2021 Pacific halibut (*Hippoglossus stenolepis*) stock assessment: Development

PREPARED BY: IPHC SECRETARIAT (I. STEWART & A. HICKS; 10 MAY 2021)

PURPOSE

To provide the IPHC's Scientific Review Board (SRB) with a response to requests made during SRB016 and SRB017 (IPHC-2020-SRB016-R, IPHC-2020-SRB017-R) and to provide the Commission with an update of the 2021 assessment development.

INTRODUCTION

In 2019, a full stock assessment (Stewart and Hicks 2020a) with external (Stokes 2019) and SRB reviews (SRB014, SRB015) was conducted. The 2020 stock assessment (Stewart and Hicks 2021) represented an update to data sources (Stewart and Webster 2021) without structural changes to the modelling. The input data files are archived each year on the stock assessment page of the IPHC's website, along with the full assessment and data overview documents. Assessment material from 2015 onward is available at that location. A summary of the 2020 assessment results (Stewart et al. 2021b) was posted to the IPHC's 97th Annual Meeting page.

For 2021, the Secretariat plans to conduct a second updated stock assessment, consistent with the schedule for conducting a full assessment and review approximately every three (3) years. Standard data sources, for which the time-series is extended and the recent years are updated annually (where needed), are expected to remain unchanged. Commercial fishery sex-ratio-at-age data from the 2020 fishery are anticipated to be available and included in preliminary models presented at SRB019, 21-23 September 2021. These sex ratios will extend the time-series, based on genetic analysis of (now) routinely collected fin-clips during standard port sampling procedures, to four years: 2017-2020. Evaluation of the necessity and estimability of time-varying selectivity for male Pacific halibut relative to females will likely be investigated in the next full assessment depending on the level of temporal variability observed in the data.

The 2021 updated stock assessment again comprises an ensemble of four equally weighted models: two long time-series models, reconstructing historical dynamics back to the beginning of the modern fishery, and two short time-series models incorporating data from 1992 to the present, a time-period for which estimates of all sources of mortality and survey indices are available for all regions. Consistent with recent analyses, management quantities represent the median of the integrated model ensemble, explicitly accounting for the uncertainty within and among models. This uncertainty forms the basis for the annual Harvest Decision Table, reporting the estimated probability for a series of management and conservation metrics under different levels of future fishery yield.

TIME-SERIES AND SOFTWARE UPDATES

In order to provide comparability between these results and all subsequent steps working toward the final 2021 stock assessment (the annual bridging analysis), this evaluation began with the final 2020 models. First, each of the four assessment models was extended by one year, including projected 2021 mortality from all sources based on the mortality limits set during AM097 (IPHC 2021). This does not affect the historical time-series' estimates, but allows for a stepwise evaluation of the effect of adding data and other making any other changes to the model prior to the final version used for management.

Next, the stock synthesis software was updated to the most recent non-beta version available, 3.30.16.02 (Methot Jr et al. 2020). The changes from the version used for the 2020 stock assessment (3.30.15.09) were unimportant to the Pacific halibut stock assessment (the results were identical to the final 2020 assessment), but maintaining a current version (when possible and efficient) reduces the likelihood of compatibility issues with plotting and other software and reduces the cumulative transitional burden (which was substantial for the 2019 stock assessment) when future changes are added. A 22% increase in model run-time was noted, despite no new features added relevant to the halibut assessment. In addition, for the two Areas-As-Fleets (AAF) models, temporary files were written during estimation unless memory buffers were increased at the command line. Although neither of these differences is prohibitive for routine use of this platform, they do illustrate one cost of using a generalized tool.

COMMISSION AND SRB REQUESTS AND RESULTS

During 2020 there were a number of assessment-related analyses requested by the Commission (e.g. evaluation of the commerical fishery minimum size limit; Stewart et al. 2021a); however, there were no requests made at AM097 specifically relating to the 2021 annual stock assessment. This likely reflects the shift in Commission focus toward the results of the IPHC's Management Strategy Evaluation (MSE), and the upcoming need for an agreed Management Procedure (MP) for setting the 2023 mortality limits. The current interim MP, in place since 2019, was intended to apply through the 2022 mortality limits (AM098).

