Summary

The Pacific Sablefish Transboundary Assessment Team (PSTAT), comprised of 12 scientists from Canada and the United States, convened 26-27 April 2018 in Seattle, WA, for a workshop to discuss sablefish (*Anoplopoma fimbria*) research and assessment approaches. Participants included representatives from the Alaska Department of Fish and Game, the Alaska Fisheries Science Center, Fisheries and Oceans Canada, Simon Fraser University, and the Northwest Fisheries Science Center. The primary objective of the workshop was to bring these scientists together to discuss range-wide sablefish data, compare stock assessment methods, discuss concerns about sablefish abundance trends, share results of recent and ongoing sablefish research, and to examine the feasibility of collaboratively developing a set of range-wide operating models (OM) for use in Management Strategy Evaluation (MSE).

Sablefish are a highly mobile, long-lived, commercially valuable groundfish that have high movement rates and range from Southern California to the Bering Sea. Stock assessment and management currently takes place at regional levels determined by political boundaries for the Alaska federal region (Hanselman et al. 2016), Alaska state region, British Columbia (DFO 2016), and the U.S. west coast (Johnson et al. 2015). Each region assumes that these are closed stocks; however, a recent genetic study suggests that northeast Pacific sablefish are not genetically distinct among these traditional management areas (Jasonowicz et al. 2017). This lack of genetic evidence for population structure suggests that regional scale fisheries management may benefit from the consideration of the range-wide structure and dynamics of sablefish (e.g., a range-wide operating model could be developed as a tool for exploring sablefish population structure).

The primary objective of the workshop was to initiate discussion about the development of a range-wide, spatially explicit OM that can be used to explore questions of ecological, biological, and management relevance. The PSTAT identified a number of key research activities that need to be undertaken to meet this objective, in the form of concurrent or sequential steps: 1) a synthesis of life history characteristics across the sablefish range, 2) analyses to

identify and develop range-wide indices of abundance, 3) evaluation of movement within and among regions, and 4) the development of a panmictic OM based on insights and data from steps 1-3. Steps 1-3 could be developed into stand-alone research products resulting in published manuscripts. Step 4 is a necessary precursor to the development of a spatially explicit OM.

A secondary objective of the workshop was to discuss similarities and differences in stock assessment approaches used in each region. The U.S. west coast sablefish assessments are done using the Stock Synthesis modeling platform (Methot and Wetzel 2013), with the model beginning in 1900. Sablefish fishery management in British Columbia (B.C.) is based on a management procedure (data collection scheme, assessment approach, and harvest control rule) developed through a MSE process where hypotheses, empirical data, and simulation play a central role in defining management objectives and assessing management performance relative to those objectives. The B.C. sablefish MSE is based on an OM that is fit in AD Model Builder (Fournier et al. 2012) and conditioned on data beginning in 1965. Alaska Department of Fish and Game assesses sablefish in northern southeast inside waters using a yield-per-recruit model scaled to the absolute abundance estimates from a mark-recapture survey, the results of which are used to set the harvest level. Lastly, the Alaska (Federal) sablefish assessment is a custom age-structured model coded in AD Model Builder beginning in 1960.

A draft work plan was developed during the workshop that identified the following key research priorities moving forward:

- A range-wide life history synthesis.
- Development of range-wide indices of abundance.
- Analysis of range-wide movement.
- Development of a panmictic operating model.
- Development of a spatially-stratified operating model.

In addition to these research priorities the group identified the need to work together to secure funding to support ongoing collaborations (e.g., Ph.D. student and funding for in-person meetings) and to develop a common data sharing agreement among regions. The group committed to continue to work together moving forward through regularly scheduled conference calls and email.

Contents

Introduction

Sablefish (*Anoplopoma fimbria*) are a highly mobile, long-lived, commercially valuable groundfish that have high movement rates and range from Southern California to the Bering Sea. Traditional stock assessment and management has taken place at regional levels determined by political boundaries for the Alaska federal region (Hanselman et al. 2016), Alaska state region, British Columbia (B.C.; DFO 2016), and the U.S. west coast (Johnson et al. 2015). Each region assumes that these are closed stocks; however, a recent genetic study suggested that northeast Pacific sablefish are not genetically distinct among these traditional management areas (Jasonowicz et al. 2017). This lack of genetic evidence for population structure suggests that regional-scale fisheries management may benefit from the consideration of the range-wide structure and dynamics of sablefish (e.g., a range-wide operating model could be developed as a tool for exploring sablefish population structure). Concurrent sablefish population declines to low abundance levels across the regions during the past few decades provides further impetus for development of a range-wide operating model that can be used to investigate the sablefish population across the northeast Pacific.

The Pacific Sablefish Transboundary Assessment Team (PSTAT), comprised of 12 scientists from Canada and the United States, convened 26-27 April 2018 in Seattle, WA, for a workshop to discuss sablefish. The participants included representatives from the Alaska Department of Fish and Game, the Alaska Fisheries Science Center, Fisheries and Oceans Canada, Simon Fraser University, and the Northwest Fisheries Science Center. The primary objective of the workshop was to bring scientists from the United States and Canada together to discuss range-wide sablefish data, compare assessment methods, discuss concerns about sablefish abundance trends, share results of recent and ongoing sablefish research, and to examine the feasibility of developing a set of range-wide operating models (OM). This report is a summary of the workshop presentations and discussions.

Canada and the United States have a long history of both formal and informal communication with the intent of sharing fisheries research knowledge and techniques. The Technical Sub-Committee (TSC) of the Canada-U.S. Groundfish Committee (https://www.psmfc.org/tsc2/) has met annually since 1960 to provide updates regarding fisheries, research, and surveys for each state, provincial, and federal participant. The Western Groundfish Conference (http://www.westerngc.org/) has been held roughly biennially since 1981, and focuses on Pacific groundfish research. Traditionally, the conference has been well-attended by scientists from both countries. Finally, during 2007, scientists from Canada and the United States met specifically to discuss sablefish science (Appendix 6).

Highlights from Regional Assessment Methods

U.S. West Coast Assessment

The U.S. west coast (WC) refers to waters off of California, Oregon, and Washington. The last 'full' stock assessment for WC sablefish was done during 2011, with an update of this assessment that uses data through 2014 being completed during 2015 (Johnson et al. 2015). NOAA assessment updates only allow for limited changes, including additional years of data and re-weighting data, but model structure cannot be changed. A new full assessment is scheduled for 2019. The WC sablefish assessments are done using the Stock Synthesis modeling platform, with the model beginning during 1900.

Approximately 50% of recent WC sablefish landings are from the hook-and-line fleet; pot and trawl fleets each land ~25%. The catch history has been reconstructed back to 1900, and shows relatively stable catches through the early 1970s, followed by large increases during the late 1970s. During the 1980s, trip limits were introduced and sablefish catches have declined since then. Sablefish are a constraining fishery for the WC, limiting participation in other fisheries, though the Annual Catch Limit (ACL) is not usually fully attained. The current stock status is in the "precautionary zone" (between 25% and 40% of the estimated unfished size of the spawning stock biomass), and the stock status trend has been downward since the 1980s.

The 2015 assessment update includes data from three fishing fleets and four surveys. The West Coast Groundfish Bottom Trawl Survey (WCGBTS) index showed a large drop in abundance between 2003 and 2008. The WCGBTS encounters age-0 sablefish in some areas along the west coast, particularly during the second pass of the survey during August and September compared with the first pass during June and July. Age-1 sablefish are more commonly sampled during the WCGBTS. In comparison, the Alaska trawl surveys don't see age-0 fish, and may only occasionally see age-1 fish.

The assessment model includes fishery-independent and fishery-dependent age and length compositions; the WCGBTS age compositions are used as conditional age-at-length so growth (and variability in size-at-age) can be estimated inside of the stock assessment for males and females. Sex-specific natural mortality is estimated in the model and steepness is fixed at 0.6. An environmental index is included in the model as a sensitivity but has little informative power because it has the same signal as the WCGBTS biological composition data. However, if the environmental index is extended backward prior to the collection of length- and age-composition data, it suggests a prolonged period of largely below-average recruitment early in the time series. While sex-specific weight-length relationships are specified as fixed inputs to the stock assessment model, the weight-length relationships for males and females are very similar. However, females occur more frequently above about 65 cm in length. The model results are sensitive to the choice of iterative re-weighting/tuning method for the compositional data but are less sensitive to individual data sources.

The Pacific Fishery Management Council (PFMC) has voiced concern about whether immigration and emigration of sablefish into the assumed WC population might influence the interpretation of spawning biomass and recruitment, which would directly impact how catches are specified. The group discussed the importance of addressing the different approaches and assumptions regarding stock productivity (e.g., recruitment, steepness, natural mortality, and growth) that are used between U.S. and Canadian regions.

British Columbia Assessment

Sablefish fishery management in British Columbia (B.C.) is based on an adaptive ecosystem-based approach in which three pillars of science -- hypotheses, empirical data, and simulation -- play a central role in defining management objectives and in assessing management performance relative to those objectives via Management Strategy Evaluation (MSE) processes. MSE is a simulation-based approach to quantifying how well alternative management procedures (data collection scheme, stock assessment method, and harvest policy rules) meet management objectives. The core elements of an MSE include measurable objectives, an operating model that provides a mathematical representation of the “true” structure and dynamics of the system, and a set of alternative management procedures (MPs) whose performance against objectives can be evaluated through closed loop simulation. Since 2006, Fisheries and Oceans Canada (DFO) and the B.C. sablefish fishing industry have collaborated on an MSE process to develop and implement a transparent and sustainable harvest strategy for sablefish in B.C. waters.

The objectives for the B.C. sablefish fishery have been developed iteratively via consultations between fishery managers, scientists, and industry stakeholders over the course of a decade (Cox and Kronlund 2009, Cox et al. 2011, DFO 2014):

1) Maintain female spawning stock biomass (SSB) above the limit reference point (LRP = 0.4 B_{MSY}) in 95% of years measured over two sablefish generations (36 years), where B_{MSY} is the operating model female spawning biomass at maximum sustainable yield (MSY);
2) When female *SSB* is between 0.4 B_{MSY} and 0.8 B_{MSY}, limit the probability of decline over the next 10 years from very low (5%) at the LRP to moderate (50%) at B_{MSY}. At intermediate stock status levels, define the tolerance for decline by linearly interpolating between these probabilities;

3) Maintain the female spawning biomass above (a) B_{MSY}, or (b) 0.8 B_{MSY} when rebuilding from the Cautious zone, in 50% of the years measured over 2 sablefish generations (36 years);
4) Maximize probability that annual catch levels remain above 1,992 t measured over two sablefish generations;
5) Maximize the average annual catch over 10 years subject to Objectives 1-4.

Objectives 1-3 are based on Canada's "Harvest Decision-Making Framework Incorporating the Precautionary Approach" policy (FPA framework; DFO 2006, 2009), which requires that fishing mortality be adjusted in relation to two levels of stock status that delineate when fishing mortality is reduced or ceased (target and limit reference points, respectively).

The B.C. sablefish OM is a state-space, two-sex, age-structured model that accounts for differences in growth, mortality, and maturation of male and female sablefish. The model includes an ageing error matrix (same as the one in the Alaska assessment with 34 age bins; 3-35+) applied to the model age proportions, the ability to model time-varying selectivity, and is coded in AD Model Builder (DFO 2016). The OM is conditioned by fitting it to fishery-specific landed catch (1965-present), indices of total abundance and age-composition for the trap fishery (1990-2009), trap-based Standardized Survey (1991-2009), and trap-based Stratified Random Survey (2003-present), along with at-sea releases (2006-present) in each of B.C.'s commercial longline trap, longline hook, and trawl fisheries. The trap based surveys cover the continental slope where the fishery occurs. Each year an average of 1,200 fish are aged from the survey and another 800 from the fishery based on a simple random design (i.e., not length stratified). The fishery age data are primarily from the trap sector with little age data for the longline or the bottom trawl fisheries. As a result, tag recovery data (from fish tagged on the survey[1]) are used to estimate selectivity for these fleets (Jones and Cox 2018). There is a minimum size limit in B.C. of 55 cm and fish greater than or equal to 55 cm must be retained or, if discarded, are counted against Individual Transferable Quota. There are no trip limits for catches. Fish that are below the size limit and released are assumed to experience mortality of 15%, 30%, and 80% in the trap, longline and trawl fisheries, respectively (Cox et al. In press).

In addition to the stratified random trap-based survey on the continental slope, an inlet survey has occurred since 1994. This survey occurs in four mainland inlets that are closed to commercial sablefish fishing. The inlet survey, which is trapped-based, collects data on catch, effort and biological characteristics, and also tags sablefish. Analyses of this tagging data suggest that the probability of moving offshore was greater than to other inlets and that those fish that moved offshore had higher probabilities of moving to more northerly areas[2].

The status of the B.C. sablefish stock is judged on the scale of the OM which was last updated in 2016. Based on this 2016 assessment sablefish lie in the Cautious Zone between the target and limit reference points under the DFO FPA Framework. However, as a result of recent above-average recruitment attributed to the 2014 year class, the biomass of sablefish in B.C. appears to be increasing. Based on the most recent estimates of sablefish catch and survey CPUE from the 2017 research and assessment survey, the current point estimate of legal-size sablefish biomass in B.C. is 31,264 t.

Alternative sablefish management procedures (i.e., combination of monitoring data, stock assessment method, harvest control rule, and measures governing at-sea release of sub-legal sablefish) have been developed and evaluated through extensive simulation testing as

[1] Sablefish have been tagged on research surveys in offshore and inlet waters since 1991 (over 380,000 fish tagged and 73,000 fish recovered). Approximately 90% of fish tagged in B.C. are recovered in B.C. with 8.5% recovered in Alaska and 1.5% recovered along the U.S. west coast.

[2] Cleary, J, C. Holt, and A. Cox. Dynamics and movement of sablefish (*Anoplopoma fimbria*) in B.C. mainland inlets. Unpublished report. Available by request; scox@sfu.ca.

part of a collaborative DFO-fishing industry MSE process since 2006 (Cox and Kronlund 2008, 2009; Cox et al. 2009, 2011; DFO 2014, 2017). The full quantitative evaluation of the ability of candidate management procedures to meet conservation and fishery objectives typically occurs every 3-5 years, with the MP identified through the MSE then implemented on an annual basis. The MP that is currently used for sablefish in B.C. (DFO 2017) is based on a state-space surplus production model fit to time-series observations of total landed catch, and the fishery-independent survey CPUE (slope survey), to forecast sablefish biomass for the coming year. These surplus production model outputs are then inputs to a harvest control rule to calculate the recommended catch of legal sablefish in a given year. The current MP includes a 5-year phased-in period to a new maximum target harvest rate of 5.5% (from 8.7% in 2018) and total allowable catch (TAC) in 2018 is 2,526 t.

The current OM assumes that the B.C. sablefish stock is a closed population, despite evidence of movement among sablefish in Alaska and U.S. waters south of B.C. (Hanselman et al. 2014) and little genetic evidence of population structure across these management regions (Jasonowicz et al. 2017). These movements may have implications for the assumptions made about sablefish stock dynamics in B.C. (i.e., recruitment, productivity) that are not currently captured in the current OM or reflected in MP performance evaluations. As a result there is increasing interest in B.C. in developing a range-wide sablefish OM to understand the potential consequences of the mismatch between sablefish stock structure and management by simulation testing current, and potential future, MPs to quantify their performance against a range of conservation and fishery objectives.

State of Alaska Assessment

There are Alaska state sablefish fisheries in northern southeast inside (NSEI), southern southeast inside (SSEI) waters, Prince William Sound (PWS), Cook Inlet, and the Aleutian Islands. Alaska Department of Fish and Game assesses sablefish in NSEI waters using a yield-per-recruit model scaled to the absolute abundance estimates from a mark-recapture survey, the results of which are used to set the harvest level. The yield-per-recruit model assumes a fixed natural mortality rate of 0.1. A pot survey is used in NSEI to capture and tag fish using Floy type tags and fin clips, with recapture events from a longline survey conducted just prior to the fishing season and via the commercial fishery. An age-structured model for NSEI is under development with a target completion date of 2018 or 2019. Fishery CPUE indices are available for SSEI and PWS.

Catches start during the early 1900s, though it is thought that data are most reliable after ~1970 and that earlier landings may include unknown proportions of catch from outside state waters (NMFS 2000). Pot and longline fishing is permitted and there is no retention requirement or minimum size limit. It was noted during discussions that Alaska state water recruitment trends are similar to those observed in Alaska federal and B.C. waters.

Federal Alaska Assessment

The Alaska sablefish assessment is a custom age-structured model coded in AD Model Builder (Hanselman et al. 2017). It has similar features to Stock Synthesis models, but has a few unique characteristics relative to other Alaska assessment models. These features include additional selectivity functions (gamma and power functions), the use of fishery CPUE as an index of abundance, and the quantification of whale depredation both on the survey and in the fishery. The assessment model begins during 1960 and models U.S. federal waters off of Alaska (3-200 miles offshore). A model-integrated projection allows for fully stochastic forecasts that better quantify the uncertainty of recommendations for harvest levels than the standard AFSC projection model which starts as point estimates at the end of the assessment period.

A full sablefish stock assessment was produced during 2017 for the 2018 fishery. New data included in the assessment model were relative abundance and length data from the 2017 longline survey, relative abundance and length data from the 2016 fixed gear fishery, length data from the 2016 trawl fisheries, age data from the 2016 longline survey and 2016 fixed gear fishery, updated catch for 2016, and projected 2017-2019 catches. Estimates of killer and sperm whale depredation in the fishery were updated and projected for 2017-2019.

The model used fixed growth rates for two periods (pre-1996, 1996-present; Echave et al. 2012), uses an age error matrix that was developed using known-age fish, has externally estimated estimates for maturity, and sigma-*r* is a fixed parameter. Natural mortality is estimated in the model (0.097) and is not sex-specific. Ages 2-31+ are modeled. In general there's not a large proportion of fish in the age-31+ group, though in a few recent years there has been an increase due to the Aleutian Islands sablefish fishery moving into previously unexploited areas.

The AFSC longline survey is a fixed station survey conducted on commercial vessels with full cost recovery, beginning during 1979. The vessels are contracted 4 years at a time and are factory longliners that generally participate in non-sablefish longline fisheries. The catch is sold and pays for the survey with the exception of NOAA-provided survey scientists. The survey is conducted annually in the Gulf of Alaska (GOA) and in alternating years in the eastern Bering Sea and the Aleutian Islands. Two sets are made per day that attempt to measure the density across depth strata between 150 and 1,000 m. Catch-per-unit-effort (CPUE sablefish/hook) is calculated in each depth stratum and then averaged across stations in the same depth stratum in each small geographic area. These CPUE values are then scaled to the calculated area sizes (Echave et al. 2013) and expanded to the larger sablefish management areas (Sigler 2000). Most catches of sablefish occur between 400 and 800 m depth. The longline survey abundance index increased 14% from 2016 to 2017 following a 28% increase in 2016 from 2015. The lowest point of the time series was 2015.

The fishery abundance index (filtered nominal CPUE scaled to the area sizes described above) decreased 23% from 2015 to 2016 and is the time series low (the 2017 data are not available yet). New regulations have been introduced that allow expansion of pot fishing to reduce depredation by whales. There was a new GOA trawl survey during 2017 that increased 89% from 2015 to 2017. This biennial bottom trawl survey only uses data from 1 to 500 m depths and is used as more of a recruitment index because the full range of sablefish depths are not covered and is also thought that large fish may outswim the net.

Spawning biomass is projected to increase rapidly from 2018 to 2022 and then stabilize under forecasted adherence to the harvest control rule. Sablefish are currently at the spawning biomass limit reference point ($B_{35\%}$) and below the target reference point ($B_{40\%}$), which automatically lowers the potential harvest rate, but the recent 2014 year class should rapidly move the stock above its target. Instead of maximum permissible allowable biological catch (ABC), we recommended a 2018 ABC of 14,957 t, which is 14% higher than the 2017 ABC. The maximum permissible ABC for 2018 is 89% higher than the 2017 ABC of 13,809 t. The 2016 assessment projected a 1% increase in ABC for 2018 from 2017. The author recommended ABCs for 2018 and 2019 are lower than maximum permissible ABC for two important reasons. First, the 2014 year class was estimated to be 2.5 times higher than any other year class observed in the current recruitment regime. Under the North Pacific Fishery Management Council tier system, sablefish are a Tier 3 stock. Tier 3 stocks have no explicit method to incorporate the uncertainty of this new year class into harvest recommendations. While there were clearly positive signs of strong incoming recruitment, there were concerns regarding the lack of older fish and spawning biomass, the uncertainty surrounding the estimate of the strength of the 2014 year class, and the uncertainty about the environmental conditions that may affect the success of the 2014 year class. These concerns warranted additional caution when recommending the 2018 and 2019 ABCs. It is unlikely that the 2014 year class will be average or below average, but projecting catches under the assumption that it is 10× average introduces risk because of uncertainty associated with this estimate. Only one large year class since 1999 has been observed, and there was only one observation of age compositions to support the magnitude of the 2014 year class. Future surveys will help determine the magnitude of the 2014 year class and will help detect if there are additional incoming large year classes other than the 2014 year class.

