Big Skate Stock Assessment Review (STAR) Panel Report

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Overview

A Stock Assessment Review (STAR) panel met during 3-7 June 2017 at the Northwest Fisheries Science Center (NWFSC) auditorium in Seattle, Washington to review a draft stock assessment for big skate (*Beringraja binoculata*). The assessment had been prepared by a stock assessment team (STAT) led by Dr. Ian Taylor of the NWFSC and was documented in Taylor et al. 2019). The Panel operated under the Pacific Fishery Management Council's (PFMC) Terms of Reference for stock assessment reviews (PFMC 2019). This same panel also reviewed a draft assessment for longnose skate (*Beringraja rhina*).

Of the eleven skate species present in the northeast Pacific off the US West Coast, big skate comprises the second most abundant species in the fishery and survey catches, after longnose skate. The density of big skates off the US West Coast is greatest on the shelf at depths < 100 m and big skate tend to be found shallower than longnose skate. A tagging study of big skates off British Columbia found that most tagged individuals were recaptured within 21 km of the tagging locations, but 15 of the tagged individuals (0.1%) moved over 1,000 km (King and McFarlane 2010). The big skate off the US West Coast are treated in the assessment as a unit stock, although there likely is exchange of individuals among the regional populations off the US West Coast, British Columbia, and the Gulf of Alaska.

Big skate is oviparous and is one of two skate species that have multiple embryos per egg case, with as many as 8 embryos in a single egg capsule. Eggs are deposited year-round on sand or mud substrates at depths of about 50-150 m and embryos hatch from eggs after 6-20 months, with time-to-hatching dependent on water temperatures. Female big skate in captivity may produce more than 350 eggs/year. Upon hatching, a new-born big skate is similar in appearance to an adult (i.e., no metamorphosis from larval to adult form).

Maximum ages of big skate off central California have been reported as 12 y for females and 11 y for males, whereas estimates for animals caught off British Columbia were reported as 26 y for females and 25 y for males. The assessment assumes a maximum age of 15 y as observed for one fish based on ages for 1034 fish from the Northwest Fisheries Science Center's West Coast Groundfish Bottom Trawl (WCGBT) Survey. Big skate can grow to attain total lengths (TL) of almost 245 cm. Length at 50% maturity was taken as 148.2 cm (TL) in the assessment.

There was no separate market category for big skate until 2015, when it was separated from an "unspecified skates" category into its own market category. In contrast, mandatory sorting of longnose skate from landings of other skate species started in 2009, following the 2007 stock assessment for longnose skate. Species-level landings of skates were derived by the state fishery agencies of California, Oregon, and Washington using estimates of species proportions based on limited species composition samples and auxiliary information. Prior to the most recent years, the landings series for big skate are relatively uncertain.

The US West Coast landings of skates (all species) were relatively limited prior to the mid-1990s, apparently due to a lack of market opportunities. It is thought that the vast majority of the skates that were caught were discarded at sea. There was a dramatic change in market conditions with the annual landed catches of big skate increasing from an average of 47.6 mt during 1985-1995 (coastwide) to an average of 328.4 mt during 1996-1999. Peak annual landings were 528 mt in 1997. At-sea observations of big skate discards did not begin until 2002. Although there were sporadic observations of longnose skate discards as far back as 1985, the early studies did not report discards of big skate.

There have not been any previous stock assessments for big skate. The current overfishing limit (OFL) for big skate is based on a proxy for F_{MSY} and the average of annual swept-area estimates of biomass from the WCGBT survey during 2010-2012.

The Panel concluded that the final base model for big skate, developed during the STAR meeting, is appropriate for use by management and constitutes the best available science. Due to the paucity of age-compositional data and consequent lack of annual recruitment deviations, the Panel considers this to be a category 2 assessment. Further, the biomass indices in the model were only weakly informative regarding scale and trends were not well fit by the model. The main sources of information determining $\ln(R_0)$ were the tension between the age-compositional data (favoring a larger $\ln(R_0)$) and the priors plus the length data (both minimized at roughly $\ln(R_0) = 8.8$). Although the biomass scale is very uncertain, there was no evidence in the assessment document or presented during the STAR Meeting indicating that the stock was in a depleted condition. The Panel applauds the STAT team for their well-structured presentation of the assessment and the competent work completed before and during the STAR meeting.

Summary of Data and Assessment Models

The assessment for big skate follows the same basic structure as used in the new assessment for longnose skate: a single coastwide stock; no recruitment deviations; steepness is fixed at 0.4; and informative prior distributions on natural mortality and on the survey-*Q* for the WCGBTS, which is the primary source of fishery-independent information. One difference from the longnose skate assessment is that in the model for big skate the sexes are kept separate to estimate sex-specific growth. Also, big skate growth is modeled using a new "growth-cessation" formulation (described more fully below). The STAT used the Stock Synthesis (SS) version 3.30.13 software.

Catch series and fishing fleet structure

The big skate STAT was unable to use the approach taken by the longnose skate STAT for estimating historical catches. The 2019 longnose skate assessment derived historical catch estimates (for years prior to 2009) on the basis of a linear regression model ($R^2 = 95.7\%$) developed from West Coast Groundfish Observer Program (WCGOP) estimates for the period 2009-2017 of total annual mortality of longnose skate (landings plus dead discards) versus total annual mortality estimates of Dover sole. For big skate the WCGOP had only produced estimates of total annual mortality (landings plus dead discards) for 2015-2017.

The STAT derived a historical catch series for big skate from the historical catch series for longnose skate, the historical reconstruction of the landings of all skates, an analysis of discards of longnose skate, and the assumption that discard rates for big skate are the same as discard rates for longnose skate. There was a linear ramp in total catch from 1916 to 1950. For the period 1950-1994 an estimate of the mean annual discard amount was calculated from the mean discard rate and the mean landings as avL = (1 - avD), where avL is the mean landings across the time period and avD is the mean discard rate. The STAT found that using annual discard rate values resulted in implausibly high inter-annual variability. The dead catch was estimated as the landings plus the dead discards, assuming 50% survival of the discarded big skate.

