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STOCK STATUS UPDATE WITH APPLICATION OF MANAGEMENT PROCEDURES FOR PACIFIC HERRING (*CLUPEA PALLASII*) IN BRITISH COLUMBIA: STATUS IN 2023 AND FORECAST FOR 2024

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), and 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. In 2022, upper stock reference (USR) point options were introduced for the major stock assessment regions (SARs), and in this assessment estimation of stock status relative to productive period USRs (DFO 2023a) are included. The overall 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) SARs (DFO 2019). Steps included operating model (OM) development (Benson et al. 2022), 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 PRD, CC, SoG, and WCVI in 2023 (DFO 2022a, 2023a).

This assessment includes new science advice on choice of USR points for all five Pacific Herring major SARs. An analysis of USR options for PRD, CC, SoG, and WCVI was completed in 2022 (DFO 2023a) and provisional USRs based on productive periods identified for each SAR was implemented in the 2022/23 Integrated Fisheries Management Plan (IFMP).

Since initiation of the Pacific Herring MSE process, MP evaluations 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.

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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 the 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.

5. The 2022 stock assessment includes an update to MP recommendations for the PRD, CC, SoG, and WCVI SARs (DFO 2022a).

Note that MPs for HG are not updated through this process. Instead, management measures to support long-term recovery of HG herring are being developed through the HG rebuilding plan process.[1]

This 2023 stock assessment includes MP recommendations for PRD, CC, SoG, and WCVI, derived in 2022 by updating herring OM conditioning (Benson et al. 2022) using the latest historic stock and fishery data from 1951 to 2021 (DFO 2022a). There are no new MP evaluations for 2023 (all probability metrics reflect the MP evaluations presented in 2022).

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 2023 and recommend harvest advice for 2024 as simulation-tested MPs to inform the development of the 2023/2024 IFMP, where appropriate. Estimated stock trajectories, current status of stocks for 2023, management procedure options, and harvest advice recommendations from those MPs for 2024 reflect methods of Cleary et al. (2019) and Benson et al. (2022) and, where applicable, recommendations from the aforementioned 2018, 2019, 2020, 2021, and 2022 MSE analyses (Section "Application of MPs and harvest options for 2024").

This Science Response results from the regional peer review of September 22, 2023 on the Stock status update with application of management procedures for Pacific Herring (*Clupea pallasii*) in British Columbia: Status in 2023 and forecast for 2024.

Background

Pacific Herring in BC are managed as five major and two minor 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.

Description of the fishery

There are several Pacific Herring fisheries in BC. After conservation, First Nations have priority access to fish for food, social, and ceremonial (FSC) purposes. Commercial fishing opportunities

[1] Haida Gwaii ’íináang | iinang Pacific Herring: An ecosystem overview and ecosystem-based rebuilding plan. Draft consultation period occurred September 26 to December 16, 2022; Final approval scheduled for fall 2023.

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 licence.

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 2023/24 FMP by DFO where possible. For further information see the 2023/24 FMP.

On the Central Coast, Heiltsuk Nation have an Aboriginal right to commercially harvest Pacific Herring SOK. The Heiltsuk currently hold nine SOK licences 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 2022/2023, the primary Pacific Herring fisheries were seine roe and gillnet roe fisheries, with a combined coast wide catch of 4,726 tonnes (t). The FB seine fishery had a coast wide catch of 1,444 t. The roe fisheries operated in SoG and PRD this season, and FB and SU fisheries in SoG only. Commercial SOK fisheries operated only in the CC in 2022/2023.

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. Progress has been made in quantifying SOK mortality sources within the new modelling framework (DFO 2023b), however those approaches are not transferable to the SCA model (Martell et al. 2012) used here.

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 is used to estimate time series of spawning biomass, instantaneous natural mortality, and age-2 recruitment from 1951 to 2023. Advice to managers for the major SARs includes posterior estimates of current stock status SB_{2023}, stock status relative to the LRP of $0.3SB_0$, and spawning biomass in 2024 assuming no catch SB_{2024}. 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 2023): 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 estimated values reflect the prior means (Cleary et al. 2019, Appendix D). Assuming $q_2 = 1$ produces a "minimum" biomass estimate buffering any other assessment and management implementation errors (Martell et al. 2012; DFO 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 last three years, the COVID-19 pandemic did not impact the collection and analysis of spawn or biological data in 2023.

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. 2022), 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". Management procedure evaluation tables were updated in 2022 (DFO 2022a).

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

1. Maintain spawning biomass at or above the LRP with at least 75% probability over three Pacific Herring generations (i.e., avoid a biomass limit; $P(SB_t \geq 0.3SB_0) \geq 0.75$),

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; $P(SB_t \geq SB_{targ}) \geq 0.50$),

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 harvest control rule (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 two hypotheses about future Pacific Herring natural mortality M:

1. M is a time-varying, density-dependent process (DDM), and

2. M is a time-varying, density-independent process (DIM).

These two hypotheses are captured as operating model (OM) scenarios in Benson et al. (2022). The DDM scenario was identified as the reference OM scenario based on discussion at the 2018 CSAS review process (DFO 2020a), while the DIM scenario was identified as a robustness OM scenario.

On June 26–28, 2023, a regional peer review occurred for "Application of a new modelling framework for the assessment of Pacific Herring (*Clupea pallasii*) major stocks and implementation in the MSE process." The details of the review process are summarized in DFO (2023b), and there were two key recommendations for implementation:

1. A process for implementing the new assessment and operating model, updates to the MSE, and identification of exceptional circumstances should be developed in a phased approach in consultation with managers, First Nations and other stakeholders.

2. A minimum three year cycle for MSE updates is recommended, unless new evidence reveals exceptional circumstances.

DFO is committed to implementing these recommendations prior to implementation of the spatially integrated statistical catch at age herring (SISCAH) modelling framework.

1. 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).

2. 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.

3. 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.

4. 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 2022/2023 herring season (July 1 to June 30). Note that we refer to 'year' instead of 'herring season' in this report; therefore 2023 refers to the 2022/2023 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 have been developed within the SISCAH modelling framework (DFO 2023b).

Combined commercial removals from 2014 to 2023 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 97% in 2023.