Additionally, projections that consider harvesting at the maximum ABC for the next 2 years, if the 2014 year class is actually average, resulted in future spawning biomass projections that are very low, where depensation (reduced productivity at low stock sizes) could occur. Recommending an ABC lower than the maximum should result in more of the 2014 year class reaching spawning biomass and achieving higher economic value. Because of these additional considerations, we assumed that the recent recruitment was equal to the previous highest recruitment event in the current regime for projections (1977, which is still 4× average). This results in more precautionary ABC recommendations to buffer for uncertainty until more observations of this potentially large year class are made. Because sablefish is an annual assessment, we will be able to consider another year of age compositions during 2018 and adjust our strategy accordingly.

A second justification for recommending a lower ABC than maximum permissible is based on estimates of whale depredation occurring in the fishery in the same way that was recommended and accepted in 2017. Because inflated survey abundance indices as a result of correcting for sperm whale depredation were included, this decrement was needed to appropriately account for depredation on both the survey and in the fishery.

Survey trends supported this moderate increase in ABC relative to last year. There was a substantial increase in the domestic longline survey index time series, and a large increase in the GOA bottom trawl survey. These increases offset the continued decline of the fishery abundance index seen in 2016. The fishery abundance index has been trending down since 2007. The International Pacific Halibut Commission (IPHC) GOA sablefish index was not used in the model but was similar to the 2015 estimate in 2016, up 5% from 2015. The 2008 year class showed potential to be large in previous assessments based on patterns in the survey age and length compositions; this year class is now estimated to be about 13% above average. There were preliminary indications of a large incoming 2014 year class, which were evident in the 2016 longline survey length compositions and now are extremely dominant in the 2016 age compositions. This year class appears to be very strong, but year classes have sometimes failed to materialize later and the estimate of this year class is extremely uncertain.

Across Region Summary and General Discussion

Prior to the workshop each region provided basic summary data, parameter estimates, and model output (Appendix 5) to facilitate discussions and comparisons of range-wide data and trends.

Catches from all regions show two primary peaks: one during the 1970s and a second during the late 1980s-early 1990s (Fig. 1). The second peak in catches is largely driven by removals from Alaska waters as catches from the WC and B.C. continued to decline after peaking during the early 1970s to early 1980s. Recent catches summed across all regions are around 20,000 t, approximately one-third of peak catches. Catches are most correlated between the Alaska fixed gear fleet and B.C. total catch; this is possibly reflective of similar management and potentially a degree of similarity in abundance trends.

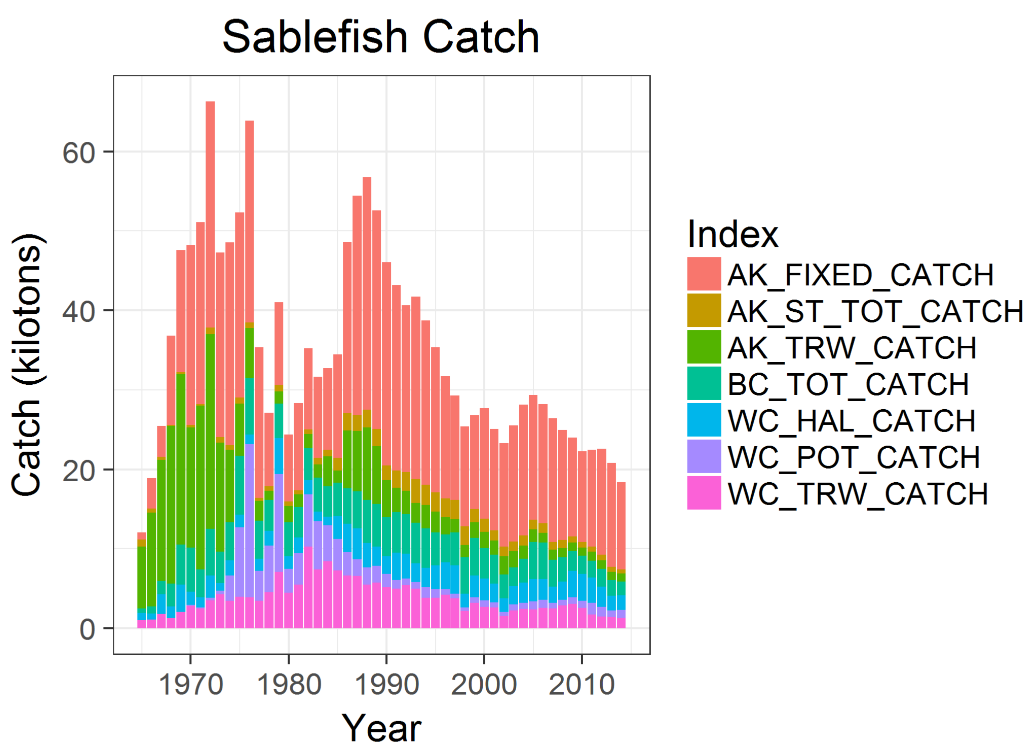

Figure 1. -- Sablefish catch by region and gear for 1965–2015, for Alaska federal (AK), Alaska state (AK_ST), British Columbia (BC), and the U.S. west coast (WC), for pot, trawl (TRW), hook-and-line (HAL), and fixed (HAL + pot) gears.

We examined population indices expressed as biomass (metric tons; Fig. 2) and abundance (numbers; Fig. 3) across regions and found some evidence of synchrony across regions in abundance indices, but not biomass indices, in recent years (~ late 2000s). The indices are defined in Table 1. These patterns are potentially confounded by multiple factors associated with the specifics of each survey (e.g., gear, depth, timing, etc.) and different characteristics of the sablefish population (e.g., abundance index is dominated by young fish). As a result the group recognized the importance of the development of range-wide abundance indices using multiple modeling approaches, including spatio-temporal modeling (e.g., VAST) that help control for these confounding factors.

Table 1. -- The definitions of the indices used in the comparison across areas.

Index	Description
	Biomass (weight)
AK_DOM_FISH_LL	Alaska Domestic Longline Fishery Relative Population Weight
AK_JP_FISH_LL	Japanese Longline Fishery Weight-Per-Unit-Effort
AK_GOA_TRW	NMFS AFSC Gulf of Alaska Bottom Trawl Survey (Biomass)
AK_ST_NSEI_WPUE	State of Alaska Northern Southeast Inside Weight per Unit Effort
AK_ST_SSEI_WPUE	State of Alaska Southern Southeast Inside Weight per Unit Effort
WC_SH_SLP_TRW	NWFSC Shelf-Slope Bottom Trawl Survey Biomass (Period 1)
WC_SH_SLP_TRW1	NWFSC Shelf-Bottom Trawl Survey Biomass (Period 1)
WC_SH_SLP_TRW2	NWFSC Shelf-Bottom Trawl Survey Biomass (Period 2)
WC_SH_TRI_TRW	NWFSC Shelf-Slope Bottom Trawl Survey Biomass (Triennial years)
	Abundance (numbers)
AK_COOP_LL	Alaska Cooperative Longline Survey Relative Population Numbers

AK_DOM_LL	Alaska Domestic Longline Survey Relative Population Numbers
AK_ST_NSEI_NPUE	State of Alaska Northern Southeast Inside Numbers per Unit Effort
AK_ST_SSEI_NPUE	State of Alaska Southern Southeast Inside Numbers per Unit Effort
BC_TRAP_FISH_NUM	British Columbia Fishery NPUE
BC_TRAP_SRV_STD	British Columbia Standard Trap Survey (Numbers)
BC_TRAP_SRV_STRAT	British Columbia Stratified Random Trap Survey (Numbers)

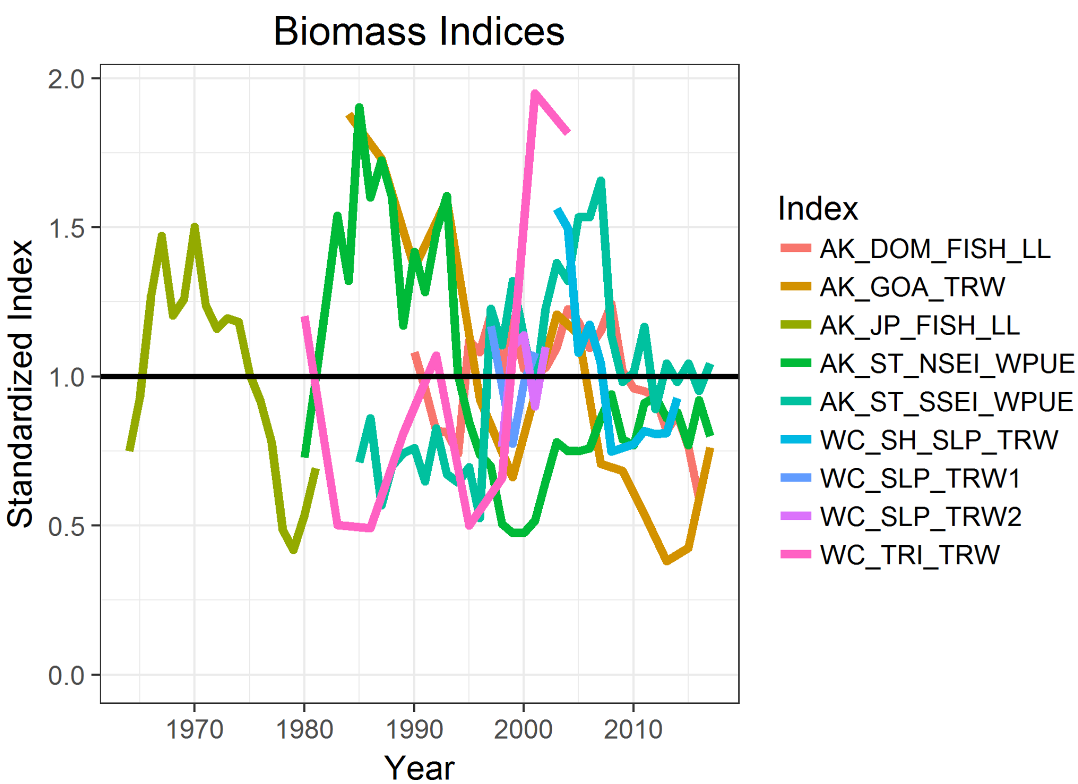

Figure 2. -- Fishery-dependent and -independent indices of sablefish biomass, standardized to a mean and standard deviation of 1, for Alaska federal (AK), Alaska state (AK_ST), and the U.S. west coast (WC).

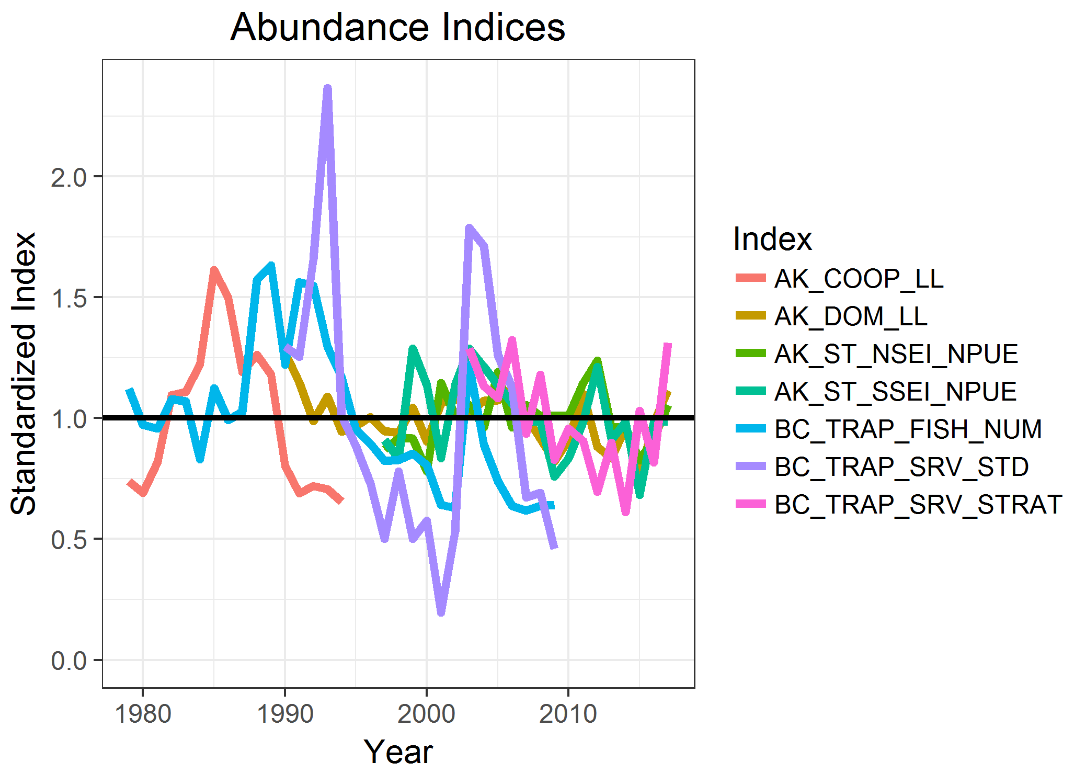

Figure 3. -- Fishery-dependent and -independent indices of sablefish abundance (in numbers of fish), standardized to a mean and standard deviation of 1, for Alaska federal (AK), Alaska state (AK_ST), and British Columbia (BC).

During the meeting, coherence in sablefish index trends was examined to determine whether trends in WC, B.C., and Alaska exhibited common patterns indicative of a range-wide population. We used the management unit estimator (MUE) method of Cope and Punt (2009), which incorporates index uncertainty into index clustering, and applied it to the following five population indices: 1) West Coast Groundfish Shelf-Slope Trawl Survey (WC), 2) British Columbia Stratified Random Trap Survey (B.C.), 3) Alaska Domestic Longline Survey (AK_LL, measured in relative population numbers), 4) State of Alaska Southern Southeast Inside CPUE survey (AK_SS), and 5) State of Alaska Northern Southeast Inside CPUE survey (AK_NS). These surveys shared 11 years of index data.

We found very strong clustering of the sablefish indices, and thus evidence of coherent trends in indices for the WC, B.C., and southern southeast inside Alaska (Fig. 4). There was strong evidence that the northern southeast inside Alaska CPUE index is strongly distinct from the other four indices.

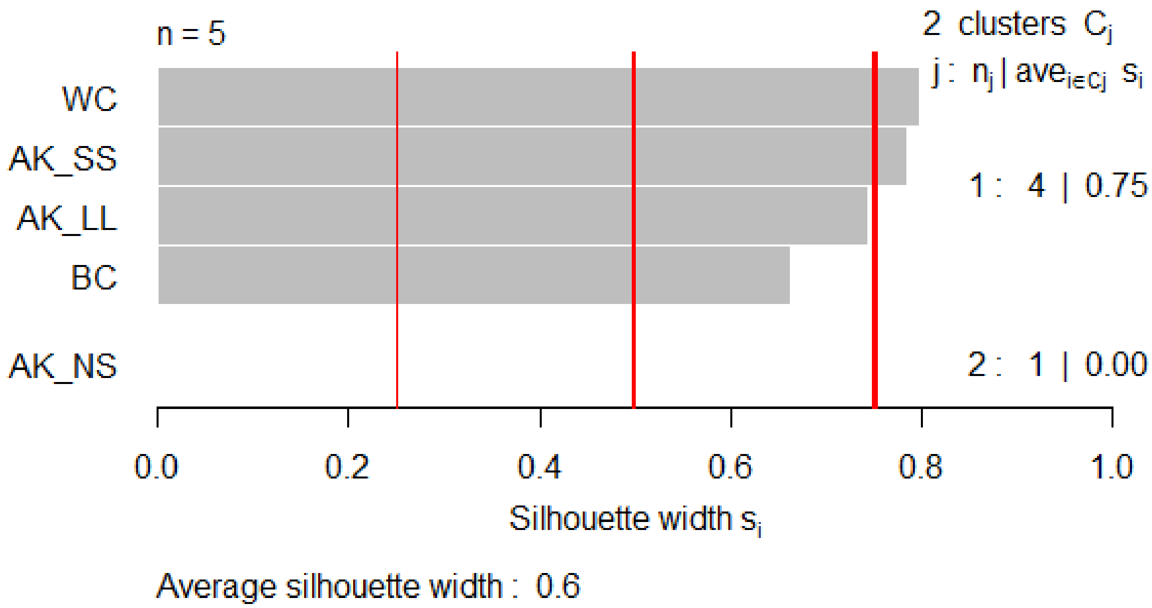

Figure 4. -- Silhouette plots for the most parsimonious clustering of sablefish indices. Silhouette widths indicate the strength of evidence for clustering of indices where values greater than 0.75 are considered very strong evidence, values greater than 0.5 strong evidence, values greater than 0.25 weak evidence and less than 0.25 no evidence (Cope and Punt 2009).

The IPHC conducts an annual range-wide longline survey for halibut that also encounters sablefish. The survey covers California through Alaska, including B.C., using multiple vessels with gear and methods standardized between vessels and regions. The regional CPUE indices (expressed as abundance) from this survey show very similar trends (Fig. 5), although the survey only samples water to 500 m so a large proportion of known sablefish habitat is not sampled in this survey, and this survey uses larger hook sizes resulting in smaller sablefish being poorly sampled. Regardless, this may be an index worth considering for future model development.

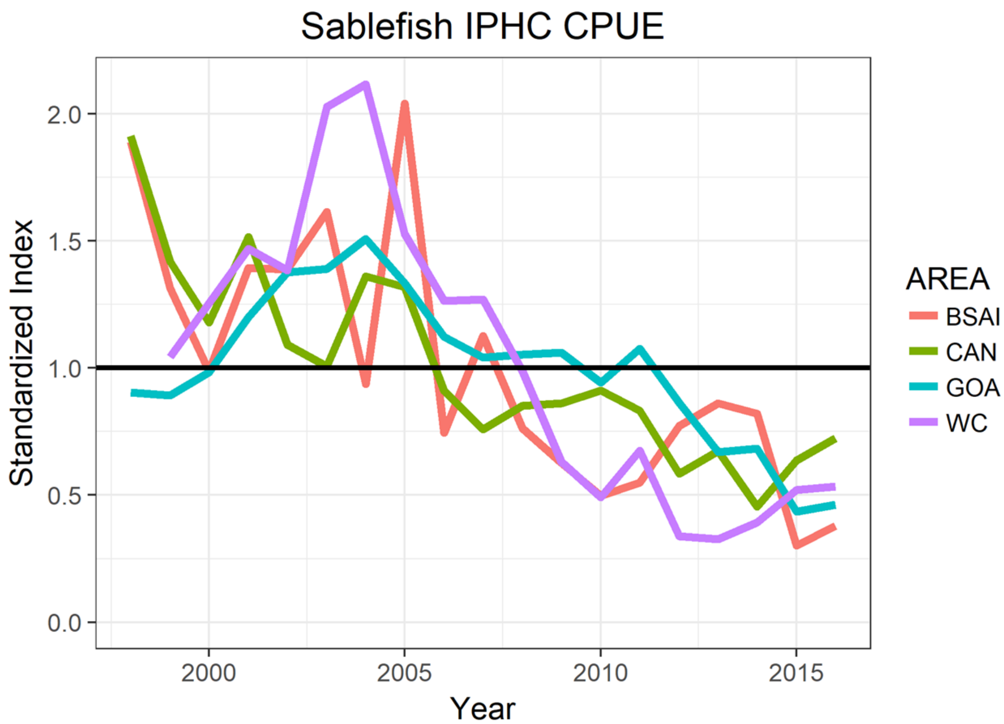

Figure 5. -- Regional abundance indices for sablefish encountered on the annual IPHC longline survey for Alaska federal regions Bering Sea-Aleutian Islands (BSAI) and Gulf of Alaska (GOA), British Columbia (CAN), and U.S. west coast (WC).

