# IPHC 5-year Biological and Ecosystem Science Research Plan: Update

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## PURPOSE

To provide the Commission with a description of progress on the IPHC 5-year Biological and Ecosystem Science Research Plan (2017-21).

## BACKGROUND

The main objectives of the Biological and Ecosystem Science Research at the IPHC are to:

1) identify and assess critical knowledge gaps in the biology of the Pacific halibut;
2) understand the influence of environmental conditions; and
3) apply the resulting knowledge to reduce uncertainty in current stock assessment models.

The primary biological research activities at IPHC that follow Commission objectives are identified and described in the IPHC Five-Year Biological and Ecosystem Science Research Plan (2017-21). These activities are summarized in five broad research areas designed to provide inputs into stock assessment and the management strategy evaluation processes (Appendix I), as follows:

1) Migration and Distribution. Studies are aimed at further understanding reproductive migration and identification of spawning times and locations as well as larval and juvenile dispersal.
2) Reproduction. Studies are aimed at providing information on the sex ratio of the commercial catch and to improve current estimates of maturity.
3) Growth and Physiological Condition. Studies are aimed at describing the role of some of the factors responsible for the observed changes in size-at-age and to provide tools for measuring growth and physiological condition in Pacific halibut.
4) Discard Mortality Rates (DMRs) and Survival. Studies are aimed at providing updated estimates of DMRs in both the longline and the trawl fisheries.
5) Genetics and Genomics. Studies are aimed at describing the genetic structure of the Pacific halibut population and at providing the means to investigate rapid adaptive changes in response to fishery-dependent and fishery-independent influences.

## UPDATE ON PROGRESS ON THE MAIN RESEARCH ACTIVITIES

1. Migration and Distribution.

   Research activities in this Research Area aim at improving existing knowledge on Pacific halibut larval and juvenile distribution. The relevance of research outcomes from these activities for stock assessment (SA) is in the improvement of estimates of productivity. These research outcomes will be used to generate potential recruitment covariates and to inform minimum spawning biomass targets by Biological Region and represent one of the top three biological inputs into SA (Appendix II). The relevance of these research outcomes for the management and strategy evaluation (MSE) process is in the improvement of the parametrization of the Operating Model and represent the top ranked biological input into the MSE (Appendix III).

1.1. Larval distribution and connectivity between the Gulf of Alaska and Bering Sea.
Principal Investigator: Lauri Sadorus (M.Sc.)
Objective: To investigate larval and juvenile connectivity of Pacific halibut within and between the Gulf of Alaska and the Bering Sea.

Knowledge of the dispersal of Pacific halibut larvae and subsequent migration of young juveniles has remained elusive because traditional tagging methods are not effective on these life stages due to the small size of the animals. This larval connectivity project, in cooperation with NOAA EcoFOCI, used two recently developed modeling approaches to estimate dispersal and migration pathways of larval and young juvenile Pacific halibut in order to better understand the connectivity of populations between the Gulf of Alaska and Bering Sea and within each of these two ocean basins. The results of this initial study have been published in the journal *Fisheries Oceanography* (Sadorus et al., 2021). Additional studies are currently planned to investigate the potential of Pacific halibut larvae to be successfully delivered from offshore spawning sites to potential inshore settlement habitats identified by the IPHC Secretariat, under different climatic regimes.

1.2. Wire tagging of U32 Pacific halibut.
Principal Investigator: Joan Forsberg (B.Sc.; Fisheries Statistics & Services Branch)
Objective: To investigate the migratory patterns of young Pacific halibut.