In 2020, the SRB made the following assessment requests during SRB016 and SRB017:

1) SRB016 (para. 21):

   "The SRB AGREED that data weighting approaches, including alternative error distributions (e.g. self-weighting), should be evaluated further in the context of the next full stock assessment, and should strive to make use of the best methods available, noting that there are a range of approaches in use for similar stock assessments. In particular, the SRB REQUESTED that the IPHC Secretariat investigate the feasibility of a logisticnormal distribution to incorporate correlated errors in age composition data (see Francis, R.I.C.C. 2014. Replacing the multinomial in stock assessment models: A first step. Fisheries Research 151: 70–84). This change may be technically challenging given the current assessment software, as well as having sexed age composition data, and could nontrivially affect the stock assessment estimates of biomass and recruitment. Therefore, the SRB does not expect new results until at least SRB018 in June 2021."

2) SRB017 (para. 21):

   "The SRB REQUESTED that the IPHC Secretariat continue to update data weighting on an annual basis, even for updated stock assessments (such as 2020), in order to maintain internal model consistency and to best reflect changes in existing and new data as they arise."

3) SRB017 (para. 23):

   "The SRB REQUESTED that the IPHC Secretariat first investigate the consequences of implementing a logistic-normal likelihood for composition data assuming no correlation structure. This would provide an initial estimate of the benefits of self-weighting fairly quickly compared to developing a full age/sex correlated version."

4) SRB017 (para. 24):

"The SRB REQUESTED that the IPHC Secretariat continue to evaluate whether the Stock Synthesis modelling framework is the most efficient for Commission needs, and to coordinate future development with the MSE framework as features and technical needs evolve together for the two efforts."

Request 1 – Logistic-normal likelihood feasibility

Data weighting in fisheries stock assessment models is used to create internal consistency between input and output error distribution assumptions and results as well as address conflicts among data sources. A CAPAM (Center for the Advancement of Population Assessment Methodology) workshop on data weighting was attended by IPHC Secretariat staff 19-23 October 2015 (See full special issue of Fisheries Research; Maunder et al. 2017). Although a wide range of analyses and approaches were presented and discussed, no clear consensus on a single approach for weighting compositional data was reached. Many methods remain in common use, including nominal sample sizes based on fish, samples or trips, the harmonic mean (McAllister and Ianelli 1997), the average age (Francis 2011; Francis 2017), and others, including the Dirichlet-multinomial (Thorson et al. 2017; Xu et al. 2020).

The Secretariat has investigated several options for an improved likelihood for use with sex-specific age composition data. For SRB016 (IPHC-2020-SRB016-07), the Secretariat focused on the Dirichlet-multinomial, and four issues were identified that made its use non-optimal for the Pacific halibut stock assessment (and likely many other assessments). These issues were:

1) Increased weighting of small samples as the estimated variance in the composition data gets large.

2) The parameterization is not self-weighting near the nominal sample size as the estimated parameter goes to a bound and requires fixing at a static value to avoid potential estimation problems.

3) The approach produced standardized residuals that were inconsistent with the likelihood assumption (far more than 2.5% > 1.96).

4) The Dirichlet-multinomial does not allow for the correlation structure known to exist among proportions-at-age (or length).

For SRB017 (IPHC-2020-SRB017-07), the Secretariat staff reviewed the recent literature on error distributions for compositional data, with a particular focus on the logistic-normal (LM). Francis (2014) introduces several likelihood function options for compositional data and provides discussion of each with relative shortcomings and advantages. He found clear theoretical support for the logistic-normal because: 1) it is self-weighting (not requiring an iterative approach), 2) his suggested parameterization can maintain the relative annual input sample sizes in the likelihood, and 3) it allows for estimated correlations among bins. His analysis did not include fitting assessment models to data, but instead relied on comparing the likelihood of previous assessment model fits to compositional data.

Other authors have both investigated and implemented versions of the logistic-normal. Cadigan (2016) used the multiplicative logistic-normal in a state-space model for Atlantic cod. His example was relatively simple compared to Pacific halibut: he had sexes-aggregated data, did not retain the annual sample sizes, and did not include correlations among the proportions, instead estimating a single variance parameter for all proportions that was then adjusted using *ad hoc* scaling of the youngest (age-2) and oldest (age-8+) bins. Schnute and Richards (1995) used what they called the 'multivariate logistic', which appears to be equivalent to the logistic-normal later described by Schnute and Haigh (2007). These authors also did not include sex-specific compositional data or include a provision to weight the variance by the observed sample size in each year. Finally, Albertsen et al. (2017) compared a range of compositional models (among other structuring choices, including comparing numbers-at-age with proportions-at-age), including the Dirichlet and logistic-normal, and finding that the latter performed better on their data sets. They considered both the additive and multiplicative versions of the logistic-normal. They used an AR(1) approach to correlation among age bins but again did not have sex-specific information.

