STOCK STATUS UPDATE WITH APPLICATION OF MANAGEMENT PROCEDURES FOR PACIFIC HERRING (*CLUPEA PALLASII*) IN BRITISH COLUMBIA: STATUS IN 2022 AND FORECAST FOR 2023

Context

Pacific Herring (*Clupea pallasii*) abundance in British Columbia (BC) is assessed using a statistical catch-age (SCA) model (Martell et al. 2012). In 2017, the Pacific Herring stock assessment included updates to the SCA model, a bridging analysis to support these changes (Cleary et al. 2019), as well as the estimation of stock productivity and current stock status relative to the new limit reference point (LRP) of $0.3SB_0$ (Kronlund et al. 2017), where SB_0 is estimated unfished spawning biomass. The structure of the SCA model has not changed since 2017.

In 2016, Fisheries and Oceans Canada (DFO) committed to renewing the current management framework to address a range of challenges facing Pacific Herring stocks and fisheries in BC. Renewal of the management framework included engaging in a management strategy evaluation (MSE) process to evaluate the performance of candidate management procedures against a range of hypotheses about future stock and fishery dynamics. As part of the MSE process, a Canadian Science Advisory Secretariat (CSAS) regional peer review occurred in 2018, where performance of Pacific Herring management procedures (MPs) were assessed against conservation objectives for the Strait of Georgia (SoG) and West Coast of Vancouver Island (WCVI) stock assessment regions (SARs) (DFO 2019). Steps included operating model (OM) development (Benson et al. In press), fitting the OM to Pacific Herring stock and fishery monitoring data (OM conditioning), and closed-loop simulations of MP performance for alternative future natural mortality scenarios. In 2019, DFO initiated the MSE process for the Haida Gwaii (HG), Prince Rupert District (PRD), and Central Coast (CC) SARs (DFO 2020a). Updates to MP evaluations were then conducted for SoG and WCVI SARs in 2020 (DFO 2021a), and for all SARs herein.

This assessment incorporates new science advice on choice of upper stock reference (USR) points for four Pacific Herring major SARs (PRD, CC, SoG, and WCVI). An analysis of options was completed in 2022 (DFO In press) and implementation of USRs will occur through the 2022/23 Integrated Fisheries Management Plan (IFMP). To support on-going consultations, five USR options are presented for PRD, CC, SoG and WCVI (Section “Application of MPs and harvest options for 2023”). For these four stocks we also update conditioning of the herring OM (Benson et al. In press) by including stock and fishery data from 1951 to 2021. These updates first appear in DFO (In press). MP evaluations presented in the harvest option tables reflect the latest OM updates.

Since initiation of the Pacific Herring MSE process, results have been included in the annual stock assessment as follows:

1. The 2018 stock assessment includes MP recommendations for the SoG and WCVI SARs (DFO 2019).

2. The 2019 stock assessment includes MP recommendations for the HG, PRD, and CC SARs (DFO 2020b), and implements the previous years' MP recommendations for the SoG and WCVI SARs.
3. The 2020 stock assessment includes an update to MP recommendations for the SoG and WCVI SARs (DFO 2021a), and implements the previous years' MP recommendations for HG, PRD, and CC SARs.
4. The 2021 stock assessment includes an update to MP recommendations for the PRD and CC SARs (DFO 2021b), and implements the previous years MP recommendations for the SoG and WCVI SARs.

MPs are not updated for HG because management measures to support long-term recovery of HG herring are being developed through the rebuilding plan process.

This 2022 stock assessment includes MP recommendations for PRD, CC, SoG, and WCVI, derived by updating herring OM conditioning (Benson et al. In press) using the latest historic stock and fishery data from 1951 to 2021. USR options first presented in DFO (In press) are included to support selection of stock-specific USRs for implementation through the 2022/23 IFMP. Management measures to support long-term recovery of HG herring, including rebuilding objectives and USR, are documented in the draft HG herring rebuilding plan.[1]

Fisheries and Oceans Canada (DFO) Pacific Fisheries Management Branch requested that DFO Pacific Science Branch assess the status of British Columbia (BC) Pacific Herring stocks in 2022 and recommend harvest advice for 2023 as simulation-tested MPs to inform the development of the 2022/2023 IFMP, where appropriate. Estimated stock trajectories, current status of stocks for 2022, management procedure options, and harvest advice recommendations from those MPs for 2023 reflect methods of Cleary et al. (2019) and Benson et al. (In press) and, where applicable, recommendations from the aforementioned 2018, 2019, 2020, and 2021 MSE analyses (Section "Application of MPs and harvest options for 2023").

This Science Response results from the Science Response Process of September 15, 2022 on the Stock status update with application of management procedures for Pacific Herring (*Clupea pallasii*) in British Columbia: Status in 2022 and forecast for 2023.

Background

Pacific Herring in BC are managed as five major and two minor stock assessment regions (SARs; Figure 1). The major SARs are Haida Gwaii (HG), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SoG), and West Coast of Vancouver Island (WCVI). The minor SARs are Area 27 (A27) and Area 2 West (A2W). We conduct formal analyses of stock trend information for the major SARs. For the minor SARs, we present available catch data, biological data, and spawn survey data (Section "Minor stock assessment regions"). Beginning in 2021 we include similar data for the special area, Area 10 (Section "Special areas"). Note that Area 10 is a subset of the Central Coast and is outside the SAR boundary. Formal analyses of stock trends are not included for minor SARs or special areas.

[1] Haida Gwaii 'íináang | iinang Pacific Herring: An ecosystem overview and ecosystem-based rebuilding plan. Draft consultation period fall 2022.

Description of the fishery

At present, there are several Pacific Herring fisheries in BC. First Nations have priority access, after conservation, to fish for food, social, and ceremonial (FSC) purposes. Commercial fishing opportunities consist of four directed fisheries: food and bait (FB), special use (SU), spawn-on-kelp (SOK), and roe herring. There is also a small recreational fishery.

First Nations fish for whole herring, herring roe, and herring eggs for FSC purposes. Whole herring are fished by seine, gillnet, rake, dip net, and jig. Herring eggs are collected as spawn on seaweed such as kelp (i.e., SOK), or spawn on tree boughs placed in spawning locations. Indigenous harvest of herring for FSC purposes may occur coast wide where authorized by a communal license.

In addition, treaty and aboriginal commercial fisheries may occur in some specific management regions. Four modern treaties (Nisga'a, Tsawwassen, Maa-nulth, and Tla'amin) have been ratified in BC and articulate a treaty right to FSC harvest of fish. Five Nuu-chah-nulth First Nations located on the West Coast of Vancouver Island – Ahousaht, Ehattesaht, Hesquiaht, Mowachaht/Muchalaht, and Tla-o-qui-aht (the Five Nations) – have aboriginal rights to fish for any species of fish, with the exception of Geoduck, within their Fishing Territories and to sell that fish. DFO developed a 2022/23 Five Nations Multi-Species Fishery Management Plan (FMP). The FMP includes specific details about the fishery, such as allocation/access, licensing and designations, fishing area, harvesting opportunities, and fishery monitoring and catch reporting. Feedback provided by the Five Nations during consultations was considered and incorporated into the 2022/23 FMP by DFO where possible.

The implementation of the Five Nations' right-based sale fishery is an ongoing process. The 2022/23 FMP is the fourth Multi-Species FMP developed to implement the right-based multi-species fishery to accommodate the Five Nations' Aboriginal rights consistent with the British Columbia Supreme Court's 2018 decision. Version 2 of the 2021 FMP, issued on December 2, 2021, was the first Multi-Species FMP developed following the British Columbia Court of Appeal (BCCA) decision of April 19, 2021, in Ahousaht Indian Band and Nation v. Canada, 2021 BCCA 155, but it only partially implemented it.

The 2022/23 FMP addresses most of the remaining issues raised by the BCCA decision, leaving some items left to review. It is DFO's intention to continue to review the FMP and make further changes in-season and amend the FMP if required. For further information see the 2022/23 FMP.

On the Central Coast, Heiltsuk First Nation have an Aboriginal right to commercially harvest Pacific Herring SOK. The Heiltsuk currently hold nine SOK licenses in this area, and SOK is harvested using the preferred means of the Heiltsuk, which is open ponding. The DFO and Heiltsuk are also committed to annual development of a Joint Fisheries Management Plan for Pacific Herring in the Central Coast.

In 2021/2022, the primary Pacific Herring fisheries were seine roe and gillnet roe fisheries, with a combined coast wide catch of 3,835 tonnes (t). The FB seine fishery had a coast wide catch of 837 t. The roe, FB and SU fisheries operated in SoG only in 2021/2022. All areas were closed for commercial SOK fisheries in 2021/2022.

A complete dockside monitoring program exists for all Pacific Herring commercial fisheries and the resulting validated catch data are included in the annual stock assessment process for all fisheries, except SOK.

The exclusion of SOK fishery data from the annual stock assessment process was identified as a key uncertainty in the most recent CSAS review of the stock assessment framework (Cleary et al. 2019). Recommendations for addressing this uncertainty will require quantifying ponding mortality and removals (i.e., eggs) associated with SOK fisheries. Although this work is underway, results are not yet available to inform the stock assessment.

Description of the stock assessment process

The SCA model is fitted to commercial catch data, fishery and survey proportion-at-age data, and a fishery-independent spawning biomass index to estimate total and spawning biomass, natural mortality, and recruitment. Observed annual weight-at-age is estimated external to the model, and maturity-at-age is a fixed input parameter. In 2017, an updated version of the SCA model was applied to assess each of the five major Pacific Herring SARs (Cleary et al. 2019). The main change from the SCA model used from 2011 to 2016 was the partitioning of variance between observation and process error to improve the estimation of the variance structure (Cleary et al. 2019). A bridging analysis was used to validate the updated model: this showed parameter estimates and biomass trajectories associated with the structural adjustments to be nearly identical to results from previous versions of the model, supporting the adoption of the revised structure (Cleary et al. 2019).

A Bayesian framework was used to estimate time series of spawning biomass, instantaneous natural mortality, and age-2 recruitment from 1951 to 2022. Advice to managers for the major SARs includes posterior estimates of current stock status (SB_{2022}), stock status relative to the LRP of $0.3SB_0$, and spawning biomass in 2023 assuming no catch (SB_{2023}). The projected spawning biomass is based on the current year's recruitment deviations from average as predicted by the Beverton-Holt stock-recruit model, and estimated natural mortality and weight-at-age, both averaged over the most recent 5-years. The Markov chain Monte Carlo (MCMC) sampling procedure follows the same method implemented by Cleary et al. (2019).

Cleary et al. (2019) reported results from two SCA model fits that differed in assumptions about dive survey catchability q_2 (from 1988 to 2022): assessment model 1 (AM1) where q_2 is estimated with a prior distribution assumed; and assessment model 2 (AM2) where $q_2 = 1$. The assumptions that the dive survey spawn index represents all the spawn deposited and that no eggs are lost to predation are strong. However, there is little information in the stock assessment data to inform an estimate of q_2; examination of the Bayes posterior shows the prior is not updated for the HG, CC, SoG, and WCVI SARs, and the estimated value reflects the prior mean (Cleary et al. 2019, Appendix D). Assuming $q_2 = 1$ produces a "minimum" biomass estimate buffering any other assessment and management implementation errors (DFO 2012; Martell et al. 2012). Application of AM1 would remove such safeguards despite recent simulation evaluation showing that large (positive) assessment errors are produced by the current assessment model even with $q_2 = 1$ (DFO 2019). Scaling the assessment with values of $q_2 < 1$ is likely to result in larger absolute assessment errors than those estimated when $q_2 = 1$ (DFO 2019). For these reasons, advice presented here is based on the AM2 parameterization, supported also by comparisons presented in DFO (2016, Table A1), and Cleary et al. (2019, Appendix D).

Analysis and response

COVID-19 pandemic

Unlike the past two years, the COVID-19 pandemic had a minor impact on the collection and analysis of biological data in 2022. Spawn surveys proceeded as usual in 2022, with dive surveys in all major SARs.

Management strategy evaluation

Fisheries and Oceans Canada (DFO) has committed to renewing the current management framework to address a range of challenges facing Pacific Herring stocks and fisheries in BC. Renewal of the management framework for Pacific Herring uses MSE to evaluate the performance of candidate MPs against hypotheses about past and future stock and fishery dynamics. The purpose of the MSE process is to identify and eliminate MPs that incur unacceptable risks to a stock (i.e., poor choices) and identify MPs that provide acceptable outcomes related to conservation and fishery management objectives. The identification of a preferred MP requires a fully specified set of measurable objectives that include reference points (typically categorized as limits and targets) and to the extent possible, specification of measurable objectives related to catch, catch variability, and socio-cultural goals. MSE is an iterative and ongoing process conducted with the participation of First Nations, the fishing industry, as well as government and non-government organizations.

The first MSE cycles for the SoG and WCVI SARs were completed in 2018 (DFO 2019). Steps included OM development (Benson et al. In press), fitting OMs to Pacific Herring stock and fishery monitoring data from 1951 to 2017, and closed-loop simulations of MP performance for alternative future natural mortality scenarios (DFO 2019). In 2019, the MSE process was extended to the HG, PRD, and CC SARs with stock and fishery monitoring data updated to include 2018 and performance evaluation of area specific MPs (DFO 2020a), with subsequent updates outlined in Section “Context”. Results from MP evaluations reflect most recent updates for all SARs.

A core set of fisheries management objectives (DFO 2020a) have been applied to each major SAR:

1. Maintain spawning biomass above the LRP with at least 75% probability over three Pacific Herring generations (i.e., avoid a biomass limit; $P(SB_t > 0.3SB_0) \geq 0.75$),
2. Maintain spawning biomass at or above the USR with at least 50% probability over three Pacific Herring generations (i.e., achieve a target biomass; $P(SB_t \geq 0.6SB_0) \geq 0.5$),
3. Maintain average annual variability (AAV) in catch below 25% over three Pacific Herring generations (i.e., minimize catch variability; AAV < 0.25), and
4. Maximize average annual catch over three Pacific Herring generations (i.e., maximize average catch).

However, a fully specified set of objectives has not yet been developed for each SAR. DFO will continue to collaborate with coastal First Nations to develop area-specific objectives specific to FSC fisheries as well as SOK fisheries. In addition, DFO will continue to engage with the herring industry, government, and non-government organizations to describe broader objectives related to conservation, economics, and access.

MPs for each SAR differ in the form of the HCR and choices of catch cap, but use the same type of monitoring data and assessment model (e.g., Cleary et al. 2019). The current stock assessment model assumes natural mortality is time-varying and this is reflected in the MSE as three hypotheses about future Pacific Herring natural mortality M:

1. M is a time-varying, density-dependent process (DDM),
2. M is a time-varying, density-independent process (DIM), and
3. M is constant over time (conM).

These three hypotheses are captured as three operating model (OM) scenarios in Benson et al. (In press). The DDM scenario was identified as the reference OM scenario based on discussion at the 2018 CSAS review process (DFO 2020a), while the DIM and conM scenarios were identified as robustness OM scenarios. In 2022 we removed the conM scenario from the list of plausible natural mortality hypotheses because MP performance has been found to be consistently over-optimistic. As such, OM updates are presented for the DDM and DIM OM scenarios only.

Several lessons were learned from the MSE analyses conducted so far:

1. The catch-at-age stock assessment model can produce large (positive) assessment errors and in such cases, assessment errors can cause over-estimation of the spawning biomass. However Herring OMs simulate these phenomena and thus assessment errors are accounted for in the MP evaluations.

2. Reduction in harvest rate from 20% to 10% was the most effective means of mitigating stock assessment errors by reducing the absolute size of the catch. The use of a catch cap, implemented as a maximum annual catch level, is an effective model-free way to further mitigate assessment errors at very high biomass levels. Simulation analyses additionally showed that outcomes are insensitive to the choice of operational control points (OCPs) in the HCR when a low harvest rate (HR) and catch cap are applied. This occurs because low biomass levels (associated with the lower OCP) are avoided for these MPs.

3. Differences in specification of Pacific Herring MPs, including HCR components, are expected a priori among SARs. The reasons relate to differences in objectives deemed important by resource users, differences in historical and current stock and fishery dynamics, and differences in the magnitude and direction of assessment model errors in each SAR. Conservation objectives such as those based on avoiding a biological limit reference point (LRP) in alignment with the DFO PA Policy (DFO 2009) are held constant among SARs based on the analyses of Kronlund et al. (2017).

4. There are many possible ways to incorporate MP performance in robustness trials into decision-making but, there is currently no accepted scientific way of combining results from multiple operating models.

5. In situations where multiple MPs meet the agreed upon objectives, further criteria, such as ranking secondary objectives, is needed in order to provide decision-makers with a tractable set of trade-off choices.

6. Outcomes of MP evaluations appear to be more heavily influenced by the last three to five years of stock status and natural mortality trends used to condition the OM. If simulations were run over a greater number of years (e.g., 50 years) performance would start to approach equilibrium and be unaffected by most recent trends in OM conditioning data.

This phenomenon is important to consider when selecting or eliminating MPs, especially if probabilities are considerably different between MP updates.

Input data

There are three types of input data used for the Pacific Herring stock assessment: catch data, biological data, and abundance data. These data are described in the following sections, and summarized in Table 1. Relative to the previous assessment, the only change to input data was to extend all the time series to include the 2021/2022 herring season (July 1 to June 30). Note that we refer to 'year' instead of 'herring season' in this report; therefore 2022 refers to the 2021/2022 Pacific Herring season.

Catch data

For the purposes of stock assessment, catch data are summarized by gear type as described in Table 1 and presented in Figure 2. As in previous years, catch data for the stock assessment model does not include mortality from the commercial SOK fishery, nor any recreational fisheries or food, social, and ceremonial (FSC) harvest. Recreational fisheries and FSC harvest are considered minor relative to commercial harvest. The commercial SOK fishery is licensed based on pounds of validated SOK product (i.e., eggs adhered to kelp), not tonnes of fish used or spawned. Currently there is no basis to validate mortality imposed on the population by this fishery, however methods for estimating SOK mortality are being developed.

Combined commercial removals from 2013 to 2022 from the roe, food and bait, and special use fisheries appear in Table 2. The proportion of coast-wide catch that comes from SoG was 22% in 1990, and 100% in 2022. Total SOK harvest (i.e., pounds of validated product) for the major SARs from 2013 to 2022 is presented in Table 3.

Biological data

Biological samples are collected as described in Cleary et al. (2019) and Table 1. Biological data inputs to the stock assessment are annual weight-at-age (Figure 4) and annual number-at-age, shown as proportion-at-age (Figure 5).

Significant declines in weight-at-age are evident for all major herring stocks from the mid-1980s to 2010. Declining weight-at-age may be due to a number of factors, including fishing effects (i.e., gear selectivity), environmental effects (e.g., changes in ocean productivity), or changes in sampling protocols (e.g., shorter time frame over which samples are collected). Declines in weight-at-age appear to have ceased since 2010.

Abundance data

The spawn index survey collects information on spawn length (i.e., distance parallel to shore), spawn width (i.e., distance perpendicular to shore), number of egg layers by vegetation type, and other data. There are two spawn survey periods defined by the predominant survey method: surface survey period from 1951 to 1987, and dive survey period from 1988 to 2022. Data from these surveys are used to calculate egg density in each spawn. Ultimately, the estimated weight of mature spawners required to produce the egg deposition is calculated and referred to as the 'spawn index'. The 2022 spawn survey followed standard dive survey protocols for the HG, PRD, CC, SoG, and WCVI SARs as described in Cleary et al. (2019). Time series of spawn index by major stock assessment region (SAR) from 1951 to 2022 are summarized in Figure 6. In 2022, there was an increase in survey biomass (i.e., index values) for the PRD and SoG SARs, and a decrease in survey biomass for HG, CC, and WCVI SARs (Figure @ref(fig:major-spawn-index; Tables 4 to 8).

Spatial spawn distribution

Tables 4 through 8 summarize the spatial distribution of survey spawn biomass (i.e., the spawn index) by proportion over the last 10 years for the major SARs. HG and SoG are summarized by Group, while PRD, CC, and WCVI are summarized by Statistical Area; the choice of spatial grouping reflects spawning behaviour and biology for each SAR based on the survey data and working group discussions with local First Nations.

Incidental mortality

In order to advance progress towards a holistic ecosystem-based management (EBM) approach for Pacific Herring, we present information to describe indirect effects on herring populations such as incidental mortality. Some fisheries and aquaculture activities in BC cause incidental mortality to Pacific Herring. Similar to SOK harvest as well as FSC and recreational catch, incidental mortality is currently only indirectly accounted for in Pacific Herring stock assessment by estimating annual rates of natural mortality, and is considered minor relative to commercial harvest.

Again this year, we include data for incidental mortality in finfish aquaculture activities by SAR from 2014 to 2021 (Figure 3). Note that incidental mortality data are reported by Pacific Fishery Management Area (PFMA) which are analogous to Statistical Areas, but PFMAs are larger and can extend beyond SAR boundaries. Data indicate the number of Pacific Herring dead and released, with the following caveats:

1. Data for 2021 are considered incomplete,
2. Unknown mortality rate for “released” fish,
3. Unknown length, weight, age, and sex of fish, and
4. “Herring-like” fish are assumed to be herring when decomposition hinders identification.

Note that we sometimes update data in previous years as DFO receives additional reports.

First Nations observations

The COVID-19 pandemic continues to impact First Nations participation in Pacific Herring survey activities as well as participation in traditional harvest activities such as FSC. In 2022, local observations were provided by coastal First Nations participants for most areas. The following descriptions were provided by First Nations contributors.

Haida Gwaii

The Selwyn Inlet stock has been showing a declining trend for at least the past 10 years. In 2021 the spawn occurred very late in the season (late April), was located in outer Selwyn near Rockfish Harbour, and was very light in deposition. The spawn in 2022 was considered to be more consistent in timing (mid April) and location (inside Selwyn near Traynor Bay), and deposition was better than in 2021, but the herring spawn was still very minimal for Selwyn Inlet standards.

This year in the Skincuttle and Upper Burnaby area, most spawning occurred on the Skincuttle side and on the east side of Burnaby Island out near Scudder Point. This stock is just barely maintaining itself. Abundance is low enough that natural recruitment just barely makes up for natural mortality, so we see some years of slight recovery followed by other years of decline, but no real growth even in the absence of a fishery for almost 20 years. Spawns in 2022 were found to be mostly light to medium in deposition.

The Juan Perez Sound inlets normally support spawns when there are a lot of recruits in the population and first time spawners can out number older repeat spawners. That has not been the case now for some time. Lately spawns have been small and infrequent in the inlets of Juan Perez Sound, as was the case in 2022.

There has not been a significant presence of herring in outer Louscoone for a number of years. In years of abundance, the local stock was always found to be well up inside the inlet and often presented a very light spawn near the head early in the season (early to mid March). This stock seldom exceeded 500 tons, however in recent years it has been much less. Other stocks, found in the outer portions of Louscoone Inlet, are thought to be more migratory and rarely spawn in Louscoone.

There was some effort for the traditional harvest of k'aaw in both Skincuttle Inlet and Selwyn Inlet in early to mid April. There were a few open kelp lines set up in Skincuttle Inlet from which only about 1,000 lb of marginal to good quality k'aaw was harvested. There were open kelp lines set up in the cove just south of Traynor Bay, Selwyn Inlet, but were reported to be unsuccessful due to disturbances by whales in the area. There were no other known attempts to harvest k'aaw on Haida Gwaii during the 2022 herring season.

Prince Rupert District

Observations for PRD had not been provided at the time the draft was submitted.