Total SOK harvest (i.e., pounds of validated product) for the major SARs from 2014 to 2023 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 spatial extent of the spawn, number of egg layers, substrate 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 2023. 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 2023 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 SAR from 1951 to 2023 are summarized in Figure 6. In 2023, there was an increase in survey biomass (i.e., index values) for the PRD and WCVI SARs, and a decrease in survey biomass for HG, CC, and SoG SARs (Figure 6; 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. Impacts of additional mortality sources will be explored with the new modelling framework.

Again this year, we include data for incidental mortality in finfish aquaculture activities by SAR from 2014 to 2022 (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. Unknown mortality rate for “released” fish,
2. Unknown length, weight, age, and sex of fish, and

3. “Herring-like” fish are assumed to be herring when decomposition hinders identification.

Note that data from previous years are updated as DFO receives additional reports.

First Nations observations

The following observations were contributed by representatives of First Nations communities.

Haida Gwaii

Herring spawns in Cumshewa Inlet have been infrequent in recent years, but when they have occurred the spawns have generally been very late in the season (late April to early May). However, in 2023 some of the earliest herring spawns in the Haida Gwaii major stock assessment area occurred along the north shore of Cumshewa Inlet. Spawns, which were generally light in deposition and inconsistent (spotty), occurred in areas near Aero Camp, Cumshewa Village, and out around Cumshewa Head to Grey Point.

The Selwyn Inlet stock continues to show a declining trend (as it has for over the past 10 years). Similar to 2021, the spawn in Selwyn Inlet in 2023 occurred very late in the season (end of April). The location of the spawn was consistent with the traditional area along the Louise Island shore in and near Traynor Bay and out toward Kilmington Point. Herring stocks in Selwyn Inlet remain at a low level of productivity with no real growth in the population. Spawns in 2023 were found to be mostly light to medium in deposition.

The Juan Perez Sound inlets normally support spawns when there are a lot of new “young of the year” in the population. There were no spawns observed in the upper Juan Perez Sound inlets during the 2023 season.

The majority of herring stocks in the Haida Gwaii major stock assessment area continue to be in Skincuttle Inlet and upper Burnaby Strait (around Burnaby Island). The abundance of stocks and deposition of spawns appear to be very similar to 2022. These stocks appear to be maintaining themselves, but are not really showing any signs of meaningful growth in spite of no active fisheries for over 20 years.

In Louscoone Inlet, local stocks would normally be found well up inside the inlet and often presented a very light spawn near the head of the inlet early in the season (early to mid March). There were no reported spawns in Louscoone Inlet in 2023. The herring stocks in Louscoone Inlet seldom exceeded 500 tons, however in recent years it has been much less. Herring observed in the outer portions of Louscoone Inlet are thought to be more migratory and rarely spawn in Louscoone.

There was no effort toward the traditional harvest of k’aaw (herring roe) in Skincuttle and Upper Burnaby in 2023. However, there were local harvesters from Skidegate that were set up during the spawn in Selwyn Inlet. As a result there was 11,000 pounds of k’aaw was estimated to have been harvested from Selwyn Inlet during the 2023 season.

Stock status update

Analyses of stock trend information is presented following methods of Cleary et al. (2019) for the Pacific Herring major SARs. This year, Markov chain Monte Carlo (MCMC) runs have a chain length of twenty million with a sample taken every four thousand iterations (i.e., thinning). Next, the first one thousand samples are discarded (i.e., burn-in), leaving four thousand samples as the posteriors. Perceptions of stock status based on outputs (i.e., posteriors) from the SCA model 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 2023). Thus, two q parameters are implemented in the estimation procedure: q_1 (1951 to 1987) with an uninformative prior, and q_2 (1988 to 2023) with an informative prior approximating 1.0.

The surface survey methodology has been used on occasion from 1988 to 2023. 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. Methods for combining surface and dive survey observations are presented for the SISCAH modelling framework (DFO 2023b), but are not implemented here.

Reference points

A biological LRP is defined for the major Pacific Herring SARs at $0.3SB_0$ (Kronlund et al. 2017). Candidate USRs 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 (2023a). In total, 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 2023 $\overline{SB}$.

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. In 2023, DFO Resource Management selected and implemented a provisional USR of $\overline{SB}$ through 2022/23 IFMP process.

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 precautionary approach (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 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 show an average increasing trend in estimated spawning biomass from 2010 to 2020 with stable catches since 1980, and catch declining over the last decade (Figure 7). Comparisons of total estimated biomass and spawning biomass are also included 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 high catches, low estimated 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 declined. A reprieve in estimated low biomass occurred following several years with above average estimated recruitment through the late 1990s, before biomass declined to persistent historic lows from 2000 to present, with a couple of low biomass peaks in 2013 and 2019 (Figure 9d). The increasing trend in the estimated natural mortality rate since 1980 (Figure 9b) largely absorbed any surplus production attributed to above average recruitment events (e.g., 1997, 2012, 2018; Figure 9c, d). Additionally estimated natural mortality has increased the last 5 years to historic highs.

The HG stock persists in a low biomass state, with many years also showing low productivity which has largely precluded stock growth (Figure 9f). Above-average recruitment of age-2 fish in 2018, leading to increases in survey biomass in 2019 and 2020 were positive signs but average to below-average recruitment since then, which estimates negative productivity, has brought biomass down to recent historical lows. 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 21,158 t, and the LRP of $0.3SB_0$ is 6,347 t (posterior medians). Compared to last year, estimated spawning biomass in 2023 SB_{2023} decreased from 5,040 to 3,204 t (posterior median), and is equivalent to 15.0% of SB_0 (Tables 19 & 24). Spawning biomass in 2023 is estimated to be above the LRP with a 7.4% 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 by the mid-1960s to the lowest estimated spawning biomass. Spawning biomass recovered by the mid-1980s estimated to be about 50% of the historic high even amid mostly below-average recruitment (Figure 10b, d, e). In the late-1980s, estimated spawning biomass began a steady decline amid slowly rising mortality rates and variable recruitment, before stabilizing at a relatively low level (but above historic lows) between 2005 and 2018. Since then estimated spawning biomass has shown modest increases in biomass with above average age-2 recruitment in 2014, 2018 and, 2022 and stable natural mortality rates (Figure 10c, d, f). Productivity in recent years is relatively high compared to the last 30 years, with the highest estimated productivity in 2022 (Figure 10f).

Fluctuations in spawning biomass trend appear to be less than in other SARs in the last 30 years, possibly because they are smaller in magnitude and offset each other as shown in Figure 10a.

