INTERNATIONAL PACIFIC HALIBUT COMMISSION 5-YEAR PROGRAM OF INTEGRATED SCIENCE AND RESEARCH (2021-26)

PREPARED BY: IPHC SECRETARIAT (D. WILSON, J. PLANAS, I. STEWART, A. HICKS, B. HUTNICZAK, R. WEBSTER, & L. ERIKSON; 14 MAY 2021)

PURPOSE

To provide the SRB with the current draft of the new IPHC 5-year program of integrated science and research (2021-26)

BACKGROUND

The IPHC has a long-standing history (since 1923) of collecting data, undertaking research, and stock assessment, devoted to describing and understanding the Pacific halibut (*Hippoglossus stenolepis*) stock and the fisheries that interact with it.

The IPHC Secretariat conducts activities to address key issues identified by the Commission, its subsidiary bodies, the broader stakeholder community, and of course, the IPHC Secretariat itself. The process of identifying, developing, and implementing our science-based activities involves several steps that are circular in nature, but result in clear project activities and associated deliverables. The process includes developing and proposing projects based on direct input from the Commission, the experience of the IPHC Secretariat given our broad understanding of the resource and its associated fisheries, and concurrent consideration by relevant IPHC subsidiary bodies, and where deemed necessary, additional external peer review.

An overarching goal of the IPHC 5-Year Program of Science and Research (2021-26) is therefore to promote integration and synergies among the various science and research activities of the IPHC Secretariat in order to improve our knowledge of key inputs into the Pacific halibut stock assessment, and Management Strategy Evaluation (MSE) processes.

DISCUSSION

The SRB is invited to review and provide additional guidance to assist the IPCH Secretariat finalise the draft plan provided at Appendix A.

RECOMMENDATION

That the SRB:

1) **NOTE** paper IPHC-2021-SRB018-10 which provides the current draft of the new IPHC 5-year program of integrated science and research (2021-26).

APPENDICES

Appendix A: DRAFT: IPHC 5-Year program of integrated science and research (2021-26) (D. Wilson, J. Planas, I. Stewart, A. Hicks, R. Webster, B. Hutniczak, & L. Erikson)

INTERNATIONAL PACIFIC HALIBUT COMMISSION

5-YEAR PROGRAM OF INTEGRATED SCIENCE AND RESEARCH

(July 2021- June 2026)

INTERNATIONAL PACIFIC

HALIBUT COMMISSION

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IPHC 2021. International Pacific Halibut Commission 5-Year program of integrated science and research (2021-26). Seattle, WA, U.S.A. *IPHC–2021–5YPISR, XX pp.*

INTERNATIONAL PACIFIC HALIBUT COMMISSION

Contact details:

International Pacific Halibut Commission
2320 W. Commodore Way, Suite 300
Seattle, WA, 98199-1287, U.S.A.
Phone: +1 206 634 1838
Fax: +1 206 632 2983
Email: secretariat@iphc.int
Website: http://www.iphc.int/

ACRONYMS

<<<To be completed>>>

DEFINITIONS

A set of working definitions are provided in the IPHC Glossary of Terms and abbreviations: https://iphc.int/the-commission/glossary-of-terms-and-abbreviations

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1. *Introduction*

The International Pacific Halibut Commission (IPHC) is an intergovernmental organization established by a Convention between Canada and the United States of America. The IPHC Convention was concluded in 1923 and entered into force that same year. The Convention has been revised several times since, to extend the Commission's authority and meet new conditions in the fishery. The most recent change occurred in 1979 and involved an amendment to the 1953 Halibut Convention. The amendment, termed a "protocol", was precipitated in 1976 by Canada and the United States of America extending their jurisdiction over fisheries resources to 200 miles. The 1979 Protocol along with the U.S. legislation that gave effect to the Protocol (Northern Pacific Halibut Act of 1982) has affected the way the fishery is conducted, and redefined the role of IPHC in the management of the fishery during the 1980s. Canada does not require specific enabling legislation to implement the protocol.

The basic texts of the Commission are available on the IPHC website: https://www.iphc.int/the-commission, and prescribe the mission of the organization as:

*"….. **to develop the stocks of [Pacific] halibut in the Convention waters to those levels which will permit the optimum yield from the fishery and to maintain the stocks at those levels**. ….." IPHC Convention,* Article I, sub-article I, para. 2). The IPHC Convention Area is detailed in Fig. 1.

The IPHC Secretariat, formed in support the Commission's activities, is based in Seattle, WA, USA. As its shared vision, ***the IPHC Secretariat aims to deliver positive economic, environmental, and social outcomes for the Pacific halibut resource for Canada and the U.S.A. through the application of rigorous science, innovation, and the implementation of international best practice.***

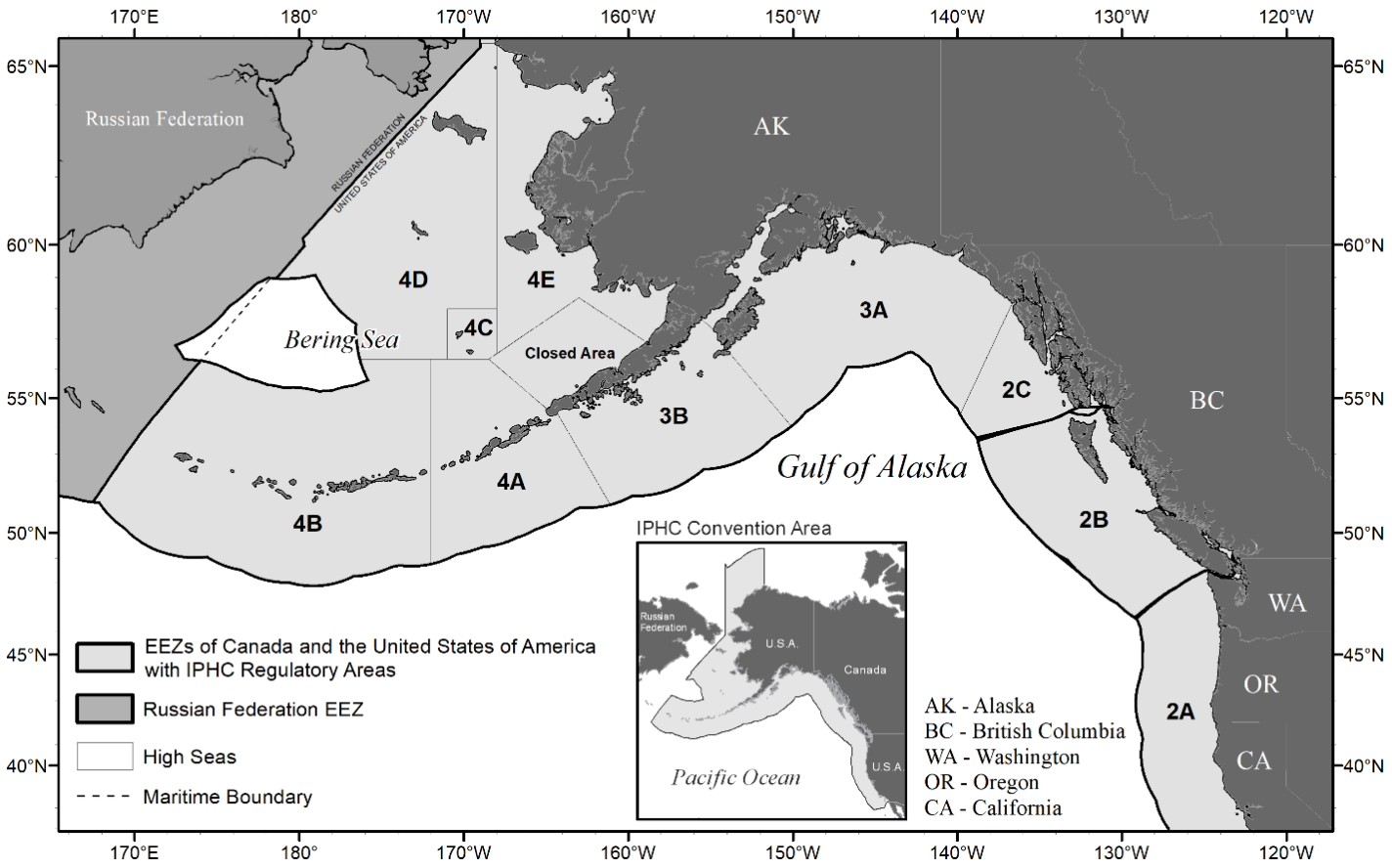

Figure 1. Map of the IPHC Convention Area (map insert) and IPHC Regulatory Areas.