Central Coast

In 2022, Heiltsuk observed that the herring season spawning behavior was similar to last year where herring spawned sporadically throughout the areas and in different areas than in previous years. This trend seems to be driven by whales, sea lions and seal populations, and water temperature. Younger and smaller age classes spawn in the normal shallower water of 0 to 5 or 10 fathoms, while the older and larger age classes now spawn deeper in 10 to 15 fathoms. The deeper spawn was harder to locate and set kelp and boughs on. The shallower herring spawns lasted a day and a half, and yielded minimal spawn for the spawn on kelp fishery. Predation by whales, seals and sea lions has continued to disrupt and move spawning herring around, causing the deeper water spawns and shifting locations. Water temperature is suspected to influence herring spawning behavior as well as predation. Water temperatures this year and last year have been colder than normal; local fishers identified this as the primary driver for the changing spawning behavior with predation as the second.

Heiltsuk sounding vessels and test boat skippers reported adequate tonnage in areas with estimates of 32,000 to 36,000 tonnes for the CC and shared that this was the low end of their estimate.

Heiltsuk fishers, sounding vessels captains and HIRMD staff observed that the dive survey vessels were late this year and cause for concern. For example, the spawn that took place in Spiller was not surveyed until 12 days afterwards. This delayed survey would have missed the greater portion of surviving spawn after predation. Concerns raised that the overall Central Coast spawn survey may not yield adequate data that reflects the actual biomass.

FSC harvesters in Area 08 observed only brief spot spawns lasting 24 hours or less. Field observation confirmed egg thickness on kelp and branches was limited to one layer for the most part. Herring observed in spawning aggregations were small in size.

Strait of Georgia

In the northern SoG in 2022, spawn observations and ancillary information regarding herring spawning activity was very limited within the Discovery Islands. One spawn was reported and a dive assessment was conducted on this spawn. Generally a second or third spawn occurs in Bute Inlet; however, no observations were made or reported this year. which doesn't indicate it didn't happen. Bute Inlet is very remote. No other indications of spawn activity were observed or reported.

In the southern SoG, the Cowichan Tribes did not actively observe herring spawn but some signs were seen. For example, a huge mass/frenzy of birds were observed in Active Pass on March 4.

West Coast of Vancouver Island

The distribution of herring spawn activity in Barkley Sound was similar to last year, but the duration was shorter and the intensity was less this year. Compared to last year, herring spawn activity in Nootka and Clayoquot Sounds was greater in both distribution and intensity, with a spawn lasting several days in Hesquiaht Harbour. In Nootka, herring spawn was sighted at Port Langford on February 24, at Nuchatlitz and Rosa Harbour on March 3, Yuquot and Santa Gertrudis Cove on March 10, Catala Island on March 13, and outer Bajo Reef on March 15. Most trees set in the Nuchatlaht and Yuquot areas for SOB collection were successful.

Area 24 had the largest spawning event (in terms of distribution and intensity) in over 20 years. A January spawn in a Hesquiaht Harbour was observed, followed by a multi-day spawn in Hesquiaht Harbour from February 24 to March 7. Spawning events were observed again in Hesquiaht Harbour later in March and around Vargas, Stubbs, and Mears (Opisaht) islands. The herring spawn was described as moderate to heavy in most areas.

In Area 23, spawns were small and short in duration around mid-March. The main spawn was around Muscle Beach/Cabbage Rocks to Macoah on March 9 and there was a spot spawn around Spilling Islets on March 10. Most trees set for SOB collections were bare or had one to two layers and so were returned to the water to hatch. A short duration spawn was observed around Mayne Bay, Lyall Point, Pinkerton Islands, St Ines, Stopper Islands, and Toquart Bay on March 27 to 29, but no trees were set as most people had left the area for the season.

Stock status update

Analyses of stock trend information is presented following methods of Cleary et al. (2019) for the Pacific Herring major SARs (AM2 only). As in previous years, Markov chain Monte Carlo (MCMC) runs have chain length 5,000,000 with a sample taken every 1,000$^{\text{th}}$ iteration (i.e., thinning). The first 1,000 samples are discarded (i.e., burn-in), leaving 4,000 samples for posteriors. Perceptions of stock status based on outputs (i.e., posteriors) from the SCA model (i.e., AM2) are summarized for each stock in a multi-panel figure (e.g., Figure 9). The panels show:

a. Model fit to scaled spawn survey data,

b. Instantaneous natural mortality rate M estimates,

c. Number of age-2 recruits,

d. Spawning biomass SB_t and total catch C_t, with reference lines at model estimates of $0.3SB_0$,

e. Recruitment deviations (log scale) from the Beverton-Holt recruitment function, and

f. Spawning biomass production $P_t = SB_{t+1} - SB_t + C_{t+1}$ for the dive survey period, with reference lines at model estimates of $0.3SB_0$.

Note that spawn survey data (i.e., spawn index) is scaled to abundance in panel (a) by the spawn survey scaling parameter q. The spawn index has two distinct periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2022). Thus, two q parameters are implemented in the estimation procedure: q_1 (1951 to 1987) with an uninformative prior, and q_2 (1988 to 2022) with an informative prior approximating 1.0.

The surface survey methodology has been used on occasion from 1988 to 2022. Generally this occurs when herring spawn is observed in locations where a dive survey team is not available, or when spawning occurs very early (e.g., January or February) or late (e.g., May) in the season. In these instances, spawning biomass estimates obtained from surface surveys for a given SAR and year are added to biomass estimates from dive surveys, and $q_2 = 1$ is assumed for the combined index. The Pacific Herring data summaries show the proportion of spawn survey data (i.e., spawn index) from the surface and dive survey methods by SAR and year. Due to the COVID-19 pandemic, only surface surveys were conducted for HG in 2020 and 2021, as well as for PRD in 2020. These surface survey observations are treated as dive survey observations and are assumed to be continuous with the dive survey time series.

Reference points

A biological limit reference point (LRP) is defined for the major Pacific Herring SARs at $0.3SB_0$ (Kronlund et al. 2017). Candidate upper stock reference (USR) points were introduced in Cleary et al. (2019) and implemented as biomass objectives in simulation analyses for WCVI and SoG in 2018 (DFO 2019), and then HG, PRD, and CC in 2019 (DFO 2020a). An analysis of USR options was undertaken in 2022 with results presented in DFO (In press). Five USR options were evaluated:

1. Average spawning biomass during a productive period $\overline{SB}_{Prod}$ (i.e., a B_{MSY} proxy; Table 29),
2. $0.4SB_0$,
3. $0.5SB_0$,
4. $0.6SB_0$, and
5. Average spawning biomass from 1951 to 2022 $\overline{SB}$.

Implementing USRs as target biomass objectives within the simulation-evaluation process allows the evaluation of MPs with respect to achieving USRs, including whether a given USR option can be achieved in the absence of commercial fisheries. Implementation of USRs for major Herring SARs will occur through the 2022/23 draft IFMP.

Stock status relative to assessment model estimates $0.3SB_0$ (i.e., LRP) and USR options are presented for PRD, CC, SoG, and WCVI SARs (Tables 25 through 28).

LRPs and USRs relate stock status to the DFO PA Policy (DFO 2009), and the same calculations are used for each Pacific Herring SAR. There is an important distinction between reference points (e.g., LRP, USR) and operational control points (OCPs) of the harvest control rule (HCR) or the management procedure (MP) used to set catch limits. Specifically, OCPs define the inflection points of a HCR and identify biomass levels where management action is taken, whereas LRPs and USRs are management objectives.

Coast wide trends

Coast wide trends in Pacific Herring biomass and contribution by SAR show an increasing trend in estimated spawning biomass from 2010 to 2020 with low catch variability (Figure 7). We also include total estimated biomass and spawning biomass for each SAR (Figure 8); these trends are presented using median posterior estimates.

Haida Gwaii

Estimated spawning biomass historic lows occurred in the late 1960s predicated by estimated low recruitment and high estimated natural mortality (Figure 9a, b, e). Under variable estimated recruitment, estimated spawning biomass recovered from that point through the early 1980s supported by declining rates of estimated natural mortality. As estimated natural mortality began increasing again in the mid 1990s, estimated biomass reached near historic lows. A reprieve in estimated low biomass was caused by above average estimated recruitment through the late 1990s, before biomass declined to persistent at historic lows from 2000 to 2010 (Figure 9d). Above average estimated recruitment of age-2 fish in 2012 supported modest increases in the spawn index in 2013 and 2015 before falling once again to near historic lows from 2016 to 2018 (Figure 9a, c, d). The increasing trend in the estimated natural mortality rate since 1980 (Figure 9b) largely absorbed surplus production attributed to above average recruitment events (e.g., 1997 and 2012; Figure 9c, d). Estimated natural mortality has declined from a peak around 2002, and has decreased in the last five years. Despite the decline in estimated natural mortality, the HG stock has been in a low biomass state, with many years also showing low productivity which has largely precluded stock growth (Figure 9f). There was an increase in survey biomass in 2019 and 2020, and above-average recruitment of age-2 fish in 2018, and below-average recruitment in 2019, 2020, and 2022. Estimated productivity in 2021/2022 is positive but follows two years of negative productivity. Overall, biomass remains low relative to historic values. The effective harvest rate U_t since 2000 has been at or near zero (Figure 15), with the last commercial roe fishery in 2002, and the last commercial SOK fishery in 2004.

Estimated unfished spawning biomass SB_0 is 22,798 t, and the LRP of $0.3SB_0$ is 6,839 t (posterior medians). Compared to last year, estimated spawning biomass in 2022 SB_{2022} increased from 9,189 to 10,777 t (posterior median), and is equivalent to 46.7% of SB_0 (Tables 19 & 24). Spawning biomass in 2022 is estimated to be above the LRP with a 87.1% probability (Table 24). Management measures to support long-term recovery of herring stocks in Haida Gwaii are being developed through the rebuilding plan process.[1]

Prince Rupert District

Estimated spawning biomass reached historic highs in the early 1960s due to low estimated mortality rate and high estimated recruitment (Figure 10a, b, e). This was followed immediately by below average recruitment and a rise to the highest estimated mortality rate, more than doubling within 10 years. In response the stock collapsed to the lowest estimated spawning biomass. Spawning biomass recovered by the mid-1980s to about 50% of the historic high even amid mostly below-average recruitment (Figure 10b, d, e). In the mid-1980s, estimated spawning biomass steadily declined amid slowly rising mortality rates and variable recruitment, before stabilizing at a relatively low level (but above historic lows) by around 2005, which was maintained until 2018. The estimated spawning biomass has since shown modest increases in biomass with above average age-2 recruitment in 2014, 2017, and 2018, and declining natural mortality (Figure 10c, d, f). Productivity in recent years is relatively high compared to the last 30 years (Figure 10f).

Fluctuations in spawning biomass appear to be less than in other SARs, possibly because some spawn index points are being under- or over-fit (e.g., 2001 to 2004, and 2010 to 2013) as shown in Figure 10a.

Estimated unfished spawning biomass SB_0 is 60,118 t, and the LRP of $0.3SB_0$ is 18,035 t (posterior medians). Compared to last year, estimated spawning biomass in 2022 SB_{2022} increased from 30,686 to 35,938 t (posterior median), and is equivalent to 58.5% of SB_0 (Tables 20 & 25). Spawning biomass in 2022 is estimated to be above the LRP with a 96.7% probability (Table 25). Commercial fisheries have occurred annually in PRD since the mid-1980s, with the exception of 2019 to 2022, during which the effective harvest rate U_t was estimated to be at or below 20% in all years except 1989 (Figure 15). Commercial catches from 2007 to 2018 remained low (below 2,000 t) and there were no commercial catches from 2019 to 2022, except SOK.

Central Coast

Estimated spawning biomass reached a historic high around 1980 following low estimated natural mortality rates and one of the highest estimated recruitments in 1979 (Figure 11a, b, c). From there a decline in estimated spawning biomass appears to be influenced initially by higher estimated natural mortality rates and highly variable estimated recruitment. An increase in estimated natural mortality lead to historically low estimated biomass levels from 2005 to 2015. Decreasing estimated natural mortality lead to moderate increases in biomass through 2020. In 2021 and 2022, increasing estimated natural mortality caused a decrease in estimated biomass, which has been mitigated in part by higher than average estimated recruitment (Figure 11a, b, e). Model estimates suggest similar spawning biomass in 2021 and 2022 (Table 21), and the analysis of surplus production shows evidence of strong production in 2016/2017 and 2018/2019, similar to the 1990 to 1999 period (Figure 11f). However, surplus production is estimated to be negative in from 2019 to 2021 and near zero for 2021/2022.

An examination of spawn biomass by herring Section shows the recent decline in herring spawn to have largely occurred in Spiller Channel (Sections 072 and 078) and Kitasu Bay/East Higgins (Section 067; Figure 12). The majority of Area 07 spawn in 2021 and 2022 is concentrated in Thompson/Stryker (Section 074). Occurrence of spawn in Thompson/Stryker from 2020 to 2022 represents the first significant spawns in this Section in many years. The mechanisms driving spawn fluctuations in the Central Coast are not well understood.

A fixed cutoff HCR was implemented in 1986, and from 1986 to 2007 the effective harvest rate U_t is estimated to fluctuate above and below the 20% target rate, with median estimates exceeding 20% in some of these years (Figure 15). Occurrences of U_t exceeding the 20% target harvest rate are due in part to positive assessment model errors, and lags in detecting a directional change in the trend.

Following a commercial fishery closure from 2007 to 2013, the CC SAR was reopened to commercial fisheries; commercial roe fisheries occurred in 2014, 2015, and 2016. Commercial SOK fisheries operated yearly from 2014 to 2019, and in 2021. SOK removals are not included in the estimation of U_t. A commercial SOK fishery did not occur in Area 07 in 2020 due to COVID-19, and was not permitted in 2022 (Table 3).

Estimated unfished spawning biomass SB_0 is 51,702 t, and the LRP of $0.3SB_0$ is 15,511 t (posterior medians). Compared to last year, estimated spawning biomass in 2022 SB_{2022} decreased from 23,453 to 23,010 t (posterior median), and is equivalent to 44.3% of SB_0

(Tables 21 & 26). Spawning biomass in 2022 is estimated to be above the LRP with a 87.7% probability (Table 26).

Strait of Georgia

The estimated spawning biomass for the SoG SAR had a historical low in the late 1960's, driven by lower than average estimated recruitment and increasing estimated natural mortality (Figure 13a, b, e). Following this, estimated spawning biomass increased as natural mortality declined (Figure 13b, d). Some declines in estimated biomass in the mid 1980's and around 2008 were mitigated by above-average recruitment. From 2010 to 2020 there is an increasing trend in estimated spawning biomass caused by above-average estimated recruitment (Figure 13b, d, e).

From 2015 to 2022 estimated natural mortality has been increasing, after a previously long stable period from 1980 to 2010. Biomass declines due to increasing mortality have been mitigated by above-average estimated recruitment in most years from 2010 to 2022, with estimated recruitment at an all time high in 2022 (Figure 13e). Estimated production was high in 2017/2018 and then declined in the last three years (Figure 13f). In 2022 estimated spawning biomass was similar to 2021, and was consistent with the forecast.

There is large uncertainty for the last few years of spawning biomass and forecast biomass SB_{2023} (Figure 13d). The large uncertainty in both spawning biomass and natural mortality estimates in 2022 may be in part a function of large opposing fluctuations in the spawn index (Figure 13a) and uncertainty in estimated age-2 recruitment. The large uncertainty around estimated age-2 recruitment in 2019 and 2020 was observed in the previous years' assessment and remains apparent now that these age-2 fish are fully recruited to the fishery and sampling gear. Analysis of surplus production shows that the SoG SAR was in high biomass state with neutral production in 2019/2020, and that production was negative for 2021/2022 (Figure 13f).

Commercial fisheries have occurred annually in SoG since the early-1970s (following the stock collapse of the late 1960s). Since implementing the fixed cutoff HCR in 1986, the effective harvest rate U_t is estimated to fluctuate above and below the 20% target rate, with median estimates distributed evenly above and below 20% (Figure 15). The model estimates the median effective harvest rate exceeded 25% in 2006 and 2017.

Estimated unfished spawning biomass SB_0 is 141,721 t, and the LRP of $0.3SB_0$ is 42,516 t (posterior medians). Compared to last year, estimated spawning biomass in 2022 SB_{2022} decreased from 83,746 to 71,163 t (posterior median), and is equivalent to 48.9% of SB_0 (Tables 22 & 27). Spawning biomass in 2022 is estimated to be above the LRP with a 89.8% probability (Table 27).

West Coast of Vancouver Island

The time series of estimated spawning biomass reached an estimated peak in the mid to late 1970s during a time period of the lowest estimated natural mortality and variable estimated recruitment (Figure 14a, b, c). From the late 1980s through to around 2008 a variable increase in estimated mortality and a generally variable but low recruitment led to decline trend, down from the peaks observed in the late 1970s (Figure 14a, b, c).

The low estimated spawning biomass persisted from 2006 to 2012, influenced by negative recruitment deviations (i.e., lower than predicted by the stock-recruit function) and the highest estimated natural mortality rates since 1951 (Figure 14a, b, f). Some increases in estimated biomass were made in the 2010s with lower estimated natural mortality and higher estimated recruitment in 2015. Since then estimated natural mortality has again increased. Biomass and production has been maintained in part by higher than average estimated recruitment in 2020 and 2021 (Figure 14 d, f). The model reconstruction of spawning biomass closely follows the trajectory of spawn index values (Figure 14a).

The absence of a commercial fishery since 2005 means the realized harvest rate has been zero for the last 15 years (Figure 15). There is modest evidence for an increase in biomass above the LRP since 2016 and positive production estimates in 2019/2020 and 2020/2021 (Figure 14f).

Investigation of WCVI MCMC diagnostics revealed autocorrelation in the estimation of fishery selectivity-at-50% ($\hat{a}_1$) and its standard deviation ($\hat{\gamma}_1$) for the “other” fisheries category (i.e., reduction, food and bait, as well as special use). Autocorrelation in parameter estimation may indicate bias in the posterior distribution or local minima. In this instance, autocorrelation likely resulting from there being no new commercial fishery data since 2005. Running longer chains in 2021 resulted in only minor improvements (DFO 2021b). If and when fisheries resume in the future, the addition of new fishery data may reduce this apparent autocorrelation and any resulting bias.

Estimated unfished spawning biomass SB_0 is 44,457 t, and the LRP of $0.3SB_0$ is 13,337 t (posterior medians). Compared to last year, estimated spawning biomass in 2022 SB_{2022} increased from 21,882 to 23,506 t (posterior median), and is equivalent to 52.7% of SB_0 (Tables 23 & 28). Spawning biomass in 2022 is estimated to be above the LRP with a 94.2% probability (Table 28).

Management performance

Management procedure performance can be investigated using the time series of effective harvest rate U. Estimated effective harvest rate U in each year t is $U_t = C_t/(C_t + SB_t)$, where C_t is catch in year t, and SB_t is estimated spawning biomass in year t. Time series of U_t relative to the target harvest rate of 20% are presented in Figure 15.

Application of MPs and harvest options for 2023

Harvest options for 2023 reflect application of simulation-tested MPs for each major SAR, derived from the Herring OM (Benson et al. 2022). OM conditioning was updated using the latest historic stock and fishery data from 1951 to 2021. MPs are not provided for HG because this is now conducted within the rebuilding plan process.

Haida Gwaii

The HG stock persisted in a low biomass state from approximately 2000 to 2018 (Figure 9). The stock was below the LRP for much of that period and shows little evidence of sustained stock growth despite the absence of commercial fisheries since 2002 (and since 2004 for the SOK fishery). Survey biomass increased from 2019 to 2020, remained stable in 2021, and declined from 2021 to 2022. Spawn biomass production was positive in 2021. Results of the simulation-evaluations found that none of the proposed MPs, including the historical and no fishing MPs, maintained spawning biomass above the LRP with high probability (i.e., at least 75%, DFO 2009).[2]

[2]“High” probability is defined as 75 to 95% by the DFO decision-making framework (DFO 2009).

In the absence of fishing, spawning biomass in 2023 SB_{2023} is forecast to be 13,458 t (posterior median; Table 24). Spawning biomass in 2023 is forecast to be below the LRP of $0.3SB_0$ (6,839 t) with a 7.6% probability, in the absence of fishing (Table 24 and Figure 16).

DFO has committed to developing and implementing a rebuilding plan for Haida Gwaii Pacific Herring. Work finalizing the draft for consultation continues via a technical working group comprised of members of the Council of Haida Nation, DFO, and Parks Canada. The consultation period is anticipated to commence in fall 2022. Guidance for developing rebuilding plans (DFO 2013) states that the primary objective of any rebuilding plan is to promote stock growth out of the Critical Zone (i.e., to grow the stock above the status-based LRP) by ensuring removals from all fishing sources are kept to the lowest possible level until the stock has cleared this zone with high probability. However, stock rebuilding does not end having met this goal, and one of the goals of the rebuilding plan will be to identify candidate threshold biomass levels greater than the LRP that are consistent with a rebuilt state.

Based on MP evaluations and the ongoing rebuilding plan process, the harvest recommendation for the HG stock in 2023 is 0 t. Because Haida Gwaii has an on-going rebuilding plan process, we did not update HG MP evaluations with recent data.

Prince Rupert District

The PRD estimated stock biomass showed little trend from 2005 to 2018, fluctuating at or near the LRP of $0.3SB_0$ (Figure 10d). Spawning biomass increased above $0.3SB_0$ in 2019 and has remained above since. Adjacent SARs (i.e., HG and CC) show evidence of recent prolonged periods of low biomass and low productivity; however these states were entered rapidly and were preceded by high biomass levels (Kronlund et al. 2017).

In the summer of 2022, we updated the conditioning of the OM for PRD with 2021 spawn, catch, and biological data. We re-ran MSE simulations to generate updated probability values for MPs presented in 2019 (DFO 2020b) and 2020 (DFO 2021c). These latest MP evaluations also appear in DFO (In press). No new MPs were included, however probability metrics for the five USRs options (DFO In press) were estimated and have been added to the harvest options tables. Updated closed-loop feedback simulations for PRD show that MPs with harvest rates at 5, 10, and 20% maintain spawning biomass above the LRP with 85 to 98% probability, over both OM scenarios (Table 30). The mean effective harvest rate U_t for the past 10 years with non-zero catches (from 2009 to 2018) is 10% (Figure 15).

While MPs with harvest rates ranging from 5% to 20% were able to meet the core conservation objective of maintaining spawning biomass above the LRP with high probability (i.e., at least 75%)[2], they also imply different trade-offs among biomass and yield objectives. Since multiple MPs meet the conservation objective, other socio-economic reasons may drive the choice for a particular MP.

In the absence of fishing, spawning biomass in 2023 SB_{2023} is forecast to be 36,296 t (posterior median; Table 25). Spawning biomass in 2023 is forecast to be below the LRP of $0.3SB_0$ (18,035 t) with a 4.8% probability, in the absence of fishing (Table 25 and Figure 16).

Harvest options for 2023, resulting from simulation-tested MPs are presented in Table 30 and include probability values that reflect updated OM conditioning. Options reflect application of MPs to the 2023 forecast biomass for PRD, whereby each MP meets the conservation objective with a minimum 75% probability under both DDM and DIM OM scenarios. For ease of comparison with MP performance evaluation, harvest options are presented along side MP performance metrics for both OM scenarios (Table 30).

Central Coast

The CC stock persisted in a low biomass, low productivity state from approximately 2005 to 2014. In years since, an increasing trend has been observed in all but the most recent two years (Figure 11a).

In the summer of 2022, we updated the conditioning of the MSE operating model for CC with 2021 spawn, catch, and biological data. These latest MP evaluations also appear in DFO (In press). No new MPs were included however probability metrics for the five USRs options (DFO In press) were estimated and have been added to the harvest options tables. The updated simulations show that MPs with harvest rates at 5% and 10% maintain spawning biomass above the LRP with 81 to 92% probability over all both OM scenarios (Table 31). The mean effective harvest rate U_t for the past 10 years with non-zero catches (from 2001 to 2016) is 12% (Figure 15).