Estimated unfished spawning biomass SB_0 is 58,800 t, and the LRP of $0.3SB_0$ is 17,640 t (posterior medians). Compared to last year, estimated spawning biomass in 2023 SB_{2023} increased from 30,606 to 44,725 t (posterior median), and is equivalent to 74.7% of SB_0 (Tables 20 & 25). Spawning biomass in 2023 is estimated to be above the LRP with a 99.3% 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).

Central Coast

Estimated spawning biomass reached a historic high around 1980 following low estimated natural mortality rates and the highest estimated recruitment 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. Spawning biomass trend declined from 1985-2005 and an increase in estimated natural mortality led to historically low estimated biomass levels from 2005 to 2015. Decreasing estimated natural mortality lead to moderate increases in biomass through 2020. In 2021 - 2023, increasing estimated natural mortality caused a decrease in estimated biomass, which was mitigated in part by higher than average estimated recruitment in 2022 (Figure 11a, b, e). Model estimates suggest slightly less spawning biomass in 2023 than 2022 (Table 21), and the analysis of surplus production shows evidence of positive production in 2018, followed by negative in both 2019 and 2020, and near neutral production in 2021 and 2022 (Figure 11f).

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), Kitasu Bay/East Higgins (Section 067) and Thompson/Stryker (Section 074; Figure 12). Occurrence of spawn in Thompson/Stryker in 2020 to 2021 represented the first significant spawns in this section in many years. The mechanisms driving spawn fluctuations in the Central Coast are not well understood.

From 1990 to 2006 the effective harvest rate U_t is estimated to fluctuate above and below 20%, with median estimates exceeding 20% in some of these years (Figure 15). Occurrences of U_t exceeding 20% 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 have operated yearly at some level from 2014 to 2021 and in 2023 (Table 3). Note that a commercial SOK fishery did not occur in Area 07 in 2020 due to COVID-19, and no commercial SOK fisheries were permitted in 2022. SOK removals are not included in the estimation of U_t.

Estimated unfished spawning biomass SB_0 is 49,515 t, and the LRP of $0.3SB_0$ is 14,854 t (posterior medians). Compared to last year, estimated spawning biomass in 2023 SB_{2023} decreased from 20,949 to 18,950 t (posterior median), and is equivalent to 38.1% of SB_0 (Tables 21 & 26). Spawning biomass in 2023 is estimated to be above the LRP with a 75.0% probability (Table 26).

Strait of Georgia

The estimated spawning biomass for the SoG SAR shows a historical low in the late 1960s, driven by high catches, lower than average estimated recruitment, and increasing estimated natural mortality (Figure 13a, b, e). In the 1970s estimated natural mortality declined, and until recent years has been relatively stable (Figure 13b). Most of the fluctuations in estimated spawning biomass have been attributed to estimated recruitment, with lower than average recruitments in the 1970s, 1980s, and in 2007 and 2009, all of which mirror dips in spawning biomass. Above average recruitments occurred in the intervening times corresponding to biomass peaks (Figure 13a, c). Three of the highest estimated recruitment years (2019, 2020, and 2022) have occurred in the last 5 years. While 2020 is one of the three highest peaks in estimated spawning biomass, rising natural mortality has moderated potential gains in estimated spawning biomass (Figure 13a, b, c). This plays out in estimated production which was high in 2019, declined to a negative value in 2021, and is slightly positive for the 2022 (Figure 13f). In 2023, the estimated spawning biomass was similar to the last two years and was consistent with the forecast.

The large opposing fluctuations in estimated recruitment and natural mortality are likely contributing to increased uncertainty in spawning biomass and forecast biomass SB_{2024} (Figure 13d).

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 138,491 t, and the LRP of $0.3SB_0$ is 41,547 t (posterior medians). Compared to last year, estimated spawning biomass in 2023 SB_{2023} decreased from 75,523 to 72,782 t (posterior median), and is equivalent to 52.1% of SB_0 (Tables 22 & 27). Spawning biomass in 2023 is estimated to be above the LRP with a 94.3% 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 lowest observed model estimates of 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 estimated recruitment led to a declining 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 occured in 2015 with lower estimated natural mortality and higher estimated recruitment, and then again after 2020 (Figure 14d, f).

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 is likely resulting from little to no catch or age composition data for that fishery in the 1970s. In an attempt to resolve parameter autocorrelation, we removed age compositions from 1984 for which there was no associated catch as well as catch from 1978 to 1996 (range: 0 t to 0.84 t), for which there are no associated age compositions. These changes did not notably improve the autocorrelation. Similarly, running longer chains (20 million vs 5 million) resulted in only minor improvements (as was observed when this was conducted in 2021 (DFO 2021b)).

Estimated unfished spawning biomass SB_0 is 46,537 t, and the LRP of $0.3SB_0$ is 13,961 t (posterior medians). Compared to last year, estimated spawning biomass in 2023 SB_{2023} increased from 34,708 to 41,190 t (posterior median), and is equivalent to 87.9% of SB_0 (Tables 23 & 28). Spawning biomass in 2023 is estimated to be above the LRP with a 100.0% probability (Table 28).

Management performance

Historic management procedure performance can be assessed 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 are presented in Figure 15.

Application of MPs and harvest options for 2024

Harvest options for 2024 reflect application of simulation-tested MPs for each major SAR, derived from the Herring OM (Benson et al. 2022). OM conditioning was updated in 2022 using historic stock and fishery data from 1951 to 2021; no MP updates were conducted for 2023. MPs are not provided for HG because this is now conducted within the HG rebuilding plan process.[1]

Haida Gwaii

The HG stock persisted in a low biomass state from approximately 2000-2018 (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 2023. 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]

In the absence of fishing, spawning biomass in 2024 SB_{2024} is forecast to be 4,272 t (posterior median; Table 24). Spawning biomass in 2024 is forecast to be below the LRP of $0.3SB_0$ (6,347 t) with a 76.6% probability, in the absence of fishing (Table 24 and Figure 16).

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

DFO has committed to developing and implementing a rebuilding plan for Haida Gwaii Pacific Herring. A technical working group comprised of members of the Council of Haida Nation, DFO, and Parks Canada co-developed a draft plan for which a consultation period was held from September 26 to December 16, 2022. Approval of the final rebuilding plan is expected for the fall/winter of 2023.

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 Haida Gwaii stock in 2024 is 0 t. All future MP evaluations will occur through the rebuilding plan process.

