# Report on Current and Future Biological and Ecosystem Science Research Activities

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## PURPOSE

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

## 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 (*Hippoglossus stenolepis*);
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 Program of Integrated Research and Monitoring (2022-2026). 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 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.
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.

## DISCUSSION 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 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).

   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. However, more recent studies have reported significant genetic population structure suggesting that Pacific halibut residing in the Aleutian Islands may be genetically distinct from other regions. Advances in genomic technology now enable researchers to examine entire genomes at unprecedented resolution. 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 provide orders of magnitude more data (millions of markers). Using low-coverage whole genome resequencing we have the capability to examine genetic structure of Pacific halibut in IPHC Convention Waters with unprecedented resolution. By studying the genomic structure of spawning populations, genetic signatures of geographic origin can be established and, consequently, could be used to identify the geographic origin of individual Pacific halibut and, therefore, inform on the movement and distribution of Pacific halibut.

        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 methods. For this purpose, genetic samples from male and female adult Pacific halibut collected during the spawning (winter) season in five known spawning grounds have been used: Western and Central Aleutian Islands, Bering Sea, Central Gulf of Alaska and British Columbia (Figure 1). Furthermore, temporal replicates at many of these locations are available and have enabled the IPHC Secretariat to evaluate the stability of genetic structure over time, ensuring confidence in the results. As a requisite for the low-coverage whole genome resequencing approach used, the IPHC Secretariat first produced a high-quality reference genome ([Jasonowicz et al., 2022](#)) that has been used to generate genomic sequences from 570 individual Pacific halibut collected from the five above-mentioned geographic areas (Figure 1) using low-coverage whole-genome resequencing (lcWGR).

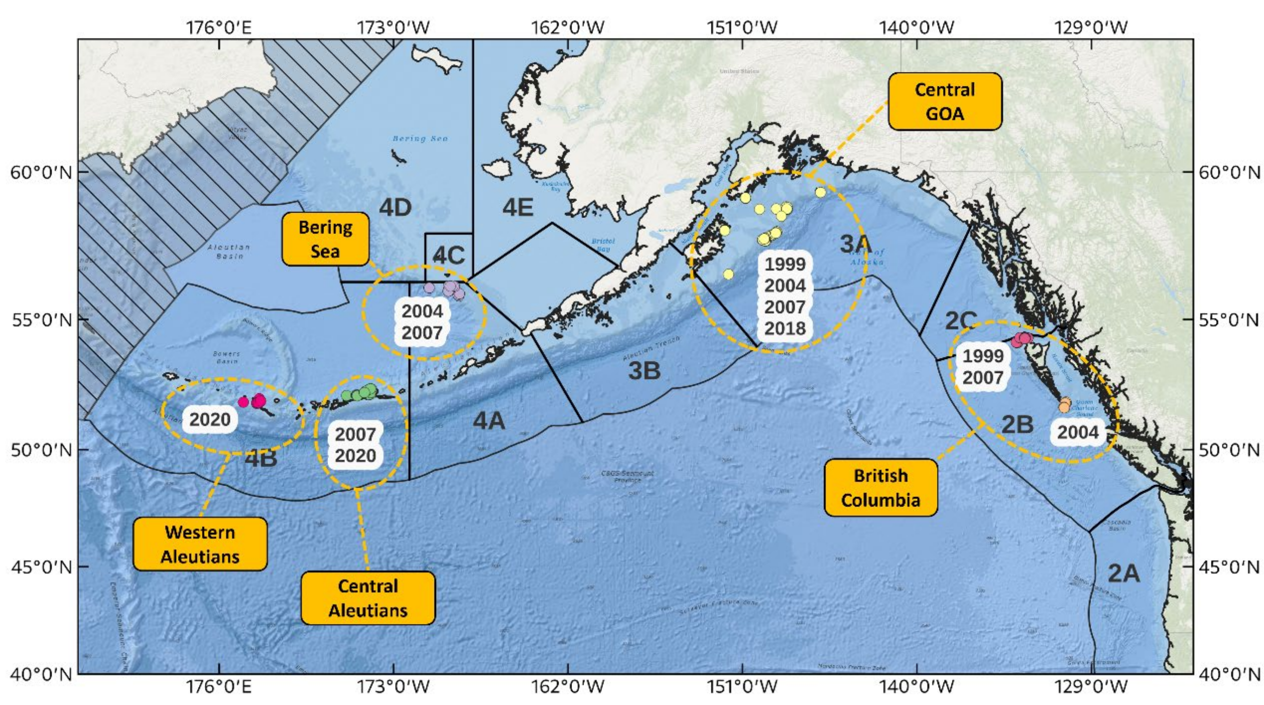



**Figure 1**. Map of sample collections made during the spawning season used for genomic analysis of population structure in Pacific halibut in the northeast Pacific Ocean.

Using the lcWGR approach, we identified approximately 10.2 million single nucleotide polymorphisms (SNPs) that have been used to evaluate population structure at the highest resolution possible. Despite the use of a very high-resolution genomic approach, preliminary analyses of population structure using a genome-wide subset of 4.7 million SNPs, indicated that no distinct genetic groups were apparent in the dataset. Multiple methods were used to characterize population structure: principal component analysis revealed a considerable degree of genetic similarity between samples collected in different geographic areas (Figure 2), and unsupervised clustering methods (K-means clustering and the estimation of admixture proportions) also failed to detect discrete genetic groups (data not shown). These results suggest that there is very little spatial structure among the five spawning groups sampled in different geographic areas within IPHC Convention Waters. Furthermore, assignment testing was carried out to assess our ability to accurately assign samples back to their location in which they were collected. Assignment accuracy was validated using cross-validation techniques and indicated a limited ability to accurately assign samples back to the geographic location in which they were collected from (data not shown). We hypothesize that the absence of distinct genetic groups among our sample collections is due to a considerable degree of geneflow among the geographic areas sampled in this study and, consequently, to the genetically panmictic nature of the Pacific halibut population sampled for this study.