Sablefish recruitment is estimated in the B.C., WC, and Alaska federal models. We found little evidence of strong temporal coherence in recruitment (in millions of recruits) among regions, but the correlation between Alaska and B.C. (0.37) was slightly stronger than between Alaska and WC estimates (0.13; Fig. 6). High recruitment years appear to be off by approximately one year between Alaska and WC, which may be partially due to differences in ageing error matrices used between the two regions. Both B.C. and Alaska use the same ageing error matrix, based on known-age fish; the WC uses double/triple age reads between labs and an age error estimator developed by André Punt (University of Washington). A uniform approach to ageing error may improve correlation of recruitment estimates between regions, as would development of similar growth, productivity, and natural mortality assumptions. The number of recruits estimated in the WC model is fairly high compared to the other regions and the maximum growth estimated by WC models is smaller than for B.C. and Alaska, so it's possible the WC model is compensating by increasing the number of recruits. Further examination of growth, productivity, and natural mortality were identified as 'low hanging fruit' for potential future range-wide operating model explorations.

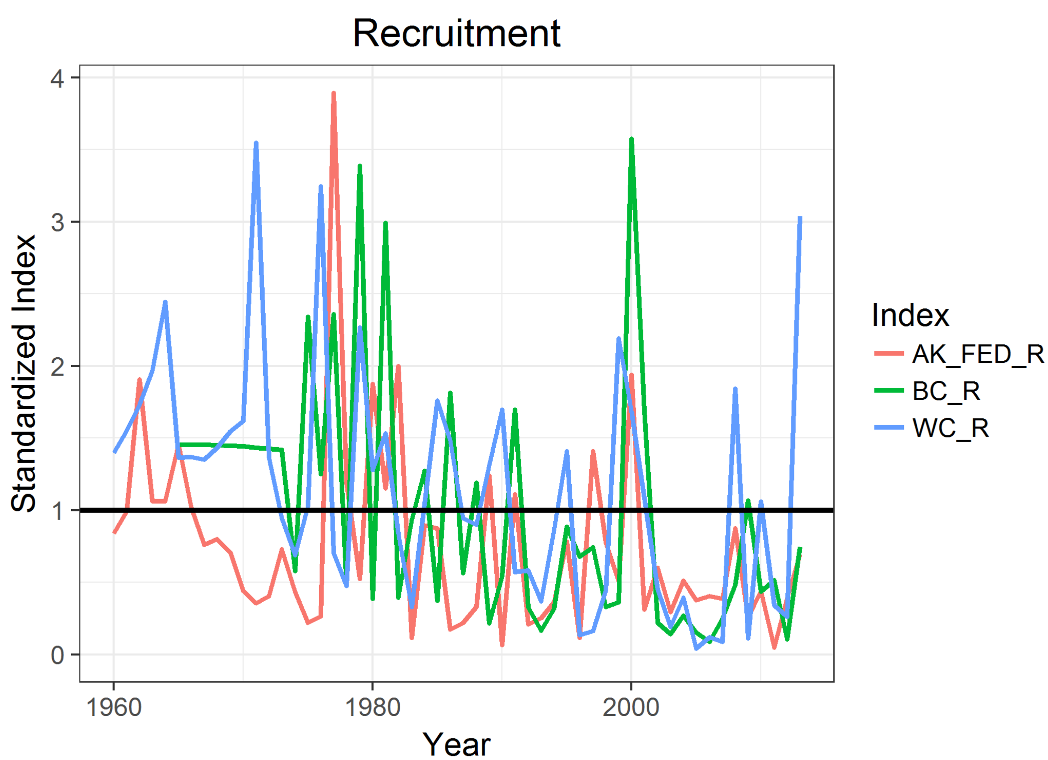

Figure 6. -- A comparison of sablefish recruitment as estimated by stock assessments for Alaska federal (AK_FED_R), British Columbia (BC_R), and U.S. west coast (WC_R) regions.

Estimated female spawning biomass trends for B.C., WC, and Alaska federal assessment are most similar from 1990 onward and have correlations of 0.58-0.96 for years 1977-2015

(Fig. 7). Alaska state trends are not included in Figure 7, and do not show the same decline in recent years.

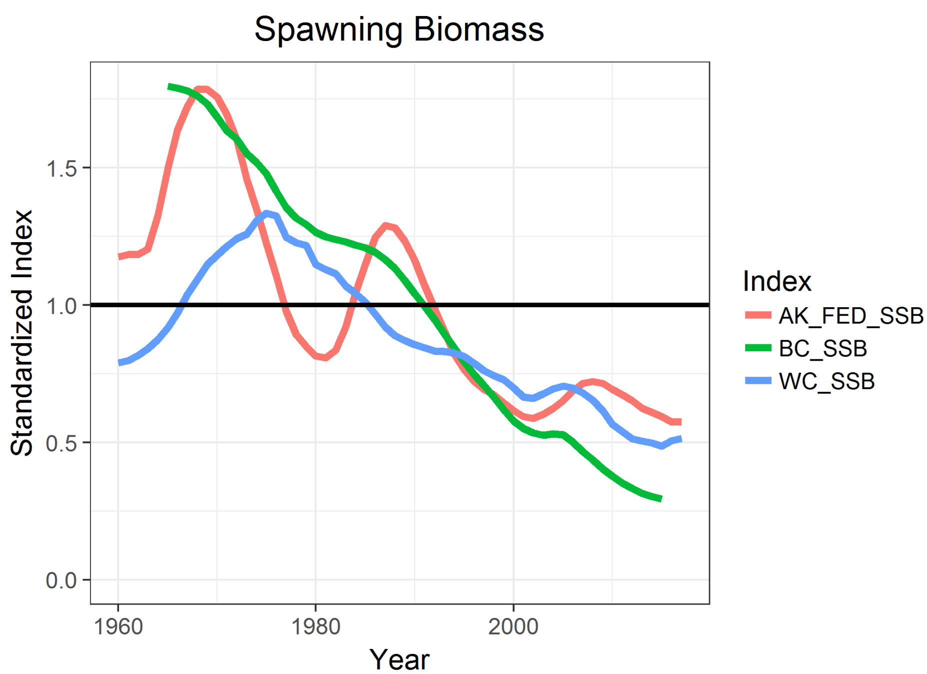

Figure 7. -- A comparison of spawning biomass estimated from sablefish assessment models for Alaska federal (AK_FED), British Columbia (BC), and U.S. west coast (WC) regions.

Observed and estimated life history traits vary between regions. Sablefish in Alaska state waters have the highest estimate of L-infinity for females and males (85 cm and 69 cm, respectively), and WC has the smallest (64 cm and 56 cm, respectively). Natural mortality is estimated for Alaska federal (0.097 for sexes combined, thought the model is sex-specific), B.C. (0.058 M, 0.104 F), and WC (0.062 M, 0.076 F), and fixed for Alaska state (0.1 for both sexes).

Maturity and fecundity data need to be synthesized among regions. The WC has a 'functional maturity' estimate that accounts for skip spawning. In skip spawning, a mature fish does not spawn, potentially due to either direct or indirect environmental influences. Alaska has conducted some studies about the validity of visual observations of maturation from the longline survey, see the AFSC research section for more details. A Ph.D. student project in B.C. has identified that maturation occurs at older ages for sablefish in more northern areas. A range-wide examination of maturation and growth was discussed as a useful research activity.

During the 2016 external review of the Alaska federal sablefish assessment model, reviewers recommended future exploration of a model that would include catch from B.C. Using the data prepared for this international sablefish workshop, the Alaska federal model was run using the summed catch time series from Alaska, B.C., and the WC (Fig. 8). The model resulted in increased estimates of spawning stock biomass but lower stock status with respect to estimated reference points (28% of B_{100} during 2017), lower natural mortality estimates, higher fishing mortality estimates, a lower ABC recommendation (though still greater than 2017 catches; lower because the NPFMC harvest control rule was triggered), and lower catchability for the Alaska federal longline survey.

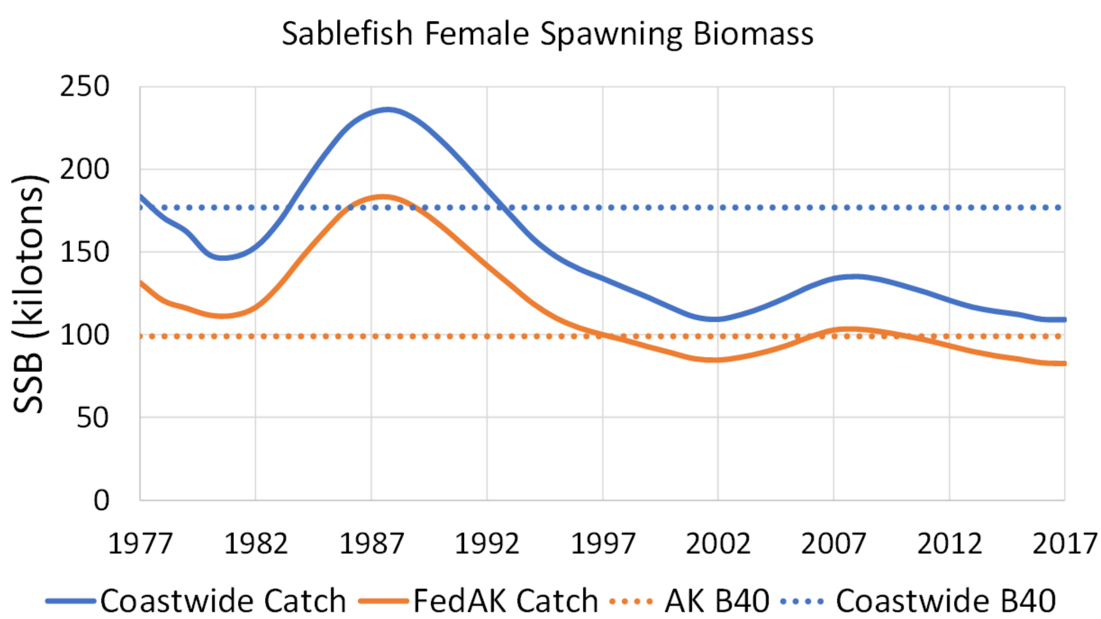

Figure 8. -- The Alaska federal assessment model was run using catch data from the WC, B.C., and state and federal Alaska regions. The spawning biomass estimates from the 'range-wide' model (blue) are shown with the spawning biomass estimates from an Alaska federal catch only model for comparison.

Range-Wide Research Priorities

The group quickly came to agreement that the primary objective of the PSTAT should be to begin development of a range-wide, spatially stratified OM that can be used to explore questions of ecological, biological, and management relevance. To meet this objective, we identified a number of key intermediate research activities that need to be undertaken to inform the structure of a range-wide spatially explicit OM: 1) a synthesis of life history characteristics across the sablefish range, 2) an analyses to identify and develop range-wide indices of abundance, 3) evaluation of movement within and among regions, and 4) the development of a single panmictic OM based on insights and data from steps 1-3. Steps 1-3 identified above could be developed into stand-alone research products resulting in published manuscripts. By cooperatively developing the OM and collaborating on these research activities, the PSTAT can iteratively explore a range of approaches for addressing key modeling questions that are currently dealt with differently between the regions. Each of these potential research activities is described in detail below.

Interim Research Activities Leading to a Spatially Explicit Operating Model

Sablefish Life History Synthesis

We recommend writing a sablefish life history and assessment review paper that summarizes and explores the current data and understanding regarding the spatial dynamics of sablefish natural mortality, age, size, growth, maturity, fecundity, and other data streams drawn from published literature and assessments from each region.

Despite genetic analyses that suggest a panmictic stock, sablefish exhibit phenotypic differences in life history characteristics throughout their range. Workshop discussions focused on possible ideas for methods to address these life history differences. The review paper would help the group understand latitudinal patterns, variations, and ranges of life history parameters observed for biological data such as maximum age and size, growth, fecundity, and maturity. Additionally, this research would compile the methods each region uses for estimating or specifying natural mortality and stock-recruitment parameters. Some regions estimate natural mortality using a prior based on a maximum age, so compiling the maximum age observed in each area, along with information about each regions age validation methods, ageing error, and distributions of ages observed will be important for informing a range-wide spatially explicit OM.

A life history review paper developed as a work product from the PSTAT could mine the literature for past maturity and fecundity research, and consider fitting maturity ogives based on data from all regions and propagating maturity uncertainty in the OM. It is unknown if there is a relationship between sablefish fecundity and spawning stock biomass. Additional research on sablefish fecundity and maturity would be beneficial as data are likely sparse for most regions. Functional maturity, a term referencing fish that will likely spawn in a given year (so accounting for mature non-spawners), is also under-studied in sablefish (see Head et al. 2014, 2016).

Range-wide Indices of Abundance

A paper that conducts analyses to develop range-wide indices of abundance using survey or fishery data (e.g., VAST and other techniques).

Fishery-dependent catch per unit effort (CPUE) indices for individual regions, or newly developed CPUE indices aggregating data across multiple regions may not be used or developed for the OM, as there may be sufficient fishery-independent information. However, if a method can be developed to combine fishery data across regions, they may be useful to explore. This manuscript and research activity would attempt to identify common patterns in fishery-dependent or independent CPUE and habitat (depth, latitude), and could examine methods for combining data across regions for shared gear types.

The IPHC survey was discussed as a potential fishery independent survey for range-wide use, as it covers a large portion of the sablefish range (latitudinally), though the depth range and hook size used are drawbacks because they are more suited to halibut than sablefish. The group expressed interest in starting simply, with fewer, ‘better’ indices. British Columbia suggested using their model which reconciles multiple indices to simulate/generate an expected mean index (modeling abundance). With this method, that could mean using that biomass trend as the time series, or the predicted values (with error) as a mean index.

Sablefish Movement Evaluation

A review and analysis of range-wide sablefish movement that could inform hypotheses for the structure of a spatially structured OM, as well as explore potential drivers of age-, region- and sex-specific movement rates. There is an extensive tagging dataset for sablefish in Alaska and B. C.. Hanselman et al. (2015) previously analyzed movement rates of Alaska sablefish and there was discussion at the workshop about expanding this analyses to include B.C. tagging data and updating the time series of recoveries to present. These tagging data could be used to inform the structure of a spatially explicit OM (e.g., movement probabilities) as well as test hypotheses about drivers of movement range-wide. The PSTAT recognized that due to confidentiality issues, such an analysis might need to use data on a relatively coarser spatial scale, but could still provide useful information about the degree of connectivity among the management regions.

Another potentially interesting component of movement analyses would be to compare a movement model using tag data to conclusions about movement made using only composition data. Many fish species don’t have tag programs, but do have age or length composition data over wide spatial areas, and comparing both for sablefish might provide general insight into how useful composition data may be for other stocks. Given the confidential nature of tag data, simpler analyses of tag data on a very coarse scale (four areas: Alaska state, Alaska federal, B.C., and WC) could also be considered to review distributions of time at large, distance traveled, general patterns in movement direction, and other summary analyses.

Panmictic Operating Model

As a general rule, the workshop participants agreed that moving forward the group should adopt a 'start simple' approach for the development of a spatially explicit OM. Therefore, it was agreed that a panmictic, single area, OM with as much pooled data as possible should be built prior to investigations of key alternative model assumptions and a spatially explicit OM.

Technical Considerations for Operating Model Development

In this section, we summarize discussions regarding data and model components that will need to be addressed during the OM development. While some issues are likely best dealt with using a unified approach (e.g., starting year, plus group age), others may require exploration of alternative approaches so that the consequences of specific assumptions (e.g., productivity, growth) are rigorously quantified.

Natural Mortality

The options discussed for addressing natural mortality (*M*) included fixing *M* (as a simplifying assumption), using a single prior if estimating *M* (if maximum ages for each region are similar), or choosing a range of fixed values and priors to explore. Additionally, likelihood profiles across a range of values of *M* from the OM could be used to evaluate the information in the data regarding values of *M*. It was noted that tools exist to explore a variety of empirical estimators of *M* relevant to establish single or multiple priors, or in defining a range of *M* values to consider[3].

Ageing Error

Ageing bias and imprecision varies to some degree across regions and ageing laboratories. Several sablefish Committee of Age Reading Experts (CARE) exchanges have

[3] https://github.com/shcaba/Natural-Mortality-Tool; http://barefootecologist.com.au/shiny_m

occurred between the Cooperative Ageing Project[4] (CAP) laboratory in Newport, OR; the AFSC in Seattle; DFO in Canada; and ADF&G in Juneau. These exchanges mostly occurred from 2002 through 2009, with an exchange currently underway during 2018 between the AFSC and the CAP laboratory. Analyses of the data from the 2002-2009 CARE exchanges during the 2011 WC sablefish stock assessment found that the CAP laboratory readers were producing younger age estimates than the other laboratories by 1-3 years. However, the CAP laboratory agreed or was within +/- 1 year of another laboratory's age estimate 65.9% of the time. The above analysis was focused on the WC. However, we have all of the CARE exchange data and plan to produce analyses that can inform the panmictic OM. Additionally, analyses estimating the between-laboratory bias and precision for all laboratories will be completed. Finally, an updated analysis of CAP laboratory ages compared to the other age laboratories since the 2010 analyses will be completed.

There are two approaches to ageing error used in the assessments presented at this workshop; 1) using a software package designed to estimate ageing bias and precision used by the NWFSC stock assessors (Punt et al. 2008, software is publicly available at https://github.com/nwfsc-assess/nwfscAgeingEror), and 2) an age error matrix developed from known-age fish used by ADFG, DFO, and AFSC (Hanselman et al. 2012). One hundred seventy-two known age fish were analyzed and it showed that half of the variance of age readings at each true age was due to variance among otoliths and half due to variance among replicate readings of individual otoliths. The fish were all < 22 years old, so the ageing error matrix beyond that age is extrapolated. Ageing error is large beyond this point and the fish are fully grown and mature, so the specification of the matrix at high plus age groups is generally inconsequential (Hanselman et al. 2012).

[4] https://www.nwfsc.noaa.gov/research/divisions/fram/popeco/aging.cfm

Ageing error can be decomposed into the difference between true age and average-read age ("bias") and variability around that average read age ("precision"). The bias and precision for ageing methods or laboratories for WC groundfish is generally estimated as a hierarchical model (Punt et al. 2008) and data consist of comparisons among and within methods or laboratories ('cross-reads' or 'double-reads'). The ageing-error model from Punt et al. (2008) estimates 1) the true proportion-at-age in the sample, and 2) the bias and precision for each of four laboratories that were assumed to have ageing error. This model treats the "true" age for each otolith as a random effect, and estimates the marginal likelihood of all other fixed effects while integrating across these random effects. Stepwise Akaike Information Criteria model selection can be used to select among all combinations of three precision models (i.e., linear and a Hollings-form for either standard deviation or coefficient of variation for precision) and two bias models (i.e., linear or Hollings-form), as well as the maximum age for which a proportion-at-age parameter was estimated (previous ranges evaluated for WC sablefish range from 2 to 80 years). A preliminary age error analysis for WC sablefish completed during 2011 resulted in a model with Hollings-form bias and Hollings-form standard deviation of precision for each laboratory. Bias was negative (i.e., reads were lower than the true age) and the standard deviation increased with true age for all laboratories (Fig. 9). This analysis assumed that ages from the tagged fish from AFSC were known without error. However, it was concluded that the 'perfect' ages derived from the tagging experiment were not broadly representative of the ageing methods for the fishery and survey samples available, and that the initial analysis of bias was heavily influenced by these few fish.

In the 2011 WC assessment, preliminary assessment modeling was performed using the estimates of ages that were both highly imprecise and negatively biased, particularly at older ages (Fig. 9). Assessment model results suggested that the degree of bias estimated from initial ageing error analyses was incompatible with observed cohorts moving through the population and produced poor residual patterns and unrealistically low estimates of natural mortality. Therefore, comparisons of a large number of survey samples from the WC and Alaska that contain much older fish were used to suggest a much greater consistency among laboratories for west coast fish. The double-reads from the NWFSC produced an estimate of imprecision suggesting that by age 50, observed ages can easily differ from true ages by as much as 10-12 years (Fig. 10).