Fishing removals in the big skate model (as in the longnose skate assessment model) are taken by four fishing fleets: the current commercial fishing fleet (1995-2018); the tribal fishing fleet (1982-2018); an historical discard fishing fleet (1916-1994); and an historical landed-catch fishing fleet (1916-1994). The model assumes that there is full retention of big skate by the tribal fishing fleet.

Discards data

The WCGOP provides data on at-sea discards by the commercial fisheries. Although the program was implemented in 2001, prior to 2015 there was no requirement to sort big skate from other skates and landings of skates were reported on fish tickets as unspecified skate. Consequently, prior to 2015 the WCGOP, which primarily collects information on fish discarded at sea, could not provide estimates of discard rates because there were no reported landings of big skate to match with the discards of big skate. However, the WCGOP provided annual mean body weights estimates for discarded big skate length (2002-2017) and length compositions for discarded big skate (2010-2017) that informed the length-based retention function estimated by the model.

Survey indices

The assessment includes biomass indices from two bottom trawl surveys: the Alaska Fisheries Science Center (AFSC) Triennial shelf survey (every third year, starting with 1980 and ending with 2004, when the survey was conducted by the NWFSC) and the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS or WCGBT survey) (annually from 2003 to 2018). The trawl survey biomass indices were derived using the Vector Autoregressive Spatial Temporal (VAST) delta-model (Thorson 2019).

Compositional data

Length compositional data were available from the current commercial fishing fleet landings (1995-1999, 2001-2018) and discards (2010-2017), the WCGBTS (2003-2018), and the Triennial shelf survey (2001 and 2004). The selection curves for the historical landed catch fishing fleet, the historical discard fishing fleet, and the tribal fishing fleet were all “mirrored” from the current commercial fishing fleet. Conditional-age-at-length compositional data were available from the WCGBT survey (2009, 2010, and 2016-2018; 138-295 fish per year) and the current commercial fishing fleet (2004, 2008-2012, and 2018; 11-201 fish per year).

Maturity and weight-length relationships

Length at maturity was calculated from samples collected and scored (based on macroscopic examination) by port samplers (278 fish, mostly from OR) and on the WCGBT Survey (55 fish). Weight-at-length data collected by the WCGBT Survey (1159 fish) were used to estimate a length-weight relationship for big skate. The weight- length relationships were very similar between the two sexes and in the SS model the sexes shared a combined weight-length relationship.

The assessment model

The assessment is a single-sex, length- and age-based age-structured model that estimated dynamics starting in 1916 with the assumption of equilibrium with no fishing prior to the start of the model. The model assumes a spatially homogenous unit stock in the waters of the US West Coast. Annual recruitment deviations were fixed at zero, meaning that annual recruitment values were taken directly from the recruitment-spawning biomass relationship, which was a Beverton & Holt curve with steepness fixed at 0.4. Natural mortality was estimated within the model using an informative prior based on Hamel (2015) and a maximum age of 15 years. Catchability for the WCGBT survey was estimated within the model using an informative prior distribution developed by the STAT during the STAR meeting. Growth (in length) was modeled using a "growth cessation" formulation (Maunder et al. 2018), which has two linear segments (one increasing; one horizontal) and a parameter to control the transition. Growth was separate for the two sexes and the growth parameters were freely estimated in the model, including the variability in length-at-age (assumed equal for both sexes).

For years prior to 1995, dead discards of big skate were derived outside of the SS model from estimates of longnose skate discard rates (derived using the relationship between annual total mortality of longnose skate and annual total mortality of Dover sole) and the assumption that big skate discard rates are equal to longnose skate discard rates. For the years from 1995 forward the model produced annual estimates of the discard fraction and the associated dead discards, informed by at-sea observations of discard fractions and a logistic, length-based retention curve. A discard mortality rate of 50% was assumed. Length-based selectivity for all four fishing fleets was based on the selection curve estimated for the current fishing fleet, informed by length compositions of retained and discarded fish. The model used the double-normal function for fishery selectivity and assumed the curve was asymptotic in form. The model had time-blocks in the parameter controlling the upper asymptote of the length-based logistic retention function, annually for 2005-2016 and one block for 2017-2018.

The assessment model used the iterative Francis method for weighting the composition data and estimated an extra standard deviation parameter for the Triennial survey and for the WCGBT Survey.

Although a number of changes to the pre-STAR base model were explored during the STAR meeting, the only change that was included in the final base model was the addition of a new prior for the WCGBT survey-*Q*. The final agreed base model was well structured, was thoroughly investigated by the STAT, and is the best currently available for the formulation of management advice.

Treatment of uncertainty

The final base model included estimates of uncertainty for estimated parameters and derived quantities such as spawning output and depletion. During the STAR Meeting the STAT also explored uncertainty of the base model results using likelihood profiles across the key parameters steepness (h) and WCGBT survey-*Q*. The likelihood profile for h (from $h = 0.3$ to 0.9) changed less than 0.5 log-likelihood units, indicating that the data provided no information on steepness. The likelihood profile for ln(survey-*Q*) showed relatively modest changes in total log-likelihood (maximum change of about 7 log-likelihood units) across a fairly wide range of values for ln(survey-*Q*) (from $\ln(Q) = -0.7$ to 0.7), indicating that the available data were relatively uninformative regarding catchability (and population scale). Further, most of the information was provided by the prior for the WCGBT survey-*Q*. The prior was more influential than the length data or the indices of abundance; the age data were almost totally uninformative.

Requests by the STAR Panel and Responses by the STAT

The pre-STAR draft assessment document was very complete and the STAT's opening presentation to the STAR Panel anticipated many questions regarding the draft model's results. This 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.

Requests below are provided sequentially by the day of the request. Responses from the STAT (which were generally delivered the following day) are given below each request. The bolded sentences within each Response (if any) are major conclusions drawn by the STAR Panel that were considered important in the construction of the final base model. Figures from responses are also often given.