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 (2023a). No new MPs were included, however probability metrics for the five USRs options (DFO 2023a) 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 97% probability, over both OM scenarios (Table 30). The mean effective harvest rate U_t for the past 10 years with non-zero catches (from 2010 to 2023) is 9% (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 2024 SB_{2024} is forecast to be 42,495 t (posterior median; Table 25). Spawning biomass in 2024 is forecast to be below the LRP of $0.3SB_0$ (17,640 t) with a 2.1% probability, in the absence of fishing (Table 25 and Figure 16).

Harvest options for 2024, resulting from simulation-tested MPs are presented in Table 30 and include probability values for the LRP and provisional USR which reflect updated OM conditioning. Options reflect application of MPs to the 2024 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. An increasing trend was observed from 2015–2020, followed by a decline from 2021–2023 (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 (2023a). No new MPs were included, however probability metrics for the five USRs options (DFO 2023a) 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 91% 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 2024 SB_{2024} is forecast to be 16,229 t (posterior median; Table 26). Spawning biomass in 2024 is forecast to be below the LRP of $0.3SB_0$ (14,854 t) with a 40.9% 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 2024. Results presented here may inform this ongoing commitment.

Strait of Georgia

The SoG has the largest biomass of the major SARs and currently comprises approximately 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 (Figure 13b). SoG MP evaluations are implemented using the Herring OM (Benson et al. 2022). MPs were first presented in 2018 (DFO 2019) and updates in 2020 (DFO 2021a) and in 2022 (DFO 2022a). 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 in 2022 (DFO 2022a), included here, show probabilities ranging from 67% to 80% (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 last three to five years of natural mortality trends used to condition the OM (Table 32), as well as to consider how biomass trends have responded under continual annual commercial fisheries.

SOG MP evaluations 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 2024 SB_{2024} is forecast to be 73,375 t (posterior median; Table 27). Spawning biomass in 2024 is forecast to be below the LRP of $0.3SB_0$ (41,547 t) with a 8.0% 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 2014 to 2023) is 17% (Figure 15). Harvest options for 2024, resulting from simulation-tested MPs, are presented in Table 32. These options reflect application of MPs to the 2024 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 2024 SB_{2024} is forecast to be 37,416 t (posterior median; Table 28). Spawning biomass in 2024 is forecast to be below the LRP of $0.3SB_0$ (13,961 t) with a 0.4% probability, in the absence of fishing (Table 28 and Figure 16).

Harvest options for 2024, resulting from simulation-tested MPs, are presented in Table 33. These options reflect application of MPs to the 2024 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).

Ecosystem considerations

The Pacific Herring assessment models environmental variability implicitly via time varying natural mortality and recruitment (e.g., implied predation and other environmental impacts); however, ecosystem indicators are not directly incorporated into the assessment model. The assessment also does not necessarily identify the mechanisms through which mortality is changing. Qualitative and quantitative summaries and analyses can help to fill this knowledge gap. As a step towards improving the understanding of the environmental conditions that affect herring, directed and standardized literature searches were conducted to identify mechanistic hypotheses that link environmental and biological pressures to Pacific Herring outcomes (responses), such as distribution, growth, migration, productivity, reproduction, and survival (Boldt et al. 2022). For a case study on Haida Gwaii herring, indicators of these mechanisticallylinked pressures and responses were assembled from multiple sources (e.g., Boldt et al. 2023), based on the Driver-Pressure-State-Impact-Response (DPSIR) framework (Elliott 2002). Indicators generally corresponded to published lists of standard indicators (e.g., Bundy et al. (2017); Boldt et al. (2014); Takahashi and Perry (2019)), with consideration for the spatial scales and herring distribution by season and life history stage (Boldt et al.).[3] Data exploration and analyses were undertaken to collate and reduce the number of indicators according to the methods of Boldt et al. (2021) and indicator selection criteria (Rice and Rochet 2005). A multi-model approach, including single pressure-response and multivariate models, was applied to determine functional forms of pressure-response relationships and identify linear and non-linear relationships (Boldt et al.).[3]

Environmental pressures that have been identified as important for herring include the timing, duration, and magnitude of upwelling, which can affect the amount of primary and secondary production available to herring (Mackas et al. 2001; Hourston and Thomson 2019); Figure 17. Other physical environmental pressures include sea surface temperature (SST), salinity, sea level, river discharge, and Ekman transport (Tester 1948; Alderdice and Hourston 1985; Stocker and Noakes 1985; Stocker et al. 1985; Schweigert and Noakes 1990; Ware 1991; Zebdi and Collie 1995). For example, Tester (1948) found that herring recruitment and survival are negatively related to sea surface temperature. Fish yield was found to be correlated with phytoplankton and zooplankton production in BC (Ware and Thompson 2005) and zooplankton biomass anomalies have been correlated with herring growth (Mackas et al. 2007). Changes in zooplankton species composition from larger-sized and lipid-rich boreal and subarctic copepod species to smaller-sized and lipid-poor southern copepod species affects the quality of food available to herring (Mackas et al. 2001; Keister et al. 2011). The timing or match-mismatch between spawning herring and the subsequent availability of prey to juveniles appears to be important in determining abundance of age-0 herring in the fall (Schweigert et al. 2013; Boldt et al. 2018). Increased water temperatures are often associated with increased abundance of herring predators and competitors (Mysak 1986; Ware and McFarlane 1986). Herring predators, include Pacific Hake, groundfish (e.g., Spiny Dogfish), Coho and Chinook Salmon, pinnipeds and Humpback Whales (Ware and McFarlane 1986, 1995; Schweigert et al. 2010). Potential herring competitors include other zooplanktivores, such as juvenile groundfish, juvenile pink, chum and sockeye salmon, Pacific Hake, and, in the past, Pacific Sardine. Spatio-temporal model results suggest that the strongest drivers of summer distribution and biomass of Pacific Herring off the WCVI include: zooplankton prey availability, predator avoidance, particularly Pacific Hake, and competition with sardines (Godefroid et al. 2019).

The Haida Gwaii herring stock has been in a low productivity phase in the absence of fishing over the last two decades. The herring responses that have shown long-term declining trends are herring biomass, age-3 weight, and condition. Trends in pressures that correspond with these herring responses include (Table 34 and Figure 18):

1. Long-term increasing SSTs, which has been correlated with poor herring productivity. In 2022, late and below average upwelling indicate reduced upwelling-based productivity.