The patterns of movement of Pacific halibut among IPHC Regulatory Areas have important implications for management of the Pacific halibut fishery. The IPHC Secretariat has undertaken a long-term study of the migratory behavior of Pacific halibut through the use of externally visible tags (wire tags) on captured and released fish that must be retrieved and returned by workers in the fishing industry. In 2015, with the goal of gaining additional insight into movement and growth of young Pacific halibut (less than 32 inches [82 cm]; U32), the IPHC began wire-tagging small Pacific halibut encountered on the National Marine Fisheries Service (NMFS) groundfish trawl survey and, beginning in 2016, on the IPHC fishery-independent setline survey (FISS). In 2021, 2,534 Pacific halibut were tagged and released on the IPHC FISS but no tagging was conducted in the NMFS groundfish trawl surveys. Therefore, a total of 6,111 U32 Pacific halibut have been wire tagged and released on the IPHC FISS and 126 of those have been recovered to date. In the NMFS groundfish trawl surveys through 2019, a total of 6,536 tags have been released and, to date, 76 tags have been recovered.

2. Reproduction.

Research activities in this Research Area aim at providing information on key biological processes related to reproduction in Pacific halibut (maturity and fecundity) and to provide sex ratio information of Pacific halibut commercial landings. The relevance of research outcomes from these activities for stock assessment (SA) is in the scaling of Pacific halibut biomass and in the estimation of reference points and fishing intensity. These research outputs will result in a revision of current maturity schedules and will be included as inputs into the SA (Appendix II), and represent the most important biological inputs for stock assessment. The relevance of these research outcomes for the management and strategy evaluation process is in the improvement of the simulation of spawning biomass in the Operating Model (Appendix III).

2.1. Sex ratio of the commercial landings.
Principal Investigators: Crystal Simchick (B.Sc.)
Objective: To provide information on the sex ratio of the commercial landings.

The IPHC Secretariat has completed the processing of genetic samples from the 2020 aged commercial landings. The IPHC Secretariat has now produced four consecutive years of commercial catch sex-ratio information (2017-2020) that will inform selectivity parameters and cumulatively reduce uncertainty in future estimates of stock size.

2.2. Maturity assessment.
Principal Investigator: Josep Planas (Ph.D.)
Objective: To characterize maturity and fecundity in female Pacific halibut.

Recent sensitivity analyses have shown the importance of changes in spawning output due to skip spawning and/or changes in maturity schedules for stock assessment (Stewart and Hicks, 2018). Information of these key reproductive parameters provides direct input to stock assessment. For example, information on fecundity-at-age and –at-size could be used to replace spawning biomass with egg output as the metric of reproductive capability in the stock assessment and management reference points. This information highlights the need for a better understanding of factors influencing reproductive biology and reproductive success of Pacific halibut. In order to fill existing knowledge gaps related to the reproductive biology of female Pacific halibut, research efforts are devoted to characterize female maturity in this species. Specific objectives of current studies include: 1) histological assessment of the temporal progression of female developmental stages and reproductive phases throughout an entire reproductive cycle; 2) investigation of skip-spawning in females; and 3) fecundity estimations.

The IPHC Secretariat has described for the first time the different oocyte stages that are present in the ovary of female Pacific halibut and how these are used to classify females histologically to specific maturity stages. This information is contained in a manuscript that was published in the *Journal of Fish Biology* (Fish et al., 2020). In brief, 8 different oocyte developmental stages have been described, from early primary growth oocytes until preovulatory oocytes, and their size and morphological characteristics established. Maturity classification was determined by assigning maturity status to the most advanced oocyte developmental stage present in ovarian tissue sections and 7 different microscopic maturity stages were established. Analysis of oocyte size frequency distribution among the seven different maturity stages provided the first direct evidence for the group-synchronous pattern of oocyte development and for determinate fecundity as the reproductive strategy in female Pacific halibut. The results of this study will be instrumental to establish a comparison of the microscopic/histological and macroscopic/field classification criteria that are currently used to assign the maturity status of females that is used in stock assessment. This first study set the stage for a subsequent in-depth study that investigate the temporal changes in reproductive development, as assessed by microscopic observations of ovarian samples collected throughout an entire annual reproductive cycle and that is now completed (Fish et al. in review). The results obtained confirm that the peak period of spawning for Pacific halibut in the central Gulf of Alaska takes place in January and February and that Pacific halibut females spawn following an annual reproductive cycle. Analysis of the temporal changes in female reproductive phase shows that spawning capable females are detected as early as August, therefore marking the beginning of the spawning capable reproductive phase. For stock assessment purposes, the spawning capable reproductive phase comprises females that are considered mature. Importantly, the detection of spawning capable females in July-August is conducive to conducting routine histological assessments of female maturity during the IPHC's FISS sample collection period (i.e. June to late August). As a result of this information, the IPHC Secretariat will collect ovarian samples in each of the four Biological Regions in order to conduct histology-based maturity curves to revise the current maturity schedule and to investigate potential spatial differences in maturity schedules.

