Lingcod Stock Assessment Review (STAR) Panel Report

NOAA Fisheries, Northwest Fisheries Science Center
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26-30 June 2017

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Overview

A Stock Assessment Review (STAR) Panel met during 26-30 June 2017 at the Northwest Fisheries Science Center (NWFSC) auditorium in Seattle, Washington to review a draft stock assessment for lingcod (*Ophiodon elongatus*). The assessment had been prepared by a stock assessment team (STAT) led by Dr. Melissa Haltuch of the NWFSC and was documented in Haltuch et al. 2017). The Panel operated under the Pacific Fishery Management Council's (PFMC) Terms of Reference for stock assessment reviews (PFMC 2016). This same panel also reviewed a draft assessment for Pacific ocean perch (*Sebastes alutus*).

Lingcod are large opportunistic top predators in the nearshore demersal ecosystem of the northeast Pacific Ocean. They range from Kodiak Island, Alaska down to Baja California, Mexico, though abundance tapers off quickly south of Point Conception in southern California. They typically occur at depths of less than 200 meters and are most abundant in areas of hard bottom with rocky relief. Lingcod are an important species for both the commercial and recreational U.S. groundfish fishery. Documented catches of lingcod span a period of more than a century, with the catches peaking during the 1980s at almost 3400 mt for Oregon and Washington and 2850 mt for California.

Lingcod are batch spawners and females lay eggs in nearshore waters during winter in nests that are guarded by males. It is not clear if females produce multiple batches of eggs and there are no studies on nest identification to define whether females contribute eggs to multiple nests. Genetic studies suggest that lingcod are genetically similar throughout their coastal range.

As in the most recent previous lingcod assessment (Hamel et al. 2009) the stock assessment team (STAT) for the new assessment treated the US west coast population of lingcod as two independent stocks separated at 42º N latitude (the seaward extension of the border between California and Oregon) and assumed that the US west coast population of lingcod is independent of lingcod populations off Mexico and Canada.

The models in the new assessment, which used the Stock Synthesis software version 3.30.03.07, were based on revised historical landings and discards, revised analyses of several historical survey data series, and data for recent landings, discards and length- and age-compositions. Results for the base models developed during the STAR meeting are summarized as follows. The northern assessment model estimates that the spawning stock biomass of lingcod off Oregon and Washington at the start of 2017 was 21,976 mt and was depleted to 57.9% of its unfished level. The stock's spawning biomass dipped below the Council's the minimum stock size threshold (MSST, 25% of unfished) for several years during the 1990s but has been above the target level (40% of unfished) since 2006. The southern assessment model estimates that the spawning stock biomass of lingcod off California at the start of 2017 was 6,742 mt and was depleted to 32.9% of its unfished level. The stock's spawning biomass dipped below the Council's MSST for a period extending from 1984 through 2014, reaching a low of 8.7% in 1998. Both assessments estimate the stocks have been increasing in recent years.

The STAR Panel concluded that the new north (WA and OR) and south (CA) assessments for lingcod constitute the best available scientific information on the current status of the US west coast population of lingcod and that they provide a suitable basis for management decisions. The Panel considers that the use of surveys, compositional data, and estimation of recruitment deviations makes this a Category 1 assessment.

Summary of Data and Assessment Models

Catch series and fishing fleet structure

Subsequent to the 2009 assessment California and Oregon completed historical groundfish catch reconstructions and a catch reconstruction for Washington was completed recently for the current assessment. Catches for the northern stock extend back to 1889 and appear to cover the entire period of commercial and recreational fishing. Catches for the southern stock of lingcod were only available from 1931 in the historical reconstruction, starting abruptly with a catch of almost 560 mt. Earlier commercial fishing data were missing from the California catch reconstruction.

Removals from the northern stock of lingcod were associated with a trawl fleet, a fixed-gear fleet, and separate recreational fishing fleets for Oregon and Washington. Although the recreational catches (and associated biological data) were partitioned to state regions, the STAT indicated it was not feasible to similarly partition the data from the commercial fishing fleets because landings reported in OR and WA could have been caught off either state. The southern model has a similar fishing fleet structure as the northern model but with only a single recreational fleet.

Survey indices

Three series of fishery-independent survey data are available for the northern stock as well as for the southern stock: early (1980-1992) and late (1995-2004) AFSC Triennial trawl surveys and the NWFSC trawl survey (2003-2016). Also available for the southern stock is the NWFSC Hook and Line survey (2004-2016), which only covers the Southern California Bight.

The survey biomass indices for the Triennial (early and late) and NWFSC surveys were estimated using the spatio-temporal delta-modeling approach described as VAST. For the draft assessment models brought to the STAR each analysis applied the VAST model to the combined survey data for both the northern and southern regions. Data from the hook and line survey were analyzed using a Bayesian delta-GLM applied to numerical abundance (rather than biomass), where a binomial model with logit link was employed to model the presence / absence of lingcod.

Fishery-dependent indices

Fishery-dependent indices were available for the northern stock for all four fleets: a trawl CPUE index derived from PacFIN logbook data (1981-1997); a commercial nearshore fixed-gear CPUE index from Oregon logbook data (2004-2016); a WA dockside recreational index (1981-2016); and an OR dockside recreational index (1986-2016). An OR onboard observer recreational index was not included in the model because the dockside sampling program has more comprehensive coverage and greater sample sizes, the two indices show generally the same pattern during the years of overlap, and the dockside index spans more years. Fishery-dependent indices for the southern stock comprised a commercial trawl CPUE index from PacFIN logbook data (1981-1997), a CA onboard observer recreational index for (1987-1998 and 2002-2016), and a central CA dockside recreational index (1980-1997). The last two indices were included in an alternative draft base model brought to the STAR but they were not used in the final southern base model (see Request 2.2).

Recreational CPUE indices and the commercial nearshore fixed-gear CPUE index from OR logbook data were calculated using a delta-GLM approach, while the fishery-dependent indices of abundance for the two commercial trawl fisheries (north and south) were calculated from PacFIN logbook data using the spatio-temporal delta-model VAST. For the southern model the spatial distribution of Pearson residuals for the trawl CPUE index exhibited broad areas (particularly off CA) of negative and positive residuals with marked inter-annual changes, suggesting the potential influence of an un-modelled process.

The STAT noted that the CPUE indices for WA or OR could reflect abundance in either state as fishers can operate in the waters of either state.

Compositional data - lengths

Length-composition data were available for all of the fishing fleets and surveys and included data for both retained and discarded fish for the commercial fleets (trawl and fixed-gear) in both the northern and southern models. The most extensive series were for the trawl fleet, which began in 1965 for the northern model and in 1978 for the southern model. The length-composition series for the southern recreational fishing fleet was also very long, starting in 1959, but its geographic coverage was more limited and variable over time. The most extensive survey length-composition series was for the NWFSC trawl survey (2003-2016).

Length-composition data series were also available from special WDFW research projects (1996-1997, and 2001-2003) and a one-year thesis project by Laurel Lam, who conducted hook and line sampling in 2016 of nearshore and offshore rocky reefs from northern WA to southern CA aboard chartered commercial passenger fishing vessels.

The NWFSC length-composition data for the northern stock exhibited clear patterns showing the progressions of strong year classes. Such patterns were much less distinct in the data for the southern stock. Also, fish of smaller lengths were observed in NWFSC catches from the south.

Biological samples from the commercial fisheries were expanded to the trip level and then to overall catch, with the annual number of port samples being employed as the input sample size for each multinomial composition. The STAT advised in the draft assessment report that many of the compositional data for the recreational fisheries lacked details for the number of fish sampled out of those landed. Consequently the recreational compositions were used without expansion. This approach may introduce bias into the resulting composition data for the recreational fisheries, as it is assumes that the length-compositions were simple random samples from the recreational landings.

Compositional data – ages

For the northern model age data were available for both commercial fishing fleets (trawl and fixed-gear, extending from 1978 to 2016, retained catch only) and both recreational fishing fleets (1979-2016 for WA; 1999-2016 for OR) and for all three surveys except the early Triennial. For the southern model there were considerably fewer age data from the fishing fleets, with data for sporadic years during 1993-2004. There were no age data from the CA recreational fishing fleet.

In the draft assessment models brought to the STAR these age data were included as marginal age-compositions for the fishing fleets and the late Triennial survey. The age data were included as conditional age-at-length (CAAL) compositions for the NWFSC trawl survey and the Lam research project.

The Stock Synthesis modeling approach assumes that length distributions are random with respect to the catches from which the samples are drawn. It is also assumed that conditional ages at length are random samples of the ages of the fish of that length within the population. Factors that could disrupt the randomness of the CAAL data include age-dependent movement and non-random spatial sampling. The potential for such disruptions should be explored, e.g. by comparing CAAL distributions among different depths and different months within a year.

As with the corresponding length data, the NWFSC CAAL data for the northern stock exhibited clear patterns showing the progression of strong year classes through annual age-compositions. Such patterns were much less distinct in the south.

During the STAR the STAT advised that ageing of lingcod is based on counts of the growth zones within spines, a method that, according to the draft assessment document, requires further validation to determine the accuracy of the ages that are assigned to the individual fish. Although the draft assessment document discussed the use of otoliths for ageing, it did not mention the use of spines.

Also, members of the STAT mentioned that port samplers sometimes encounter difficulties selecting fish for ageing due to the reluctance of fishers to allow cutting the fish to extract spines or identify the sex. This is more of an issue with larger fish, particularly in the recreational fisheries. Recent commercial sampling by WDFW has also been more limited because commercial buyers prefer to purchase fish that have not been cut. However, WDFW does sample the tribal commercial trawl fishery, which generally catches smaller fish. Recent WDFW commercial sampling appears to be biased towards smaller fish. These sampling issues were identified as a potential source of bias in the construction of marginal distributions of lingcod ages, especially given there was no adjustment for selective subsampling of lengths for age determination.

Discards data

Data on discard rates were available from the West Coast Groundfish Observer Program for both northern and southern assessment models for the trawl and fixed-gear fleets for the period 2002-2015. Data on discard length-compositions (to inform retention curves) were available for both assessment models and both commercial fishing fleets for 2004-2015. Discard mortality rates of 7% for fixed-gear catches and 50% for trawl catches were applied in the assessment models.

Maturity and weight-length relationships

The assessment models employ updated estimates of functional maturity based on data collected between 2013 and 2016. The estimated length at 50% maturity for females in the north is 57 cm and 52 cm in the south. Fecundity is assumed to be proportional to female body weight.

The plot of the weight-length relationships for unsexed lingcod lay below those for both females and males, which is an anomaly requiring further investigation and explanation.

Bridging analysis

The northern and southern models developed in SS2 for the 2009 assessment of lingcod were converted to the new SS3 software (ver. 30.03.07). Bridging analyses demonstrated that the time series of spawning biomass and stock depletion produced using the SS3 software matched the values produced using the SS2 version of the model.

The northern and southern assessment models

The transitioned SS3 versions of the 2009 assessment northern and southern models for lingcod were updated to the structure proposed for use in the 2017 assessment, models configured as two separate single area, two-sex models, representing the northern Washington and Oregon area and the southern Californian area, respectively. For each area, the period represented by the model extended from 1889 to 2016. Sex ratio at birth was fixed at 1:1 and the models started from unexploited equilibrium conditions. The population dynamics of the lingcod were described within the model using ages 0 to 25 years, with age 25 representing a ‘plus group’. In the northern model length bins ranged from 10 to 130 cm, in two cm increments, with the first and last bins as accumulators for fish less than 10 cm or greater than 130 cm. In the southern model length bins ranged from 4 to 130 cm. Although mature female biomass was used as a proxy for reproductive output, it remains uncertain whether this approach is fully appropriate given that male lingcod guard nests from predators.