2. *Science and Research objectives*

The IPHC has a long-standing history (since 1923) of collecting data, undertaking research, and stock assessment, devoted to describing and understanding the Pacific halibut (*Hippoglossus stenolepis*) stock and the fisheries that interact with it.

The IPHC Secretariat conducts activities to address key issues identified by the Commission, its subsidiary bodies, the broader stakeholder community, and of course, the IPHC Secretariat itself. The process of identifying, developing, and implementing our science-based activities involves several steps that are circular in nature, but result in clear project activities and associated deliverables. The process includes developing and proposing projects based on direct input from the Commission, the experience of the IPHC Secretariat given our broad understanding of the resource and its associated fisheries, and concurrent consideration by relevant IPHC subsidiary bodies, and where deemed necessary, additional external peer review.

An **overarching goal** of the *IPHC 5-Year Program of Science and Research (2021-26)* is therefore to promote integration and synergies among the various science and research activities of the IPHC Secretariat in order to improve our knowledge of key inputs into the Pacific halibut stock assessment, and Management Strategy Evaluation (MSE) processes.

The science and research activities conducted by the IPHC Secretariat are directed towards fulfilling the following five (5) **objectives** within areas of data collection, biological and ecological research, stock assessment, MSE, and fisheries economics, with the overall aim of proving an integrated program of science and research (Fig 2):

1) **Fisheries data**: collect representative fishery dependent and fishery-independent data on the distribution and abundance of Pacific halibut through ongoing monitoring activities;
2) **Biology and Ecology**: identify and assess critical knowledge gaps in the biology and ecology of Pacific halibut within its known range, including the influence of environmental conditions on population and fishery dynamics;
3) **Stock assessment**: apply the resulting knowledge to reduce uncertainty in current stock assessment models and the stock management advice provided to the Commission;
4) **Management Strategy Evaluation (MSE)**: to provide inputs that inform the MSE process, which will evaluate the consequences of alternative management options, known as harvest strategies.
5) **Fishery economics**: to provide stakeholders with an accurate and all-sectors-encompassing assessment of the economic impact of the Pacific halibut resource in Canada and the United States of America.

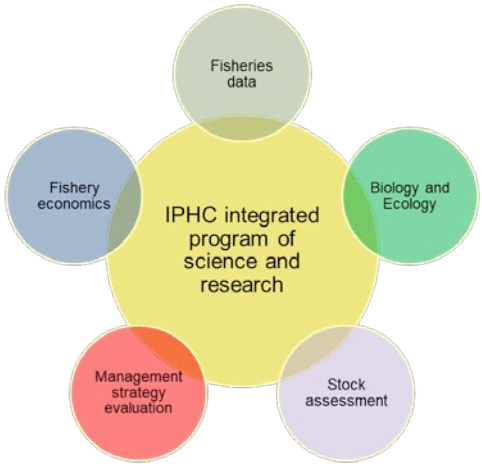

Figure 2. Core areas of the IPHC's integrated program of science and research.

3. *Strategy*

The IPHC Strategic Plan (2019-23) (the Plan) contains five (5) enduring strategic goals in executing our mission, including our overarching goal and associated science and research objectives. Although priorities and tasking will change over time in response to events and developments, the Plan provides a framework to standardise our approach when revising or setting new priorities and tasking. The Strategic goals as they apply to the science and research activities of the IPHC Secretariat, are operationalised through a multi-year tactical activity matrix (Appendix I) at the organisational and management unit (Branch) level (Fig. 3). The tactical activity matrix is described in the sections below, and has been developed based on the core needs of the Commission, in developing and implementing robust, scientifically-based management decisions on an annual, and multi-year level.

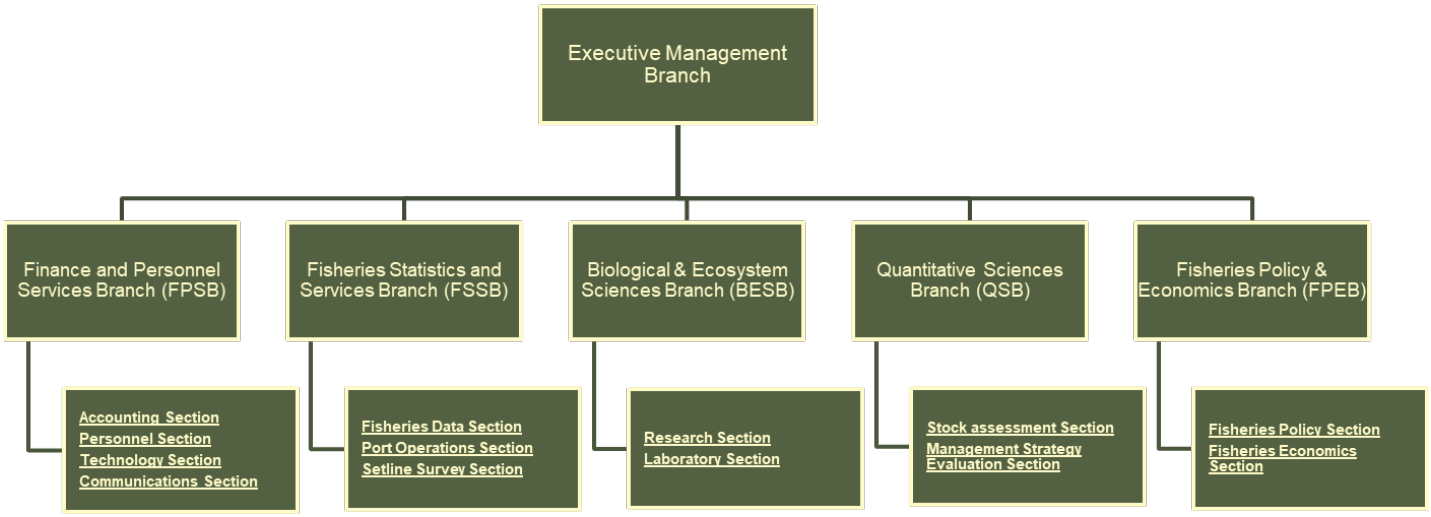

Figure 3. IPHC Secretariat organisation chart (May 2021).

4. *Core focal areas and activities*

The goals of the main activities of the *5-Year program of integrated science and research (2021-26)* are integrated across the organisation, involving regular monitoring (fisheries-dependent and –independent data collection), biological and ecological research, modelling (FISS and stock assessment), Management Strategy Evaluation (MSE), and fishery economic analysis, as outlined in the following sub-sections.

4.1 Fisheries data

Objective: Collect fishery-dependent and fishery-independent data on the distribution and abundance of Pacific halibut, as well as other key biological data, through ongoing monitoring activities.

4.1.1 ***Fishery-dependent data***. The IPHC estimates all Pacific halibut removals taken in the IPHC Convention Area and uses this information in its yearly stock assessment and other analyses. The data are compiled by the IPHC Secretariat and include data from Federal and State agencies of each Contracting Party. Specific activities in this area include:

- **Directed commercial fisheries data**: The IPHC Secretariat collects logbooks, otoliths, tissue samples, and associated sex-length-weight data from directed commercial landings coastwide (Fig. 4). A sampling rate is determined for each port by IPHC Regulatory Area. The applicable rate is calculated from the current year's mortality limits and estimated percentages of weight of fish landed, and estimated percentages of weight sampled in that port to allow for collection of the target number of biological samples by IPHC Regulatory Area. An example of the data

collected and the methods used are provided in the annually updated directed commercial sampling manual (e.g. IPHC Directed Commercial Landings Sampling Manual 2021). Directed commercial fishery landings are recorded by the Federal and State agencies of each Contracting Party and summarized each year by the IPHC. Discard mortality for the directed commercial fishery is currently estimated using a combination of research survey (USA) and observer data (Canada).