Request No. 1*: Explore possible changes to the prior distribution on survey q for the West Coast Bottom Trawl Survey.*

Rationale: The scale of the population is determined by the assumed prior of the survey q for the West Coast Bottom Trawl Survey, which was based on the 2007 longnose skate assessment. Longnose skate have a very different depth distribution than big skate, which occur in shallower depths than longnose skate or the West Coast Bottom Trawl Survey.

STAT Response:

The ongoing West Coast Groundfish Bottom Trawl Survey (WCGBT Survey) seems to cover the stock's spatial distribution relatively well, except that big skate is also distributed in shallow waters (less than 55 m) that the WCGBTS does not cover. During the STAR Meeting the STAT performed an analysis of the amount of the stock distributed in the shallow water (less than 55m deep) region not covered by the WCGBTS. The STAT used catch data provided by the WCGOP program to evaluate the effect of the un-surveyed nearshore (depths less than 55m) on estimates of biomass. Ratios of hauls containing big skate to all hauls were calculated for each of four depth bins: (0-25], (25-55], (55-75], and (75-100] meters. These ratios were normalized to the (55-75] meter bin. The median biomass values for hauls in those same depth bins were also calculated. The ratios among the first three bins were applied to the catch rates in the survey for the 55-75 bin for extrapolation into the shallower water. The extrapolated catch rates are shown in the top panel in Figure 1, with the grey region representing the extrapolation depths. The lower panel shows the estimated biomass after adjustment for the area associated with each category. The biomass in the unfished area was equal to 25.8% of the total biomass.

This analysis provided the basis for revising the prior distribution for the WCGBT Survey catchability coefficient, as shown in Table 1. The result of this whole exercise was judged by the panel to be an improvement of the assessment. **The STAR Panel and STAT agreed that the final base model should use the revised prior for the WCGBT survey-*Q*.**

In the pre-STAR base model for big skate the log-normal prior for WCGBT survey-*Q* was equivalent to the prior established for the longnose skate assessment; it had a log-scale mean of -0.188 and standard deviation (SD) of 0.187 (median catchability of 0.829). In the final base model the log-normal prior has log-scale mean of -0.355 (median catchability of 0.701) and SD of 0.326 (corresponding to an assumption that the minimum and maximum values in Table 1 correspond to the 1^{st} and 99^{th} percentiles).

The Panel requested runs with priors for survey-*Q* having different means, which indicated that the estimated values for survey-*Q* closely follow the prior. This result was consistent with the likelihood profile over survey-*Q*, in which the total likelihood was dominated by the prior for survey-*Q*. Thus, the prior on WCGBT survey-*Q* strongly influences the model results. Both the model and experience with trawl surveys for skates from the Northeast Atlantic indicated that the survey-*Q* could be much lower than the 0.70 used here. A survey-*Q* much higher than 0.7 would imply that there is significant herding of skates into the path of the trawl, which seems unlikely. This may explain the evident asymmetry of the confidence limits relative to the "best guess".

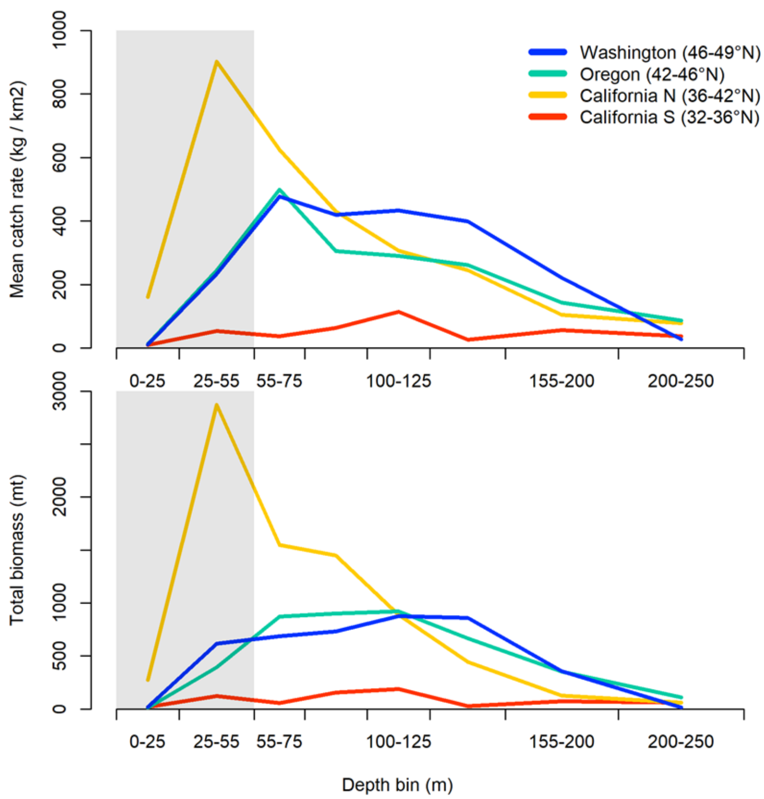

Figure 1. Information from the WCGOP on the depth distribution of big skate off the US West Coast. The STAT used this information for developing a new prior distribution for the WCGBT survey catchability coefficient.

Table 1. Calculations related to the new prior for WCGBT survey catchability

2019 Big Skate revision			
Factor	**minimum**	**best guess**	**maximum**
Depth availability	0.6	0.75	0.9
Latitudinal availability	1	1	1
Vertical availability	0.75	0.85	0.95
Probability of capture given in net path	**0.75**	**1**	**1.5**

Habitat availability (extrapolation into untrawable areas)	1	1.1	1.2
Product of all factors	0.338	0.701	1.539
Values on a logarithmic scale	-1.086	**-0.355**	0.431

***Request No. 2**: Explore changes to the model to provide better fits to the trawl surveys.*

Rationale: The models explored to date do not fit the survey trends well.

Context: The STAR panelists were concerned by the apparent inability of the base model (and all the variants considered) to fit the increasing trend evident in the WCGBTS index.