2. An increase in total zooplankton biomass and hence prey availability, but with changes to the community composition (i.e., lipid-poor southern copepods increased during and then decreased after the 2014-2016 marine heat wave).

[3] Boldt, J.L., C.N. Rooper, J.S. Cleary, C. Fu, M. Galbraith, R. Hourston, A. Peña, and R.I. Perry. Incorporating ecosystem information into science advice - a case study for Haida Gwaii Pacific Herring. In prep.

3. An increase in marine mammal predator abundances (i.e., Steller Sea Lion and Humpback Whale abundance).
4. Decreases in some groundfish predators and competitors (i.e., Pacific Hake, North Pacific Spiny Dogfish biomass, Arrowtooth Flounder), with recent (2021) increases in survey catch rates of some species (e.g., Pacific Cod).

Conclusions

The 2023 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 2023.

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 2024 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 2023 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 2023). Note: the ‘spawn index’ is not scaled by the spawn survey scaling parameter q.

Source	Data	Years
Roe gillnet fishery	Catch	1972 to 2023
Roe seine fishery	Catch	1972 to 2023
Other fisheries	Catch	1951 to 2023
Test fishery (seine)	Biological: number-at-age	1975 to 2023
Test fishery (seine)	Biological: weight-at-age	1975 to 2023
Roe seine fishery	Biological: number-at-age	1972 to 2023
Roe seine fishery	Biological: weight-at-age	1972 to 2023
Roe gillnet fishery	Biological: number-at-age	1972 to 2023
Other fisheries	Biological: number-at-age	1951 to 2023
Other fisheries	Biological: weight-at-age	1951 to 2023
Surface survey	Abundance: spawn index	1951 to 1987
Dive survey	Abundance: spawn index	1988 to 2023

Table 2. Total landed Pacific Herring catch in tonnes from 2014 to 2023 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**
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
2023	0	168	0	6,002	0

Table 3. Total Pacific Herring spawn-on-kelp harvest, reported as pounds of eggs on kelp, from 2014 to 2023 in the major stock assessment regions (SARs). See Table 2 for description.

	SAR				
Year	**HG**	**PRD**	**CC**	**SoG**	**WCVI**
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
2023	0	0	42,022	0	0

Table 4. Haida Gwaii SAR: spawn index in tonnes for Pacific Herring and proportion of spawn index by Group from 2014 to 2023. 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**
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
2023	1,584	0.038	0.962	0.000

Table 5. Prince Rupert District SAR: spawn index in tonnes for Pacific Herring and proportion of spawn index by Statistical Area from 2014 to 2023. 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**	**03**	**04**	**05**
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
2023	42,202	0.000	0.720	0.280

Table 6. Central Coast SAR: spawn index in tonnes for Pacific Herring and proportion of spawn index by Statistical Area from 2014 to 2023. 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**	**06**	**07**	**08**
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
2023	17,551	0.152	0.766	0.081

Table 7. Strait of Georgia SAR: spawn index in tonnes for Pacific Herring and proportion of spawn index by Group from 2014 to 2023. 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. 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**	**14&17**	**ESoG**	**Lazo**	**SDodd**
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	86,114	0.801	0.024	0.154	0.021
2023	74,507	0.769	0.013	0.205	0.013

Table 8. West Coast of Vancouver Island SAR: spawn index in tonnes for Pacific Herring and proportion of spawn index by Statistical Area from 2014 to 2023. 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**	**23**	**24**	**25**
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
2023	77,005	0.163	0.754	0.083

Table 9. Haida Gwaii SAR: key parameters in the Pacific Herring statistical catch-age model. Parameters are summarised by posterior (5^{th}, 50^{th}, and 95^{th} 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 2023; $\overline{R}_{init}$ 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 2023; 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	188.162	246.248	339.544	245.657
h	0.647	0.783	0.895	0.803
M	0.216	0.399	0.679	0.369
$\overline{R}$	128.673	152.372	183.084	159.530
$\overline{R}_{init}$	8.642	28.970	152.237	31.528
ρ	0.236	0.297	0.372	0.288
ϑ	0.751	0.902	1.081	0.970
q_1	0.348	0.428	0.514	0.422
q_2	0.983	0.999	1.015	0.998
τ	0.786	0.879	0.984	0.857
σ	0.502	0.573	0.653	0.545

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	264.891	346.106	515.876	331.622
h	0.528	0.688	0.842	0.720
M	0.254	0.451	0.750	0.435
$\overline{R}$	181.851	210.214	242.368	216.016
$\overline{R}_{init}$	67.546	213.591	1,034.672	261.614
ρ	0.206	0.270	0.344	0.268
ϑ	0.966	1.179	1.428	1.256
q_1	0.462	0.537	0.626	0.530
q_2	0.984	1.001	1.017	1.000
τ	0.699	0.785	0.881	0.764
σ	0.413	0.477	0.553	0.462

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	330.093	414.138	532.675	402.875
h	0.659	0.794	0.902	0.815
M	0.268	0.474	0.802	0.451
$\overline{R}$	246.684	276.211	311.881	277.740
$\overline{R}_{init}$	53.184	192.898	1,169.451	268.432
ρ	0.175	0.233	0.307	0.213
ϑ	1.023	1.234	1.478	1.304
q_1	0.276	0.321	0.366	0.323
q_2	0.983	0.999	1.015	0.999
τ	0.704	0.787	0.879	0.777
σ	0.376	0.435	0.506	0.404

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	1,374.886	1,704.500	2,279.855	1,637.380
h	0.566	0.714	0.861	0.744
M	0.268	0.465	0.784	0.451
$\overline{R}$	968.985	1,104.525	1,257.963	1,123.790
$\overline{R}_{init}$	41.649	161.445	851.229	272.608
ρ	0.202	0.269	0.349	0.254
ϑ	1.266	1.547	1.879	1.647
q_1	0.879	1.037	1.207	1.032
q_2	0.983	0.999	1.016	0.999
τ	0.607	0.687	0.772	0.673
σ	0.358	0.416	0.485	0.393

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	456.033	579.648	760.133	566.379
h	0.607	0.732	0.855	0.744
M	0.342	0.604	1.016	0.583
$\overline{R}$	335.170	383.620	439.855	386.674
$\overline{R}_{init}$	33.371	155.397	1,185.430	261.843
ρ	0.238	0.308	0.387	0.297
ϑ	1.102	1.328	1.599	1.432
q_1	0.711	0.844	0.993	0.853
q_2	0.983	0.999	1.016	0.999
τ	0.641	0.720	0.813	0.701
σ	0.420	0.480	0.548	0.455

Table 14. Haida Gwaii SAR: age-2 recruitment from 2014 to 2023 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
2014	65.088	95.709	141.309	97.372
2015	48.168	71.349	105.230	72.186
2016	103.476	150.293	218.345	154.217
2017	176.130	254.498	367.013	262.435
2018	378.856	533.918	764.356	554.968
2019	44.284	70.198	112.646	72.762
2020	26.441	42.601	69.620	44.859
2021	102.266	161.844	265.176	172.771
2022	74.979	124.912	208.826	130.166
2023	24.555	46.322	86.853	45.660

Table 15. Prince Rupert District SAR: age-2 recruitment from 2014 to 2023 for the Pacific Herring statistical catch-age model. See Table 14 for description.

