Report on Current and Future Biological and Ecosystem Science Research Activities

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PURPOSE

To provide the Commission with a description of progress towards research activities described in the IPHC's five-year Program of Integrated Research and Monitoring (2022-2026).

BACKGROUND

The primary biological and ecological research activities at the 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 integrated with stock assessment (SA) and the management strategy evaluation (MSE) processes (Appendix I) and are summarized in five main areas, 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 II) and the MSE process (Appendix III) 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 focusing on 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 the 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 the SA (Appendix II). 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 III).

1.1. Population genomics. Understanding population structure is imperative for sound management and conservation of natural resources. Pacific halibut in US and Canadian waters are managed as a single, panmictic population on the basis of tagging studies and historical (pre-2010) analyses of genetic population structure that failed to demonstrate significant differentiation in the eastern Pacific Ocean. While genetic techniques previously employed in fisheries management have generally used a small number of markers (i.e. microsatellites, ~10-100), whole-genome scale approaches can now be conducted with lower cost and are able to provide orders of magnitude more data (millions of markers) that allow investigating genetic variation in fish populations at an unprecedented resolution.

The main purpose of the present study is to conduct an analysis of Pacific halibut population structure in IPHC Convention waters using state-of-the-art low-coverage whole genome resequencing (lcWGR) methods that leverage the reference genome for Pacific halibut generated by the IPHC Secretariat (Jasonowicz et al., 2022). We have recently conducted additional sequencing of genetic samples in order to balance the sample sizes for the sample collections that comprise our genetic baseline (i.e. samples collected in the winter during the spawning season) (Figure 1) and to increase the total number of samples available for analysis. With the additional 161 samples sequenced, our baseline dataset is now finalized and it consists of 731 separate individuals (Figure 1, Table 1).

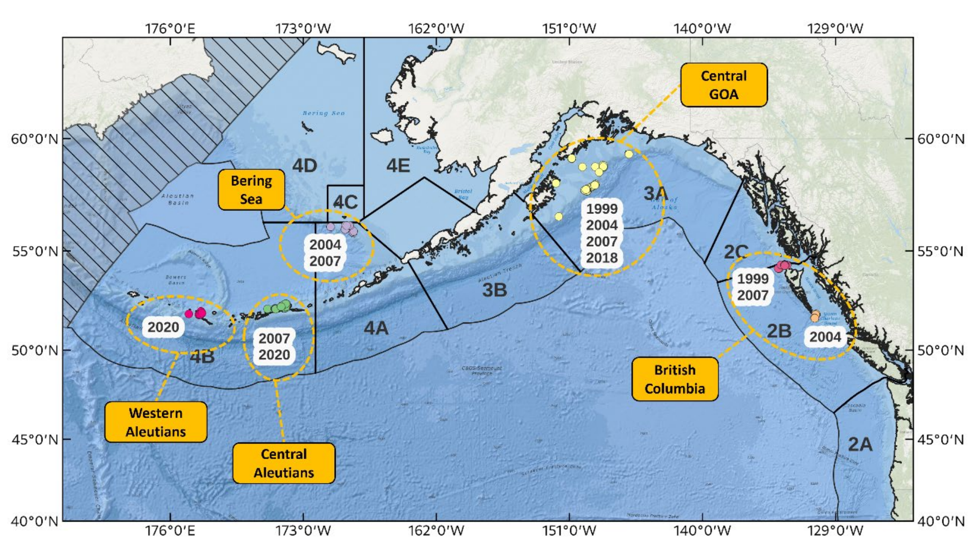


Figure 1. Map of sample collections made during the spawning season used for genomic analysis of population structure in Pacific halibut in the northeast Pacific Ocean.

Winter Collections (baseline samples)					
	1999	2004	2007	2018	2020
British Columbia (winter)	59	63	61		
GOA (winter)	61	61	61	60	
Bering Sea (winter)		61	61		
Central AI (winter)			61		61
Western AI (winter)					61

Table 1. Final sample sizes for each area in the baseline dataset by year of sample collection after a minimum sequencing depth threshold of 1x is applied.

We have identified 8,460,466 Single Nucleotide Polymorphisms (SNPs) in fully assembled autosomal regions of the Pacific halibut genome. Following the removal of 751,285 SNPs in regions of the genome identified as problematic for read mapping and SNPs with a global minor allele frequency (MAF) < 0.05, we retained 3,676,428 SNPs for further analysis. We conducted principal component analysis (PCA) and, after removing 22 outlier samples in the baseline dataset, the results evidenced a single cluster of samples with a large degree of overlap among the geographic areas (Figure 2).

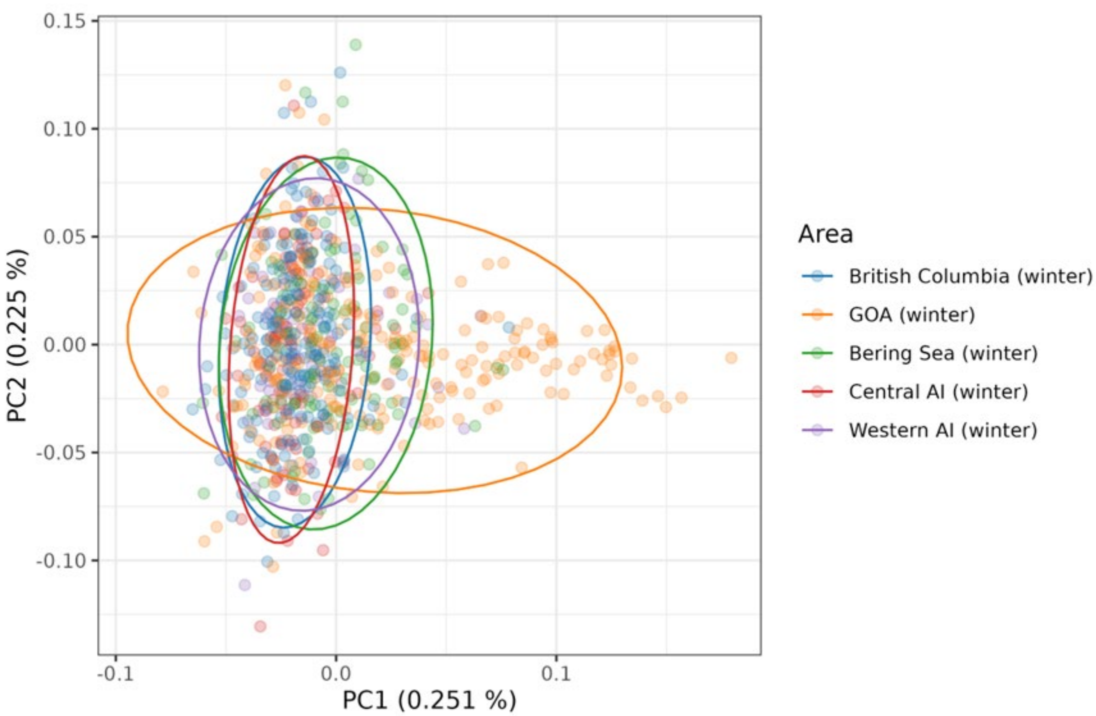


Figure 1. PCA biplot of the first two PC axes for 709 Pacific halibut collected during the spawning season (winter) in IPHC Convention Waters. Individuals are colored by geographic area in all panels with 95% confidence ellipses drawn for each geographic area.