STAT Response:

The STAT team took this request seriously and developed entirely new model scenarios in which the assessment was started in 1980. These scenarios estimated the initial status and numbers at age, rather than using the reconstructed catches to establish the depletion and initial numbers at age when more reliable data sources began to be available. A model scenario in which initial conditions were flexible produced trends in biomass similar to the base model (Figure 2). A model with somewhat more restrictive initial conditions produced a population trajectory that was more able to capture the increasing trend in the survey indices, but was only able to do so by beginning in a much depleted state. The STAT team felt that the first model was not significant enough of a departure from the base model to be useful and that the second model was unrealistic given the magnitude of the catch relative to the observed swept-area biomass values in the surveys.

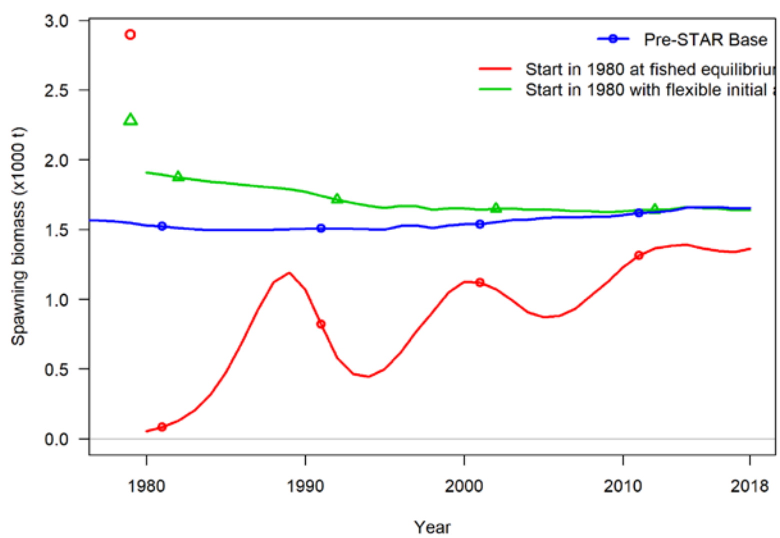

Figure 2. Alternate model configurations used to attempt to fit the survey indices better.

The inability to fit the increasing trend in the survey data likely arises from a conflict among data sources. The survey length composition data change very little over the period for which observations are available (1995 to present). This implies that the fishery is not impacting the population structure to a great degree. However, the survey index of abundance increases by 78% from 2003 to 2018 as catches decline by roughly 3 tons per year (Figure 3).

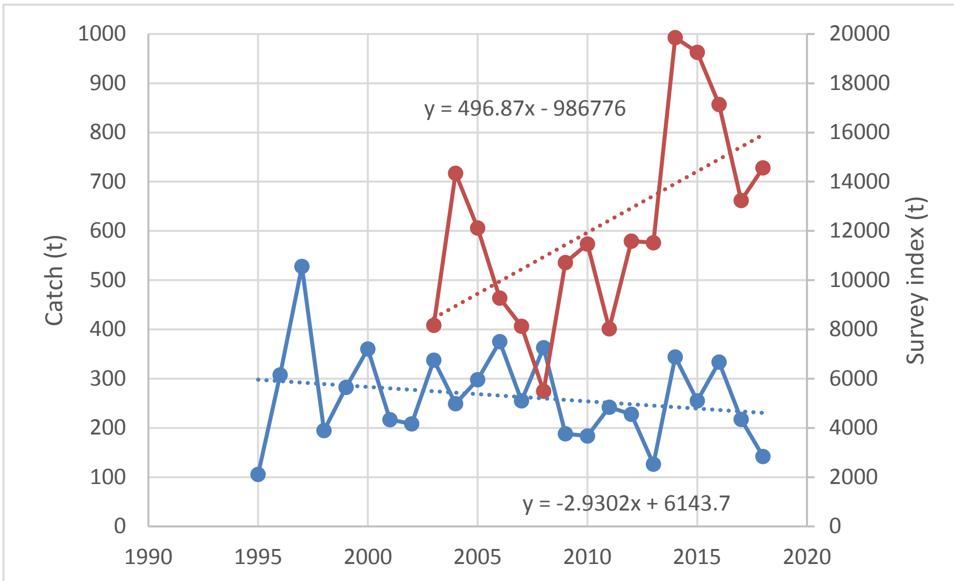

Figure 3. Time series of big skate catch (blue) and the WCGBT biomass index (red) with trend lines added.

The prevailing paradigm in stock assessment is to down-weight the length composition data in order to fit the survey indices of abundance (see Francis, 2011, for example). However, the two skate assessments presented during this STAR meeting display the opposite character: they eschew the survey indices in favor of the length composition data. This is a critical modeling hurdle that should be addressed in future iterations of this assessment. Consideration of the expected influence of the somewhat peculiar recruitment dynamics (continuous recruitment throughout the year) on observed length composition data might offer a potential research path.

Request No. 3: *Explore a time-varying M model.*

Rationale: To explore this as a mechanism to better fit survey trends.

Context: Natural mortality is by far the largest component of total mortality since the assessments suggest fishing mortality is negligible for both skate species. Because the assessment assumes *M* to be constant it is difficult to fit the surveys since the variation in these indices implies changes in survival over time, or other changes such as in recruitment or selectivity that are treated as deterministic or assumed constant.

STAT Response:

A set of time-varying *M* models was brought to the Panel. Under different assumptions about the variability in *M* and the correlation among years, these models had small or large changes in *M*. They were better able to fit the various data sources (see Figure 4). Estimates of *M* are shown in Figure 5 and show some dynamic behavior during the time period when survey data are available. The additional complexity was seen by the STAT as insufficiently supported by the data. These runs should be seen as exploratory.