The lack of structure observed here is not surprising given our current knowledge and understanding of Pacific halibut biology. Annual migration rates estimated from tag recovery data suggest that there is ample opportunity for individuals to move among IPHC Regulatory Areas throughout their lives (Webster et al. 2013). Analysis of tag recovery data has shown that approximately 11% of Pacific halibut tags are recovered in a different IPHC Regulatory Area than they are released (Carpi et al. 2021). This varies by Regulatory Area but for most IPHC Regulatory Areas, the percentage of migrants observed exceeds 10% (Carpi et al. 2021). Additionally, strong oceanographic connectivity between the Bering Sea and Gulf of Alaska has been linked to a considerable degree of larval exchange between these areas. It has been estimated that 47%-58% of larvae originating from spawning grounds in the Western Gulf of Alaska are transported to the Bering Sea (Sadorus et al. 2021). These rates can still be as high as 4.5%-8.6% for larvae originating from spawning grounds in the Eastern Gulf of Alaska (Sadorus et al. 2021).

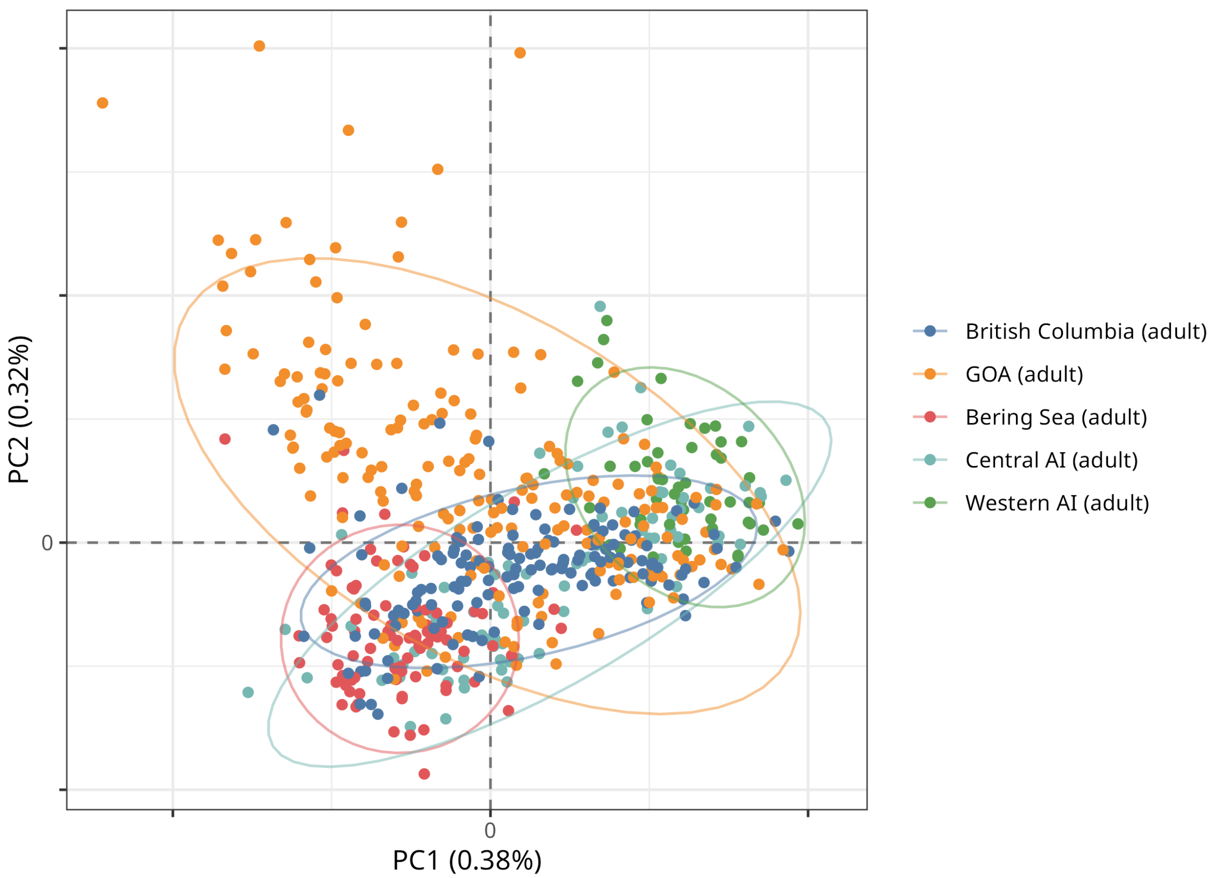



**Figure 2.** Genetic relationships among individual samples visualized using principal component analysis. Each point represents an individual fish and each fish is colored by the geographic area in which they were sampled. Note the lack of distinct clusters and overlap among areas. Circles represent 95% confidence ellipses.

The concept of a 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. However, while it is important to note that we cannot simply prove that panmixia exists by failing to reject it, the results presented here are consistent with the current assessment practices of the Pacific halibut stock in IPHC Convention Waters which is treated as a single coastwide stock (Stewart and Hicks 2024).