Harvest options listed in Table 31 reflect application of MPs to the 2023 forecast biomass for CC, whereby each MP meets the conservation objective with a minimum 75% probability under both DDM or DIM OM scenarios.

Since multiple MPs meet the conservation objective of maintaining spawning biomass above the LRP with at least 75%, other socio-economic objectives may drive the choice for a particular MP. Additionally, the current CC OM is unable to directly address Heilstuk Nation conservation objectives related to herring age and size, nor objectives on a finer spatial scale or those specific to SOK fisheries. These limitations exist for all five major stocks.

In the absence of fishing, spawning biomass in 2023 SB_{2023} is forecast to be 18,656 t (posterior median; Table 26). Spawning biomass in 2023 is forecast to be below the LRP of $0.3SB_0$ (15,511 t) with a 33.0% probability, in the absence of fishing (Table 26 and Figure 16).

Finally, DFO acknowledges commitment to the Heiltsuk Nation for the development of a Joint Fisheries Management Plan for Pacific Herring in the Central Coast in 2023. Results presented here may inform this ongoing commitment.

Strait of Georgia

The SoG has the largest biomass of the major SARs and comprises more than 50% of the total coast wide biomass (Figure 7). Estimated spawning biomass trends remained stable and high from 2011 through 2020 despite increases in estimated natural mortality rates in the last three to five years. SoG MP evaluations are implemented using the Herring OM (Benson et al. 2022) and were first presented in 2018 (DFO 2019). MP updates were conducted in 2020 (DFO 2021a) and again herein. Each update shows differences in MP performance against the conservation objective for both OM scenarios. Initial simulations show the probability of meeting the conservation objective ranges from 91% to 100% (DFO 2019), depending on the scenario and MP. Subsequent updates in 2020 show a decline in conservation performance with probabilities ranging from 75% to 88% (DDM and DIM only, DFO (2021a)), and the updates included here show probabilities ranging from 67% to 87% (Table 32).

These comparisons highlight the importance of considering the lessons learned from the MSE process (Section “Management strategy evaluation”) when selecting or rejecting MPs. In this case it may be important to consider how the recent MP updates may be influenced by the the last three to five years of natural mortality trends used to condition the OM (Table 32).

MSE updates presented here show the conservation objective is met with the minimum 75% probability when simulating MPs with 10% and 15% harvest rates. However MPs with 20%

harvest rates (e.g., HS30-60_HR20 and minE30_HR20), which previously met the minimum 75% probability level (DFO (2019) and DFO (2021a)) now show probability values ranging from 67% to 74% (across both DDM and DIM OMs).

In situations where estimated natural mortality trends show a sudden increasing or decreasing trend in the terminal three to five years, MP evaluations may more reliably reflect the relative ranking of MP performance, as opposed to realized short term performance. In all cases the simulated MP performance from previous years can inform selection or elimination of MPs.

In the absence of fishing, spawning biomass in 2023 SB_{2023} is forecast to be 61,792 t (posterior median; Table 27). Spawning biomass in 2023 is forecast to be below the LRP of $0.3SB_0$ (42,516 t) with a 19.6% probability, in the absence of fishing (Table 27 and Figure 16).

The mean effective harvest rate U_t for the past 10 years with non-zero catches (from 2013 to 2022) is 18% (Figure 15). Harvest options for 2023, resulting from simulation-tested MPs, are presented in Table 32. These options reflect application of MPs to the 2023 forecast biomass for SoG, whereby each MP meets (or has been shown to meet) the conservation objective with a minimum 75% probability. All MPs and scenarios listed in Table 32 include updated performance metrics under both scenarios (DFO 2021a).

West Coast of Vancouver Island

The WCVI stock persisted in a low biomass, low productivity state from approximately 2004 to 2014. In recent years, biomass remained low relative to historic levels, but above the LRP of $0.3SB_0$.

In 2022, with updated 2021 data, closed-loop feedback simulations for WCVI show the conservation objective is met under the DDM OM scenario with between 80 and 84% probability, and the same MPs failed to meet the conservation objective under the DIM OM scenario, where natural mortality rates are most similar to the last 10 years ($p =$ 61 to 65%).

In the absence of fishing, spawning biomass in 2023 SB_{2023} is forecast to be 20,298 t (posterior median; Table 28). Spawning biomass in 2023 is forecast to be below the LRP of $0.3SB_0$ (13,337 t) with a 15.0% probability, in the absence of fishing (Table 28 and Figure 16).

Harvest options for 2023, resulting from simulation-tested MPs, are presented in Table 33. These options reflect application of MPs to the 2023 forecast biomass for WCVI, under the two OM scenarios. All MPs and scenarios listed in Table 33 include updated performance metrics under both scenarios (DFO 2021a).

Conclusions

The 2022 Science Response includes formal analyses of stock trend information for the Pacific Herring major SARs using the stock assessment framework reviewed in 2017 (Cleary et al. 2019) with data updated to include 2022.

DFO has committed to developing and implementing a rebuilding plan for Haida Gwaii Pacific Herring. Based on MP evaluations, the harvest recommendation for the HG SAR is 0 t.

The MSE process identifies a range of MPs that meet the conservation objective with at least 75% probability for the PRD, CC, SoG, and WCVI SARs for the DDM reference OM scenario (DFO 2020a, 2021a). Harvest options or MP calculations for 2023 for these four SARs is combined with MP evaluations (probabilities) arising from the latest MSE update. Tables also include MP performance and harvest options for the DIM robustness OM scenario (Tables 30 to 33).

Science advice for the minor SARs is limited to presentation of catch data, biological data, and spawn survey data (Section "Minor stock assessment regions"). Similarly, science advice for the special area, Area 10 is limited to presentation of catch data, biological data, and spawn survey data (Section "Special areas").

Tables

Table 1. Input data for the 2022 Pacific Herring statistical catch-age model for the major SARs. The spawn index has two distinct periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2022). Note: the 'spawn index' is not scaled by the spawn survey scaling parameter q.

Source	Data	Years
Roe gillnet fishery	Catch	1972 to 2022
Roe seine fishery	Catch	1972 to 2022
Other fisheries	Catch	1951 to 2022
Test fishery (seine)	Biological: number-at-age	1975 to 2022
Test fishery (seine)	Biological: weight-at-age	1975 to 2022
Roe seine fishery	Biological: number-at-age	1972 to 2022
Roe seine fishery	Biological: weight-at-age	1972 to 2022
Roe gillnet fishery	Biological: number-at-age	1972 to 2022
Other fisheries	Biological: number-at-age	1951 to 2022
Other fisheries	Biological: weight-at-age	1951 to 2022
Surface survey	Abundance: spawn index	1951 to 1987
Dive survey	Abundance: spawn index	1988 to 2022

Table 2. Total landed Pacific Herring catch in tonnes from 2013 to 2022 in the major stock assessment regions (SARs). Legend: Haida Gwaii (HG), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SoG), and West Coast of Vancouver Island (WCVI). Note: 'WP' indicates that data are withheld due to privacy concerns.

	SAR				
Year	HG	PRD	CC	SoG	WCVI
2013	0	2,027	0	16,547	0
2014	0	2,003	687	20,310	0
2015	0	2,163	626	19,968	0
2016	0	2,425	213	21,310	0
2017	0	2,849	0	25,279	0
2018	0	417	0	19,067	0
2019	0	0	0	21,419	0
2020	0	0	0	10,439	0
2021	0	0	0	14,396	0
2022	0	0	0	4,672	0

Table 3. Total Pacific Herring spawn-on-kelp harvest, reported as pounds of eggs on kelp, from 2013 to 2022 in the major stock assessment regions (SARs). See Table 2 for description.

	SAR				
Year	**HG**	**PRD**	**CC**	**SoG**	**WCVI**
2013	0	72,895	0	0	0
2014	0	113,269	239,861	0	0
2015	0	84,066	169,470	0	0
2016	0	WP	351,953	0	0
2017	0	82,597	392,747	0	0
2018	0	20,832	289,358	0	0
2019	0	WP	356,042	0	0
2020	0	0	44,857	0	0
2021	0	0	294,269	0	0
2022	0	0	0	0	0

Table 4. Haida Gwaii SAR: spawn index in tonnes for Pacific Herring and proportion of spawn index by Group from 2013 to 2022. Legend: 'Cumshewa/Selwyn' is Section 023 and 024; 'Juan Perez/Skincuttle' is Sections 021 and 025; and 'Louscoone' is Section 006. Note: the 'spawn index' is not scaled by the spawn survey scaling parameter q, and 'NA' indicates that data are not available.

		Proportion		
Year	**Spawn index**	**Cumshewa/Selwyn**	**Juan Perez/Skincuttle**	**Louscoone**
2013	16,025	0.057	0.864	0.079
2014	10,566	0.068	0.932	0.000
2015	13,102	0.060	0.940	0.000
2016	6,888	0.053	0.947	0.000
2017	3,016	0.018	0.982	0.000
2018	4,588	0.234	0.766	0.000
2019	11,624	0.065	0.919	0.016
2020	20,423	0.077	0.923	0.000
2021	18,234	0.025	0.975	0.000
2022	5,281	0.150	0.850	0.000

Table 5. Prince Rupert District SAR: spawn index in tonnes for Pacific Herring and proportion of spawn index by Statistical Area from 2013 to 2022. See Table 4 for description.

		Proportion		
Year	**Spawn index**	**03**	**04**	**05**
2013	25,755	0.026	0.750	0.224
2014	17,125	0.148	0.595	0.257
2015	17,407	0.056	0.756	0.188
2016	18,985	0.007	0.808	0.185
2017	19,235	0.052	0.632	0.317
2018	14,155	0.057	0.667	0.277
2019	27,190	0.010	0.452	0.538
2020	25,845	0.026	0.542	0.432
2021	33,062	0.068	0.717	0.214
2022	35,220	0.001	0.793	0.207

Table 6. Central Coast SAR: spawn index in tonnes for Pacific Herring and proportion of spawn index by Statistical Area from 2013 to 2022. See Table 4 for description.

		Proportion		
Year	**Spawn index**	**06**	**07**	**08**
2013	20,369	0.217	0.777	0.006
2014	13,309	0.287	0.673	0.040
2015	32,146	0.223	0.706	0.072
2016	32,508	0.245	0.726	0.028
2017	23,517	0.359	0.584	0.057
2018	12,264	0.322	0.626	0.052
2019	46,255	0.323	0.641	0.036
2020	42,713	0.417	0.550	0.033
2021	28,674	0.257	0.697	0.045
2022	22,711	0.259	0.703	0.038

Table 7. Strait of Georgia SAR: spawn index in tonnes for Pacific Herring and proportion of spawn index by Group from 2013 to 2022. Legend: '14&17' is Statistical Areas 14 and 17 (excluding Section 173); 'ESoG' is eastern Strait of Georgia; 'Lazo' is above Cape Lazo; and 'SDodd' is South of Dodd Narrows. See Table 4 for description.

		Proportion			
Year	**Spawn index**	**14&17**	**ESoG**	**Lazo**	**SDodd**
2013	83,693	0.928	0.000	0.055	0.016
2014	120,468	0.758	0.020	0.212	0.010
2015	104,481	0.525	0.014	0.354	0.106
2016	129,502	0.902	0.000	0.090	0.009
2017	81,064	0.806	0.000	0.194	0.000
2018	91,939	0.984	0.001	0.014	0.000
2019	63,038	0.985	0.001	0.014	0.000
2020	116,151	0.758	0.109	0.126	0.007
2021	70,938	0.773	0.032	0.196	0.000
2022	85,817	0.804	0.020	0.154	0.021

Table 8. West Coast of Vancouver Island SAR: spawn index in tonnes for Pacific Herring and proportion of spawn index by Statistical Area from 2013 to 2022. See Table 4 for description.

		Proportion		
Year	**Spawn index**	**23**	**24**	**25**
2013	12,258	0.337	0.061	0.602
2014	13,937	0.631	0.093	0.276
2015	11,323	0.372	0.185	0.442
2016	20,528	0.577	0.266	0.157
2017	16,476	0.320	0.138	0.542
2018	28,107	0.331	0.194	0.475
2019	17,030	0.228	0.163	0.610
2020	18,761	0.562	0.288	0.150
2021	29,339	0.150	0.728	0.122
2022	23,707	0.243	0.503	0.254

Table 9. Haida Gwaii SAR: key parameters in the Pacific Herring statistical catch-age model. Parameters are summarised by posterior (5th, 50th, and 95th percentile) and maximum posterior density (MPD) estimates. Legend: R_0 is unfished age-2 recruitment; h is steepness of the stock-recruitment relationship; M is instantaneous natural mortality rate; $\overline{R}$ is average age-2 recruitment from 1951 to 2022; $\overline{R}_{init}$ is average age-2 recruitment in 1950; ρ is the fraction of total variance associated with observation error; ϑ is the precision of total error; q is catchability for surface (1951 to 1987; q_1) and dive (1988 to 2022; q_2) survey periods; τ is the standard deviation of process error (i.e., recruitment); and σ is the standard deviation of observation error (i.e., survey index). Note: τ and σ are calculated values.

Parameter	5%	50%	95%	MPD
R_0	188.180	248.409	339.616	249.530
h	0.656	0.789	0.896	0.810
M	0.219	0.403	0.735	0.370
$\overline{R}$	127.034	152.784	183.710	160.741
$\overline{R}_{init}$	8.599	29.583	206.839	31.734
ρ	0.228	0.290	0.361	0.280
ϑ	0.744	0.909	1.084	0.976
q_1	0.350	0.429	0.524	0.420
q_2	0.983	0.999	1.016	0.998
τ	0.790	0.883	0.996	0.859
σ	0.497	0.564	0.643	0.536

Table 10. Prince Rupert District SAR: key parameters in the Pacific Herring statistical catch-age model. See Table 9 for description.

Parameter	5%	50%	95%	MPD
R_0	246.237	324.271	494.224	309.075
h	0.522	0.684	0.841	0.717
M	0.250	0.446	0.753	0.427
$\overline{R}$	166.662	193.477	224.175	200.253
$\overline{R}_{init}$	63.719	210.091	1,054.318	250.507
ρ	0.210	0.275	0.353	0.272
ϑ	0.968	1.187	1.426	1.266
q_1	0.479	0.560	0.647	0.549
q_2	0.985	1.001	1.017	1.001
τ	0.695	0.780	0.884	0.758
σ	0.416	0.481	0.556	0.464

Table 11. Central Coast SAR: key parameters in the Pacific Herring statistical catch-age model. See Table 9 for description.

Parameter	5%	50%	95%	MPD
R_0	330.556	416.765	543.936	404.411
h	0.665	0.794	0.902	0.817
M	0.263	0.480	0.806	0.450
$\overline{R}$	243.592	275.811	312.951	276.943
$\overline{R}_{init}$	51.968	202.024	1,182.953	267.824
ρ	0.175	0.235	0.309	0.214
ϑ	0.998	1.214	1.452	1.290
q_1	0.275	0.320	0.372	0.323
q_2	0.983	0.999	1.016	0.999
τ	0.709	0.793	0.891	0.780
σ	0.379	0.439	0.510	0.407

Table 12. Strait of Georgia SAR: key parameters in the Pacific Herring statistical catch-age model. See Table 9 for description.

Parameter	5%	50%	95%	MPD
R_0	1,389.342	1,739.825	2,539.313	1,659.370
h	0.549	0.709	0.850	0.744
M	0.261	0.467	0.783	0.451
$\overline{R}$	952.224	1,098.080	1,279.658	1,125.740
$\overline{R}_{init}$	41.433	156.399	979.075	271.656
ρ	0.201	0.269	0.352	0.255
ϑ	1.218	1.495	1.829	1.594
q_1	0.865	1.040	1.224	1.029
q_2	0.983	1.000	1.016	0.999
τ	0.616	0.697	0.791	0.683
σ	0.366	0.424	0.493	0.400

Table 13. West Coast of Vancouver Island SAR: key parameters in the Pacific Herring statistical catch-age model. See Table 9 for description.

Parameter	5%	50%	95%	MPD
R_0	452.919	574.558	753.969	562.844
h	0.604	0.727	0.854	0.740
M	0.341	0.608	1.017	0.583
$\overline{R}$	334.319	382.485	442.342	386.293
$\overline{R}_{init}$	33.035	164.404	1,277.463	262.713
ρ	0.236	0.307	0.385	0.294
ϑ	1.108	1.338	1.604	1.439
q_1	0.704	0.842	0.991	0.851
q_2	0.983	0.999	1.015	0.999
τ	0.640	0.718	0.810	0.701
σ	0.418	0.477	0.546	0.452

Table 14. Haida Gwaii SAR: age-2 recruitment from 2013 to 2022 for the Pacific Herring statistical catch-age model. Recruitment in millions is summarised by posterior (5th, 50th, and 95th percentile) and maximum posterior density (MPD) estimates.

Year	5%	50%	95%	MPD
2013	44.728	67.069	99.151	68.817
2014	68.315	101.767	152.472	106.092
2015	50.311	74.304	110.738	77.142
2016	100.773	150.912	224.220	157.524
2017	164.105	240.484	351.275	251.668
2018	320.649	472.712	690.625	496.140
2019	29.383	49.941	86.336	51.311
2020	19.770	33.663	59.345	34.137
2021	103.345	169.174	276.279	171.401
2022	39.132	71.613	136.564	71.347

Table 15. Prince Rupert District SAR: age-2 recruitment from 2013 to 2022 for the Pacific Herring statistical catch-age model. See Table 14 for description.

Year	5%	50%	95%	MPD
2013	57.678	82.199	117.166	85.066
2014	300.188	421.109	585.931	436.362
2015	133.982	191.344	274.770	199.339
2016	62.333	96.028	147.493	101.337
2017	211.028	310.067	447.783	321.257
2018	581.650	816.129	1,154.045	848.536
2019	35.068	55.292	88.268	56.870
2020	142.406	230.490	367.285	233.497
2021	95.747	199.124	375.070	208.472
2022	65.068	210.016	656.947	205.557

Table 16. Central Coast SAR: age-2 recruitment from 2013 to 2022 for the Pacific Herring statistical catch-age model. See Table 14 for description.

Year	5%	50%	95%	MPD
2013	129.140	168.842	219.346	169.337
2014	382.352	499.428	645.228	503.803
2015	126.894	170.423	228.251	172.166
2016	143.264	190.082	254.394	193.059
2017	200.815	265.584	354.923	271.928
2018	861.380	1,132.910	1,491.991	1,163.510
2019	56.337	80.019	112.464	81.636
2020	358.211	511.555	724.973	524.423
2021	203.243	328.940	526.194	331.019
2022	510.030	829.755	1,328.516	836.008

Table 17. Strait of Georgia SAR: age-2 recruitment from 2013 to 2022 for the Pacific Herring statistical catch-age model. See Table 14 for description.

Year	5%	50%	95%	MPD
2013	1,253.243	1,599.345	1,995.570	1,610.790
2014	1,371.551	1,745.235	2,183.153	1,757.110
2015	1,168.841	1,507.765	1,940.248	1,520.410
2016	1,040.248	1,354.880	1,768.911	1,376.520
2017	1,049.778	1,372.540	1,802.729	1,399.270
2018	1,196.700	1,555.925	2,047.919	1,587.240
2019	2,412.344	3,221.240	4,256.904	3,274.050
2020	1,762.244	2,386.575	3,256.604	2,417.640
2021	993.205	1,371.680	1,910.300	1,381.280
2022	3,106.754	4,613.985	6,727.992	4,578.950

Table 18. West Coast of Vancouver Island SAR: age-2 recruitment from 2013 to 2022 for the Pacific Herring statistical catch-age model. See Table 14 for description.

Year	5%	50%	95%	MPD
2013	237.024	322.724	440.980	323.819
2014	189.646	258.547	346.866	259.198
2015	671.327	893.572	1,195.411	904.328
2016	100.355	136.529	186.553	138.220
2017	105.190	142.568	193.856	144.279
2018	325.736	447.992	611.724	456.339
2019	228.294	314.569	443.067	322.471
2020	629.332	906.124	1,304.005	928.469
2021	528.806	780.672	1,176.588	795.460
2022	349.246	569.599	940.055	564.951

Table 19. Haida Gwaii SAR: spawning biomass and depletion from 2013 to 2022 for the Pacific Herring statistical catch-age model. Spawning biomass and depletion are summarised by the posterior (5th, 50th, and 95th percentile) and maximum posterior density (MPD) estimates in thousands of tonnes. Note: depletion is relative spawning biomass SB_t/SB_0, where SB_t is spawning biomass in year t, and SB_0 is estimated unfished spawning biomass.

	Spawning biomass				Depletion			
Year	5%	50%	95%	MPD	5%	50%	95%	MPD
2013	8.975	12.001	15.875	12.193	0.353	0.523	0.749	0.559
2014	6.810	9.114	12.061	9.211	0.268	0.396	0.570	0.422
2015	4.955	6.664	8.827	6.710	0.196	0.291	0.421	0.308
2016	3.986	5.424	7.272	5.455	0.158	0.239	0.344	0.250
2017	5.104	7.070	9.722	7.098	0.201	0.311	0.454	0.325
2018	7.706	10.700	14.850	10.767	0.304	0.470	0.701	0.493
2019	9.844	13.502	18.927	13.458	0.387	0.593	0.893	0.617
2020	8.115	11.230	15.547	10.847	0.325	0.493	0.730	0.497
2021	6.222	9.189	13.614	8.719	0.255	0.401	0.628	0.400
2022	5.749	10.777	18.975	10.164	0.246	0.467	0.844	0.466

Table 20. Prince Rupert District SAR: spawning biomass and depletion from 2013 to 2022 for the Pacific Herring statistical catch-age model. See Table 19 for description.

	Spawning biomass				Depletion			
Year	5%	50%	95%	MPD	5%	50%	95%	MPD
2013	13.773	16.876	20.756	17.133	0.172	0.280	0.399	0.309
2014	12.868	15.829	19.572	16.097	0.160	0.263	0.377	0.290
2015	14.920	18.684	23.426	19.032	0.186	0.310	0.449	0.343
2016	13.035	16.490	20.905	16.726	0.164	0.273	0.399	0.301
2017	11.467	15.001	19.590	15.124	0.147	0.248	0.363	0.273
2018	15.229	19.759	25.895	19.746	0.195	0.327	0.473	0.356
2019	24.691	32.311	42.674	31.879	0.325	0.536	0.779	0.575
2020	22.860	30.427	40.949	29.439	0.312	0.504	0.731	0.531
2021	21.675	30.686	43.484	29.225	0.307	0.504	0.762	0.527
2022	21.700	35.938	56.547	33.560	0.326	0.585	0.955	0.605

Table 21. Central Coast SAR: spawning biomass and depletion from 2013 to 2022 for the Pacific Herring statistical catch-age model. See Table 19 for description.

	Spawning biomass				Depletion			
Year	5%	50%	95%	MPD	5%	50%	95%	MPD
2013	12.433	15.488	19.336	15.527	0.216	0.298	0.409	0.313
2014	13.158	16.567	20.678	16.666	0.229	0.320	0.437	0.336
2015	16.440	20.615	25.735	20.875	0.283	0.398	0.545	0.421
2016	16.270	20.344	25.471	20.677	0.279	0.393	0.534	0.417
2017	15.965	20.080	25.237	20.520	0.277	0.389	0.532	0.413
2018	17.933	22.990	29.180	23.433	0.311	0.444	0.609	0.472
2019	25.678	33.740	44.194	34.327	0.451	0.653	0.906	0.692
2020	21.735	28.639	37.640	28.815	0.385	0.554	0.771	0.581
2021	16.968	23.453	32.347	23.201	0.309	0.454	0.641	0.467
2022	12.999	23.010	39.470	22.384	0.249	0.443	0.763	0.451

Table 22. Strait of Georgia SAR: spawning biomass and depletion from 2013 to 2022 for the Pacific Herring statistical catch-age model. See Table 19 for description.