We also conducted assignment testing using the same procedure as previously detailed. With the increased sample sizes afforded by the additional baseline samples, we were able to potentially increase the accuracy of the population specific allele frequency estimates required for conducting individual assignment tests. Nevertheless, our results showed reduced overall assignment accuracy of < 33% when using 5,000 SPNs for the assignment tests.

The concept of stock and the ability to define management units is central to sound management of marine fishes (Begg et al. 1999; Cadrin 2020). Advances in genomic technology have led to the development of useful and powerful tools that can aid in the delineation of management units (Bernatchez et al. 2017). Despite using very high-resolution genomic methods to characterize genomic variation in spawning groups of Pacific halibut collected over large spatial and temporal scales, the results presented here are consistent with genetic panmixia. From a management perspective, these results support IPHC's current stock assessment practices that model the Pacific halibut stock as a single coastwide unit [(Stewart and Hicks 2024](#)) (Figure 3). A paper describing these results is currently being written for publication in a leading peer-reviewed journal.

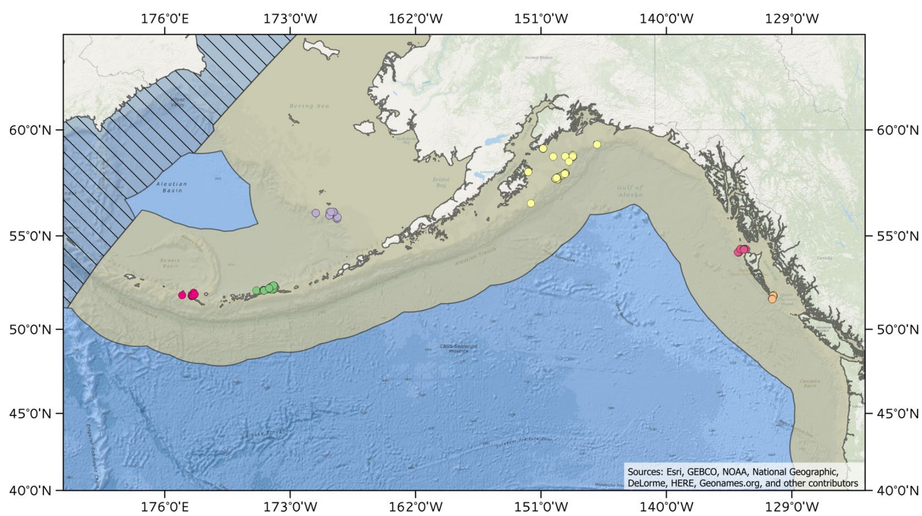


Figure 3. IPHC Convention Waters contain a single genetic group of Pacific halibut. Circles indicate the location of the winter-collected samples from known spawning areas used for the population genomic studies. Samples are colored by geographic area.

1.2. <u>Development of a genomics-based method for estimating age of Pacific halibut</u>. The IPHC Secretariat aims to develop a genetic method for aging Pacific halibut using fin tissue, a sample that can be easily collected from either live or dead individuals. This method is based on the identification of DNA methylation patterns in fin tissue that are associated with age through the development of an age estimation model (i.e., an epigenetic clock) for Pacific halibut. The first epigenetic clock was developed for humans in 2013 (Horvath, 2013), and it predicted age with great accuracy (r = 0.96) and with a mean aging error (MAE) of 3.6 years. Subsequently, epigenetic clocks have been developed for several fish species that demonstrated improved accuracy (*r* between 0.84 and 0.99) and lower average MAE (0.87 years, or 3.5% of the total lifespan of the species examined) (reviewed in Piferrer and Anastasiadi, 2023).

Patterns of DNA methylation (i.e. a natural process of regulation of gene expression that consists in the covalent modification of the nucleobase cytosine in the genomic DNA sequence) in Pacific halibut will be investigated by performing genome-wide DNA methylation at single base-pair resolution using reduced representation bisulfite sequencing (RRBS) by leveraging the high-quality genome assembly available for Pacific halibut (Jasonowicz et al. 2022). RRBS is an efficient and cost-efficient method to identify methylation patterns (i.e., CpG sites) in DNA because it targets bisulfite sequencing to a well-defined set of genomic regions with high CpG density that can be sequenced at high read depth. Age-associated DNA methylation patterns will be modelled to generate an epigenetic age predictor (i.e. epigenetic clock) for Pacific halibut constructed using elastic net penalized regression models that select a group of CpG sites that have a monotonically increasing relationship with age in the selected training data set. By implementing these linear models that select and weight age-correlated CpG sites, chronological age of Pacific halibut will be estimated based on the percentage methylation at these key CpG sites in fin tissue samples.

Fin clips from 250 individuals collected in the FISS seasons from 2021 to 2024 were selected for the generation of an epigenetic clock for Pacific halibut. These genetic samples correspond to fish with known ages (i.e. read twice by the traditional break and bake aging method) between 6 to 30 years and include 10 individual samples (5 males and 5 females) per year of age. All 250 genetic samples have been processed and submitted for sequencing and, once available, the sequencing data will be analyzed using a bioinformatic platform specifically developed in house for this project.

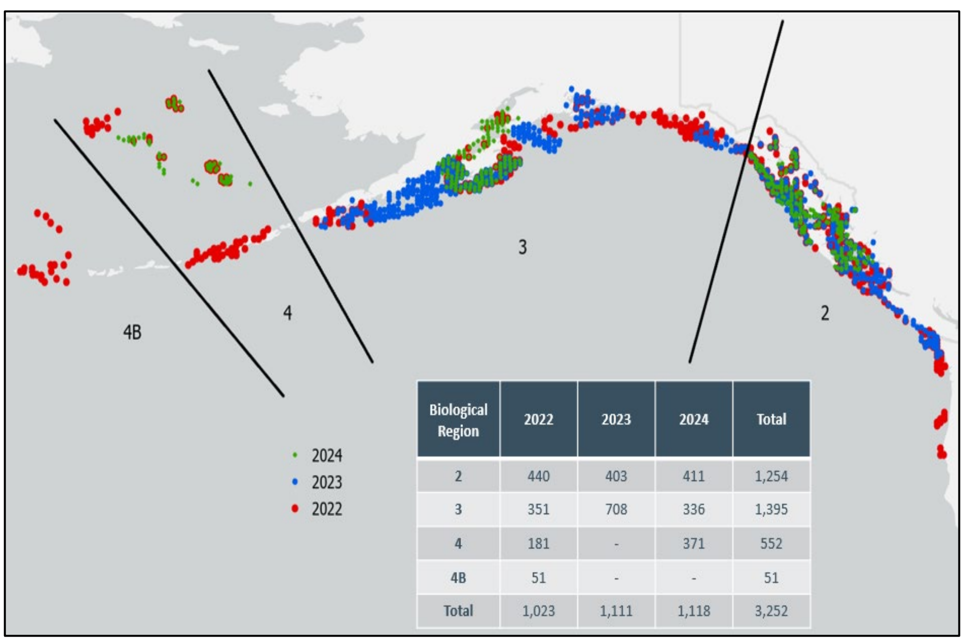
2. Reproduction.

