Development of a framework to investigate fishing intensity and distributing the total constant exploitation yield (TCEY) for Pacific halibut fisheries

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PURPOSE

To provide an update of International Pacific Halibut Commission (IPHC) Management Strategy Evaluation (MSE) activities relating to the definition and development of a framework to evaluate management procedures for distributing the TCEY.

1 INTRODUCTION

The Management Strategy Evaluation (MSE) at the International Pacific Halibut Commission (IPHC) has completed an initial phase of evaluating management procedures relative to the coastwide scale of the Pacific halibut stock and fishery. Results of the MSE simulations were presented at the 95th Session of the IPHC Annual Meeting (AM095) and the 13th Session of the IPHC Management Strategy Advisory Board (MSAB013). The next phase, which is underway, investigates management procedures related to the distribution of the Total Constant Exploitation Yield (TCEY). The TCEY is the mortality limit composed of mortality from all sources except under-26-inch (66.0 cm, U26) non-directed discard mortality, and is determined by the Commission at each Annual Meeting for each IPHC Regulatory Area.

The development of an MSE framework aims to support the scientific, forecast-driven study of the trade-offs between fisheries management scenarios. Crafting this tooling requires

- the definition and specification of a multi-area operating model;
- an ability to condition model parameters using historical catch and survey data and other observations;
- integration with, use of, or comparison against stock assessment tools or data;
- identification and development of management procedures with closed-loop feedback into the operating model;
- definition and validation of performance metrics to evaluate the efficacy of applied management procedures.

Updates on the recent efforts in these areas are outlined in Section 2. Likewise, a significant effort developing the software underpinning these simulations is underway, which is outlined in section 3.

2 FRAMEWORK ELEMENTS

The MSE framework includes elements that simulate the Pacific halibut population and fishery (Operating Model, OM) and management procedures with a closed-loop feedback (Figure 1). Specifications of some elements are described below, with additional technical details in document IPHC-2019-MSAB014-INF01, which is a living document that is being updated as development occurs.