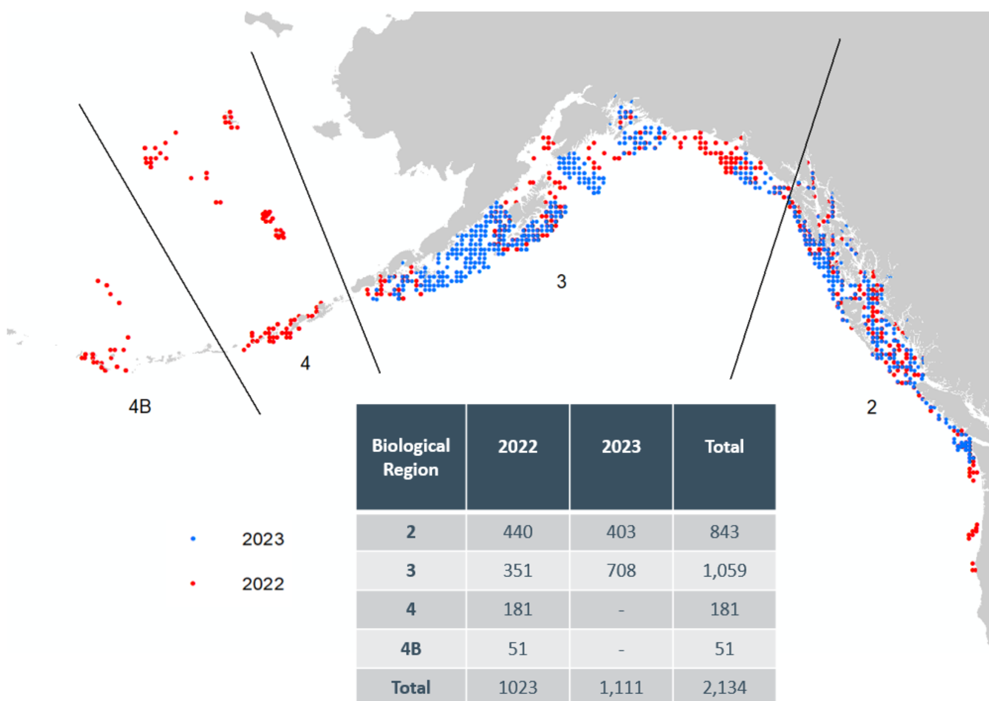
2. Reproduction.

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).

Each year, the fishery-independent setline survey (FISS) collects biological data on the maturity of female Pacific halibut that are used in the stock assessment to estimate spawning stock biomass. Currently used estimates of maturity at age using macroscopic visual criteria collected in the FISS indicate that the age at which 50% of female Pacific halibut are sexually mature is 11.6 years on average. However, female maturity schedules have not been revised in recent years and may be outdated. In addition, the currently used macroscopic visual criteria used to score female maturity in the field have an undetermined level of uncertainty and need to be contrasted with more accurate microscopic (i.e. histological) criteria. In order to address these issues, the IPHC Secretariat has conducted for the first time a thorough histological assessment of the temporal progression of female developmental stages and reproductive phases throughout an entire reproductive cycle. The outcomes of these studies have paved the way for upcoming studies to update and improve the accuracy of maturity schedules based on histological-based data and to guide efforts towards assessing fecundity in Pacific halibut.

In brief, 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 upcoming studies aimed at updating maturity ogives by histological assessment and at investigating fecundity in Pacific halibut. One of the most important results obtained show that the period of time when gonad samples can be collected in the FISS (June-August) is an appropriate temporal window during which Pacific halibut females that are developing towards the spawning capable reproductive phase and, therefore, considered mature for stock assessment purposes, can be identified. Furthermore, the potential use of easily obtained biological indicators in predictive models to assign reproductive phase in Pacific halibut was demonstrated. The results of these studies have been published in the journals *Journal of Fish Biology (*Fish et al. 2020, https://doi.org/10.1111/jfb.14551), and *Frontiers in Marine Science (*Fish et al. 2022; https://doi.org/10.3389/fmars.2022.801759).

2.1. Update of maturity schedules based on histological-based data. The coastwide maturity schedule (i.e. the proportion of mature females by age) that is currently used in SA is based on visual (i.e. macroscopic) maturity data collected in IPHC's Fishery-Independent Setline Survey (FISS). However, the coastwide maturity schedule has not been revised in recent years and it may have an undetermined degree of uncertainty. For this reason, the IPHC Secretariat is undertaking studies to revise the female maturity schedule coastwide and in all four IPHC Biological Regions through histological (i.e. microscopic) characterization of maturity. To accomplish this objective, the IPHC Secretariat started collecting ovarian samples for histology during the 2022 and 2023 FISS seasons. The 2022 FISS sampling resulted in a total of 1,023 ovarian samples collected in Biological Regions 2, 3, 4 and 4B. Due to a reduced FISS design, in 2023 sampling only occurred in Biological Regions 2 and 3 and 1,111 ovarian samples were collected (Figure 3).




| Biological Region | 2022 | 2023 | Total |
|---|---|---|---|
| 2 | 440 | 403 | 843 |
| 3 | 351 | 708 | 1,059 |
| 4 | 181 | - | 181 |
| 4B | 51 | - | 51 |
| Total | 1023 | 1,111 | 2,134 |

**Figure 3**. Map of 2022 and 2023 maturity samples for histology collected on FISS. Red dots (2022) and blue dots (2023) indicate a distinct FISS station in which a sample was collected.

When examining the age and length distribution of fish collected for sampling in 2022 and 2023, the distribution of fish appeared to be right-skewed for both parameters, but more pronounced for age (Figure 4). For the samples collected in 2023, the total range of ages was from 5 to 33 years old, and the total range of lengths was from 50 to 190 cm. The largest proportion of sampled fish was from 7 to 10 years old, and from 80 to 90 cm in length. A Welch's two sample t-test was used to determine differences between age and length samples for 2022 and 2023. No significant difference was found among years for age ($t(1994.2) = -1.71$, $p = 0.09$) and length ($t(1984.4) = 1.75$, $p = 0.08$) (data not shown).