In previous Secretariat investigations of the LN, the issue of the treatment of the nominal sample size as a maximum was not considered, but is very important to the simultaneous tuning of process and observation error. The LN relies on an estimated variance parameter (σ) to determine the overall weighting of the compositional data. This parameter may be multiplied by some function of the input sample size (*n*) in each year (*y*) to retain the inter-annual variability created by the sampling intensity, as well as the variability inherent in the compositional data for each data set. This seemingly reasonable approach increases the weight as the sample size increases, but less so at very large sample sizes relative to the mean ($\bar{n}$):

$$\sigma_y = \sigma \left({}^{\bar{n}}/_{n_y} \right)^{0.5}$$

The Pacific halibut models are allowing for process error in selectivity (via time-varying selectivity parameters) that is iterated along with sample sizes determining the compositional data weighting. This process has been found to be robust, but requires some constraint to achieve convergence. Starting from a small value for the input σ for each fleet and parameter combination where temporal variability was allowed, process error is increased until the tuned value is consistent with the degree of variability observed among the deviations (SE_{devs}^2) and the average uncertainty of the deviations themselves $\bar{\sigma}_{dev}{}^2$. This approach is very close to that outlined by Thompson and Lauth (2012) and is consistent with the preferred method for tuning this and other types of process error (such as recruitment deviations) in stock synthesis (Methot and Taylor 2011; Methot et al. 2019):

$$\sigma_{tuned} \sim \sqrt{SE_{devs}^2 + \bar{\sigma}_{dev}{}^2}$$

After the initial tuning of the process error, the input sample sizes (inversely related to the observation error for the composition data) are then reduced, where needed, via the Francis approach. Critically, the input sample sizes at this step are not increased beyond the nominal values, thus they are treated as defining a ‘minimum variance’ for the age composition data. Nominal inputs represent the number of survey sets and fishery trips (and not the number of individual fish measured, which would be much larger). Previous investigation by the Secretariat across many assessment models has found that exceeding the nominal sample sizes during iterative tuning can lead to cases where models will fit one or more data sources to the exclusion of other data sets and/or lead to dramatically increased estimates or process error as the weighting and process error increase together.

For the LN, it is not clear how the concept of nominal sample sizes as a maximum could be mapped into any of the currently available parameterizations. This represents an important shortcoming when comparing likelihood options (Table 1), particularly relevant to the Pacific halibut assessment models that was not identified in previous evaluations.

Identification of the best error distribution for fitting to age composition data remains an open question in stock assessment. All currently available approaches have moderate to substantial shortcomings, either in the treatment of correlations among age categories (and between sexes), the need for iteration during fitting, the ability to use information on heterogeneity in annual sample size, the ability to limit and estimate the effective sample size, or combinations of all these. The Secretariat continues to recommend that a graduate student project or other collaboration is likely to be the best path forward to derive and test a candidate logistic-normal or other likelihood implementation that meets all of the needs of the current Pacific halibut stock assessment. Even with a candidate logistic-normal formulation, it may take longer than a year for it to be implemented and tested in stock synthesis.

Table 1. Comparison of desirable properties of several candidate likelihoods for use with sex-specific age composition data. Inspired by table 2 in Francis (2014).

Likelihood property	Multinomial	Dirichlet-multinomial	Logistic-normal
Self-weighting (no iteration)	No	Yes	Yes
Includes correlations among ages	No	No	Possibly
Includes annual sample size variation	Yes	Yes	Yes
Maintains relative sample sizes (scale independent)	Yes	No	Yes
Allows for zeros	Yes	Yes	No
Provides internally consistent residuals	Yes	No	Unknown
Includes nominal maximum sample size	Yes	Yes	No
Currently available in stock synthesis	Yes	Yes	No