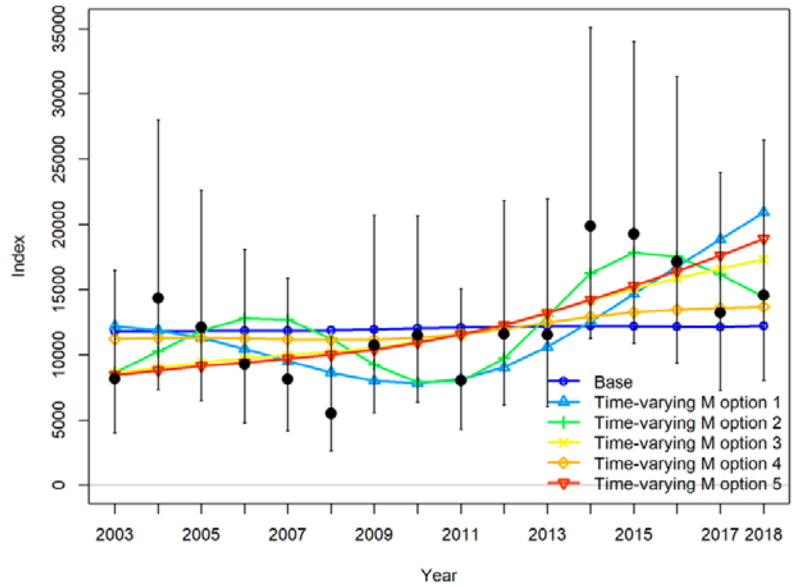

Figure 4. Fit to the WCGBT survey under different assumptions on time varying *M*.

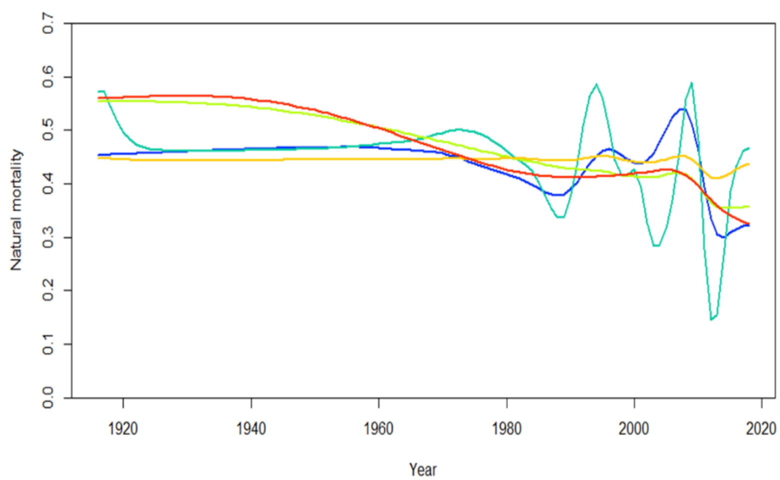

Figure 5. Estimates of time varying *M*. The largest changes are seen during the period when survey data are available.

Request No. 4*: Provide a run with the new prior from request #1 with diagnostics, fits, and likelihood profiles, if possible.*

Rationale: The scale of the population is determined by the assumed prior of the survey-*Q* for the West Coast Bottom Trawl Survey, which was derived for the 2007 longnose skate assessment. Longnose skate have a very different depth distribution than big skate which occur in shallower depths than longnose skate or the West Coast Bottom Trawl Survey. The new prior has more information specific to big skate distribution.

STAT Response:

A full set of r4ss outputs for this new candidate base model were provided through the FTP site. Likelihood profiles over the WCGBT survey catchability and steepness for this model were provided. The profile with no prior on catchability is the same as for the pre-STAR base model (since the only changes were in the prior) (see Figure 6).

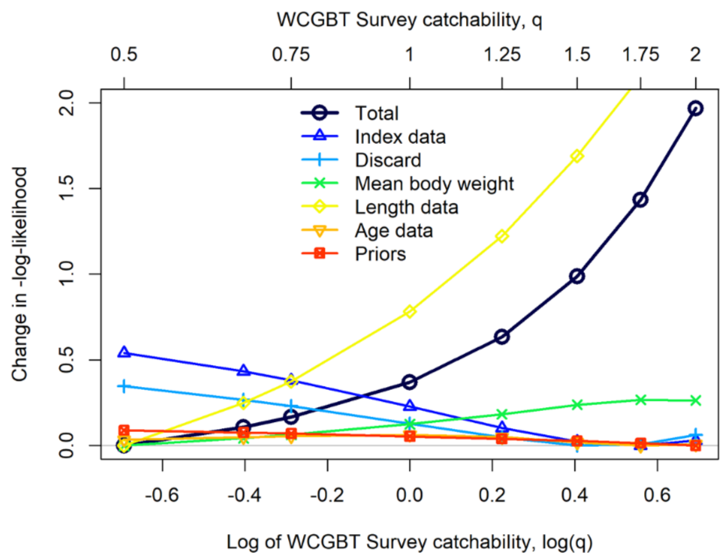

Figure 6. Likelihood profile over WCGBT ln(survey-*Q*) with no prior on the WCGBTS catchability coefficient (survey-*Q*).

With the new prior included, the profile over catchability showed that the prior remains more influential about catchability than the length data and the indices of abundance. The age data remained almost totally uninformative about catchability (Figure 7).

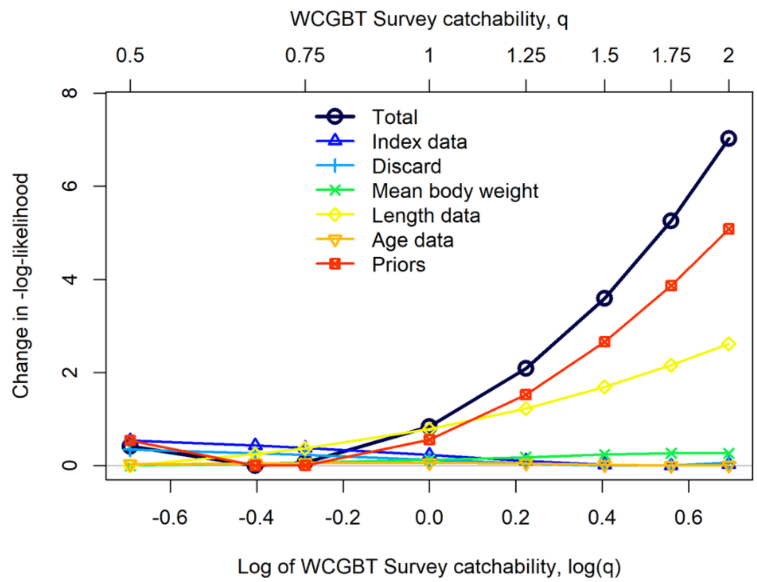

Figure 7. Likelihood profile over WCGBT ln(survey-*Q*) including the new prior on the WCGBTS catchability coefficient, with ln(survey-*Q*) mean = -0.355 and SD = 0.326 (median catchability of 0.701).