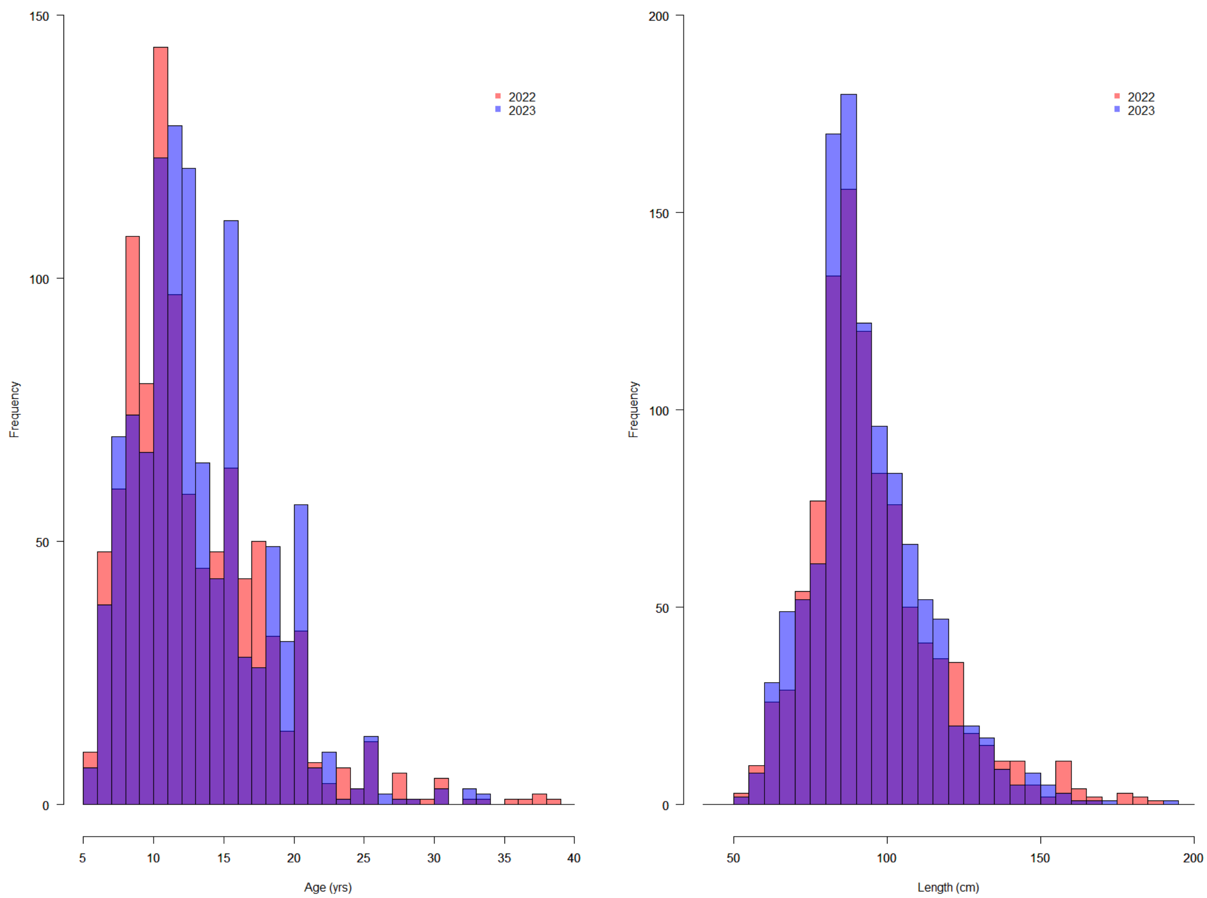



**Figure 4**. Histograms showing distribution of age and length of female Pacific halibut collected for maturity samples in the 2022 (red) and 2023 (blue) FISS. The purple color indicates overlap between the two years.

Ovarian samples from 2022 and 2023 were processed for histology and IPHC Secretariat staff finalized scoring samples for maturity using histological maturity classifications, as previously described in Fish et al. (2020, 2022). Following this maturity classification criteria, all sampled Pacific halibut females were assigned to either the mature or immature categories. Mature female Pacific halibut are deemed to have at least reached early vitellogenesis (Vtg1) for oocyte development.

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) to the 2022 and 2023 data using year as a factor (Figure 5). When comparing Biological Regions 2 and 3 (the only two Biological Regions with two consecutive years of data) spatial and temporal differences in maturity ogives become apparent. First, the maturity ogive for Biological Region 2 shows lower steepness than that for Biological Region 3 in both years, indicating that Biological Region 2 has a lower proportion of mature females from ages 7 to 25 than Biological Region 3 over the period of ovarian sample collection during the FISS. Second, the maturity ogive in Biological Region 2 increased markedly in steepness between 2022 and 2023, indicating an increase in the proportion of mature females at younger ages, whereas the maturity ogive in Biological Region 3 was very similar across the two years. Future collection of ovarian samples in additional years will be required to establish any potential temporal and/or spatial differences in maturity ogives.

The models estimated maturity-at-age curves for each IPHC Biological Region. Due to a significant year effect in the GAM model, IPHC Secretariat pooled the maturity data by region to remove the year effect from the model. Noting that sample size was not proportional to population size for each region, we used the estimated regional abundance proportions from IPHC’s most recent FISS space-time model as weights in estimating a coastwide maturity ogive (Figure 6). The value of the coastwide ogive at each age is calculated as the abundance proportion at age times the proportion mature at age summed across regions. The modeled coastwide ogive for maturity-at-age appear to fall between the maturity ogives for Biological Regions 2 and 3. This is expected as these two regions currently have the highest estimated abundance. Maturity is used to assign the numbers of fish at each age in the SA model to either a reproductive or non-reproductive state. The total reproductive output of these fish in the SA is then estimated by multiplying the number of reproductive fish at each age by their average somatic weight and then by the fecundity per age or body weight (currently assumed to be 1 for all body weights and ages). Therefore, defining our coastwide maturity ogive in terms of numbers of fish is consistent with its use in the SA. Conversely, defining it in terms of biomass would require converting back to maturity in numbers for use in the SA. Age at 50% maturity was calculated from the coastwide ogive using an optimizing routine in R 4.3.2 (function optim). Age at 50% maturity (A50) was calculated to be 10.3 years, which is over one year younger than our current estimates from macroscopic (field) data of 11.6 years. This is indicating that a higher proportion of female Pacific halibut are maturing at a younger age than previously indicated, which could have implications for overall spawning stock biomass (SSB) estimates.