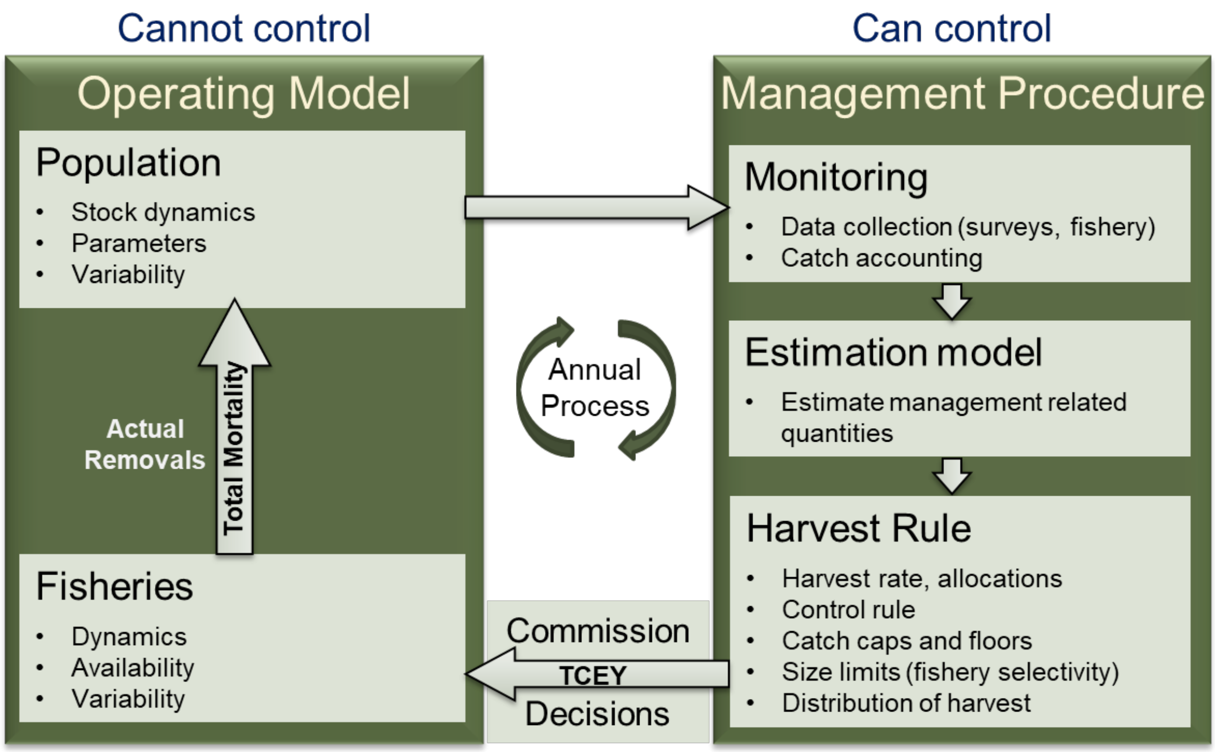

Figure 1: Illustration of the closed-loop simulation framework with the operating model (OM) and the Management Procedure (MP). This is the annual process on a yearly timescale.

2.1 Multi-area operating model

The generalized operating model will be able to model multiple spatial components, which is necessary because mortality limits are set at the IPHC Regulatory Area level (Figure 2) and some objectives are defined at that level. The technical details of the multi-area operating model are supplied in document IPHC-2019-MSAB014-INF01 that is currently under development, but some background information on specific components is supplied below.

2.1.1 Population and fishery spatial specification

The emerging understanding of Pacific halibut diversity across the geographic range of its stock indicates that IPHC Regulatory Areas should be only considered as management units and do not represent relevant sub-populations (Seitz et al. 2017). The structures of two of the four current Pacific halibut stock assessment models was developed around identifying portions of the data (fishery-independent and fishery-dependent data) that correspond to differing biological and population processes within the larger Pacific halibut stock. This approach, referred to as 'areas-as-fleets' is commonly used in stock assessments (Waterhouse et al. 2014), and was the approach recommended for inclusion in the ensemble developed in 2014 during the SRB review of models (Cox et al. 2016, Stewart & Martell 2015, 2016).

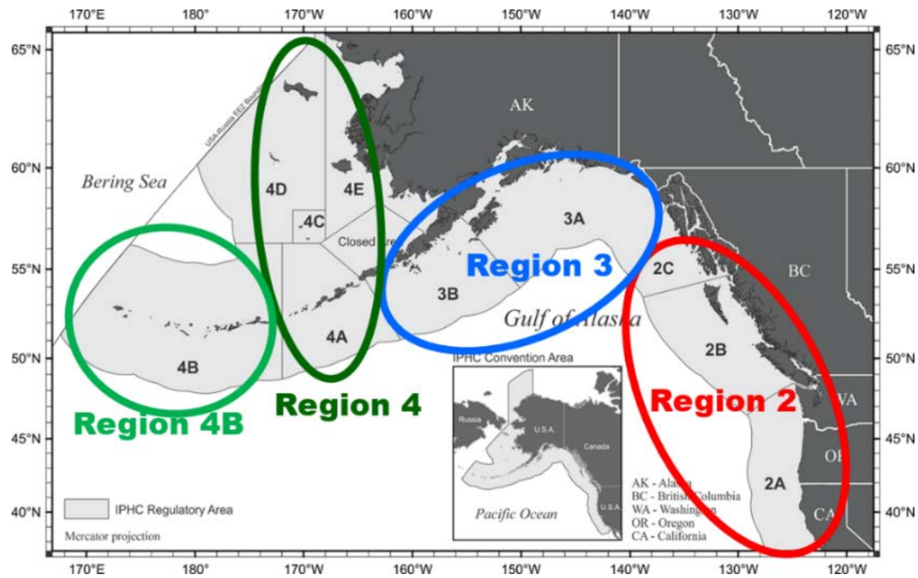

Figure 2: Biological Regions overlaid on IPHC Regulatory Areas. Region 2 comprises 2A, 2B, and 2C, Region 3 comprises 3A and 3B, Region 4 comprises 4A and 4CDE, and Region 4B comprises solely 4B.