In the draft base model for the north that was described in the draft assessment document, the rate of natural mortality (*M*) for females was calculated from the Hamel (2015) lognormal prior using a maximum age of 21 years and fixed at the median value 0.257 year^{-1}, steepness (*h*) was fixed at 0.8, and recruitment variability (σ_R) was fixed at 0.6 in the northern model and at 0.7 in the southern model. Natural mortality of males was estimated based on the same lognormal prior as used (but fixed to the median value) for the females. Due to the paucity of large fish in the NWFSC CAAL data (or due to conflicts with other data), the value of female length at the maximum age (14 years in the northern model) was fixed at 112 cm and the female growth coefficient (k) was fixed at 0.173. Other growth parameters were freely estimated. In the southern model it was possible to freely estimate all the growth parameters. Prior to the STAR the STAT received additional data and made several corrections to the input data. The STAT brought alternative models to the STAR for consideration. During the course of the STAR meeting there were additional changes to the models, as described in the Requests section below.

Commercial fleets in both the north and south were disaggregated into trawl and fixed-gear; there were two recreational fleets in the north (WA and OR) and a single recreational fleet in the south. Both models included broad sets of time blocks to reflect management changes that had affected the fisheries and thereby allow for possible changes in selectivity and retention in the commercial fleet and selectivity in the recreational fleets.

In calculating the log-likelihood components the numbers of trawl tows (for the trawl surveys) and port samples (for the commercial fishing fleets) were used as input sample sizes for the length- and marginal age-compositions. The numbers of sampled fish were used as the sample sizes for the recreational composition data. The numbers of fish with ages were used as the sample sizes for the CAAL compositions. Sample sizes of the composition data were reweighted using a one-step application of the Francis (2011) method. An iterative reweighting procedure (based on R4SS output) was used to ensure reasonable bias adjustments for recruitment variability. The σ_R parameter values were slightly tuned, from 0.6 in the draft northern model to 0.55 in the final base model; from 0.7 in the draft southern model to 0.75 in the final southern base model.

For the draft base models brought to the STAR each of the surveys included an estimated parameter (extra_SD) to allow for extra variability beyond the input sampling error. In the final northern base model there were no estimated extra_SD parameter for the Triennial surveys and the NWFWSC survey. In the final southern base model there was an estimated extra_SD parameter only for the Trawl CPUE index.

In the draft base models brought to the STAR the estimation of recruitment deviations began with 1985. Following further exploration of the model in response to requests during the STAR, the final base models estimated recruitment deviations from the start of the modeled period (1889).

Selection curves for all fleets and surveys were estimated assuming a double-normal pattern, and all fleets had dome-shaped selection curves during 2016 (except selectivity for males by the late Triennial survey). Selection curves for the commercial fisheries were estimated to be asymptotic in earlier time blocks. Retention within the various time blocks was estimated. Survey catchabilities were calculated analytically, such that estimates were median unbiased.

The STAT undertook considerable exploration of alternative model assumptions and presented these to the panel on the first day of the STAR. This exploration included fixing female natural mortality and h at different input values, and removing individual indices and individual length and age data sets. Outputs from the models were sensitive to the starting year for calculation of recruitment deviations. Jitter analyses demonstrated that the north model appeared robust to alternative initial parameter values but the south model was not as reliable with 52 of 100 jittered starting values producing improved log-likelihoods, some of which representing marked improvements in fit. Analyses undertaken by the STAT in response to discussions with the STAR Panel, and requests subsequently made by the STAR Panel (see below), led the STAT to modify and refine the assessment models for the north and south, resulting in models that the STAT proposed as new base models for these two areas.

During reviews of fits to the models it was recognized that some of the fishery marginal age-compositions were biased, some due to incorrect assumptions about sex-ratio at length and others due to non-random subsampling of fish for age-reading. To remove the influence of these data the final northern and southern base model used none of the available fishery marginal age-compositions included in the original draft models, but made use of all the indices and length-compositions and the CAAL compositions from the NWFSC survey and the Lam study. The final base models maintained the same basic structures as the draft base models and many of the same assumptions. Complete descriptions of the base models are provided in the *Description of the Base Model* section below.

The final agreed base models are well structured, have been thoroughly investigated by the STAT, and are the best currently available for the formulation of management advice.

Treatment of uncertainty

Likelihood profiles were produced for ln(*R*0), steepness and natural mortality, key parameters in determining stock productivity and status. The likelihood profile for a parameter is created by treating the parameter as fixed over a range of values and calculating the likelihood for each component (data source). Likelihood profiles indicate the relative strength of the information contained in each data source and the mutual coherence of the data sources (given the assumed model structure and fixed parameters).

In the case of the final northern base model the likelihood profiles indicated the data contain insufficient information to estimate steepness. The likelihood profiles for female *M* indicated that the indices, and the length- and CAAL compositions favor an estimate of female natural mortality larger than 0.3 year^{-1}, which is considerably higher than the fixed value of 0.257 year^{-1} in the final base model. With female natural mortality fixed at 0.257 year^{-1} and steepness at 0.7, the estimate for ln(R0) is fairly well determined, but the profile indicates tension between the value favored by the CAAL compositions and that favored by both the length-compositions and the indices. Inconsistency among different data components is not unusual but may indicate an overly constraining model structure (e.g., time-invariant parameters that should be time-varying).

For the southern model the likelihood profiles for steepness indicated sensitivity to the length-compositions from the Lam project (a one-year project) and the recreational fishing fleet, suggesting that these would be influential if steepness was estimated. The likelihood profile for female M indicated many of the data sources favor a value at least as great as the upper bound, 0.3 year^{-1}, as was the case in the northern model (given the assumed model structure and fixed parameter values). Likewise, ln(R0) was fairly well determined, but indicated tension between the value favored by the CAAL compositions and that favored by the indices.

Sensitivity runs are probably the most important source of information on uncertainty as they can be used to map out the possible effects of structural errors and model assumptions, which are difficult to assess but often the greatest source of uncertainty. Although there was insufficient time during the STAR to explore sensitivity runs for the final base models, the STAT provided a series of sensitivity runs for the models leading up to the base model. These adequately covered low to high ranges for steepness and natural mortality, which are two key parameters that were fixed in the final base models because they could not be reliably estimated.

Requests by the STAR Panel and Responses by the STAT

The pre-STAR draft document was reasonably complete, which allowed for an efficient and effective review that could quickly identify the most important questions and allocate review time accordingly. The STAT provided thorough responses to all requests.

Request 1.1: *Run separate VAST runs for all surveys (NWFSC and Triennial) in the northern and southern models with graphical comparisons for both. These will become part of the new base case datasets.*

Context: In prior assessment cycles it was standard practice to use a delta-GLMM approach with spatially stratified data. In the current assessment cycle many of the assessment teams are using a newer approach that does not explicitly consider the data as coming from distinct spatial strata but instead includes spatial autocorrelation. The software package has the acronym VAST (vector autoregressive spatial temporal).

Rationale: Given there are large differences in attributes of the northern and southern models (modeled as separate stocks), it makes sense to separate all the data sources.

Response: Separate northern and southern VAST analyses were run using the NWFSC and Triennial survey data. Figure 1 below shows the resulting estimates for the two separate regions (orange) compared with those produced by the VAST approach using survey data for both regions (blue) in a single analysis and then post-stratifies the estimated biomass (as the STAT had done for the draft models brought to the STAR). By separating the northern and southern data, the VAST analysis could be run at higher spatial resolution (a larger number of "knots") but with the potential loss of shared information on the performance of the survey vessels.

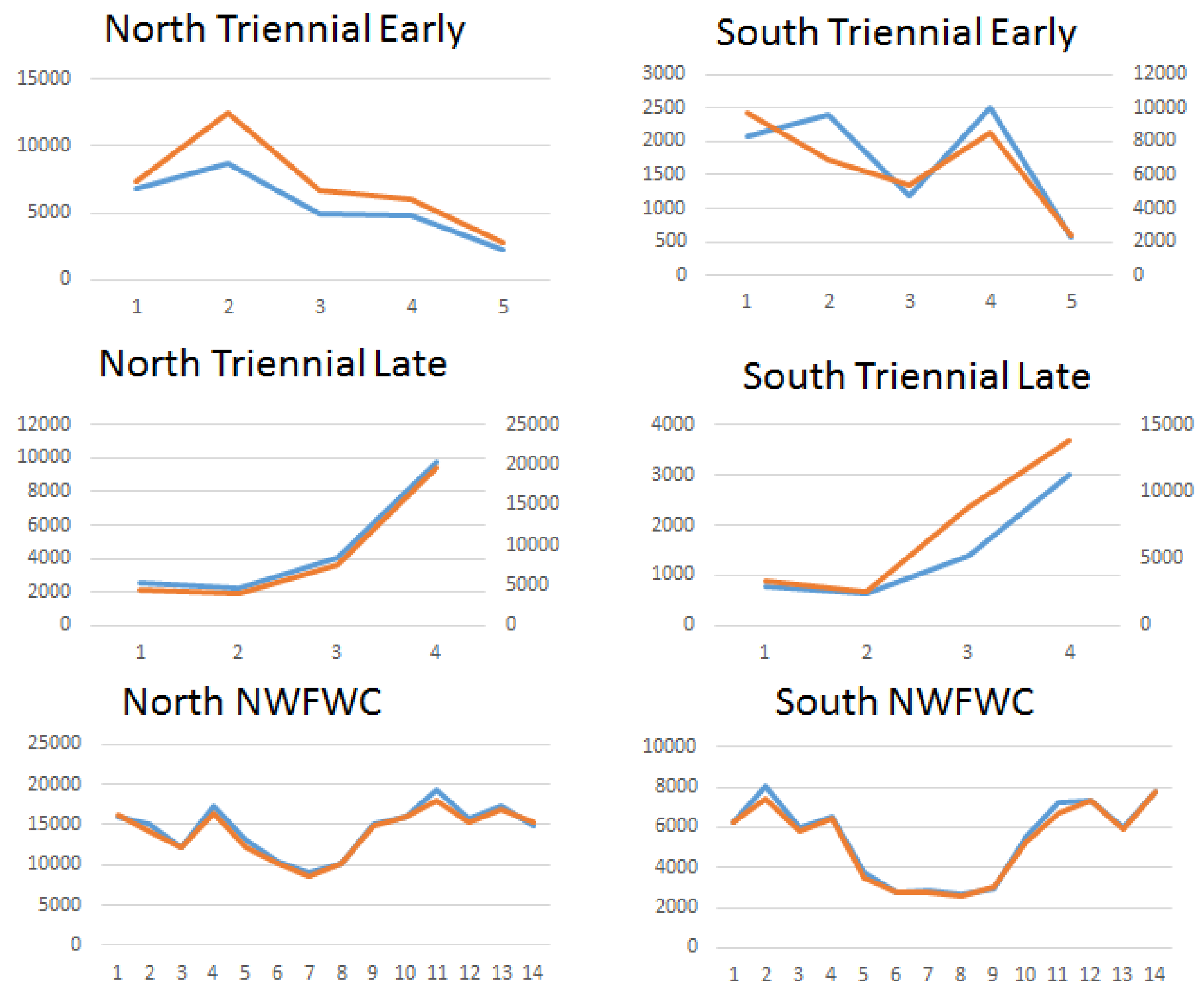

Figure 1. Comparison of estimates produced by VAST when NWFSC and Triennial survey data from North and South are analyzed together (blue) or independently (orange).

Whether the northern and southern data were analyzed independently or combined had very little influence on the NWFSC survey biomass indices. However, for some of the Triennial survey series there was a small effect on the trends in the indices and sometimes there was a strong effect on their scales. For example, for the southern early Triennial survey the index values from independent analyses were four times larger than the values from the combined analysis.

The effects on the models' estimates of spawning biomass of using the independent VAST survey indices are illustrated below in Figure 2 for the northern stock and Figure 3 for the southern stock. Using the independent VAST index for the NWFSC survey corresponds to the light-blue lines (with vertical dashes in the northern model and triangles in the southern model); using the independent VAST index for the Triennial surveys corresponds to the green lines (with vertical dashes in the northern model and triangles in the southern model). The other lines in these figures correspond to requests below.