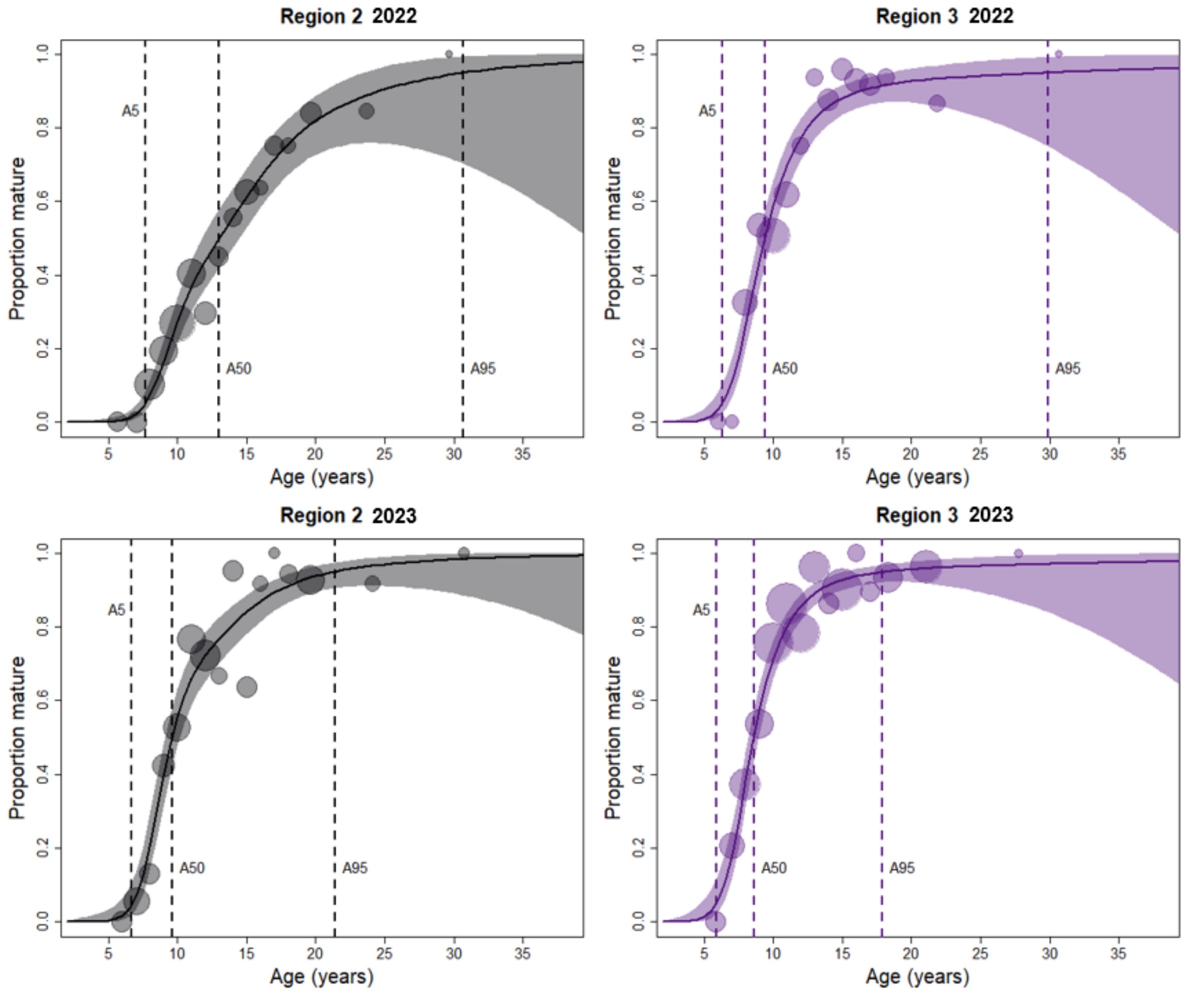



**Figure 5**. Female Pacific halibut age-at-maturity by IPHC Biological Region and year using best-fit GAM, with color shading indicating 95% CI for each IPHC Biological Region. Vertical dash lines indicate age at 5% (A5), 50% (A50), and 95% (A95) maturity.

IPHC Secretariat continued to collect ovarian samples in the 2024 FISS. A total of 1,118 samples were collected for 2024, with 411 samples in Biological Region 2, 336 in Biological Region 3, and 371 in Biological Region 4. These samples will allow us to further investigate both spatial and temporal differences in histological-based female Pacific halibut maturity.