Furthermore, the IPHC Secretariat is also establishing a comparison of the microscopic (e.g. histological) and macroscopic (e.g. visual) maturity classification criteria to determine whether field classification criteria that are currently used to assign the maturity status of females that is used in stock assessment needs to be revised in light of the improved knowledge on ovarian development.

3. Growth.
   Principal Investigator: Josep Planas (Ph.D.)
   Objective: To investigate somatic growth variation as a driver for changes in size-at-age.

   Research activities conducted in the Research Area on Growth aim at providing information on somatic growth processes driving size-at-age in Pacific halibut. The relevance of research outcomes from these activities for stock assessment resides, first, in their ability to inform yield-per-recruit and other spatial evaluations for productivity that support mortality limit-setting, and, second, in that they may provide covariates for projecting short-term size-at-age and may help delineate between fishery and environmental effects, thereby informing appropriate management responses (Appendix II). The relevance of these research outcomes for the management and strategy evaluation process is in the improvement of the simulation of variability and to allow for scenarios investigating climate change (Appendix III).

   The IPHC Secretariat has conducted studies aimed at elucidating the drivers of somatic growth leading to the decline in size-at-age by investigating the physiological mechanisms that contribute to growth changes in the Pacific halibut. The two main objectives of these studies have been: 1) the identification and validation of physiological markers for somatic growth; and 2) the application of molecular growth markers for evaluating growth patterns in the Pacific halibut population.

The IPHC Secretariat has completed a study funded by the North Pacific Research Board (NPRB Project No. 1704; 2017-2020) to identify relevant physiological markers for somatic growth. This study resulted in the identification of 23 markers in skeletal muscle that were indicative of temperature-induced growth suppression and 10 markers in skeletal muscle that were indicative of temperature-induced growth stimulation. These markers represented genes and proteins that changed both their mRNA expression levels and abundance levels in skeletal muscle, respectively, in parallel with changes in the growth rate of Pacific halibut. A manuscript describing the results of this study is currently in preparation (Planas et al., In Preparation).

In addition to temperature-induced growth manipulations, the IPHC Secretariat has conducted similar studies as part of NPRB Project No. 1704 to identify physiological growth markers that respond to density- and stress-induced growth manipulations. The respective justifications for these studies are that (1) population dynamics of the Pacific halibut stock could be affected by fish density, and (2) stress responses associated with capture and release of discarded Pacific halibut may affect subsequent feeding behavior and growth. Investigations related to the effects of density and stress exposure are still underway.

4. Discard Mortality Rates (DMRs) and Survival Assessment.
Information on all Pacific halibut removals is integrated by the IPHC Secretariat, providing annual estimates of total mortality from all sources for its stock assessment (SA). Bycatch and wastage of Pacific halibut, as defined by the incidental catch of fish in non-target fisheries and by the mortality that occurs in the directed fishery (i.e. fish discarded for sublegal size or for regulatory reasons), respectively, represent important sources of mortality that can result in significant reductions in exploitable yield in the directed fishery. Given that the incidental mortality from the commercial Pacific halibut fisheries and bycatch fisheries is included as part of the total removals that are accounted for in the SA, changes in the estimates of incidental mortality will influence the output of the SA and, consequently, the catch levels of the directed fishery. Research activities conducted in this Research Area aim at providing information on discard mortality rates and producing guidelines for reducing discard mortality in Pacific halibut in the longline and recreational fisheries. The relevance of research outcomes from these activities for SA resides in their ability to improve trends in unobserved mortality in order to improve estimates of stock productivity and represent the most important inputs in fishery yield for SA (Appendix II). The relevance of these research outcomes for the management and strategy evaluation process is in fishery parametization (Appendix III).