The new prior on catchability influenced the level of spawning biomass but the biomass trend predicted from the new prior was similar to the trend predicted using the old prior (i.e., the model did not provide a good fit to the WCBGTS index).

The likelihood profile over steepness (*h*) indicated that there is almost no information in the model regarding *h* and that the value assumed in the assessment (0.4) was relatively low (Figure 8). Steepness could equally well be any value between 0.4-0.7, for example.

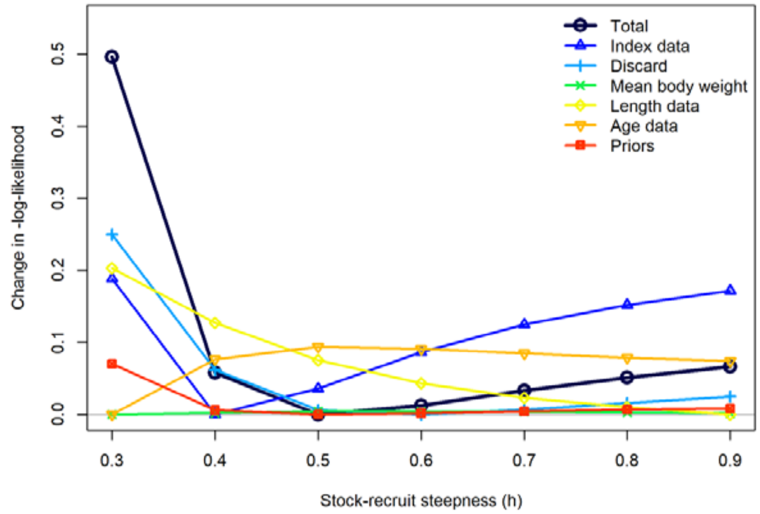

Figure 8. Likelihood profile over steepness.

Request No. 5: *Provide the diagnostics, fits, and the likelihood profiles associated with the model from run #4 with Dirichlet weighting. For the likelihood profiles, 1) do not allow the Dirichlet weights to change from the maximum likelihood values; and 2) allow full implementation of the Dirichlet weighting. For both treatments, do not let the estimated SDs for the surveys to change from their maximum likelihood estimates.*

Rationale: To confirm the model with Dirichlet weights better estimates scale without relying as heavily on the survey-*Q* prior. There is a need to understand what is driving this counter-intuitive result. This may provide the basis for a new base model.

STAT Response:

The STAT attempted to develop the requested model with Dirichlet weights and produced a likelihood profile over catchability of the WCGBT Survey. However, the resulting profile curves indicated a problem with non-convergence. **The STAR Panel agreed with the STAT's decision to cease further exploration of using the Dirichlet multinomial for weighting the compositional data.** The final base model uses the iterative Francis approach to weight the compositional data (as in the pre-STAR base model).

Request No. 6: *Repeat run #4 with no survey q prior and a run with the mean of the survey q prior with half the mean of the prior from run #4.*

Rationale: To ensure the model is capable of estimating [stock biomass] scale.

STAT Response:

The STAT completed the requested runs. The prior for survey-*Q* from request #4 had a median value of 0.701 (corresponding to log(survey-*Q*) = -0.355). A model with the prior at half this value (0.3505, ln(Survey-*Q*) = -1.048) had a maximum likelihood estimate for survey-*Q* of 0.343 (ln(Survey-*Q*) = -1.070), indicating that the estimated value is closely following the prior.

After considering the results from Requests 1 and 4-6, **the STAT and STAR Panelists agreed that the model as configured for run #4 should be the final base model**. This model had the same configuration as the pre-STAR base model but used the new, revised prior distribution for the WCGBT survey catchability coefficient, ln(survey-*Q*) mean of -0.355 and standard deviation of 0.326 (median catchability of 0.701).

The STAT and STAR Panel agreed that uncertainty in the decision table should be bracketed using the WCGBT ln(survey-Q) as the major access of uncertainty.

The base model's estimate for log(survey-*Q*) was -0.403 with an estimated standard deviation of 0.315 (median WCGBT survey-*Q* = 0.668).

Using the formula of 1.15 units of standard deviation to get low and high values leads to ln(survey-*Q*) = -0.766 and -0.041, corresponding to median catchability values of 0.465 and 0.960. The high value was associated with a low state of nature near the 25th percentile for the base model's estimate for 2019 spawning biomass estimate, whereas the 12.5th percentile was the target for the decision table. A model with ln(survey-Q) = 0.223, (median q = 1.250) provided a better match to the 12.5th percentile for 2019 spawning biomass (Figure 9).

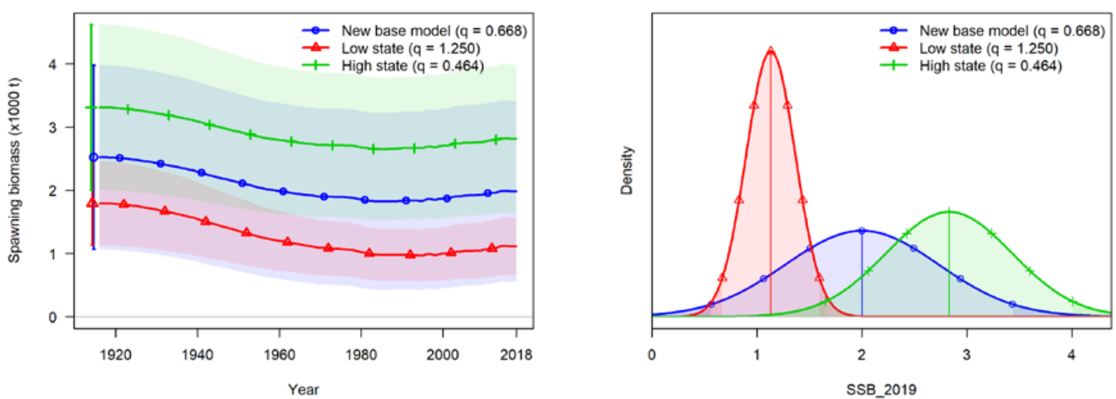

Figure 9. Final base model and low and high states of nature for the decision table.

