Report on Current and Future Biological and Ecosystem Science Research Activities

PREPARED BY: IPHC SECRETARIAT (J. PLANAS, 12 DECEMBER 2022)

PURPOSE

To provide the Commission with a description of the biological and ecosystem science research projects conducted and planned by the IPHC Secretariat and contemplated within the IPHC's Five-year Program of Integrated Research and Monitoring (2022-2026).

BACKGROUND

The primary biological research activities at IPHC that follow Commission objectives are identified and described in the IPHC Five-Year Program of Integrated Research and Monitoring (2022-2026). These activities are summarized in five broad research areas designed to provide inputs into stock assessment (SA) and the management strategy evaluation (MSE) processes, as follows:

1) Migration and Population Dynamics. Studies are 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.
2) Reproduction. Studies are aimed at providing information on the sex ratio of the commercial catch and to improve current estimates of maturity and fecundity.
3) Growth. Studies are 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.
4) Mortality and Survival Assessment. Studies are aimed at providing updated estimates of discard mortality rates in the guided recreational fisheries and at evaluating methods for reducing mortality of Pacific halibut.
5) Fishing Technology. Studies are aimed at developing methods that involve modifications of fishing gear with the purpose of reducing Pacific halibut mortality due to depredation and bycatch.

A ranked list of biological uncertainties and parameters for SA (Appendix I) and the MSE process (Appendix II) and their links to research activities and outcomes derived from the five-year research plan are provided.

UPDATE ON PROGRESS ON THE MAIN RESEARCH ACTIVITIES

1. Migration and Population Dynamics.

   The IPHC Secretariat is currently conducting studies on Pacific halibut juvenile habitat and movement through conventional wire tagging, as well as studies that incorporate genomics approaches in order to produce useful information on population structure, 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 I). Furthermore, the relevance of these research outcomes for the MSE process is in biological parameterization and validation of movement estimates, on one hand, and of recruitment distribution, on the other hand (Appendix II).

1.1. Estimation of Pacific halibut juvenile habitat. The IPHC Secretariat recently completed a study to investigate the connectivity between spawning grounds and possible settlement areas based on a biophysical larval transport model (please see paper in the journal Fisheries Oceanography: https://doi.org/10.1111/fog.12512). Although it is known that, following the pelagic larval phase, Pacific halibut begin their demersal stage as approximately 6-month-old juveniles, settling in shallow nursery (settlement) areas, near or outside the mouths of bays (please see paper in *Reviews in Fish Biology and Fisheries*: https://doi.org/10.1007/s11160-021-09672-w), very little information is available on the geographic location and physical characteristics of these areas. In order to fill this knowledge gap and set the stage for future studies to further investigate the connectivity between spawning and nursery grounds, the IPHC Secretariat has initiated studies to identify potential settlement areas for juvenile Pacific halibut throughout IPHC Convention Waters. A first objective of this study is to create a map of suitable settlement habitat by combining available bathymetry information (e.g. benthic sediment composition and shoreline morphological data) and information on recorded presence of age-0, age-1 and age-2 Pacific halibut juveniles as well as absence of young Pacific halibut noted by various nursery habitat projects focused on other flatfish species. Data sources are currently being collected.

1.2. Wire tagging of U32 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 2022, 1,499 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 7,610 U32 Pacific halibut have been wire tagged and released on the IPHC FISS to date. Of these, a total of 149 tags have been recovered to date. In the NMFS groundfish trawl surveys through 2019, a total of 6,421 tags have been released and, to date, 78 tags have been recovered.

1.3. Population genomics. The primary objective of the studies that the IPHC Secretariat is currently conducting is to investigate the genetic structure of the Pacific halibut population and to conduct genetic analyses to inform on Pacific halibut movement and distribution within the Convention Area.