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 the 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 some of the most important biological inputs for the SA. The relevance of these research outcomes for the MSE 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. The IPHC Secretariat has completed the processing of genetic samples from the 2024 aged commercial landings.

2.2. Reproductive assessment. Recent sensitivity analyses have shown the importance of changes in spawning output due to changes in maturity schedules and/or skip spawning and fecundity for the SA (Stewart and Hicks, 2018). Information on these key reproductive parameters provides direct input to the SA. For example, information on fecundity-at-age and -size could be used to replace spawning biomass with egg output as the metric of reproductive capability in the SA and management reference points. This information highlights the need for a better understanding of factors influencing reproductive biology and success of Pacific halibut. To fill existing knowledge gaps related to the reproductive biology of female Pacific halibut, research efforts are devoted to characterizing female reproduction in this species. Specific objectives of current studies are: 1) to update maturity schedules based on histological-based data; 2) to calibrate historical visual maturity schedules using histological-based data; and 3) to conduct fecundity estimations.

2.2.1. <u>Update of maturity schedules based on histological-based data</u>. The IPHC Secretariat is undertaking studies to revise maturity schedules in all four IPHC Biological Regions through histological (i.e. microscopic) characterization of maturity, as reported previously. The coastwide maturity schedule (i.e. the proportion of mature females by age) that was previously used in the SA was based on visual (i.e. macroscopic) maturity classification in the field (Fishery-independent Setline Survey (FISS)). To revise previously used maturity schedules, the IPHC Secretariat has collected ovarian samples for histology during the 2022, 2023 and 2024 FISS seasons. The 2022 FISS sampling resulted in a total of 1,023 ovarian samples collected. Due to a reduced FISS design in 2023, sampling only occurred in Biological Regions 2 and 3 and resulted in a total of 1,111 ovarian samples collected. In 2024, 411, 336 and 371 ovarian samples were collected in Biological Regions 2, 3 and 4, respectively. In total, 3,252 ovarian samples have been collected for histology coastwide between 2022 and 2024 (Figure 4).



Biological Region	2022	2023	2024	Total
2	440	403	411	1,254
3	351	708	336	1,395
4	181	-	371	552
4B	51	-	-	51
Total	1,023	1,111	1,118	3,252

Figure 4. Coastwide map of 2022, 2023 and 2024 maturity samples for histology collected on FISS. Red dots (2022), blue dots (2023) and green dots (2024) indicate a distinct FISS station in which a sample was collected.

The IPHC Secretariat continued to collect ovarian samples for maturity in the 2025 FISS. 2025 FISS sampling resulted in the successful collection of 1,276 ovarian samples from all four Biological Regions: 275 samples in Biological Region 2, 380 samples in Biological Region 3, 355 samples in Biological Region 4, and 266 samples in Biological Region 4B. These samples will allow us to further investigate both spatial and temporal differences in histological-based female Pacific halibut maturity.

Ovarian samples from 2022 to 2024 were processed for histology and scored for maturity using histological maturity classifications previously developed and used by the IPHC Secretariat (Fish et al. 2020, 2022). Following these, all sampled Pacific halibut females were assigned to either the mature or immature categories. Maturity ogives (i.e., the relationships between the probability of maturity determined by histological assessments and variables including IPHC Biological Region, age, and year) were estimated by fitting generalized additive models (GAM) with logit link (i.e., logistic regression). We first ran the best-fit logistic GAM model using log(Age) and Biological Region for the 2022 to 2024 samples to compare spatial trends among Biological Regions (Figure 5).

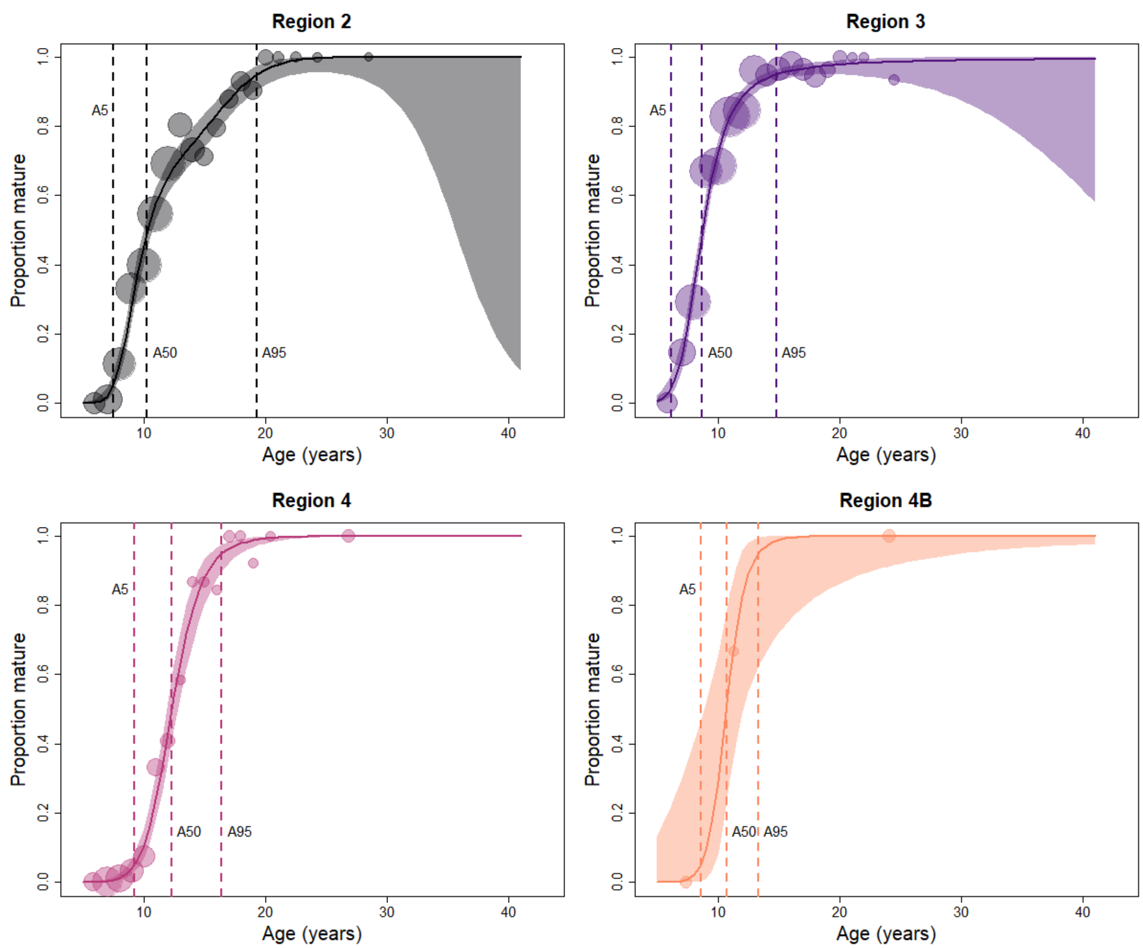


Figure 5. Female Pacific halibut age at maturity by IPHC Biological Region using best-fit logistic GAM. Vertical dashed lines represent the A_5, A_{50} and A_{95} values.