Recommendation 2 – update data weighting

One of the outcomes from the review of the full 2019 stock assessment was the recommendation to update the data-weighting each year and to track how that weighting changes over time. Data weighting was therefore updated for the final 2020 stock assessment. There were relatively small changes to all components relative to the weighting in the final 2019 stock assessment (Table 2). A minor increase in the fixed sample size was applied to the recreational sex-specific age composition data in the AAF long model. Recreational data have been down-weighted substantially in all recent assessments to allow estimation of selectivity, but minimize the effects of these data on other model estimates (Stewart and Hicks 2019). Preliminary model runs after adding the sex-specific recreational data (new to the 2020 assessment) indicated that the additional parameters describing the male selectivity offset showed occasional poor convergence under the previous weighting; therefore, the sample sizes were increased slightly until selectivity parameters showed better estimation behavior. This had no appreciable effect on management-relevant model outputs such as spawning biomass. In the long-term, it would be preferable to have recreational sampling for age information from all components within the coastwide recreational fishery such that the data could be considered representative and weighting treated naturally along with all other data sets. However, at this time it appears unlikely that sampling in recreational fisheries outside of IPHC Regulatory Area 3A will routinely include otoliths. Attempts to use length data to infer age distributions for recreational data have been hampered by the lack of reliable IPHC Regulatory Area-specific annual age-length keys for small/young Pacific halibut outside of the Bering Sea.

Table 2. Comparison of data weighting implied by the Francis method (iterated average input sample sizes) for age composition data from the final 2019 and 2020 assessments. Historical assessments did not use sex-specific commercial (2018 and earlier) or recreational (2019 and earlier) information.

	2019 Assessment	2020 Assessment	Change from 2019
Coastwide short			
Directed commercial fishery	38	43	5
Directed discards[1]	9	9	0
Non-directed discards[1]	5	5	0
Recreational[1]	5	5	0
FISS	263	264	1
Coastwide long			0
Directed commercial fishery	136	140	4
Directed discards[1]	6	6	0
Non-directed discards[1]	2.5	2.5	0
Recreational[1]	2.5	2.5	0
FISS	65	63	-2
AAF short			0
Region 2 directed commercial fishery[2]	538	531	-7
Region 3 directed commercial fishery[2]	278	273	-5
Region 4 directed commercial fishery[2]	26	24	-2
Region 4B directed commercial fishery[2]	22	22	0
Directed discards[1]	6	6	0
Non-directed discards[1]	5	5	0
Recreational[1]	5	5	0
Region 2 FISS	7	10	3
Region 3 FISS	22	18	-4
Region 4 FISS	88	83	-5
Region 4B FISS	42	43	1
AAF long			0
Region 2 directed commercial fishery[2]	271	272	1
Region 3 directed commercial fishery[2]	167	166	-1
Region 4 directed commercial fishery[2]	30	29	-1
Region 4B directed commercial fishery[2]	22	22	0
Directed discards[1]	6	6	0
Non-directed discards[1]	2.5	2.5	0
Recreational[1,3]	5	7.5	2.5
Region 2 FISS	8	6	-2
Region 3 FISS	15	8	-7
Region 4 FISS	97	86	-11
Region 4B FISS	54	54	0

[1]Inputs downweighted, and not iteratively reweighted (Stewart and Hicks 2019).

[2]Sample size equal to maximum (input based on number of samples).

[3]Sample size increased slightly to allow estimation of male selectivity offsets based on sex-specific age composition data available for the 2020 analysis.

Request 3 – Logistic-normal likelihood without correlation structure

Based on the evaluation described for Request 1 (above) the Secretariat has not yet investigated a logistic-normal likelihood without explicit correlation structure.

Recommendation 4 – continue to evaluate stock synthesis for IPHC needs

The IPHC has relied on a variety of model platforms for implementing its stock assessment, many of which have been developed specifically for Pacific halibut (e.g., Clark and Hare 2006; Deriso et al. 1985; Quinn et al. 1990). From 2012 to 2014, the IPHC transitioned from a single stock assessment model to an ensemble of models including alternative structural assumptions. At the same time, the software platform was also transitioned from the previous halibut-specific model implemented directly in ADMB to models using stock synthesis (Methot and Wetzel 2013a; Methot and Wetzel 2013b). This transition was made in order to speed the evaluation of a wide range of alternative models, facilitate quantitative summary of multiple models, reduce the potential for undiagnosed coding errors, and provide for more tranparent review.

The benefits of using a generalized platform for the Pacific halibut stock assessment come with costs, which include lack of some parameterizations that might be desirable, delayed development of new approaches, and in some cases run times that are inflated due to unused model features. These pros and cons have been discussed previously by the SRB and were noted in the 2019 external review (Stokes 2019).

The source code for stock synthesis was publicly released on 2 March 2021. A GitHub repository is now available, containing the source code, which will allow for easier investigation of specific details of currently implemented features and testing of custom additions for potential submission to the official platform. It also fosters a formal tracking and response framework for new features. These changes represent an important improvement in accessibility, particularly for organizations like the IPHC. However, the code itself remains extensive and highly challenging to modify in meaningful ways. It is not clear to what degree the IPHC may be able to actually develop new additions to the code, or whether direct access will likely foster improved communication with the development team.