The STAR Panel recommended that, for consistency with the decision to model lingcod as two separate stocks, the STAT should use the survey biomass indices based on the separate VAST analyses.

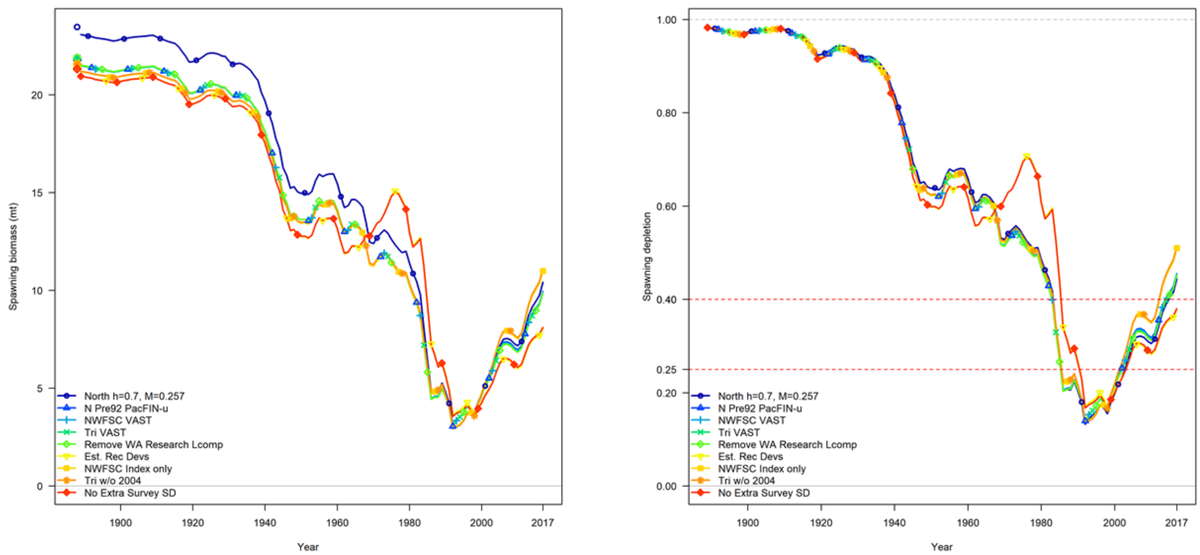

Figure 2. Spawning biomass trajectories for the northern stock of lingcod produced by introducing modifications to the alternate assessment model to address various STAR Panel requests. The STAT used fixed growth parameters when refitting the model to explore the influence of each modification.

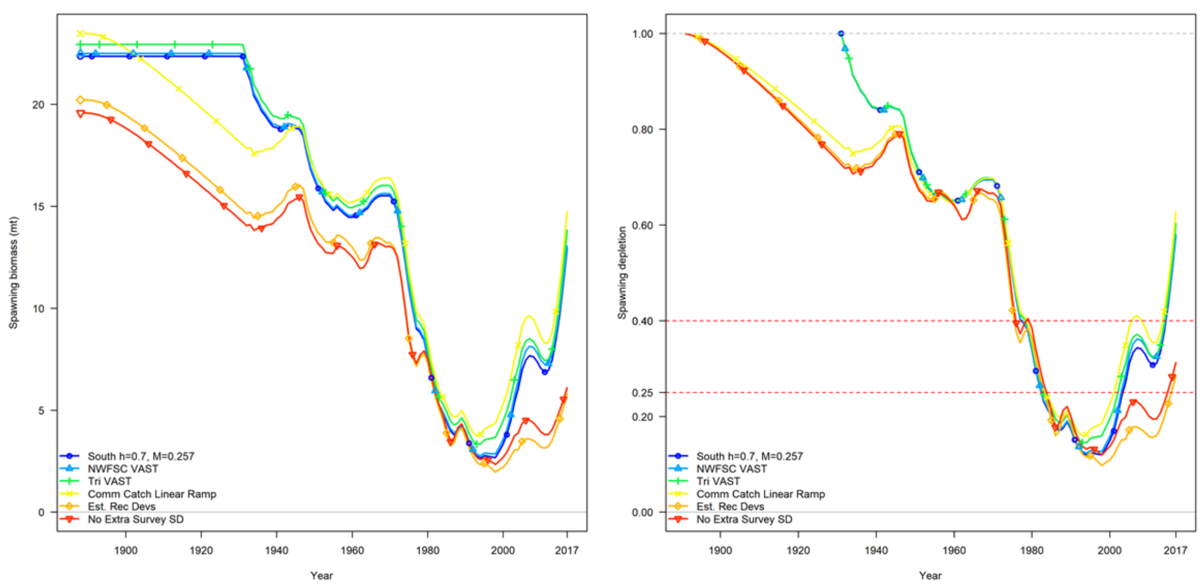

Figure 3. Spawning biomass trajectories for the southern stock of lingcod produced by introducing modifications to the alternate assessment model to address various requests by the STAR Panel. The STAT used fixed growth parameters when refitting the model to explore the influence of each modification.

Request 1.2: *Create combined sex, length- and age-compositional data for all commercial fishery samples in the northern model from early years through 1991. Confirm the length-compositions of aged fish are representative of the length-compositions of unaged fish. These data will become part of the new base case.*

Context: Residual plots from the draft northern base model indicated extremely large male lingcod (> 80 cm) associated with the Trawl fleet for several early years in the series (Appendix Fig.A.1). Such large male lingcod were highly inconsistent with the length-at-age data from the NWFSC trawl survey. A quick review by the STAT of PacFIN database summaries suggested that the presence of unsexed fish was limited to years prior to 1992.

Rationale: When there are unsexed fish in fishery samples the software used to develop the compositions applies an assumed sex ratio, which may introduce errors in the derived compositions. With regard to the second part of the request, because fish for age-readings may not be selected randomly, it is important to verify that the age-compositions reflect the length-compositions, which are treated as representative of fishery landings.

Response: The STAT combined the compositional data as requested. The resulting trend in the estimated time-series of spawning biomass differed only slightly from the corresponding series for a similar model that had the original data (blue lines with triangles in Figure 2).

Histograms of aggregated age- and length-compositions of lingcod collected from the catches by Washington and Oregon commercial fishers suggested that the (marginal) age-compositions might not be representative of the corresponding length-compositions. However, the data for the histograms were aggregated over many years and could not be easily compared because of differing length-bin structures. Following discussion, it was agreed that pinpointing the source of the apparent discrepancies in the composition data would require a more detailed examination (described below). A suggestion that the commercial fishery age-composition data be excluded from the assessment model was rejected because both the STAR Panel and Assessment Team were reluctant to lose this potentially valuable information source. The STAR Panel endorsed further investigation to identify commercial fishery marginal age-composition data deemed to be unrepresentative.

Using information from the PacFIN Biological Data System for Washington and separately for Oregon, the STAT compiled annual numbers of fish-lengths and fish-lengths-with-ages based on 20-cm length-bins. The compilation provided convincing evidence that for 2010 and later years, the proportions of small fish in length samples from Washington that had been aged exceeded the proportions of larger fish that had been aged. The proportions of aged fish in the different length classes in the annual length samples from Oregon were highly variable, but again it was clear that samples for ages were not consistently representative of the length samples from which they had been drawn. If samples from either state were affected, the combined data for the northern stock would be biased. When compiling the marginal age-compositions the STAT had not adjusted for non-uniform sampling of fish for age-reading.

The STAR Panel concluded that the fishery marginal age-compositions from the northern stock were often not representative of the length-compositions, and thus the associated fishery marginal age-compositions for this stock are not representative of the stock's age-composition. Subsequent discussion revealed issues sometimes associated with sampling lingcod. In Washington, permission to cut sampled fish (particularly larger fish) to extract spines for ageing and to sex those fish was often refused, thus resulting in biased samples. It is likely that port samplers in Oregon and Washington encountered similar issues when obtaining lingcod samples for ageing. Furthermore, for the 2009 lingcod assessment as well as the new assessment ODFW staff had been instructed to deliberately over-sample small and large lingcod when selecting structures for age-reading. More detailed examination of the age- and length-composition is necessary to determine whether the bias extends to the age data for all years.

There was discussion of whether the available age data could be used as conditional age-at-length (CAAL) compositions. When constructing CAAL compositions using standard methods the data from individual hauls are aggregated without expanding for (possibly) different densities of fish at each sampling location. If there are age-dependent movements of lingcod, or the spatial distribution of the stock is age-dependent for some reason, then CAAL distributions based on sample data from surveys or fishery catches are also likely to be non-representative of the overall conditional distributions of age-at-length. In future research, consideration should be given to comparing CAAL distributions from different depths or regions to explore whether these are consistent with the hypothesis that CAAL data are representative of the overall CAAL distribution for the stock.

The STAR Panel advised that, for the current assessment, the CAAL compositions could be used but fishery marginal age-compositions should not be used.

Request 1.3: *For historical catches in the southern model, do a linear ramp up from zero catch starting with the first year of catch in the northern model to 1930, when catches in the southern model are better documented (and non-zero catches begin in the draft model), as a sensitivity.*

<u>Rationale</u>: The large catch in 1930 (implying an abrupt start to the fishery) is implausible.

<u>Response</u>: The STAT developed the ramp in historical catches as requested. The effect of this change on the estimated biomass trajectory was a gradual decrease in spawning biomass during the initial decades of the assessment period, as shown by the yellow lines in Figure 3.

The STAR Panel advised that it would be appropriate to include such linear ramping in the final base model for the southern stock and that, for future lingcod assessments, reconstructed catches for California should be extended for years prior to 1930.

Request 1.4: *For both the northern and southern models fix steepness (h) at 0.7; fix female natural mortality (M) at the median value of the prior (M = 0.257, based on a maximum age of 21 years).*

<u>Context</u>: In the draft version of the north and south assessment models steepness was fixed at 0.8, female M was fixed at the median of the prior (0.257 yr^{-1}), male M was estimated, and most of the growth parameters were estimated. The STAT brought to the STAR an alternative configuration that estimated steepness and M (both sexes) but had fixed growth parameters (based on initial model runs). These alternative models estimated steepness at 0.681 in the north and 0.680 in the south. This request explores an intermediate configuration with steepness fixed near the values estimated in the alternative models.

<u>Rationale</u>: Steepness of 0.7 is the same as used for similar species (e.g., cabezon).

<u>Response</u>: When the assessment model was refitted to data for the northern stock of lingcod, with fixed h = 0.7, and female M = 0.257 yr^{-1} for females, and fixed growth, spawning biomass in 2017 was estimated to be depleted to ~45% (the dark blue lines with circles in Figure 2). For

the southern stock, when the same values were employed for steepness and natural mortality of females and growth was fixed, depletion in 2017 was estimated to be ~60% (the dark blue lines with circles in Figure 3). The Triennial survey biomass index for 2004 was badly underestimated.

Request 1.5: *For both the northern and southern models provide the fishery time blocks and rationale for the breaks.*

Rationale: This information was lacking in the draft assessment document.

Response: The STAT provided tables (Appendix Tables 1 and 2) for the north and south models indicating the fishing fleets, span of years covered by each block, and descriptions of why the blocking was included. The draft assessment models began with non-zero catches in 1889 for the north and in 1931 for the south. The most complicated blocking structure was for the trawl fleets (north and south). It included four blocks for changes in retention parameters and five blocks for changes in selection parameters. The rationale for including these breaks was to account for the implementation of regulations, area closures, and the catch shares program.

Request 1.6: *For both the northern and southern models provide a model run with recruitment deviations estimated from the beginning of the model.*

Context: In the draft models recruitment deviations started in 1985. The STAT explained that attempts to include additional recruitment deviations in earlier versions of the base models had produced implausible patterns in the deviations and odd results.

Rationale: There may be information to inform recruitment earlier in the model.

Response: The STAT advised that, following the modifications suggested by the STAR Panel to the models for the northern and southern stocks, the difficulty of estimating recruitment deviations from the starting year of the model had been resolved.