	Spawning biomass				Depletion			
Year	5%	50%	95%	MPD	5%	50%	95%	MPD
2013	60.318	70.988	83.018	70.988	0.298	0.499	0.670	0.531
2014	67.805	80.293	94.599	80.406	0.333	0.563	0.760	0.602
2015	65.471	77.424	92.163	77.866	0.321	0.544	0.735	0.583
2016	66.409	78.279	93.112	78.823	0.327	0.550	0.743	0.590
2017	58.954	69.684	83.573	70.471	0.293	0.488	0.666	0.528
2018	58.384	69.874	84.830	70.548	0.297	0.490	0.675	0.528
2019	64.531	80.594	101.772	81.086	0.337	0.563	0.794	0.607
2020	76.106	96.092	122.217	95.314	0.406	0.667	0.938	0.714
2021	62.348	83.746	110.628	81.679	0.350	0.582	0.826	0.612
2022	41.600	71.163	115.208	68.219	0.249	0.489	0.827	0.511

Table 23. West Coast of Vancouver Island SAR: spawning biomass and depletion from 2013 to 2022 for the Pacific Herring statistical catch-age model. See Table 19 for description.

	Spawning biomass				Depletion			
Year	**5%**	**50%**	**95%**	**MPD**	**5%**	**50%**	**95%**	**MPD**
2013	6.595	8.454	10.722	8.412	0.133	0.189	0.263	0.194
2014	9.435	12.261	15.773	12.244	0.190	0.274	0.380	0.283
2015	13.434	17.222	21.946	17.318	0.269	0.384	0.535	0.400
2016	18.112	23.212	29.824	23.568	0.368	0.521	0.719	0.544
2017	14.106	18.165	23.182	18.384	0.288	0.408	0.559	0.425
2018	12.331	16.182	21.070	16.314	0.253	0.364	0.500	0.377
2019	12.065	16.306	21.854	16.377	0.254	0.367	0.514	0.378
2020	13.542	18.418	24.623	18.293	0.287	0.411	0.582	0.423
2021	15.544	21.882	30.848	21.405	0.332	0.488	0.715	0.495
2022	13.263	23.506	40.789	22.683	0.294	0.527	0.915	0.524

Table 24. Haida Gwaii SAR: proposed reference points for the Pacific Herring statistical catch-age model. Reference points are summarised by posterior (5th, 50th, and 95th percentile) estimates. All biomass numbers are in thousands of tonnes. Legend: SB_0 is estimated unfished spawning biomass; SB_t is spawning biomass in year t; and SB_{2023} is projected spawning biomass in 2023 assuming no fishing. Note that the age-10 class is a 'plus group' which includes fish ages 10 and older.

Reference point	**5%**	**50%**	**95%**
SB_0	18.179	22.798	29.565
$0.3SB_0$	5.454	6.839	8.870
SB_{2022}	5.749	10.777	18.975
SB_{2022}/SB_0	0.246	0.467	0.844
$SB_{2022}/0.3SB_0$	0.819	1.556	2.814
$P\ (SB_{2022} < 0.3SB_0)$	-	0.128	-
SB_{2023}	6.176	13.458	29.564
SB_{2023}/SB_0	0.272	0.582	1.297
$SB_{2023}/0.3SB_0$	0.906	1.940	4.324
$P\ (SB_{2023} < 0.3SB_0)$	-	0.076	-
$P\ (SB_{2023} < 0.6SB_0)$	-	0.527	-
Proportion aged 3	0.08	0.30	0.67
Proportion aged 4 to 10	0.25	0.56	0.81

Table 25. Prince Rupert District SAR: proposed reference points for the Pacific Herring statistical catch-age model. See Table 24 for description.

Reference point	5%	50%	95%
SB_0	45.856	60.118	92.585
$0.3SB_0$	13.757	18.035	27.776
SB_{2022}	21.700	35.938	56.547
SB_{2022}/SB_0	0.326	0.585	0.955
$SB_{2022}/0.3SB_0$	1.085	1.951	3.183
$P\ (SB_{2022} < 0.3SB_0)$	-	0.033	-
SB_{2023}	19.969	36.296	63.012
SB_{2023}/SB_0	0.303	0.588	1.061
$SB_{2023}/0.3SB_0$	1.010	1.959	3.535
$P\ (SB_{2023} < 0.3SB_0)$	-	0.048	-
$P\ (SB_{2023} < 0.6SB_0)$	-	0.523	-
Proportion aged 3	0.05	0.18	0.47
Proportion aged 4 to 10	0.48	0.75	0.90

Table 26. Central Coast SAR: proposed reference points for the Pacific Herring statistical catch-age model. See Table 24 for description.

Reference point	5%	50%	95%
SB_0	41.691	51.702	66.631
$0.3SB_0$	12.507	15.511	19.989
SB_{2022}	12.999	23.010	39.470
SB_{2022}/SB_0	0.249	0.443	0.763
$SB_{2022}/0.3SB_0$	0.831	1.478	2.545
$P\ (SB_{2022} < 0.3SB_0)$	-	0.123	-
SB_{2023}	9.551	18.656	38.018
SB_{2023}/SB_0	0.183	0.359	0.727
$SB_{2023}/0.3SB_0$	0.611	1.198	2.422
$P\ (SB_{2023} < 0.3SB_0)$	-	0.330	-
$P\ (SB_{2023} < 0.6SB_0)$	-	0.888	-
Proportion aged 3	0.08	0.26	0.59
Proportion aged 4 to 10	0.33	0.60	0.82

Table 27. Strait of Georgia SAR: proposed reference points for the Pacific Herring statistical catch-age model. See Table 24 for description.

Reference point	5%	50%	95%
SB_0	111.298	141.721	229.122
$0.3SB_0$	33.389	42.516	68.737
SB_{2022}	41.600	71.163	115.208
SB_{2022}/SB_0	0.249	0.489	0.827
$SB_{2022}/0.3SB_0$	0.831	1.630	2.757
$P\ (SB_{2022} < 0.3SB_0)$	-	0.102	-
SB_{2023}	33.032	61.792	122.514
SB_{2023}/SB_0	0.209	0.424	0.819
$SB_{2023}/0.3SB_0$	0.697	1.414	2.729
$P\ (SB_{2023} < 0.3SB_0)$	-	0.196	-
$P\ (SB_{2023} < 0.6SB_0)$	-	0.804	-
Proportion aged 3	0.11	0.30	0.60
Proportion aged 4 to 10	0.29	0.53	0.75

Table 28. West Coast of Vancouver Island SAR: proposed reference points for the Pacific Herring statistical catch-age model. See Table 24 for description.

Reference point	5%	50%	95%
SB_0	36.169	44.457	56.706
$0.3SB_0$	10.851	13.337	17.012
SB_{2022}	13.263	23.506	40.789
SB_{2022}/SB_0	0.294	0.527	0.915
$SB_{2022}/0.3SB_0$	0.978	1.756	3.049
$P\ (SB_{2022} < 0.3SB_0)$	-	0.058	-
SB_{2023}	10.365	20.298	40.080
SB_{2023}/SB_0	0.232	0.453	0.892
$SB_{2023}/0.3SB_0$	0.774	1.509	2.973
$P\ (SB_{2023} < 0.3SB_0)$	-	0.150	-
$P\ (SB_{2023} < 0.6SB_0)$	-	0.752	-
Proportion aged 3	0.09	0.26	0.56
Proportion aged 4 to 10	0.32	0.57	0.78

Table 29. Year range for calculating average spawning biomass of Pacific Herring during a productive period $\overline{SB}_{Prod}$ in the major stock assessment regions (SARs). Note: Haida Gwaii is excluded because this is conducted within the rebuilding plan process.

SAR	Years
Prince Rupert District	1983 to 1992
Central Coast	1990 to 1999
Strait of Georgia	1988 to 2007
West Coast of Vancouver Island	1990 to 1999

Table 30. Prince Rupert District SAR: management procedure (MP) performance for the Pacific Herring statistical catch-age model. Performance metrics are given for two operating model (OM) scenarios: density-dependent natural mortality (DDM) and density-independent natural mortality (DIM). Performance criteria are calculated over three Pacific Herring generations (i.e., 15 years) from the start of the projection period for all objectives (Obj). MPs are ordered within each scenario by performance of achieving Objective 1. The recommended total allowable catch (TAC) and associated harvest rate (HR) are calculated for each MP using posterior densities values. Legend: limit reference point (LRP); upper stock reference (USR); P is probability; maximum (Max); SB_t is spawning biomass in year t; SB_0 is estimated unfished spawning biomass; $\overline{SB}_{Prod}$ is average spawning biomass during a productive period (Table 29); $\overline{SB}$ is average spawning biomass; average annual variability (AAV); and $\overline{C}$ is average catch. MPs are defined in DFO (2019) and DFO (2020a). Biomass and catch are in thousands of tonnes (t). Note: 'NA' indicates that TAC and HR do not apply, either because the MP specifies no fishing at current projected biomass level, or the MP specifies no fishing. The Herring Industry Advisory Board objective is reported as $0.4SB_0$.

Scenario		Conservation Obj 1 (LRP) $P \geq 75\%$	USR options					Yield Obj 3 $< 25\%$	Yield Obj 4 Max	2023	
OM	**MP**	$SB_t > 0.3SB_0$	$\geq \overline{SB}_{Prod}$	$\geq 0.4SB_0$	$\geq 0.5SB_0$	$\geq 0.6SB_0$	$\geq \overline{SB}$	**AAV**	$\overline{C}$	**TAC**	**HR**
DDM	NoFish_FSC	98%	86%	93%	89%	81%	95%	0.00	0.14	NA	NA
DDM	HS50-60_HR20_cap2.5	97%	80%	92%	83%	73%	92%	36.62	2.13	2.50	0.05
DDM	HS30-60_HR05	97%	82%	92%	84%	75%	92%	45.71	2.33	1.62	0.05
DDM	HS30-60_HR10_cap2.5	96%	79%	91%	83%	73%	91%	26.53	2.25	2.50	0.05
DDM	minE50_HR10	96%	79%	89%	63%	77%	87%	39.83	4.21	3.29	0.10
DDM	minE30_HR10	94%	67%	86%	74%	61%	84%	30.73	4.48	3.62	0.10
DDM	minE50_HR20	93%	55%	81%	64%	48%	78%	50.09	6.43	5.22	0.15
DIM	NoFish_FSC	94%	71%	87%	76%	65%	87%	0.00	0.14	NA	NA
DIM	HS30-60_HR05	93%	65%	83%	71%	57%	82%	51.69	1.82	1.62	0.05
DIM	HS50-60_HR20_cap2.5	92%	63%	82%	69%	56%	80%	42.60	1.96	2.50	0.05
DIM	HS30-60_HR10_cap2.5	91%	61%	80%	68%	55%	78%	35.58	2.07	2.50	0.05
DIM	minE50_HR10	89%	56%	78%	63%	49%	74%	52.38	3.35	3.29	0.10
DIM	minE30_HR10	87%	52%	74%	59%	47%	70%	33.96	3.77	3.62	0.10
DIM	minE50_HR20	85%	31%	68%	38%	51%	64%	63.44	5.10	5.22	0.15

Table 31. Central Coast SAR: management procedure performance for the Pacific Herring statistical catch-age model. See Table 30 for description.

Scenario		Conservation Obj 1 (LRP) $P \geq 75\%$	USR options					Yield Obj 3 $< 25\%$	Yield Obj 4 Max	2023	
OM	**MP**	$SB_t > 0.3SB_0$	$\geq \overline{SB}_{Prod}$	$\geq 0.4SB_0$	$\geq 0.5SB_0$	$\geq 0.6SB_0$	$\geq \overline{SB}$	**AAV**	$\overline{C}$	**TAC**	**HR**
DDM	NoFish_FSC	92%	69%	83%	76%	68%	78%	0.00	0.14	NA	NA
DDM	HS30-60_HR05	91%	64%	82%	73%	62%	74%	40.76	1.74	0.18	0.01
DDM	minE50_HR10	90%	58%	81%	69%	56%	70%	53.22	2.92	0.00	0.00
DDM	HS30-60_HR10_cap5	90%	58%	80%	68%	56%	69%	38.83	2.92	0.36	0.02
DIM	NoFish_FSC	85%	54%	74%	64%	51%	65%	0.00	0.14	NA	NA
DIM	HS30-60_HR05	83%	48%	71%	58%	44%	59%	50.38	1.38	0.18	0.01
DIM	minE50_HR10	82%	43%	68%	52%	40%	54%	70.82	2.21	0.00	0.00
DIM	HS30-60_HR10_cap5	81%	43%	67%	52%	40%	54%	52.19	2.45	0.36	0.02

Table 32. Strait of Georgia SAR: management procedure performance for the Pacific Herring statistical catch-age model. See Table 30 for description.

		Conservation						Yield			
		Obj 1 (LRP)						Obj 3	Obj 4		
Scenario		$P \geq 75\%$	USR options					$< 25\%$	Max	2023	
OM	**MP**	$SB_t > 0.3SB_0$	$\geq 0.8\overline{SB}_{Prod}$	$\geq 0.4SB_0$	$\geq 0.5SB_0$	$\geq 0.6SB_0$	$\geq \overline{SB}$	**AAV**	$\overline{C}$	**TAC**	**HR**
DDM	NoFish_FSC	80%	60%	68%	54%	41%	65%	0.00	0.14	NA	NA
DDM	HS30-60_HR10	77%	53%	63%	46%	33%	59%	69.87	4.92	2.50	0.04
DDM	minE30_HR10	76%	50%	60%	44%	31%	57%	47.88	6.15	6.01	0.10
DDM	HS30-60_HR15	76%	49%	59%	42%	27%	56%	64.75	6.97	3.75	0.06
DDM	HS30-60_HR20	74%	44%	54%	23%	37%	52%	65.70	8.80	5.00	0.08
DDM	minE30_HR15	73%	45%	54%	39%	25%	53%	45.96	8.59	8.97	0.15
DDM	minE30_HR20	70%	39%	50%	33%	20%	48%	49.45	10.79	11.81	0.20
DIM	NoFish_FSC	78%	57%	65%	51%	41%	63%	0.00	0.14	NA	NA
DIM	HS30-60_HR10	75%	51%	59%	45%	33%	58%	71.39	4.58	2.50	0.04
DIM	minE30_HR10	74%	51%	59%	45%	33%	58%	67.87	4.36	6.01	0.10
DIM	HS30-60_HR15	73%	48%	56%	41%	28%	55%	68.93	6.48	3.75	0.06
DIM	HS30-60_HR20	72%	43%	52%	37%	23%	51%	67.81	8.18	5.00	0.08
DIM	minE30_HR15	70%	45%	53%	38%	26%	52%	50.49	7.88	8.97	0.15
DIM	minE30_HR20	67%	40%	49%	34%	21%	47%	48.10	10.04	11.81	0.20

Table 33. West Coast of Vancouver Island SAR: management procedure performance for the Pacific Herring statistical catch-age model. See Table 30 for description. Note that representation of Nuu-chah-nulth objectives has been modified this year: $0.75SB_0$ is reported as $\overline{SB}_{Prod}$ (calculated over three herring generations), SB_{AVE} appears as $\overline{SB}$, and $0.65SB_0$ is omitted.

Scenario		Conservation Obj 1 (LRP) $P \geq 75\%$	USR options					Yield Obj 3 $< 25\%$	Yield Obj 4 Max	2023	
OM	**MP**	$SB_t > 0.3SB_0$	$\geq \overline{SB}_{Prod}$	$\geq 0.4SB_0$	$\geq 0.5SB_0$	$\geq 0.6SB_0$	$\geq \overline{SB}$	**AAV**	$\overline{C}$	**TAC**	**HR**
DDM	NoFish_FSC	84%	33%	71%	57%	45%	43%	0.00	0.14	NA	NA
DDM	minE30_HR05	82%	27%	68%	54%	41%	39%	59.45	1.01	1.01	0.05
DDM	HS30-60_HR10_cap2	82%	27%	67%	53%	40%	38%	60.72	1.15	1.02	0.05
DDM	HS50-60_HR10	82%	25%	67%	52%	37%	36%	89.73	1.28	0.00	0.00
DDM	HS30-60_HR15_cap2	81%	27%	67%	53%	40%	39%	57.13	1.30	1.53	0.06
DDM	HS50-60_HR15	81%	23%	64%	48%	33%	32%	82.56	2.08	0.00	0.00
DDM	minE30_HR10	80%	24%	65%	50%	35%	34%	75.21	1.87	2.03	0.10
DIM	NoFish_FSC	65%	17%	51%	36%	25%	25%	0.00	0.14	NA	NA
DIM	HS30-60_HR10_cap2	63%	15%	48%	32%	21%	22%	71.81	0.79	1.02	0.05
DIM	minE30_HR05	63%	15%	48%	32%	22%	22%	70.09	0.76	1.01	0.05
DIM	HS30-60_HR15_cap2	62%	15%	47%	31%	21%	22%	80.94	0.83	1.53	0.06
DIM	HS50-60_HR10	62%	14%	46%	30%	20%	20%	96.54	0.72	0.00	0.00
DIM	HS50-60_HR15	61%	12%	44%	28%	18%	19%	107.55	1.00	0.00	0.00
DIM	minE30_HR10	61%	13%	43%	29%	19%	20%	83.98	1.26	2.03	0.10

Figures

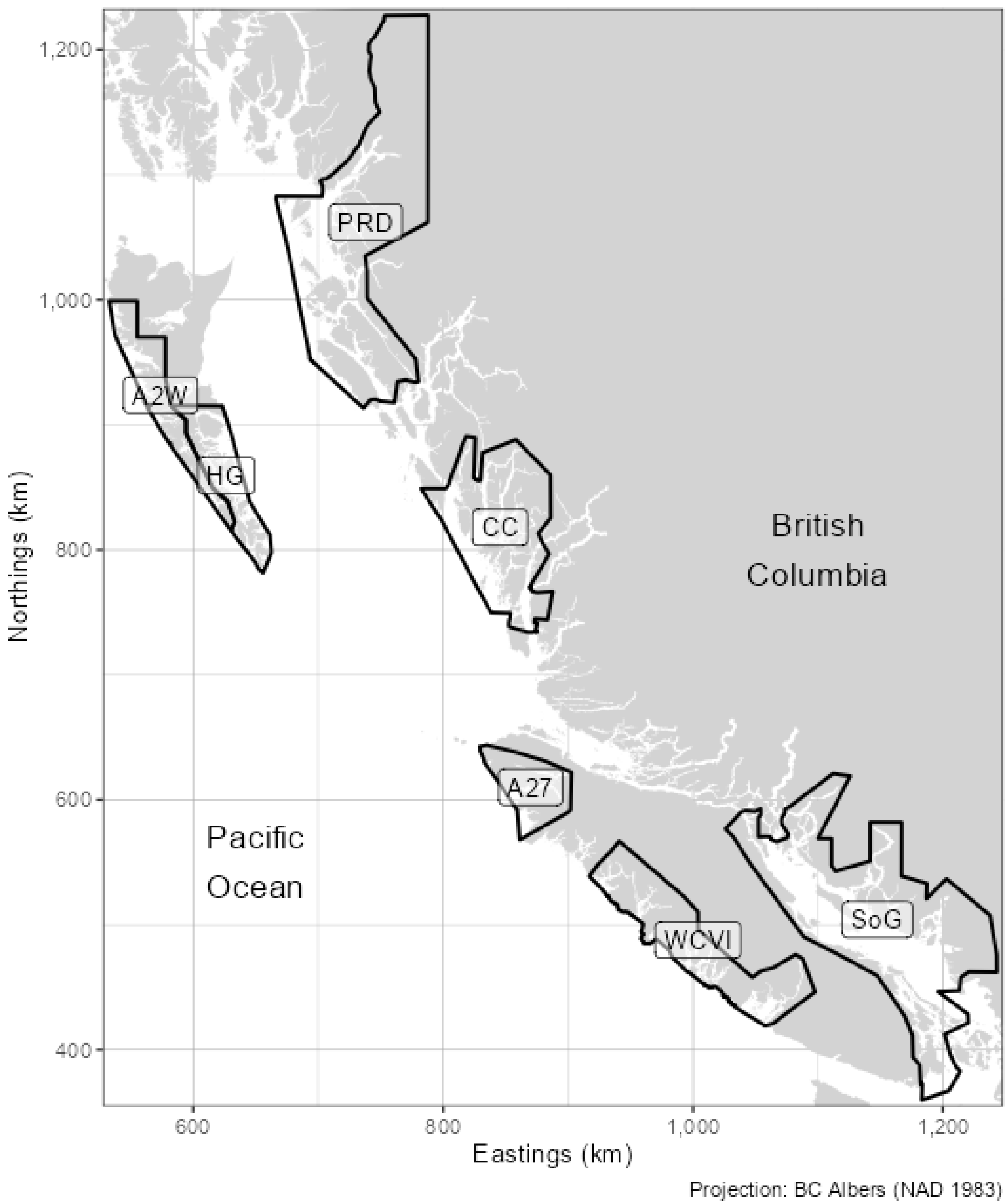

Figure 1. Boundaries for Pacific Herring SARs in British Columbia. The major SARs are Haida Gwaii (HG), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SoG), and West Coast of Vancouver Island (WCVI). The minor SARs are Area 27 (A27) and Area 2 West (A2W). Units: kilometres (km).