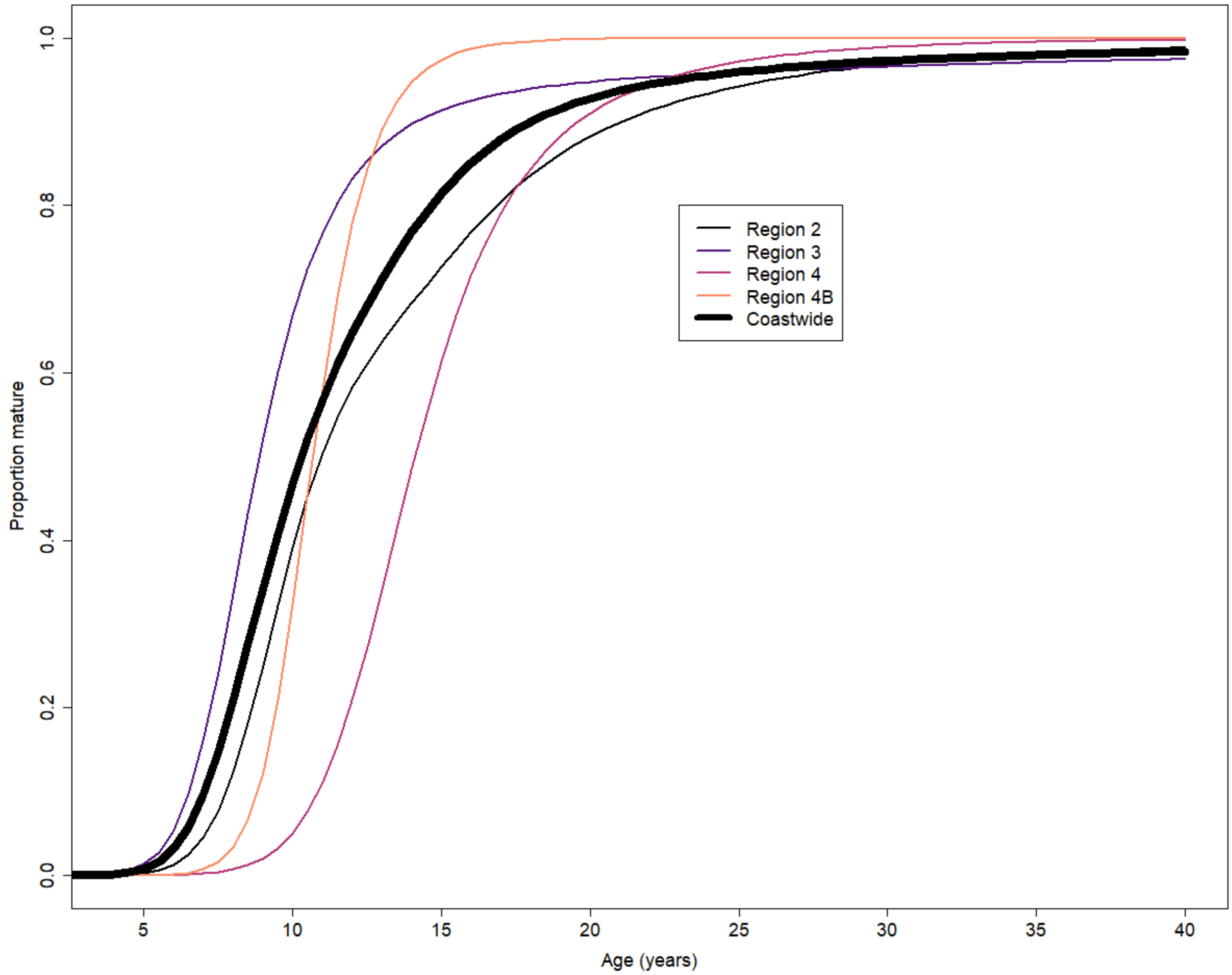



**Figure 6.** Coastwide maturity-at-age ogive (thick black line) generated from estimated regional abundance proportions. Shown without CI to better visualize differences between the coastwide and Biological Region ogives.

2.2. 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). 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 fecundity estimations were collected during the 2023 FISS. Sampling was conducted in IPHC Biological Region 3, with a total of 456 fecundity samples collected. In 2024, sampling was conducted in IPHC Biological Regions 2 and 4, with 149 and 359 fecundity samples collected, respectively, for a total of 508 fecundity samples in 2024. Using histology, as described in 2.2.1, only samples deemed mature will be processed for fecundity estimations.

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 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 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. 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 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.

The IPHC Secretariat, with funding by a grant from the Saltonstall-Kennedy Program NOAA (NA17NMF4270240; 2017-2020), has completed 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%. These results have been published in the journal *North American Journal of Fisheries Management (*Loher et al. 2022; https://doi.org/10.1002/nafm.10711).

The IPHC Secretariat has also concluded investigations on the relationships among hook release techniques (e.g., gentle shake, gangion cutting, and hook stripping), injury levels, stress levels and physiological condition of released fish, as well as the environmental conditions that the fish experienced during capture. Gentle shake and gangion cutting resulted in the same injury and viability outcomes with 75% of sublegal fish in Excellent condition, while the hook stripper produced the poorest outcomes (only 9% in Excellent condition). Hook stripping also resulted in more severe injuries, particularly with respect to tearing injuries, whereas gentle shake and gangion cutting predominantly resulted in a torn cheek, effectively the injury incurred by the hooking event. Physiological stress indicators (plasma levels of glucose, lactate, and cortisol) did not significant change with viability outcomes, except for higher lactate plasma levels in fish categorized as Dead. Hematocrit was significantly lower in fish that were categorized as Dead. Furthermore, 89% of fish classified as Dead were infiltrated by sand fleas, present in several sets in deeper and colder waters. Our results indicated that avoiding the use of hook strippers and minimizing soak times in areas known to have high sand flea activity result in better survival outcomes. These results have been published in the journal *Ocean and Coastal Management (*Dykstra et al. 2024; https://doi.org/10.1016/j.ocecoaman.2024.107018).

4.2. Discard mortality rates of Pacific halibut in the charter recreational fishery.

The Pacific halibut recreational fishery (combined guided and unguided) is an important contributor (20%) to the total fishery-induced mortality, with 3,473 metric tons (7.6 million pounds) of removals in 2021. Under current regulations, the number of fish captured, handled and discarded by the Pacific halibut recreational fisheries is significant. Capture-related events impose stress and injury to the fish and, consequently, decrease the survival of discarded fish. In contrast to the trawl and longline Pacific halibut fisheries, discard mortality rates (DMRs) have not been determined experimentally in the recreational fisheries and are currently based on DMR information generated from commercial gear using J-hooks combined with rates derived for other sport fisheries, and coarsely applied to recreational hook type and creel census data. This project aims at better understanding the role of fishing practices and capture conditions on injury profile, physiological stress levels and survival in the Pacific halibut recreational fisheries in order to estimate DMRs. Recent reductions in Pacific halibut catch limits place added importance for improved DMR estimates applied to the recreational fishery.

The primary components of this project were to: 1) collect information on hook types and sizes and handling practices used in the guided recreational Pacific halibut fisheries of the central and eastern Gulf of Alaska (IPHC Regulatory Areas 2C and 3A) that account for a significant portion (83%) of coastwide recreational mortalities; 2) quantify relationships between gear types employed and the size composition of captured Pacific halibut; 3) characterize injury profiles and physiological stress levels in relation to commonly-employed capture and handling protocols, and; 4) quantify and characterize survival of discarded Pacific halibut in order to evaluate the relative accuracy of currently-employed DMRs. Funding for these projects was provided by the National Fish and Wildlife Foundation and the North Pacific Research Board.