For the northern stock, such estimation changed the trajectory of estimates of spawning biomass with greater variation between 1950 and 1980 and a 2017 depletion of ~36% (the yellow line in Figure 2). The bias adjustment ramp for recruitment deviations was examined and appeared appropriate. The fit to the NWFSC survey indices was improved and the fit to the early Triennial survey indices looked good. The Triennial survey index for 2004 was still poorly estimated.

The estimate of initial spawning biomass of the southern stock was markedly reduced when recruitment deviations were estimated to the starting year of the model (the orange line in Figure 3). Spawning biomass of this stock remained lower than the estimates produced by the version of the model employed for Request 1.3 (linear ramp from zero for catches prior to 1930) until ~1980, declining to slightly lower levels than the estimates of that earlier model, before recovering to a reduced extent to a 2017 depletion of ~30%.

Such responses in the estimates of spawning biomass of both stocks (but particularly that of the southern stock) suggests that the input data contain information on age structure that are described better by allowing for recruitment variation in the early years of the model. The STAR Panel concurred with the STAT that recruitment deviations should be estimated from the first year of the assessment period (1889) for both the northern and southern stocks of lingcod.

Request 1.7: *Provide box-and-whiskers plots of the NWFSC survey length-at-age data from early vs. late in the time series.*

Rationale: Check to see if growth is varying over time.

Response: The STAT advised that, for female lingcod, the rate of increase in length over the first four age classes appeared slightly greater in the later period (2013-2016) than in the earlier period (2004-2006) (Fig. 4) but there is considerable overlap. There appear to be more old females in the more recent period, with lengths at age appearing to have approached an asymptote. In the earlier period, lengths at age had not approached their asymptote as closely as in the later period. The plotted data for the earlier period support the decision by the STAT to fix the length at maximum age when growth had not slowed sufficiently at older ages to facilitate estimation of this growth parameter. The patterns were similar in the south, with more old fish in the more recent than earlier period.

For both the northern and southern stocks, there was no strong evidence of a large change in growth between the two periods. The possibility that growth of the northern and southern lingcod may have changed over the period considered by the assessment models cannot be discounted.

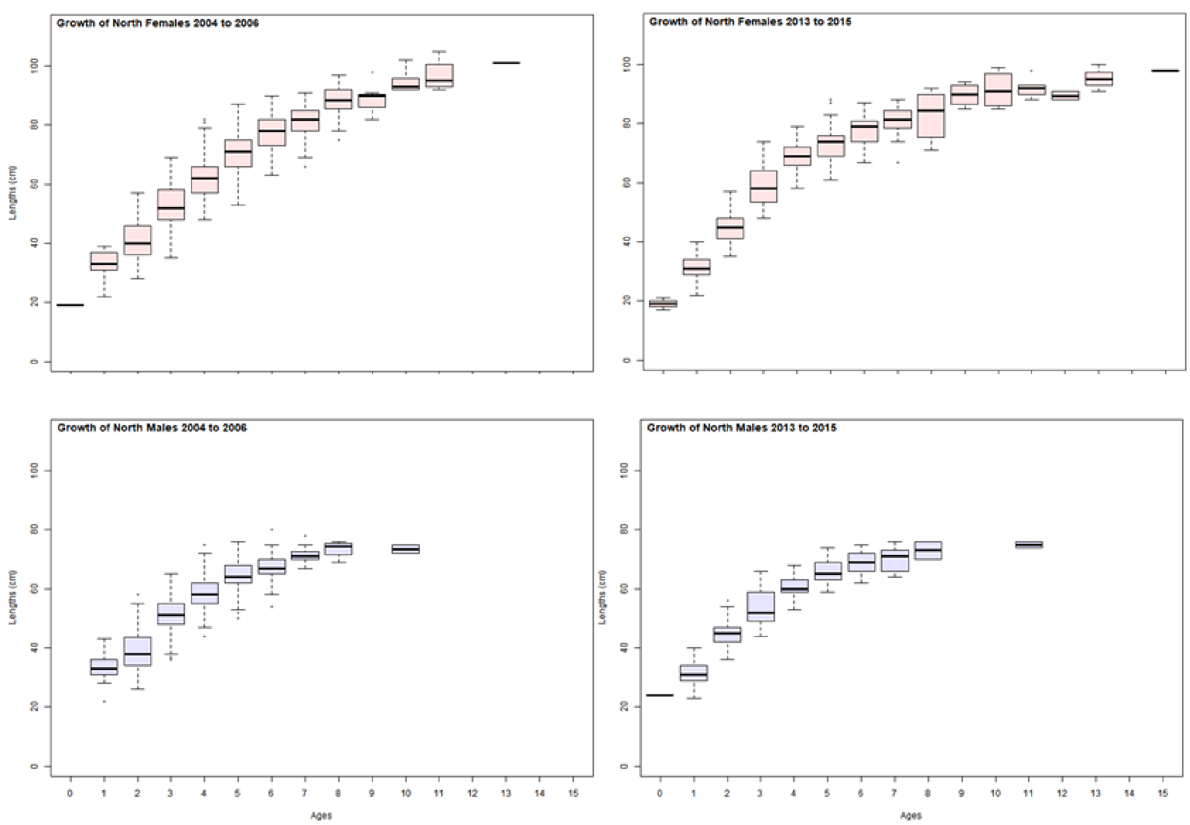

Figure 4. Box and whisker plot of lengths at age for lingcod in the northern stock as indicated by data from the NWFSC survey. The upper panels are for the females; the lower panels are for the males. The left-hand panels are from early years (2003-2006); the right-hand panels are from recent years (2013-2015). Plots for data from the southern area showed similar patterns.

Request 1.8: *For both the northern and southern models do a model run removing all indices except the NWFSC survey. Then add the Triennial survey without the 2004 data point. Compare results.*

Rationale: To understand the impact of individual survey series starting with the NWFSC survey, which is considered the most reliable. The second part of the request is to better understand the effect of the Triennial survey with the 2004 data point, which the model doesn't fit well and which may be influencing the overall model results.

Response: Removal of all indices except that for the NWFSC survey resulted in a slight reduction in the estimate of initial spawning biomass of lingcod in the northern stock, a decline to a similar level in the 1990s as estimated for earlier model runs, but a slightly greater recovery to a 2017 depletion of ~50% (light-orange line in Figure 2). The STAT advised that fishery marginal age-compositions were still employed when fitting this model, and had not yet been removed. It was noted that, although survey or fishery indices may have been excluded when fitting the assessment model, it would useful to include them in the model but flagged as non-informative data to examine the extent to which estimates of these indices matched input values. Subsequent addition of the indices for the Triennial survey to the model, without the 2004 value, produced spawning biomass estimates that were indistinguishable from those produced using the NWFSC survey indices. Removal of the option for the model for the northern stock to estimate an additional SD for the survey indices made little change to the trend of the spawning biomass (the red line in Figure 2).

For the southern stock of lingcod, removal of all indices other than those from the NWFSC survey resulted in a very marked increase in initial spawning biomass, with a decline by ~1990 to levels similar to those produced other model runs for earlier STAR Panel requests, before a marked recovery to a 2017 depletion of ~80% (the light-orange line in Figure 5, below). Subsequent addition of the indices for the Triennial survey, without the 2004 value, produced a slight reduction in the levels of spawning biomass for all years of the modelled period and in the value of 2017 depletion (the orange line in Fig.5 below). Removal of the option to include an additional SD in the survey indices for the southern stock produced a marked change in the levels of the estimates of spawning biomass (the red line in Figure 5). When indices were penalized by not adding extra SDs, estimates of spawning biomass reverted to values similar to those obtained for the version of the model fitted when estimating recruitment deviations from the first year of the modeled period, and well below the values produced when dropping all indices other than the NWFSC and Triennial indices. For this model, spawning biomass recovered by 2017 to a depletion of ~30%. The STAR Panel concluded that such evidence of tension among the different indices for the southern stock required further investigation.

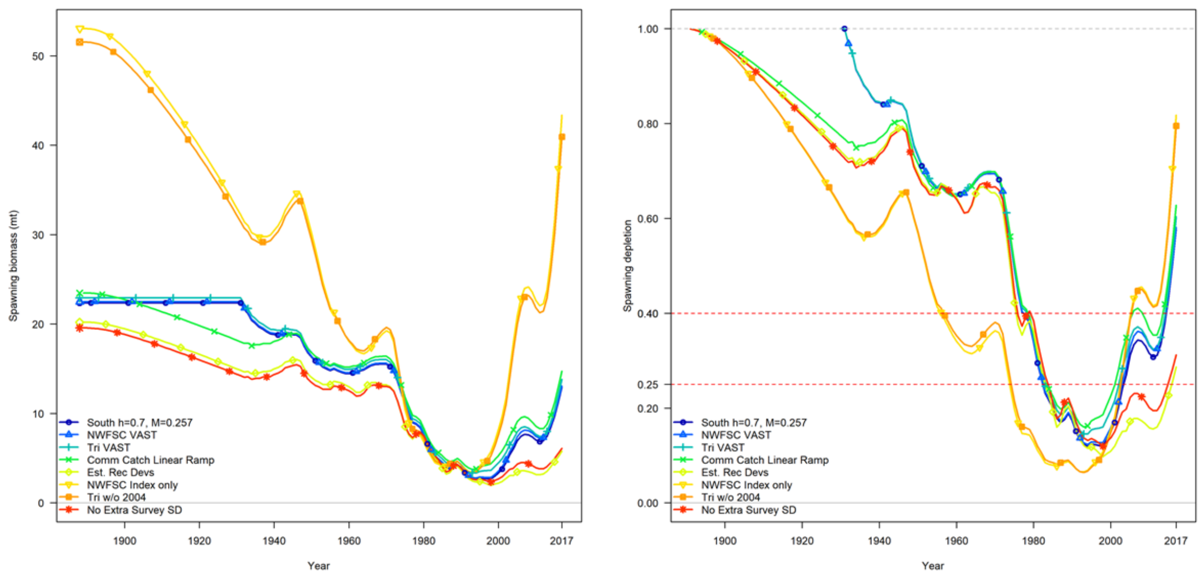

Figure 5. Spawning biomass trajectories for the southern stock as shown in Figure 4 with the additional modifications of Request 1.8.

Request 1.9: *In the northern model drop the WA Research compositional data.*

<u>Context</u>: These data had been included in the draft model to provide information for estimating selection for the fixed-gear fleet, but members of the STAT were uncertain that the gear used for this research project was comparable to the commercial fixed-gear.

<u>Rationale</u>: The fixed-gear fleet currently has compositional data for the same time period.

<u>Response</u>: Removal of the WA Research comp. data produced only a slight change in the estimates of spawning biomass. The STAR Panel endorsed this modification to the model for the northern stock.

Request 2.1: *Exploration of structure for a possible base model for the North.*

Step 1: Explore a simplified model for the northern stock with the following specifications (follow-up from Request 1.8).

- Use only NWFSC and Triennial surveys with associated CAAL and length-compositions.
- Use fishery length-compositions only (i.e., no fishery marginal age-compositions).
- Estimate recruitment deviations starting at the beginning of the modeling period with no estimated extra SD for the surveys. Estimate growth as in original proposed base model but also estimate female Length at A2 (not estimated in the draft base model). Maintain the same time-blocking as the draft base model. Estimate male *M* (as in the draft base model).
- No iterative re-weighting of the compositional data or recruitment bias adjustment parameters.

Step 2: Sequentially add the following inputs and compare likelihoods at each step.

- Trawl CPUE index.

- OR Nearshore CPUE index (commercial fixed-gear).
- WA Rec. Dockside CPUE index.
- OR Rec. Dockside CPUE index.

Step 3: Add CAAL data sequentially as follows for as many time periods as seems suitable and as time permits. Compare fits to the science center surveys at each step.

- Trawl compositions.
- Fixed-gear compositions.
- OR Recreational compositions (lower priority).
- WA Recreational compositions (lower priority).