Year	5%	50%	95%	MPD
2014	318.784	436.918	596.500	448.309
2015	138.401	194.520	274.858	200.971
2016	73.825	110.204	163.652	113.983
2017	233.645	332.644	478.025	345.578
2018	682.033	953.822	1,321.938	978.966
2019	53.552	78.911	116.619	80.287
2020	167.844	249.418	369.353	254.199
2021	100.294	172.519	293.320	168.994
2022	436.296	822.152	1,383.187	853.679
2023	70.165	264.087	1,052.887	241.583

Table 16. Central Coast SAR: age-2 recruitment from 2014 to 2023 for the Pacific Herring statistical catch-age model. See Table 14 for description.

Year	5%	50%	95%	MPD
2014	382.145	492.645	631.764	494.168
2015	129.115	170.318	225.949	171.559
2016	146.382	193.317	258.231	195.921
2017	208.210	275.198	367.718	280.219
2018	866.579	1,139.545	1,486.522	1,172.220
2019	72.347	99.273	136.654	102.359
2020	346.194	481.236	655.764	499.170
2021	190.064	282.240	414.609	291.443
2022	715.203	1,059.135	1,563.780	1,088.590
2023	165.751	277.993	446.444	272.866

Table 17. Strait of Georgia SAR: age-2 recruitment from 2014 to 2023 for the Pacific Herring statistical catch-age model. See Table 14 for description.

Year	5%	50%	95%	MPD
2014	1,371.342	1,727.660	2,145.691	1,743.520
2015	1,184.512	1,517.170	1,916.099	1,532.290
2016	1,054.946	1,373.810	1,785.038	1,399.790
2017	1,063.001	1,390.405	1,818.912	1,424.750
2018	1,186.017	1,569.275	2,049.421	1,599.600
2019	2,402.889	3,179.285	4,177.075	3,257.970
2020	1,746.690	2,332.695	3,074.688	2,380.630
2021	1,074.289	1,448.050	1,947.873	1,465.840
2022	2,089.607	2,847.640	3,857.244	2,863.210
2023	1,258.047	1,859.750	2,807.076	1,836.720

Table 18. West Coast of Vancouver Island SAR: age-2 recruitment from 2014 to 2023 for the Pacific Herring statistical catch-age model. See Table 14 for description.

Year	5%	50%	95%	MPD
2014	191.884	259.872	349.232	263.198
2015	680.512	906.272	1,207.029	924.168
2016	100.191	136.936	187.721	139.897
2017	101.026	139.228	192.830	143.276
2018	313.441	428.646	594.728	441.928
2019	211.793	296.982	408.559	304.265
2020	577.503	803.099	1,106.270	822.433
2021	480.067	676.737	976.662	690.247
2022	585.089	866.936	1,272.472	863.945
2023	486.630	814.805	1,356.198	815.654

Table 19. Haida Gwaii SAR: spawning biomass and depletion from 2014 to 2023 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**
2014	6.637	8.830	11.828	8.770	0.284	0.416	0.600	0.435
2015	5.052	6.736	9.022	6.683	0.215	0.317	0.459	0.332
2016	4.369	5.829	7.859	5.813	0.186	0.274	0.398	0.289
2017	6.027	7.991	10.705	8.089	0.251	0.377	0.548	0.402
2018	9.257	12.442	16.692	12.731	0.388	0.586	0.858	0.632
2019	10.920	15.091	20.924	15.561	0.460	0.711	1.066	0.773
2020	7.633	10.835	15.359	11.067	0.326	0.513	0.774	0.549
2021	4.699	6.615	9.392	6.564	0.203	0.313	0.466	0.326
2022	3.412	5.040	7.547	4.830	0.151	0.238	0.370	0.240
2023	1.445	3.204	6.982	2.876	0.068	0.150	0.334	0.143

Table 20. Prince Rupert District SAR: spawning biomass and depletion from 2014 to 2023 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**
2014	13.428	16.294	19.895	16.456	0.176	0.276	0.384	0.300
2015	15.188	18.767	23.368	19.032	0.203	0.320	0.446	0.347
2016	12.819	16.100	20.301	16.286	0.171	0.274	0.388	0.297
2017	11.079	14.388	18.550	14.521	0.150	0.244	0.352	0.265
2018	14.616	18.907	24.687	19.070	0.200	0.319	0.463	0.348
2019	23.473	30.468	40.119	30.550	0.322	0.513	0.754	0.557
2020	20.575	27.005	35.788	26.559	0.290	0.454	0.662	0.484
2021	18.458	24.964	33.752	24.065	0.266	0.421	0.610	0.439
2022	21.275	30.606	43.664	29.330	0.316	0.515	0.769	0.535
2023	26.026	44.725	72.888	42.823	0.408	0.747	1.271	0.781

Table 21. Central Coast SAR: spawning biomass and depletion from 2014 to 2023 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**
2014	13.485	16.657	20.471	16.684	0.243	0.336	0.448	0.350
2015	16.812	21.096	26.206	21.252	0.305	0.427	0.571	0.445
2016	16.819	21.109	26.283	21.374	0.306	0.425	0.570	0.448
2017	16.792	21.007	26.194	21.409	0.306	0.424	0.568	0.449
2018	18.840	23.709	29.506	24.260	0.343	0.478	0.646	0.509
2019	25.967	33.868	43.356	34.759	0.480	0.678	0.938	0.729
2020	21.094	27.769	36.496	28.464	0.395	0.559	0.782	0.597
2021	15.949	21.188	28.093	21.333	0.302	0.424	0.596	0.447
2022	15.300	20.949	28.591	20.545	0.296	0.419	0.599	0.431
2023	10.816	18.950	32.741	17.985	0.212	0.381	0.658	0.377