Although stock synthesis currently meets the assessment modelling needs for the IPHC, several features would be useful for further development of our assessment models. These include implementation of random effects for time-varying processes (e.g., recruitment and selectivity), more flexible movement and tagging parameterizations, and alternative likelihoods such as the logistic-normal. Looking farther forward, during 2020 and 2021 the beginnings of a 'next generation' stock assessment that would succeed stock synthesis were made. Called the "NOAA's fisheries integrated modelling system" this effort is intended to reconcile the various models used in different areas of the U.S. It will be important for the IPHC to remain involved in this effort, as it did with the recent CAPAM workshop (Hoyle et al. 2020), along with other non-NOAA Fisheries organizations.

The MSE operating model (largely based on the structure of the current stock assesment, but programmed independently) has and will continue to refine the Secretariat's understanding of key biological processes and technical modelling needs that may feed back to the stock assessment. Additionally, the MSE framework will be useful for testing the stock assessment behavior under various assumptions through simulation. Ultimately, the choice of a medium- to long-term assessment platform may depend on the type of MP selected by the Commission. The current compressed stock assesment analysis conducted each fall in order to provide annual management information is based on the current year's data and must be stable and simple enough to be completed in less than two weeks. If a management procedure based on modelled survey trends, or a multi-year procedure is adopted, it may be uneccesary to conduct annual stock assessments. That type of procedure and timeline could allow for the development of more complex stock assessment ensembles/models (including fully Bayesian analyses), given extended development time between assessments. Therefore, the MSE, adoption of a management procedure by the IPHC and strategic planning for the stock assessment modelling platform should be considered together and the long-term focus should be on selecting the most efficient tools to meet management needs as they continue to evolve.

INTEGRATION WITH RESEARCH PLANNING

In response to previous SRB requests to better integrate research planning with stock assessment and MSE priorities, a ranking system has been developed that includes separate and explicit (but not necessarily different) priorities for the research supporting the stock assessment and the MSE (see IPHC-2021-SRB018-10). The stock assessment priorities have been subdivided into three categories: Assessment data collection and processing, biological inputs, and fishery yield. It is important to note that ongoing monitoring, including the annual FISS and port sampling programs is not considered research and is therefore not included in this list despite the critical importance of these collections.

Within the three assessment categories, the following topics have been identified as top priorities in order to focus attention on their importance for the stock assessment and management of Pacific halibut. A brief narrative is provided here to supplement the information provided in the 5-year research plan and to highlight the specific use of products from these studies in the stock assessment.

<u>Assessment data collection and processing</u>:

1) *Commercial fishery sex-ratio-at-age via genetics and development of methods to estimate historical sex-ratios-at-age*

   Commercial fishery sex-ratio information has been found to be closely correlated with the absolute scale of the population estimates in the stock assessment, and has been identified as the greatest source of uncertainty since 2013. With only three years (2017-2019) of commercial sex-ratio-at-age information available for the 2020 stock assessment, the annual genetic assay of fin clips sampled from the landings remain critically important. When the time series grows longer, it may be advantageous to determine the ideal frequency at which these assays need to be conducted. Development of approaches to use archived otoliths, scales or other samples to derive historical estimates could provide valuable information on earlier time-periods (with differing fishery and biological properties), and therefore potentially reconcile some of the considerable historical uncertainty in the present stock assessment.

2) *Whale depredation accounting and tools for avoidance*

   Whale depredation currently represents a source of unobserved and unaccounted-for mortality in the assessment and management of Pacific halibut. A logbook program has been phased in over the last several years, in order to record whale interactions observed by commercial fishermen. While this program may allow for future estimation of depredation mortality (e.g., perhaps following the approach of Peterson and Hanselman 2017), such estimates will likely come with considerable uncertainty. Reduction of depredation mortality through improved fishery avoidance and/or catch protection would be a preferable extension and/or solution to basic estimation. As such, research to provide the fishery with tools to reduce depredation is considered a closely-related high priority.