Biological Region 2 is estimated to have an A_{50} value (age at 50% mature) of 10.3 years, with a dip in the curve from ages 11 to 20. This dip gives Biological Region 2 the oldest A_{95} value (age at 95% mature) among all Biological Regions at 19.3 years. Biological Region 3 is estimated to have the youngest maturing females among Biological Regions with an A_{50} of 8.7 years. Biological Region 4 shows older maturing females with an estimated A_{50} of 12.3 years. Biological Region 4B has the steepest maturity curve (A_5= 8.6, A_{95}= 13.3), indicating a rapid progression in maturity between the ages of 9 and 13.

To examine temporal changes in maturity across all Biological Regions, we ran the best-fit logistic GAM with Biological Region and year as factors, and plotted the three years of histological data by Biological Region (Figure 6). Overall, there appeared to be a shift to the left in maturity ogives from 2022 to 2024 in the three Biological Regions (2, 3, and 4) with multiple years of data, indicating younger maturing females in 2024 than in 2022 and 2023. This could potentially be indicative of a particular year class maturing through the population; however, this is difficult to discern with only three years of data. Therefore, it will be important to continue to monitor temporal trends in histological-based maturity ogives.

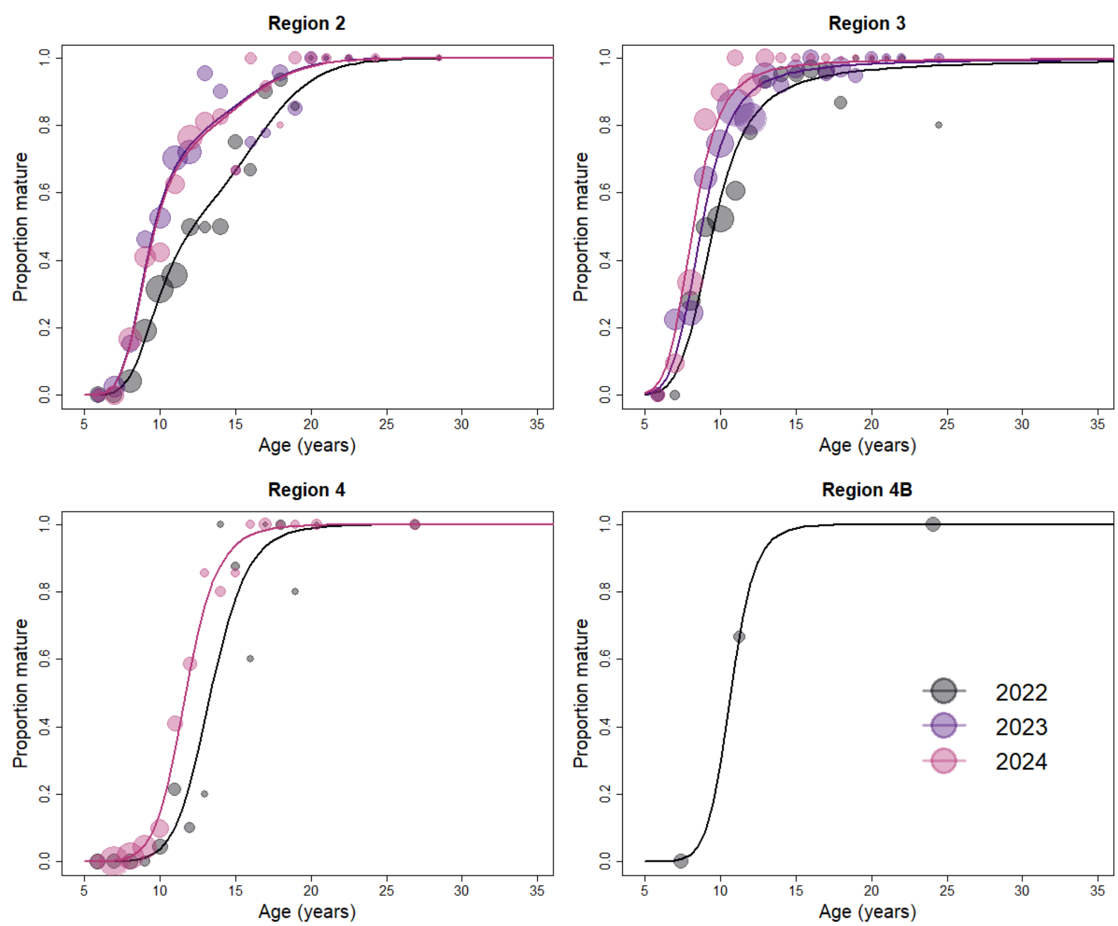


Figure 6. Female Pacific halibut age at maturity by IPHC Biological Region and year using best-fit logistic GAM.

To estimate a coastwide ogive with the 2022-2024 histology-based maturity data, we removed the year effect from the logistic GAM model and pooled all years by Biological Region. The logistic GAM estimated maturity curves for each IPHC Biological Region. Noting that sample size was not proportional to population size for each region, we used the average estimated regional abundance proportions from 2022-2024 from IPHC's space-time modeling of FISS numbers per unit effort (NPUE) data as weights in estimating a coastwide maturity ogive (Figure 7). Histology-based age at 50% maturity (A_{50}) was at 9.8 years, lower than the previously used maturity estimates from visual (field) data (A_{50} = 11.6 years).