- **Non-directed commercial discard mortality data**: The IPHC accounts for non-directed commercial discard mortality by IPHC Regulatory Area and sector. Non-directed commercial discard mortality estimates are provided by State and Federal agencies of each Contracting Party, and compiled annually for use in the stock assessment and other analysis. https://www.iphc.int/data/datatest/non-directed-commercial-discard-mortality-fisheries.
  Non-directed commercial discard mortality of Pacific halibut is estimated because not all fisheries have 100% monitoring and not all Pacific halibut that are discarded are assumed to die. The IPHC relies upon information supplied by observer programs run by Contracting Party agencies for non-directed commercial discard mortality estimates in most fisheries. Non-IPHC research survey information or other sources are used to generate estimates of non-directed commercial discard mortality in the few cases where fishery observations are unavailable. Trawl fisheries off Canada British Columbia are monitored and non-directed commercial discard mortality information is provided to IPHC by DFO. NOAA Fisheries operates observer programs off the USA West Coast and Alaska, which monitor the major groundfish fisheries. Data collected by those programs are used to estimate non-directed commercial discard mortality.

- **Subsistence fisheries data**: Subsistence fisheries are non-commercial, customary, and traditional use of Pacific halibut for direct personal, family, or community consumption or sharing as food, or customary trade. The primary subsistence fisheries are the treaty Indian Ceremonial and Subsistence fishery in IPHC Regulatory Area 2A off northwest Washington State (USA), the First Nations Food, Social, and Ceremonial (FSC) fishery in British Columbia (Canada), and the subsistence fishery by rural residents and federally-recognized native tribes in Alaska (USA) documented via Subsistence Halibut Registration Certificates (SHARC). Subsistence fishery removals of Pacific halibut, including estimated subsistence discard mortality, are provided by State and Federal agencies of each Contracting Party, estimated, and compiled annually for use in the stock assessment and other analysis. https://www.iphc.int/datatest/subsistence-fisheries.

- **Recreational fisheries data**: Recreational removals of Pacific halibut, including estimated recreational discard mortality, are provided by State agencies of each Contracting Party, estimated, and compiled annually for use in the stock assessment and other analysis. https://www.iphc.int/data/datatest/pacific-halibut-recreational-fisheries-data.

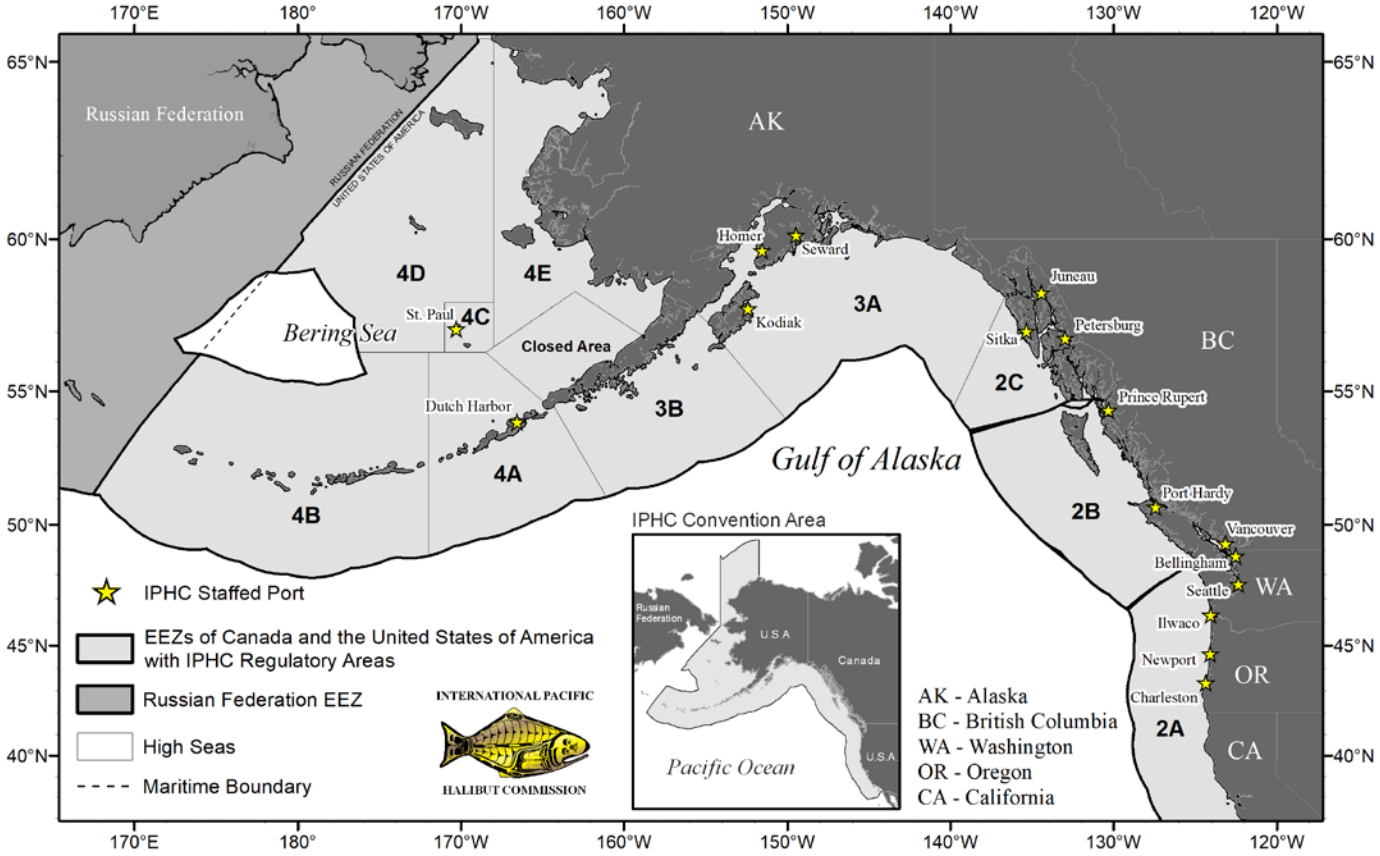

Figure 4. Ports where the IPHC samples directed commercial landings throughout the fishing period.

4.1.2 ***Fishery-independent data***. Data collection and monitoring activities aimed at providing a standardised time-series of biological and ecological data that is independent of the fishing fleet.

- **Fishery-independent setline survey (FISS)**: The IPHC Fishery-Independent Setline Survey (FISS) provides catch-rate information and biological data on Pacific halibut that are independent of the fishery. These data, collected using standardized methods, bait, and gear during the summer of each year, provide the primary index of population abundance used in the stock assessment. The FISS is restricted to the summer months, but encompasses nearly all of the commercial fishing grounds in the Pacific halibut fishery. The standard FISS grid totals 1,890 stations (Fig. 5). Biological data collected on the FISS (e.g. the length, weight, age, and sex composition of Pacific halibut) are used to monitor changes in biomass, growth, and mortality of the Pacific halibut population. In addition, records of non-target species caught during FISS operations provide insight into bait competition, and serve as an index of abundance over time, making them valuable to the potential management and avoidance of non-target species. An example of the data collected and the methods used are provided in the annually updated FISS sampling manual (e.g. IPHC FISS Sampling Manual 2021).