Table 22. Strait of Georgia SAR: spawning biomass and depletion from 2014 to 2023 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
2014	68.542	80.117	94.471	80.682	0.395	0.580	0.776	0.615
2015	66.704	78.221	92.022	78.829	0.386	0.565	0.754	0.601
2016	67.335	79.305	93.863	79.968	0.391	0.572	0.765	0.610
2017	59.177	70.298	83.869	71.041	0.346	0.506	0.677	0.542
2018	58.423	69.315	82.898	70.181	0.338	0.499	0.666	0.535
2019	64.210	79.007	97.405	79.911	0.380	0.568	0.772	0.609
2020	75.785	94.769	118.980	95.152	0.455	0.680	0.938	0.725
2021	69.012	87.617	111.412	86.676	0.418	0.628	0.866	0.661
2022	57.169	75.523	101.186	73.581	0.358	0.542	0.765	0.561
2023	44.374	72.782	118.224	70.140	0.293	0.521	0.872	0.535

Table 23. West Coast of Vancouver Island SAR: spawning biomass and depletion from 2014 to 2023 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
2014	9.642	12.453	16.047	12.536	0.187	0.266	0.372	0.277
2015	13.459	17.394	22.276	17.616	0.261	0.372	0.519	0.389
2016	17.777	23.063	29.982	23.554	0.344	0.494	0.691	0.521
2017	13.522	17.593	22.653	17.873	0.265	0.376	0.518	0.395
2018	11.754	15.263	19.566	15.471	0.231	0.326	0.446	0.342
2019	11.734	15.407	20.226	15.586	0.233	0.331	0.458	0.344
2020	13.654	18.054	24.187	18.161	0.273	0.389	0.544	0.401
2021	17.763	24.044	32.801	23.869	0.360	0.514	0.725	0.527
2022	24.152	34.708	49.404	34.119	0.501	0.740	1.081	0.754
2023	24.419	41.190	67.475	40.234	0.502	0.879	1.454	0.889

Table 24. Haida Gwaii SAR: proposed reference points for the Pacific Herring statistical catch-age model. Reference points are summarised by posterior (5^{th}, 50^{th}, and 95^{th} percentile) estimates. All biomass numbers are in thousands of tonnes. Legend: SB_0 is estimated unfished spawning biomass; $\overline{SB}_{Prod}$ is average spawning biomass during a productive period (Table 29); SB_t is spawning biomass in year t; P is probability; and SB_{2024} is projected spawning biomass in 2024 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	16.951	21.158	27.565
$0.3SB_0$	5.085	6.347	8.270
$0.75\overline{SB}_{Prod}$	18.192	24.435	34.556
SB_{2023}	1.445	3.204	6.982
SB_{2023}/SB_0	0.068	0.150	0.334
$P\ (SB_{2023} < 0.3SB_0)$	–	0.926	–
$P\ (SB_{2023} < 0.75\overline{SB}_{Prod})$	–	1.000	–
SB_{2024}	1.629	4.272	11.348
SB_{2024}/SB_0	0.077	0.199	0.526
$P\ (SB_{2024} < 0.3SB_0)$	–	0.766	–
$P\ (SB_{2024} < 0.75\overline{SB}_{Prod})$	–	0.995	–
Proportion aged 3	0.09	0.36	0.73
Proportion aged 4 to 10	0.12	0.34	0.63

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	45.092	58.800	88.710
$0.3SB_0$	13.528	17.640	26.613
$\overline{SB}_{Prod}$	27.870	33.917	41.970
SB_{2023}	26.026	44.725	72.888
SB_{2023}/SB_0	0.408	0.747	1.271
$P\ (SB_{2023} < 0.3SB_0)$	–	0.007	–
$P\ (SB_{2023} < \overline{SB}_{Prod})$	–	0.214	–
SB_{2024}	22.177	42.495	77.550
SB_{2024}/SB_0	0.358	0.702	1.321
$P\ (SB_{2024} < 0.3SB_0)$	–	0.021	–
$P\ (SB_{2024} < \overline{SB}_{Prod})$	–	0.296	–
Proportion aged 3	0.04	0.14	0.40
Proportion aged 4 to 10	0.54	0.80	0.92

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	40.117	49.515	63.028
$0.3SB_0$	12.035	14.854	18.908
$\overline{SB}_{Prod}$	26.724	31.465	37.592
SB_{2023}	10.816	18.950	32.741
SB_{2023}/SB_0	0.212	0.381	0.658
$P\ (SB_{2023} < 0.3SB_0)$	–	0.250	–
$P\ (SB_{2023} < \overline{SB}_{Prod})$	–	0.927	–
SB_{2024}	8.425	16.229	32.869
SB_{2024}/SB_0	0.168	0.330	0.656
$P\ (SB_{2024} < 0.3SB_0)$	–	0.409	–
$P\ (SB_{2024} < \overline{SB}_{Prod})$	–	0.939	–
Proportion aged 3	0.07	0.22	0.52
Proportion aged 4 to 10	0.37	0.63	0.83

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	110.173	138.491	195.779
$0.3SB_0$	33.052	41.547	58.734
$0.8\overline{SB}_{Prod}$	55.213	64.476	75.919
SB_{2023}	44.374	72.782	118.224
SB_{2023}/SB_0	0.293	0.521	0.872
$P\ (SB_{2023} < 0.3SB_0)$	–	0.057	–
$P\ (SB_{2023} < 0.8\overline{SB}_{Prod})$	–	0.356	–
SB_{2024}	39.952	73.375	133.012
SB_{2024}/SB_0	0.275	0.520	0.953
$P\ (SB_{2024} < 0.3SB_0)$	–	0.080	–
$P\ (SB_{2024} < 0.8\overline{SB}_{Prod})$	–	0.369	–
Proportion aged 3	0.09	0.26	0.53
Proportion aged 4 to 10	0.37	0.61	0.80

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	37.836	46.537	59.598
$0.3SB_0$	11.351	13.961	17.879
$\overline{SB}_{Prod}$	27.227	33.582	41.714
SB_{2023}	24.419	41.190	67.475
SB_{2023}/SB_0	0.502	0.879	1.454
$P\ (SB_{2023} < 0.3SB_0)$	–	0.000	–
$P\ (SB_{2023} < \overline{SB}_{Prod})$	–	0.287	–
SB_{2024}	20.066	37.416	68.207
SB_{2024}/SB_0	0.425	0.804	1.480
$P\ (SB_{2024} < 0.3SB_0)$	–	0.004	–
$P\ (SB_{2024} < \overline{SB}_{Prod})$	–	0.404	–
Proportion aged 3	0.08	0.23	0.50
Proportion aged 4 to 10	0.41	0.66	0.85

Table 29. Year range for calculating proportion of average spawning biomass of Pacific Herring during a productive period $\overline{SB}_{Prod}$ in the major stock assessment regions (SARs).