The first component of the existing project was initiated in May of 2019 and was composed of fleet outreach exercises that were conducted in the Alaskan ports of Homer, AK and Seward, AK in IPHC Regulatory Area 3A, and in Juneau, AK and Sitka, AK in IPHC Regulatory Area 2C. Working directly with each port's charter association and the ADF&G, stakeholder meetings were conducted in order to explain project objectives, solicit the involvement of local guided recreational fishing captains, receive feedback with respect to project logistics, and answer questions and concerns that fleet members might have regarding the work. This was followed by the distribution of a voluntary survey – developed in collaboration with the University of Alaska, Fairbanks – soliciting detailed information regarding gear configurations (hook types and sizes) employed and fish handling practices (e.g., fish manipulated by hand or net, hook-release method, time out of water), that was administered to guided recreational fishing captains via the IPHC's commercial port sampling program over the course of the 2019 fishing season. Results showed that the guided recreational fleet predominantly uses circle hooks (75-100%), followed by jigs. Predominant hook release methods included reversing the hook (54%) or twisting the hook out with a gaff (40%), and the fish were generally handled by supporting both the head and tail (65%), while other discard techniques reported included handling by the operculum (10%) or by the tail alone

(10%). The data obtained from the 2019 guided recreational fleet survey provided the basis for structuring the field work that was conducted during the summer of 2021.

The second component of the study was to conduct field studies informed by common gear and handling practices as determined by the fleet survey. The IPHC Secretariat chartered the guided recreational vessel F/V High Roller (operated by Alaska Premier Charters) from 21-27 May 2021 in IPHC Regulatory Area 2C (out of Sitka, AK). The research charter in IPHC Regulatory Area 3A (out of Seward, AK) was conducted on the fishing vessel Gray Light (operated by Graylight Fisheries) on 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 to establish a comparison of the two most common gear types used in the Pacific halibut recreational fishery.

In IPHC Regulatory Area 2C, we captured, sampled and released 243 Pacific halibut 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), we captured, sampled, and released 118 Pacific halibut 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.

For all Pacific halibut captured in IPHC regulatory area 2C, we recorded the time from hooking to release, length and weight, the injury code and release viability category using the standard IPHC criteria, and air and fish temperature. In addition, from each fish we collected a blood sample, measured somatic fat content with the use of a Distell Fat Meter, took a picture of the hooking injury, collected a fin clip for genetic sexing and tagged the fish with an opercular wire tag prior to release. Pacific halibut captured in IPHC Regulatory Area 3A were subjected to the same sampling protocol except for 80 fish that were tagged with acceleration-logging survivorship pop-up archival transmitting (sPAT) tags. sPAT-tagged fish were selected only among those fish that were classified in the “excellent” viability category and did not have a blood sample taken to minimize handling-related stress. The deployed sPAT tags were programmed to be released after 96 days. Seventy-six (76) of the 80 sPAT tags provided useable data reports. Survival analysis (R package = “survival”) produced a mortality rate estimate of 1.35% with a 95% CI of 0.0-3.95%. This estimate represents the first field corroborated estimate of recreational discard mortality and 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). Furthermore, these results affirm the use of current recreational discard mortality estimation methodologies embedded in mortality estimates that feed into the SA and MSE process.

Fish size distributions were nearly identical between the two IPHC Regulatory Areas. Larger hooks (16/0) caught significantly larger fish compared to the smaller hook (12/0) for fish caught out of Seward, but no difference in fish sizes by hook size was seen in fish landed out of Sitka. Hook size had no effect on injury distributions. The majority (97%) of Pacific halibut captured were classified in the Excellent viability category.

Using the collected blood samples, stress parameters measured in the plasma (i.e. blood constituents without red blood cells) of captured and released Pacific halibut included the stress hormone cortisol and the metabolites glucose and lactate. Plasma cortisol, glucose and lactate levels did not vary by release viability, nor by fish recovered to date, but appeared to increase with fight time, suggestive of a positive relationship between stress levels and fight time in recreationally captured Pacific halibut. Interestingly, the observed plasma cortisol, glucose and lactate levels were markedly lower than those measured in commercially caught individuals.

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) 38 tags have been recovered (36 from IPHC Regulatory Area 2C and 2 from IPHC Regulatory Area 3A). Of the 80 fish tagged with sPAT tags, seven were recaptured by the fishery, and an additional two tethers have been recaptured since the main body successfully reported in data.

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. 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).

Removal of captured fish from fishing gear (known as depredation) is a growing problem among many hook-and-line fisheries worldwide. In the north Pacific Ocean, both Killer (*Orcinus orca*) and Sperm (*Physeter macrocephalus*) whales are involved in depredation behavior in Pacific halibut, sablefish (*Anoplopoma fimbria*), and Greenland turbot (*Reinhardtius hippoglossoides*) longline fisheries. In 2011 and 2012, fisheries observers estimated that 21.4% of sablefish sets, 9.9% of Greenland turbot sets, and 6.9% of Pacific halibut sets were affected by whale depredation in the Bering Sea (Peterson et al. 2014). Reductions in catch per unit effort (CPUE) when whales were present ranged across geographic regions from 55%-69% for sablefish, 54%-67% for Greenland turbot, and 15-57% for Pacific halibut (Peterson et al. 2014). These impacts also incur significant time, fuel, and personnel costs to fishing operations. From a fisheries management perspective, depredation creates an additional and highly uncertain source of mortality, loss of data (e.g. compromised survey activity), and reduces fishery efficiency. Stock assessments of both Pacific halibut and sablefish have adjusted their analysis of fishery-independent data to account for the effects of whale depredation on catch rates. In the sablefish assessment, fishery limits are also adjusted downward to reflect expected depredation during the commercial fishery. In recent years, whale depredation has been limiting fishers' ability to harvest their Greenland turbot allocations and they have been well below (35-78% in the last 5 years) the total allowable catch for that fishery. Meanwhile, potential risks to the whales include physical injury due to being near vessels and gear, disruption of social structure and developing an artificial reliance on food items that can be affected by fishery dynamics.