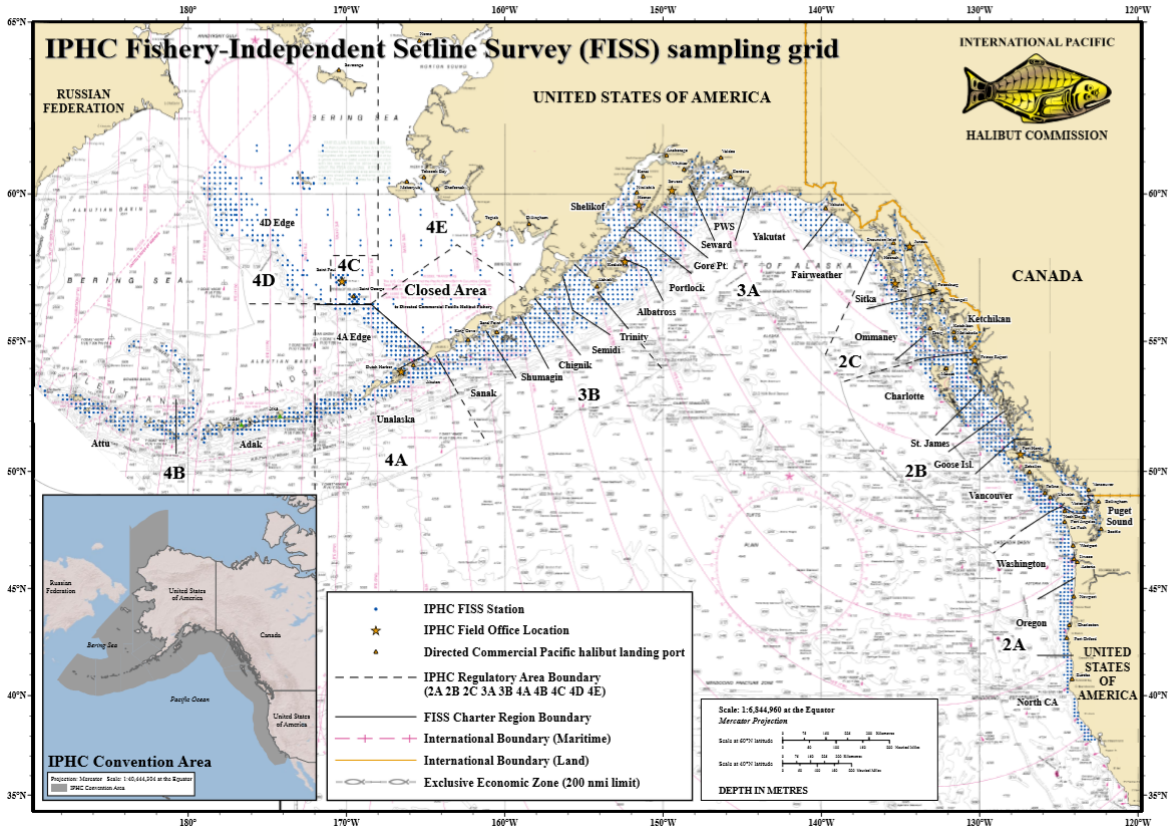

Figure 5. IPHC Fishery-Independent Setline Survey (FISS) with full sampling grid shown.

- **Fishery-independent Trawl Survey (FITS)**: Since 1996, the IPHC has participated annually in the NOAA Fisheries trawl surveys operating in the Bering Sea (Fig. 6) and Aleutian Islands/Gulf of Alaska (Fig. 7). The information collected from Pacific halibut caught on these surveys, together with data from the IPHC Fishery-Independent Setline Survey (FISS) and commercial Pacific halibut data, are used directly in estimating indices of abundance and in the stock assessment and to monitor population trends, growth/size, and to supplement understanding of recruitment, and age composition of young Pacific halibut.

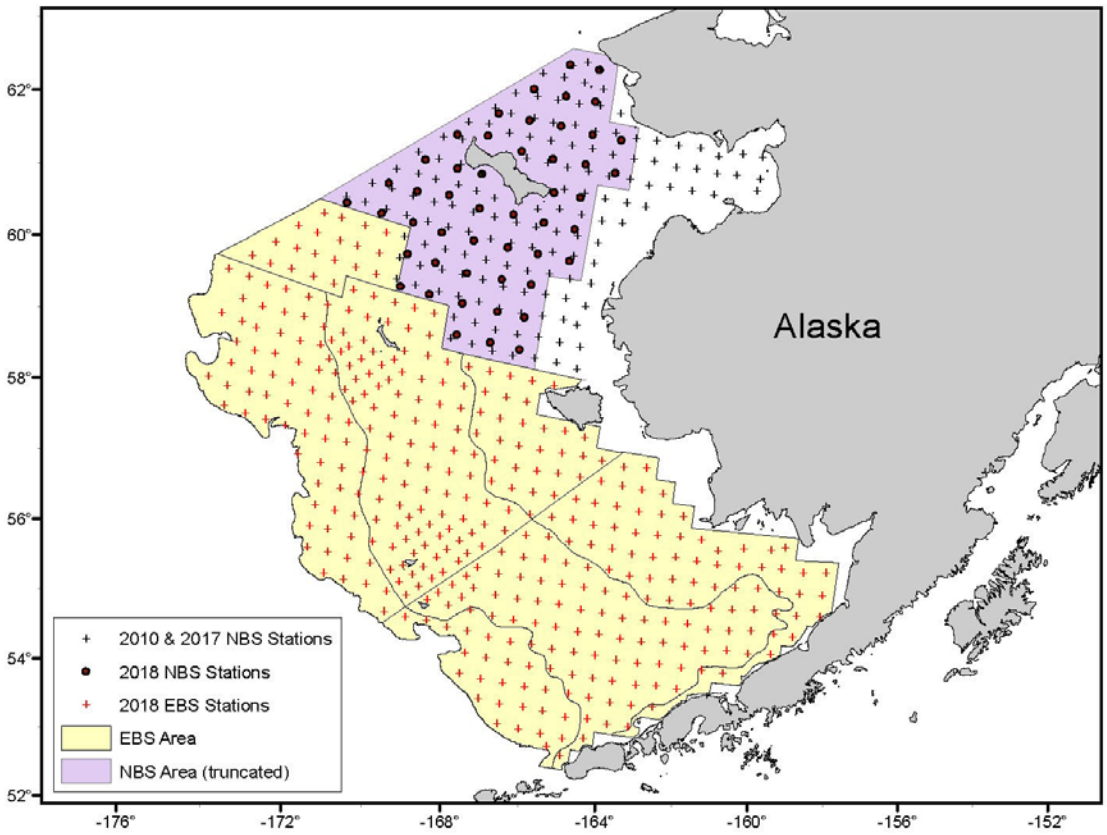

Figure 6. Sampling station design for the 2018 NOAA Bering Sea bottom trawl survey. Black dots are stations sampled in the 2018 "rapid-response" NBS trawl survey and black plus signs are stations sampled in the 2010 and 2017 standard NBS trawl surveys.