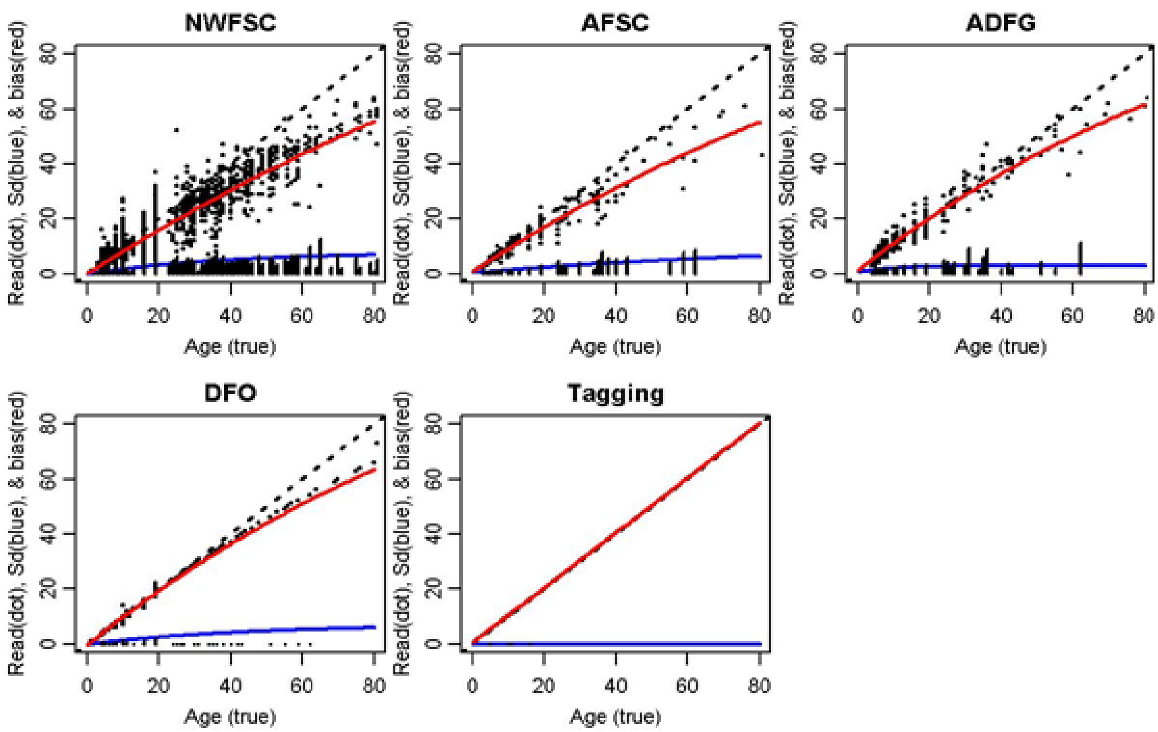

Figure 9. -- Summary of ageing bias, and imprecision, for various ageing laboratories used in preliminary modeling of age bias and imprecision during the 2015 WC sablefish assessment, produced using the nwfscAgeingError package. Black points represent observed ages, black bars the observed standard deviation of observed age at estimated true age. Dashed line indicates a 1:1 relationship. Solid lines indicate the predicted observed age at estimated true age (upper red line in each panel) and the predicted standard deviation of observed age at estimated true age (lower blue line in each panel).

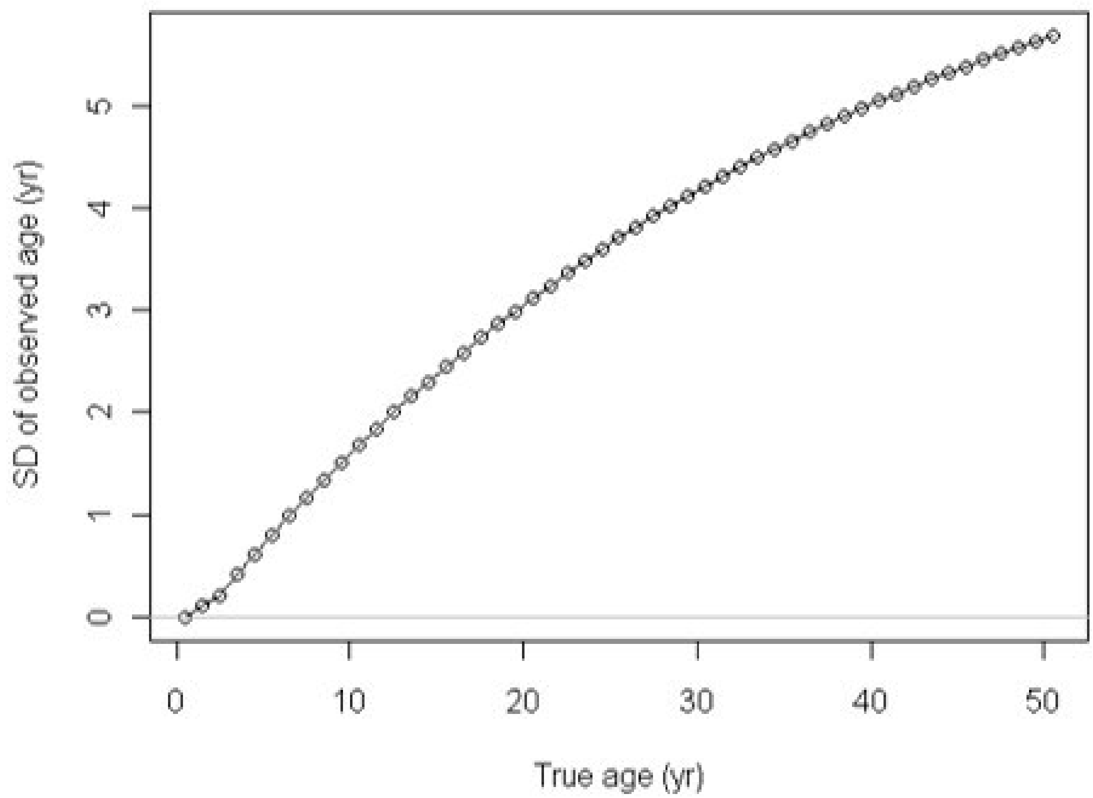

Figure 10. -- Estimated relationship describing the variability of observed age conditioned on true age.

Age and Length Composition

Age and length composition data should be provided in expanded form, with all observed ages and lengths represented instead of using a terminal plus group. This will facilitate combining compositions across regions and exploration of alternative values for plus groups. Plus group ages and length can be determined based on data, and sensitivity to the plus group values can be explored in sensitivity analyses. Previous spatial analyses of Alaska trawl survey length compositions suggest that the best indicator of strong recruitment for Alaska occurs when small sablefish are present in Western GOA. This kind of analysis across regions might improve understanding of recruitment. There was also discussion about finding a common way to standardize age compositions from surveys across regions. The IPHC must have to deal with this, so the sablefish group could learn from their techniques.

Model Initialization

Each region uses a different starting year for their assessment and management process. The WC has reconstructed catch data back to 1900, and uses this starting year because their management uses virgin biomass as a reference point. The Alaska Federal sablefish assessment starts at a lightly fished equilibrium in 1960 (0.1 mean *F*), recruitment deviations are estimated back to 1931 to populate the first numbers at age row. The WC assessment model assumes average unfished biomass in model start year (1900) and the BC operating model assumes unfished equilibrium conditions beginning in 1965 because there was little observed catch prior to this date. The group discussed the pros and cons to different starting years, and noted that it would be important to consider a starting year which captures peak removals. There was concern about the ability of some regions to develop catch reconstructions, so one alternative discussed was to estimate an initial *F* if the model start year isn't reflective of unfished biomass, or to create a 'ramp up' of catches from a starting point for regions without catch reconstruction.

Discards

The workgroup briefly discussed how discarded fish are addressed in each region. Because Canadian regulations have a minimum size limit of 55 cm, they apply discard mortality rates to discarded fish based on a review of the literature (DFO 2016). The WC stock assessment assumes discard rates based on prior research accepted by the PFMC (Johnson et al. 2015). The accepted discard mortality rates are 50% for trawl discards and 20% for fixed gear discards (Section 1.2 in the 2016 SAFE http://www.pcouncil.org/wp-content/uploads/2017/02/SAFE_Dec2016_02_28_2017.pdf). The group will need to decide whether to include discards in their OM, and if so, what discard mortality rates to apply. Across regions, fleets catching sablefish include hook-and-line, trawl, and pot/trap.

Recruitment and Productivity

Recruitment and productivity are addressed differently between regions, and will likely be key areas where alternative assumptions and parameterizations will be explored and where further research is needed. Operating models with and without a stock-recruitment relationship can be developed to mimic the assumptions used by representative regions. There is evidence of spawning in all regions, based on size and age of captured fish, though there may be different factors affecting recruitment success in each region.

After development of a panmictic sablefish OM, more complex models (i.e., spatially explicit OMs) can be developed to address specific questions. It will be important to structure spatial OMs based on biology instead of existing management boundaries.

Other Technical Discussions

Many other research needs, potential analyses, or general ideas were discussed that are not tied to the development of the panmictic OM. We describe each of these below.

Operating model development beyond the panmictic model could be spatially explicit and include sablefish movement using either data-based or hypothetical movement rates to explore consequences of movement. Analyses of oceanographic or environmental drivers of recruitment and spatial patterns in spawning stock biomass might be improved if range-wide movement estimates are available. Numerous questions about movement rates that might be explored using a spatial OM include: does movement vary over time, depth, oceanographic conditions, climate, age, or length? The group also noted that there has been some archival tag use to try to understand vertical movement, and there's a proposal to look at acoustic tagging to try to understand inshore-offshore movement. Finally, the group mentioned that it would be useful to conduct more tagging of age-0 and age-1 sablefish to help inform growth and early life movement.

Otolith microchemistry was discussed as a potential means to obtaining growth rates for young fish, spawning location, early life history spatial and temporal movement patterns, and, ultimately, drivers of recruitment strength. The fractionation of oxygen isotopes in the otolith ($^{18}O/^{16}O$, measured as $\delta\,^{18}O$) is inversely related to temperature. This measurement can be used to reconstruct the temperature history of fish since birth. Otolith annuli increment width measurements are related to the body growth of a fish. There are studies that have successfully measured $\delta\,^{18}O$ through time and compared it to annual increment widths. This type of study has the potential to link growth with temperature changes, which could be interpreted as migration. These measurements can also be used to compare growth and migratory behavior in response to interannual environmental fluctuations. Below are some questions that hypothetically could be answered with a $\delta\,^{18}O$ study and the issues that make this work difficult.

The goals of a potential study of sablefish otoliths could be to evaluate 1) what season and age sablefish move from inshore waters to the shelf and from the shelf to the slope; 2) how growth is related to temperature and migration timing; and 3) how interannual environmental fluctuations affect growth and migration. Wild fish would be the focus of the study and previously collected otoliths from young-of-the-year sablefish raised at known temperatures and rations could be used to develop a known relationship between $\delta\,^{18}O$ and temperature for sablefish.

There are a few reasons why it would be difficult to conduct this research with sablefish. First, the start and end locations of translucent zones (slow growth) are difficult to identify, particularly in the first winter. Therefore, it is not possible to measure annuli increment widths. Second, sablefish have small otoliths. After the second summer the bands are narrow and there is not enough material to collect the required multiple samples within each zone. Using a micro-mill, the cost per sample is ~$15 (there are many samples collected per otolith), plus staff time. This is very time consuming work.

The high-precision ion microprobe (in Madison, WI) is a second machine that can be used to mill samples from otoliths. This machine can take very small samples within narrow zones and so it is possible to collect samples from ages after the second summer. The cost is ~$1,000 per otolith, not including the otolith preparation, which is expensive. It is best to use a known-age sablefish, or a very young fish so that the birth year can be identified and additional environmental information can be included in data analyses.

Research that leads to better understanding of the drivers of recruitment success (or failure) would be beneficial. This could be in the form of examining distributional shifts in recruitment in terms of oceanographic conditions (ROMS modeling), otolith analyses to link movement, recruitment and environment, range-wide fecundity studies, and identification of spawning time and place for each region (via field work or modeling currents and larval fish distribution). A joint 2-year NOAA-funded project is getting underway to develop a full life cycle model using an Individual Based Model for sablefish. The goal of this project is to use the results of Individual Based Models as an input to a spatially-explicit tag-integrated model in order to inform the source and apportionment of recruitment and how that might affect harvest strategies.

Finally, the group posed the following questions related to range-wide sablefish research and management that could be addressed by panmictic or spatially explicit OMs: How much production is coming from recruitment versus migration? How robust are management procedures to recruitment uncertainty? Are there common environmental drivers between regions? Is recruitment common between all areas or does it only look similar due to common environmental drivers? Is there a time lag between strong recruitment events in different regions? When does spawning occur in the different regions? Might this drive some regional differences in recruitment strength due to match/mismatch with environment?

Logistical Considerations

The group discussed some of the logistical considerations around sharing data between regions. For the most part, data not derived from fisheries aren't sensitive to confidentiality restrictions and should be shareable between regions. Fishery data can be aggregated to meet confidentiality restrictions in many cases. The group suggested that there may be sufficient fishery-independent data for initial model development, avoiding the confidentiality issues associated with fishery-dependent data. Nonetheless, there will need to be a formal data sharing agreement (at a minimum between DFO and NOAA) and the development of this agreement was identified as a high priority.

Based on the discussions on technical considerations, a draft work plan was developed. The work plan identifies and prioritizes some of the work products necessary to develop the panmictic OM, and identified who may be able to complete the work and a general timeline. A Salstonstall-Kennedy proposal has been submitted, which, if funded, would allow a graduate student to work on some of the panmictic OM components that this workshop identified as critical. In addition, funding for a Post-Doctoral researcher through DFO's International Governance Strategy has been secured which will help contribute to some components in the work plan. Additional external funding sources were discussed, and it is hoped that once the group has some completed work to show the potential for success, we may want to consider a proposal to North Pacific Research Board, other larger funding agencies and/or additional student fellowship opportunities, to continue our progress. The NWFSC and AFSC will submit a joint proposal to the internal Regional stock assessment Work Plan RFP for support in fiscal years 2019-2021.

High Priority Projects and Tasks for Coastwide Analyses

1. Life history review
2. CPUE/Indices development
3. Movement rate analysis: broad scale, range-wide

4. Panmictic OM development
5. Spatially explicit OM development
6. Composition data mining
7. Examining ageing error
8. Range-wide examination of maturity and growth
9. Examine length and age compositions to decide bin sizes and plus group length/age
10. Determine common method for standardizing age compositions
11. Determine bin size for length data

The group agreed that regular communication would be critical in making timely progress on a range-wide OM as well as other collaborative research on sablefish. To ensure communication, the group discussed holding check-in phone calls roughly quarterly for the larger group, and smaller, more targeted group communication via email and phone as needed. The group will also explore opportunities to secure funding for in-person meetings as necessary.

Recent and Ongoing Sablefish Research

Ongoing and recently completed sablefish research is described in this section. Citations for published research are provided where available; ongoing projects list project and researcher names where available.

Northwest Fisheries Science Center

Recruitment Drivers

Tolimieri, N., M. A. Haltuch, Q. Lee, M. G. Jacox, and S. J. Bograd. 2018. Oceanographic drivers of sablefish recruitment in the California Current. Fish. Oceanogr. 1–17. DOI: 10.1111/fog.12266.

Oceanographic processes and ecological interactions can strongly influence recruitment success in marine fishes. Here, we develop an environmental index of sablefish recruitment with the goal of elucidating recruitment-environment relationships and informing stock assessment. We start with a conceptual life-history model for sablefish *Anoplopoma fimbria* on the U.S. WC to generate stage- and spatiotemporally-specific hypotheses regarding the oceanographic and biological variables likely influencing sablefish recruitment. Our model includes seven stages from prespawn female condition through benthic recruitment (age-0 fish) for the northern portion of the west coast U.S. sablefish stock (40° N–50° N). We then fit linear models and use model comparison to select predictors. We use residuals from the stock-recruitment relationship in the 2015 sablefish assessment as the dependent variable (thus removing the effect of spawning stock biomass). Predictor variables were drawn primarily from ROMS model outputs for the California Current Ecosystem. We also include indices of prey and predator abundance and freshwater input. Five variables explained 57% of the variation in recruitment not accounted for by the stock-recruitment relationship in the sablefish assessment. Recruitment deviations were positively correlated with 1) colder conditions during the spawner preconditioning period, 2) warmer water temperatures during the egg stage, 3) stronger cross-shelf transport to near-shore nursery habitats during the egg stage, 4) stronger long-shore transport to the north during the yolk-sac stage, and 5) cold surface water temperatures during the larval stage. This result suggests that multiple mechanisms likely affect sablefish recruitment at different points in their life history.

West Coast MSE - Climate Change and Productivity

Assessing the effects of climate change on U.S. west coast sablefish productivity and on the performance of alternative management strategies.

Haltuch, M.A., Z. T. A'mar, N. Bond, and J. L. Valero.

United States WC sablefish are economically valuable, making assessing and understanding the impact of climate change on the California Current stock a priority for 1) forecasting future stock productivity, and 2) testing the robustness of management strategies to climate impacts. Sablefish recruitment is related to large-scale climate forcing that drives regional alongshore and cross-shelf ocean transport that affects regionally correlated sea level, zooplankton communities that pelagic young-of-the-year sablefish feed upon. This study forecasts trends in future sablefish productivity using SL from Global Climate Models (GCMs) and explores the robustness of harvest control rules (HCRs) to climate driven changes in recruitment using MSE. Most GCMs suggest that after about 2040 there will be a slight trend towards lower SLs, suggesting favorable conditions for sablefish in the CC by 2060. Future sablefish recruitment is likely to be similar to historical recruitment but may be less variable. Decadal trends in SL result in recruitments persisting at lower levels through about 2040 followed by higher levels from about 2040 through 2060. Although this MSE suggests that spawning biomass and catches will decline, and then stabilize, into the future under both HCRs, the sablefish stock does not fall below the stock size that leads to fishery closures.

Spatial Distribution of Recruitment

Examining spatial distributions of recruitment from the U.S. west coast groundfish bottom trawl survey.

Tolimieri, N., M. A. Haltuch, and J. Wallace.

VAST modeling of annual age-0 sablefish spatial distributions in the California Current using the WCGBTS data from 2003 through 2015. This work is producing both maps of spatial distributions of newly settled sablefish as well as produces an index of abundance for these age-0 fish. This WC data shows a strong and spatially widespread recruitment event during 2008 and 2013.

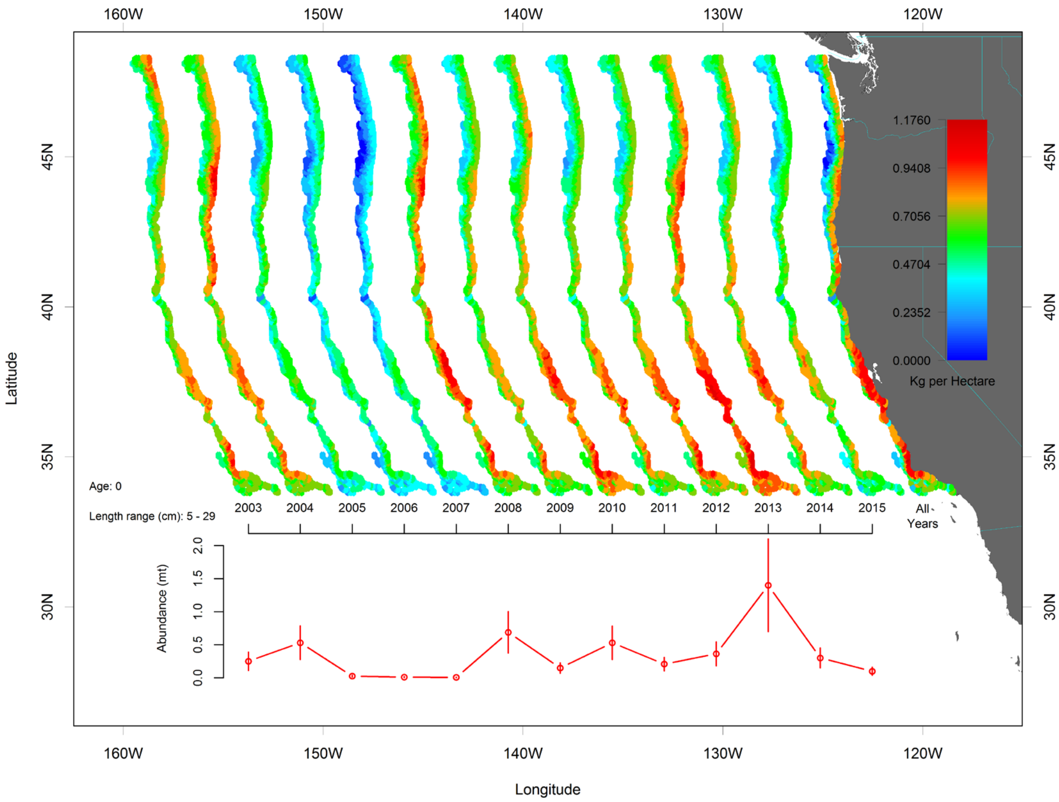

Figure 11. -- Annual maps of the distribution and density (kg per hectare) of approximately age-0 sablefish in the U.S. waters of the California current (upper panel) for the years 2003-2015 as well as a sum across all years (rightmost map). The model estimated index of approximately age-0 sablefish from 2003 to 2015 (bottom panel).