Rationale: There is evidence that the fishery age-compositions are not representative of the length-compositions (Request 1.4). The marginal age-compositions are judged by the STAT to be biased. The sequential steps of this request may indicate which data are most informative and where data conflicts arise. The hope is the model as constructed sequentially will become the final base and determine which data are included in the model.

Response: The STAT presented a tabular summary of the results for the requested steps (Appendix Table A.3), and noted that they made no attempt to estimate the Hessian when fitting the models (i.e., there was no confirmation of convergence). First, likelihoods and parameter estimates were determined for the simplified model based on the NWFSC and triennial survey indices. The addition of the trawl CPUE index improved the fit to the early and late Triennial survey indices by 11.6 and 6 negative log-likelihood (NLL) units, respectively, but the NLL associated with the NWFSC survey index degraded by over 22 units. Addition of the OR Nearshore CPUE (fixed-gear) index, the WA Rec. Dockside CPUE index, and the OR Rec. Dockside CPUE index further degraded the fit to the NWFSC survey index with each additional index (by < 2 NLL units at each step). The quality of the fit to the late Triennial survey indices remained relatively unchanged while that of the early Triennial survey indices was first degraded then successively improved as the subsequent two fisheries indices were added.

Conditional age-at-length (CAAL) compositional data from the different sources were then introduced sequentially. An attempt to fit the model with a subset of the CAAL for the trawl fishery failed but the STAT were able to add the full set of CAAL data for the trawl fishery without too large an increase in model run-time. This improved the fit to the NWFSC survey index but degraded the fit to both the early and late Triennial survey indices. The process responsible for this trade-off in fit was unclear.

Growth parameter estimates (except for the female length at Amax, fixed at 112) were also affected by the addition of the CAAL compositional data, with (for example) marked reductions in the estimates of female length at the minimum age and in the female growth curve coefficient (k).

When fitting only the survey and fishery indices (models A-E in Table A.3), the only conditional ages at length (CAAL) included were those for the NWFSC and Triennial survey indices. With the addition of CAAL data from the fisheries the SDs for growth increased markedly, suggesting tension in the different data sources regarding growth. It is possible that the trade off with the Triennial survey relates to a change in growth between the early and late periods, or a change in selectivity. The attempt to then fit the CAAL data for fixed-gear compositions failed to find a solution in a reasonable amount of time (model G in Table A.3), but the CAAL data for OR Recreational compositions and WA Recreational compositions were added successfully (models H and I in Table A.3). The fit to the NWFSC survey indices remained relatively unchanged from the previous model runs, while the fit of both the early and late Triennial survey indices first improved then deteriorated. Female growth parameter estimates remained at levels considerably lower than the estimates obtained earlier by fitting the fishery indices.

After examining the likelihoods and parameter estimates resulting from the above exploration, the STAT explored two further runs (not shown in Table A.3). For the first, a model employing all survey and fishery indices and only the OR Recreational CAAL data was fitted. The second run used all survey and fishery indices and both the OR Recreational and WA recreational CAAL data. The fit to both the NWFSC and the early Triennial survey indices improved from that produced using a model with only survey and fishery indices. There was relatively little further change when the second set of CAAL data was added.

The STAT provided plots of spawning biomass and spawning biomass relative to unfished spawning biomass to allow comparison of the effect of the various scenarios on parameter estimates (Fig.6). Inclusion of the fishery indices reduced the extent to which the northern stock of lingcod was depleted in the 1990s and raised the level to which, in 2017, the stock was depleted from ~30 to ~40%. This change in trajectory appears to explain, at least in part, the marked change in likelihood when the first of the fishery indices was added to the model. Addition of the CAAL data to the model produced spawning biomass trajectories that differed markedly from those of the survey and fishery indices.

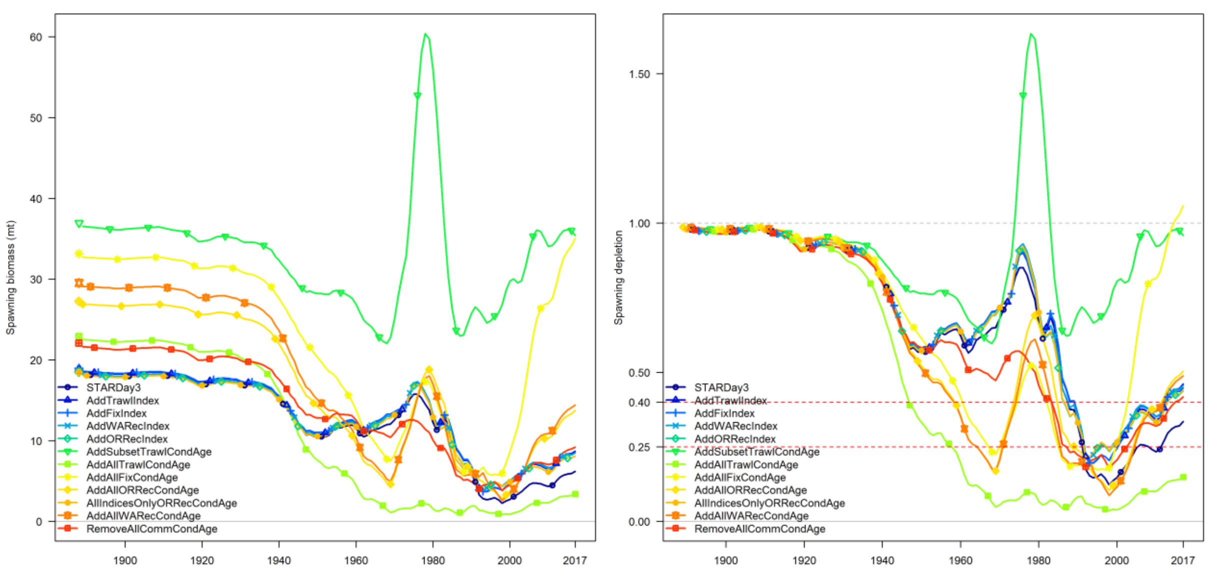

Figure 6. Spawning biomass trajectories for the northern lingcod stock produced when fitting the various scenarios explored for STAR Panel Request 2.1.

The inconsistencies between the survey and fishery indices and the information in the CAAL data that are evident in the summary table (Table A.3) and in the trajectories of spawning biomass (Fig.6) could be due to factors such as changes in the growth of individuals in earlier versus later periods, changes in selectivity, the appearance of larger than average recruitment at the end of the period, or unrepresentative samples of ages at length for the population as a whole. The latter might arise from age-dependent ontogenetic movements or spatial distributions.

The STAR Panel endorsed the STAT decision, based on the results of the analyses undertaken to respond to this STAR Panel request, to explore a candidate base for northern lingcod that employed all survey and fishery indices and the CAAL data for the survey indices but excluded CAAL data from the fisheries.

Request 2.2: *Exploration of structure for a possible base model for the South. Follow same steps as Request 2.1 for the southern model. Maintain the linear ramp-up of catches from the year when the northern model starts.*

Rationale: Same as for Request 2.1.

Response: As with the results for the northern stock, but to a lesser extent, the negative log-likelihood for the fit to the NWFSC survey index for the southern stock was reduced as the fishery indices were successively added (Appendix Table A.4). While the fit of the late Triennial survey indices similarly deteriorated with successive addition of fisheries indices, the fit of the early Triennial survey indices gradually improved as the trawl and recreational observer fishery indices were added. It was noted that spatial coverage of the fisheries indices differed and that only the NWFSC survey covered the full latitudinal range for the stock. Addition of the CAAL data resulted in a marked deterioration in the fit of the NWFSC survey indices, and, to a lesser extent, deterioration in the fit of both the early and late Triennial survey indices. As with the northern stock, the value of the coefficient, k, of the von Bertalanffy growth curve for females declined when the CAAL data were included in the model stock.

Discussion of the results revealed that, although the "Wadsworth index" (Central CA dockside recreational index) had been employed in the 2009 previous assessment, the methods employed when calculating the indices were not fully documented and techniques for analyzing recreational dockside data have advanced since 2009 in connection with the assessments of nearshore species conducted in 2015 (PFMC, 2015). For the current assessment, with the information and data available, it would be difficult to defend the use of this index when calculating the likelihood and fitting the model. If the Wadsworth index is to be used in future assessments, the data employed and methods used for developing the index should be re-examined and the analyses reworked so that the approaches employed may be critically assessed and, if necessary, refined.

Examination of the trends in the time series of estimates of spawning biomass, and ratio of spawning biomass to unfished spawning biomass (Fig.7) demonstrates that, for the southern stock, successive addition of the fisheries indices reduced the extent to which the stock became depleted in the late 1990s and decreased the value of 2017 depletion from ~60% when the assessment model employs only survey indices to ~24%, i.e., slightly less than the minimum stock size threshold, following addition of all fishery indices.

Inclusion of CAAL data results in markedly different trajectories of spawning stock biomass and ratio of spawning biomass to unfished spawning biomass demonstrating the inconsistency between the survey and fisheries indices and the CAAL data. As with the northern stock, such inconsistency could be due to factors such as changes in the growth of individuals in earlier and later periods, changes in selectivity, the appearance of larger than average recruitment at the end of the period, or unrepresentative samples of ages at length for the population as a whole. The latter might arise from age-dependent ontogenetic movements or spatial distributions.

The STAR Panel endorsed the decision by the STAT, based on the results of the analyses undertaken to respond to this STAR Panel request, to explore as a candidate base model for southern lingcod that employed all the survey and fishery indices (except the CA recreational onboard observer index) in combination with the CAAL data for the survey indices but none of the CAAL data for the fisheries.

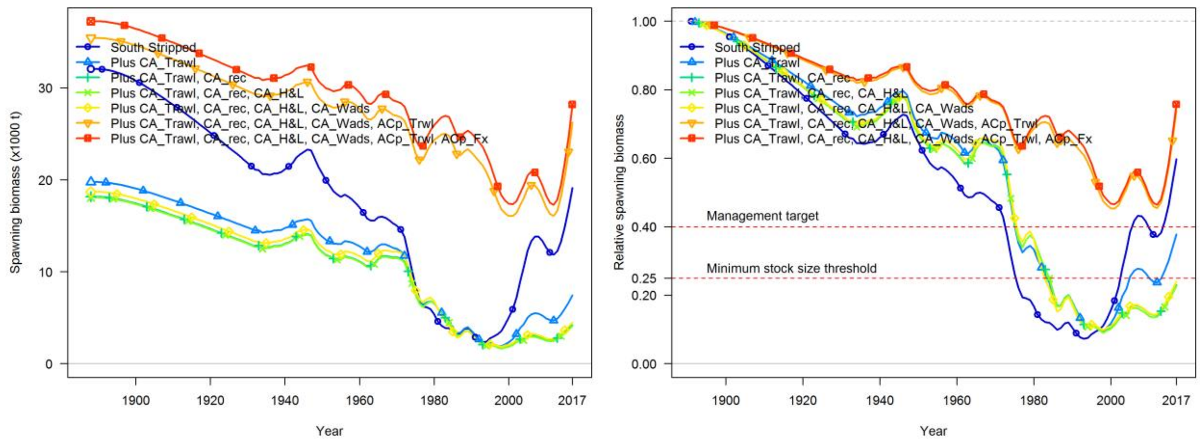

Figure 7. Spawning biomass trajectories for the southern lingcod stock produced when fitting the various scenarios explored for STAR Panel Request 2.2.

Request 3.1: *Explore a potential North base model that has the following specifications, using request 1 from day 3 (Request 2.1), including all indices.*

- No initial F.
- Estimate the female length at Amax (which so far has been fixed at 112 cm).
- CAAL only from the NWFSC survey and Lam study.
- Estimate extra SD on fishery CPUE indices.
- Retain all length-compositional data.
- Retune the mode and provide full diagnostics.
- If time allows, provide likelihood profiles across fixed values for female *M* and steepness (*h*) as in original draft base.
- If time allows, fix *h* and estimate *M*, and vice versa.

Rationale: These specifications converge on a consensus base model; this request is needed as a final check on its suitability.