1.3.1. Pacific halibut genome and characterization of the sex determining region in Pacific halibut. The IPHC Secretariat has updated the Pacific halibut genome assembly. The updated Pacific halibut genome has an estimated size of 602 Mb, 24 chromosome-length scaffolds that contain 99.8% of the assembly and a N_{50} scaffold length of 27.3 Mb. The Pacific halibut whole genome sequencing data are openly available in NCBI at https://www.ncbi.nlm.nih.gov/bioproject/622249, under BioProject PRJNA622249, and the updated assembly is openly available in NCBI at https://www.ncbi.nlm.nih.gov/assembly/GCA_022539355.2/ with GenBank assembly accession number GCA_022539355.2. The master record for the whole genome shotgun sequencing project has been deposited at DDBJ/ENA/GenBank under the accession JAKRZP000000000 and is openly available in NCBI at https://www.ncbi.nlm.nih.gov/nuccore/JAKRZP000000000. Sample metadata is openly available in NCBI at https://www.ncbi.nlm.nih.gov/biosample?Db=biosample&DbFrom=bioproject&Cmd=Link&LinkName=bioproject_biosample&LinkReadableName=BioSample&ordinalpos=1&IdsFromResult=622249, under BioSamples SAMN14503176, SAMN25516224, SAMN25600010 and SAMN25600011. This improved genome assembly will increase our ability to resolve Pacific halibut population structure at a fine scale using the proposed approach (Section 1.3.2).

Using the updated genome assembly, we conducted genome-wide analyses of sex-specific genetic variation by pool sequencing by mapping reads from male and female pools to the Pacific halibut genome assembly. We identified a potential sex-determining region in chromosome 9 of approximately 12 Mb containing a high density of female-specific SNPs. Within this sex-determining region, we identified among the annotated genes a potential candidate for the master sex-determining gene in Pacific halibut. Mapping of previously identified Pacific halibut RAD-tags associated with sex (Drinan et al., 2018) to the updated Pacific halibut genome assembly resulted in the alignment of 55 of the 56 RAD-tags, all of which mapped to the putative SD region, including the two tags containing the sex-linked markers currently used for genetic sex identification (2.1.1). These results, together with data on the Pacific halibut genome sequencing and assembly, have been published in the journal *Molecular Ecology Resources* (https://doi.org/10.1111/1755-0998.13641).

1.3.2. Studies to resolve the genetic structure of the Pacific halibut population in the Convention Area. This project has recently received funding from the North Pacific Research Board (NPRB Project No. 2110; Appendix III). The IPHC Secretariat has generated genomic sequences from 610 individual Pacific halibut collected from five spawning groups in different geographic areas (Figure 1) using low-coverage whole-genome resequencing (lcWGR). The lcWGR approach offers a cost-effective way to develop a large number (~millions) of single nucleotide polymorphisms (SNPs) that can be used as genetic markers to evaluate population structure with very high resolution. Using this method, the IPHC Secretariat is working to establish a baseline of genetic diversity using sample collections made during the spawning season and will use this data set

to develop genomic tools (i.e. genetic marker panels) that can be applied to conduct mixed stock analysis and identify the population of origin for samples collected outside of the spawning season.