Request No. 7*: Catch streams for the decision table should be as follows:*

a) Assume the 2017-2018 average total catch for 2019 and 2020 catches;

b) Low catch stream: 250 mt/year;

c) The default harvest control rule: 494 mt/year;

d) High catch stream: ACL = ABC (P = 0.45);*

e) Use the category 2 sigma schedule recommended by the SSC (see Table 3 of the March SSC Report).

Rationale: To define the removal assumptions in the decision table.

STAT Response:

In the final assessment document the STAT used the catch streams specified in this request.

Description of the Base Model and Alternative Models used to Bracket Uncertainty

The base model

The final base model for big skate was structured as having one area and one season, and two sexes, and covered the period 1916-2018, with catches beginning in 1916 from an unfished, equilibrium age-distribution. The model has no recruitment deviations, meaning annual recruitment values were drawn from the underlying Beverton and Holt recruitment-spawning biomass function, for which steepness (*h*) was fixed at 0.4. Natural mortality (*M*) was estimated as 0.4492^{-y} using a log-normal prior with a median value of 0.36^{-y} (on the arithmetic scale), corresponding to a maximum age of 15 years. The model used an internal structure for ages that ranged from zero to an accumulator age of 20 y and an internal structure for lengths that ranged from 20 to 250 cm in 5-cm increments. Parameters defining length-at-age and its variability were fully estimated.

Fishery removals were modeled using four fishing fleets to account for (1) dead discards of skates during a historical period (1916-1994), (2) landed catches during the historical period, (3) landed catches and dead discards during the modern era (1995-2018), and (4) Tribal catches (full retention assumed) during the modern era. The discarding process was modeled using a length-based retention function that included an estimated parameter for the horizontal asymptote that could vary annually during the period 2005 to 2016 and during a time-block for 2017-2018. Fishing fleet selection and retention curves were estimated for fishing during the modern era and applied as the selection and retention curves for fishing during the historical period. The model assumed a time-invariant 50% discard mortality fraction.

The final base model was informed by survey biomass indices from (1) the AFSC Triennial shelf bottom trawl survey (every third year during 1980-2004) and (2) the NWFSC's WCGBT shelf-slope survey (2010-2017). Length-compositional data to inform length-selection curves for the surveys were available for the AFSC Triennial survey (2001 and 2004) and the WCGBT survey (2003-2018).

The selection curves for both surveys used the double-normal form with estimated parameters for the *Peak* and *Ascending slope*, and estimated offsets for females for the difference in length at peak selectivity and for the maximum selectivity at that peak. The selection curve for the WCGBT Survey also had an estimated *Descending slope* parameter to allow it to take a domed shape. The selection curve for the Triennial survey was forced to be asymptotic.

Length compositional data to inform length-based selection and retention curves for all fishery removals were available from the current commercial fishing fleet's landings (1995-2018) and discards (2010-2017). The selection curves for all fishing fleets used the double-normal form and an assumed asymptotic shape with estimated offsets for females for the difference in length at peak selectivity and for the maximum selectivity at that peak.

Data to inform the discard processes took the form of annual observations of length-composition from fishery discards (2010-2017, WCGOP), mean body weights (2002-2017, WCGOP), observations of annual discard fractions (2009-2017), and estimates of annual discard fractions (2002-2017).

The estimated discard fractions for 2002-2014 were derived from the combination of big skate and unspecified skate in the WCGOP data for the years 2002-2014. The estimated discard fractions for 2015-2017, when there was dockside sorting of big skate, were derived from the observed at-sea discards of big skate and the landings of big skate from the corresponding observed trips.

Conditional age-at-length compositional data to inform growth (primarily) were available from the WCGBTS (2009, 2010, 2016-2018; a total of 949 fish) and from the commercial fishing fleet's landings (2004, 2008-2012, 2018; a total of 730 fish).

In the final base model the weights for the length- and conditional age-at-length compositional data were estimated iteratively using the Francis approach and the model had estimated *extra_SD* parameters for the Triennial shelf survey and the WCGBT Survey indices.

Following the STAR the STAT conducted additional jitter runs to confirm convergence of the final base model. The STAT did not find a better fitting model than the one reviewed on the final day of the STAR.

Bracketing uncertainty

The STAR and STAT agreed that the decision table for big skate should use the WGCBT survey-*Q* parameter as the major access of uncertainty. The base model's estimate for the WGCBT ln(survey-*Q*) was -0.403 with an estimated standard deviation of 0.315. The STAT got the high state of nature (large biomass) from ln(survey-*Q*) minus 1.15 times the estimated standard deviation, corresponding to a survey-*Q* value of about 0.464. The same approach when applied to get the low state of nature (small biomass) did not produce a sufficiently extreme spawning biomass. The STAT found that a model with ln(survey-*Q*) = 0.223 (corresponding to a survey-Q of 1.250) provided a better match to the 12.5^{th} percentile in 2019 spawning biomass.

Recommended sigma value and the basis for the recommendation

The sigma value (the ln-scale coefficient of variation for SB_{2019}, measuring scientific uncertainty) from the final base model was 0.3658, which is less than the default sigma value recommended by the Council's Scientific and Statistical Committee for category 1 stocks (0.5) or category 2 stocks (1.0). The STAR Panel recommends using the default sigma value for catch projections for big skate.

Recommended assessment category

Given that the final base model for big skate does not include sufficient compositional data to reliably estimate recruitment deviations, and given that there is little information other than the prior for the WCGBT survey-*Q* to set the scale of the stock biomass, the STAR Panel recommends assigning the big skate assessment to category 2 (sub-category d: *Full age-structured assessment, but results are substantially more uncertain than assessments used in the calculation of the P* buffer*).