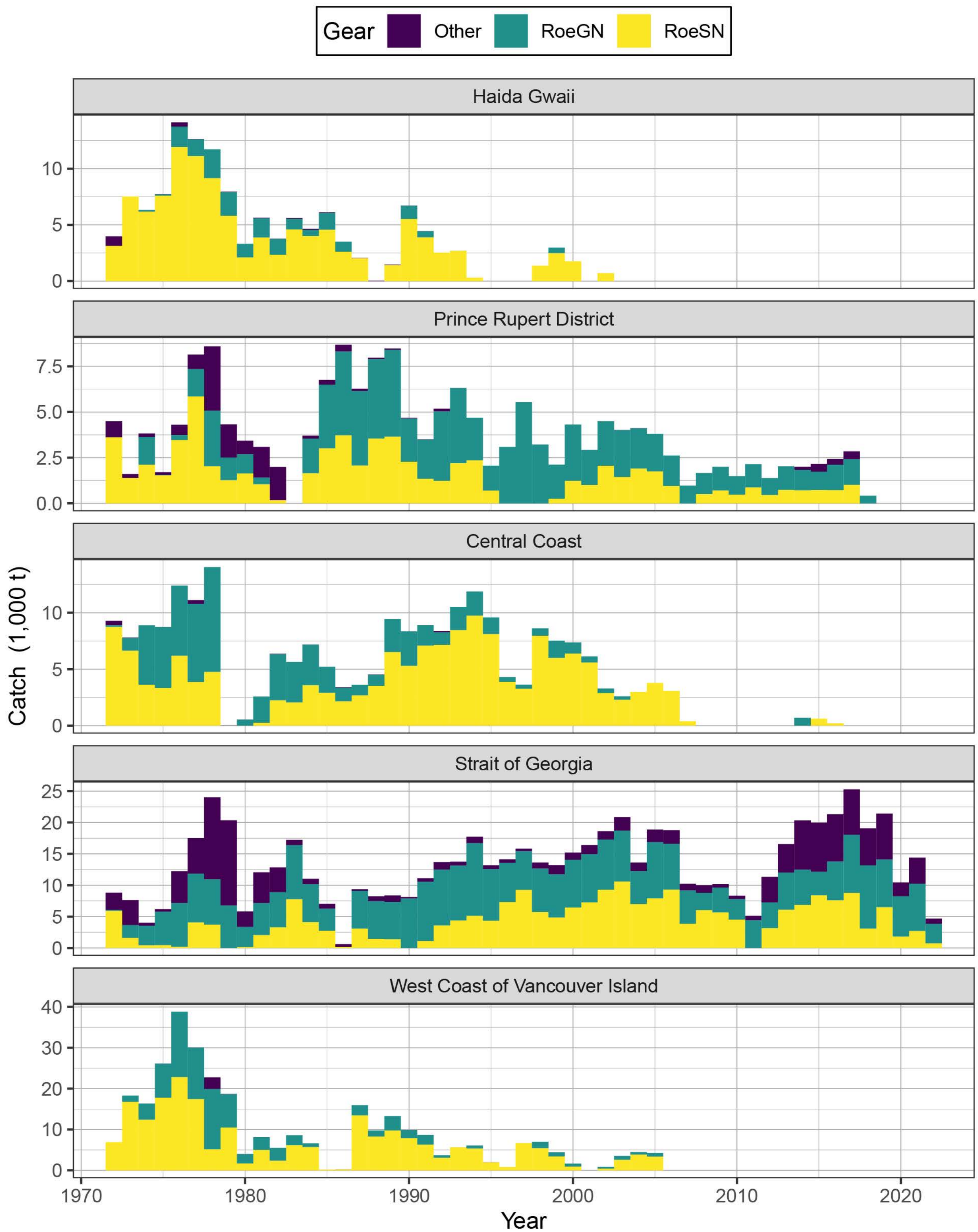

Figure 2. Total landed Pacific Herring catch in thousands of tonnes (t) from 1972 to 2022 in the major SARs. See Figures 9 to 14 for catches during the reduction period (1951 to 1971). Legend: 'Other' represents the reduction, the food and bait, as well as the special use fishery; 'RoeGN' represents the roe gillnet fishery; and 'RoeSN' represents the roe seine fishery.

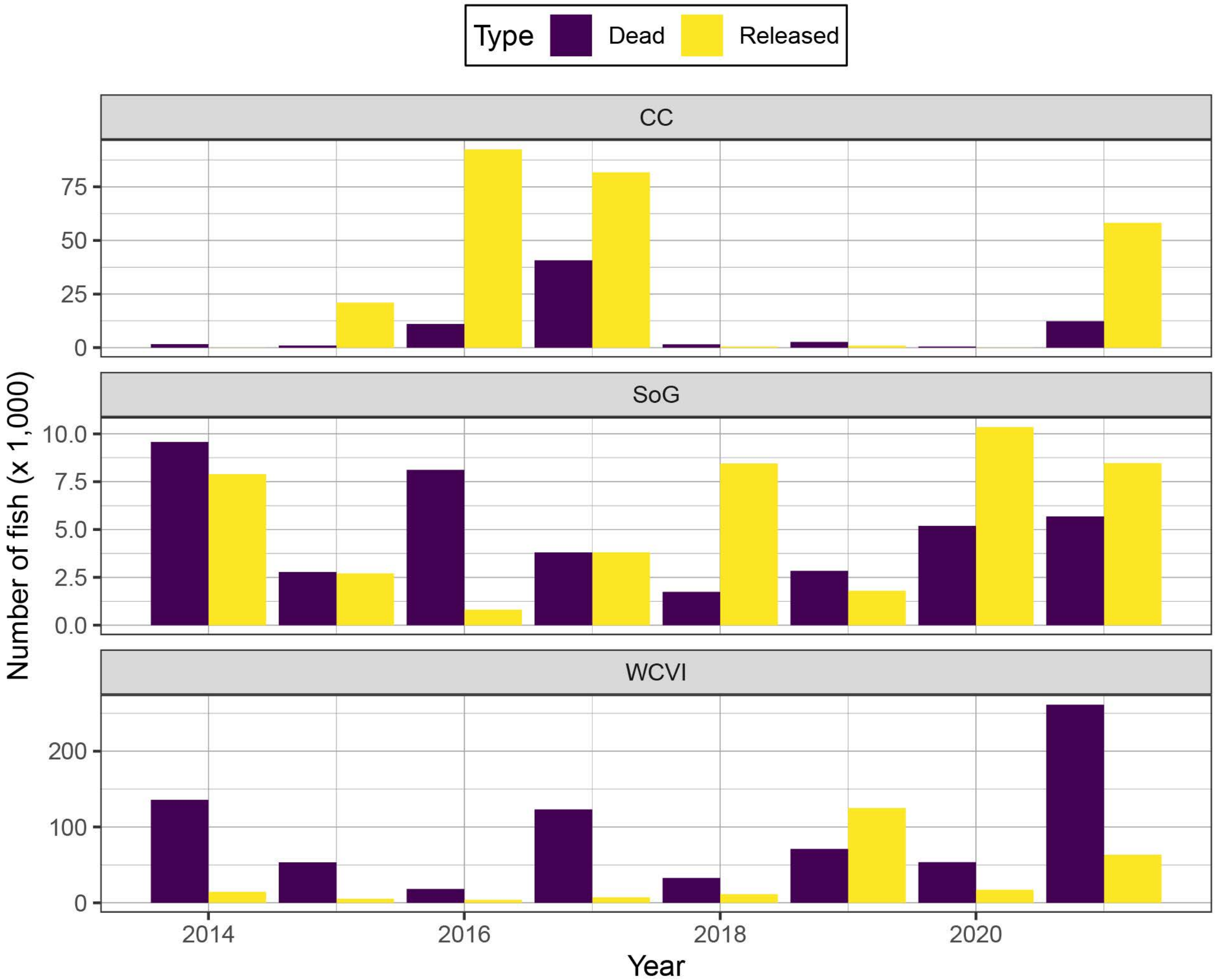

Figure 3. Incidental Pacific Herring mortality in aquaculture activities in thousands of fish from 2014 to 2021 in the major SARs. Notes: data for 2021 may be incomplete, figure may include data outside SAR boundaries, and figure excludes SARs with no reported incidental mortality.

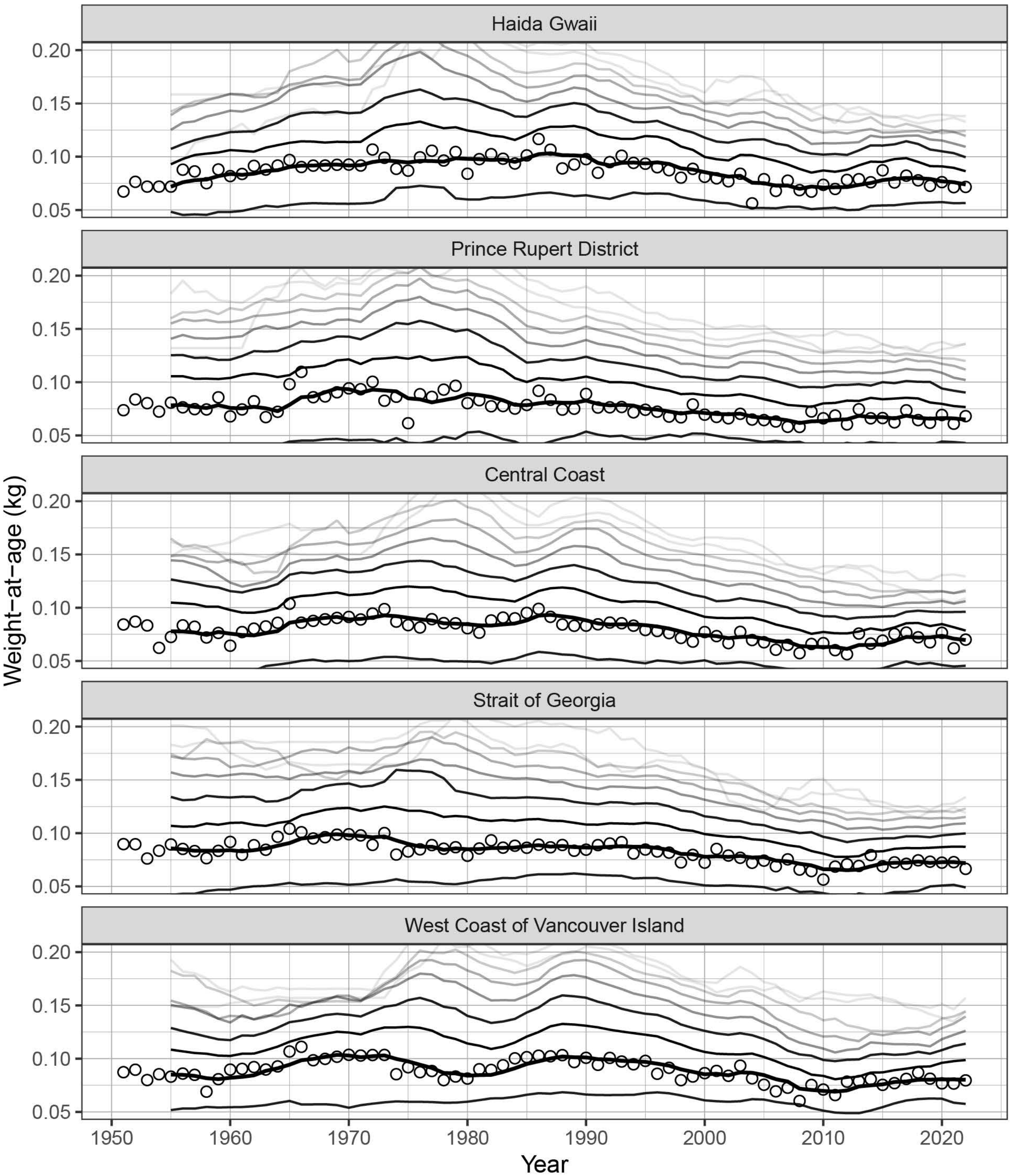

Figure 4. Mean weight-at-age for Pacific Herring in kilograms (kg) from 1951 to 2022 in the major SARs. Lines show 5-year running means for age-2 to age-10 herring, incrementing up from bottom line and shaded from darker to lighter, except thickest line shows age-3 herring. Circles show mean for age-3 herring. In years where there are no biological samples for an age class, values are imputed as the mean of the previous 5 years, except for the beginning of the time series which are imputed by extending the first non-missing value backwards. Biological summaries only include samples collected using seine nets (commercial and test) due to size-selectivity of other gear types such as gillnet. The age-10 class includes fish ages 10 and older. Vertical axes are cropped at 0.05 to 0.20 kg.

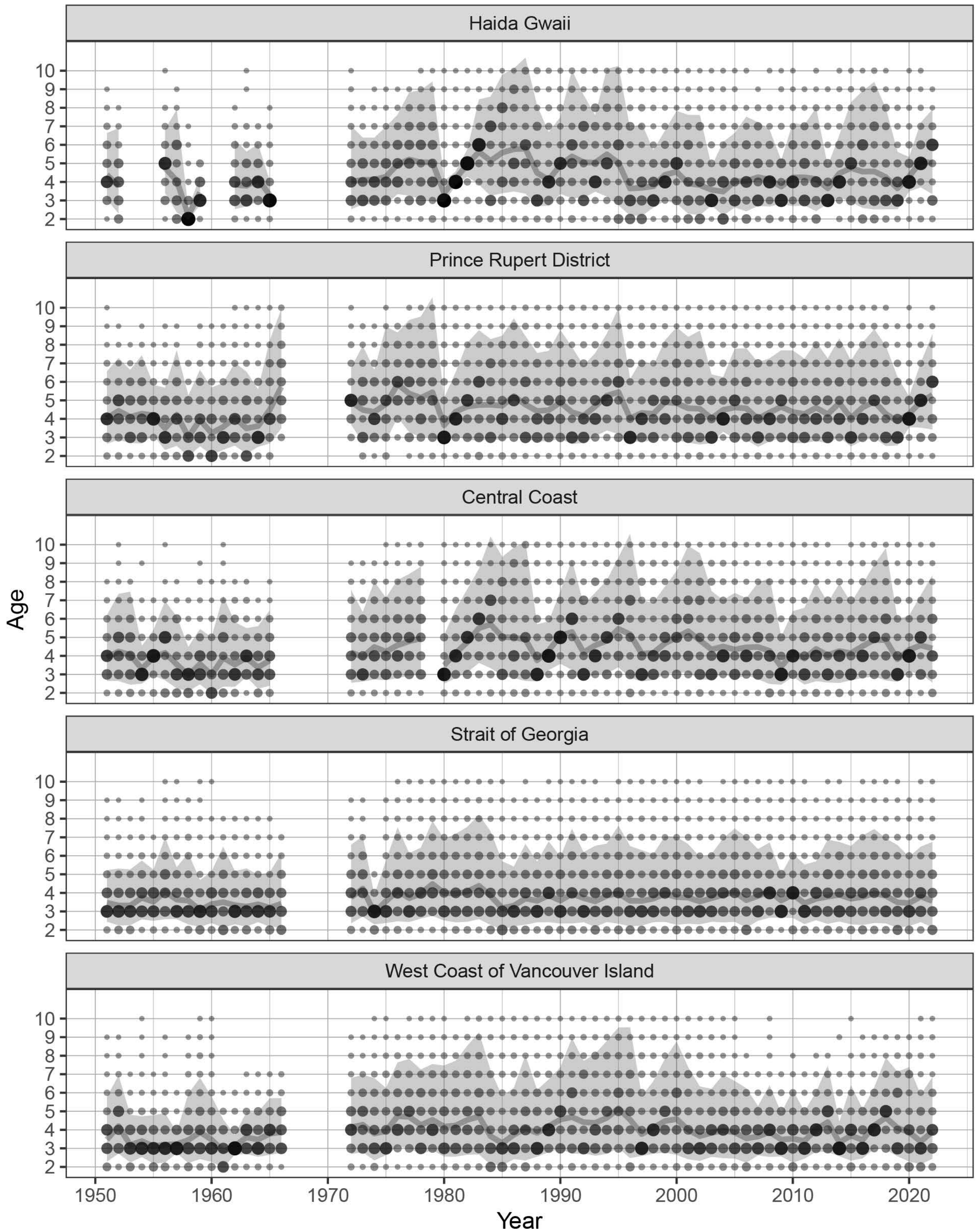

Figure 5. Proportion-at-age for Pacific Herring from 1951 to 2022 in the major SARs. Dot size and colour indicates age class proportion for the year; each year adds up to 1.0. The gray line is the mean age, and the shaded area is the approximate 90% distribution. Biological summaries only include samples collected using seine nets (commercial and test) due to size-selectivity of other gear types such as gillnet. The age-10 plus class includes fish ages 10 and older.

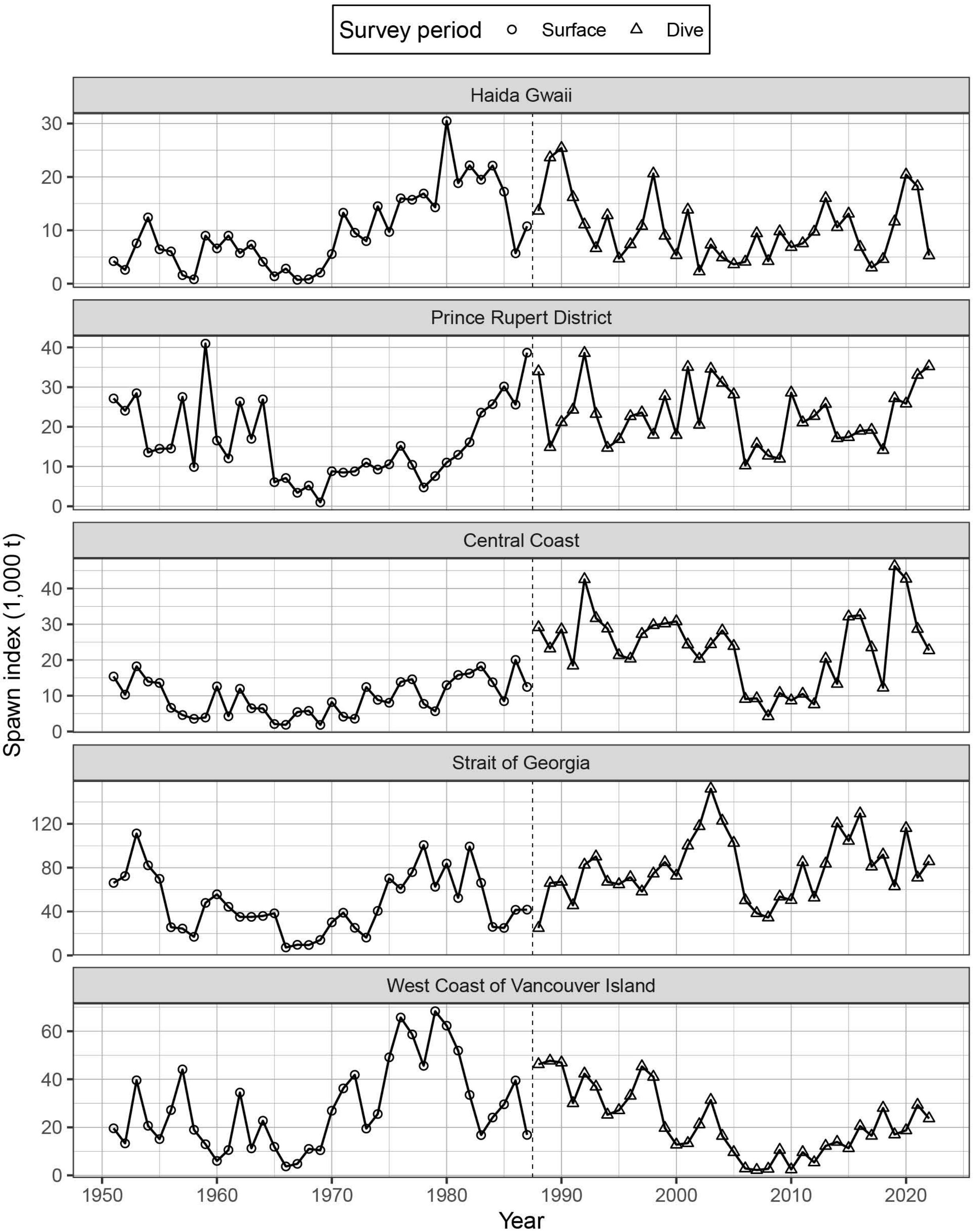

Figure 6. Spawn index in thousands of tonnes (t) for Pacific Herring from 1951 to 2022 in the major SARs. The dashed vertical line delineates between two periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2022). Note: the 'spawn index' is not scaled by the spawn survey scaling parameter q.

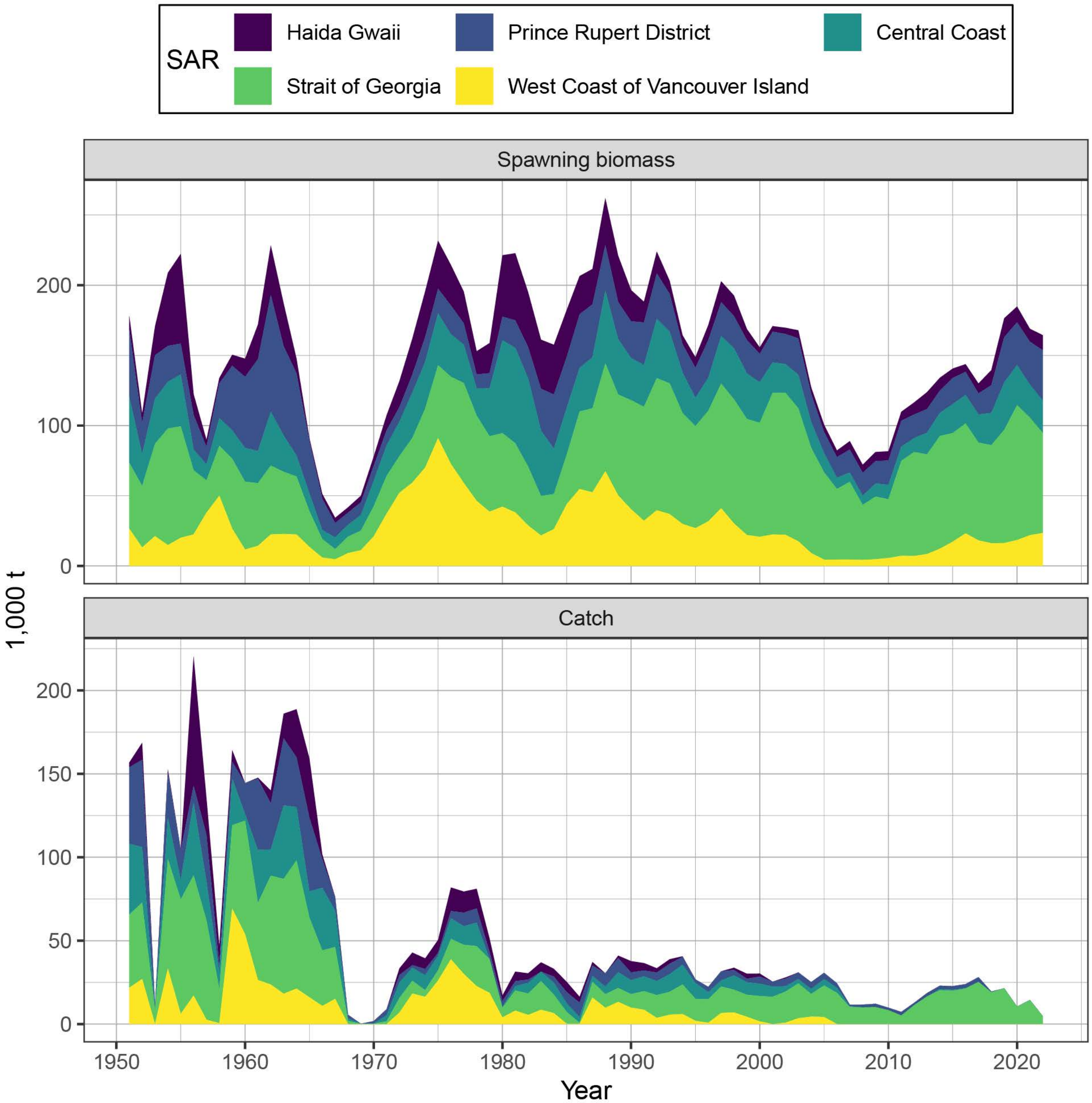

Figure 7. Spawning biomass and catch in thousands of tonnes (t) for Pacific Herring from 1951 to 2022 in the major SARs. Spawning biomass is represented by median posterior estimates.