For this reason, the IPHC Secretariat is conducting two research projects to investigate the effects of capture and release on survival and to improve estimates of DMRs in the directed longline and guided recreational Pacific halibut fisheries:

4.1. Evaluation of the effects of hook release techniques on injury levels and association with the physiological condition of captured Pacific halibut and estimation of discard mortality using remote-sensing techniques in the directed longline fishery.

Principal Investigator: Claude Dykstra (B.Sc.)
Objective: To provide estimates of discard mortality and best-handling practices in the Pacific halibut directed fishery.

The IPHC Secretariat, with funding by a grant from the Saltonstall-Kennedy Grant Program NOAA (NA17NMF4270240; 2017-2020), has conducted studies to evaluate the effects of hook release techniques on injury levels, their association with the physiological condition of captured Pacific halibut and, importantly, has generated experimentally-derived estimates of discard mortality rate (DMR) in the directed longline fishery. The initial results on individual survival outcomes for Pacific halibut released in excellent condition as the viability category assigned to the fish following capture indicate a range of DMRs between 4.2% (minimum) and 8.4% (maximum), that is consistent with the currently-applied DMR value of 3.5%. A manuscript describing these results has been accepted for publication in the *Journal of North American Fishery Management* (Loher et al., In Press).

The IPHC Secretariat is currently conducting modeling analyses of potential relationships between individual physiological characteristics of discarded Pacific halibut, environmental conditions and handling practices, as well as on the ability of electronic monitoring systems to capture release methods and individual lengths of captured fish.

4.2. Discard mortality rates of Pacific halibut in the charter recreational fishery.
Principal Investigator: Claude Dykstra (B.Sc.)
Objective: To provide estimates of discard mortality and best-handling practices in the Pacific halibut guided recreational fishery.

The IPHC Secretariat is conducting a research project to better characterize the nature of charter recreational fisheries with the ultimate goal of better understanding discard practices relative to that which is employed in the directed longline fishery. This project has received funding from the National Fish and Wildlife Foundation (NFWF Project No. 61484) and the North Pacific Research Board (NPRB Project No. 2009) (Appendix IV). The experimental field components of this research project took place in Sitka, Alaska (IPHC Regulatory Area 2C) from 21-27 May 2021, and in Seward, Alaska (IPHC Regulatory Area 3A) from 11-16 June 2021. In brief, Pacific halibut were captured with the use of 12/0 and 16/0 circle hooks that best reflect the gear currently used and fish sizes were targeted to cover the Pacific halibut size distribution recorded by ADFG on an annual basis. All injuries were documented, along with length, weight, somatic fat measurements (using the Distell Fatmeter), and a blood sample (for measuring the levels of physiological stress indicators in plasma) was collected for each fish, before they were tagged and released. Environmental information on temperature (bottom/surface) and time (fight time, time on deck) was also tracked. Eighty (80) Pacific halibut of Excellent release viability were fitted with satellite pop-up archival tags (sPAT) for near term survival estimation in IPHC Regulatory Area 3A. Analyses of survival data and levels of blood stress indicators are currently underway.

5. Genetics and genomics.
   Principal Investigator: Andy Jasonowicz (M.Sc.)
   Objective: To investigate the genetic structure of the Pacific halibut population and to conduct genetic analyses to inform on Pacific halibut movement and distribution in the Convention Waters.

   The IPHC Secretariat is conducting studies that incorporate genomics approaches in order to produce useful information on population structure and distribution and connectivity of Pacific halibut. The relevance of research outcomes from these activities for stock assessment (SA) resides (1) in the introduction of possible changes in the structure of future stock assessments, as separate assessments may be constructed if functionally isolated components of the population are found (e.g. IPHC Regulatory Area 4B), and (2) in the improvement of productivity estimates, as this information may be used to define management targets for minimum spawning biomass by Biological Region. These research outcomes provide the second and third top ranked biological inputs into SA (Appendix II). Furthermore, the relevance of these research outcomes for the management and strategy evaluation process is in biological parametization and validation of movement estimates, on one hand, and of recruitment distribution, on the other hand (Appendix III).