Many efforts have been made over the years to mitigate this problem, with fishers generally limited to simple methods that can be constructed, deployed, or enacted without significantly disrupting normal fishing operations, or without violating gear regulations. Existing approaches include catch protection, physical and auditory deterrents, and spatial or temporal avoidance. These approaches have had variable degrees of success and ease of adoption, but none have solved the problem. Terminal gear modification and catch protection have been identified as an avenue with the highest likelihood of ‘breaking the reward cycle’ in depredation behaviors. Particularly for Pacific halibut and Greenland turbot, two species whose catches are prohibited and closely regulated, respectively, in trawl fisheries and that are difficult to capture efficiently in pots, novel approaches to protection of longline catch are necessary.

This project focuses on investigating strategies aimed at protecting longline-caught fish, through low cost, easy to adopt gear modifications that securely retain catch, while breaking the ‘reward cycle’ in depredation. The project, that received funding from the Bycatch Reduction Engineering Program (BREP)-NOAA, has been structured in two parts. First, in early 2022 we conducted a virtual International Workshop (link) on protecting fishery catches from whale depredation with industry (affected fishers, gear manufacturers), gear researchers and scientists to identify methods to protect fishery catches from depredation.

The second part of the project involved developing the top catch protection design outcomes of the Workshop into functional prototypes and conducting field testing in longline sea trials. The two selected catch protection devices were: 1) an underwater shuttle (Figure 7) and 2) a branch gear with a sliding shroud system.

The results from the field testing conducted in May 2023 indicated that the shuttle was a safe and effective gear type which entrained comparable quantities, sizes, and types fish as the control gear, whereas the sliding shroud and branch gear had substantial logistical issues that would need to be addressed before scaling up to a fishery level.

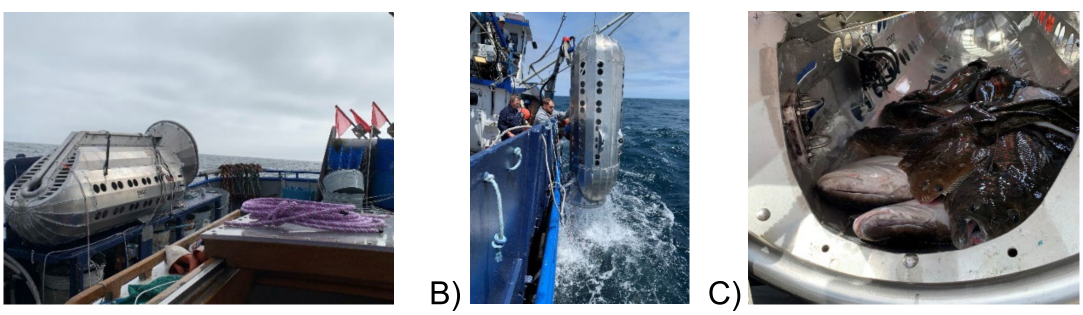
A) B) C)


**Figure 7.** Shuttle unit stowed on vessel (A), shuttle being hoisted onto vessel during retrieval (B), and fish contained within the shuttle before emptying on deck (C).

Based on the success of the first two components of this work, the IPHC was successful in securing additional funding from BREP-NOAA to expand testing of the shuttle concept in the presence of depredating Orcas in Alaskan waters (Appendix IV). The work will further examine refinements (attachment protocols, gangion/hook strength), statistical testing of catch rates, and catch composition (size ranges, species, catch volume) when using the device, as well as allow for quantification of removals of fish from non-shuttle treatments by depredating whales. The work was initially scheduled for 2024; however, our initial requests for tenders did not generate sufficient interest and the grant period of performance has been extended until April of 2026 to accommodate conducting the field work in 2025. For that purpose, the IPHC Secretariat is preparing requests for tenders for submission in late 2024.

## RECOMMENDATION/S

1) That the RAB **NOTE** IPHC-2024-RAB025-06, 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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## APPENDICES

**Appendix I:** Biological research areas in the 5-Year Program of Integrated Research and Monitoring (2022-2026) and ranked relevance for stock assessment and management strategy evaluation (MSE).

**Appendix II:** List of ranked research priorities for stock assessment

**Appendix III:** List of ranked research priorities for management strategy evaluation (MSE)

**Appendix IV:** Summary of current competitive research grants awarded to IPHC

# APPENDIX I

## Biological research areas in the 5-Year Program of Integrated Research and Monitoring (2022-2026) and ranked relevance for stock assessment and management strategy evaluation (MSE)

| 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 research priorities for stock assessment

| 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 | Migration and population dynamics | 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 | | 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 | Fishing technology | 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 | Fishing technology | 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 research priorities for management strategy evaluation (MSE)

| 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 and population dynamics | Larval and juvenile connectivity studies |
| | Stock structure of IPHC Regulatory Area 4B relative to the rest of the Convention Area | | | 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 competitive research grants awarded to IPHC

| Project # | Grant agency | Project name | PI | Partners | IPHC Budget ($US) | Grant period | Research area | Management implications | Research prioritization |
|---|---|---|---|---|---|---|---|---|---|
| **1** | **Bycatch Reduction Engineering Program-NOAA** | Full scale testing of devices to minimize whale depredation in longline fisheries (NOAA Award Number NA23NMF4720414) | IPHC | Alaska Fisheries Science Center-NOAA | $199,870 | November 2023 – April 2026 | Fishing technology | Mortality estimations due to whale depredation | 3 |
| **2** | **Alaska Sea Grant (pending award)** | Development of a non-lethal genetic-based method for aging Pacific halibut (R/2024-05) | IPHC APU | Alaska Fisheries Science Center-NOAA (Juneau) | $60,374 | January 2025-December 2026 | Population dynamics | Stock structure | 2 |
| **Total awarded ($)** | | | | | **$260,244** | | | | |