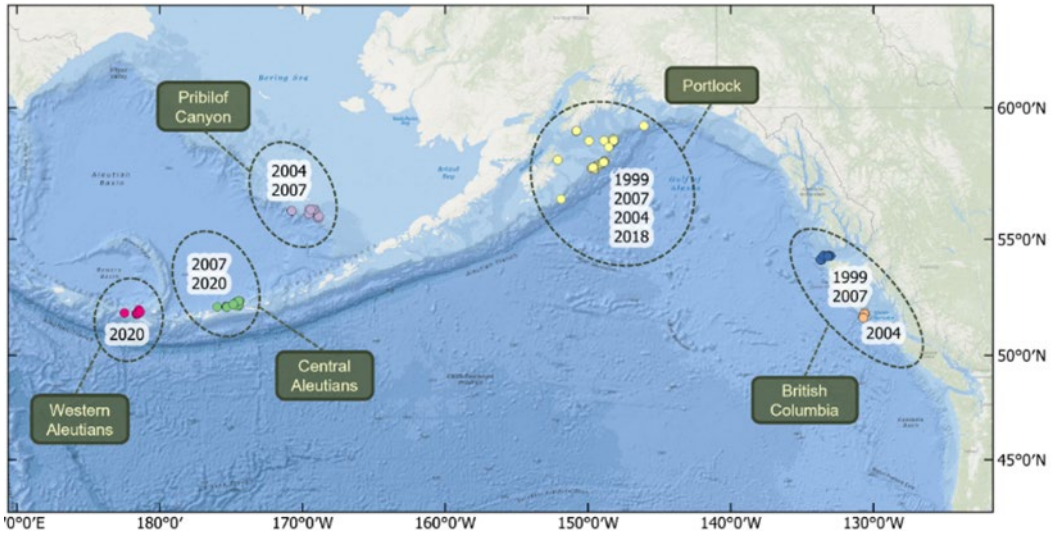


Figure 1. Map of sample collections made during the spawning season used for genomic analysis of population structure in Pacific halibut in the Northeast Pacific Ocean.

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 I), and represent the most important biological inputs for stock assessment (please see document IPHC-2021-SRB018-06). The relevance of these research outcomes for the management and strategy evaluation (MSE) process is in the improvement of the simulation of spawning biomass in the Operating Model (Appendix II).

2.1. Sex ratio of the commercial landings. The IPHC Secretariat has completed the processing of genetic samples from the 2021 aged commercial landings, completing five consecutive years of sex ratio information (2017-2021).

2.2. Maturity assessment. 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 on these key reproductive parameters provides direct input to stock assessment. For example, information on

fecundity-at-age and fecundity–at-size could be used to replace spawning biomass with egg output as the metric of reproductive capability in SA and management reference points. This information highlights the need for a better understanding of factors influencing reproductive biology and 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 and fecundity 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) update of maturity schedules based on histological-based data; and, 3) fecundity determinations.

2.2.1. Histological assessment of the temporal progression of female developmental stages and reproductive phases throughout an entire reproductive cycle. The IPHC Secretariat has completed the first detailed examination of temporal changes in female ovarian developmental stages, reproductive phases, and biological indicators of Pacific halibut reproductive development. The results obtained by ovarian histological examination indicate that female Pacific halibut follow an annual reproductive cycle involving a clear progression of female developmental stages towards spawning within a single year. These results provide foundational information for future studies aimed at updating maturity ogives by histological assessment and at investigating fecundity in Pacific halibut. Furthermore, the potential use of easily-obtained biological indicators in predictive models to assign reproductive phase in Pacific halibut was demonstrated. The results of this study have been published in the journals *Journal of Fish Biology* (https://doi.org/10.1111/jfb.14551) and *Frontiers in Marine Science (*https://doi.org/10.3389/fmars.2022.801759).

2.2.2. Update of maturity schedules based on histological-based data. The IPHC Secretariat is undertaking studies to revise maturity schedules in all four Biological Regions through histological (i.e. microscopic) characterization of maturity. The maturity schedule that is currently used in SA was based on past visual (i.e. macroscopic) maturity classifications in the field (FISS). In order to be able to accomplish this objective, the IPHC Secretariat has collected ovarian samples for histology in the 2022 FISS by targeting Biological Regions 2, 3, 4 and 4B. Ovarian samples are currently being processed for histology and are expected to be available for examination by early 2023. Subsequently, histological maturity classifications will be conducted by IPHC Secretariat staff to generate biological region-specific maturity ogives. A comparison between macroscopic and histological maturity classification criteria will be established.

2.2.3. Fecundity estimations. Different methods for fecundity determinations were investigated and, based on the current literature and recommendations from experts in the field, the auto-diametric method was selected as the method of choice (Witthames et al., 2009). The IPHC Secretariat is currently designing plans for ovarian sample collection for fecundity estimations during the 2023 FISS.

3. Growth.

   Research activities conducted in this Research Area 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 (SA) 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 I). The relevance of these research outcomes for the management and strategy evaluation (MSE) process is in the improvement of the simulation of variability and to allow for scenarios investigating climate change (Appendix II).

   The IPHC Secretariat has conducted studies aimed at elucidating the drivers of somatic growth leading to historical changes 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. Results from these studies are currently being analyzed and a draft manuscript intended for peer-reviewed publication is being prepared.

4. Mortality 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 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 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 at 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 I). The relevance of these research outcomes for the management and strategy evaluation (MSE) process is in fishery parametrization (Appendix II).