   Understanding population structure is imperative for sound management and conservation of natural resources (Hauser, 2008). Pacific halibut in Canadian and USA waters are managed by the International Pacific Halibut Commission (IPHC) as a single coastwide unit stock since 2006. The rationale behind this management approach is based on our current knowledge of the highly migratory nature of Pacific halibut as assessed by tagging studies (Webster et al., 2013) and of past analyses of genetic population structure that failed to demonstrate significant differentiation in the North-eastern Pacific Ocean population of Pacific halibut by allozyme (Grant, 1984) and small-scale microsatellite analyses (Bentzen, 1998; Nielsen *et al.*, 2010). However, more recent studies have reported slight genetic population structure on the basis of genetic analysis conducted with larger sets of microsatellites suggesting that Pacific halibut captured in the Aleutian Islands may be genetically distinct from other areas (Drinan et al., 2016). These findings of subtle genetic structure in the Aleutian Island chain area are attributed to limited movement of adults and exchange of larvae between this area and the rest of the stock due to the presence of oceanographic barriers to larval and adult dispersal (i.e. Amchitka Pass) that could represent barriers to gene flow. Unfortunately, genetic studies suggesting subtle genetic structure (Drinan et al., 2016) were conducted based on a relatively limited set of microsatellite markers and, importantly, using genetic samples collected in the summer (i.e. non-spawning season) that may not be representative of the local spawning population. With the collection of winter (i.e. spawning season) genetic samples in the Aleutian Islands by the IPHC in early 2020, a collection of winter samples from 5 different geographic areas across the North-eastern Pacific Ocean (i.e. British Columbia, Central Gulf of Alaska, Bering Sea, Central and Western Aleutian Islands) is now available to re-examine the genetic structure of the Pacific halibut population. Importantly, novel, high-throughput and high-resolution genomics approaches are now available for use, such as low-coverage whole genome resequencing, in order to describe with unprecedented detail the genetic structure of the Pacific halibut population. The recently sequenced Pacific halibut genome, described in a manuscript currently in review in a peer-reviewed journal (Jasonowicz et al., 2021) constitutes an essential resource for the success of the whole genome resequencing approach. The results from the proposed genomic studies will provide important information on spawning structure and, consequently, on the genetic baselines of source populations. Importantly, the results from these studies will provide management advice regarding the relative justifiability for considering the western Aleutians as a genetically-distinct substock. This work has recently received funding from the North Pacific Research Board (NPRB Project No. 2110) (Appendix IV).

6. Other research.

The IPHC Secretariat (PI's: Mr. Claude Dykstra and Dr. Ian Stewart) has been successful in securing funding from NOAA's 2021 Bycatch Reduction Engineering Program (BREP) to conduct a project entitled "Gear-based approaches to catch protection as a means for minimizing whale depredation in longline fisheries" (Appendix IV). This project aims to identify potential methods for protecting hook captured fish from whale depredation and to develop and field-test several simple low-cost catch-protection designs that can be deployed effectively using current longline fishing techniques. The proposed work entails conducting a workshop with industry (affected fishers, gear researchers, scientists) in February 2022 to identify methods to protect fishery catches from depredation. The top two or three catch protection design outcomes from the workshop will be incorporated into functional prototypes and field tested later in 2022 on longline sea trials targeting flatfish.

## RECOMMENDATION/S

That the Commission **NOTE** paper IPHC-2022-AM098-11 which outlines progress on the IPHC 5-year Biological and Ecosystem Science Research Plan.

## References


Bentzen, P., Britt, J., and Kwon, J., 1998. Genetic variation in Pacific halibut (*Hippoglossus stenolepis*) detected with novel microsatellite markers. Report of Assessment and Research Activities. International Pacific Halibut Commission, Seattle, WA, pp. 229–241.