Archival Sablefish Tagging

Goetz, R., A. J. Jasonsowicz, and S. B. Roberts. 2018. What goes up must come down: Diel vertical migration in the deep-water sablefish (*Anoplopoma fimbria*) revealed by pop-up satellite archival tags. Fish. Oceanogr. 27:127–142.

Pop-up satellite archival tags (PSATs) were used to observe the fine-scale depth selection behavior of adult sablefish tagged off the Washington coast during the summer from

June to August. Tags were physically retrieved after they surfaced using direction-finding equipment so that complete datasets over the entire deployment were obtained from 14 tags. PSATs that recorded depth and temperature every 4 min during the deployment confirm that sablefish inhabit depths of 750 m or greater. However, a majority of the tagged fish underwent extensive vertical migrations that averaged 254.4 m overall and occurred at a 24-hour periodicity. Variations were observed among individuals in the amount of the deployment during which vertical migrations occurred, ranging from 12.37% to 63.48% of the time. During the vertical migration, fish ascended towards the surface at night and descended prior to daylight (i.e., diel vertical migration). Sablefish generally inhabited temperatures of 5° C but during the vertical migrations were found at temperatures from 6° to 10° C. Sablefish are opportunistic feeders with a large proportion of their diet being fish, euphausiids and cephalopods. Because these prey items also exhibit diel vertical migrations, it is possible that the vertical migratory behavior displayed by the sablefish was in response to the movements or the location of their prey.

Canadian Sablefish Research

Bottom Contact in Sablefish Fisheries

Doherty, B., S. D. Johnson, and S. P. Cox. 2017. Using autonomous video to estimate the bottom-contact area of longline trap gear and presence–absence of sensitive benthic habitat. Can. J. Fish. Aquat. Sci. 999:1-16.

Bottom longline hook and trap fishing gear can potentially damage sensitive benthic areas (SBAs) in the ocean; however, the large-scale risks to these habitats are poorly understood because of the difficulties in mapping SBAs and in measuring the bottom-contact area of longline gear. In this paper, we describe a collaborative academic–industry–government approach to obtaining direct presence–absence data for SBAs and to measuring gear interactions with seafloor habitats via a novel deepwater trap camera and motion-sensing systems on commercial longline traps for sablefish (*Anoplopoma fimbria*) within SG̲aan K̲inghlas – Bowie Seamount Marine Protected Area. We obtained direct presence–absence observations of cold-water corals (Alcyonacea, Antipatharia, Pennatulacea, Stylasteridae) and sponges (Hexactinellida, Demospongiae) at 92 locations over three commercial fishing trips. Video, accelerometer, and depth sensor data were used to estimate a mean bottom footprint of 53 m^2 for a standard sablefish trap, which translates to 3,200 m^2 (95% CI = 2,400–3,900 m^2) for a 60-trap commercial sablefish longline set. Our successful collaboration demonstrates how research partnerships with commercial fisheries have potential for massive improvements in the quantity and quality of data needed for conducting SBA risk assessments over large spatial and temporal scales.

Risk Assessment Framework for Quantifying Bottom Fishing Impacts on Sensitive Benthic Habitats

Doherty, B., S. Rossi, and S. P. Cox.

Sensitive benthic habitats commonly occur in important fishing areas but are vulnerable to damage from bottom contact fishing gear. To maintain access to fishing grounds, fisheries must demonstrate that risks to seafloor ecosystems are low and conservation objectives can be achieved in the presence of fishing. Despite increasing requirements to manage fishing gear interactions with habitats there are few quantitative approaches for assessing risks from bottom-contact fishing, largely due to a lack of information on the location of sensitive benthic habitats, the long-term damage caused from different bottom-contact fishing gears, and the potential for recovery. We developed a risk assessment framework for quantifying damage and recovery of deep-sea coral habitats over 30-years of bottom-longline trap fishing that 1) uses presence-absence models to predict coral habitat distribution in fishing areas, 2) estimates historical bottom contact from sablefish (*Anoplopoma fimbria*) longline trap fishing gear, and 3) estimates coral fishing mortality and recovery using a spatial population model for Gorgonian (Alcyonacea) corals. Our assessment of Gorgonian corals in the SGaan Kinghlas – Bowie Seamount (SK-B) Marine Protected Area estimated that biomass is currently at 71.7 (90% CI =70.6-73.2%) of unfished levels within the fishable area of the seamount (3% of the MPA), which is above levels that would trigger conservation actions under most fisheries policies (i.e., 20-40% B_0). Our quantitative risk assessment approach provides valuable information for ecosystem-based fisheries management that can be used to investigate different management measures designed to reduce fishing risks to sensitive benthic habitats while minimizing economic losses from closing fishing areas.

Linking Decision-making for Fisheries and Sensitive Benthic Habitats Using Management Strategy Evaluation with Spatial Assessment Models

Rossi, S., B. Doherty, and S. P. Cox.

Large-scale area closures are increasingly used to protect sensitive benthic habitats from bottom-contact fisheries, creating trade-offs between anticipated conservation benefits and economic fishing opportunities. Predicting conservation outcomes under different management procedures designed to protect habitat (e.g., area closures, effort controls, gear restrictions, bycatch limits, encounter protocols) is difficult due to uncertainties in assessing fishing risks to bottom habitats and fleet responses to new management measures. We linked an assessment of coral habitat in the SGaan Kinghlas – Bowie Seamount (SK-B) Marine Protected Area with a spatial population dynamics model for sablefish at SK-B in a management strategy evaluation framework. We projected coral and sablefish dynamics 30 years into the future under a variety of MPs (e.g., fixed or variable fishing effort, permanent area closures, monitoring and updating of area closures) and evaluated each using a suite of performance measures (e.g., catch, CPUE, sablefish biomass, coral biomass). Projections produced median coral biomass estimates ranging from 68 to 80% of unfished levels in the fishable SK-B area. All MPs had minimal impact on sablefish at SK-B, as catches were low relative to immigration from coastal stocks. This research demonstrates how habitat and fisheries stock assessments can be linked to evaluate whether conservation and fisheries objectives are likely to be achieved under different management decisions.

Tagging Studies

Jones, M. K., and S. P. Cox. 2018. Size-selectivity for British Columbia sablefish (*Anoplopoma fimbria*) estimated from a long-term tagging study. Fish. Res. 199:94-106.

The underlying size-distribution of commercial fish stocks is usually unknown, so fishery size-selectivity must be estimated as a latent process embedded within age-structured stock assessments. However, dome-shaped fishery size-selectivity, in particular, is often inestimable because decreasing selectivity is confounded with mortality at older ages. In this paper, we test for dome-shaped selectivity in B.C.'s sablefish fishery using a long-term tagging data set. We incorporate alternative fishery size-selectivity assumptions within a mark-recapture framework based on an asymptotic logistic model and dome-shaped models using gamma and normal probability density functions. We also fit each model using both time-invariant and time-varying parameterizations. Our results strongly suggest dome-shaped size-selectivity for tagged sablefish in longline trap, longline hook, and bottom trawl fisheries. Time-varying models were generally favored over time-invariant models, although alternative time-varying models often produced similar statistical fits. Dome-shaped selectivity in longline fisheries could be a function of fishery targeting, fish movement, or by lower reporting rates for large size-classes.

Dynamics and Movement of Sablefish (*Anoplopoma fimbria*) in B.C. Mainland Inlets[5]

Cleary, J., C. Holt, and S. P. Cox.

Since 1994, B.C. mainland inlets have been closed to commercial sablefish harvesting. This action, was intended to protect juvenile sablefish (*Anoplopoma fimbria*) and spawning stocks that may reside in these inlets. Previous evidence based on preliminary analysis of tag

[5] Note this unpublished research was completed in 2007.

recovery data suggests that a portion of sablefish move from inlets, offshore. Therefore, inlet fish may be providing a "reserve" stock that contributes to the offshore fishery. However, the potential contribution of these unharvested inlet populations to the offshore fishery has not been quantified. Furthermore, the closure of mainland inlets to fishing has in essence created a large marine closure for sablefish, which provides a unique opportunity to examine source and sink dynamics of fish populations from a large-scale protected area to a fishery. A survey of four mainland inlet localities (referred to simply as mainland inlets) was implemented in 1995 to collect data on catch, effort, and biological characteristics. During these surveys, several thousand sablefish have been tagged and their recoveries in subsequent surveys and the offshore commercial fishery have been recorded. With these data we were able to investigate trends in relative abundance of inlet populations and the relationship between inlet and offshore populations. Specifically, we used the catch, effort, and biological data to develop inlet-specific trends in two indices of relative abundance (kilograms and numbers of fish caught per unit effort, CPUE). We further examined trends in CPUE for various portions of the population categorized according to body size (divided into legal-sized and sublegal-sized fish), maturity (divided into mature and immature fish), and sex (divided into female and male). We found that the northern inlets (Portland Inlet and Gil Island) tended to have higher average CPUE than the southern inlets (Finlayson and Dean/Burke Channels). All inlets exhibited peaks in CPUE in 1999, 2003, and 2004, but peaks in the northern inlets were larger and more consistent across biological categories than those in the southern inlets.

We developed a spatially explicit mark-recapture model to estimate the probability of movement of sablefish from mainland inlets to offshore fishing areas using sablefish tag release and recovery data. We found that for all four mainland inlets, of the fish tagged and released in the mainland inlets, probabilities were much higher for fish moving offshore than moving to other inlets or remaining in the inlet of origin. The sablefish that moved offshore were more likely to move to more northern offshore areas, especially Areas 3 and 5 (northern B.C.) and rarely moved into the southernmost areas (Areas 1 and 2). There were several limitations to the findings of this research. First, the trends observed in CPUE are for the four mainland inlets surveyed and cannot be extended to the entire population of sablefish in B.C. inlets. Fish collected during the inlet survey may be a biased sample of the entire population. Second, we concentrated our analysis on tag recoveries and movement from the mainland inlets to B.C. offshore fishing areas. Because we did not consider tag recoveries in adjacent fisheries or waters (e.g., Hecate Strait or Alaska), we cannot determine whether the majority of migrating sablefish reach the offshore fishing grounds or are instead intercepted by other fisheries.

Biological Sampling

Development of an alternative method for the biological sampling of catch using sablefish heads

Temple, K., A. R. Kronlund, K. Castle, J. Supernault, and M. Wyeth.

Stock assessment of sablefish in B.C. requires information on individual fish size, age, and sex in the commercial fisheries. Since product is landed J-cut, these data are currently obtained from a voluntary catch sampling program where samples are randomly selected from longline trap or hook gear and are returned whole to port. A tag-release recovery program used to estimate gear selectivity is also in place, and relies on voluntary return of tagged sablefish from all gear types. We are investigating the potential for obtaining biological information using only sablefish heads. This requires 1) Demonstrating that head measurements can be used to reliably predict fork length for both sexes; 2) Developing an at-sea sampling program where fishermen segregate returned heads by sex; 3) Developing an audit program of sex determination accuracy using genetic methods; and 4) Revising shore-side sampling of sablefish to collect head measurements, genetic tissue, and otoliths. Our preliminary results show a strong relationship between head dimensions (eye diameter, inter-orbital distance, snout length, upper jaw length, and post-orbital to preoperculum distance) and fork length, with correlation coefficients ranging from 0.938 for eye diameter to 0.976 for snout length. A pilot project was also initiated to test the feasibility for commercial vessels to assess sex and return heads for biological sampling, and development of a genetic test to determine gender. Successful application of this research may result in increased participation in the voluntary catch sampling and tagging programs and improve biological data from all commercial gear types that intercept sablefish.

Juvenile Sablefish

Sensitivity of management procedure performance to incentives that promote juvenile sablefish avoidance in groundfish fisheries

Cox, S.P. and S. Johnson.

Fishing-related mortality of juvenile sablefish was identified in the sablefish MSE process as an important factor determining both the rate of stock rebuilding and medium- to long-term yield. We analyzed the sensitivity of management procedure performance to incentives aimed at lowering mortality of juvenile sablefish. Incentive structure was based on a cap on the total allowable biomass juvenile sablefish that could be released at-sea, implemented as a proportion of the sector-specific total allowable catch (TAC). Caps act like a TAC, where fishing would continue as normal until the cap was exceeded, following which all intercepted sablefish, regardless of size, would count against a sector's TAC. Under these conditions, we assumed that caps initiate some level of avoidance behavior to prevent sablefish from becoming a choke point for other fisheries. We simulated different combinations of caps and subsequent avoidance rates to investigate performance relative to the status quo (Management Procedure adopted in 2017) and to a full accountability option. Performance was measured against sablefish fishery management objectives, as well as a comparison of pre- and post-incentive fishing mortality rates, as a proxy for how "choked" a fishery would be. Overall, we found that a combination of moderate levels of both caps and avoidance was most realistic and performed better than either one on their own. Furthermore, improving avoidance can have large positive benefits for sablefish survival to legal size and, thus, overall stock rebuilding and future yield. We also tested the sensitivity of the baseline management procedure to a reduction in future discard-induced mortality, which we found to have no qualitative effect.

Alaska Department of Fish and Game

The sablefish mark-recapture experiment in Chatham Strait is ongoing and anticipated to be extended into the near future. Regular reports on the results of this study are available from ADF&G. During the course of the 2017 pot survey portion of the mark-recapture project, genetic samples have been collected for potential future examinations of inside versus outside waters sablefish stock structure.

Since new policy in state waters allows for a sablefish live market in southeast Alaska, an escape ring selectivity study has been proposed. Current requirements for Clarence Strait are that there must be two 10.16 cm inside diameter escape rings on either side of a pot. The study will explore the selectivity associated with 7.62 cm and 10.16 diameter escape rings as well as no escape rings.

There has been some discussion that Chatham Strait may be a different spawning population than the range-wide population, due to the larger size of females in Chatham Strait. It has been proposed to tag large, presumed female sablefish with satellite pop-up tags during the May/June pot survey. These tags would be programmed to release during the presumed winter spawning time in order to identify spawning grounds. This work will be done in collaboration with the satellite tagging study performed by the AFSC and discussed in more detail below.

Alaska Fisheries Science Center

New Fishery Regulations

Pot gear has been allowed in the GOA since 2017. The catch in pots was ~10% of the total catch in 2017. There will be difficulties incorporating these new fishery data into assessment. Issues to tackle will be catchability/selectivity, how to combine a pot time series to a hook-and-line index and how to compare pot fishery data to the longline survey.

Electronic monitoring (EM) is now allowed on vessels over 39 feet. The number of vessels choosing EM over an observer has been increasing (90 vessels in 2017 and 114 vessels in 2018). The potential shortfalls to EM are a lack of lengths, tissue collections, and whale observations and species identification issues.

There will be a NPFMC discussion paper presented at the October meeting of the NPFMC providing options for allowing the release of small sablefish. This is in response to large catches of fish from the 2014 and one more possibly large recent year classes. If this was adopted discard mortality rates would need to be chosen.

Outreach

A newsletter (The Black Cod Almanac) is in its third year of production. This annual report was created to provide updates on assessment, management, and research to stakeholders. It also includes the location and dates of the survey stations so that the fleet can avoid the stations prior to sampling.

A website is under development that would provide data on groundfish tag releases and recoveries for fish tagged by NOAA in Alaska. Data would be available for download and also displayed interactively on a map. Only non-confidential data will be provided online (i.e., the data will be summarized by large areas).

Satellite Tagging

Over 100 satellite tags have been deployed on adult sablefish on the summer longline survey over the past several years. Many of the tags were programmed to pop-up during the winter close to the spawning season. Analysis on these data are ongoing.

Process Studies

From 2010 through 2014 the Gulf of Alaska Integrated Ecosystem Research Project, funded by the North Pacific Research Board, included sablefish as a focal species. Sablefish is also now a focus of the Recruitment Processes Alliance at the AFSC. The inter-divisional program was designed to better understand recruitment variability. The programs within the RPA focus on the growth and survival of eggs, larvae, and juveniles. Projects include both field and laboratory components.

Growth and energy allocation studies of age-0 sablefish were completed at the Auke Bay Laboratory in Juneau (AFSC) by the Recruitment Energetics and Coastal Assessment Program (Joseph Krieger, Ashwin Sreenivasan, Ron Heintz). Sablefish were captured at-sea and experiments were carried out at temperatures from 5° to 20° C at varying rations. Growth was most efficient between 12 and 16 degrees. This data may be used to estimate the effects of changing temperatures and food availability on growth and distribution in the wild.

A time series of age-0 otoliths were obtained by Wes Strasburger (AFSC, Ecosystem Monitoring and Assessment Program) in the GOA from 1) gill nets set during AFSC longline surveys (1995-2004), 2) surface trawl surveys (2014-future), and 3) sea bird bill loads from Middleton Island (1997- future). Wes will measure daily increment widths, which have a tight, linear relationship with fish length, and compare these increment widths to those from otoliths of fish kept at varying temperatures and food rations in a laboratory environment. Trophic position will be measured using stable isotope analyses, and trophic position will be compared to the measured growth rates. The study will also include an evaluation of diet. These measurements can be used to develop an annual growth index for age-0 sablefish, to relate growth to the environment, and to predict age-2 recruitment.

Age-1 and age-2 sablefish are tagged annually in St. John the Baptist Bay in Southeast Alaska, which is the only location where juveniles have been found with regularity. Some have been tagged with archival tags and later recaptured as adults. In addition to this tagging, more recently age-0 fish were caught in surface trawls in the GOA and tagged and released. There are plans to continue these efforts every other year as funding permits.

Maturity Studies

Special collections of female sablefish were made in December of 2011 and 2015, within 1-3 months of spawning, nearby Kodiak Island. Skip spawning sablefish were documented using histology in both years. However, skip spawning was more prevalent in 2011 (21% of fish that had spawned in the past or would in the current season) than in 2015 (5%). Skip spawners were primarily found in gullies in 2011 and fish were absent from the same locations in 2015.

Samples were collected during the 2015 AFSC Alaska longline survey in the GOA in July and August. There were a greater proportion of fish in later stages of vitellogenesis in August than in July, particularly in the second half of August. Maturity classifications in August will have higher accuracy because it is likely that fish have initiated development by this time.

There are four legs on the GOA portion of the AFSC longline survey in Alaska. On each leg different scientists are deployed. Even though everyone classifies maturity using the same photographs, during this time of year it is very difficult to determine maturity accurately, particularly when ovarian development is occurring throughout the survey. A comparison of maturity-at-age curves using maturity classifications from at-sea (macroscopic) or histology slides (microscopic), curves were sometimes very close to one another and on other legs they were very different. This may be due to an effect of geography, timing (July vs. August), or the observer. When someone with experience with sablefish maturity classified maturity based on photographs of ovaries at-sea (“standardized macroscopic method”), the age-at-maturity curve matched closely to histology on all legs. This indicates that standardizing maturity classifications with one observer, even if using just photographs, will likely be more accurate and consistent than using rotating at-sea scientists with less expertise in sablefish maturity.

For female sablefish, the body condition (Fulton’s condition factor) and the relative liver weight both increased throughout the AFSC longline survey, from early July through August. Fish that would spawn also had higher values than immature fish. Using these variables as well as length and age, the maturity of each fish was predicted using logistic models. Age-at-maturity curves using these predictions closely matched the age-at-maturity curves using classifications from histology slides. These results demonstrate that we may be able to predict maturity on survey legs in the Central GOA, which occur in August without any macroscopic or microscopic evaluations of maturity. These models are currently being used to estimate female age-at-maturity for 1998-present.

Joint Projects

The Spatial Processes And Stock Assessment Methods (SPASAM) working group is a cross-Science Center initiative through NOAA which is using sablefish as one of several test cases for spatial model simulations.