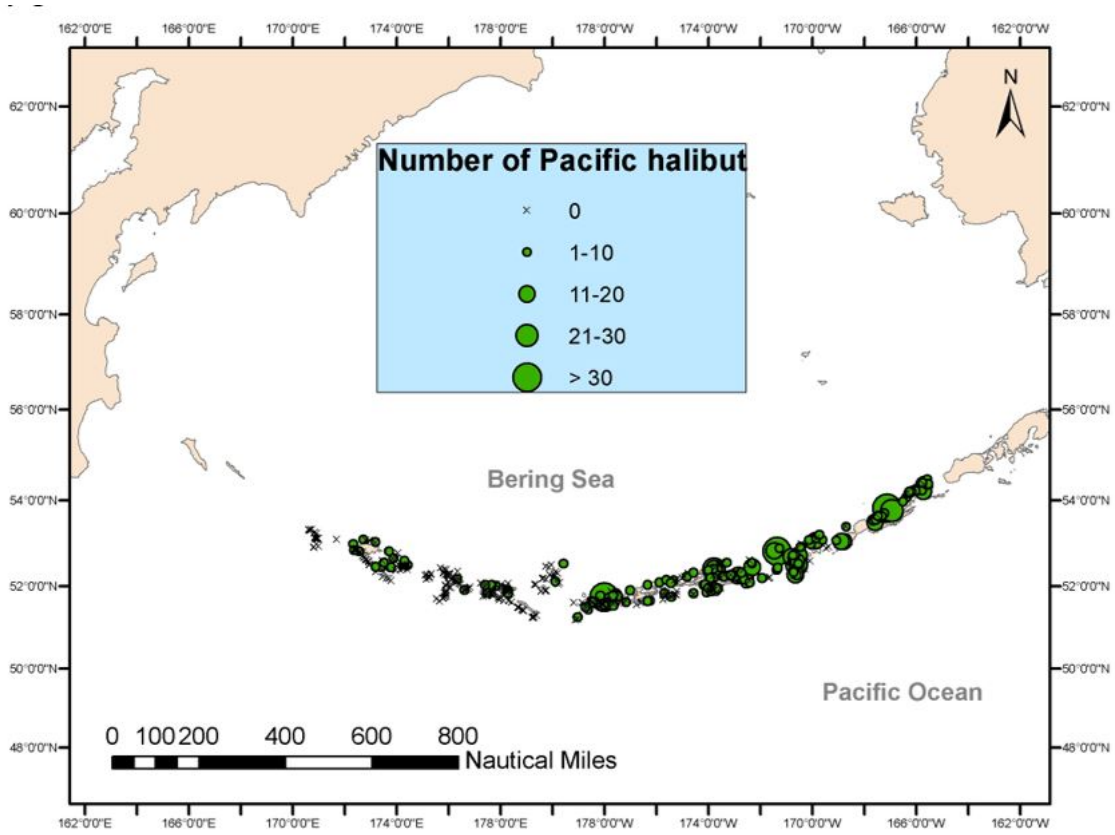

Figure 7a. Sampling stations and catch for the 2018 NOAA-Fisheries Aleutian Islands bottom trawl survey.

[2021 Map to be added]

Figure 7b. Sampling stations and catch for the yyyy NOAA-Fisheries Gulf of Alaska bottom trawl survey.

4.2 Biology and Ecology

Objective: Identify and assess critical knowledge gaps in the biology and ecology of Pacific halibut within its known range, including the influence of environmental conditions on population and fishery dynamics.

4.2.1 ***Migration and Population Dynamics***. Genetic and genomic studies aimed at improving current knowledge of Pacific halibut migration and population dynamics throughout all life stages in order to achieve a complete understanding of stock structure and distribution across the entire distribution range of Pacific halibut in the North Pacific Ocean and the biotic and abiotic factors that influence it (specifically excluding satellite tagging). Specific objectives in this area include:

- Improve current knowledge of the genetic structure of the Pacific halibut population through the use of state-of-the-art low-coverage whole genome resequencing approaches. Establishment of genetic signatures of spawning sites.
- Improve our understanding of the mechanisms and magnitude of larval connectivity in the North Pacific Ocean. Identification of environmental and biological predictors of larval abundance and recruitment.

- Improve our understanding of spawning site contributions to nursery/settlement areas in relation to year-class, recruit survival and strength, and environmental conditions in the North Pacific Ocean. Measure of genetic diversity of Pacific halibut juveniles from the eastern Bering Sea and the Gulf of Alaska.
- Improve our understanding of the relationship between nursery/settlement origin and adult distribution and abundance over temporal and spatial scales. Genomic assignment of individuals to source populations and assessment of distribution changes.
- Integrate analyses of Pacific halibut connectivity and distribution changes by incorporating genomic approaches.
- Improve estimates of population size, migration rates among geographical regions, and demographic parameters (e.g. fecundity-at-age, survival rate), through the application of close-kin mark-recapture-based approaches.
- Improve our understanding of the influences of oceanographic and environmental variation on connectivity, population structure and adaptation at a genomic level using seascape genomics approaches.

4.2.2 ***Reproduction***. Studies aimed primarily at addressing two critical issues for stock assessment analysis based on estimates of female spawning biomass: 1) the sex ratio of the commercial catch and 2) maturity estimations. Specific objectives in this area include:

- Continued improvement of genetic methods for accurate sex identification of commercial landings from fin clips and otoliths in order to incorporate recent and historical sex-at-age information into the stock assessment process.
- Improve our understanding of the temporal progression of reproductive development and gamete production during an entire annual reproductive cycle in female and male Pacific halibut.
- Update current maturity-at-age estimates.
- Provide estimates of fecundity-at-age and fecundity-at-size.
- Investigate the possible presence of skip spawning in Pacific halibut females.
- Improve accuracy in current staging criteria of maturity status used in the field.
- Investigate possible environmental effects on the ontogenetic establishment of the phenotypic sex and their influence on sex ratios in the adult Pacific halibut population.
- Improve our understanding of potential temporal and spatial changes in maturity schedules and spawning patterns in female Pacific halibut and possible environmental influences.
- Improve our understanding of the genetic basis of variation in age and/or size-at-maturity, fecundity, and spawning timing, by conducting genome-wide association studies.

4.2.3 ***Growth***. Studies aimed at describing the role of factors responsible for the observed changes in size-at-age and at evaluating growth and physiological condition in Pacific halibut. Specific objectives in this area include:

- Evaluate possible variation in somatic growth patterns in Pacific halibut as informed by physiological growth markers, physiological condition, energy content and dietary influences.

- Investigate the effects of environmental and ecological conditions that may influence somatic growth in Pacific halibut. Evaluate the relationship between somatic growth and temperature and trophic histories in Pacific halibut through the integrated use of physiological growth markers.
- Improve our understanding of the genetic basis of variation in somatic growth and size-at-age by conducting genome-wide association studies.

4.2.4 ***Mortality and Survival Assessment***. Studies aimed at providing updated estimates of discard mortality rates (DMRs) for Pacific halibut in the guided recreational fisheries and at evaluating methods for reducing mortality of Pacific halibut. Specific objectives in this area include:

- Provide information on the types of fishing gear and fish handling practices used in the Pacific halibut recreational (charter) fishery as well as on the number and size composition of discarded Pacific halibut in this fishery.
- Establish best handling practices for reducing discard mortality of Pacific halibut in recreational fisheries.
- Investigate new methods for whale avoidance and/or deterrence for the reduction of Pacific halibut depredation by whales and for improved estimation of depredation mortality.
- Investigate physiological and behavioral responses of Pacific halibut to fishing gear in order to reduce Pacific halibut bycatch.

4.2.5 ***Climate Change Studies aimed …***

<<In development>>>

4.2.6 ***Fishing technology Studies aimed …***

<<In development>>>

4.3 Stock assessment

Objective: apply the resulting knowledge to reduce uncertainty in current stock assessment models and the stock management advice provided to the Commission.

The IPHC conducts an annual stock assessment, using data from the fishery-independent setline survey (FISS), the commercial Pacific halibut and other fisheries, as well biological information from its research program. The assessment includes the Pacific halibut resource in the IPHC Convention Area, covering the Exclusive Economic Zones of Canada and the United States of America. Data sources are updated each year to reflect the most recent scientific information available for use in management decision making.

The 2020 stock assessment relied on an ensemble of four population dynamics models to estimate the probability distributions describing the current stock size, trend, and demographics. The ensemble is designed to capture both uncertainty related to the data and stock dynamics (due to estimation) as well as uncertainty related to our understanding of the way in which the Pacific halibut stock functions and is best approximated by a statistical model (structural uncertainty).

Stock assessment results are used as inputs for harvest strategy calculations, including mortality tables for the upcoming year that reflect the IPHCs harvest strategy policy and other considerations, as well as the harvest decision table which provides a direct tool for the management process. The harvest decision table uses the probability distributions from short-term (three year) assessment projections to evaluate the trade-offs between

alternative levels of potential yield (catch) and the associated risks to the stock and fishery.

The stock assessment research priorities have been subdivided into three categories:

1) Assessment data collection and processing;
2) biological inputs; and
3) fishery yield.

It is important to note that ongoing monitoring, including the annual FISS and directed commercial landings sampling programs is not considered research and is therefore not included in this list despite the critical importance of these collections. These are prescribed in Section 4.1 above.

Within the three assessment categories, the following topics have been identified as 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 highlighted elsewhere in this document, and to highlight the specific use of products from these studies in the stock assessment.

4.3.1 Assessment data collection and processing:

4.3.1.1 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 (2017-19) of commercial sex-ratio-at-age information available for the 2020 stock assessment, the annual genetic assay of fin clips sampled from the landings remains 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.

4.3.1.2 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, 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.

4.3.2 Biological inputs:

4.3.2.1 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.

