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

1.2. Wire tagging of U32 Pacific halibut. The patterns of movement of Pacific halibut among IPHC Regulatory Areas have important implications for management of the Pacific halibut fishery. The IPHC Secretariat has undertaken a long-term study of the migratory behavior of Pacific halibut through the use of externally visible tags (wire tags) on captured and released fish that must be retrieved and returned by workers in the fishing industry. In 2015, with the goal of gaining additional insight into movement and growth of young Pacific halibut (less than 32 inches [82 cm]; U32), the IPHC began wire-tagging small Pacific halibut encountered on the National Marine Fisheries Service (NMFS) groundfish trawl survey and, beginning in 2016, on the IPHC fishery-independent setline survey (FISS). As of 28 July 2022, 1,330 Pacific halibut have been tagged and released on the 2022 IPHC FISS but no tagging was conducted in the NMFS groundfish trawl surveys in 2022. Therefore, a total of 7,441 U32 Pacific halibut have been wire tagged and released on the IPHC FISS and 135 of those have been recovered to date. In the NMFS groundfish trawl surveys through 2019, a total of 6,421 tags have been released and, to date, 78 tags have been recovered.

1.3. Population genomics. 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 modern high-resolution genomic techniques. Recent studies have reported significant genetic population structure that suggest Pacific halibut residing in the Aleutian Islands may be genetically distinct from other regions. Genetic differentiation of the population on either side of Amchitka Pass was indicated, suggesting a possible basis for separating IPHC Regulatory Area 4B into two management subareas. However, these results were confounded by (1) the use of a small number of genetic markers and (2) the use of samples collected outside of the spawning season (i.e. winter) in some areas. These analyses employed summer-collected (i.e., non-spawning season) samples west of Amchitka Pass which may not be representative of the local spawning population, but rather a mixture of spawning groups on the feeding grounds. Therefore, it is advisable to re-assess those conclusions using samples collected during the spawning season and modern, high-resolution genomic techniques.

In January and February of 2020, the IPHC Secretariat conducted genetic sample collections on either side of Amchitka Pass (IPHC Regulatory Area 4B) during the spawning season to address the limitations of previous studies. These samples, in combination with previous samples collected during the spawning season (i.e. Bering Sea, Central Gulf of Alaska and waters off British Columbia) (Figure 1) will be used to re-evaluate stock structure of Pacific halibut in IPHC Convention waters. The temporal replicates at many of these locations will enable the IPHC Secretariat to evaluate the stability of genetic structure over time, ensuring confidence in the results. The IPHC Secretariat has recently produced a high-quality reference genome and has generated genomic sequences from 570 individual Pacific halibut collected from five geographic areas (Figure 1) using low-coverage whole-genome resequencing (lcWGR). Using the lcWGR approach, we have identified approximately 10.2 million single nucleotide polymorphisms (SNPs) that are currently being used to evaluate population structure at the highest resolution possible. Despite the very high resolution genomic data, our initial analyses of population structure using a genome-wide set of 4.7 million SNPs indicate very little spatial structure among the spawning groups sampled in IPHC convention waters (Figure 2). Since evolutionary processes may not act uniformly across the genome, current work is aimed at identifying regions of the genome that contain outlier SNPs which may increase our power to characterize population structure and determine the source population for samples collected outside of the spawning season.