The SPASAM project is evaluating approaches for incorporating spatial dynamics into stock assessments using a spatially-explicit simulation-estimation framework, with a focus on data requirements, technical aspects, and performance of spatial harvest control rules. A suite of spatially-explicit operating models have been developed to test the robustness of spatially-explicit and spatially-aggregated stock assessment models to estimation of stock status. The operating models are also being used to simulate spatially-explicit biological reference points to evaluate the performance of commonly implemented harvest control rules assuming both correct and incorrect spatial structure (panmictic, spatial heterogeneity, metapopulation, and natal homing). These simulations can provide an indication of how important assumed population structure is for the reliable determination of stock status and catch advice. The objectives of this research are to address the following questions:

- If spatial dynamics are suspected *a priori*, but data are insufficient to apply a spatially-explicit stock assessment model, what methods for catch apportionment to sub-areas are robust and what levels of spatial aggregation for defining population dynamics are sufficient (given sample size limitations)?

- At what level of population mixing and for what types of population structure does it become important to consider regional estimates of biological reference points and fishing mortality rates (e.g., F_{MSY}, $B_{35\%}$)?
- What parameters can be robustly estimated spatially (e.g., catchability, connectivity) given different levels of data availability and quality, and population structure?
- What data types are most informative (e.g., conventional tagging versus fine-scale catch information) for estimating spatial parameters (e.g., movement)?
- With what level of accuracy and precision must data and assessment model processes be assigned to the proper stock unit (i.e., what are the consequences of incorrectly defined stock boundaries)?
- Can spatially explicit recruitment dynamics (e.g., larval mixing) be explicitly estimated and does ignorance of spatial processes during early life history stages result in assessment bias?

Operating models are being developed based on several stocks from different regions that have unique and shared characteristics in terms of biology and data (e.g., Atlantic menhaden, sablefish in Alaska, Atlantic herring, Gulf of Mexico red snapper, and Pacific hake), which cover common population structures for marine fish populations (e.g., patchily distributed unit population, natal homing, and metapopulation). Several of these stocks have tag-recapture data sets to inform movement patterns or larval individual-based models to identify larval connectivity, which can inform the operating models. Operating models are coded in R, and the estimation models are coded in AD Model Builder based on commonly used statistical catch-at-age models in the NOAA Fisheries Toolbox (e.g., AMAK, ASAP, BAM, and SS3; https://www.nefsc.noaa.gov/nft/index.html).

The PSTAT discussed the possibility of learning from or using OM components from the SPASAM group, though it may be too early to know how much overlap between these two groups may be possible.

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Appendices

Appendix 1

Meeting Agenda

International Sablefish Workshop

Date: Thursday, 26 April and Friday, 27 April 2018

Location: UW School of Fisheries (Room 106)

Objectives

- Discuss range-wide sablefish data, assessment methods, and sablefish abundance trends
- Reach consensus on a collaborative plan to better understand the population dynamics of sablefish stocks range-wide
- Examine the feasibility of a range-wide sablefish stock assessment

Outputs

- Workshop report summarizing meeting presentations and discussions, and potential collaborative efforts and implications of range-wide sablefish analyses
- Summary work plan for range-wide sablefish analyses, including a prioritized list of unfunded research needs that would help with the unified modeling work

Agenda: Day 1

Start time	**Subject**
8:30a	Roundtable introductions
8:45a	Review, revise, adopt agenda Objectives and outputs
9:00a	Existing assessment methods and models: U.S. West Coast / NWFSC • Review existing sablefish data and assessment methods (e.g., how and how frequently do you assess, model type and platform, what are key data sources, recent trends, tagging programs overview, etc.) • Q&A
9:30a	Existing assessment methods and models continued: British Columbia / DFO and Simon Fraser University
10:00a	BREAK
10:15a	Existing assessment methods and models continued: Alaska / ADFG
10:45p	Existing assessment methods and models continued: Alaska / AFSC
11:15p	Across-region summary and general discussion
11:30p	LUNCH (group lunch nearby)
12:30p	Stock-wide model development • Strategic considerations (e.g., what are our specific research questions?; what are benefits to collaboration?; sticking points?)
1:30 p	Stock-wide model development continued… • Technical considerations (e.g., model structure and type, data inputs, movement, key assumptions and sensitivities to explore)
2:15p	BREAK
2:00p	Stock-wide model development continued… • Logistical considerations (e.g., data sharing agreements, workplan, communications and funding opportunities)
4:00 p	Review & summarize day’s progress
4:30p	ADJOURN

Agenda: Day 2

Start time	Subject
8:30a	Recap of day 1 • Overview of day 2 agenda
9:00a	Treatment of data sources • Discussion on if and how to use and model range wide data (e.g., biological data)
10:00a	BREAK
10:15a	Treatment of data sources continued…
11:30a	LUNCH
12:30p	Current and proposed research updates – U.S. West Coast / NWFSC • Brief presentations on each partners ongoing, recently completed and proposed research • Q&A
12:50	Current and proposed research updates continued… – British Columbia / DFO and Simon Fraser University
1:10	Current and proposed research updates continued… – Alaska / ADFG
1:30	Current and proposed research updates continued… – Alaska / AFSC
2:00p	BREAK
2:30p	Wrap up discussion • Action items, next steps, final reflections
3:30p	ADJOURN

Appendix 2

Meeting Participants

Aaron Berger, Northwest Fisheries Science Center, USA

Brendan Connors, Department of Fisheries and Oceans, Canada

Jason Cope, Northwest Fisheries Science Center, USA

Sean Cox, Simon Fraser University, Canada

Kari Fenske, Alaska Fisheries Science Center, USA

Melissa Haltuch, Northwest Fisheries Science Center, USA

Dana Hanselman, Alaska Fisheries Science Center, USA

Maia Kapur, Pacific Islands Fisheries Science Center, USA

Lisa Lacko, Department of Fisheries and Oceans, Canada

Chris Lunsford, Alaska Fisheries Science Center, USA

Cara Rodgveller, Alaska Fisheries Science Center, USA

Ben Williams, Alaska Department of Fish and Game, USA

Additional participants in follow-up conference calls:

Michelle Jones, Simon Fraser University, Canada, and Oregon Department of Fish and Wildlife, USA.

Appendix 3

Glossary of Terms and Acronyms Used in This Document

ABC: Acceptable biological catch. See below.

Acceptable biological catch (ABC): The acceptable biological catch is a scientific calculation of the sustainable harvest level of a fishery used historically to set the upper limit for fishery removals by the U.S. Fishery Management Councils. It is calculated by applying the estimated (or proxy) harvest rate that produces maximum sustainable yield (MSY, see below) to the estimated exploitable stock biomass (the portion of the fish population that can be harvested).

AFSC: Alaska Fisheries Science Center (National Marine Fisheries Service). One of five regional federal fisheries Science Centers with research facilities in Seattle, Washington, but with laboratories in Kodiak and Juneau, Alaska, and Newport, Oregon. Provides the scientific information and analysis necessary for the conservation, management, and utilization of Alaska's living marine resources.

B40%: The level of female spawning biomass corresponding to 40% of unfished equilibrium female spawning biomass, i.e. $B_{40\%} = 0.4\ B_0$.

B.C.: British Columbia, Canada.

BMSY: The estimated female spawning biomass which theoretically would produce the maximum sustainable yield (MSY) under equilibrium fishing conditions (constant fishing and average recruitment in every year). Also see $B_{40\%}$ (above).

Catch-per-unit-effort (CPUE): A raw or (frequently) standardized and model-based metric of fishing success based on the catch and relative effort expended to generate that catch. Catch-per-unit-effort is often used as an index of stock abundance in the absence of fishery independent indices and/or where the two are believed to be proportional.

Closed-loop simulation: A subset of an MSE that iteratively simulates a population using an operating model, generates data from that population and passes it to an estimation model, uses the estimation model and a management strategy to provide management advice, which then feeds back into the operating model to simulate an additional fixed set of time before repeating this process.

CPUE: Catch-per-unit-effort (see above).

CV: Coefficient of variation. A measure of uncertainty defined as the standard deviation (SD, see below) divided by the mean.

DFO: Department of Fisheries and Oceans (Canada). See Fisheries and Oceans Canada.

F: Instantaneous rate of fishing mortality (or fishing mortality rate); see below.

Fishery Management Councils: Eight regional Fishery Management Councils are the basis for federal fisheries management in the United States.

F_{SPR} = 40%: The rate of fishing mortality estimated to give a spawning potential ratio (SPR, see below) of 40%. Therefore, by definition this satisfies 0.4 = spawning biomass per recruit with F_{SPR} = 40% spawning biomass per recruit with no fishing, and SPR(F_{SPR} = 40%) = 40%.

Female spawning biomass: The biomass of mature female fish at the beginning of the year. Sometimes abbreviated to spawning biomass.

Fisheries and Oceans Canada: Federal organization which delivers programs and services that support sustainable use and development of Canada's waterways and aquatic resources.

F_{MSY}: The rate of fishing mortality estimated to produce the maximum sustainable yield (MSY) from the stock.

Harvest strategy: A formal system for managing a fishery.

Harvest control rule (HCR): A process for determining an ABC from a stock assessment. Also see default harvest policy (above).

Magnuson-Stevens Fishery Conservation and Management Act: The MSFCMA, sometimes known as the “Magnuson-Stevens Act”, established the 200-mile fishery conservation zone, the regional fishery management council system, and other provisions of U.S. marine fishery law.

Management Strategy Evaluation (MSE): A formal process for evaluating Harvest Strategies (see above).

Markov-Chain Monte-Carlo (MCMC): A numerical method used to sample from the posterior distribution (see below) of parameters and derived quantities in a Bayesian analysis. It is more computationally intensive than the maximum likelihood estimate (see below), but provides a more accurate depiction of parameter uncertainty.

Maximum sustainable yield (MSY): An estimate of the largest sustainable annual catch that can be continuously taken over a long period of time from a stock under equilibrium ecological and environmental conditions.

MCMC: Markov-Chain Monte-Carlo (see above).

MSE: Management Strategy Evaluation (see above).

MSY: Maximum sustainable yield (see above).

NA: Not available.

National Marine Fisheries Service: See NOAA Fisheries below.

NMFS: National Marine Fisheries Service. See NOAA Fisheries below.

NPFMC: North Pacific Fishery Management Council (NPFMC):): One of eight regional fishery management councils established by the Magnuson Fishery Conservation and Management Act of 1976. Responsible for setting management regulations for Alaska federal sablefish fisheries.

NOAA Fisheries: The division of the U. S. National Oceanic and Atmospheric Administration (NOAA) responsible for conservation and management of offshore fisheries (and inland salmon). This is also known as the National Marine Fisheries Service (NMFS), and both names are commonly used at this time.

NWFSC: Northwest Fisheries Science Center (National Marine Fisheries Service).). One of five regional federal fisheries Science Centers with research facilities in Seattle, Washington, and with a laboratory and Newport, Oregon. Provides the scientific information and analysis necessary for the conservation, management, and utilization of west coast (WC) living marine resources.

Operating Model (OM): A model used to simulate data for use in the MSE (see above). The operating model includes components for the stock and fishery dynamics, as well as the simulation of the data sampling process, potentially including observation error. Cases in the MSE represent alternative configurations of the operating model.

OM: Operating Model (see above).

Pacific Fishery Management Council (PFMC): One of eight regional fishery management councils established by the Magnuson Fishery Conservation and Management Act of 1976. Responsible for setting management regulations for west coast (WC) sablefish fisheres.

R_0: Estimated annual recruitment at unfished equilibrium.

SD: Standard deviation. A measure of variability within a sample.

Simulation: A model evaluation under a particular state of nature, including combinations of parameters controlling stock productivity, stock status, and the time series of recruitment deviations.

Spawning biomass: Abbreviated term for female spawning biomass (see above).

Spawning biomass per recruit: The expected lifetime contribution of an age-0 recruit, calculated as the sum across all ages of the product of spawning biomass at each age and the probability of surviving to that age.

Spawning potential ratio (SPR): The ratio of the spawning biomass per recruit under a given level of fishing to the estimated spawning biomass per recruit in the absence of fishing; i.e. for fishing mortality rate *F*, SPR(*F*) = spawning biomass per recruit with *F* spawning biomass per recruit with no fishing. Often expressed as a percentage, it achieves a value of 100% in the absence of fishing and declines toward zero as fishing intensity increases.

SPR: Spawning potential ratio (see above).

$SPR_{40\%}$: See target spawning potential ratio.

SS: Stock Synthesis (see below).

Steepness (*h*): A stock-recruit relationship parameter representing the proportion of R_0 expected (on average) when the female spawning biomass is reduced to 20% of B_0.

Stock Synthesis (SS): The age-structured stock assessment model used for stock assessments in some regions.

t: Metric ton(s). A unit of mass (often referred to as weight) equal to 1,000 kilograms or 2,204.62 pounds. Previous stock assessments used the abbreviation “mt” (metric tons).

TAC: Total allowable catch (see below).

Total allowable catch (TAC): The maximum fishery removal allowed.

U.S.: United States.

WC: west coast (of the United States), defined here as the U.S. states of Washington, Oregon, and California.

Year class: A group of fish born in the same year. See also ‘cohort’ and ‘recruitment’.

Appendix 4

Management History by Region

Northwest Fisheries Science Center

Summary of Key Events in the Sablefish Fishery and Management History

Year	Source
1942 - 1946	Market demands likely increase retention of previously unmarketable sablefish.
1955	First minimum size limit (26 inches, in OR and WA, later removed).
1982	First trip limits imposed on the trawl fishery.
1983	22-inch minimum size limit north of Point Conception (allowance for some smaller fish).
1990-1993	Increasingly shorter fixed-gear seasons.
1997-1999	Sequential reductions in landings limits begin.
2003	Rockfish conservation areas close large portions of the shelf to trawling and fixed-gear fleets.
2004	Implementation of the West Coast Trawl Buyback Program.
2011	Rationalization of the Limited Entry trawl sector.

Fisheries and Oceans Canada

Summary of Retained Landings and Management for British Columbia

Year	Retained landings(t)	Management measures and other events of note
1945 -		Application of weight-based size limits introduced, that when converted to fork length effectively created a 63 cm fork length limit; a 54 cm fork length in 1965 and by 1977 the current regulated size limit of 55 cm fork. By regulation, sub-legal sablefish must be released at-sea by all license categories
1977 -		Establishment of the Canadian 200-mile Economic Exclusion Zone that resulted in departure of foreign fleets fishing sablefish in Canadian waters by 1981. Establishment of total allowable catch management.
1981	3830	Introduction of license limitation which created 49 license holders fishing either longline trap or longline hook gear. Currently 48 licenses are available. A fixed allocation of 8.75% of the Sablefish TAC is assigned to the trawl sector, based on historical average trawl landings.
1982	4028	
1983	4346	
1984	3827	
1985	4193	
1986	4449	
1987	4630	
1988	5403	
1990	4905	Introduction of Individual Transferable Quota management to Sablefish license sector
1991	5112	
1992	5007	
1993	5110	
1994	5002	Voluntary cessation of directed fishing for sablefish in mainland inlets because inlets are considered to be rearing areas for juveniles.
1995	4179	

1996	3471	Introduction of fishery-independent at-sea observers to the trawl fleet which resulted in improved accounting for retained and released catches, including catches of sablefish.
1997	4142	
1998	4592	
1999-00	7012	Changes to the definition of a fishing “year”, including adjustments to start and end dates and to the length of the fishing year. These changes often resulted in sablefish fishing years which did not coincide with the calendar year.
2000-01	3884	
2001-02	3075	
2002-03	2206	
2003-04	2983	
2004-05	4249	
2005-06	4498	
2006-07	4004	Introduction of electronic at-sea catch monitoring to the non-trawl groundfish fleets, including the sablefish licensed fleet
2007-08	3429	
2008-09	1514	
2009-10	2159	
2010-11	2396	
2011-12	2142	
2012-13	1962	
2013-14	1844	
2014-15	1751	
2015-16	1823	
2016-17	1761	
2017-18	1565	

Alaska Fisheries Science Center

Summary of management measures with time series of catch, ABC, OFL, and TAC.

Year	Catch (t)	OFL	ABC	TAC	Management measure
1980	10,444			18,000	Amendment 8 to the Gulf of Alaska Fishery Management Plan established the West and East Yakutat management areas for sablefish.
1981	12,604			19,349	
1982	12,048			17,300	
1983	11,715			14,480	
1984	14,109			14,820	
1985	14,465			13,480	Amendment 14 of the GOA FMP allocated sablefish quota by gear type: 80% to fixed gear and 20% to trawl gear in WGOA and CGOA and 95% fixed to 5% trawl in the EGOA.
1986	28,892			21,450	Pot fishing banned in Eastern GOA.
1987	35,163			27,700	Pot fishing banned in Central GOA.
1988	38,406			36,400	
1989	34,829			32,200	Pot fishing banned in Western GOA.
1990	32,115			33,200	Amendment 15 of the BSAI FMP allocated sablefish quota by gear type: 50% to fixed gear in and 50% to trawl in the EBS, and 75% fixed to 25% trawl in the Aleutian Islands.
1991	26,536			28,800	

1992	24,042			25,200	Pot fishing banned in Bering Sea (57 FR 37906).
1993	25,417			25,000	
1994	23,580			28,840	
1995	20,692			25,300	Amendment 20 to the Gulf of Alaska Fishery Management Plan and 15 to the Bering Sea/Aleutian Islands Fishery Management Plan established IFQ management for sablefish beginning in 1995. These amendments also allocated 20% of the fixed gear allocation of sablefish to a CDQ reserve for the Bering Sea and Aleutian Islands.
1996	17,393			19,380	Pot fishing ban repealed in Bering Sea except from June 1-30.
1997	14,607	27,900	19,600	17,200	Maximum retainable allowances for sablefish were revised in the Gulf of Alaska. The percentage depends on the basis species.
1998	13,874	26,500	16,800	16,800	
1999	13,587	24,700	15,900	15,900	
2000	15,570	21,400	17,300	17,300	
2001	14,065	20,700	16,900	16,900	
2002	14,748	26,100	17,300	17,300	
2003	16,411	28,900	18,400	20,900	
2004	17,520	30,800	23,000	23,000	
2005	16,585	25,400	21,000	21,000	

2006	15,551	25,300	21,000	21,000	
2007	15,958	23,750	20,100	20,100	
2008	14,552	21,310	18,030	18,030	Pot fishing ban repealed in Bering Sea for June 1-30 (74 FR 28733).
2009	13,062	19,000	16,080	16,080	
2010	11,931	21,400	15,230	15,230	
2011	12,978	20,700	16,040	16,040	
2012	13,869	20,400	17,240	17,240	
2013	13,645	19,180	16,230	16,230	
2014	11,588	16,225	13,722	13,722	
2015	10,973	16,128	13,657	13,657	NPFMC passes Amendment 101 to allow pot fishing in the GOA
2016	10,257	13,397	11,795	11,795	Whale depredation accounted for in survey and fishery
2017	10,670	15,428	13,083	13,083	Pot fishing begins in the GOA

Appendix 5

Assessment Model Parameter Values

The parameter values in the table below were compiled for the PSTAT workshop, and reflect the parameter estimates or fixed values from each regions sablefish stock assessment

Parameter	Sex	Alaska Federal	Alaska State	British Columbia	U.S. West Coast
Length-at-age (cm)					
linf	F	80.20	85.16	72.00	
vbk	F	0.22	0.09	0.25	
t0	F	1.95	-9.08	32.50	
linf	M	67.80	69.09	68.00	
vbk	M	0.29	0.12	0.29	
to	M	2.27	-8.82	32.50	
Length-weight (cm/kg)					
a	F	2.99E-06	8.32E-06	4.95E-06	3.27E-06
b	F	3.30	3.06	3.18	3.28
a	M	2.99E-06	1.12E-05	8.16E-06	3.33E-06
b	M	3.30	2.99	3.06	3.27
Weight-at-age (kg)					
winf	F	5.50	6.40		
vbk	F	0.24	0.10		

t0	F	-1.39	-7.38		
beta	F	3.00	0.29		
winf	M	3.20			
vbk	M	0.36			
t0	M	-1.11			
beta	M	3.00			
Mortality					
M	F	0.097		0.104	0.076
M	M	0.097		0.058	0.062
Maturity-at-age (logistic)					
a50	F	6.60		5	
delta	F	0.84			
a50	M			5	
delta	M				
Maturity-at-length (logistic)					
l50	F	65			58
delta	F	0.40			-0.13
l50	M	57			
delta	M	0.40			
Stock Synthesis length-at-age					
L_at_Amin_Fem_GP_1	F				26.149
L_at_Amax_Fem_GP_1	F				64.2267
VonBert_K_Fem_GP_1	F				0.326784
CV_young_Fem_GP_1	F				0.078497

CV_old_Fem_GP_1	F	0.118391
L_at_Amin_Mal_GP_1	M	0
L_at_Amax_Mal_GP_1	M	56.2739
VonBert_K_Mal_GP_1	M	0.415657
CV_young_Mal_GP_1	M	0
CV_old_Mal_GP_1	M	0.0779401

Appendix 6

Sablefish Workshop Summary, 2007

"Sablefish issues aren't just black and white"

Sablefish Workshop Summary

February 21-23, 2007

Seattle, Washington

Introduction

In 1983 and 1993, sablefish (*Anoplopoma fimbria*) symposia were held that brought together scientists to share information and discuss future needs of sablefish research in the North Pacific. In 2004 a meeting was called at the Western Groundfish Conference to discuss the formation of a sablefish working group which would work to organize a third sablefish symposium. In the interim, an informal sablefish workshop was held 21-23 February 2007 at the Alaska Fisheries Science Center in Seattle. The purpose of the workshop was to bring together sablefish assessment scientists from the United States and Canada to exchange information, to describe ongoing work, to identify new avenues for research, and to investigate cooperative research opportunities.