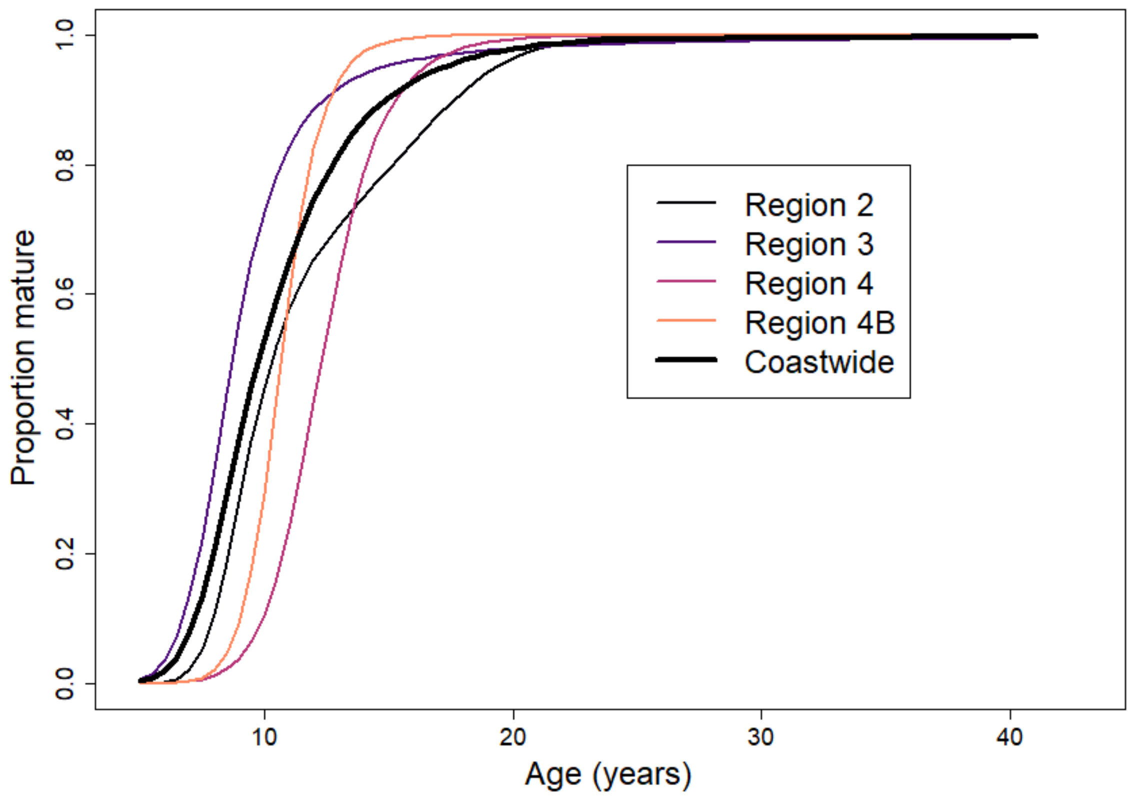


Figure 7. Coastwide maturity ogive generated from 2022-2024 average estimated regional abundance proportions (thick black line) and individual Biological Region ogives (color lines).

2.2.2 Calibration of historical visual maturity schedules using histology-based data. After creating a new coastwide maturity ogive using histology-based maturity estimates from 2022 to 2024 (Figures 7 and 8, black lines), we created a new coastwide visual maturity ogive based on visual (field) maturity estimates from the same females (Figure 8, blue line), yielding an A_{50} value of 10.3 years. When comparing this new coastwide visual ogive to the previous SA ogive (Figure 8, red line), a higher proportion of mature females is observed between the ages of 8 to 13 years.

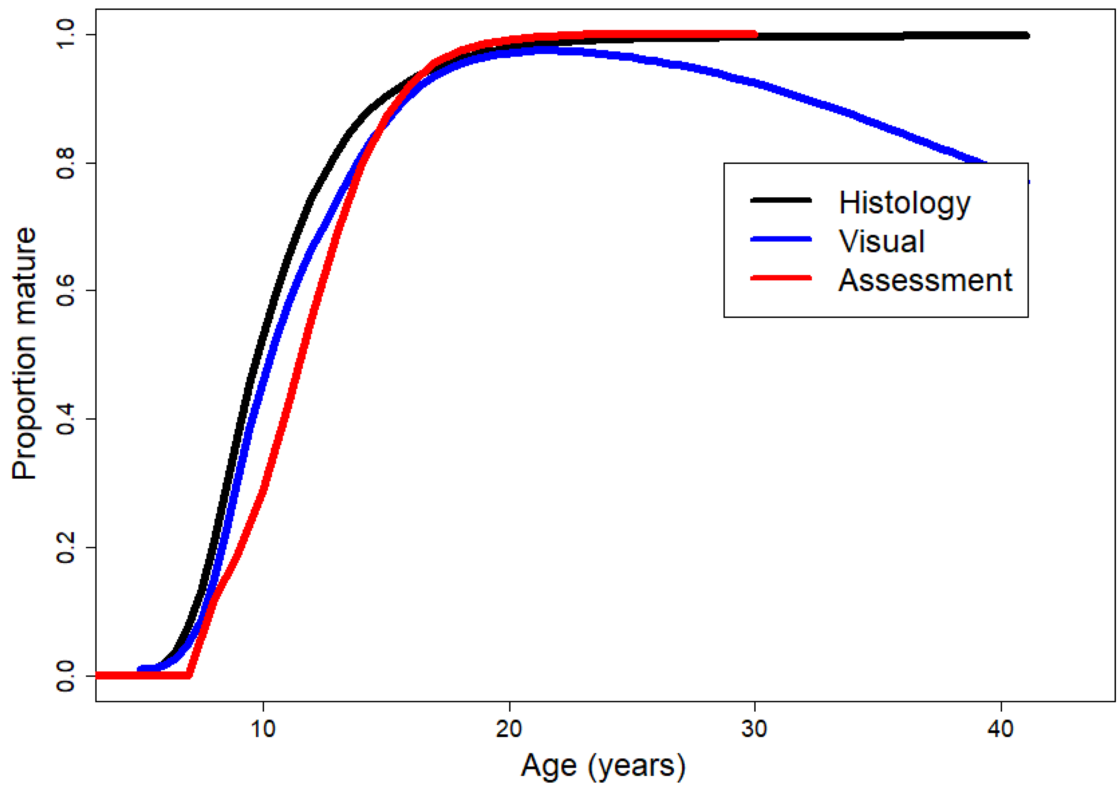


Figure 8. Coastwide maturity ogive generated from 2022-2024 average estimated regional abundance proportions using histological (black) and visual (blue) maturity estimation methods. The previous coastwide ogive (red) used in SA is shown for reference.

The IPHC Secretariat has been collecting visual maturity data during the FISS since 2002 with ages determined using the current break-and-burn method. To create a maturity time series consistent with the more accurate histological assessments, we first developed a calibration between histological and visual maturity curves from the 2022-2024 data. Just as maturity curves are estimated for each Biological Region, we estimated separate calibration factors for each region. The coastwide calibrated visual maturity ogives for each year of the 2002-2024 time series are shown in Figure 9. These results evidence two temporal shifts, one characterized by the maturity curves shifting to the right (i.e. females maturing at a later age) from approximately 2005 to 2015, and the second characterized by the maturity curves shifting to the left (i.e. females maturing at an earlier age) from approximately 2016 until 2024. Studies are planned to identify possible drivers of these temporal shifts in age-at-maturity in female Pacific halibut.