   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. The results of the study reporting discard mortality rate estimations in the directed longline fishery have been published in the journal *North American Journal of Fisheries Management* (https://doi.org/10.1002/nafm.10711). The results of the second component of this study, namely the relationships among hook release techniques, injury levels, stress levels and physiological condition of released fish, are presently being written for publication in a peer-reviewed journal.

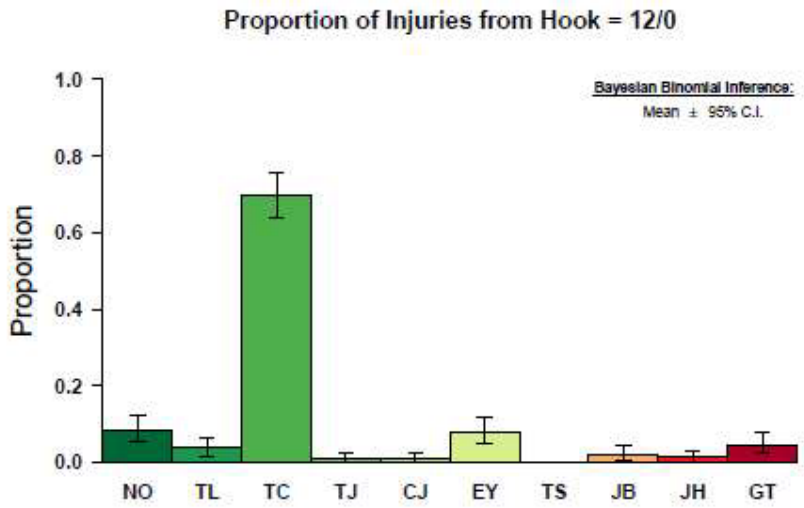
4.2. Estimation of discard mortality rates in the charter recreational sector. The IPHC Secretariat is conducting a research project to better characterize the nature of charter recreational fishery with the ultimate goal of better understanding discard practices in this fishery relative to that which is employed in the directed longline fishery. This project has received funding from the National Fish and Wildlife Foundation and the North Pacific Research Board (Appendix III). 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.

The fishing vessels were required to fish 6 rods at a time, three (3) rigged with 12/0 circle hooks and three (3) rigged with 16/0 circle hooks in order to establish a comparison of the two most common gear types used in the Alaskan Pacific halibut recreational fishery, as informed by the survey conducted in 2019 and subsequent discussions. In IPHC Regulatory Area 2C (Sitka, AK), 243 Pacific halibut were captured, sampled and released that were on average 80.1 ± 19.0 cm in fork length (range from 52 to 149 cm) and 7.4 ± 7.5 Kg in weight (range from 1.5 to 49.75 Kg). In IPHC Regulatory Area 3A (Seward, AK), 118 Pacific halibut were captured, sampled and released that were on average 72.5 ± 14.1 cm in fork length (range from 42 to 110 cm) and 5.0 ± 3.3 Kg in weight (range from 0.55 to 17 Kg). Therefore, a total of 361 Pacific halibut were captured, sampled and released in the two research charters conducted

The proportion of the different types of injuries incurred over the hooking and release process were determined for Pacific halibut captured with 12/0 hooks and 16/0 hooks. For Pacific halibut captured with 12/0 hooks, approximately 70% of the fish had injuries corresponding to torn cheek, a type of minor injury that is incurred by the hook penetrating the cheek musculature through a single location during the capture event (Figure 2A). All other injuries were in much smaller proportion. Very similar distribution of injuries were observed in Pacific halibut captured with 16/0 hooks, again with a predominance of torn cheek injuries (Figure 2B). Overall, the predominant injury profile of Pacific halibut captured with either type of hook and subsequently released corresponded to relatively minor injuries. In accordance with this observation, release viabilities of captured Pacific halibut corresponded mostly to the excellent viability category (350/361 fish), followed by reduced numbers of fish in the moderate and poor viability categories (9/361 and 2/361 fish, respectively) and no fish in the dead viability category (0/361).