Biological inputs:

1) *Maturity, skip-spawning and fecundity*

Management of Pacific halibut is currently based on reference points that rely on relative female spawning biomass. Therefore, any changes to our understanding of reproductive output – either across age/size (maturity), over time (skip spawning) or as a function of body mass (fecundity) are crucially important. Each of these components is a direct scalar to the annual reproductive output estimated in the assessment. Ideally, the IPHC would have a program in place to monitor each of these three reproductive traits over time and use that information in the estimation of the stock-recruitment relationship, and the annual reproductive output relative to reference points. This would reduce the potential for biased time-series estimates created by non-stationarity in these traits (illustrated via sensitivity analyses in several of the recent assessments). However, at present we have only historical time-aggregated estimates of maturity and fecundity schedules. Therefore, the current research priority is to first update our estimates for each of these traits to reflect current environmental and biological conditions. After current stock-wide estimates have been achieved, a program for extending this information to a time-series can be developed.

2) *Stock structure of IPHC Regulatory Area 4B relative to the rest of the convention area*

The current stock assessment and management of Pacific halibut assume that IPHC Regulatory Area 4B is functionally connected with the rest of the stock, i.e., that recruitment from other areas can support harvest in Area 4B and that biomass in Area 4B can produce recruits that may contribute to other Areas. Tagging (Webster et al. 2013) and genetic (Drinan et al. 2016) analyses have indicated the potential for Area 4B to be demographically isolated. An alternative to current assessment and management structure would be to treat Area 4B separately from the rest of the coast. This would not likely have a large effect on the coastwide stock assessment as Area 4B represents only approximately 5% of the surveyed stock (Stewart et al. 2021b). However, it would imply that the specific mortality limits for Area 4B could be very important to local dynamics and should be separated from stock-wide trends. Therefore, information on the stock structure for Area 4B has been identified as a top priority.

3) Meta-population dynamics (connectivity) of larvae, juveniles and adults

The stock assessment and current management procedure treat spawning output, juvenile Pacific halibut abundance, and fish contributing to the fishery yield as equivalent across all parts of the Convention Area. Information on the connectivity of these life-history stages could be used for a variety of improvements to the assessment and current management procedure, including: investigating recruitment covariates, structuring spatial assessment models, identifying minimum or target spawning biomass levels in each Biological Region, refining the stock-recruitment relationship to better reflect source-sink dynamics and many others. Spatial dynamics have been highlighted as a major source of uncertainty in the Pacific halibut assessment for decades, and will continue to be of high priority until they are better understood.

Fishery yield:

1) *Biological interactions with fishing gear*

In 2020, 16% of the total fishing mortality of Pacific halibut was discarded (Stewart et al. 2021b). Discard mortality rates can vary from less than 5% to 100% depending on the fishery, treatment of the catch and other factors (Leaman and Stewart 2017). A better understanding of the biological underpinnings for discard mortality could lead to increased precision in these estimates, avoiding potential bias in the stock assessment. Further, improved biological understanding of discard mortality mechanisms could allow for reductions in this source of fishing mortality, and thereby increased yield available to the fisheries.

2) *Guidelines for reducing discard mortality*

   Much is already known about methods to reduce discard mortality, in non-directed fisheries as well as the directed commercial and recreational sectors. Promotion and adoption of best handling practices could reduce discard mortality and lead to greater retained yield.

Looking forward, the IPHC has recently considered adding close-kin genetics (e.g., Bravington et al. 2016) to its ongoing research program. Close-kin genetics can potentially provide estimates of the absolute scale of the spawning output from the Pacific halibut population. This type of information can be fit directly in the stock assessment, and if estimated with a reasonable amount of precision, even a single data point could substantially reduce the uncertainty in the scale of total population estimates. Data collection of genetic samples from 100% of the sampled commercial landings has been in place since 2017 (as part of the sex-ratio monitoring) and routine comprehensive genetic sampling of FISS catch will begin in 2021. The analysis to produce reproductive output estimates from close-kin genetics is both complex and expensive, and it could take several years for this project to get fully underway.

2021 FISHING AND FISS

During 2020, observed mortality was below the Commission limits for nearly all fisheries coastwide. The Commission also had to rely on a reduced FISS design reflecting the unique challenges to both the value of the catch as well as the logistics of conducting normal operations. This led to an assessment with slightly greater uncertainty (both quantified and unquantified) than in recent years, but also a reduced level of fishing intensity relative to that projected based on the adopted mortality limits.

Unlike the reduced design in 2020, the planned 2021 FISS will include sampling in all IPHC Regulatory Areas. In addition, a NOAA Fisheries trawl survey is anticipated for the eastern and northern Bering Sea in 2021, which should provide for a very robust modelled survey index in IPHC Area 4CDE.