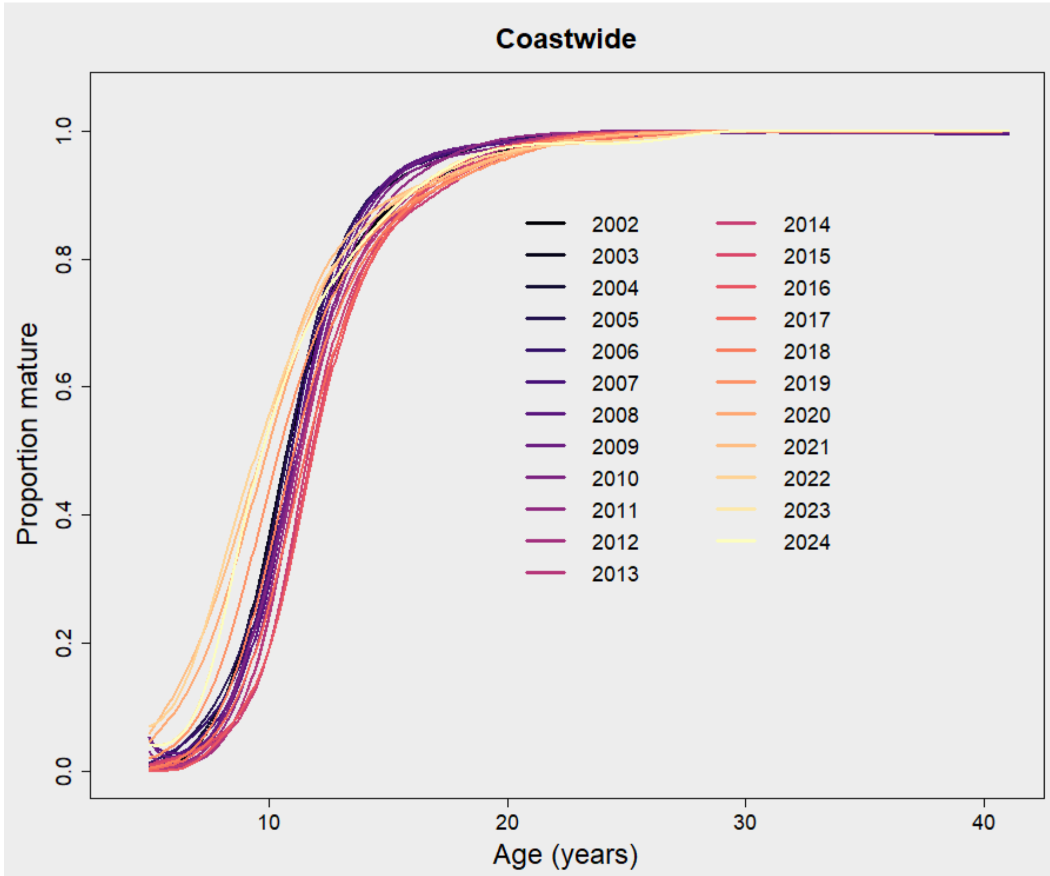


Figure 9. Estimated calibrated maturity ogives as a function of age.

A mean coastwide calibrated visual maturity ogive for the 2002-2024 time series was generated by averaging across all three-year rolling data windows (i.e. 2002-2004, 2003-2005, 2004-2006, etc.) (Figure 10, overlapping green and black lines). This new coastwide calibrated visual ogive has an A_{50} value of 11.0 years, that is, 0.6 years lower than that of the visual maturity ogive previously used in SA (A_{50} = 11.6 years, as derived exclusively from two years of maturity data from IPHC Regulatory Areas 2B and 3A; Figure 10, red line). These results, although not directly comparable because of differences in the length of the data series and in the geographic coverage, suggest that the new coastwide calibrated maturity ogive estimates a higher proportion of younger maturing females ages 8-15 years as well as a lower proportion of older maturing females ages 15-20 years when compared to the previously used maturity ogive. These shifts in the maturity curves are to be expected as the histology-based data provide a better indicator of younger maturing females, but also of older immature females. The new coastwide maturity ogive using calibrated visual maturity estimates from the 2002 to 2024 FISS has been incorporated into the 2025 Pacific halibut SA. Please refer to document IPHC-2025-SRB026-07 for the complete bridging analysis.

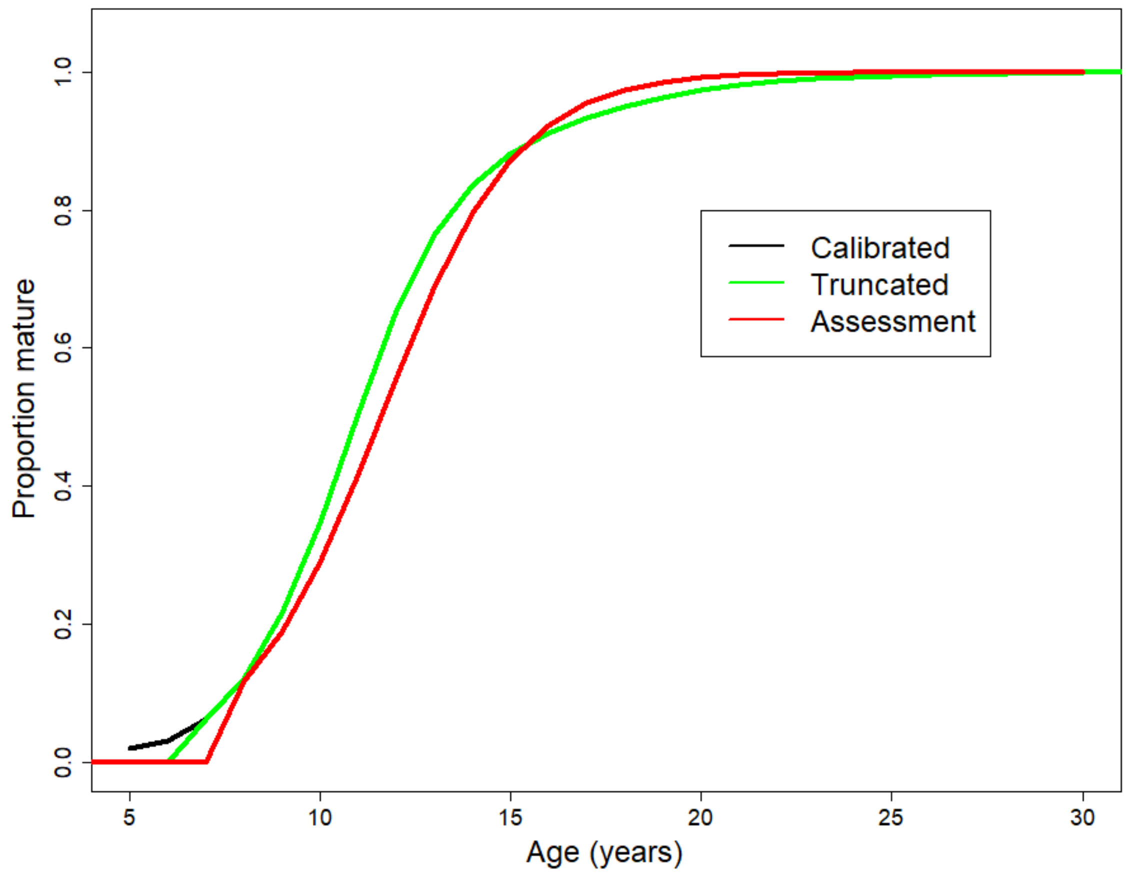


Figure 10. Estimated mean calibrated visual maturity ogive (black) with same ogive overlayed but truncated to zero at age 7 (green) because no females under this age have been found to be mature. The previous coastwide ogive (red) used in stock assessments prior to 2025 is shown for reference.