Response: Following further exploration, the STAT found that, when fitting all growth parameters, the estimated value of female length at the maximum reference age (Amax, 14 years) was reduced from the value that had previously been fixed. However, the selectivity for the trawl fishery became asymptotic rather than dome shaped, a result the STAT deemed inconsistent with knowledge of this fishery. The STAT decided that it was necessary to fix female length at maximum age rather than leave it freely estimated so that the trawl fishery selection would not become asymptotic. The STAT set it at 110 rather than 112 cm, the value that had previously been employed; and the resulting trawl fishery selectivity was dome-shaped. The STAR Panel accepted this change. The STAR Panel and STAT examined the R4SS output for the model, and the STAR Panel accepted the STAT's recommendation that the model be accepted as the North lingcod base model.

The STAR Panel and STAT examined the likelihood profiles for *h*, *M* and *R*0 to explore possible options for specifying the required 12.5 and 87.5% levels of uncertainty for the low and high alternative states for the decision table. With the various data sources now in the model neither *M* nor *h* seemed to suitable candidates. However, it appeared that the likelihood profile for *R*0 (Fig.8) would provide a reasonable mechanism for bracketing the uncertainty.

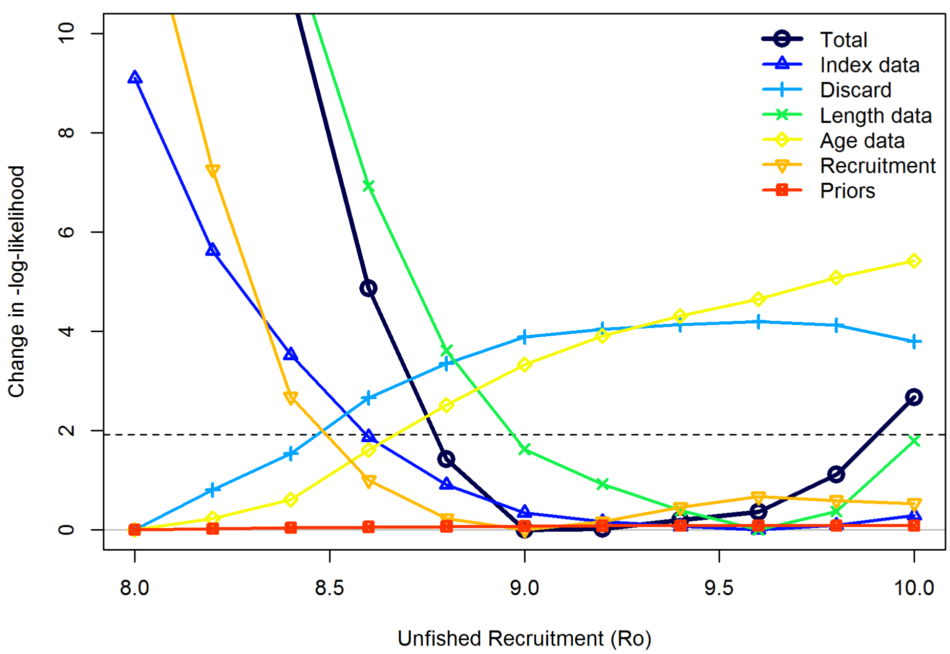

Figure 8. Likelihood profile for ln(*R*0) for the potential northern base model. Note that the X-axis label in the figure is incorrect.

Request 3.2: *Explore a potential South base model that has the following specifications using request 1 from day 3 (Request 2.2).*

- Include all fishery-independent indices.
- Include trawl CPUE index w/ extra SD estimated.
- Include CAAL comp. data only from the NWFSC survey and the Lam study.
- Retune the model and provide full diagnostics.
- If time allows, provide likelihood profiles across fixed values for female *M* and steepness (*h*) as in original draft base.

- If time allows, fix *h* and estimate *M*, and vice versa.

Rationale: These specifications converge on a consensus base model; this request is needed as a final check on its suitability.

Response: The STAR Panel and STAT examined the R4SS output for the model, and the STAR Panel accepted the STAT's recommendation that the model be accepted as the South lingcod base model.

The STAT produced likelihood profiles for *h*, *M* and *R*0 the model to determine options for specifying the 12.5 and 87.5% levels of uncertainty required for the low and high alternatives for the decision table. Although the profile for *h* suggested it would be possible to estimate *h*, when this was done, the spawning biomass was driven to unrealistic, very low values of depletion. The key variables driving this profile were the Californian recreational and Lam surveys, where the CAALs of the latter survey appeared to have oversampled the older fish possibly as a result of sampling in areas closed to fishing. The likelihood profile for *M* demonstrated that, if an attempt was made to estimate *M*, the age- and length-compositions would drive the estimate towards an upper bound.

The likelihood profile across ln(*R*0) for the southern base model appeared to provide a mechanism for producing low and high alternatives for the decision table, as had also been proposed for the northern model (Fig.9). The STAR Panel suggested the STAT use the likelihood profile to locate low and high values for ln(*R*0) corresponding to the 12.5 and 87.5 percentiles of the distribution of values of negative log-likelihood centered on the minimum value of negative log-likelihood. Twice the difference between a value of the total negative log-likelihood and the total negative log-likelihood at the minimum would be expected to have a Chi-square distribution with 1 df. Thus, the values of ln(*R*0) at the points of intersection of the likelihood profile for the total and a horizontal line a certain number of log-likelihood units greater than the minimum value of the likelihood profile could be used as the 12.5 and 87.5 percentiles of the distribution of values of ln(*R*0) (i.e., the 75th percentiles). The base models would then be re-fitted, after fixing ln(*R*0), to estimate the values required for the decision table of the assessment report. The STAR Panel endorsed this approach, but requested that the STAT confirm that the estimates of spawning biomass associated with the 12.5 and 87.5 percentiles of ln(*R*0) encompass the 12.5 and 87.5 percentiles based on the base model estimate of 2017 spawning biomass and its associated standard error.

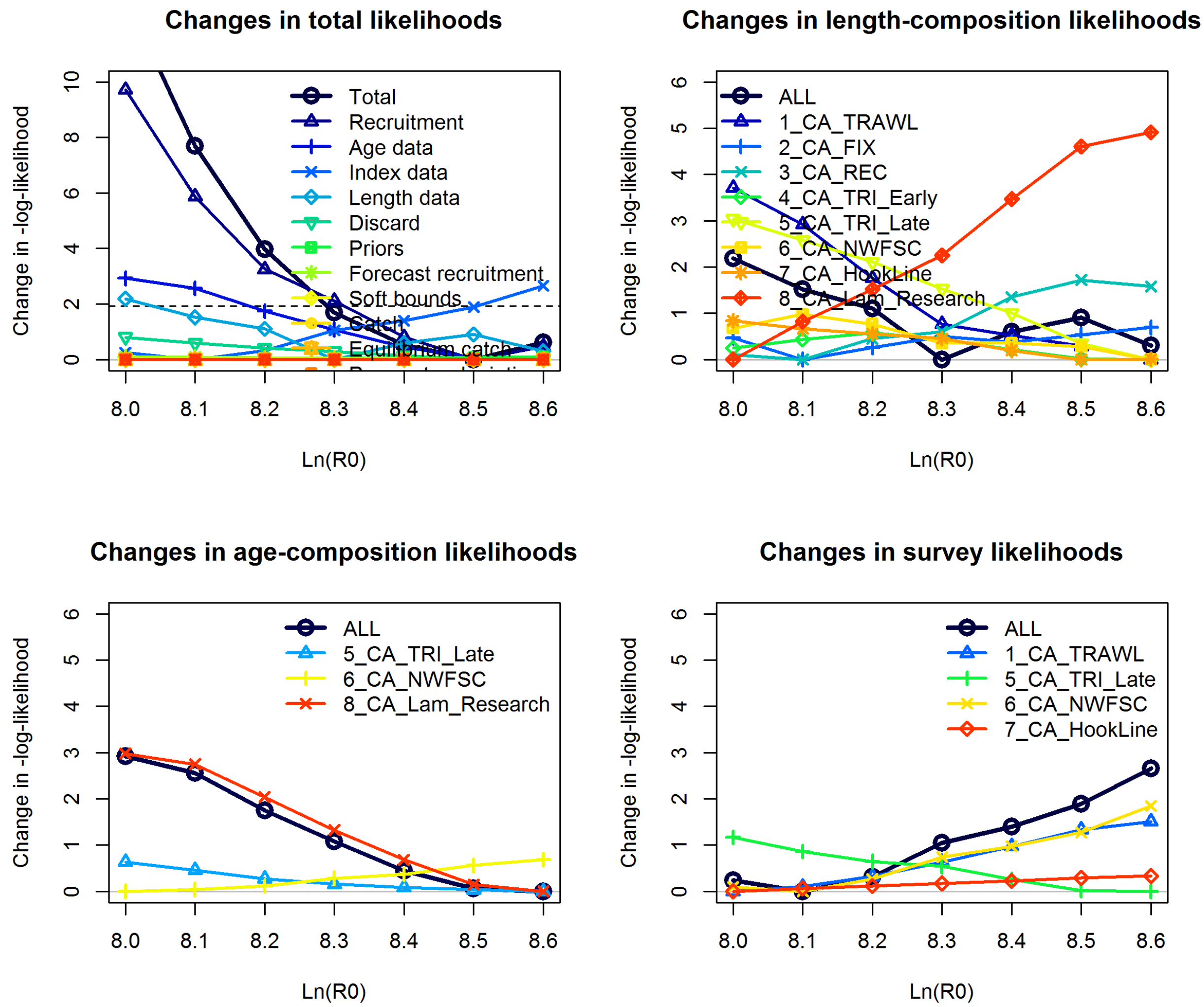

Figure 9. Likelihood profile for ln(*R*0) for the potential southern base model.

Request 4.1*: *Build decision tables for the northern and southern stocks based on the ln(R0) profiles, choosing the states of nature from the values of ln(R0) where the change in the negative log likelihood is 1.18 log-likelihood units from the global minimum for ln(R0). The goal is to achieve bounds at least as wide as the 12.5% and 87.5% quantiles of the estimated 2017 spawning biomass.*

Rationale:	Other approaches for constructing the decision tables (e.g., using *M* or *h*) did not provide enough contrast.

Response:	The STAT did not have time during the STAR meeting to complete the construction of the decision tables. The STAR Panel Chair will review the tables when they are completed.

* After the STAR meeting the Panel Chair, in discussion with the other Panelists and members of the Scientific and Statistical Committee's Groundfish Subcommittee, determined that the correct value to use for the change in negative log-likelihood is 0.662 rather than 1.18, which is the value corresponding

to 87.5% confidence limits rather than the intended 75% confidence limits. This was communicated to Dr. Melissa Haltuch via email on 07/13/2017.

Description of the Base Models (Northern and Southern) and Alternative Models used to Bracket Uncertainty

The northern and southern models shared numerous features. Each was for a single area and modeled the stock present there using a single season, a single growth-morph, two-sexes, and covered the period 1889-2016, with catches and recruitment deviations beginning in 1889 from an unfished equilibrium; the main period for recruitment deviations was 1965-2015. Both models had steepness fixed at 0.7; female natural mortality (*M*) fixed at 0.257 $year^{-1}$ (the median of a prior based on a maximum age of 21 years), and male *M* was estimated (based on the same prior). Both models used the same internal structure for ages (ranging from zero to an accumulator age of 25) and similar internal structures for lengths (2-cm length bins ranging from 10 to 130 cm in the northern model and from 4 to 130 cm in the southern model). The parameters for the growth curves (length-at-age) were fully estimated except for the parameter controlling female length at age-14 in the northern model.

Both models were informed by survey biomass indices and biological data (length-compositions) from the early (1980-1992) and late (1995-2004) Triennial trawl survey and the NWFSC trawl survey (2003-2016), by marginal age-compositions from the late Triennial trawl survey, and by conditional age-at-length compositions data from the NWFSC trawl survey and the Lam research project (2016). Both models had trawl and fixed-gear commercial fishing fleets that included length-based retention to account for discarding with observations from the West Coast Groundfish Observer Program of discard rates (2002-2015) and discard length-compositions (2004-2015). Both models were informed by trawl fishery CPUE indices for the period 1981-1997 and these indices had estimated parameters for extra variability (Extra_SD).