Twelve participants attended the meeting representing the Alaska Fisheries Science Center, Northwest Fisheries Science Center, Alaska Department of Fish and Game, Fisheries and Oceans Canada, Sigma Plus Consulting, and Simon Fraser University. Each agency provided general overviews of the sablefish stocks, fisheries, and management in their respective jurisdictions. Roundtable discussions were held that focused on specific topics such as stock assessment, survey methodologies, life history studies, harvest strategy evaluations, and recruitment processes. What follows is a summary of the presentations and recommendations of the workshop participants for future research.

Fishery Management

Overview by Region

National Marine Fisheries Service - Alaska Federal (NMFS – Alaska)

The Alaska Fisheries Science Center (AFSC) presented an overview of sablefish fishery and management activities in the federally managed Alaska Exclusive Economic Zone (EEZ). Heavy fishing by foreign vessels during the 1970’s led to a substantial decline in sablefish stocks in Alaska, which prompted fishery regulations and sharply reduced catches. The U.S. longline fishery began expanding in 1982 in the Gulf of Alaska, and in 1988 the fishery harvested all sablefish taken in Alaska, except minor joint venture catches.

The federally managed fishery in Alaska went to Individual Fishing Quota (IFQ) management in 1995. Quota shares were assigned initially to vessel owners or leaseholders who made at least one landing in the years 1988-1990. Each year, IFQs are assigned to individuals by multiplying the percentage of quota share they own by the annual harvest limit set for the sablefish fishery. Recent quotas have been near 20,000 metric tons (t). The majority of the sablefish catch comes from the eastern and central Gulf of Alaska, but the fishery also operates in the western Gulf of Alaska, Bering Sea, and Aleutian Islands. Fixed gear harvests approximately 85% of the sablefish quota and trawl gear approximately 15%. Pot fishing is banned in the GOA but is allowed in the Bering Sea and Aleutian Islands and accounts for nearly half of the IFQ catch in those areas. The sablefish fishery in Alaska is primarily a small boat fishery with nearly 400 vessels, and the season lasts from approximately 1 March – 15 November. Fishery data are collected by fishery observers and through required and voluntary logbook programs. Harvests are strictly regulated and documented through IFQ landing reports and ADF&G fish tickets. Scientific data from the fishery are limited since fishery observers are not required on vessels under 60 ft. Vessels over 60 ft are required to carry a fishery observer at least part of the time and are required to submit fishery logbooks. Data from vessels less than 60 ft come from landing tickets and a voluntary fishery logbook program.

The North Pacific Fishery Management Council (NPFMC) has established harvest rules that rely on biological reference points including fishing mortality and stock biomass levels to determine the status of the stock and subsequent harvest levels. Sablefish are managed under Tier 3 of NPFMC harvest rules, which assume reliable point estimates of fishing mortality and stock biomass levels are known. Each year a Stock Assessment and Fishery Evaluation report (SAFE) (http://www.afsc.noaa.gov/refm/stocks/assessments.htm) is prepared and reviewed for sablefish under the Guidelines for Fishery Management Plans published by NMFS (http://www.publicaffairs.noaa.gov/releases2005/jun05/noaa05-082.html). This SAFE report summarizes biological and analytical results about sablefish stock status and includes acceptable biological catch (ABC) and overfishing level (OFL) recommendations for future years. The authors present their findings to the NPFMC Groundfish Plan Teams in September and November for initial review. Plan Team recommendations are then submitted to the NPFMC Scientific and Statistical Committee (SSC) for further review and final recommendations on ABC before final decisions on total allowable catches (TAC) and allocations are made by the NPFMC.

Many sablefish research activities are ongoing at the AFSC in addition to producing annual SAFE reports. A migration model is currently being updated to include recent tagging data and help address sablefish movement in Alaska and potentially help address quota apportionment by regions. Pot fishing has increased dramatically since 2000 in the Bering Sea and Aleutian Islands, and management and stock assessment concerns exist related to cannibalism in pots, escape ring sizes, soak times, and the effectiveness of biodegradable escape panels. Sablefish stomachs are currently being examined in the pot fishery for evidence of cannibalism. New research using satellite technology and physical oceanography are being investigated to better understand recruitment and help estimate the strength of year classes before they become available to the fishery. Parameters such as natural mortality, growth, and age at maturity are being investigated and values from older studies are being updated with new information. Finally, incorporating ecosystem considerations into stock assessments is continually evolving and improving our knowledge of sablefish and their interactions with other species and the environment.

Alaska Department of Fish and Game – State of Alaska, Southeast Alaska Sablefish (ADF&G)

The ADF&G presented an overview of the sablefish fishery and sablefish research activities for Southeast Alaska. There are two fisheries in the internal waters of southeast Alaska open to sablefish fishing, Chatham Strait, and Clarence Strait. Both areas are managed as equal quota share fisheries, and both have a longline hook survey. The Chatham Strait area has the longer fishing history compared to Clarence Strait and receives far more research and management attention.

Commercial fishing has been documented in Chatham Strait since 1867. From 1985 to 1993, Chatham was managed under a limited entry program with quotas around 2.2 million round pounds; total catches ranged from 3 to 6 million round pounds. Since 1994 the Chatham fishery has been managed under a shared quota system. Adherence to quotas has improved; however quotas declined from about 4.1 million round pounds in 1994 to just over 2 million round pounds in 2006, in response to declining abundance.

Research and stock assessment activities began in 1980. The Department has conducted a longline survey for CPUE, a pot survey for releasing tagged fish, monitored CPUE and catch locations of the fishery, enumerated the abundance of marked and unmarked fish from fishery landings, and collected biological samples (length, weight, otoliths, sex, and sexual maturity) from the fishery, longline survey, and pot survey. Since 2000, the gear configuration and soak time of the longline survey has been comparable to that of NMFS in the Gulf of Alaska. Since 1997, the Department has released fish with Floy tags, PIT tags, sonic tags, and/or fin clips. Tagging was originally done on the longline survey, but due to concerns over hook-shyness, marked fish have been released from pot surveys since 2000.

The ADF&G manages all sablefish inside of the 3-mile state waters of Alaska as mandated by the Magnuson-Stevens Act. State sablefish fisheries occur in the Aleutian Islands, Cook Inlet, Prince William Sound, and Chatham Strait and Clarence Strait in Southeast Alaska. Ranges of catch in the different regions are between about 40,000 kg in Cook Inlet to one million kilograms in Chatham Strait. Longlining is the primary harvest method used in the state fishery, but there is some pot fishing in Clarence Strait and the Aleutian Islands. Fishery data comes from logbooks and landing reports.

Since statehood, the Chatham fishery has occurred in the late summer and fall. In 2004 and 2005 the Department allowed early season fishing in January, February and April.

Information regarding length frequency, maturity and ages (not yet analyzed) was collected from commercial fishing vessels that fished in the off season and carried a Department observer aboard. The initial results of the sampling indicate that February is the peak of the spawning period, but that very few ripe females were captured in late January and early February. Additionally, a broader size distribution of fish was caught during these off season fishing events than were caught during the regular fishing season.

Currently ADF&G is collecting histological information for Chatham sablefish and will continue to collect samples during the winter spawning season. This will be used in part to attempt to validate macroscopic maturity assessment. Future work for the Department will also include trying to answer questions about spawning location, behavior, and timing. Detailed bathymetry and backscatter information collected by NOAA will be available to ADF&G for Chatham Strait at the end of 2007. With that information ADF&G will be able to better describe and quantify sablefish habitat in Chatham Strait.

Department of Fisheries and Oceans – British Columbia (DFO - BC)

Canadian sablefish are managed under the auspices of a collaborative agreement between Fisheries and Oceans Canada and the Canadian Sablefish Association. An Individual Vessel Quota (IVQ) management system was instituted in 1990 for the sablefish fishery where the directed catch is allocated in proportion to quota owned. There are forty-eight IVQ licenses in the directed fishery. An allocation of 8.75% of the total allowable catch accommodates sablefish bycatch in the multi-species trawl fishery. The fishery is managed as one geographic unit and occurs along the entire coastline, except that no directed fishery exists in coastal inlets. The directed sablefish fishery is primarily a longline trap (80%) and longline hook fishery. Average catch over the last 30 years is approximately 4,200 t with a minimum size limit of 55 cm fork length for all gear sectors. Fishery data is collected through mandatory logbooks, observer coverage in the trawl fishery, and mandatory dockside validation for all sectors. Starting in 2006 there is also mandatory at-sea camera coverage as a component of the Groundfish Integration Pilot Program. The Groundfish Integration Program is designed to provide comprehensive catch reporting by species and quota management through at-sea monitoring of catch, mandatory dockside validation, and the requirement to own or lease quota to cover the catch of all quota-managed groundfish species. Quota shares for species groups are attained by purchase or trading among license holders and can occur between gear sectors.

National Marine Fisheries Service – West Coast US (NMFS – West Coast)

The Northwest Fisheries Science Center assesses all sablefish in U.S. offshore waters from northern Washington to southern California. The sablefish stock size has decreased since the 1940s. Fishery landings in 1990 were about 10,000 t but have decreased to about 5,500 t. The three gear types participating in the sablefish fishery are trawl, hook-and-line, and pot gear. A coast-wide ABC exists, but there are tribal allocations as well as gear allocations (~45% trawl and ~45% fixed). The trawl fleet is managed primarily through bi-monthly trip limits whereas multiple regulations are used to manage the fixed gear fleet. Fishery data comes primarily from fishery observers and logbooks. Observer coverage for the trawl fishery is approximately 20-30% and for the hook-and-line fishery approximately 10%.

Overarching Issues and Recommendations

Whale depredation

Whale depredation is a major issue for the sablefish hook-and-line fishery in Alaska. Killer whales have depredated longline gear for many years in the Bering Sea, Aleutian Islands, western Gulf of Alaska, and Prince William Sound. Killer whale depredation is not prevalent in Chatham Strait or Frederick Sound. Sperm whale depredation has become very prevalent in the eastern and central Gulf of Alaska. Whale depredation in BC has not been reported as a major concern, possibly because the majority of fishing is done using trap gear and resident whales in B.C. may not have acquired the learned behavior. However, predation on newly released tagged fish by marine mammals has been observed. Current research regarding sperm whale depredation is being done by the AFSC and the SEASWAP project http://www.seaswap.info/index.html out of Sitka, Alaska.

Pot Regulations

Pot fishing in the Alaska federal IFQ fishery is banned in the Gulf of Alaska but has increased greatly since 2000 in the Bering Sea and Aleutian Islands. Recent attention has been given to pot fishing regulations in Alaska. Regulatory issues such as escape ring and biodegradable escape panel requirements have been raised in addition to biological concerns such as cannibalism in pots. In 2006, the NPFMC requested that NMFS Alaska sablefish researchers conduct studies to address these issues. In British Columbia, pots (more properly called traps) have been used for years in the sablefish fishery and are the primary gear type in the directed fishery. Pots have also been used for years in the U.S. West Coast fishery and are allowed in some ADF&G managed fisheries. The group discussed the pot fisheries in those areas and the range of regulations that have been applied.

DFO scientists noted that escape rings were introduced voluntarily by the industry in 1997 and by regulation in 1998 to increase the efficiency of their fishing operation, increase the size of retained fish, and promote stock health. The regulation specified that a 3-1/2 in diameter plug must be able to pass through the opening. Fishermen/DFO scientists noted fish of specific sizes being gilled in the escape rings. This phenomenon has initiated experimentation with escape ring shapes and construction on the part of the industry. Originally metal rings constructed from 3/16 to 1/4 inch diameter stainless steel stock were tied into the trap mesh to serve as escape rings. The twine resulted in a rough inside diameter and decreased the inside diameter of the ring; this may contribute to fish becoming gilled or reducing the size of fish that can escape via the rings. Alternative ring material such as a ring milled from 3/4 inch thick acrylic stock (like cutting board material) were tried, with a groove milled around the ring to enable attachment to the trap mesh. This provided a smooth inside surface and the increased width of material appears to reduce gilling. Openings made from polyethylene board with outer holes for rigging also provided a smooth opening and decreased gilling. Regardless of the design, escape rings with a minimum 3-1/2 inch diameter have been required by regulation since 1998, and their use was initiated, and strongly supported by the industry.

Biodegradable panels are also required by law in the Canadian sablefish fishery. Canadian researchers found that a rectangular panel with biodegradable twine on three sides was more effective for “rot” panels than a single slash sewn shut with biodegradable twine. Note that ADF&G also requires biodegradable panels to be used in all groundfish pots. ADF&G regulations require a single slash 18 inches in length in the pot sidewall that is laced with biodegradable cotton twine. The group agreed a biodegradable “rot” panel is likely an effective way to reduce the biological consequences of ghost fishing.

Workshop participants discussed previous experience with studies that examined the effectiveness of escape rings. Testing escape ring sizes, or effectiveness, is complicated because conducting experiments which enumerate the fish that escape from the traps is difficult. Canadian researchers have conducted escape ring studies but cautioned that objectives need to be clear and numerous replicates are necessary. To successfully measure the effectiveness of escape rings, methodologies must allow for all fish to be retained including those that exit the pot through the escape ring. The group also cautioned that possibly undesirable sex-specific selectivity may result from the use of escape rings because larger female sablefish are more likely to be retained.

The group agreed the potential for cannibalism of small fish in pots is low. Preliminary results from a study done in 2006 in the Bering Sea indicate that the minimum size of sablefish caught in pots was 40cm and that no cannibalism was recorded. Canadian researchers concurred that despite not doing any directed cannibalism studies many stomach content analyses have been performed, and cannibalism has never been documented. Smaller sablefish (< 40 cm) are also rare in trap catches in British Columbia.

The working group lauded the initiative of the Canadian fishermen to take responsibility for such an aspect of their operation rather than require regulatory inducements to improve the benefits from the stock. The Canadian scientists agreed that the Canadian industry has shown pro-active behavior with respect to many aspects of the sablefish fishery.

Survey Descriptions/Issues

Overview by Region

NMFS - Alaska

Since 1978, the U. S. National Marine Fisheries Service (NMFS), Alaska Fisheries Science Center (AFSC) has conducted annual longline surveys with Japan (Japan-U.S. cooperative longline survey, 1978-94) and alone (1987-present, domestic longline survey). The survey has covered the upper continental slope (1978-present) and selected gullies (1987-present) of the Gulf of Alaska and the upper continental slope of the eastern Bering Sea (1982-94, biennially since 1997) and Aleutian Islands region (1980-94, biennially since 1996). A unique aspect of this survey is that the charter vessel retains most of the catch as compensation after the scientific data are recorded, which reduces government costs. The survey is conducted by catcher processors that retain the catch, while providing vessel, fuel, fishing crew, contract biologists, bait, and gear. NMFS provides the chief scientist and data processing equipment. It is a fixed station survey, covering the upper continental slope of the Gulf of Alaska annually and alternating each year between the Aleutian Islands and the Bering Sea. The survey is conducted each year by one vessel, occurs in the summer, and samples 87 stations taking approximately 3 months to complete. The survey objectives are to determine the relative abundance and size composition of commercially important species including sablefish, determine migration patterns of sablefish by tagging, and determine the age composition of sablefish through otoliths collections. The longline survey is the primary data input for the sablefish stock assessment used to manage the Alaska fishery within the EEZ.

The survey subsamples for length, age, maturity, and sex composition and tags fish in each area surveyed. The current survey uses 2 m spaced circle hooks hand-baited with squid.

Catch rates are used to compute area weighted catch per unit effort values, which are treated as relative abundance indices in the stock assessment and area apportionments.

NMFS has also conducted a multispecies groundfish trawl survey every 2-3 years in the Aleutian Islands and the Gulf of Alaska. A trawl survey is conducted in the Bering Sea shelf every year. This survey provides an absolute biomass index for each area and collects lengths and weights of sablefish. The stock assessment has recently begun incorporating shelf trawl survey information to supplement assessment of pre-recruit sablefish, which occur frequently in areas inshore of the longline survey area.

Survey concerns:

1. Killer and sperm whale depredation occurs on the survey gear. Killer whale depredation is easily detected and at current levels of depredation affected stations can be excluded from analyses. Sperm whale depredation is difficult to detect, but the effect on catch rates is estimated to be small.
2. Larger vessels, including those that conduct the survey, are changing to auto-bait systems. Our ability to maintain the same gear and hand-baiting method in future surveys is a concern.
3. Hook competition is noted between sablefish and other species taken on the survey. Continued research is planned to evaluate the effect on the estimation of relative abundance from survey data.
4. Survey data collection improvements are being investigated, particularly progressing towards more electronic data collection.

ADF&G

A longline survey was started in the primary fishery area of Chatham Strait in 1988 and has continued to present. Survey stations were randomly placed and remain constant from year to year. The geographic coverage of the longline survey was increased in 1989 and 1997. Catch rates, age, size, sex, and maturity are obtained. Various changes to the survey have occurred over the years, such as soak time, vessel sources, longline type (snap vs. fixed), effort per station, and bait type (herring to squid). Longline survey CPUE is a relative index of abundance that has been used as an aid in quota setting and has also been an input of age-structured models. The longline survey was also used to release marked fish from 1997 to 1999.

A pot survey was implemented in 2000 to release marked fish and has continued to present. Approximately 5,000-7,000 marked sablefish are released annually. Length measurements are collected on all fish. In addition, fish are subsampled for age, size, sex and maturity. Marked fish are recaptured during port sampling of commercial harvest. Mark-recapture or exploitation rate calculations based on tagged fish have provided the basis for the stock assessment since 2000.

Fisheries and Oceans Canada – B.C.

There are two surveys directed at sablefish that combine the functions of generating catch rate based abundance indices, release of tagged sablefish, and biological sampling. These surveys utilize sets of 25 traps with escape rings sewn shut. Outputs from these surveys are used for stock assessment.

1. Standardized survey with stock indexing, tagging and inlets components:

- Traditional standardized trap survey series from 1990 to 2006. The survey is conducted in 9 localities, with one 25 trap string per 100 fm depth interval (50 – 650 fm). Soak time is 24 hours using squid as bait.

- Traditional tagging survey re-initiated in 1991. This survey is conducted in October - November at 11 offshore localities with tagging goals of 300-1,000 fish per area.
- Combined indexing and tagging sets in four mainland inlets. About half of the sablefish captured are tagged and released with the balance of the catch directed to biological samples.

2. Stratified random survey with stock indexing and tagging components:

- Stratified random trap survey to distribute tags randomly in 5 areas based on bathymetry and past fishing effort. Each area is stratified into 3 depth strata between 100–750 fms, with strata divided into 2 km by 2 km sampling units. In 2006, six replicates were achieved for each of the 15 combinations of area and depth strata. About one-third of the sablefish captures are tagged and released and one-third sacrificed for biological samples, with the balance surplus used for science needs.

Several multi-species groundfish trawl surveys have been initiated in the last three years. These surveys intercept sablefish but at this time it is not clear how useful they will be for stock assessment modeling. Divergence in catch rate time trends between the standardized survey and stratified random survey in the offshore zone suggest that the former may be sensitive to recruitment to the fishery.

NMFS–West Coast

The pot survey conducted since the early 1980s was discontinued in 1992. The current trawl survey began in the early 2000s to replace the previous triennial shelf survey and trawl slope survey conducted by the AFSC. The current survey is a stratified random block design with 15- minute tows. The survey was expanded to the Mexican border recently and is to be conducted annually depending on funding.