To date, of the 281 fish that were tagged with opercular wire tags (243 fish in IPHC Regulatory Area 2C and 38 in IPHC Regulatory Area 3A) 28 tags have been recovered: 19 from IPHC Regulatory Area 2C and 9 from IPHC Regulatory Area 3A.

A)



B)

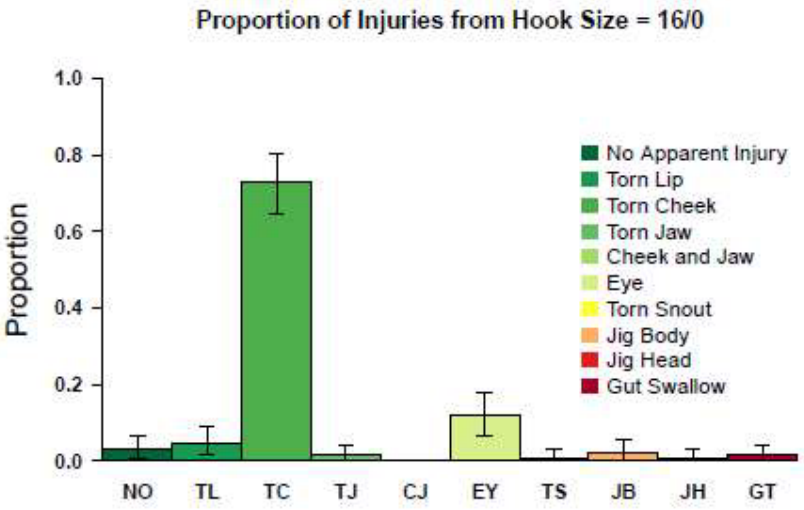


Figure 2. Proportion of the different types of injuries in fish captured with 12/0 hooks (top) and 16/0 hooks (bottom). The legend of injury types corresponds to the abbreviations in the horizontal axis.

In order to directly assess the survival of discarded Pacific halibut from the recreational fishery, 80 fish in the excellent viability category were tagged with satellite-transmitting electronic archival tags equipped with accelerometers (sPAT tags). To date, 76 out of the 80 released sPAT tags provided data reports. Of the 4 sPAT tags that did not provide data, 2 sPAT tags never reported and 2 tags did not have sufficient data for successful interpretation. Therefore, 95% of the sPAT tags deployed provided survival information, a similar data transmission success as compared to our recently published report on the use of sPATs to evaluate survival of Pacific halibut discarded from the longline

fishery (please see paper in the journal *North American Journal of Fisheries Management*: https://doi.org/10.1002/nafm.10711). Of the 76 useable sPAT tags, 48 tags were at liberty for the full duration of the pre-programmed 96-day period, whereas 21 sPAT tags reported prematurely for unknown reasons, with an average time of at liberty reporting of 37.1 days (range of 3.6-76.8 days). The remaining 7 sPAT tags were physically recovered by fishery captures, with an average time at liberty of 58 days (range of 37.1-69.1 days). Of the physically recovered tags, one was recovered 2 Km from its release location, another one 16 Km from its release location and the remaining 5 tags were recovered less than 0.5 Km from their release location.

Final analysis of the accelerometer data from all 76 tags that successfully reported data, following the survival criteria previously reported (https://doi.org/10.1002/nafm.10711), indicates that only one discarded fish in the excellent viability category was confidently estimated to have died (its tag reported 8.3 days after deployment). Therefore, our experimentally-derived estimates of discard mortality from the guided recreational fishery point towards a 1.35% (95% CI 0.00-3.95%) discard mortality rate for Pacific halibut released in excellent viability category captured and released from circle hooks. This estimate is consistent with the supposition that fish discarded in the recreational fishery from circle hooks in excellent condition have a mortality rate that is arguably lower than 3.5%, as is currently used for excellent viability fish released in the commercial fishery (Meyer, 2007). As this estimate does not factor in mortality rates on fish in less than excellent condition, does not inform mortality rates on non-circle hooks (J-hooks, jigs, other), nor directly applies to fish captured and released from non charter practices, changes to the overall recreational discard mortality estimation are not currently contemplated. The deduced discard mortality rate estimated in the present study is lower than the minimum 4.2% discard mortality rate recently estimated for Pacific halibut discarded in excellent viability category from the longline fishery (https://doi.org/10.1002/nafm.10711). The difference in estimated survival between Pacific halibut captured and discarded from the two types of fisheries is consistent with the lower capture (hooking) and release time, under best practice handling conditions, of Pacific halibut captured by the recreational fishery. These results represent the first report of experimentally-derived estimates of mortality of Pacific halibut captured and discarded in the recreational fishery.