4.3.2.2 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.

4.3.2.3 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.

4.3.3 Fishery yield:

4.3.3.1 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.

4.3.3.2 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 mark-recapture 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 genetic analysis required to produce data allowing the estimation of reproductive output and other population parameters from close-kin mark-recapture modelling is both complex and expensive, and it could take several years for this project to get fully underway.

4.4 Management Strategy Evaluation (MSE)

Objective: to provide inputs that inform the MSE process, which will evaluate the consequences of alternative management options, known as harvest strategies.

Management Strategy Evaluation (MSE) is a process to evaluate the consequences of alternative management options, known as harvest strategies. MSE uses a simulation tool to determine how alternative harvest strategies perform given a set of pre-defined fishery and conservation objectives, taking into account the uncertainties in the system and how likely candidate harvest strategies are to achieve the chosen management objectives.

MSE is a simulation technique based on modelling each part of a management cycle. The MSE uses an operating model to simulate the entire population and all fisheries, factoring in management decisions, the monitoring program, the estimation model, and potential ecosystem effects using a closed-loop simulation.

Undertaking a MSE has the advantage of being able to reveal the trade-offs among a range of possible management decisions. Specifically, to provide the information on which to base a rational decision, given harvest strategies, preferences, and attitudes to risk. The MSE is an essential part of the process of developing, evaluating and agreeing to a harvest strategy.

The MSE process involves:

- Defining fishery and conservation objectives with the involvement of stakeholders and managers;
- Identifying harvest strategies (a.k.a. management procedures) to evaluate;
- Simulating a Pacific halibut population using those harvest strategies;
- Evaluating and presenting the results in a way that examines trade-offs between objectives;
- Applying a chosen harvest strategy;
- Repeating this process in the future in case of changes in objectives, assumptions, or expectations.

There are many tasks that would improve the MSE framework and the presentation of future results to the Commission. The tasks can be divided into five general categories, which are common to MSE in general:

1. **Objectives**: The goals and objectives that are used in the evaluation.
2. **Management Procedures (MPs)**: Specific, well-defined management procedures that can be coded to produce simulated TCEYs for each IPHC Regulatory Area.
3. **Framework**: The specifications and computer code for the closed-loop simulations including the operating model and how it interacts with the MP.
4. **Evaluation**: The performance metrics and presentation of results. This includes how the performance metrics are evaluated (e.g. tables, figures, and rankings), presented to the Commission and its subsidiary bodies, and disseminated for outreach.

5. **Application**: Specifications of how a MP may be applied in practice and re-evaluated in the future, including responses to exceptional circumstances.

All of these categories provides inputs and outputs of the MSE process, but the Framework category benefits most from the integration of biological and ecosystem research because the operating model and the simulation of the monitoring program, the estimation model, and potential ecosystem effects are determined from this knowledge. MSE priorities for this important aspect have been subdivided into two categories: 1) biological parameterisation and 2) fishery parameterization. In detail, the following topics have been identified as top priorities.

4.4.1 Biological and population parameterization

4.4.1.1 Distribution of life stages and stock connectivity

Research topics in this category will mainly inform parameterization of movement in the OM, but will also provide further understanding of Pacific halibut movement, connectivity, and the temporal variability. This knowledge may also be used to refine specific objectives to reflect reality and possible outcomes.

This research includes examining larval and juvenile distribution which is a main source of uncertainty in the OM that is currently not fully incorporated. Outcomes will assist with conditioning the OM, verify patterns from the OM, and provide information to develop reasonable sensitivity scenarios to test the robustness of MPs.

Also included in this number one priority is stock structure research, especially with regard to IPHC Regulatory Area 4B. The dynamics of this IPHC Regulatory Area are not fully understood and it is useful to continue research on the connectivity of IPHC Regulatory Area 4B with other IPHC Regulatory Areas.

Finally, genomic analysis of population size is also included in this ranked category because that would help inform development of the OM as well as the biological sustainability objective related to maintaining a minimum spawning biomass in each IPHC Regulatory Area. An understanding of the spatial distribution of population size will help to inform this objective as well as the OM conditioning process (e.g. close-kin mark-recapture).

4.4.1.2 Spatial spawning patterns and connectivity between spawning populations

An important parameter that can influence simulation outcomes is the distribution of recruitment across Biological Regions. Continued research in this area will improve the OM and provide justification for parameterising temporal variability. Research includes assigning individuals to spawning areas and establishing temporal and spatial spawning patterns. Outcomes may also provide information on recruitment strength and the relationship with environmental factors.

4.4.1.3 Understanding growth variation

Changes in the average weight-at-age of Pacific halibut is one of the major drivers of changes in biomass over time. The OM currently simulates temporal changes in weight-at-age via a random autocorrelated process which is unrelated to population size or environmental factors. Ongoing research in drivers related to growth in Pacific halibut will help to improve the simulation of weight-at-age.

4.4.2 Fishery parameterization

The specifications of fisheries and their parameterizations involved consultation with Pacific halibut stakeholders but some aspects of those parameterizations benefit from targeted research. One specific example is knowledge of discarding and discard mortality rates in directed and non-directed fisheries. Discard mortality can be a

significant source of fishing mortality in some IPHC Regulatory Areas and appropriately modelling that mortality will provide a more robust evaluation of MPs.

<<New Program of Work to be added here in summary form once the Commission reviews and approves at the next Special Session of the Commission: June 2021>>

Outcomes of the MSE process will not only inform the Commission on trade-offs between harvest strategies and assist in choosing an optimal strategy for management of the Pacific halibut resource, but will inform the other activities of fisheries monitoring, biological and ecological research, stock assessment, and fishery economics.

4.5 Fishery economics

Objective: to provide stakeholders with an accurate and all-sectors-encompassing assessment of the economic impact of the Pacific halibut resource in Canada and the United States of America.

Under the Convention, the IPHC's mandate is optimum management of the Pacific halibut resource, which necessarily includes an economic dimension. Fisheries economics is an active field of research around the world in support of fisheries policy and management. Adding the economic expertise to the Secretariat, the IPHC has become the first regional fishery management organization (RFMO) in the world to do so.

The goal of the IPHC economic study is to provide stakeholders with an accurate and all-sectors-encompassing assessment of the economic impact of the Pacific halibut resource that includes the full scope of Pacific halibut's contribution to regional economies of Canada and the United States of America. The economic effects of changes to harvest policies can be far-reaching. Altered catch limits have an impact on the direct users of the stock (commercial harvesters, recreational anglers, subsistence fishers), but at the same time, there is a ripple effect through the economy. Fisheries operations create demand for inputs from other sectors while at the same time support industries further along the value chain that rely on the supply of fish, such as seafood processors. The viability of the Pacific halibut sectors is vital to the prosperity of fisheries-dependent households, having a considerable impact on coastal communities. The economic impacts are transmitted cross-regionally through business-to-business transactions (trade in commodities), labor commuting patterns, and the dissemination of profits along the value chain. There is also an inflow if economic benefits to the local economies from outside when non-residents partake in local leisure activities that would not attract the same number of visitors if not for the opportunity to catch this iconic fish of the Pacific Northwest. Pacific halibut's value is also in its contribution to the diet through subsistence fisheries and importance to the traditional users of the resource. To native people, traditional fisheries constitute a vital aspect of local identity and a major factor in cohesion.

Understanding such a broad scope of regional impacts is essential for designing policies with desired effects depending on regulators' priorities. The ability to trace the economic impacts cross-regionally is particularly important in the context of shared resources and joint management, such as the case of collective management of Pacific halibut by the IPHC. Moreover, the study informs on the community impacts of the Pacific halibut resource throughout its range, highlighting communities particularly dependent on economic activities that rely on Pacific halibut. A good understanding of the localized effects is pivotal to policymakers who are often concerned about community impacts, particularly in terms of impact on employment opportunities and households' welfare.