Biological Regions (Figure 2) were therefore defined with boundaries that matched some of the IPHC Regulatory Area boundaries for the following reasons. First, data (particularly historical data) for stock assessment and other analyses are most often reported at the IPHC Regulatory Area scale and are largely unavailable for sub-Regulatory Area evaluation. Particularly for historical sources, there is little information to partition data to a portion of a Regulatory Area. Second, it is necessary to distribute TCEY to IPHC Regulatory Areas for quota management. If a Region is not defined by boundaries of IPHC Regulatory Areas (i.e. a single IPHC Regulatory Area is in multiple Regions) it will be difficult to create a distribution procedure that accounts for biological stock distribution and distribution of the TCEY to Regulatory Areas for management purposes. It is unlikely that there is a set of Regions that accurately delineates the stock biologically since different aspects of the stock differ over varying scales, and movement occurs among Biological Regions.

To a certain degree, Pacific halibut within the same Biological Region share common biological traits different from adjacent Biological Regions. These traits include sex ratios, age composition, and size-at-age, and historical trends in these data may be indicative of biological diversity within the greater Pacific halibut population. Furthermore, tagging studies have indicated that within a year, larger Pacific halibut tend to undertake feeding and spawning migrations within a Biological Region, and movement between Biological Regions typically occurs between years (Loher & Seitz 2006; Seitz et al. 2007; Webster et al. 2013).

Given the goals to divide the Pacific halibut stock into somewhat biologically separate regions and preserve biocomplexity across the entire range of the Pacific halibut stock, Biological Regions are considered by the IPHC Secretariat, and supported by the SRB (paragraph 31 IPHC-2018-SRB012-R), to be the best option for biologically-based areas to meet management needs. They also offer an appropriate and parsimonious spatial separation for modeling inter-annual population dynamics.

However, as mentioned earlier, mortality limits are set for IPHC Regulatory Areas and thus directed fisheries operate at that spatial scale. Furthermore, since some fishery objectives have been defined at the IPHC Regulatory Area level, the TCEY will need to be distributed at that scale. Even though the population is modelled at the Biological Region scale, fisheries can be modelled at the IPHC Regulatory Area scale by using an areas-as-fleets approach within Biological Regions. This requires modelling each fleet with separate selectivities and harvest rates that operate on the exploitable biomass in the entire Biological Region. The following is a discussion of the pros and cons of this method.

First, modelling the population dynamics at the IPHC Regulatory Area scale would require intra-annual dynamics to be modelled within a year, divided into seasons to model movement between IPHC Regulatory Areas. There is evidence that such intra-annual movements occur (Loher & Seitz, 2006) and fisheries in adjacent IPHC Regulatory Areas may intercept the same pool of fish. Using Biological Regions assumes that all fisheries within a Region have access to the pool of Pacific halibut in that Region. This greatly simplifies the calculations and eliminates the need to parameterize intra-annual movement. However, if a fishery does not interact with the pool of fish in a Biological Region, harvest rates determined for each fishery may be inaccurate because the assumed exploitable biomass is incorrect (harvest rate is simply catch divided by exploitable biomass), and some fisheries may intercept ages/sizes of Pacific halibut that they commonly do not interact with. This is unlikely to occur and will have very little effect on the results of this MSE because harvest rates are not explicitly used in the management procedures of this MSE (mortality limits are used for management) and similarity of age/size compositions were used to define Biological Regions.

Additionally, calculating statistics specific to IPHC Regulatory Areas may be difficult. For example, simulating the proportion of biomass in each IPHC Regulatory Area (e.g., to mimic the current interim management procedure) requires simulating a survey biomass for each IPHC Regulatory Area, and likewise determining some objectives related to IPHC Regulatory Area may be difficult to calculate (such as the proportion of O26 fish in each IPHC Regulatory Area). The distribution of the population within a Biological Region would have to be approximated, which could be done assuming a probability density function based on past observations with some variability (e.g., a Beta distribution with different shapes). This concept is currently under development.