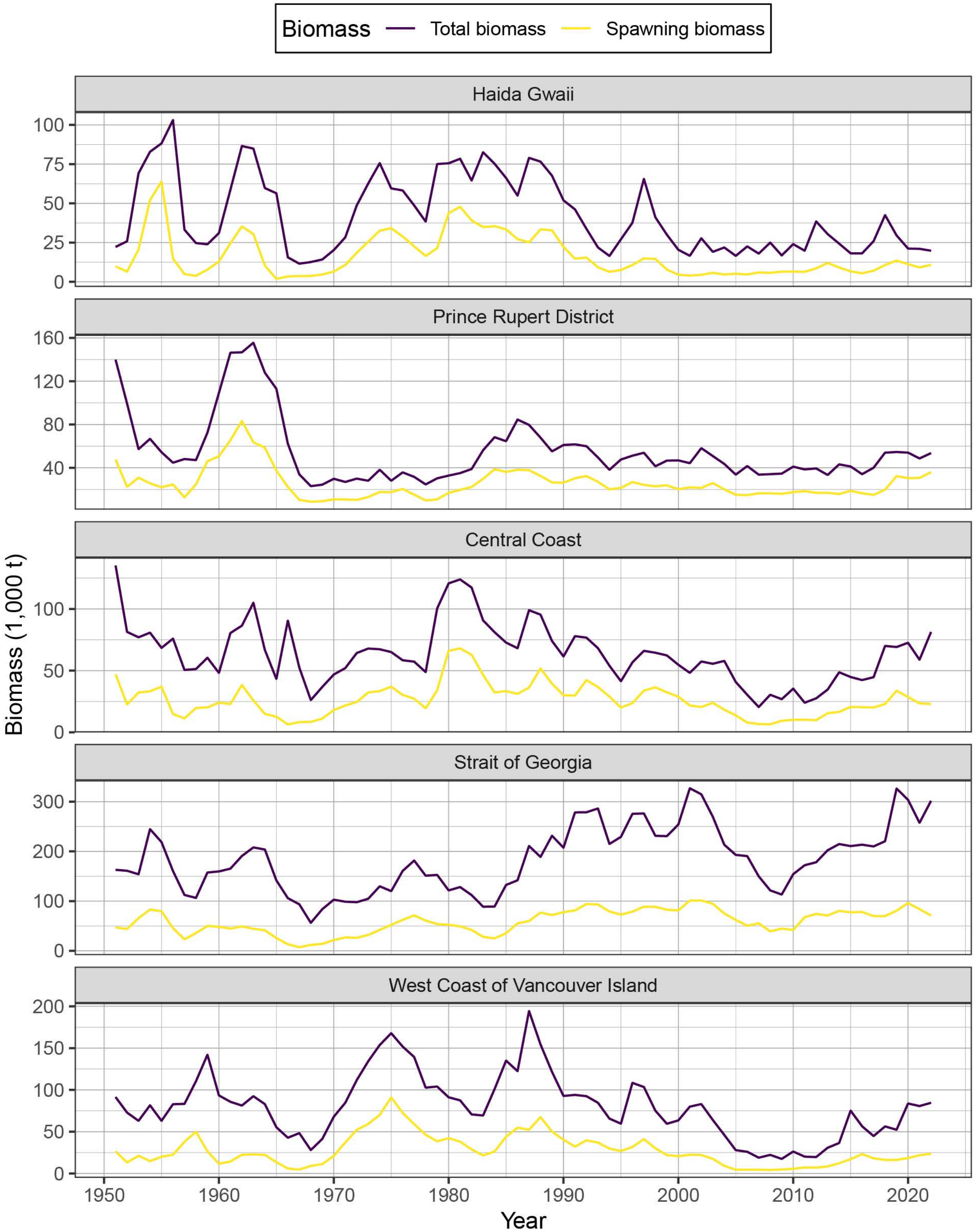

Figure 8. Total biomass and spawning biomass in thousands of tonnes (t) for Pacific Herring from 1951 to 2022 in the major SARs. Biomass is represented by median posterior estimates.

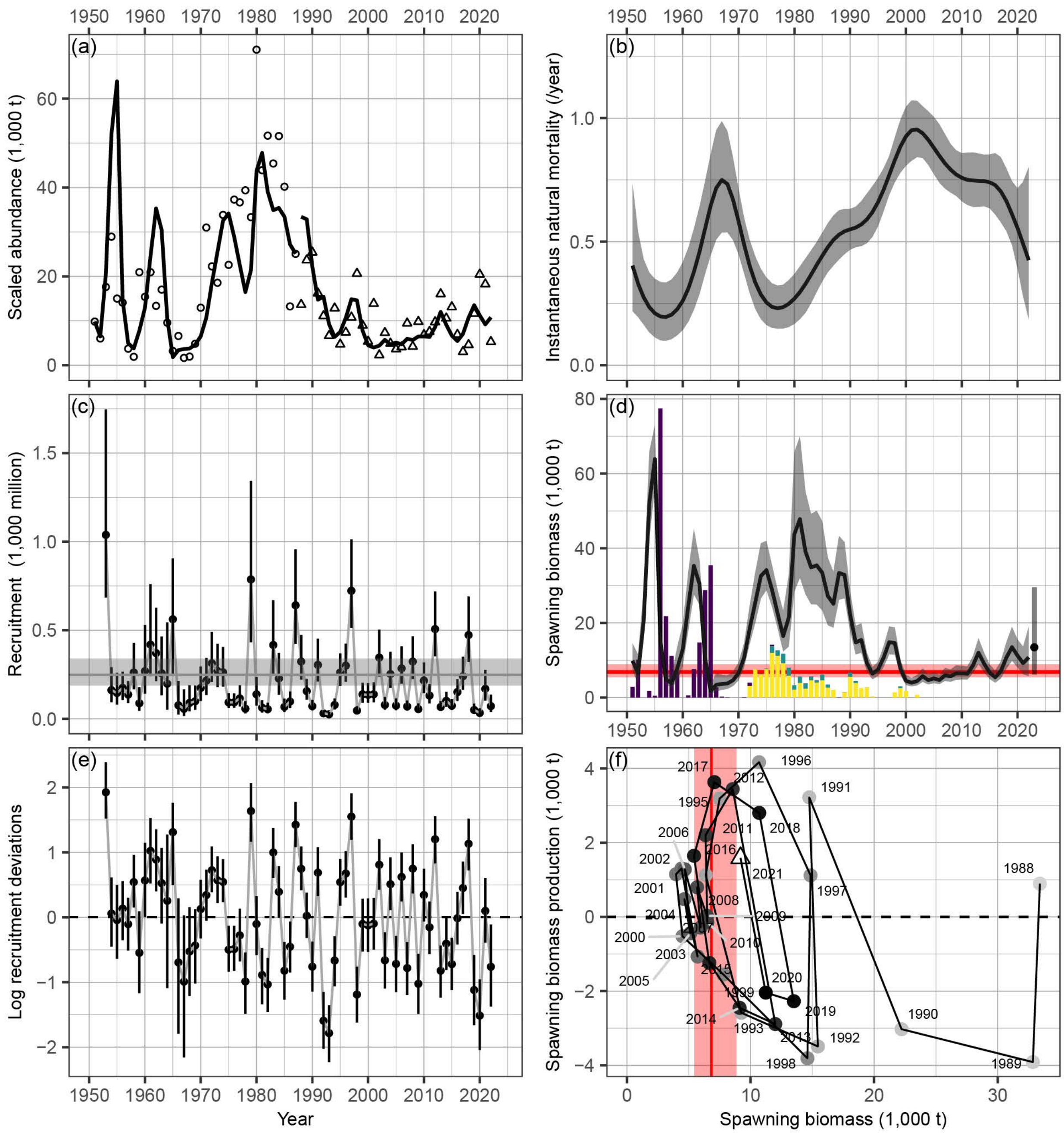

Figure 9. Haida Gwaii SAR: statistical catch-age model output for Pacific Herring from 1951 to 2022. ***Panel (a)****: Model fit (lines) to scaled abundance (points; Figure 6). Spawn index is scaled to abundance by the spawn index scaling parameter q.* ***Panel (b)****: Instantaneous natural mortality rate (year^{-1}).* ***Panel (c)****: Reconstructed number of age-2 recruits in thousands of millions from 1953 to 2022. Horizontal line indicates unfished age-2 recruitment R_0.* ***Panel (d)****: Spawning biomass (line), and forecast spawning biomass in 2023 in the absence of fishing (point). Coloured vertical bars indicate commercial catch (Figure 2).* ***Panel (e)****: Log recruitment deviations from 1953 to 2022.* ***Panel (f)****: Phase plot of spawning biomass production for the dive survey period (1988 to 2021). Points are chronologically shaded light to dark; triangle indicates 2021. Legend: biomass and catch are in thousands of tonnes (t); points and time-series lines are median posterior estimates; bands and error bars are 90% credible intervals; dashed horizontal lines indicate zero; and red lines indicate the median limit reference point $0.3SB_0$, where SB_0 is estimated unfished spawning biomass.*

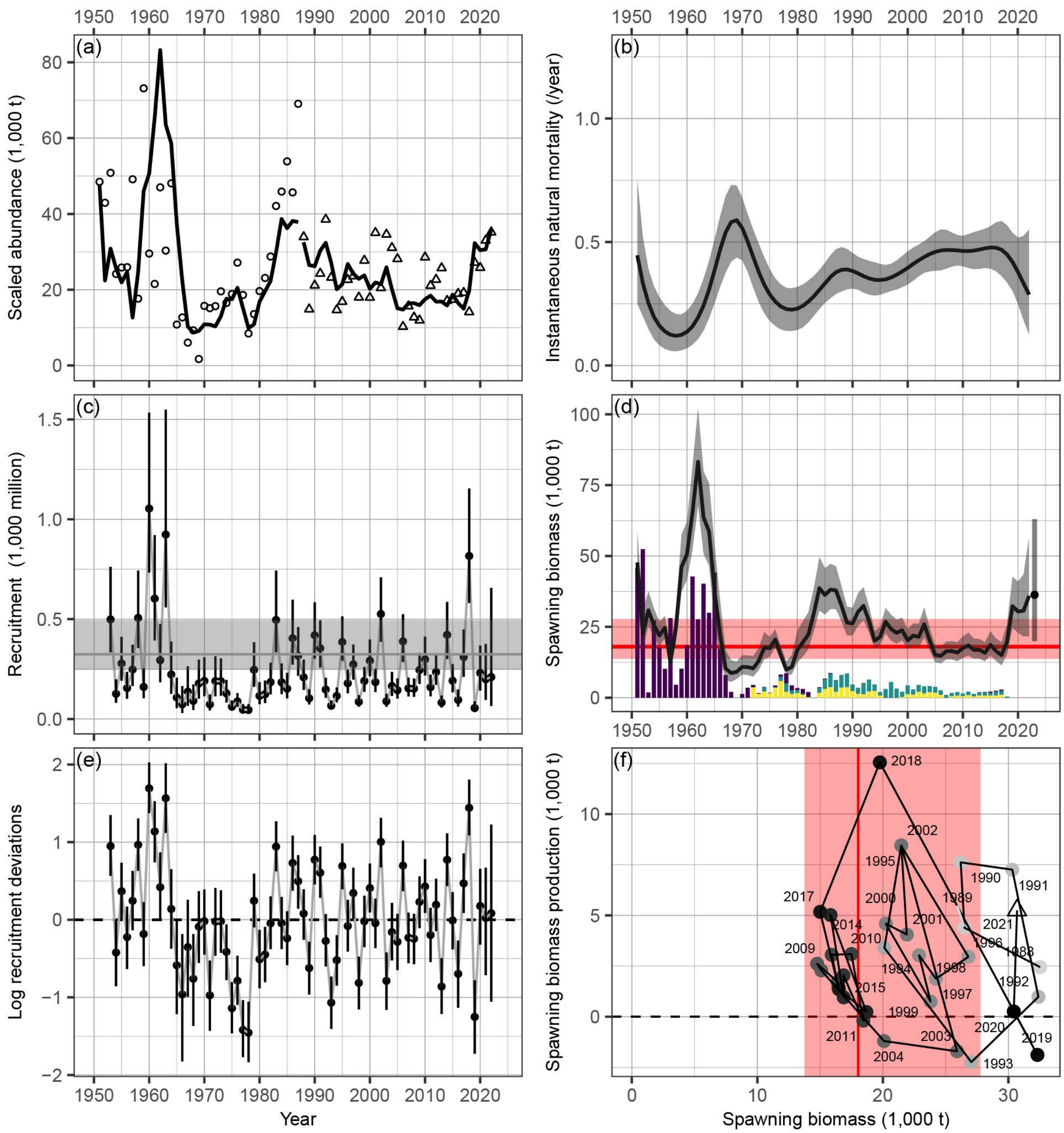

*Figure 10. Prince Rupert District SAR: statistical catch-age model output for Pacific Herring from 1951 to 2022. **Panel (a)**: Model fit (lines) to scaled abundance (points; Figure 6). Spawn index is scaled to abundance by the spawn index scaling parameter q. **Panel (b)**: Instantaneous natural mortality rate (year^{-1}). **Panel (c)**: Reconstructed number of age-2 recruits in thousands of millions from 1953 to 2022. Horizontal line indicates unfished age-2 recruitment R_0. **Panel (d)**: Spawning biomass (line), and forecast spawning biomass in 2023 in the absence of fishing (point). Coloured vertical bars indicate commercial catch (Figure 2). **Panel (e)**: Log recruitment deviations from 1953 to 2022. **Panel (f)**: Phase plot of spawning biomass production for the dive survey period (1988 to 2021). Points are chronologically shaded light to dark; triangle indicates 2021. Legend: biomass and catch are in thousands of tonnes (t); points and time-series lines are median posterior estimates; bands and error bars are 90% credible intervals; dashed horizontal lines indicate zero; and red lines indicate the median limit reference point $0.3SB_0$, where SB_0 is estimated unfished spawning biomass.*

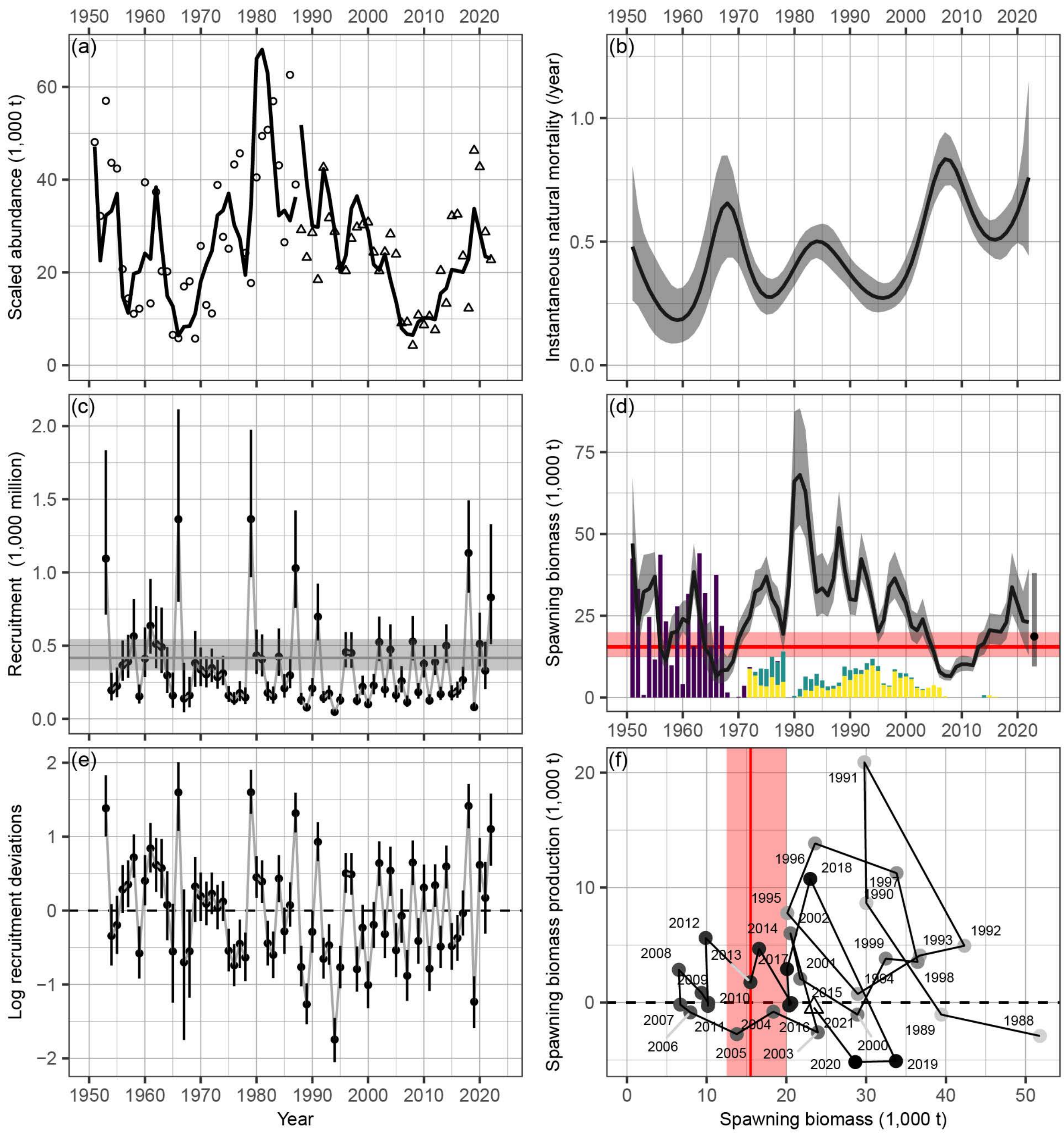

Figure 11. Central Coast SAR: statistical catch-age model output for Pacific Herring from 1951 to 2022. ***Panel (a)****: Model fit (lines) to scaled abundance (points; Figure 6). Spawn index is scaled to abundance by the spawn index scaling parameter q.* ***Panel (b)****: Instantaneous natural mortality rate (year^{-1}).* ***Panel (c)****: Reconstructed number of age-2 recruits in thousands of millions from 1953 to 2022. Horizontal line indicates unfished age-2 recruitment R_0.* ***Panel (d)****: Spawning biomass (line), and forecast spawning biomass in 2023 in the absence of fishing (point). Coloured vertical bars indicate commercial catch (Figure 2).* ***Panel (e)****: Log recruitment deviations from 1953 to 2022.* ***Panel (f)****: Phase plot of spawning biomass production for the dive survey period (1988 to 2021). Points are chronologically shaded light to dark; triangle indicates 2021. Legend: biomass and catch are in thousands of tonnes (t); points and time-series lines are median posterior estimates; bands and error bars are 90% credible intervals; dashed horizontal lines indicate zero; and red lines indicate the median limit reference point $0.3SB_0$, where SB_0 is estimated unfished spawning biomass.*

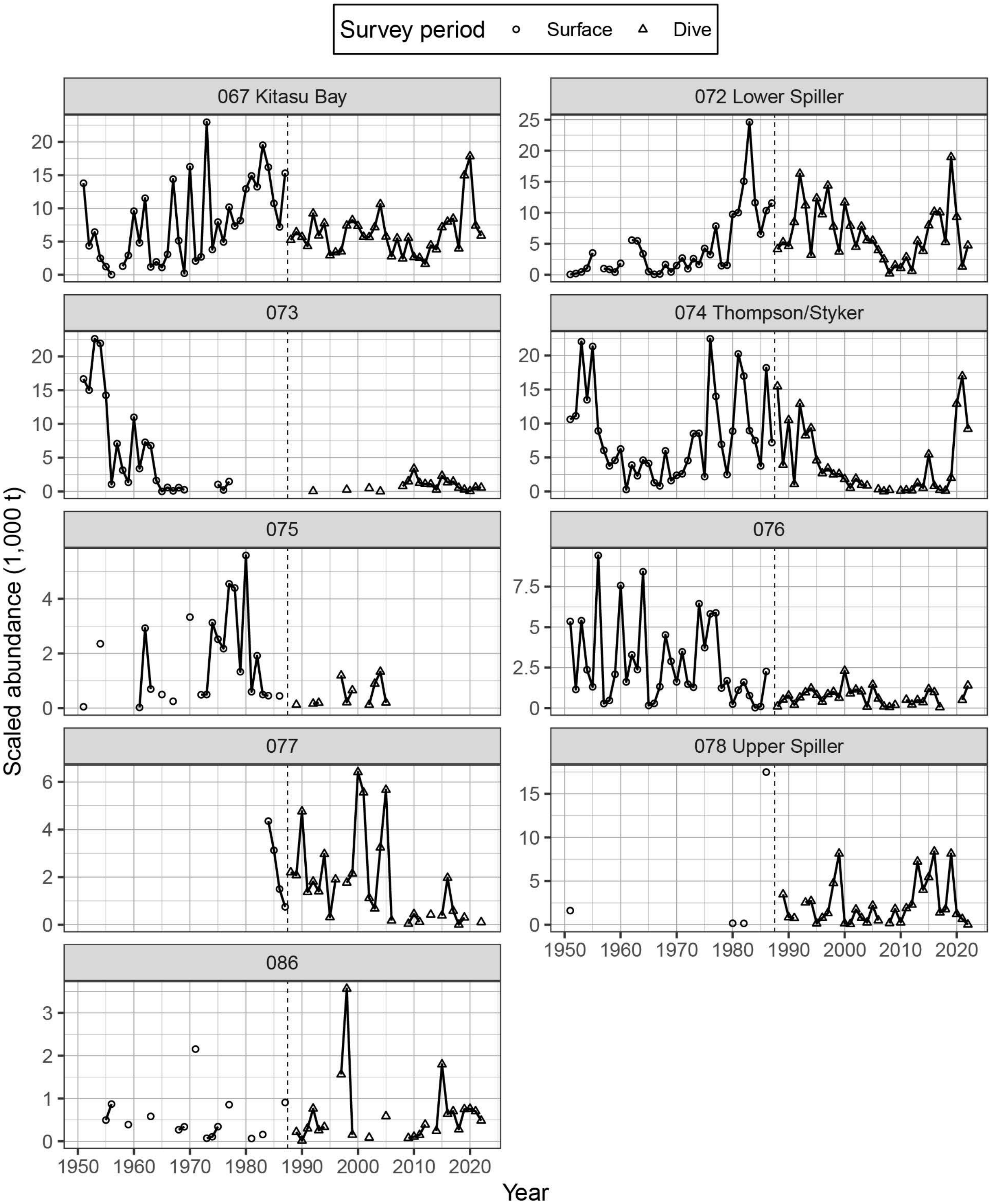

Figure 12. Central Coast SAR: scaled abundance in thousands of tonnes (t) of Pacific Herring in selected Sections from 1951 to 2022. The spawn index is scaled to abundance by the spawn survey scaling parameter q (median posterior estimate). The dashed vertical line delineates between two periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2022).