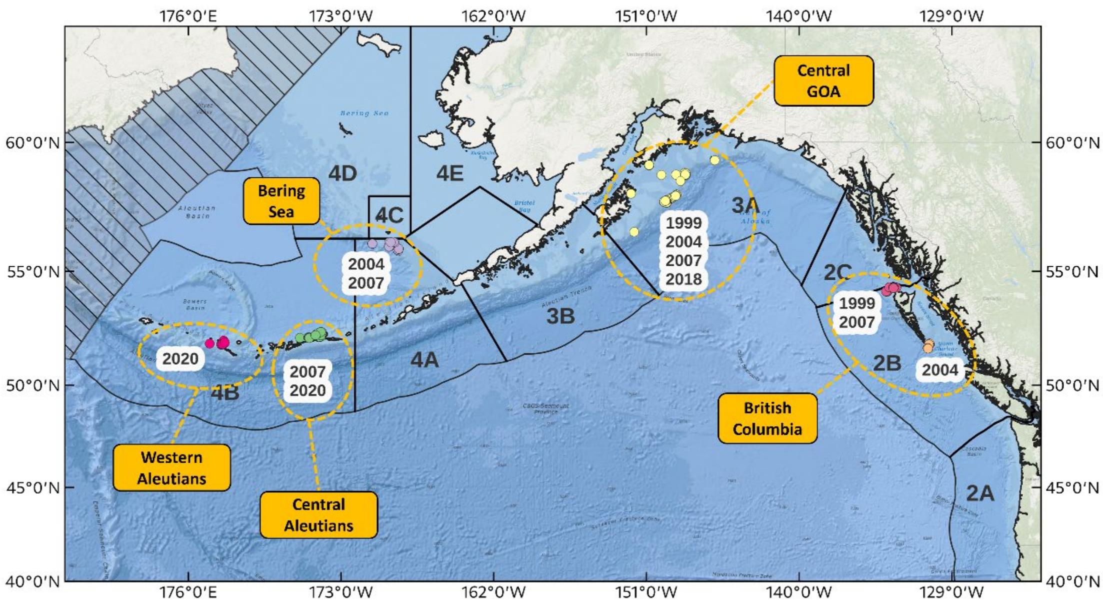

Figure 1. Map of sample collections made during the spawning season used for genomic analysis of population structure in Pacific halibut in the northeast Pacific Ocean.

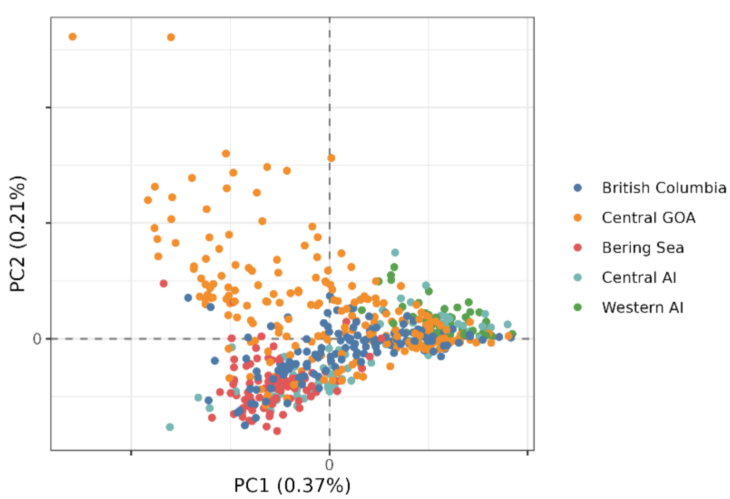

Figure 2. Genetic relationships among individual samples visualized using principal component analysis. Each point represents an individual fish and each fish is colored by the geographic area in which they were sampled. Note the lack of distinct clusters and overlap among areas.

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*: https://doi.org/10.1111/jfb.14551, and *Frontiers in Marine Science*: https://doi.org/10.3389/fmars.2022.801759.

   In 2022, the IPHC Secretariat initiated studies to revise maturity schedules in all four biological regions through histological (i.e. microscopic) characterization of maturity. For that purpose, the IPHC Secretariat collected ovarian samples for histology during the 2022 FISS. The FISS sampling resulted in a total of 1,023 ovarian samples collected coastwide for histological analysis, with 440 ovarian samples from Biological Region 2,351 samples from

Biological Region 3, 181 from Biological Region 4, and 51 samples from Biological Region 4B. Ovarian samples have been processed for histology and IPHC Secretariat staff are currently finalizing 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 will be assigned to either the mature or immature categories. IPHC Secretariat continued to collect ovarian samples in 2023 on the FISS. This will allow us to investigate both spatial and temporal differences in female Pacific halibut maturity. Due to the reduction in FISS design for 2023, sampling efforts only took place in IPHC Biological Regions 2 and 3. A total of 1,110 ovarian samples were collected for histological analysis, with 403 samples from Biological Region 2, and 707 samples from Biological Region 3. Maturity ogives will be generated by age and length at a coastwide scale as well as at a biological region scale.

An important existing knowledge gap regarding the reproductive biology of Pacific halibut is the current lack of understanding of fecundity-at-age and fecundity-at-size. Information on these two parameters could be used to replace spawning biomass with egg output as the metric of reproductive capability in the stock assessment and management reference points. The IPHC Secretariat has investigated different available methods for fecundity determinations and, based on the current literature and recommendations from experts in the field, the auto-diametric method was selected as the method of choice (Witthames et al., 2009. *Fish. Bul*. 107:148-164). For this purpose, the IPHC Secretariat collected gonad samples for fecundity estimations during the 2023 FISS. IPHC Secretariat targeted Biological Region 3 for this collection, with a total of 456 gonad samples collected.

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 Grant 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:* https://doi.org/10.1002/nafm.10711.

The results of the second component of this study, namely the relationships among hook release techniques, injury levels, stress levels and physiological condition of released fish, are presently being written for publication in a peer-reviewed journal.

4.2. 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 (components 1-4) and the North Pacific Research Board (component 4).

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%. These are the first field corroborated estimates of recreational discard mortality and 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. Hook size had no effect on fish size or injury distributions. Furthermore, 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 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 (data not shown).