2.1.2 Maturity

Spawning biomass for Pacific halibut is currently calculated from a maturity-at-age ogive that is assumed to be constant over years, and the potential for skip spawning is not modelled. Stewart & Hicks (2017) examined the sensitivity to a trend in declining spawning potential (caused by a shift in maturity or increased skip spawning) and found that under that condition there was a bias in both scale and trend of recent estimated spawning biomass. Ongoing research on maturity and skip spawning will help to inform future implementations of the basis for and variability in the determination of spawning output.

2.1.3 Movement

Many data sources are available to inform Pacific halibut movement. Decades of tagging studies and observations have shown that important migrations characterize both the juvenile and adult stages and apply across all regulatory areas. The conceptual model of halibut ontogenetic and seasonal migration, including main spawning and nursery grounds, as per the most current knowledge, is presented in Figure 3 and detailed below. Figure 3 is a live map and it will be updated as new information become available.

The Pacific halibut spawning season spans from November to March. Spawning has been reported to occur on grounds located along the continental slope and in depressions on the continental shelf, concentrated mainly in the central part of the Gulf of Alaska and Eastern Bering Sea (St-Pierre 1984). In early spring, adults undertake a migration to the feeding areas they were occupying before the spawning migration, while eggs and larvae are dispersed northwards and westward (Skud 1977; Valero & Webster 2011).

Larval stages are found in deep waters and exploit the deepwater circulation pattern to move inshore (Thompson & van Cleve 1936; Skud 1977; Bailey et al. 2008; Sohn et al. 2016). Few of the larvae might enter the Alaskan gyre and be carried offshore, far from the common nursery grounds, and eventually die (Skud 1977). Between the larval stages and the settlement of juveniles, individuals move to shallow waters undertaking abrupt vertical ontogenetic migrations (Sohn et al. 2016). Halibut juveniles settle on sand substrata mixed with mud and granule in shallow waters, near or outside mouths of bay (Norcross et al. 1997; Moles et al. 1995; Bailey et al. 2008). In the Bering Sea, juveniles are found over the shelf, along the west side of the Alaskan Peninsula and close to Pribilof Island, while in the Gulf of Alaska they are most abundant around Kodiak Island and along the western and central Gulf. Almost no individuals 0 to 3 years old are found in Southeast Alaska and British Columbia, where the population is characterized with individuals of 4 years of age and older (IPHC 1998). Young Pacific halibut in the Gulf of Alaska between the age of 2 and 5 years old undertake a backward southerly and easterly migration (Hilborn et al. 1995). More recent tagging results have also shown that adults continue to migrate throughout their life, even though the percentage of migrating fish decreases as they age (Valero & Webster 2011, Webster et al. 2013).

Despite evidence of a fully mixed stock, genetic studies and additional tagging experiments have suggested a degree of basin-scale segregation among spawning groups (Seitz et al. 2017; Seitz et al. 2011). In particular, older Pacific halibut spend the summer feeding season around the Aleutian Islands and in the Bering Sea and appear to also spawn there, indicating a high retention rate for these older Pacific halibut in the region (Seitz et al. 2011). Also, results from an ocean circulation model suggest that the contribution of Gulf of Alaska spawners to Eastern Bering Sea recruitment is small (Vestfals et al. 2014). Genetic studies have also identified a different genetic structure in the western Aleutian Islands compared to the rest of the stock, suggesting a low migration rate outside this region (Drinan et al. 2016).

In light of this, a framework was developed in 2015 to represent the IPHC working hypothesis concerning movement-at-age among biological regions (IPHC-2019-AM095-08). Each biological region spans multiple regulatory areas (Figure 3). It is believed that within a year, halibut move from one regulatory area to another, but tend to remain within the same biological region. The definition of biological regions is supported by several lines of evidence. First of all, Genetic studies have separated the component of the Pacific halibut population in the Aleutian island west of Samalga Pass (Drinan et al. 2016). Second, environmental conditions in the Northeast Pacific suggest a loose division into three main oceanographic regions, the west coast of US and Canada, the Gulf of Alaska, and the Bering Sea (Sadorus et al. 2016). Further, analysis of size-at-age and growth parameters by region have shown differences that could be explained by different environmental conditions, e.g., habitat quality, prey availability, or water temperature (Martell et al. 2012; Sullivan et al. 2016). Finally, a study on the zoogeography of halibut parasites in the Northeast Pacific has shown breakpoints between the parasites' species composition between fish in area 3 (Gulf of Alaska) and in southern areas (Blaylock et al. 1998).