2.2.3. Fecundity estimations. The IPHC Secretariat has initiated studies that are aimed at improving our understanding of Pacific halibut fecundity. This will allow us to estimate fecundity-at-size and -age and could be used to replace spawning biomass with egg output as the metric for reproductive capability in stock assessment and management reference points. Fecundity determinations will be conducted using the auto-diametric method (Thorsen and Kjesbu 2001; Witthames et al., 2009) and IPHC Secretariat staff received training on this method by experts in the field (NOAA Fisheries, Northeast Fisheries Science Center, Wood Hole, MA) in May 2023. Ovarian samples for the development and application of the auto-diametric method to estimate fecundity in female Pacific halibut have been collected during the FISS in 2023, 2024 and 2025, as well as two special collections in IPHC Regulatory Area 2B in 2024 and 2025 (Figure 11). In 2023, sampling was conducted only in Biological Region 3, with a total of 452 fecundity samples collected. In 2024, sampling was conducted in Biological Regions 2 and 4, with 149 and 359 fecundity samples collected, respectively. In the Fall of 2024, 271 additional fecundity samples targeting large females (85-200+ cm in fork length) were collected in Biological Region 2. For 2025, in addition to 878 samples collected in all four Biological Regions in the FISS, 242 fecundity samples were collected in Biological Region 2 in a special project targeting large females during the late Summer/early Fall. This comprehensive collection of ovarian samples will be used initially for the development of the auto-diametric method, followed by actual fecundity estimations by age and by size (length and weight).

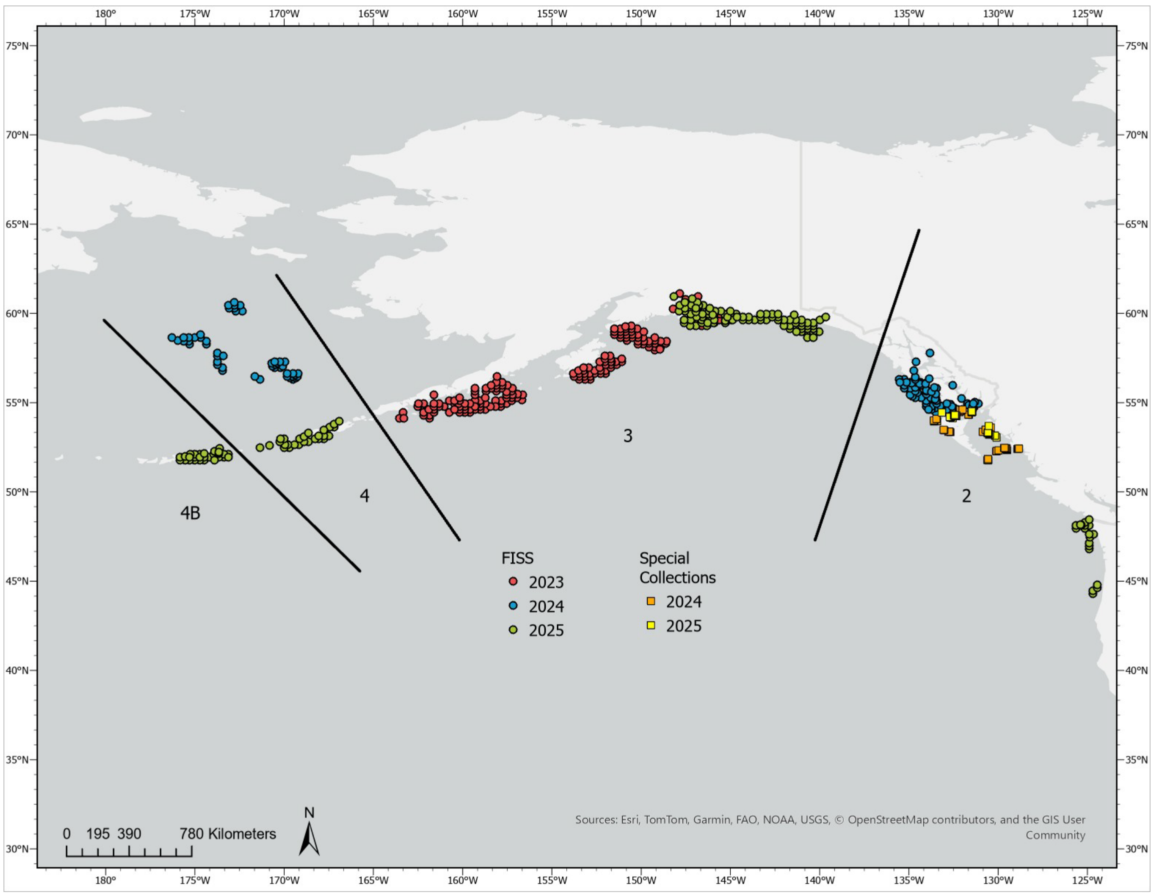


Figure 11. Coastwide map of 2023, 2024 and 2025 samples for fecundity collected on FISS (circle colors), and 2024 and 2025 special collection fecundity samples in IPHC Regulatory Area 2B (square colors).

3. <u>Growth</u>.

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 the 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 II). The relevance of these research outcomes for the MSE 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. By conducting integrated transcriptomic, proteomic and stable isotope analyses, we have demonstrated that temperature promotes growth plasticity in juvenile Pacific halibut, and identified growth biomarkers that could help characterize somatic growth variation in the Pacific halibut population. The results of these studies have been recently published in a leading peer-reviewed journal (Planas et al., 2025).

Future studies designed to better understand the relative role of potential factors underlying changes in size-at-age are being planned within the framework of the revised IPHC Integrated Research and Monitoring Plan (IPHC 2026).

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 SA. Bycatch and wastage of Pacific halibut, as defined, respectively, 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), 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 the SA resides in their ability to improve trends in unobserved mortality to improve estimates of stock productivity and represent the most important inputs in fishery yield for the SA (Appendix II). The relevance of these research outcomes for the MSE process is in fishery parametrization (Appendix III).