4.5.1 The priorities of the IPHC fisheries economics program can be subdivided into four categories:

4.5.1.1 Primary economic data collection

In order to accurately capture the economic impact of the Pacific halibut, the IPHC designed a series of surveys to gather information from the sectors relying on the Pacific halibut resource. The survey target groups are commercial fishers, processing plant operators, and charter business owners. The goal of the survey is to improve the understanding of each sector's production structure (i.e., data on the distribution of revenue between profit and expenditure items), profitability (including the viability of the sector depending on the stock condition), and distribution of earnings. The compiled survey data serves as an input to the economic impact assessment model.

4.5.1.2 Development of the Pacific halibut multiregional economic impact assessment (PHMEIA) model

PHMEIA model is a multiregional model based on a social accounting matrix (SAM) framework that describes the economic interdependencies between sectors and regions developed to assess the economic contribution of Pacific halibut resource to the economy of the United States and Canada. The model describes the within-region production structure of the Pacific halibut sectors (fishing, processing, charter). In addition, it accounts for interregional spillovers, which represent economic stimulus in the regions other than the one in which the harvest occurs. This is done by tracing Pacific halibut-dependent earnings from the landing stage to beneficial owners of the resource.

It is important to note that accurate characterization of the Pacific halibut sectors in the PHMIA model requires active participation of IPHC stakeholders, including commercial fishers, processing plant operators, and charter business owners in developing the necessary data for analysis.

4.5.1.3 Provide stakeholders with a user-friendly tool visualizing the spatial distribution of economic impacts

The complexity of Pacific halibut supply-side restriction in the form of region-based allocations suggests the need for a tool enabling regulators to assess various combinations of quota allocations easily. To address this, the results of the PHMEIA model are complemented by an interactive web-based application allowing users to estimate and visualize joint economic impacts based on custom changes simultaneously applied to all IPHC-managed Pacific halibut producing areas. In addition, the app highlights the spatial variation of the economic impacts and the importance of cross-regional flows in assessing the dependence of fishing communities on the Pacific halibut resource.

4.5.1.4 Provide input to the management strategy evaluation

The PHMIA model translating the changes in harvest allocations by IPHC regulatory area directly to economic impact by region is well adapted to use with the Pacific halibut management strategy evaluation (MSE) framework. Socio-economic performance metrics presented alongside already developed biological/ecological performance metrics bring the human dimension to the MSE framework, adding to the IPHC's portfolio of tools for assessing policy-oriented issues for the Pacific halibut throughout the Convention Area.

4.5.2 Looking forward, the following areas have been identified as priorities for the IPHC fisheries economics program.

4.5.2.1 Expanding the static SAM model to a computable general equilibrium model

Relaxing the assumption of fixed technical coefficients by specifying these coefficients econometrically as a function of relative prices of inputs is one of the most compelling extensions to the static SAM model. Such models, generally referred to as computable general equilibrium (CGE) models, require research to develop

credible functional relationships between prices and consumption that would guide economic agents' behavior in the model. The CGE approach is a preferred way forward when expanding the model usability and applying it in conjunction with the Pacific halibut management strategy evaluation. In addition, the dynamic model is well suited to analyze the impact of a broad suite of policies or external factors that would affect the stock over time.

4.5.2.2 Improving the spatial granularity of the SAM model

Extending the community analysis beyond a simplified approach described in the IPHC-2021-SRB018-09 (section *Community impacts in Alaska*) to a full community level (or any other spatial scale) SAM-based model requires significant investment in identifying the economic relationships between different sectors or industries (including both seafood and non-seafood industries) within each broader-defined region, this including deriving estimates on intra-regional trade in commodities and flow of earnings. It is an appealing extension of the current model with a great potential for more accurate estimates of the community effects.

4.5.2.3 Study of recreational demand

It is important to note that while it is reasonable to assume that changes in harvest limits have a relatively proportional impact on production by commercial fishers (unless these are dramatic and imply fleet restructure or a significant shift in prices), the effects on the recreational sector are not so straightforward. A separate study estimating changes in saltwater recreational fishing participation as a response to the changing recreational harvest limits is necessary to assess policy impacts in the recreational sector rather than provide a snapshot economic impact. Such studies typically require surveying recreational fishers.

4.5.2.4 Study of demand for Pacific halibut products

Catches can be converted to revenues, but one has to determine what price to multiply harvests by. Since price fluctuates with harvest levels, pragmatic assessment of harvest limits changes needs to be supplemented with a model of demand for Pacific halibut. The demand-adjusted prices provide more economics-sound projections of gross revenues in the sector.

The demand model can also be used to estimate final consumer benefits from changing Pacific halibut harvests and prices (i.e., consumer surplus). In 2019, fresh Alaskan Pacific halibut fillets routinely sold for USD 24-28 a pound, and often more, downtown Seattle. Understanding the formation of the price paid by final consumers is an important step in assessing the contribution of Pacific halibut along the entire value chain, from the hook to the plate.

4.5.2.5 Assessment of the economic impact of other sources of Pacific halibut mortality

All-sectors-encompassing quantitative assessment of the economic impact of the Pacific halibut resource necessitates the development of a methodological approach for the remaining sources of Pacific halibut mortality, including subsistence fishing, bycatch, and research catch. Methods adopted for the commercial and charter sector are not adequate for this portion of the harvest.

4.5.2.6 Uncertainty in the PHMEIA model

The PHMEIA model results focus on the magnitude of the Pacific halibut contribution to the economy and its spatial distribution. To increase confidence in the PHMEIA results, the model needs to consider sources of input variations and the cumulative effect of interactions among them. The natural next step is to conduct sensitivity analysis to account for the uncertainties in the system. The current framework would benefit from proposing methods for calculating the range (confidence intervals) of impacts from input variations within a PHMEIA framework, explicitly accounting for multiple sources of input variations.

5. *Measures of Success*

The Secretariat's success in the implementing the *IPHC 5-Year Program of Integrated Science and Research (2021-26)* will be measured according to the following criteria:

5.1 Timely delivery of specified products

Each project line items will contain specific deliverables that constitute useful inputs into the stock assessment and the management strategy evaluation process and support their implementation in the decision making process at the level of the Commission.

<<<In development>>>

- Fisheries Data
  - o
- Biology and Ecology
  - o
- Stock Assessment
  - o
- Management Strategy Evaluation
  - o
- Fishery Economics
  - o

5.2 Positive contributions from the Scientific Review Board (SRB) and the Research Advisory Board (RAB)

Periodic review of projects and associated deliverables by both the SRB and RAB as appropriate.

5.3 External research funding

At least 20% of the funds for this program to be sourced from external funding bodies on an annual basis.

<<<In development>>>

- Fisheries Data
  - o
- Biology and Ecology
  - o
- Stock Assessment
  - o
- Management Strategy Evaluation
  - o
- Fishery Economics

5.4 Peer-reviewed journal publication

Publication of research outcomes from activities contemplated in this program in peer-reviewed literature. Each sub-project shall be published in a timely manner.

<<<In development>>>

- Fisheries Data
  - o

- Biology and Ecology
  - o
- Stock Assessment
  - o
- Management Strategy Evaluation
  - o
- Fishery Economics

6. *Future Strategic Science and Research Activities*

Along with the implementation of the medium- and long-term activities contemplated in this *IPHC 5-Year Program of Integrated Science and Research (2021-26)*, the IPHC Secretariat shall strive to:

1) Establish world-leading programs in fisheries research, particularly on genomics and genetics.
2) Establish new collaborative agreements and interactions with research agencies and academic institutions.
3) Promote the international involvement of the IPHC by continued and new participation in international scientific organizations and by leading international science and research collaborations.
4) Incorporation of talented students and early researchers in research activities contemplated.