A recent pot study designed to estimate the proportion of population missed by restricting the trawl survey to 700 fm clearly indicated that the trawl survey is not reaching the full extent of sablefish population. Pot gear tended to catch more large sablefish than the trawl gear, due somewhat to availability differences as well as gear selectivity.

Survey concerns: Lack of a long-term time series and limited coverage of sablefish population by current survey.

Stock assessment

Overview by Region

NMFS – Alaska

The AFSC models the entire federally managed Alaska sablefish fishery as one population, integrating data from the Bering Sea, Aleutian Islands, and the Gulf of Alaska. This is done because analysis of tag recovery data has shown significant movement between areas implying that the existence of small, genetically unique stocks is unlikely. The model is sex-specific because males and females have different growth and maturity rates, and females attain higher maximum sizes. The model incorporates data from a variety of sources such as the historical Japanese longline survey and fisheries, the annual domestic NMFS longline survey, the biennial NMFS bottom trawl survey in the Gulf of Alaska, and the domestic fixed and trawl gear fisheries. The data provided by these sources include catch, relative abundance, age and length compositions, size-at-age, and maturity-at-age.

The model is a separable age-structured model coded in AD Model Builder, which uses a maximum likelihood and Bayesian approach to estimate parameters such as fishing mortality, absolute abundance, selectivity and catchability. The model is updated annually in conjunction with new longline survey and fishery data. The model is also used to project the population forward in time to calculate fishing mortality and quotas for subsequent years under various scenarios. These quotas are allocated to smaller management areas by computing a weighted 5-year average of survey and fishery catch rates by area. Bayesian MCMC methods are used to quantify the uncertainty of estimates. Current estimates show spawning biomass to be about 38% of unfished levels, which is close to the target of $B_{40\%}$.

ADF&G - Alaska

The ADF&G manages all sablefish fisheries inside of the 3-mile state waters boundary as mandated by the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). Sablefish management is a mosaic of different levels of complexity and techniques in sub-regions in the State of Alaska. Regional catches range between about 40,000 kg in Cook Inlet to one million kilograms in Chatham Strait. Area quotas have been historically set using different methods. Several area quotas are set as a proportion of the overall NMFS quota or have no assessment. By far the largest level of harvest and biomass occurs in the Southeast Alaska Region. Therefore, this area is where the most state sablefish assessment research has been focused. The Department has explored a number of different methods for biomass estimation and forecasting. Methods have included the Petersen mark-recapture estimator, exploitation rate estimators, and age structured models. In the recent past, they have estimated current-year biomass with mark-recapture data and the Petersen estimator. To forecast, they divided the overall abundance into abundance-by-age-class using the age composition from the longline survey, applied 10% mortality, assumed an equal number of age-4 recruits for the following year, and converted abundance to biomass using weight-at-age from the longline survey. To set annual quotas they applied an $F_{40\%}$ spawners-per-recruit harvest rate (same as AFSC) to the lower 90% confidence limit of the forecasted biomass. When these quotas are used for management, additional reductions are made to the recommended quota to account for bycatch from other fisheries and other estimated sources of mortality. The Department plans to continue mark-recapture studies. Despite difficulties with inconsistent age compositions over time and in accounting for fish movement in and out of Chatham Strait, the Department is revisiting the possibility of developing an age-structured assessment model for Chatham sablefish with the assistance of Franz Mueter.

DFO-B.C.

A wide variety of stock assessment models have been applied to B.C. sablefish data with 17 different models attempted over the last 20 years. In the late 1990s modeling complexity had progressed to an integrated mark-recapture age-structured model. Since that time the model was simplified to a monthly tagging model that incorporated several indices of stock abundance and was used to generate decision tables. The sablefish stock assessment team is now focused on evaluating management procedures and is conducting stakeholder consultation to refine fishery objectives. Unlike the situation in the United States, there is no legislative enactment like the MSFCMA in Canada that requires fisheries be managed to maximum sustained yield.

NMFS - West Coast

The Northwest Fisheries Science Center assesses all sablefish in U.S. offshore waters from northern Washington to Southern California. The assessment is based on data from bottom trawl surveys, pot surveys, and fishery data. These data include catch and discard mortality, logbook catch-per-unit-effort, relative abundance, age-and-length compositions, size-at-age and maturity-at-age. The sablefish assessment for the West Coast is one of the few that incorporates an environmental index to aid in estimating recruitment. This index is based on Northern coastal sea level and Ekman transport. This index is incorporated in the stock-recruit relationship where high sea level predicts warmer water in-shore and lower recruitment.

The West Coast assessment is updated every 3 years, the last update was in 2005. The assessment currently uses Stock Synthesis II (SS2), an AD Model Builder based package produced by Rick Methot that allows the assessment scientist to choose from a wide array of data sources, functional relationships and graphical outputs. The outputs of the model indicate that stock abundance is relatively low. Parameters that are difficult to estimate in the model are catchability and steepness of the stock-recruitment relationship. A tendency for steepness to gravitate toward 0.2 is suspected to reflect a change in productivity that has resulted in its current depleted status. Movement of sablefish between areas is suspected, but only limited tagging data is available to evaluate this hypothesis. Therefore, a spatially explicit model is intractable at this time. Harvest rates are computed at an $F_{45\%}$ SPR level, which is slightly more conservative than that used in Alaska. The SS2 package allows the use of prior distributions and Bayesian outputs such as the joint posterior distribution of natural mortality and catchability.

Overarching Issues and Recommendations

Model complexity and accessibility to stakeholders

The group recognized that stock assessments with more model complexity might work better under different management systems. In any system, the basic framework of the models needs to be understandable to all stakeholders involved. This does not preclude a complex age-structured assessment, but requires that the methods used be coherent, logical, and well documented so that stakeholders trust the results. In addition, different data sources are not always consistent. Complex models that integrate inconsistent data may be unstable due to a flat likelihood surface. The group noted that frequent changes to the structural components of the assessment model should be avoided to minimize confusion for fishery managers and stakeholders. While changing models is necessary when new concerns arise, in general a model should get to an acceptably reliable configuration and be applied over as long a period as possible. However, a proactive stock assessment scientist should make small, incremental improvements as new information comes to light.

Use of environmental indicators

The group acknowledged that using environmental data as a way to get upcoming recruitment information faster and more accurately is enticing, and the NMFS-West Coast efforts are laudable. However, the group recommended that any efforts to incorporate environmental indices into stock assessments should be preceded by a thorough understanding of biological mechanisms on recruitment, not strictly correlative success. In addition, it was proposed that any indices to be used in the stock assessment should be retrospectively tested to see if they would indeed result in more efficient management.

Communication and collaboration

The group indicated that much can be learned by meeting with other regions' assessment authors who often share similar or related issues. Some regions use quite different parameter estimates for life history quantities even though there may not be evidence to support that the fish are that different between areas. The group recommended that further collaboration concentrate on resolving or explaining these differences and the best ways to estimate certain parameters. The group also suggested that in the future, after data-sharing agreements have been put in place, a coast-wide assessment model might produce interesting and useful results.

Pot gear as an assessment concern

The group discussed the recent increase in pot gear in the Bering Sea and Aleutian Islands in Alaska. Assessment scientists agreed that the Alaska model is sufficiently complex, and that modeling pot gear and catch separately may lead to over-parameterization, given the marginal observer coverage on vessels with pot gear and that the model already estimates many selectivity curves.

Catch accounting and control rules

The group recognized that one of the most difficult issues for a stock assessment is the lack of good catch data. The group agreed that sablefish catch under IFQ systems are well estimated, but incidental catch and discards are less likely to be well measured. Once catch is well measured, then there must be a way to control catch to a level of biological sustainability. This should be done by having defined control rules to reduce fishing mortality when abundance appears to drop below some threshold. The group recommended that accounting for all fishing mortality, and having rules in place to control that mortality are the essential precursors to a successful stock assessment program.

Tagging, Movement, and Migration

Overview by Region

NMFS – Alaska

Sablefish have been tagged by the Japanese and NMFS surveys in Alaska in large numbers since 1978, with the exception of 1994 and 1995 when no adult tags were released. A total of about 330,000 tags have been released, with recent releases averaging around 5,000 per year. Approximately 12,000 tags have been recovered as of 2005. Presently, about 600 tags per year are being recovered. These recoveries have been primarily in Alaska waters, with a small percent recovered in Canada, and < 1% recovered on the U.S west coast.

A paper by Heifetz and Fujioka (1991) used a Markovian movement model to estimate migration between large management areas and into Canada. Their general conclusion based on model estimates was to support previously reported information that small fish move west and then return as they get larger to spawning locations in the Eastern Gulf of Alaska.

Recently, this model was recoded into AD Model Builder, which will be more amenable to the geometric growth of data, be easier to test more complex stock hypotheses, and more accurately account for uncertainty. Preliminary results from this model were shown to the group and showed that the conclusions were similar, but lend less support for a strong westerly movement of small fish (e.g. they are just as likely to move east or west). The model is capable of estimating movement rates to B.C., but does not have the required data to estimate rates from B.C. to Alaska.

Future plans are to attempt new movement hypotheses, with more dimensionality, and include smaller scale directional movement (e.g., inshore vs. offshore or radial directionality).

Eventually, this information may become important in Alaska for spatially-explicit stock assessment and apportionment of quotas.

Recently, this model was recoded into AD Model Builder, which will 1) be more amenable to the geometric growth of data, 2) allow more complex stock hypotheses to be tested, and 3) more accurately account for uncertainty. Preliminary results from this model were shown to the group and while results were similar to those found by earlier researchers, they provided less support for a strong westerly movement of small fish (e.g., they are just as likely to move east or west). The model is capable of estimating movement rates to B.C., but does not have the required data to estimate rates from B.C. to Alaska.

Future plans are to attempt new movement hypotheses, with more dimensionality, and include smaller scale directional movement (e.g., inshore vs. offshore or radial directionality). Eventually, this information may become important in Alaska for spatially-explicit stock assessment and apportionment of quotas.

ADF&G –Alaska

Alaska Department of Fish and Game has been tagging sablefish in Chatham Strait since the 1950s. ADF&G uses their tag-recovery data to both examine fish movement and to determine exploitation rates of the fishery. For a relatively small area, it was noted that there is a large amount of releases.

Recoveries from the 1970s and 1980s showed that roughly 12% of tags were found outside of Chatham Strait, while within the last 5 years only 1.5% have been found outside of Chatham Strait. NMFS data exist to show how many fish are moving into Chatham, but they have not been analyzed recently.

ADF&G presented posters that qualitatively indicated that many of the fish tagged in Chatham and Clarence Straits were recovered just on the B.C. side of the equidistant line between Canada and Alaska. In addition, these releases were recovered, albeit less frequently, further south along the B.C. continental slope.

DFO – B.C.

Department of Fisheries and Oceans in B.C. have done extensive tagging since 1977 with about 350,000 releases as of 2003. They are currently releasing about 15,000 tags per year, with high recovery rates of 2,000-5,000 per year. Reporting rates for tagged animals is presumed to be quite high.

Tagging data from fish tagged in inlets were presented, with a modeling procedure similar to Alaska that was used to estimate annual migration rates between areas. The preliminary results showed that inlet fish move extensively, with the majority going either offshore or to Alaska waters. In addition, a few fish were recovered in the U.S. west coast fisheries and Mexico, but most were intercepted in the southern British Columbia fishery. Data from offshore tagging were not presented, but it was estimated that about 80% of the offshore tags are recovered in the same general location. In general, inlet fish were smaller fish (< 10 years-old), while fish tagged offshore were larger fish (> 10 years-old).

NMFS – West Coast

The West Coast has done a few isolated tagging experiments, but do not have an active tagging program. They do return recovered tags to NMFS – Alaska, ADF&G, and DFO – B.C.

Overarching Issues and Recommendations

Data Sharing

The group agreed that it would be worthwhile to pool resources when working on migration and tagging issues. Previous attempts at sharing tag data between NMFS and DFO have yielded limited benefits. However, renewed interest in tagging studies may provide an opportunity for mutually beneficial collaboration among agencies involved in sablefish. The group established some general guidelines that should be established prior to any new data sharing:

1. DFO, NMFS, and ADF&G all have rules governing data-sharing with other agencies, particularly for international cooperators. These protocols must be investigated and the limitations clearly outlined to collaborators.
2. All three agencies have rules governing the use of confidential fishery data, particularly when a location can be identified to one vessel, or one haul, which is the case for tag-recovery data. Adoption of an appropriate spatial scale for analyses could be established that will be useful for tagging models, but remain consistent with confidentiality guidelines.
3. There is a need to establish the objectives of tagging analyses prior to the exchange of tagging data. This step would identify the expected products from the arrangement and who (agencies and scientists) will participate in the collaboration;
4. Once data confidentiality and research objectives are established, some effort is required to explain to stakeholders how a data-exchange can be to their benefit. This may include identifying how the findings of research on tagging models can result in management benefits for a highly migratory species like sablefish.

The group identified several topics worthy of collaboration among agencies:

1. Exchanging physical tags among agencies and releasing them might be a way to see if reporting rates are different depending on the tagging method.
2. Since they are highly migratory, a coast-wide stock assessment model integrating data from the Bering Sea to the southern U.S. west coast would be an interesting exercise.
3. Likewise, a coast-wide migration model would provide the clearest picture of the overall migration pattern of sablefish. NMFS – Alaska and DFO – B.C. have both made progress on migration models for their respective areas, but much more could be done with the combined data sets from the three agencies.

Life History Parameters

Age at 50% Maturity

Female age at 50% maturity estimates ranges from 3 to 4 years in B.C. to 7 years used by ADF&G. NMFS in Alaska currently uses an estimate of 6.5 years for females based on Sasaki's work in 1985. The group discussed several possible explanations for the different estimates and agreed differences may be attributable to artifacts of ageing techniques, which would make comparisons of maturity estimates difficult. Differences also exist in the staging criteria used in macroscopic evaluations of maturity, which may contribute to different age-at-maturity curves. Time of sampling was discussed. Past work has shown that summer samples are not ideal for determining maturity state. ADF&G and NMFS are currently doing histological work and collaboration was discussed. Ideally, fall and winter samples will be collected in 2007, which may provide updated maturity estimates based on histological methods rather than macroscopic evaluations.

Growth

Growth curves used by ADF&G and NMFS were shown and compared. Male growth curves are nearly identical but female curves differ between the agencies. Weight-at-length relationships between ADF&G-NMFS are very similar but weight-at-age relationships differ. Recommendations by the group were for ADF&G to look at the depth at which samples were collected because both NMFS and DFO provided data that indicate size can be a function of depth and that fish in deep water tend to be smaller at age than fish caught in shallower depths. Differences in growth relationships could also be attributed to differences in ageing between agencies.

Natural Mortality

The following natural mortality (M) values are used:

NMFS – Alaska	0.10

ADF&G - Alaska	0.10
DFO – British Columbia	0.08
NMFS – West Coast	0.056

The different values used for natural mortality were discussed. The group noted many of the estimates were derived years ago and methodologies were not certain. One method relies on oldest aged fish, but estimates of age are dependent on the ageing techniques, which differ by region. Oldest ages range from 87 years in B.C. to 94 years in Alaska. It was agreed that the values used for natural mortality in complex models are not as crucial as some other parameters because natural mortality is often confounded with other parameters. This results in a trade-off against other parameters being estimated and therefore may be biased to achieve the best fit to the data. For simplistic forecasting methods, however, natural mortality values do make a considerable difference. No new studies are planned to address natural mortality but updating oldest age estimates for each agency may be worthwhile.

Life History

Juvenile sablefish (1-2 year-olds) are commonly found in major inlets in B.C. and in small bays and inlets in southeast Alaska. Little is known about juveniles in western Alaska other than they are often reported near harbors and inshore areas when there are strong year classes.

Sablefish spawning habits and locations are uncertain. Older sablefish are usually considered to be most dense in Southeast Alaska, but are found throughout the Alaska range. Recent data exploration has shown there may be a concentration of older sablefish in the western Aleutians. From analysis of data there does not appear to be any evidence of senescence in sablefish. Historical winter surveys found spawning fish in the mouth of Chatham Strait, an area where large older fish are commonly found. Recently, ADF&G conducted a winter fishery (January-April) to help define spawning areas, but ripe females were rarely caught which was interpreted as indicating either hook shyness or an absence of ripe females in those areas surveyed. In B.C., peak catches occur in the winter and ripe females are commonly caught. Analysis of the winter B.C. fishery data may help define spawning habits of sablefish and possibly identify spawning aggregations.

Recruitment

Understanding recruitment processes for groundfish is considered to be a formidable task by most and an intractable task by others. The U.S. west coast assessment has found some environmental proxies that are used in their stock assessment for helping predict recruitment (Schirripa and Colbert 2005). NMFS – Alaska presented some ideas on determining sablefish recruitment through environmental factors. The sources and spatial scales of data that are available for monitoring recruitment in Alaska were reviewed and include the following:

1. NMFS – ABL gillnet survey conducted on the annual longline survey from 1995 to 2004, which caught young-of-the-year sablefish;
2. OCC/BASIS surface trawl survey from 2003-present catches juveniles (5-20 cm) in the Bering Sea;
3. NMFS – biennial/triennial trawl surveys have caught larger (1+ year-olds) juveniles in different locations since 1977, and fish appear to move into the Bering Sea in large recruitment years;
4. Satellite data from NASA may provide reliable proxies of underlying processes to help reduce recruitment uncertainty;
5. Anecdotal reports of widespread abundance of age 1+ juveniles in nearshore waters should be documented as an indicator of exceptionally high egg/larval/young-of-year survival;
6. Recruitment is measured by the longline survey, but not until age 3-4 based on age compositions of the catch.

Evidence of young-of-the-year sablefish found on the BASIS survey in the Bering Sea suggests that pockets of spawning biomass in the Aleutians or Bering Sea Slope contribute more recruits than expected to the population. Jeff Fujioka (AFSC) suggested that the cumulative effects of trawling in the eastern Bering Sea could have degraded the habitat for juvenile sablefish which used to be abundant there in the late 1970s according to trawl survey results.

NMFS – Alaska is exploring integrating some or all of the data sources listed above into a recruitment index to improve understanding of the pre-recruitment life history of sablefish. The group agreed that such knowledge would be useful and should be pursued. Some of the group suggested that if recruitment could be predicted with some accuracy several years earlier, this would promote more efficiency in setting quotas. Another question about recruitment to be answered is why stakeholders often see potentially large year classes disappear in the following several years of survey data. A mechanistic explanation of why some apparently strong year classes do not materialize in the fishery would be well received by stakeholders. The group concluded that detecting recruitments within the first few years is difficult, but remains as a research priority.

Ageing Session

Delsa Anderl, AFSC Age and Growth Program, gave an excellent presentation on sablefish age determination and answered questions for workshop participants. Delsa provided a summary of the protocols in place for sablefish ageing at the AFSC, presented a summary and results of the inter-agency Committee of Age Reading Experts (CARE) sablefish otolith exchange, provided an overview of validation studies that have been done for sablefish, and provided examples illustrating the difficulties involved with sablefish ageing. AFSC protocol uses two experienced age readers who age approximately 2,000 sablefish per year. One reader ages 100% of the samples and a second reader ages a 20% random sample of those. Since 2000, average agreement is 38.5% with a CV of 10.8%.

The CARE project has four participating agencies for sablefish and consistently exchanges sablefish otoliths. In 2007 each agency contributed 20-25 (N = 89) non-randomly selected otoliths, which are read by each group resulting in four sets of data. Percent agreement ranged from about 13% to 29% between agencies, and all groups were generally in agreement for fish under 15 years. Agencies are working together and are using CARE results to improve sablefish ageing techniques.

To date there have been six age validation studies for sablefish, and the AFSC is currently working on a study where otoliths are being read from known-age fish that were tagged beginning in 1985. This study is an extension of the work documented by Heifetz et al. (1999). Sablefish are a difficult species to age because they exhibit a broad "checky" pattern in early years, and the rules used for interpretation of patterns at the otolith edge differ from those applied to other species. These difficulties in pattern interpretation for sablefish lead to lumping or splitting issues in assigning fish age. Future studies for sablefish ageing include continuing the known age study and performing bomb-derived C-14 validation of select otolith patterns to help validate the criteria used to interpret these patterns.

CARE information is available on the website: http://www.psmfc.org/care/index.htm.

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