This conceptual model will inform the development of the MSE operating model framework and will be used as a starting point to incorporate variability and alternative movement hypotheses in Pacific halibut movement dynamics. Movement will be modelled as the proportion of individuals that move from one region to another. For this purpose, a transition matrix for each age class or group of ages and sex will be used. The matrix dimension will correspond to the number of regions considered. In the case of halibut, the matrix will be a 4x4 matrix (i.e. 4 biological regions), and each cell of the matrix will correspond to the proportion of fish moving from region in row j to region in column k. Tagging data will be used to inform the transition matrix, and different hypothesis will be tested. Also, all hypotheses will be compared to similar approaches used in the past (i.e., Quinn et al. 1990; Hilborn 1995).

2.2 Management Procedure

The management procedure consists of three elements. Monitoring (data generation) is the code that simulates the data from the operating model and is used by the estimation model. It simulates the data collection and sampling process and can introduce variability, bias, and any other properties that are desired. The Estimation Model (EM) is analogous to the stock assessment and simulates estimation error in the process. Using the data generated, it produces an annual estimate of stock size and status and provides the advice for setting the catch levels for the next time step. Simplifications may be necessary to keep simulation times within a reasonable time. The Harvest Rule is the application of the estimation model output along with the scale and distribution management procedures (Figure 1) to produce the catch limit for that year. The details of the management procedure are in development and concepts described in IPHC-2019-MSAB012-07 Rev_1 will be considered.