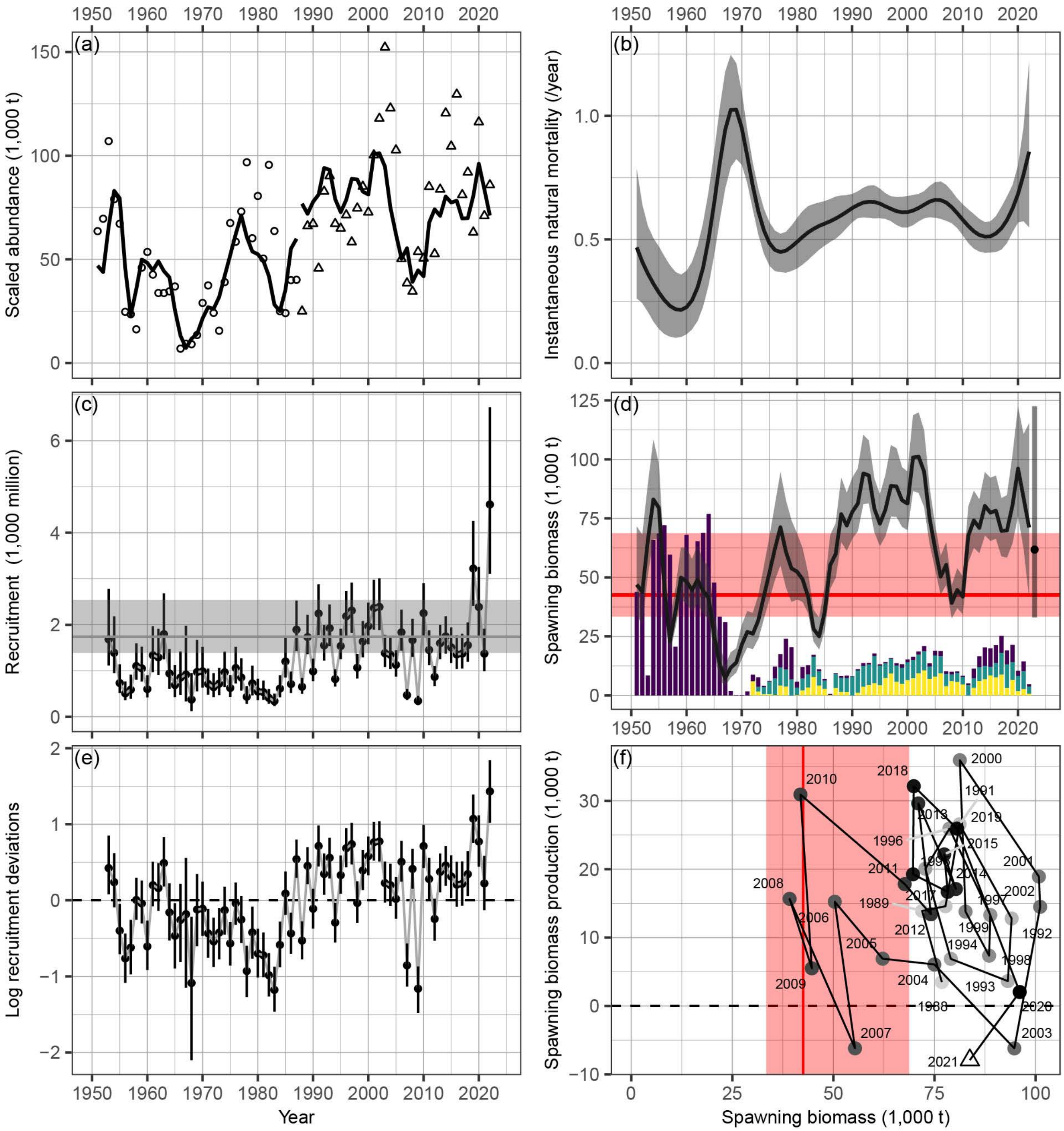

*Figure 13. Strait of Georgia SAR: statistical catch-age model output for Pacific Herring from 1951 to 2022. **Panel (a)**: Model fit (lines) to scaled abundance (points; Figure 6). Spawn index is scaled to abundance by the spawn index scaling parameter q. **Panel (b)**: Instantaneous natural mortality rate (year^{-1}). **Panel (c)**: Reconstructed number of age-2 recruits in thousands of millions from 1953 to 2022. Horizontal line indicates unfished age-2 recruitment R_0. **Panel (d)**: Spawning biomass (line), and forecast spawning biomass in 2023 in the absence of fishing (point). Coloured vertical bars indicate commercial catch (Figure 2). **Panel (e)**: Log recruitment deviations from 1953 to 2022. **Panel (f)**: Phase plot of spawning biomass production for the dive survey period (1988 to 2021). Points are chronologically shaded light to dark; triangle indicates 2021. Legend: biomass and catch are in thousands of tonnes (t); points and time-series lines are median posterior estimates; bands and error bars are 90% credible intervals; dashed horizontal lines indicate zero; and red lines indicate the median limit reference point $0.3SB_0$, where SB_0 is estimated unfished spawning biomass.*

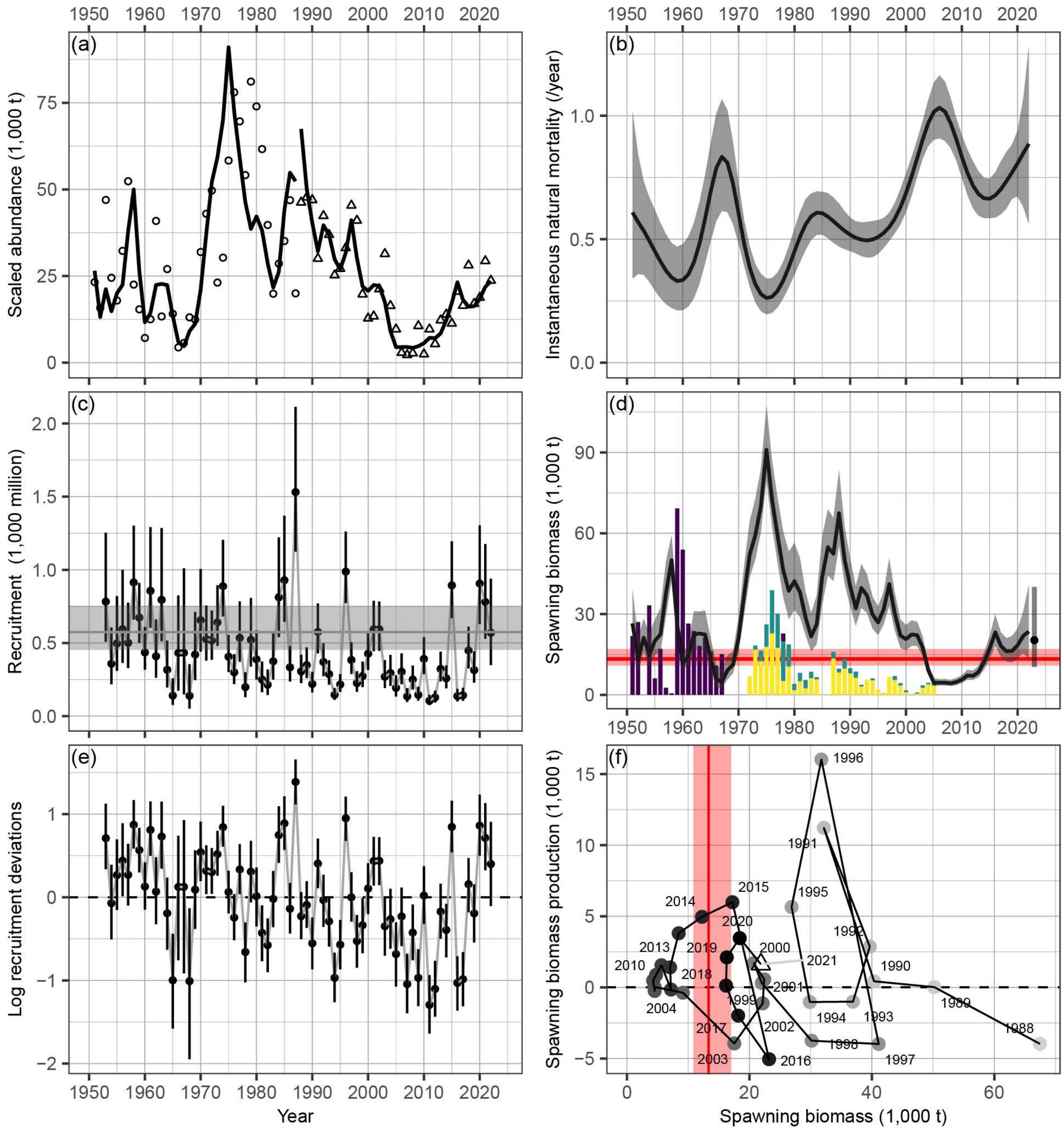

*Figure 14. West Coast of Vancouver Island SAR: statistical catch-age model output for Pacific Herring from 1951 to 2022. **Panel (a)**: Model fit (lines) to scaled abundance (points; Figure 6). Spawn index is scaled to abundance by the spawn index scaling parameter q. **Panel (b)**: Instantaneous natural mortality rate (year^{-1}). **Panel (c)**: Reconstructed number of age-2 recruits in thousands of millions from 1953 to 2022. Horizontal line indicates unfished age-2 recruitment R_0. **Panel (d)**: Spawning biomass (line), and forecast spawning biomass in 2023 in the absence of fishing (point). Coloured vertical bars indicate commercial catch (Figure 2). **Panel (e)**: Log recruitment deviations from 1953 to 2022. **Panel (f)**: Phase plot of spawning biomass production for the dive survey period (1988 to 2021). Points are chronologically shaded light to dark; triangle indicates 2021. Legend: biomass and catch are in thousands of tonnes (t); points and time-series lines are median posterior estimates; bands and error bars are 90% credible intervals; dashed horizontal lines indicate zero; and red lines indicate the median limit reference point $0.3SB_0$, where SB_0 is estimated unfished spawning biomass.*

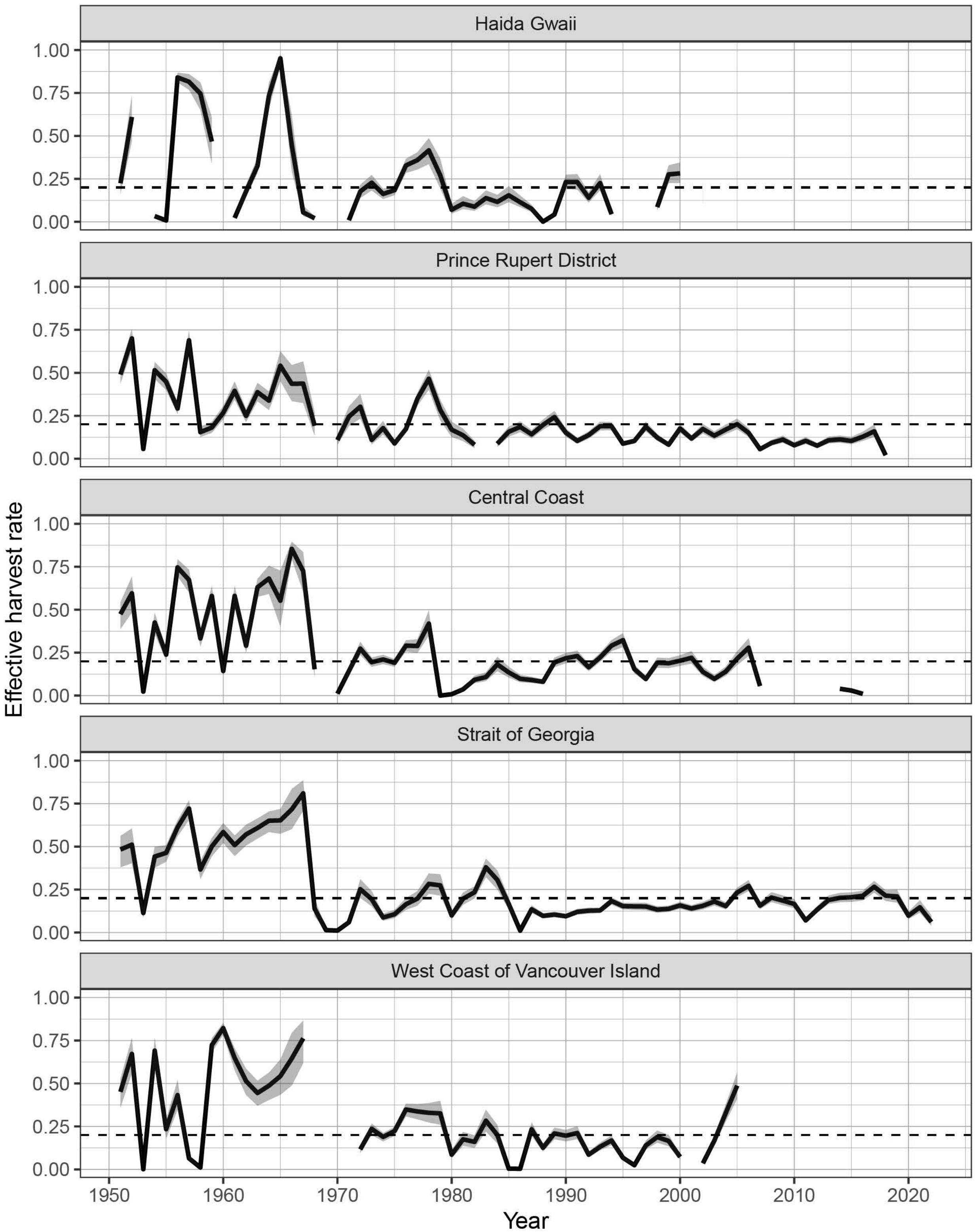

Figure 15. Effective harvest rate U_t for Pacific Herring from 1951 to 2022 in the major SARs. Effective harvest rate is $U_t = C_t/(C_t + SB_t)$ where C_t is catch in year t, and SB_t is estimated spawning biomass in year t. Black lines and shaded ribbons indicate medians and 90% credible intervals for U_t, respectively. Horizontal dashed lines indicate $U_t = 0.2$.

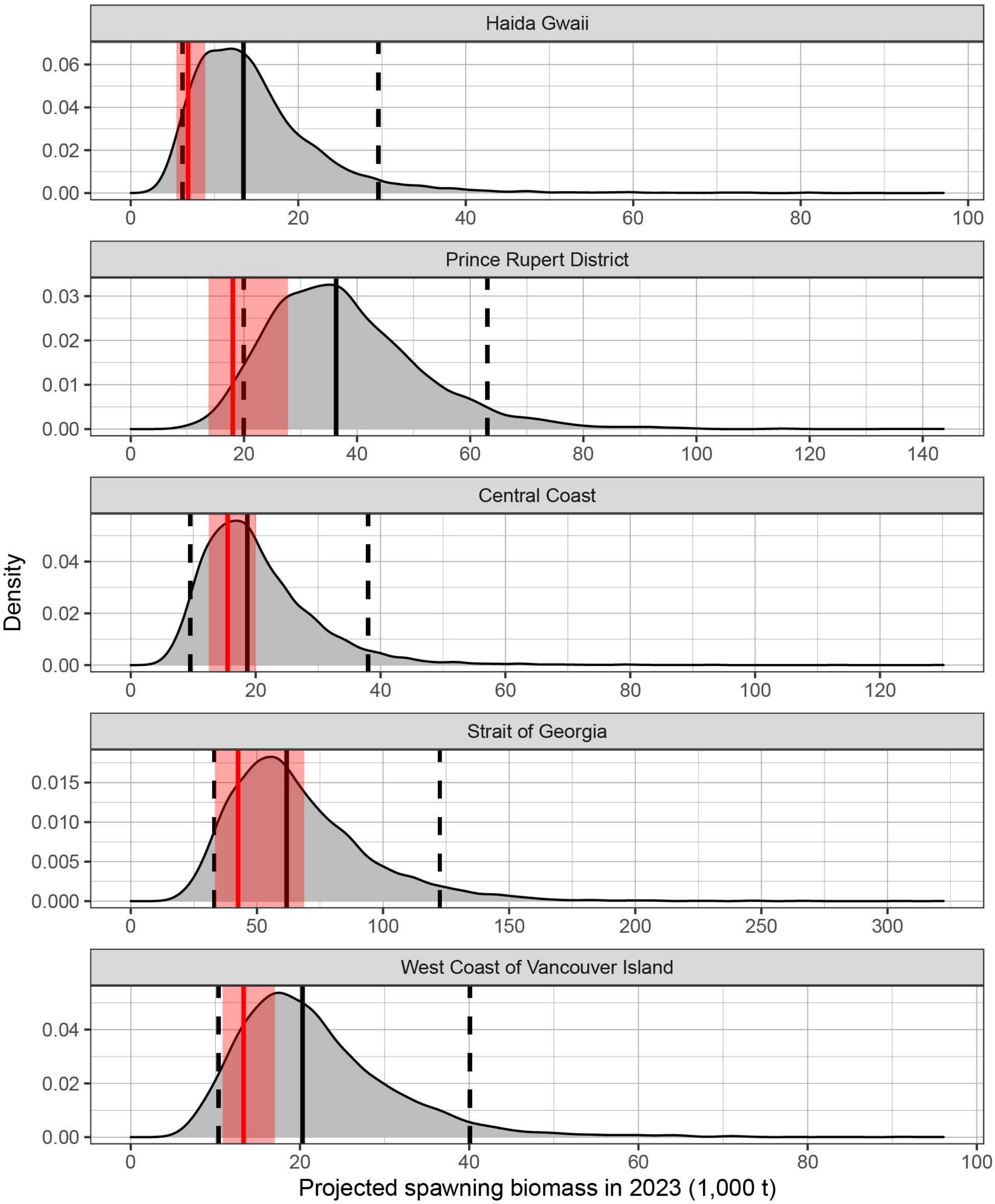

Figure 16. Projected spawning biomass of Pacific Herring assuming no fishing in 2023 SB_{2023} in thousands of tonnes (t) in the major SARs. Solid and dashed black lines indicate median posterior estimate and 90% credible intervals for SB_{2023}, respectively. Vertical red lines and shaded red areas indicate medians and 90% credible intervals for the limit reference point $0.3SB_0$, respectively, where SB_0 is estimated unfished spawning biomass.

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Approved by

Andrew Thomson
Regional Director
Science Branch, Pacific Region
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September 20, 2022

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Appendix

Minor stock assessment regions

We do not conduct formal analyses of stock trend information for the two Pacific Herring minor SARs: Area 27 (A27) and Area 2 West (A2W). However, we provide the spawn index and proportion of spawn index by Section from 2013 to 2022 for A27 and A2W (Tables 34 and 35, respectively). For Area 27, we provide the spawn index by Section from 1978 to 2022 (Figure 17). We also provide landed commercial catch (Figure 18), incidental catch (Figure 19), biological data including weight-at-age (Figure 20) and proportion-at-age (Figure 21), as well as spawn index (Figure 22) from 1978 to 2022.

Special areas

We do not conduct formal analyses of stock trend information for the Pacific Herring special area, Area 10 (A10; Figure 23). Note that Area 10 is a subset of the Central Coast and is outside the SAR boundary. As with the minor SARs, we provide the spawn index and proportion of spawn index by Section from 2013 to 2022 (Table 36). Note that 2022 spawn data may be incomplete; DFO has not received data collected by the Gwa'sala-'Nakwaxda'xw Nation. We also provide biological data including weight-at-age (Figure 24) and proportion-at-age (Figure 25), as well as spawn index (Figure 26) from 1978 to 2022. Note that there is no commercial catch or incidental catch in Area 10 from 1978 to 2022.

Tables

Table 34. Area 27 SAR: spawn index in tonnes for Pacific Herring and proportion of spawn index by Section from 2013 to 2022. See Table 4 for description.

		Proportion			
Year	**Spawn index**	**271**	**272**	**273**	**274**
2013	914	0.000	0.000	1.000	0.000
2014	1,307	0.000	0.000	1.000	0.000
2015	2,169	0.000	0.000	1.000	0.000
2016	814	0.000	0.000	1.000	0.000
2017	26	0.000	0.000	1.000	0.000
2018	1,045	0.000	0.000	1.000	0.000
2019	192	0.000	0.000	1.000	0.000
2020	NA	0.000	0.000	0.000	0.000
2021	1,653	0.000	0.000	1.000	0.000
2022	NA	0.000	0.000	0.000	0.000

Table 35. Area 2 West SAR: spawn index in tonnes for Pacific Herring and proportion of spawn index by Section from 2013 to 2022. See Table 4 for description.

		Proportion				
Year	**Spawn index**	**001**	**002**	**003**	**004**	**005**
2013	2,076	0.000	0.983	0.017	0.000	0.000
2014	1,368	0.000	1.000	0.000	0.000	0.000
2015	NA	0.000	0.000	0.000	0.000	0.000
2016	3,001	0.000	1.000	0.000	0.000	0.000
2017	NA	0.000	0.000	0.000	0.000	0.000
2018	617	0.000	0.269	0.000	0.000	0.731
2019	2,884	0.000	1.000	0.000	0.000	0.000
2020	6,834	0.000	1.000	0.000	0.000	0.000
2021	1,377	0.000	1.000	0.000	0.000	0.000
2022	3,299	0.000	1.000	0.000	0.000	0.000

Table 36. Area 10 special area: spawn index in tonnes for Pacific Herring and proportion of spawn index by Section from 2013 to 2022. See Table 4 for description.

		Proportion		
Year	**Spawn index**	**101**	**102**	**103**
2013	267	0.000	1.000	0.000
2014	493	0.000	1.000	0.000
2015	NA	0.000	0.000	0.000
2016	588	0.000	0.967	0.033
2017	2,206	0.000	1.000	0.000
2018	477	0.000	1.000	0.000
2019	570	0.000	1.000	0.000
2020	888	0.000	1.000	0.000
2021	350	0.000	1.000	0.000
2022	NA	0.000	0.000	0.000

Figures

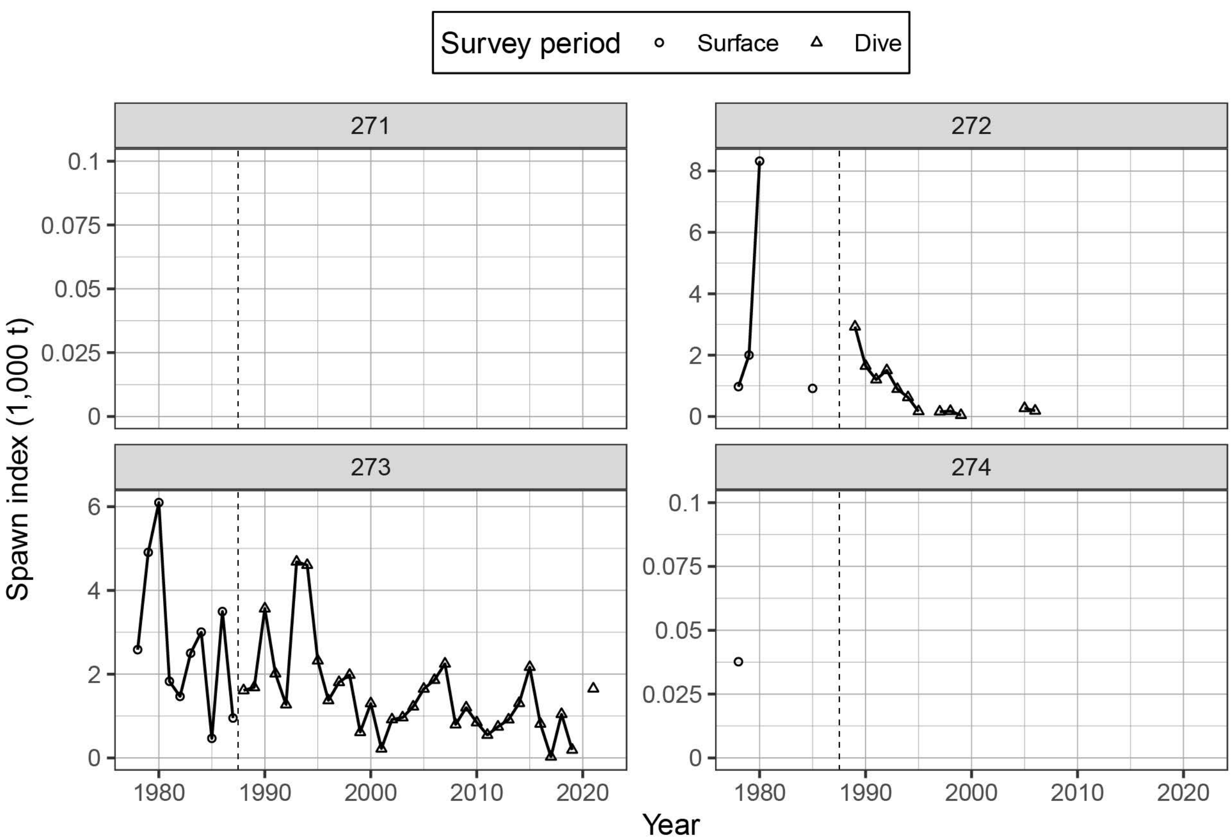

Figure 17. Area 27 SAR: spawn index in thousands of tonnes (t) of Pacific Herring by Section from 1978 to 2022. The dashed vertical line delineates between two periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2022). Note: the ‘spawn index’ is not scaled by the spawn survey scaling parameter q.