Both models used double-normal, length-based selection curves for all fleets and did not constrain any fleets to have asymptotic selectivity.

Neither model used the age data available from the fishing fleets due to concerns about the apparent influence of non-random selection of fish for age-reading and age-data that included fish that had been un-sexed or possibly miss-sexed.

The models differed in terms of the following structural features.

Feature	Northern model	Southern model
Recruitment variability ()	0.55	0.75
Maturity	L50% = 56.7 cm Slope = -0.269	L50% = 52.3 cm Slope = -0.219
Growth	Length at age 14 fixed at 110 cm	
Fishing fleets	OR recreational WA recreational	CA recreational
Survey indices		Central CA hook and line
Fishery CPUE indices	OR nearshore commercial fixed-gear OR recreational dockside WA recreational dockside	

Feature	Northern model	Southern model
Indices with Extra_SD	OR nearshore commercial fixed-gear OR recreational dockside WA recreational dockside	

The models also differed in the time-blocking used with the fixed-gear and recreational fishing fleets.

In both models the length- and CAAL compositional data were tuned using the Francis approach. There was no iterative re-weighting applied to the survey indices but some indices had associated Extra_SD parameters that were freely estimated (indicated in the table above). Both models also were tuned to have suitable bias adjustments for recruitment variability and there were slight adjustments to the σ_R parameter values relative to the draft models brought to the STAR.

To bracket uncertainty for the decision table the STAT used low and high fixed values for ln(R0) to achieve estimates of spawning biomass in 2017 that corresponded to the 12.5th and 87.5th percentiles estimated for the base model (i.e., base model SB_{2017} +/- 1.15 times its estimated standard deviation).

Following the STAR the STAT conducted additional jitter runs to confirm convergence of the final base models. The STAT found a slightly better fitting southern base model than the model reviewed on the final day of the STAR.

Technical Merits of the Assessments

- The new north and south assessment models for lingcod make good use of the large amounts of data available for these stocks.
- The STAT was able to resolve problems encountered during the 2009 assessment for lingcod that resulted in the removal of all the available age data during the 2009 STAR.
- The STAT was fully responsive to STAR Panel requests and demonstrated considerable skill revising the draft base models in response to Panel requests, producing presentations to illustrate the relevant results, and working with the Panel to develop acceptable base models that addressed the major concerns to the extent they were tractable during the course of the review.

Technical Deficiencies of the Assessments

Overall, there were no serious technical deficiencies with the north and south lingcod assessments. Although there were some unusual patterns in the residuals for the biomass indices and compositional data, these are likely due to inconsistent trends within and between different data sources that only a much more complicated model structure could rectify.

Areas of Disagreement Regarding STAR Panel Recommendations

Among STAR Panel members (including GAP, GMT, and PFMC representatives):

None.

Between the STAR Panel and the STAT Team:

None.

Management, Data, or Fishery Issues Raised by the GMT or GAP Representatives during the STAR Panel Meeting

None.

Unresolved Problems and Major Uncertainties

The final base models left a number of problems unresolved.

- The models did not use the available age data sampled from the fishing fleets due to concerns that unsexed fish had been assigned equally to the sexes without regard to length and because of evidence there had been non-random subsampling of fish for age-reading.
- The available age-readings had been done by at least two laboratories. It was unclear that age-reading protocols had been employed consistently.
- In the northern model the STAT fixed the parameter for female length at age 14 years because when this parameter was freely estimated the model estimated asymptotic selection for the trawl fishery and greatly altered the estimates of spawning biomass. It was unclear what data sources were responsible for this result.
- Sensitivity analyses for draft versions of both models indicated they were sensitive to underlying structural assumptions such as the starting year for recruitment deviations and which indices were included. Although the revisions to the models developed during the STAR may have lessened the sensitivity of the models by removing sources of tension and keeping the more reliable data, there was not sufficient time during the review to explore the sensitivity of the final base models.

There are several major sources of uncertainty in the assessments for lingcod off the U.S. West Coast.

- <u>Stock structure</u>: Aspects of the length- and age-compositions evident in the NWFSC survey data strongly indicate spatial patterns that probably cannot be well mimicked with separate, independent models for the north and the south (Appendix Fig. A.3).
- <u>Key productivity parameters</u>: Neither the northern model nor the southern model were able to estimate the steepness or the female natural mortality parameters given the available data. Values for these key parameters had to be fixed but there is very little knowledge to inform the choice of those values. As such this is a source of considerable uncertainty. During review of this report the STAT suggested that including the age-composition data in the northern base model (data had been removed during the STAR) would allow estimation of M and h.
- <u>Habitat area, north versus south</u>: The northern and southern base models estimate appreciable differences in the unfished spawning biomass of lingcod (37,974 mt in the north versus 20,462 mt in the south). It is unknown whether such a difference is consistent with the habitat areas suitable to support lingcod in the north versus the south.

Prioritized Recommendations for Future Research and Data Collection

Specific recommendations for the next lingcod assessment

Prior to the next iteration of this assessment the age data available from the fishing fleets should be carefully screened to identify and possibly rectify aberrant data.

1. There should be a study to cross-validate age-readings of lingcod among the different laboratories contributing age data to the assessment. It may be necessary to develop laboratory-specific (and possibly year-specific) ageing-error vectors.
2. Available information on lingcod catches, abundance trends, and age-compositions should be acquired from Canadian and Mexican authorities to take an initial step towards a more spatially-comprehensive view of lingcod population trends and dynamics.
3. The next iteration of this assessment could be an update assessment. If a full assessment is done it should explore developing a spatial model that encompasses the northern and southern areas rather than again treating them as independent stocks, as in the current and previous assessments.

General recommendations for all assessments

1. Modify the software used to develop length- and age-compositions from PacFIN data so that unsexed fish are flagged rather than including them in compositions after the automatic application of an assumed sex-ratio (e.g., 50:50). If the analysts preparing the composition data need to develop sex-ratio coefficients to accommodate unsexed fish (e.g., by length-bin), the assessment documents should clearly state the methods and data used for this purpose and the resulting sex-ratio coefficients.
2. If assessments use marginal age-compositions the STATs should evaluate whether the raw data are consistent with random sub-sampling from the available lengths. If the ages appear to have been subsampled non-randomly (e.g., no more than 5 fish from any length-bin), the age data should be suitably expanded to reflect the variable sampling fraction.
3. A standard approach for combining conditional age-at-length sample data into annual CAAL compositions should be developed and reviewed. If age data are not selected in proportion to the available lengths, simple aggregation of the ages by length-bin may provide biased views of the overall age-composition and year-class strength.
4. Comprehensively evaluate whether the Triennial survey should be split into early and late segments and the basis for making the decision. The lingcod assessment split the Triennial survey into separate early and late surveys, whereas there was a single Triennial survey in the draft assessment for Pacific ocean perch brought to this STAR.

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Appendix

Table A.1. Blocking structure for the north. *The table does not indicate the initial blocks, which began with the start of the model in1889 in the final base model.*

Time Block	***Relevant Fleets***	***Rationale***
1998-2010	*Fixed (retention)*	
2011-2016		*Catch shares program*
1998-2006	*Trawl (retention)*	*Begin Implementation of Ground Fish (Gfish) Regulations*
2007-2009		*Gfish Regulations*
2010		*Pre-catch share behavior change*
2011-2016		*Catch shares program*
1973-1982	*Trawl (size sel)*	*Gear regulatory changes*
1983-1992		*Gear regulatory changes*
1993-2002		*Gear regulatory changes*
2003-2010		*Rebuilding, Closed Areas*
2011-2016		*Catch shares program*
1999-2016	*Oregon recreational (size sel)*	*Regulatory change*

Table A.2. Blocking structure for the south. *The table does not indicate the initial blocks, which began with the start of the model in1889 in the final base model.*

Time Block	*Relevant Fleets*	*Rationale*
1998-2001	*Fixed (retention, size sel)*	*Begin Implementation of Gfish Regulations*
2002		
2003-2010		*Rebuilding, Closed Areas*
2011-2016		*Post-catch shares*
1998-2006	*Trawl (retention)*	*Begin Implementation of Gfish Regulations*
2007-2009		*Gfish Regulations*
2010		*Pre-catch share behavior change*
2011-2016		*Catch shares program*
1973-1982	*Trawl (size sel)*	*Gear regulatory changes*
1983-1992		*Gear regulatory changes*
1993-2002		*Gear regulatory changes*
2003-2010		*Rebuilding, RCA, CCA*
2011-2016		*Post-catch shares*
1959-1974	*CA recreational (size sel)*	*MB regional comps*
1975-1989		*S. Cal. regional comps*
1990-2003		*MRFSS*
2004-2016		*RecFIN*

Table A.3. Summary of northern model fits, parameter estimates, and derived quantities for the STAT's response to Request 2.1.

A	Simple: NWFSC & Triennial indices and comp. data, no fishery indices or comp. data		
B	+ Trawl Index	F	+ Trawl CAAL
C	+ Fixed-Gear Index	G	+ Fixed-Gear CAAL
D	+ WA Rec Index	H	+ OR Rec CAAL
E	+ OR Rec Index	I	+ WA Rec CAAL

North lingcod models =	A	B	C	D	E	F	G	H	I
TOTAL_like	1376.5	1364.0	1352.8	1333.9	1311.3	15847	19426	19522	20328
Likelihood components									
Surv_N_TRI_Early	-5.51	-17.15	2.41	-18.85	-24.54	2.67		-3.35	1.40
Surv_N_TRI_Late	0.37	-5.59	-5.60	-4.96	-4.58	0.54		-2.09	0.44
Surv_N_NWFSC	-21.11	1.45	1.26	2.89	3.74	-18.13		-18.57	-19.55
Len_N_TRI_Early	27.15	27.14	27.14	27.23	27.81	46.18		45.46	47.30
Len_N_TRI_Late	20.59	20.16	20.10	19.89	19.66	28.70		27.12	31.64
Len_N_NWFSC	70.90	71.48	71.80	72.30	72.17	94.16		107.58	106.85
Age_N_TRI_Late	25.12	24.68	24.72	24.68	24.72	38.08		32.15	38.07
Age_N_NWFSC	356.31	359.91	360.00	360.74	360.42	658.73		650.31	650.25
Survey_like	-26.24	-42.44	-54.53	-74.39	-99.79	-88.69	-31.91	-84.23	-84.68
Discard_like	-48.18	-50.95	-50.74	-52.34	-52.26	-38.36	-43.81	-47.68	-36.58
Length_comp_like	1003.2	1007.6	1008.2	1010.3	1013.1	1272.2	1337.6	1386.1	1365.7
Age_comp_like	444.8	447.6	447.7	448.3	448.0	14691	18136	18257	19071
Parm_priors_like	0.34	0.37	0.37	0.36	0.35	0.12	0.12	0.08	0.15
Parameters									
NatM_p_1_Fem_GP_1	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257
L_at_Amin_Fem_GP_1	16.32	16.17	16.23	16.22	16.24	8.89	12.09	12.97	11.98
L_at_Amax_Fem_GP_1	112	112	112	112	112	112	112	112	112
VonBert_K_Fem_GP_1	0.126	0.127	0.126	0.126	0.126	0.090	0.074	0.065	0.060
CV_young_Fem_GP_1	0.141	0.141	0.141	0.142	0.142	0.483	0.235	0.250	0.281
CV_old_Fem_GP_1	0.070	0.070	0.070	0.070	0.069	0.010	0.500	0.500	0.500
NatM_p_1_Mal_GP_1	0.297	0.301	0.303	0.300	0.299	0.189	0.246	0.226	0.257
L_at_Amin_Mal_GP_1	15.81	15.62	15.58	15.58	15.57	10.00	10.00	10.00	10.00
L_at_Amax_Mal_GP_1	76.33	75.56	75.44	75.24	75.21	41.91	110.00	58.84	66.51
VonBert_K_Mal_GP_1	0.295	0.307	0.309	0.311	0.311	0.779	0.062	0.427	0.352
CV_young_Mal_GP_1	0.158	0.159	0.159	0.159	0.159	0.010	0.500	0.010	0.012
CV_old_Mal_GP_1	0.072	0.074	0.074	0.075	0.076	0.500	0.500	0.500	0.500
Derived quantities									
SSB_Unfished_1000_mt	18.55	18.89	18.96	18.63	18.52	22.90	33.16	27.26	29.53
Recr_Unfished_millions	4.0447	4.1119	4.1292	4.0644	4.0417	5.7527	7.1241	5.9992	6.6346
Bratio_2017 (depletion)	0.3348	0.4609	0.4472	0.4549	0.4377	0.1484	1.0577	0.5038	0.4884

Table A.4. Summary of southern model fits, parameter estimates, and derived quantities for the STAT's response to Request 2.1.