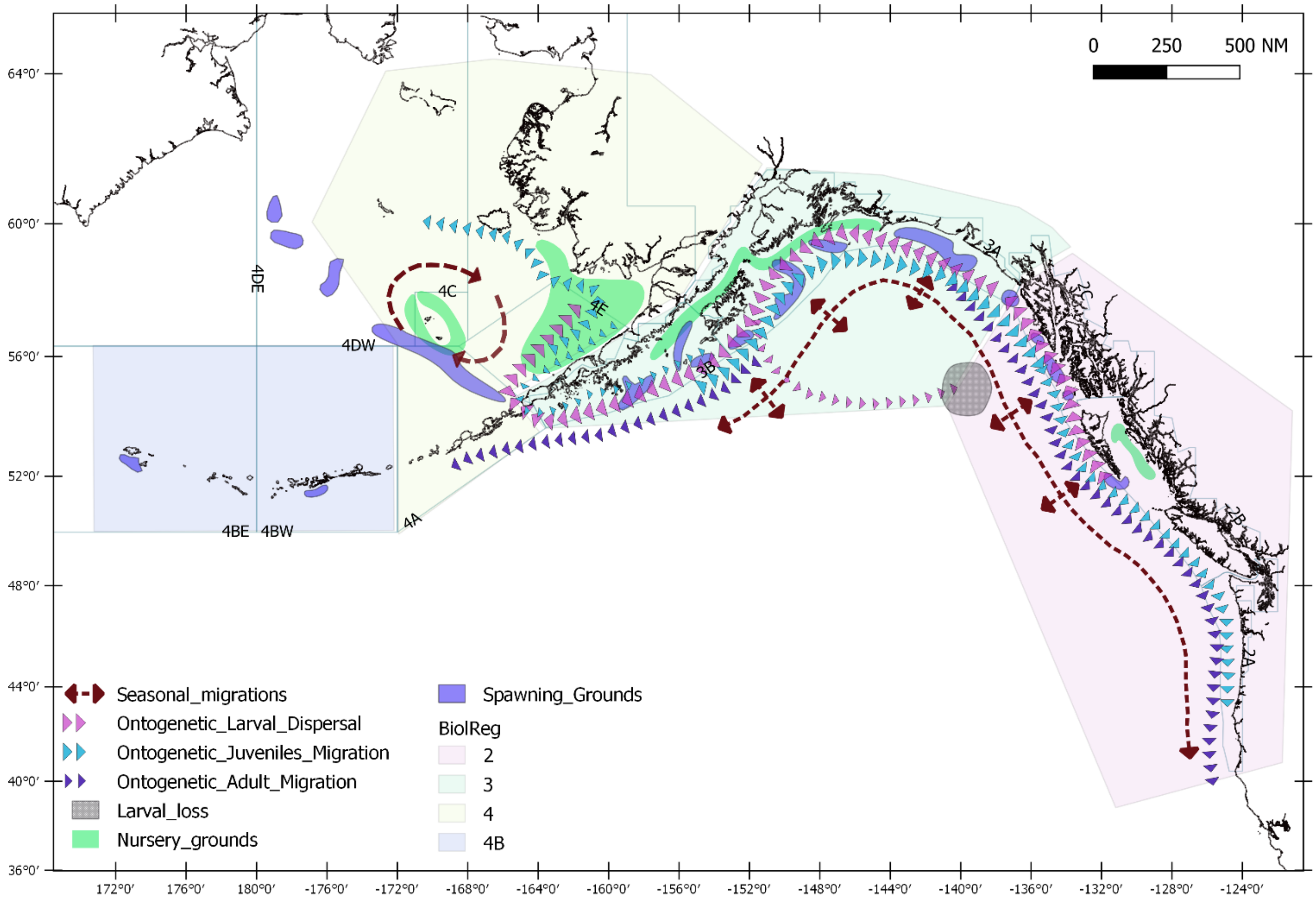

Figure 3: Conceptual model of halibut movement and migration. Broken arrows indicate main seasonal movements (to spawning and to feeding grounds). Arrow-shaped lines indicate ontogenetic movements and the possibility to stop anywhere along the lines. Round polygons indicate main settlement areas for juveniles and main spawning grounds. The grey circle represents the possibility of larvae loss when these enter the Alaskan Gyre. Biological regions are represented by the four large irregular shaded polygons.

3 Technical Development

In concert with the ongoing scientific and procedural elaboration of the MSE framework, the initial development of computer software to simulate the population and offer input to analysis and management strategy is underway. Generally, the software underpinning the MSE simulations and analysis and reporting tools must be robust, return reproducible results, and be easy to use and well-documented so that the MSE scientific staff can focus on analysis rather than technical issues. From an engineering perspective, the software must be performant to reduce lengthy run times and extensible to ease the addition of new features, and therefore written with standard software development and testing processes and tools. Structurally, the software will resemble the MSE process, highlighting the interplay between forecast models conditioned on historical data that characterize the stock, and a management procedure to be evaluated against conservation and fishery objectives.

To date, several areas have begun development, including

- Implementation of an operating model in the C++ programming language;
- Integration of the Automatic Differentiation Model Builder (ADMB) for conditioning the initial model to the present day;
- Creation of flexible templates for management procedures, for fast prototyping and analysis;
- Development of user-friendly configuration tools to ease and parallelize model runs and analysis;
- Use of flexible, open-source libraries to ease data analysis and processing;
- Visualization and reporting tools written in R and related packages.

Later stages of development will focus on robust testing of the implemented algorithms, comparison of its outputs with other implementations to validate accuracy, and, ultimately, ongoing performance optimization (through code restructuring or various forms of parallelization) to reduce runtimes.

4 RECOMMENDATIONS

That the MSAB:

a) **NOTE** paper IPHC-2019-MSAB014-08 which provides the MSAB with an update on the development of the IPHC MSE framework and a description of some of the specifications.

b) **NOTING** document IPHC-2019-MSAB014-INF01, **RECOMMEND** specifications and technical details that should be updated or added to the document for the development of a closed-loop simulation framework to evaluate management procedures related to coastwide scale and distribution of the TCEY.

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6 APPENDICES

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