<<<In development>>>

- Fisheries Data
  - o
- Biology and Ecology
  - o
- Stock Assessment
  - o
- Management Strategy Evaluation
  - o
- Fishery Economics
  - o

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APPENDICES

Appendix I: Integration of science and research activities

Appendix II: Proposed schedule of outputs

Appendix III: Proposed schedule with funding and staffing indicators

APPENDIX I

Integration of science and research activities

(in development: Fisheries Data, Fishery Economics to be added)

Research areas	Research activities	Research outcomes	Relevance for stock assessment	Specific analysis input in stock assessment (SA)	SA Rank	Relevance for MSE	MSE Rank
Migration and Population Dynamics	Larval and juvenile connectivity and early life history studies	Improved understanding of larval and juvenile distribution	Improve estimates of productivity	Will be used to generate potential recruitment covariates and to inform minimum spawning biomass targets by Biological Region	3. Biological input	Improve parametization of the Operating Model	1. Biological parameterization and validation of movement estimates. 2. Biological parameterization and validation of recruitment distribution
	Population structure	Stock structure of IPHC Regulatory Area 4B relative to the rest of the Convention Area	Altered structure of future stock assessments	If 4B is found to be functionally isolated, a separate assessment may be constructed for that IPHC Regulatory Area	2. Biological input		
	Adult migration and distribution	Assignment of individuals to source populations and assessment of distribution changes	Improve estimates of productivity	Will be used to define management targets for minimum spawning biomass by Biological Region	3. Biological input		
	Close-kin mark-recapture studies	Genomic analysis of population size and connectivity		Population size estimates to fit in the stock assessment			
	Seascape genomics	Identification of adaptive loci, decipher genomic basis of adaptation and detect genomic responses to environmental change		Will be used to define management targets for minimum spawning biomass by Biological Region			
	Genome-wide association analyses	Understand the genetic basis of phenotypic variation, including size-at-age, age-at-maturity, spawning timing, etc.		May help to delineate between effects due to fishing and those due to environment, thereby informing appropriate management response			
Reproduction	Histological maturity assessment	Updated maturity schedule	Scale biomass and reference point estimates	Will be included in the stock assessment, replacing the current schedule last updated in 2006	1. Biological input	Improve simulation of spawning biomass in the Operating Model	
	Examination of potential skip spawning	Incidence of skip spawning		Will be used to adjust the asymptote of the maturity schedule, if/when a time-series is available this will be used as a direct input to the stock assessment			
	Fecundity assessment	Fecundity-at-age and -size information		Will be used to move from spawning biomass to egg-output as the metric of reproductive capability in the stock assessment and management reference points			
	Examination of accuracy of current field macroscopic maturity classification	Revised field maturity classification		Revised time-series of historical (and future) maturity for input to the stock assessment			
	Sex ratio of current commercial landings	Sex ratio-at-age	Scale biomass and fishing intensity	Annual sex-ratio at age for the commercial fishery fit by the stock assessment	1. Assessment data collection and processing		
	Historical sex ratios based on archived otolith DNA analyses	Historical sex ratio-at-age		Annual sex-ratio at age for the commercial fishery fit by the stock assessment			
	Recruitment strength and variability	Establishment of temporal and spatial maturity and spawning patterns	Improve stock-recruitment curve for more precise assessment	May be used to provide a weighted spawning biomass calculation and or inform targets for minimum spawning biomass by Biological Region		Improve simulation of recruitment variability and parametization of recruitment distribution in the Operating Model	2. Biological parameterization and validation of recruitment variability and distribution
Growth	Evaluation of somatic growth variation as a driver for changes in size-at-age	Validation of physiological markers for growth pattern evaluation	Scale stock productivity and reference point estimates	May inform yield-per-recruit and other spatial evaluations of productivity that support mortality limit-setting		Improve simulation of variability and allow for scenarios investigating climate change	3. Biological parameterization and validation for growth projections
		Environmental influences on growth patterns		May provide covariates for projecting short-term size-at-age. May help to delineate between effects due to fishing and those due to environment, thereby informing appropriate management response			
		Dietary influences on growth patterns and physiological condition		May provide covariates for projecting short-term size-at-age. May help to deleineate between effects due to fishing and those due to environment, thereby informing appropriate management response			
Mortality and survival assessment	Discard mortality rate estimate: recreational fishery	Experimentally-derived DMR	Improve estimates of unobserved mortality	Will improve estimates of discard mortality, reducing potential bias in stock assessment results and management of mortality limits		Improve estimates of stock productivity	1. Fishery parameterization
	Best handling practices: recreational fishery	Guidelines for reducing discard mortality		May reduce discard mortality, thereby increasing available yield for directed fisheries	2. Fishery yield		
	Whale depredation accounting and tools for avoidance	New tools for fishery avoidance/deterence; improved estimation of depredation mortality	Improve mortality accounting	May reduce depredation mortality, thereby increasing available yield for directed fisheries. May also be included as another explicit source of mortality in the stock assessment and mortality limit setting process depending on the estimated magnitude	2. Assessment data collection and processing		
	Biological interactions with fishing gear	Physiological and behavioral responses to fishing gear	Reduce incidental mortality	May increase yield available to directed fisheries	1. Fishery yield		

APPENDIX II

Proposed schedule of outputs

(in development: Yet to incorporate elements outside BESB)

Research areas	Research activities	2021		2022				2023				2024				2025				2026	
Migration and Population Dynamics	Larval and juvenile connectivity and early life history studies																				
	Population structure																				
	Adult migration and distribution																				
	Close-kin mark-recapture studies																				
	Seascape genomics																				
	Genome-wide association analyses																				
Reproduction	Histological maturity assessment																				
	Examination of potential skip spawning																				
	Fecundity assessment																				
	Examination of accuracy of current field macroscopic maturity classification																				
	Sex ratio of current commercial landings																				
	Historical sex ratios based on archived otolith DNA analyses																				
	Recruitment strength and variability																				
Growth	Application of physiological markers for growth pattern evaluation																				
	Environmental influences on growth patterns																				
	Dietary influences on growth patterns and physiological condition																				
Mortality and survival assessment	Discard mortality rate estimate: recreational fishery																				
	Best handling practices: recreational fishery																				
	Whale depredation accounting and tools for avoidance																				
	Biological interactions with fishing gear																				

APPENDIX III

Proposed schedule of funding and staffing indicators

(in development: Yet to incorporate elements outside BESB)

Research areas	Research activities	Required FTEs/Year	IPHC FTEs/Year	2021		2022			2023			2024			2025				2026		IPHC Funds	Grant Funds
Migration and Population Dynamics	Larval and juvenile connectivity and early life history studies	0.45	0.45				RS (0.25 FTE)					RB2 (0.2 FTE)									Yes	No
	Population structure	1	1		RB1																Yes	Proposed
	Adult migration and distribution	1																			Yes	Proposed
	Close-kin mark-recapture studies	1	0																		No	Planning
	Seascape genomics	1	0																		No	Planning
	Genome-wide association analyses	1	0																		No	Planning
Reproduction	Histological maturity assessment	0.75	0																		Yes	No
	Examination of potential skip spawning	0.25	0																		Yes	No
	Fecundity assessment	0.5	0.25								RS										Yes	No
	Examination of accuracy of current field macroscopic maturity classification	0.25																			Yes	No
	Sex ratio of current commercial landings	0.5	0.75	LT																	Yes	No
	Historical sex ratios based on archived otolith DNA analyses	0.5																			Yes	No
	Recruitment strength and variability	0.5	0																		Yes	Planning
Growth	Application of physiological markers for growth pattern evaluation	0.25	0.25	LT																	Yes	No
	Environmental influences on growth patterns	0.5	0.5								RS										No	Planning
	Dietary influences on growth patterns and physiological condition	0.5	0.2								RB2										No	Planning
Mortality and survival assessment	Discard mortality rate estimate: recreational fishery	0.5	1							RB 3											No	Yes
	Best handling practices: recreational fishery	0.5																			No	Yes
	Whale depredation accounting and tools for avoidance	0.5																			No	Pending
	Biological interactions with fishing gear	0.5																			No	Pending

Current IPHC staff (Total 4.4 FTEs):
RS: Research Scientist (PhD). Full time permanent position (100% research; 1 FTE)
RB1: Research Biologist 1 (Geneticist; MSc). Full time temporary position (until April 2022; 1 FTE). 55% of salary requested in grant application.
RB2: Research Biologist 2 (Early Life History; MSc). Full time permanent position (40% research; 0.4 FTE)
RB3: Research Biologist 3 (DMR; MSc candidate). Full time permanent position (100% research; 1 FTE)
LT: Laboratory Technician (MSc). Full time temporary position (100% research; 1 FTE)