As of the middle of May, it appears unlikely that the reduced actual mortality that occurred in 2020 relative to projections will persist again in 2021. Most fisheries appear to be achieving more normal operations this year, and there are indications of somewhat better prices. Of note, the Commission adopted a later season ending date for 2021 (7 December rather than 15 November). This may lead to a greater proportion of the landings remaining at the time the assessment data is finalized (31 October), and therefore additional uncertainty in the actual mortality. However, this challenge has always been present to some degree as almost all sectors must be projected to the end of the calendar year. These projections are always replaced with actual estimates in the following stock assessment and therefore are likely to have a minimal effect on the overall results.

RECOMMENDATION/S

That the SRB:

a) **NOTE** paper IPHC-2021-SRB018-06 which provides a response to requests from SRB016 and SRB017, and an update on model development for 2021.
b) **REQUEST** any further analyses to be provided at SRB019, September 2021.

REFERENCES

Albertsen, C.M., Nielsen, A., and Thygesen, U.H. 2017. Choosing the observational likelihood in state-space stock assessment models. Canadian Journal of Fisheries and Aquatic Sciences **74**(5): 779-789. doi:10.1139/cjfas-2015-0532.

Bravington, M.V., Skaug, H.J., and Anderson, E.C. 2016. Close-Kin Mark-Recapture. Statistical Science **31**(2): 259-274. doi:10.1214/16-sts552.

Cadigan, N.G., and Marshall, C.T. 2016. A state-space stock assessment model for northern cod, including under-reported catches and variable natural mortality rates. Canadian Journal of Fisheries and Aquatic Sciences **73**(2): 296-308. doi:10.1139/cjfas-2015-0047.

Clark, W.G., and Hare, S.R. 2006. Assessment and management of Pacific halibut: data, methods, and policy. International Pacific Halibut Commission Scientific Report No. 83, Seattle, Washington. 104 p.

Deriso, R.B., Quinn, T.J., II, and Neal, P.R. 1985. Catch-age analysis with auxiliary information. Canadian Journal of Fisheries and Aquatic Sciences **42**: 815-824.

Drinan, D.P., Galindo, H.M., Loher, T., and Hauser, L. 2016. Subtle genetic population structure in Pacific halibut Hippoglossus stenolepis. J Fish Biol **89**(6): 2571-2594. doi:10.1111/jfb.13148.

Francis, R.I.C.C. 2011. Data weighting in statistical fisheries stock assessment models. Canadian Journal of Fisheries and Aquatic Sciences **68**: 1124-1138.

Francis, R.I.C.C. 2014. Replacing the multinomial in stock assessment models: A first step. Fisheries Research **151**: 70-84. doi:10.1016/j.fishres.2013.12.015.

Francis, R.I.C.C. 2017. Revisiting data weighting in fisheries stock assessment models. Fisheries Research **192**(5-15). doi:10.1016/j.fishres.2016.06.006.

Hoyle, S.D., Maunder, M.N., and A'Mar, Z.T. 2020. Frameworks for the next generation of general stock assessment models: 2019 CAPAM workshop report. New Zealand Fisheries Assessment Report2020/39. 84 p.

IPHC. 2019. Report of the 15th session of the IPHC Scientific Review Board (SRB015). Seattle, Washington, U.S.A., 24-26 September 20-19. IPHC-2019-SRB015-R, 18 p.

IPHC. 2021. Report of the 97th session of the IPHC annual meeting (AM097). Electronic meeting. 25-29 January 2021. IPHC-2021-AM097-R. 50 p.

Leaman, B.M., and Stewart, I.J. 2017. 2.12 Research basis for estimated discard mortality rates used for Pacific halibut in longline and trawl fisheries. IPHC Report of Assessment and Research Activities 2016: 133-172.

Maunder, M.N., Crone, P.R., Punt, A.E., Valero, J.L., and Semmens, B.X. 2017. Data conflict and weighting, likelihood functions and process error. Fisheries Research **192**: 1-4. doi:10.1016/j.fishres.2017.03.006.

McAllister, M.K., and Ianelli, J.N. 1997. Bayesian stock assessment using catch-age data and the sampling - importance resampling algorithm. Canadian Journal of Fisheries and Aquatic Sciences **54**: 284-300.

Methot Jr, R.D., Wetzel, C.R., Taylor, I.G., and Doering, K. 2020. Stock synthesis user manual version 3.30.16. NOAA Fisheries. 225 p.