Drinan, D.P., Galindo, H.M., Loher, T., and Hauser, L., 2016. Subtle genetic population structure in Pacific halibut *Hippoglossus stenolepis*. Journal of Fish Biology 89, 2571-2594.

Drinan, D.P., Loher, T., and Hauser, L., 2018. Identification of Genomic Regions Associated With Sex in Pacific Halibut. Journal of Heredity 109, 326-332.

Fish, T., Wolf, N., Harris, B. P., and Planas, J. V. 2020. A comprehensive description of oocyte developmental stages in Pacific halibut, *Hippoglossus stenolepis*. Journal of Fish Biology 97, 1880-1885. http://dx.doi.org/10.1111/jfb.14551.

Fish, T., Wolf, N., Smeltz, T. S., Harris, B. P., Planas, J. V. 2021. Reproductive biology of female Pacific halibut (*Hippoglossus stenolepis*) in the Gulf of Alaska. Frontiers in Marine Science. (In Review).

Grant, W.S., Teel, D. J., and Kobayashi, T., 1984. Biochemical Population Genetics of Pacific Halibut (*Hippoglossus stenolepis*) and Comparison with Atlantic Halibut (*Hippoglossus hippoglossus*). Canadian Journal of Fisheries and Aquatic Sciences 41, 1083-1088.

Hauser, L., and Carvalho, G. R., 2008. Paradigm shifts in marine fisheries genetics: ugly hypotheses slain by beautiful facts. Fish and Fisheries 9, 333-362.

Jasonowicz, A.C., Simeon, A., Zahm, M., Cabau, C., Klopp, C., Roques, C., Iampietro, C., Lluch, J., Donnadieu, C., Parrinello, H., Drinan, D.P., Hauser, L., Guiguen, Y., Planas, J.V. 2021. Generation of a chromosome-level genome assembly for Pacific halibut (*Hippoglossus stenolepis*) and characterization of its sex-determining genomic region. Molecular Ecology Resources (In Review).

Loher, T., Dykstra, C.L., Hicks, A., Stewart, I.J., Wolf, N., Harris, B.P., Planas, J.V. 2021. Estimation of post-release longline mortality in Pacific halibut (*Hippoglossus stenolepis*) using acceleration-logging tags. North American Journal of Fisheries Management (In Press).

Nielsen, J.L., Graziano, S.L., Seitz, A.C., 2010. Fine-scale population genetic structure in Alaskan Pacific halibut (*Hippoglossus stenolepis*). Conservation Genetics 11, 999-1012.

Planas, J.V., Jasonowicz, A., Simeon, A., Rudy, D., Timmins-Schiffman, E., Nunn, B.L., Kroska, A., Wolf, N., and Hurst, T.P. Physiological signatures of temperature-induced growth manipulations in white skeletal muscle of juvenile Pacific halibut (*Hippoglossus stenolepis*). (In Preparation).

Sadorus, L.; Goldstein, E.; Webster, R.; Stockhausen, W.; Planas, J.V.; Duffy-Anderson, J. 2021. Multiple life-stage connectivity of Pacific halibut (*Hippoglossus stenolepis*) across the Bering Sea and Gulf of Alaska. Fisheries Oceanography. 30:174-193. https://onlinelibrary.wiley.com/doi/abs/10.1111/fog.12512

Stewart, I.J., and Hicks, A. 2020. Assessment of the Pacific halibut (*Hippoglossus stenolepis*) stock at the end of 2019. Int. Pac. Halibut Comm. Annual Meeting Report: IPHC-2020-SA-01.

Webster, R.A., Clark, W.G., Leaman, B.M., Forsberg, J.E., Hilborn, R., 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, 642-653.

## APPENDICES

**Appendix I:** Integration of ongoing biological research activities, stock assessment and management strategy evaluation.