Recommendation on the next assessment for this stock

The STAR Panel recommends that the next assessment for big skate could be an update assessment, given the caveat that future fishing removals remain well below the OFL. The status of this stock appears to be well above the management target, skates are not high-value targets, and seems unlikely that the status of this stock will change markedly in the next decade. Further, it seems unlikely that a category 1 assessment for big skate could be developed until several years of additional age-compositional data have accumulated.

Technical Merits of the Assessment

- The assessment made use of the latest version of Stock Synthesis (SS3), which is a flexible modelling framework that can utilize a variety of disparate data and can be applied when time series data are discontinuous or where there are intermittent observations on length or age. It is therefore an appropriate choice for the assessment considered at the meeting.
- The draft assessment document for big skate was well constructed and thorough in its description of the draft base model brought to the STAR and the underlying data that informed the assessment.
- The STAT's approach for estimating historical catches of big skate, using the discard estimates for longnose skate, was innovative. The STAT explored several alternative approaches (e.g., estimated time-series of fishing mortality rates for petrale sole) and conducted sensitivity analyses to gauge the importance of the historical catches.
- The base model was able to mimic the length-dependent sex-ratios and unusual bimodal shape of the male length compositional data (not evident in data for the females) using a reasonably parsimonious approach (with sex-specific selection).
- The STAT used the relatively new feature in Stock Synthesis of catch-multipliers as a mechanism for exploring uncertainty associated with the historical catches. The STAR Panel views this as an important technical improvement over the usual approach of doubling or halving the historical catch series. That said, however, uncertainty in the catch history was not incorporated into the final base model's estimates of uncertainty.
- The STAT was very responsive to the STAR Panel's requests and the STAT demonstrated considerable skill revising the draft base model in response to Panel requests, producing presentations to illustrate the relevant results, and working with the Panel to develop an acceptable base model that addressed the major concerns raised during the review.
- The development of a new informative prior for the WCGBT Survey catchability coefficient was a significant undertaking and its use in the base model was a large improvement to the assessment relative to the pre-STAR assessment.
- The final base model incorporates several sources of uncertainty that typically are very challenging to include: uncertainty in natural mortality (M) and uncertainty in survey-Q.
- For the final base model the log-likelihood profile over M suggests that this elusive parameter was robustly estimated, despite the paucity of age-compositional data.

Technical Deficiencies of the Assessment

- Overall, there were no serious technical deficiencies with this assessment for big skate, which made good use of the available data and available modeling approaches. That said, some STAR Panelists were concerned by the model's poor fit to the WCGBTS index, which suggested a slightly increasing trend in biomass. Although the STAT tried several modifications that improved the fit to the index (e.g., including recruitment deviations and time-variation in *M*), the STAT was uncomfortable using these more complex models given the paucity of underlying information to support the greater model complexity.

- Given the great uncertainty surrounding historical catches of big skate, it seems overly cumbersome to start the model from an unfished state in the far-distant past.
- The log-likelihood profile over steepness (*h*) indicated weak support for the 0.4 value assumed by the STAT.
- The log-likelihood profile over ln(R_0) (in the pre-STAR draft assessment) and over ln(WCGBT survey-*Q*) (developed during the STAR Meeting) indicated there is scant data to inform the model on the overall scale of biomass.
- The model was unable to track the WCGBT survey index, probably because natural mortality was assumed time-invariant, as was fishery selectivity, and recruitment was deterministic with almost no annual variability. Because fishing mortality was negligible, it means the underlying modeled population could show little variation and the indices were seen by the model as noise. However, the WCGBT survey index shows autocorrelation between the annual biomass values, which strongly suggests the survey index is tracking population changes. While the WCGBT survey is probably the best information available on population change, the survey index is in effect being down-weighted through model mis-specification.

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 *Technical Deficiencies* section above describes several modeling issues that warrant further consideration. Below are some other, slightly more general issues that the final base model left unresolved.

- Big skate off the U.S. West Coast may be a fraction of a much large population extending into Canada or even Alaska. Modelling only a part of the total population might contribute to the lack of correspondence between the survey indices and other data sources, as seen in the ln(R_0) profiles and the model's weak support for the assumed steepness (0.4). While this comment is not intended to reflect badly on the STAT's capabilities, it is important to recognize that stock structure could potentially be a major source of uncertainty regarding the assessment results.
- The prior distribution for the WCGBT Survey-*Q*, which the STAT developed "on-the-fly" at the STAR Meeting, was influential and provided most of the information on the biomass

scale in the assessment. The prior would probably benefit from further evaluation as the on-going WCGBT Survey and WCGOP accumulate additional information on the spatial distribution of big skate.

Recommendations for Future Research and Data Collection

- Explore how to resolve assessment models in which survey trends conflict with length (and age) composition data. **High priority.**
- Consider providing an age-structured surplus production model to compare with SS results to better understand data conflicts. **High priority.**
- Investigate factors contributing to estimated lower selectivity for females than males.
- Investigate evidence for continuous recruitment (e.g., year-round spawning).
- Develop a nearshore survey that will provide a relative abundance index for species such as big skate (i.e., a survey using a remotely operated vehicle (ROV) is unlikely to find species that hide or camouflage such as skates).
- Explore ways to separately weight compositional data for landings and discards assigned to the same fishing fleet.
- Explore a mechanism to determine the extra SD in a survey based on the minimum value necessary to fit the survey given the conflicts in the data sources for the assessment.
- Explore more flexible forms of natural mortality (e.g., Lorenzen 1996) since this is the dominant mortality for such a lightly exploited species.
- Explore the true maximum age of big skate on the US West Coast (e.g., the Canadian maximum age was 26 years, which has not been seen in catches from the US West Coast)
- Conduct a tagging study for skates that includes injection of the animals with oxytetracyclene to provide information for age validation.
- Explore the maturity function given the apparent very late maturation of big skates relative to their longevity.
- Explore the available research literature to better understand skate productivity and what density-dependent mechanisms are operating (e.g., steepness).

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