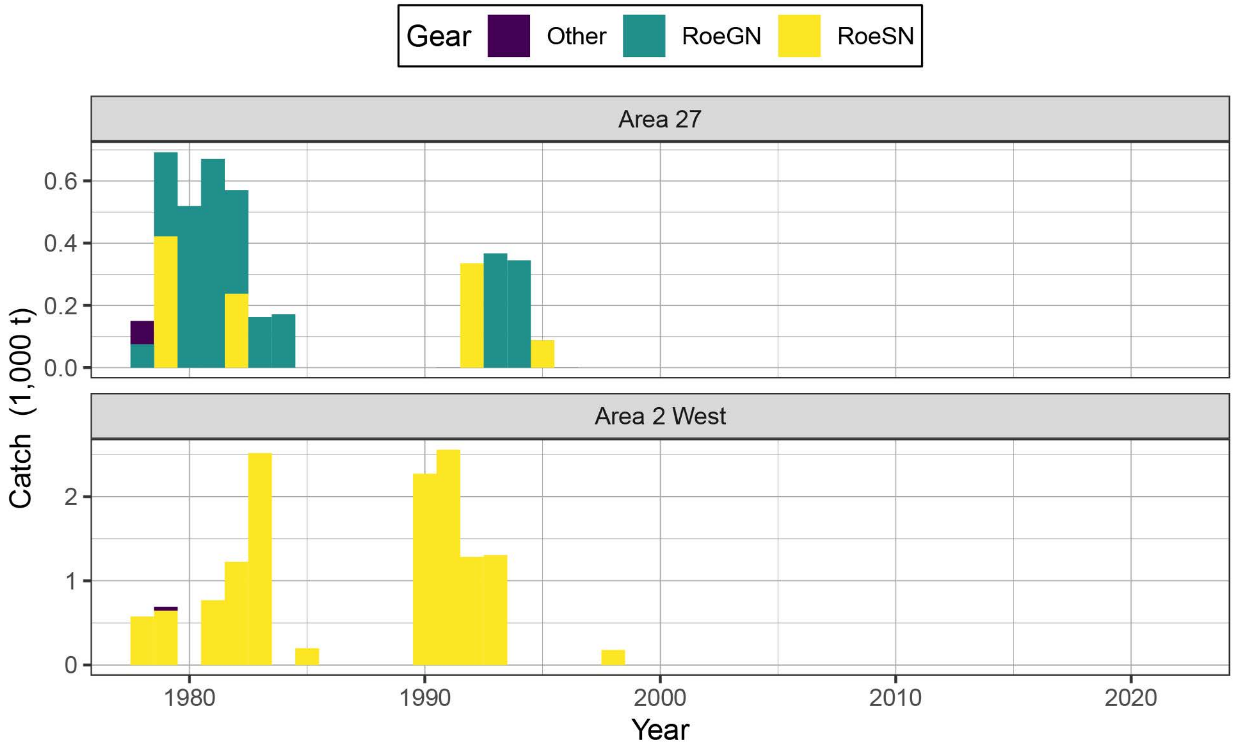

Figure 18. Total landed Pacific Herring catch in thousands of tonnes (t) from 1978 to 2022 in the minor SARs. See Figure 2 for description.

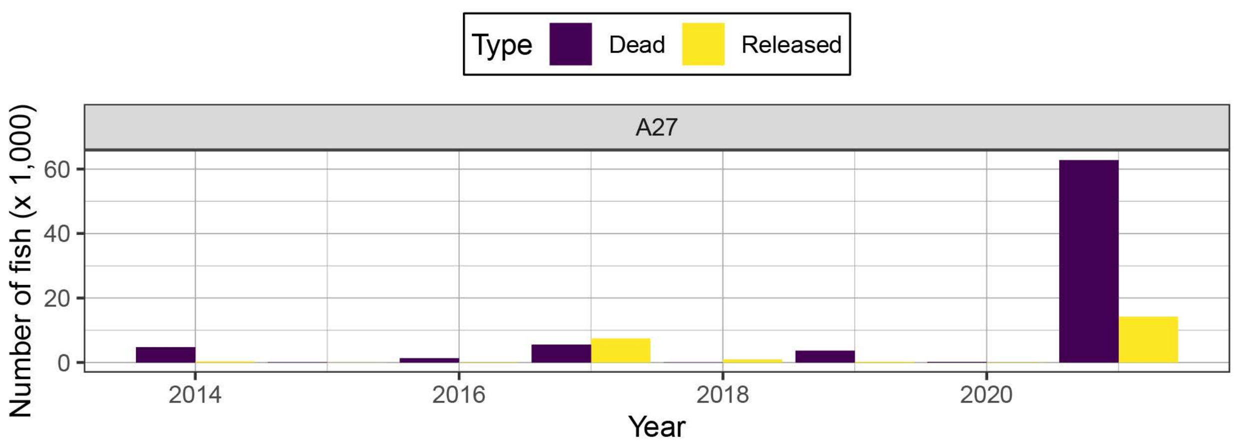

Figure 19. Incidental Pacific Herring mortality in aquaculture activities in thousands of fish from 2014 to 2021 in the minor SARs. See Figure 3 for description.

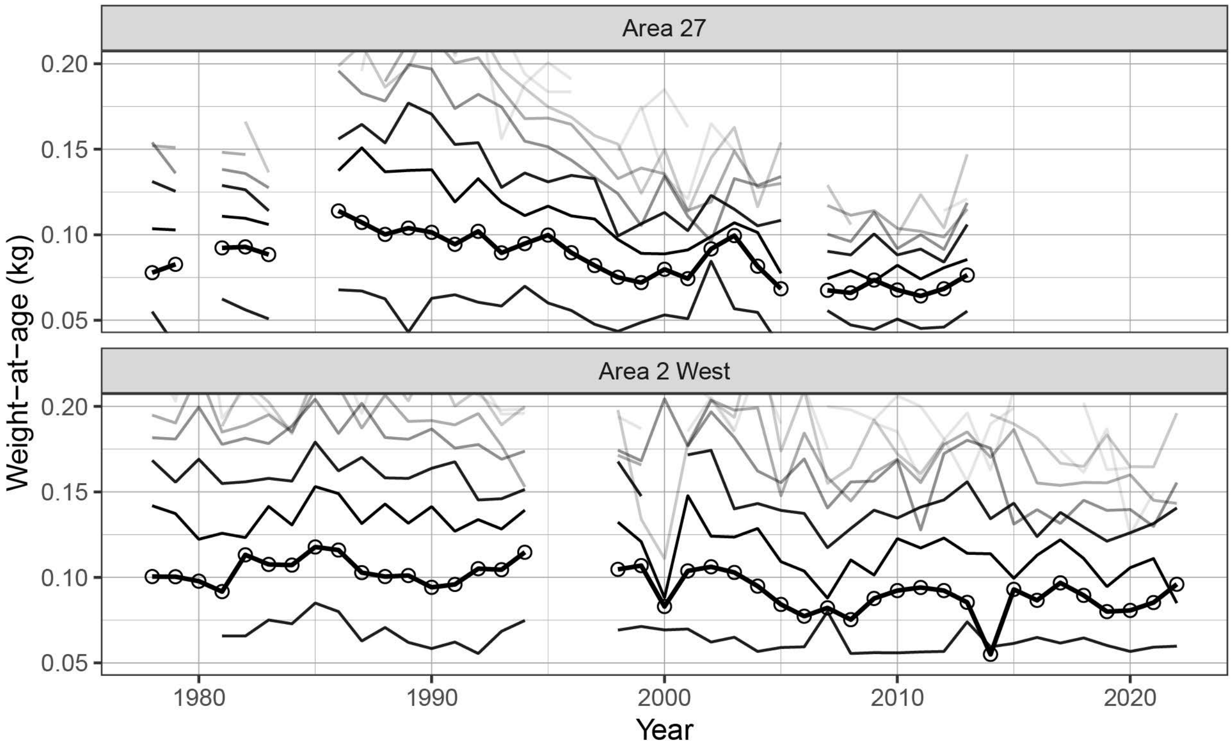

Figure 20. Mean weight-at-age for Pacific Herring in kilograms (kg) from 1978 to 2022 in the minor SARs. Circles show mean for age-3 herring. Lines show means for age-2 to age-10 herring, incrementing up from bottom line and shaded from darker to lighter. The thick line shows age-3 herring. Biological summaries only include samples collected using seine nets (commercial and test) due to size-selectivity of other gear types such as gillnet. The age-10 class includes fish ages 10 and older. Note: vertical axes are cropped at 0.05 to 0.20 kg.

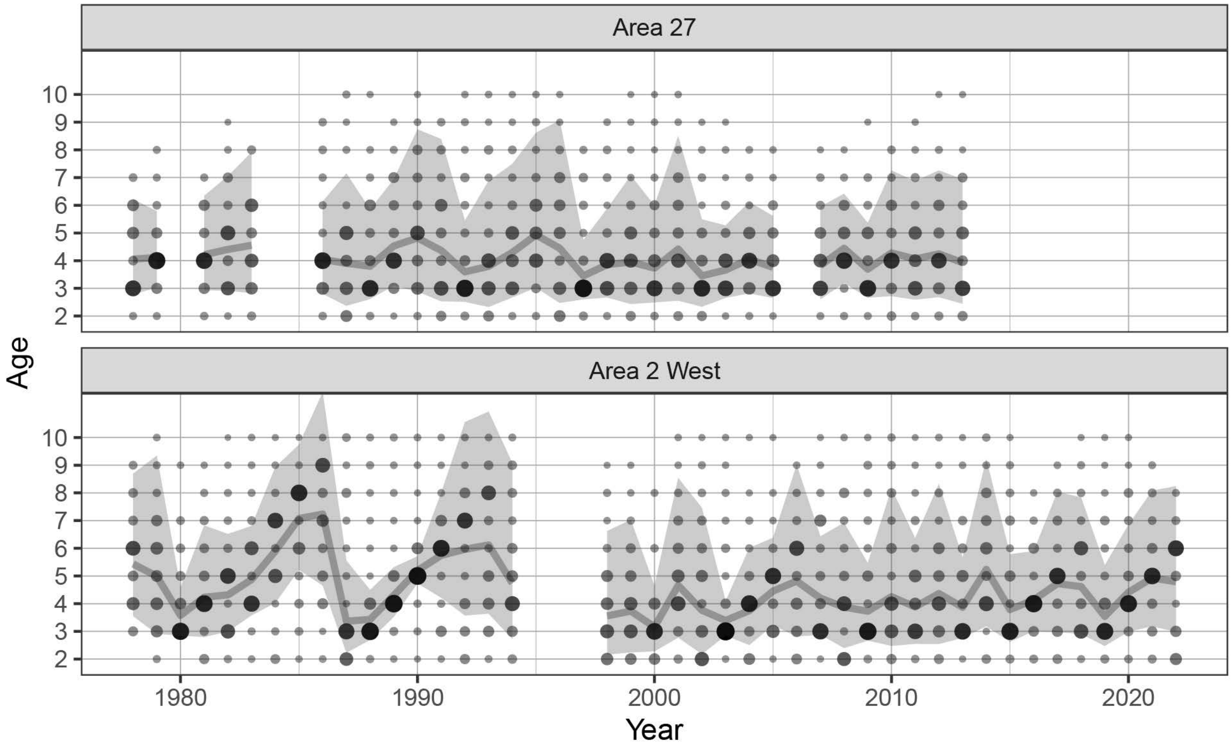

Figure 21. Proportion-at-age for Pacific Herring from 1978 to 2022 in the minor SARs. See Figure 5 for description.

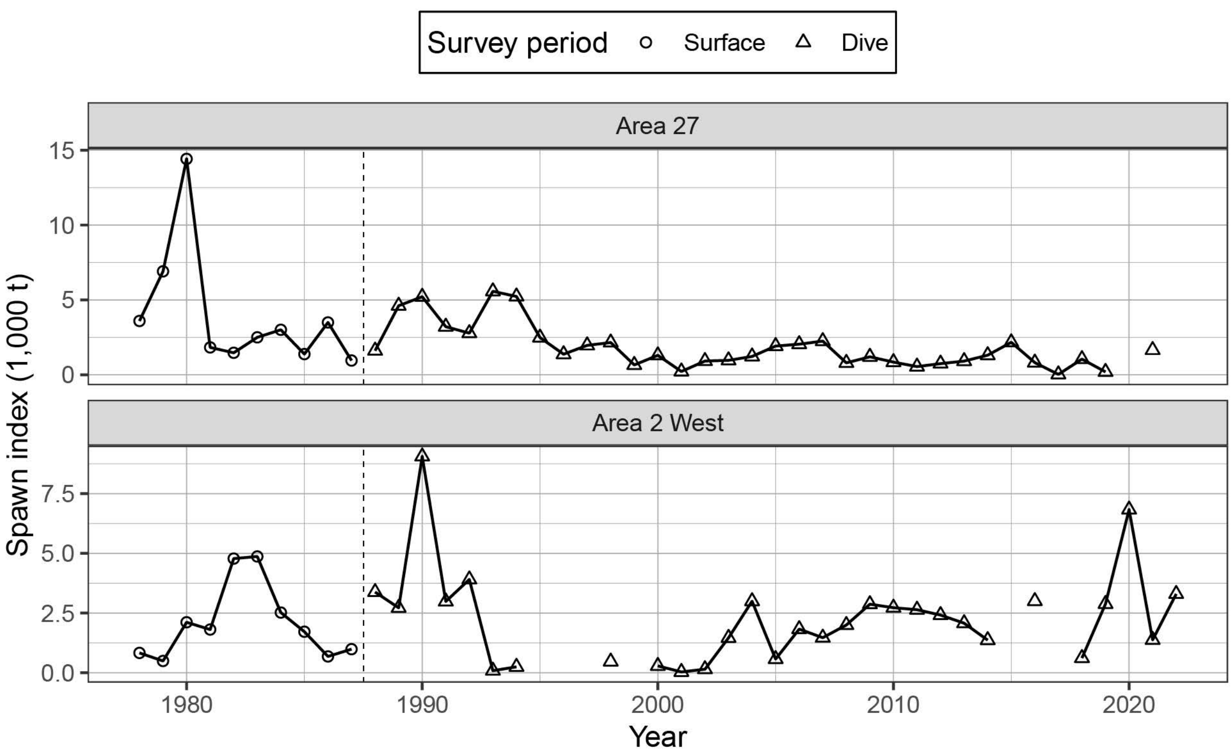

Figure 22. Spawn index in thousands of tonnes (t) for Pacific Herring from 1978 to 2022 in the minor SARs. See Figure 6 for description.

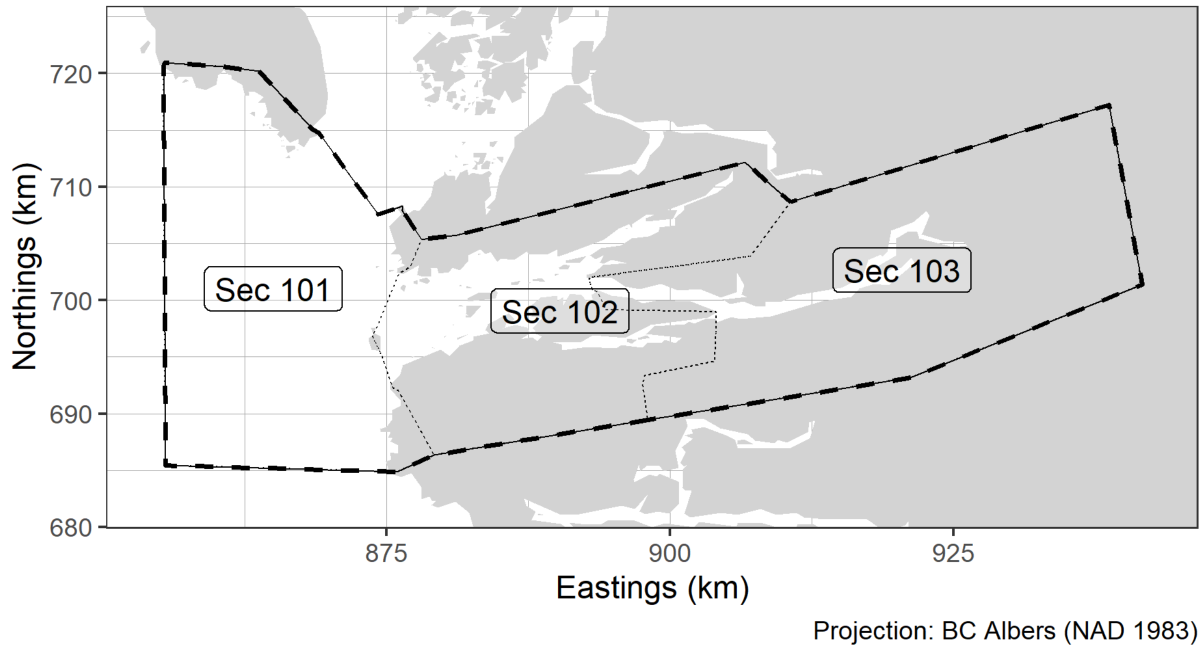

Figure 23. Sections (Sec) included in the Pacific Herring special area, Area 10 (A10). Note that special areas are not stock assessment regions (SARs); therefore they are excluded from regular monitoring and analyses. In addition, note that A10 is a subset of the Central Coast Sections that are outside the SAR boundary. Units: kilometres (km).

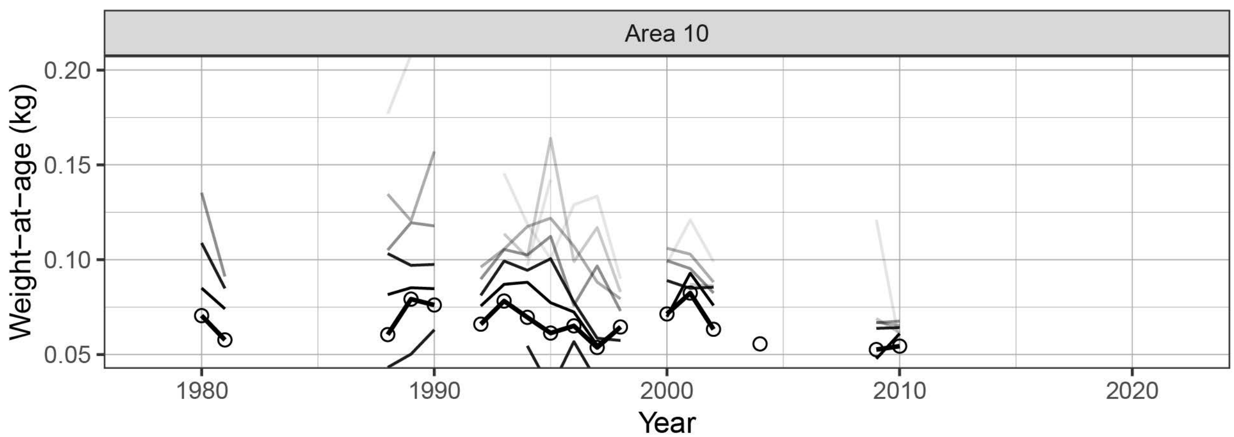

Figure 24. Mean weight-at-age for Pacific Herring in kilograms (kg) from 1978 to 2022 in the special area, Area 10. See Figure 20 for description.

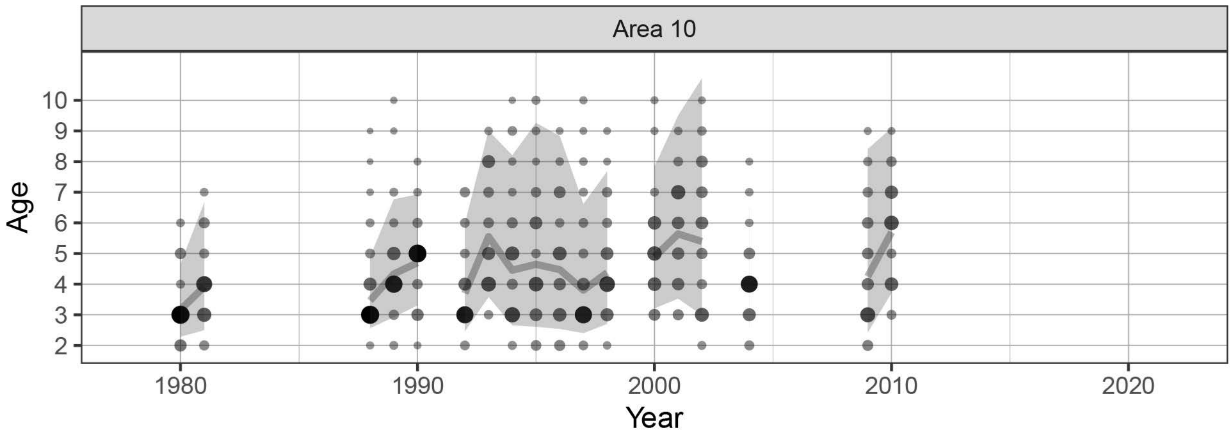

Figure 25. Proportion-at-age for Pacific Herring from 1978 to 2022 in the special area, Area 10. See Figure 5 for description.

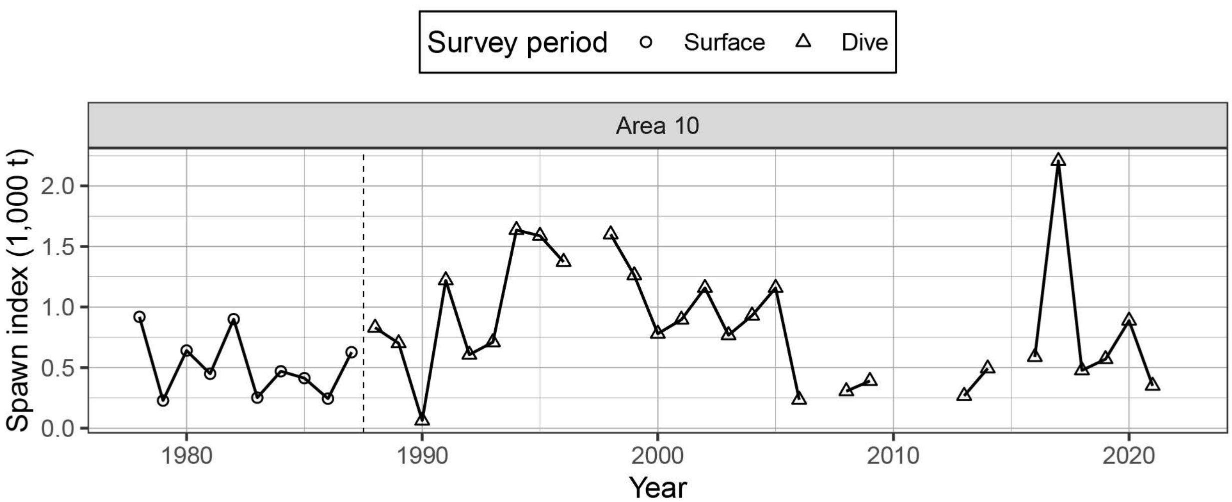

Figure 26. Spawn index in thousands of tonnes (t) for Pacific Herring from 1978 to 2022 in the special area, Area 10. See Figure 6 for description.

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ISSN 1919-3769
ISBN 978-0-660-45602-7 Cat No. Fs70-7/2022-046EPDF

Correct Citation for this Publication:

DFO. 2022. Stock status update with application of management procedures for Pacific Herring (*Clupea pallasii*) in British Columbia: Status in 2022 and forecast for 2023. DFO Can. Sci. Advis. Sec. Sci. Resp. 2022/046.

Aussi disponible en français :

*MPO. 2022. Mise à jour de l'état des stocks avec application des procédures de gestion pour le hareng du Pacifique (*Clupea pallasii*) en Colombie-Britannique: État en 2022 et prévisions pour 2023. Secr. can. des avis sci. du MPO. Rép. des Sci. 2022/046.*