**Appendix II:** List of ranked biological uncertainties and parameters for stock assessment and their links to potential research areas and research activities (2017-21)

**Appendix III:** List of ranked biological uncertainties and parameters for management strategy evaluation and their potential links to research areas and research activities (2017-21)

**Appendix IV:** Summary of awarded collaborative research grants current in 2021

# APPENDIX I

## Integration of ongoing biological research activities, stock assessment and management strategy evaluation

| Research areas | Research activities | Research outcomes | Relevance for stock assessment | Relevance for MSE | Specific analysis input | SA Rank (Top 3) | MSE Rank (Top 3) |
|---|---|---|---|---|---|---|---|
| **Migration** | Larval and juvenile connectivity and early life history studies | Improved understanding of larval and juvenile distribution | Improve estimates of productivity | Improve parametization of the Operating Model | Will be used to generate potential recruitment covariates and to inform minimum spawning biomass targets by Biological Region | 3. Biological input | 1. Biological parameterization and validation of movement estimates |
| **Reproduction** | Histological maturity assessment | Updated maturity schedule | Scale biomass and reference point estimates | Improve simulation of spawning biomass in the Operating Model | Will be included in the stock assessment, replacing the current schedule last updated in 2006 | 1. Biological input | |
| | 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 | Improve simulation of recruitment variability and parametization of recruitment distribution in the Operating Model | May be used to provide a weighted spawning biomass calculation and or inform targets for minimum spawning biomass by Biological Region | | 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 | Identification and application of markers for growth pattern evaluation | Scale stock productivity and reference point estimates | Improve simulation of variability and allow for scenarios investigating climate change | May inform yield-per-recruit and other spatial evaluations of productivity that support mortality limit-setting | | 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 | | |
| **Mortality and survival assessment** | Discard mortality rate estimate: longline fishery | Experimentally-derived DMR | Improve trends in unobserved mortality | Improve estimates of stock productivity | Will improve estimates of discard mortality, reducing potential bias in stock assessment results and management of mortality limits | | 1. Fishery parameterization |
| | Discard mortality rate estimate: recreational fishery | | | | Will improve estimates of discard mortality, reducing potential bias in stock assessment results and management of mortality limits | | 2. Fishery parameterization |
| | Best handling practices: longline fishery | Guidelines for reducing discard mortality | | | May reduce discard mortality, thereby increasing available yield for directed fisheries | | |
| | Best handling practices: recreational fishery | Guidelines for reducing discard mortality | | | May reduce discard mortality, thereby increasing available yield for directed fisheries | | |
| **Genetics and genomics** | Population structure | Stock structure of IPHC Regulatory Area 4B relative to the rest of the Convention Area | Altered structure of future stock assessments | Improve parametization of the Operating Model | If 4B is found to be functionally isolated, a separate assessment may be constructed for that IPHC Regulatory Area | 2. Biological input | 1. Biological parameterization and validation of movement estimates. |
| | Distribution | Assignment of individuals to source populations and assessment of distribution changes | | | Will be used to define management targets for minimum spawning biomass by Biological Region | 3. Biological input | 2. Biological parameterization and validation of recruitment distribution |

# APPENDIX II

## List of ranked biological uncertainties and parameters for stock assessment and their links to potential research areas and research activities (2017-21)

| SA Rank | Research outcomes | Relevance for stock assessment | Specific analysis input | Research Area | Research activities |
|---|---|---|---|---|---|
| 1. Biological input | Updated maturity schedule | Scale biomass and reference point estimates | Will be included in the stock assessment, replacing the current schedule last updated in 2006 | Reproduction | Histological maturity assessment |
| | 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 | | Examination of potential skip spawning |
| | 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 | | Fecundity assessment |
| | Revised field maturity classification | | Revised time-series of historical (and future) maturity for input to the stock assessment | | Examination of accuracy of current field macroscopic maturity classification |
| 2. Biological input | 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 | Genetics and Genomics | Population structure |
| 3. Biological input | 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 | | Distribution |
| | Improved understanding of larval and juvenile distribution | | Will be used to generate potential recruitment covariates and to inform minimum spawning biomass targets by Biological Region | Migration | Larval and juvenile connectivity studies |
| 1. Assessment data collection and processing | Sex ratio-at-age | Scale biomass and fishing intensity | Annual sex-ratio at age for the commercial fishery fit by the stock assessment | Reproduction | Sex ratio of current commercial landings |
| | Historical sex ratio-at-age | | Annual sex-ratio at age for the commercial fishery fit by the stock assessment | | Historical sex ratios based on archived otolith DNA analyses |
| 2. Assessment data collection and processing | 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 | Mortality and survival assessment | Whale depredation accounting and tools for avoidance |
| 1. Fishery yield | Physiological and behavioral responses to fishing gear | Reduce incidental mortality | May increase yield available to directed fisheries | Mortality and survival assessment | Biological interactions with fishing gear |
| 2. Fishery yield | Guidelines for reducing discard mortality | Improve estimates of unobserved mortality | May reduce discard mortality, thereby increasing available yield for directed fisheries | Mortality and survival assessment | Best handling practices: recreational fishery |