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) 34 tags have been recovered (32 from IPHC Regulatory Area 2C and 2 from IPHC Regulatory Area 3A).

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 (Hippoglossus stenolepis), 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. PLoS ONE 9(2): e88906). 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 is structured in two parts. First, in early 2022 we conducted a virtual International Workshop 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. Presentations were made from companies and researchers on a) underwater shuttles that unhook, and transport catch to the surface (e.g. Patagonian toothfish) by Sago Solutions from Norway, b) shrouding devices involving triggerable spokes or mesh panels attached to the gear to obscure catches of tuna by researchers from Paradep from France, and c) light weight expandable spring coil pots by Cod Coil from the U.S. Each presentation outlined what their product is, it’s mode of action, method of interaction with the gear, functionality, costs (catch rates, money, time, safety, storage), modifications to consider, critical considerations, and ease of modification for flatfish fisheries. Common successes and failures of various iterations of these products, and general observations were discussed and summarized in the published report of the Workshop, with a particular focus on those elements that are suitable to be adapted for the protection of longline captured Pacific halibut.

Second, this project aims to incorporate 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: a) an underwater shuttle and b) a branch gear with a sliding shroud system.

The underwater catch-protection shuttle (Figure 3) was manufactured by Sago Solutions. The aluminum shuttle operates by sliding down the groundline during the hauling event, encountering the hooks and catch near the seabed, mechanically unhooking fish and entraining them in the storage area (Figure 3). After securing the catch, the device encounters a stopper and is hauled to the surface with fish inside. At the surface the device is hoisted aboard using a boom and winch. Pilot testing consisted of ten sets, each with two 100 hook skates, one acting as a control, and the other equipped with the shuttle.

A)  B)  C) 

Figure 3. 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).

Branch line fishing is a modification of longline fishing, wherein hooks are affixed to weighted side branches as opposed to the main groundline. This configuration allows for the introduction of a shroud device, which slides down to cover the hooks and associated catch during the hauling event. Shrouds were created by modifying commercially available ‘slinky pots’ to have an opening on one end, and a closed end cap on the other (Figure 4). Hooks with short stiff gangions (Figure 4) were attached to snaps of decreasing tension, to keep fish close to the branch line with minimal fouling, while allowing the hooks to slide together when the shroud slides over them. Pilot testing consisted of single sets with six branch lines of 48’ affixed on 100’ spacing along the groundline. Ten gangions and hooks were snapped to the branch lines on 4’ spacing. Three branch lines had a shroud attached and three branch lines acted as controls.

A)  B) 

Figure 4. Shroud showing end cap and openings (A), and variable strength snaps attached to hooks by shortened stiff gangions (B).

The purpose of the field testing was to (1) investigate the logistics of setting, fishing, and hauling the two pilot catch protection devices, and (2) investigate the basic performance of the gear on catch rates and fish size compared to traditional gear.

Field testing occurred out of Newport, OR in May 2023 on a 56’(17m) vessel (F/V Pacific Surveyor) with an open deck design, and a typical boom and winch capacity. Extensive still and video footage from camera deployment in and outside the devices provided a comprehensive data stream of gear performance and related fish behavior. Branch line fishing resulted in shrouds generally sliding down the branches and covering the gear/catch as designed; however, substantial logistical issues would need to be addressed before scaling up to a fishery level. After a moderate learning curve for the in-line attachment of the shuttle, it proved to be a safe and effective gear type, entraining comparable quantities, sizes, and types of fish as the control sets. Further refinement of gangion and hook specifications are recommended to minimize damage to fish.

The IPHC was recently successful in securing funding (NOAA BREP program) for further testing of the shuttle concept in the presence of depredating Orcas in Alaskan waters. This work is planned for 2024 and will allow for further 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.

RECOMMENDATION/S

1) That the RAB **NOTE** IPHC-2023-RAB024-06, which 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).

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 awarded research grants current in 2023

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 awarded research grants current in 2023

Project #	Grant agency	Project name	PI	Partners	IPHC Budget ($US)	Management implications	Grant period
1	**Bycatch Reduction Engineering Program-NOAA**	Gear-based approaches to catch protection as a means for minimizing whale depredation in longline fisheries (NOAA Award Number NA21NMF4720534)	IPHC	Deep Sea Fishermen's Union, Alaska Fisheries Science Center-NOAA, industry representatives	$99,700	Mortality estimations due to whale depredation	November 2021 – October 2023
2	**North Pacific Research Board**	Pacific halibut population genomics (NPRB Award No. 2110)	IPHC	Alaska Fisheries Science Center-NOAA	$193,685	Stock structure	February 2022 – January 2024
Total awarded ($)					**$293,385**		