5. Fishing technology.

The IPHC Secretariat has determined that research to provide the Pacific halibut fishery with tools to reduce Pacific halibut mortality by whale depredation is considered a high priority. This research is now contemplated as one of the research areas of high priority within the 5-year Program of Integrated Research and Monitoring (2022-2026). Towards this goal, the IPHC secretariat has recently obtained funding from NOAA's Bycatch Research and Engineering Program (BREP) to investigate gear-based approaches to catch protection as a means for minimizing whale depredation in the Pacific halibut and other longline fisheries (NOAA Award NA21NMF4720534; Appendix III). The objectives of this study are to: 1) work with fishermen and gear manufacturers, via direct communication and through an international workshop, to identify effective methods for protecting hook-captured flatfish from

depredation; and 2) develop and pilot test 2-3 simple, low-cost catch-protection designs that can be deployed effectively using current longline fishing techniques and on vessels currently operating in the Northeast Pacific Ocean.

The first phase of this project consisted in recruiting participants for a catch protection workshop from the scientific community and from the harvesters active in the waters of Alaska, British Columbia and the U.S. west coast. Initial screening of research conducted around the world led to invitations to three different groups actively working on development of catch protection devices (Sago Solutions, Norway; National Institute for Sustainable Development (IRD) – Marine Biodiversity, Exploitation, and Conservation Unit (MARBEC), University of Montpellier – CNRS-INFREMER-IRD National Centre for Scientific Research, Centre d'Etudes Biologiques de Chisé, France; and Fish Tech Inc., United States). In parallel, harvesters active in the Pacific halibut and Greenland Turbot fisheries as well as scientists involved in marine mammal research were actively recruited for participation. The "1st International Workshop on Protecting Fishery Catches from Whale Depredation (WS001)" was held electronically on 9 February 2022. The Workshop brought together 74 participants from 6 countries, ranging from research scientists to active harvesters. A report summarizing the material presented and discussions was produced and posted in the IPHC's website along with video recordings of the entire workshop: https://www.iphc.int/venues/details/1st-international-workshop-on-protecting-fishery-catches-from-whale-depredation-ws001.

Current efforts are devoted to the development of designs for two devices (i.e. shuttle and shroud) for field testing in the Spring of 2023.

RECOMMENDATION/S

That the Commission:

1) **NOTE** paper IPHC-2023-AM099-12 which provides a report on current and planned biological and ecosystem science research activities contemplated in the IPHC's Five-Year Program of Integrated Research and Monitoring (2022-2026).

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APPENDIX I

List of ranked biological uncertainties and parameters for stock assessment (SA) and their links to potential research areas and research activities

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 II

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

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 III

Summary of active research grants during the reporting period

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 No. 61484)	IPHC	Alaska Pacific University, U of A Fairbanks, charter industry	$98,902	Bycatch estimates	April 2019 – November 2021
2	**North Pacific Research Board**	Pacific halibut discard mortality rates (NPRB No. 2009)	IPHC	Alaska Pacific University,	$210,502	Bycatch estimates	January 2021 – March 2022
3	**Bycatch Reduction Engineering Program - NOAA**	Gear-based approaches to catch protection as a means for minimizing whale depredation in longline fisheries (NA21NMF4720534)	IPHC	Deep Sea Fishermen's Union, Alaska Fisheries Science Center-NOAA, industry representatives	$99,700	Mortality estimations due to whale depredation	November 2021 – October 2023
4	**North Pacific Research Board**	Pacific halibut population genomics (NPRB No. 2110)	IPHC	Alaska Fisheries Science Center-NOAA	$193,685	Stock structure	December 2021- January 2024
Total awarded ($)					**$602,789**		