## APPENDIX III

## List of ranked biological uncertainties and parameters for management strategy evaluation (MSE) and their potential links to research areas and research activities (2017-21)

| MSE Rank | Research outcomes | Relevance for MSE | Research Area | Research activities |
|---|---|---|---|---|
| 1. Biological parameterization and validation of movement estimates | Improved understanding of larval and juvenile distribution | Improve parametization of the Operating Model | Migration | Larval and juvenile connectivity studies |
| | Stock structure of IPHC Regulatory Area 4B relative to the rest of the Convention Area | | Genetics and Genomics | Population structure |
| 2. Biological parameterization and validation of recruitment variability and distribution | Assignment of individuals to source populations and assessment of distribution changes | Improve simulation of recruitment variability and parametization of recruitment distribution in the Operating Model | | Distribution |
| | Establishment of temporal and spatial maturity and spawning patterns | Improve simulation of recruitment variability and parametization of recruitment distribution in the Operating Model | Reproduction | Recruitment strength and variability |
| 3. Biological parameterization and validation for growth projections | Identification and application of markers for growth pattern evaluation | Improve simulation of variability and allow for scenarios investigating climate change | Growth | Evaluation of somatic growth variation as a driver for changes in size-at-age |
| | Environmental influences on growth patterns | | | |
| | Dietary influences on growth patterns and physiological condition | | | |
| 1. Fishery parameterization | Experimentally-derived DMRs | Improve estimates of stock productivity | Mortality and survival assessment | Discard mortality rate estimate: recreational fishery |

# APPENDIX IV

## Summary of awarded collaborative research grants current in 2021

| Project # | Grant agency | Project name | PI | Partners | IPHC Budget ($US) | Management implications | Grant period |
|---|---|---|---|---|---|---|---|
| 1 | **National Fish & Wildlife Foundation** | Improving the characterization of discard mortality of Pacific halibut in the recreational fisheries (NFWF Award No. 61484) | IPHC Dr J. Planas and Mr Claude Dykstra | Alaska Pacific University, U of A Fairbanks, charter industry | $98,902 | Bycatch estimates | 1 April 2019 – 1 November 2021 |
| 2 | **North Pacific Research Board** | Pacific halibut discard mortality rates (NPRB Award No. 2009) | IPHC Dr. J. Planas | Alaska Pacific University | $210,502 | Bycatch estimates | 1 January 2021 – 31 March 2022 |
| 3 | **Bycatch Reduction Engineering Program-NOAA** | Gear-based approaches to catch protection as a means for minimizing whale depredation in longline fisheries (NOAA Award Number NA21NMF4720534) | IPHC Mr. Claude Dykstra and Dr. I. Stewart | Deep Sea Fishermen's Union, Alaska Fisheries Science Center-NOAA, industry representatives | $99,700 | Whale depredation | 1 November 2021 – 30 April 2022 |
| 4 | **North Pacific Research Board** | Pacific halibut population genomics (NPRB Award No. 2110) | IPHC Dr. J. Planas | Alaska Fisheries Science Center-NOAA | $193,685 | Stock structure | 1 December 2021 – 31 January 2024 |
| **Total awarded ($)** | | | | | **$602,789** | | |