Methot, R.D., and Taylor, I.G. 2011. Adjusting for bias due to variability in estimated recruitments in fishery assessment models. Canadian Journal of Fisheries and Aquatic Sciences **68**: 1744-1760.

Methot, R.D., and Wetzel, C.R. 2013a. Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. Appendix A: Technical description of the Stock Synthesis assessment program. Fisheries Research **142**: 26 p.

Methot, R.D., and Wetzel, C.R. 2013b. Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. Fisheries Research **142**(0): 86-99. doi:http://dx.doi.org/10.1016/j.fishres.2012.10.012.

Methot, R.D., Wetzel, C.R., and Taylor, I.G. 2019. Stock Synthesis User Manual Version 3.30.13. NOAA Fisheries. Seattle, WA. 213 p.

Peterson, M.J., and Hanselman, D. 2017. Sablefish mortality associated with whale depredation in Alaska. ICES Journal of Marine Science: Journal du Conseil: fsw239. doi:10.1093/icesjms/fsw239.

Quinn, T.J.I., Deriso, R.B., and Neal, P.R. 1990. Migratory catch-age analysis. Canadian Journal of Fisheries and Aquatic Sciences **47**: 2315-2327.

Schnute, J.T., and Richards, L.J. 1995. The influence of error on population estimates from catch-age models. Canadian Journal of Fisheries and Aquatic Sciences **52**: 2063-2077.

Schnute, J.T., and Haigh, R. 2007. Compositional analysis of catch curve data, with an application to *Sebastes maliger*. ICES Journal of Marine Science **64**: 218-233.

Stewart, I., and Hicks, A. 2019. 2019 Pacific halibut (*Hippoglossus stenolepis*) stock assessment: development. IPHC-2019-SRB014-07. 100 p.

Stewart, I., and Hicks, A. 2020a. Assessment of the Pacific halibut (*Hippoglossus stenolepis*) stock at the end of 2019. IPHC-2020-SA-01. 32 p.

Stewart, I., and Hicks, A. 2020b. Update on the development of the 2020 stock assessment. IPHC-2020-SRB017-07. 13 p.

Stewart, I., and Hicks, A. 2021. Assessment of the Pacific halibut (*Hippoglossus stenolepis*) stock at the end of 2020. IPHC-2021-SA-01. 33 p.

Stewart, I., and Webster, R. 2021. Overview of data sources for the Pacific halibut stock assessment, harvest policy, and related analyses. IPHC-2021-SA-02. 54 p.

Stewart, I., Hicks, A., and Carpi, P. 2020. 2020 Pacific halibut (*Hippoglossus stenolepis*) stock assessment: development. IPHC-2020-SRB016-07. 26 p.

Stewart, I., Hicks, A., and Hutniczak, B. 2021a. Evaluation of directed commercial fishery size limits in 2020. IPHC-2021-AM097-09. 28 p.

Stewart, I., Hicks, A., Webster, R., and Wilson, D. 2021b. Stock assessment: Summary of the data, stock assessment, and harvest decision table for Pacific halibut (*Hippoglossus stenolepis*) at the end of 2020. IPHC-2021-AM097-08. 19 p.

Stokes, K. 2019. Independent peer review for the 2019 IPHC stock assessment. August 2019. 31 p. https://www.iphc.int/uploads/pdf/sa/2019/stokes_2019-independent_peer_review_for_the_2019_iphc_stock_assessment.pdf.

Thompson, G.G., and Lauth, R.R. 2012. Chapter 2: Assessment of the Pacific cod stock in the Eastern Bering Sea and Aleutian Islands area. *In* NPFMC Bering Sea and Aleutian Islands SAFE. p. 245-544.

Thorson, J.T., Johnson, K.F., Methot, R.D., and Taylor, I.G. 2017. Model-based estimates of effective sample size in stock assessment models using the Dirichlet-multinomial distribution. Fisheries Research **192**: 84-93. doi:10.1016/j.fishres.2016.06.005.

Webster, R.A., Clark, W.G., Leaman, B.M., and Forsberg, J.E. 2013. Pacific halibut on the move: a renewed understanding of adult migration from a coastwide tagging study. Canadian Journal of Fisheries and Aquatic Sciences **70**(4): 642-653. doi:10.1139/cjfas-2012-0371.

Xu, H., Thorson, J.T., and Methot, R.D. 2020. Comparing the performance of three data-weighting methods when allowing for time-varying selectivity. Canadian Journal of Fisheries and Aquatic Sciences **77**(2): 247-263. doi:10.1139/cjfas-2019-0107.