4.1. Estimation of discard mortality rates in the charter recreational sector. Results from a recently completed study investigating discard mortality rates and characteristics of fish captured and released using guided recreational fishery practices are currently being prepared for publication in a peer-reviewed journal.

Future activities with respect to this research area are being contemplated within the framework of the revised IPHC Integrated Research and Monitoring Plan (IPHC 2026).

5. Fishing technology.

The IPHC Secretariat has determined that research to provide the Pacific halibut fishery with tools to reduce whale depredation is considered a high priority (Appendix I). This research is included as one of the research areas of high priority within the 5-year Program of Integrated Research and Monitoring (2022-2026). Important management implications of these studies reside in improving estimations of mortality of Pacific halibut in the directed commercial fishery that will lead to improved estimates of stock productivity (Appendix II). Depending on the estimated magnitude of whale depredation, this may be included as another explicit source of mortality in the SA and mortality limit setting process.

The IPHC secretariat has been investigating gear-based approaches to catch protection as a means for minimizing whale depredation in the Pacific halibut and other longline fisheries with funding from NOAA's Bycatch Research and Engineering Program (BREP) (NOAA Awards NA21NMF4720534 and NA23NMF4720414; Appendix IV). The results and outcomes of the initial pilot phase of this project indicated that the underwater shuttle was a safe and effective catch protection device which entrained comparable quantities, sizes, and species of fish as the control gear. The second phase of this project took place in May 2025 in IPHC Regulatory Area 4A aboard a chartered commercial fishing vessel (Figure 12). This involved refining effective methods related to the deployment and use of the underwater shuttle, and conducting tests in the presence of orcas to demonstrate the efficacy and safety of the gear. Eighteen sets were successfully completed, generating 15 sets of shuttle and control catch comparison data along with close to 80 hours of underwater footage combined (control, shuttle exterior, shuttle interior). Depredating orcas were present at 6 of the paired sets (Figure 12B,D).

A) B) C) D)

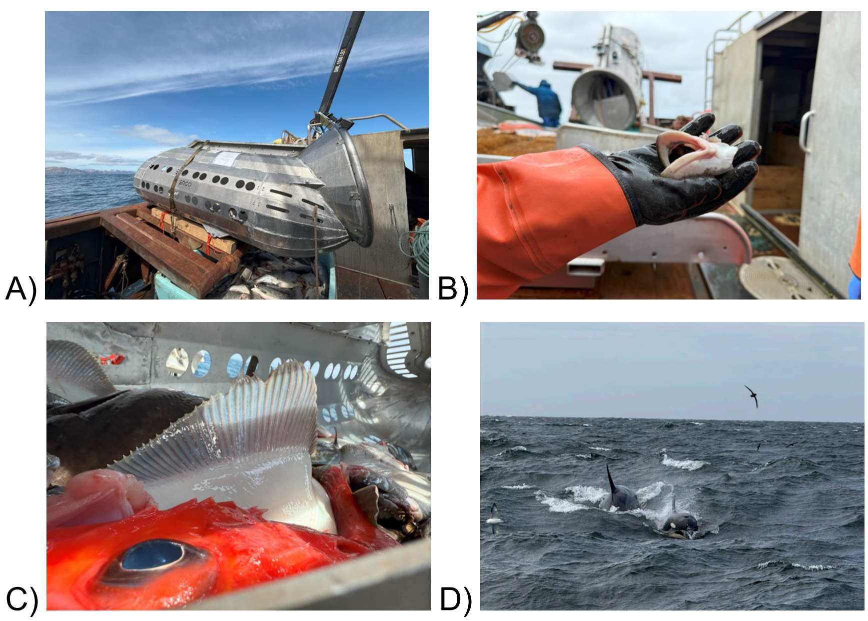


Figure 12. A) Shuttle device in transport. B) Typical evidence (lips only) of whale depredation. C) Catch entrained within the shuttle. D). Killer whales rapidly approaching the hauling site.

Preliminary comparisons of data from 10 sets with completed video review show good entrainment for Pacific halibut, but high escapement for sablefish. Catch rate comparisons between the control gear and the shuttle (deployed across two skates of gear or 200 hooks) demonstrated capacity for good entrainment by the shuttle, but with variable rates overall between sets. The IPHC Secretariat is currently reviewing the remainder of the video data and conducting the final catch data analyses.

The shuttle device was tested again during two commercial quota trips conducted from 6 October – 23 October 2025 in the same fishing vessel with an IPHC field specialist aboard. No cameras were used during this phase. While the shuttle was only deployed for a total of 4 sets over this effort due to weather challenges and lack of whales present on many fishing days, these sets will be included in the overall catch data analysis.

RECOMMENDATION/S

That the Commission:

1) **NOTE** paper IPHC-2026-AM102-14, that provides a report on current and planned biological and ecosystem science and research activities contemplated in the IPHC's Five-Year Program of Integrated Research and Monitoring (2022-2026).

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APPENDIX I

Integration of biological research, stock assessment (SA) and management strategy evaluation (MSE): rationale for biological research prioritization

Research areas	Research activities	Research outcomes	Relevance for stock assessment	Relevance for MSE	Specific analysis input	SA Rank	MSE Rank	Research priorization
Migration and population dynamics	Population structure	Population structure in 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 and recruitment distribution	2
	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		2
	Larval and juvenile connectivity 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	1. Biological parameterization and validation of movement estimates	2
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		1
	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			1
	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			1
	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			1
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	5
		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			5
		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			5
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 yield	1. Fishery parameterization	4
	Discard mortality rate estimate: recreational fishery				Will improve estimates of discard mortality, reducing potential bias in stock assessment results and management of mortality limits			4
	Best handling and release practices	Guidelines for reducing discard mortality			May reduce discard mortality, thereby increasing available yield for directed fisheries	2. Fishery yield		4
Fishing technology	Whale depredation accounting and tools for avoidance	New tools for fishery avoidance/deterence; improved estimation of depredation mortality	Improve mortality accounting	Improve estimates of stock productivity	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	1. Assessment data collection and processing		3

APPENDIX II

List of ranked biological uncertainties and parameters for stock assessment (SA) and their links to biological 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 III

List of ranked biological uncertainties and parameters for management strategy evaluation (MSE) and their links to biological 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 IV

Summary of current external research grants

Project #	Grant agency	Project name	PI	Partners	IPHC Budget ($US)	Management implications	Grant period
1	**Bycatch Reduction Engineering Program - NOAA**	Full scale testing of devices to minimize whale depredation in longline fisheries (NA23NMF4720414)	IPHC	NOAA Fisheries - Alaska Fisheries Science Center (Seattle)	$199,870	Mortality estimations due to whale depredation	November 2023 – April 2026
2	**Alaska Sea Grant**	Development of a non-lethal genetic-based method for aging Pacific halibut (R/2024-05)	IPHC, Alaska Pacific Univ. (APU)	Alaska Fisheries Science Center-NOAA (Juneau)	$60,374	Stock structure	January 2025-January 2027
Total awarded ($)					**$260,244**		