A	Simple: NWFSC & Triennial indices and comp. data, no fishery indices or comp. data		
B	+ Trawl Index	F	+ Trawl CAAL
C	+ Recr. Observer Index	G	+ Fixed-Gear CAAL
D	+ Hook & Line Survey Index		
E	+ Wadsworth Index		

South lingcod models =	A	B	C	D	E	F	G
TOTAL_like	1327.1	1306.3	1293.4	1293.0	1287.4	2003.4	2034.0
Likelihood components							
Surv_N_TRI_Early	-2.00	-2.26	-2.27	-2.27	-2.21	-1.67	-1.67
Surv_N_TRI_Late	-2.13	-1.58	-0.34	-0.23	-0.16	0.03	0.04
Surv_N_NWFSC	-15.39	-14.99	-13.20	-12.39	-12.51	-9.96	-9.89
Len_N_TRI_Early	22.85	24.17	24.32	24.33	24.10	33.24	33.46
Len_N_TRI_Late	106.45	106.59	107.83	108.01	108.30	115.92	116.48
Len_N_NWFSC	37.35	37.76	37.05	36.77	36.69	35.72	35.69
Age_N_TRI_Late	20.46	19.82	20.20	20.24	20.42	19.17	19.02
Age_N_NWFSC	357.83	356.87	357.29	357.42	357.76	445.10	447.07
Survey_like	-19.52	-46.18	-59.09	-59.27	-67.61	-52.26	-51.69
Discard_like	-9.14	-9.24	-8.75	-8.67	-8.49	-8.02	-8.01
Length_comp_like	907.8	910.0	904.3	903.7	906.6	950.6	952.4
Age_comp_like	444.6	444.1	445.4	445.5	445.6	1109.5	1137.7
Parm_priors_like	0.42	0.43	0.51	0.52	0.52	0.58	0.58
Parameters							
NatM_p_1_Fem_GP_1	0.257	0.257	0.257	0.257	0.257	0.257	0.257
L_at_Amin_Fem_GP_1	18.13	18.08	17.96	17.93	17.96	19.07	19.10
L_at_Amax_Fem_GP_1	93.92	93.62	92.92	92.71	92.92	90.84	90.87
VonBert_K_Fem_GP_1	0.126	0.128	0.134	0.136	0.134	0.099	0.098
CV_young_Fem_GP_1	0.153	0.154	0.156	0.156	0.156	0.144	0.143
CV_old_Fem_GP_1	0.067	0.067	0.066	0.066	0.067	0.064	0.064
NatM_p_1_Mal_GP_1	0.310	0.312	0.326	0.326	0.326	0.335	0.335
L_at_Amin_Mal_GP_1	18.21	18.24	18.09	18.05	18.02	18.45	18.46
L_at_Amax_Mal_GP_1	84.69	84.71	82.82	82.57	82.28	76.01	75.82
VonBert_K_Mal_GP_1	0.156	0.153	0.166	0.168	0.171	0.188	0.189
CV_young_Mal_GP_1	0.138	0.138	0.142	0.143	0.143	0.138	0.138
CV_old_Mal_GP_1	0.088	0.090	0.082	0.081	0.079	0.087	0.088
Derived quantities							
SSB_Unfished_1000_mt	32.04	19.76	18.16	18.07	18.69	35.42	37.24
Recr_Unfished_millions	7.543	4.697	4.416	4.422	4.545	9.423	9.889
Bratio_2017 (depletion)	0.5974	0.3777	0.2298	0.2259	0.2395	0.7411	0.7571

Figure A.1. Pearson residuals for the encounter rates (left panels) and positive catch rates (right panels) from the application of the VAST to the trawl fishery logbook data series.

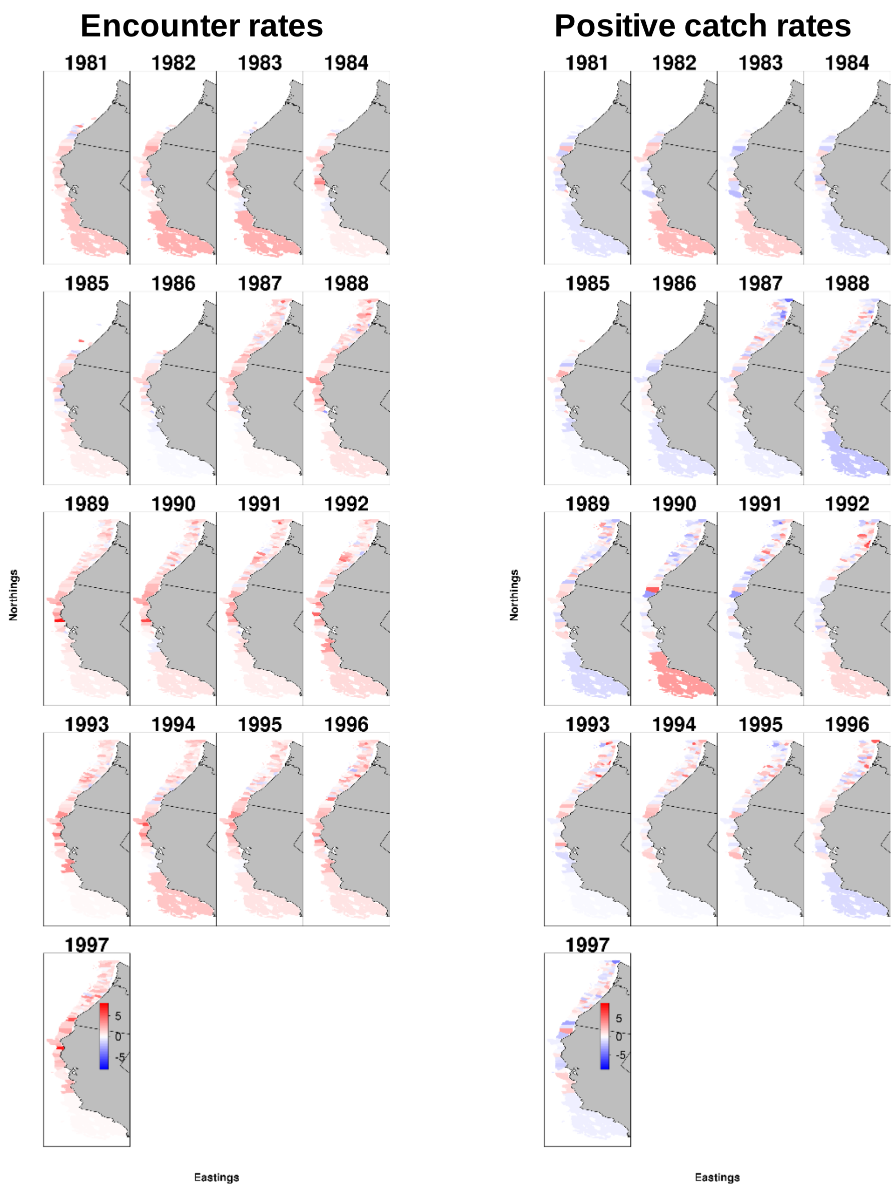

Figure A.2. Length-compositions of retained lingcod in the northern Trawl fishery. *Note that the observed distributions of females and males are mirror images for 1971-1974, which is inconsistent with the expectation that female lingcod attain large sizes than male lingcod.*

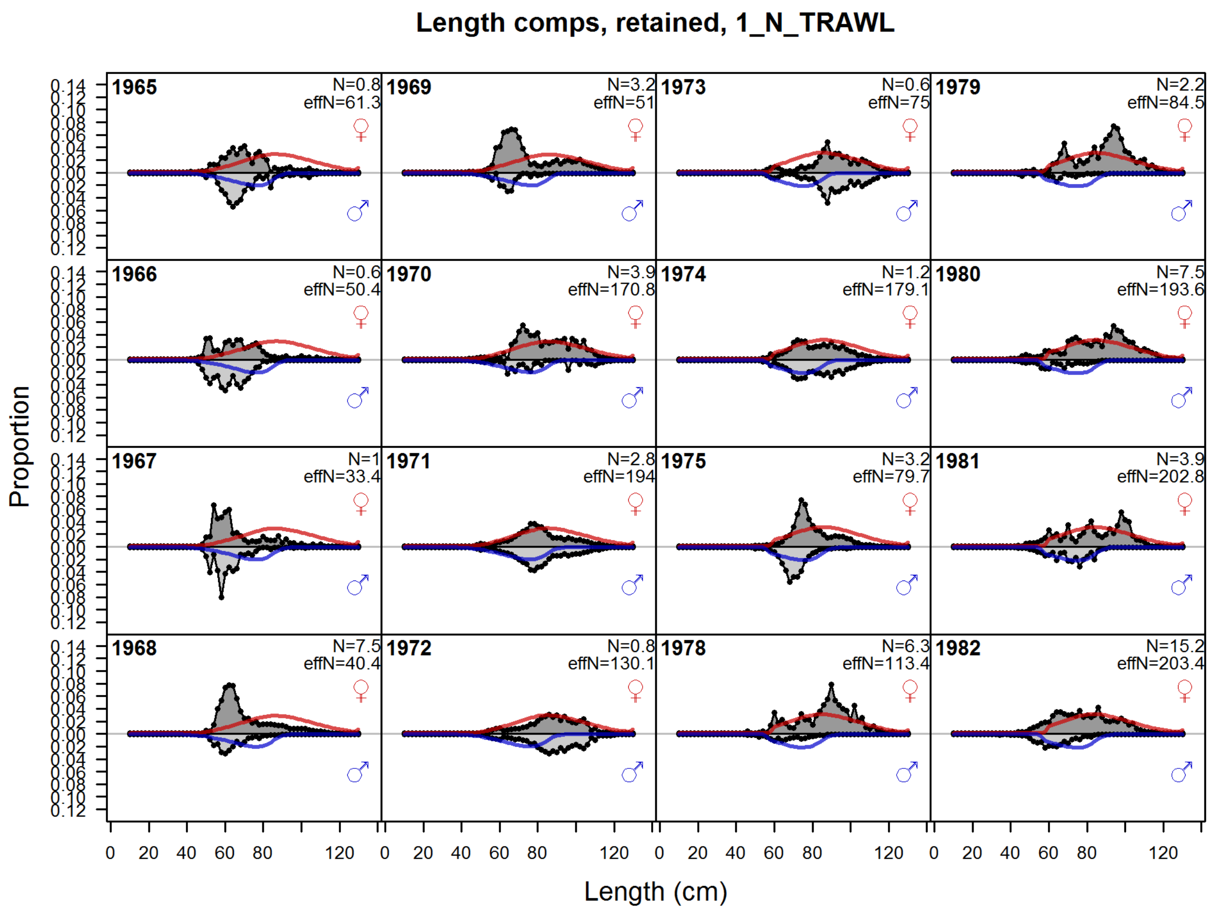

Figure A.3. Age-compositions from the NWFSC trawl survey by state area. *This figure is based on a slide shown by the STAT on Day 1 of the STAR.*