SAR	Years	Proportion
Haida Gwaii	1975 to 1985	0.75
Prince Rupert District	1983 to 1992	1.00
Central Coast	1990 to 1999	1.00
Strait of Georgia	1988 to 2007	0.80
West Coast of Vancouver Island	1990 to 1999	1.00

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) in 2024 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); average annual variability (AAV) in catch; and $\overline{C}$ is average annual catch. MPs are defined in DFO (2019) and DFO (2020a). Biomass and catch are in thousands of tonnes (t). Note: Dashes or 0.00 indicate that TAC and HR do not apply because the MP specifies no fishing. Also note that TAC and HR are median values calculated by the MP using posterior distributions of SB_{2024} and SB_0. The HR is derived according to the MP shape and is equivalent to TAC/SB_{2024}. In cases where MPs include a cap, the cap is constant regardless of estimated SB_{2024}, and higher SB_{2024} leads to lower HR.

Scenario		Conservation Obj 1 (LRP) $P \geq 75\%$	Biomass Obj 2 (USR) P	Yield Obj 3 $< 25\%$	Yield Obj 4 Max	2024	
OM	**MP**	$SB_t \geq 0.3SB_0$	$SB_t \geq \overline{SB}_{Prod}$	**AAV**	$\overline{C}$	**TAC**	**HR**
DDM	NoFish_FSC	98%	86%	0.00	0.14	–	–
DDM	HS30-60_HR05	97%	82%	45.71	2.33	2.06	0.05
DDM	HS50-60_HR20_Cap2.5	97%	80%	36.62	2.13	2.50	0.05
DDM	HS30-60_HR10_Cap2.5	96%	79%	26.53	2.25	2.50	0.05
DDM	MinE50_HR10	96%	79%	39.83	4.21	4.14	0.10
DDM	MinE30_HR10	94%	67%	30.73	4.48	4.25	0.10
DDM	MinE50_HR20	93%	55%	50.09	6.43	8.01	0.20
DIM	NoFish_FSC	94%	71%	0.00	0.14	–	–
DIM	HS30-60_HR05	93%	65%	51.69	1.82	2.06	0.05
DIM	HS50-60_HR20_Cap2.5	92%	63%	42.60	1.96	2.50	0.05
DIM	HS30-60_HR10_Cap2.5	91%	61%	35.58	2.07	2.50	0.05
DIM	MinE50_HR10	89%	56%	52.38	3.35	4.14	0.10
DIM	MinE30_HR10	87%	52%	33.96	3.77	4.25	0.10
DIM	MinE50_HR20	85%	31%	63.44	5.10	8.01	0.20

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

		Conservation	Biomass	Yield			
		Obj 1 (LRP)	Obj 2 (USR)	Obj 3	Obj 4		
Scenario		$P \geq 75\%$	P	$< 25\%$	Max	2024	
OM	MP	$SB_t \geq 0.3SB_0$	$SB_t \geq \overline{SB}_{Prod}$	AAV	$\overline{C}$	TAC	HR
DDM	NoFish_FSC	92%	69%	0.00	0.14	–	–
DDM	HS30-60_HR05	91%	64%	40.76	1.74	0.08	0.01
DDM	HS30-60_HR10_Cap5	90%	58%	38.83	2.92	0.16	0.01
DDM	MinE50_HR10	90%	58%	53.22	2.92	0.00	0.00
DIM	NoFish_FSC	85%	54%	0.00	0.14	–	–
DIM	HS30-60_HR05	83%	48%	50.38	1.38	0.08	0.01
DIM	MinE50_HR10	82%	43%	70.82	2.21	0.00	0.00
DIM	HS30-60_HR10_Cap5	81%	43%	52.19	2.45	0.16	0.01

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

		Conservation	Biomass	Yield			
		Obj 1 (LRP)	Obj 2 (USR)	Obj 3	Obj 4		
Scenario		$P \geq 75\%$	P	$< 25\%$	Max	2024	
OM	MP	$SB_t \geq 0.3SB_0$	$SB_t \geq 0.8\overline{SB}_{Prod}$	AAV	$\overline{C}$	TAC	HR
DDM	NoFish_FSC	80%	60%	0.00	0.14	–	–
DDM	HS30-60_HR10	77%	53%	69.87	4.92	5.36	0.07
DDM	MinE30_HR10	76%	50%	47.88	6.15	7.31	0.10
DDM	HS30-60_HR15	76%	49%	64.75	6.97	8.05	0.11
DDM	HS30-60_HR20	74%	44%	65.70	8.80	10.73	0.15
DDM	MinE30_HR15	73%	45%	45.96	8.59	10.96	0.15
DDM	MinE30_HR20	70%	39%	49.45	10.79	14.59	0.20
DIM	NoFish_FSC	78%	57%	0.00	0.14	–	–
DIM	HS30-60_HR10	75%	51%	71.39	4.58	5.36	0.07
DIM	MinE30_HR10	74%	51%	67.87	4.36	7.31	0.10
DIM	HS30-60_HR15	73%	48%	68.93	6.48	8.05	0.11
DIM	HS30-60_HR20	72%	43%	67.81	8.18	10.73	0.15
DIM	MinE30_HR15	70%	45%	50.49	7.88	10.96	0.15
DIM	MinE30_HR20	67%	40%	48.10	10.04	14.59	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.

Scenario		Conservation Obj 1 (LRP) $P \geq 75\%$	Biomass Obj 2 (USR) P	Yield Obj 3 $< 25\%$	Yield Obj 4 Max	2024	
OM	**MP**	$SB_t \geq 0.3SB_0$	$SB_t \geq \overline{SB}_{Prod}$	**AAV**	$\overline{C}$	**TAC**	**HR**
DDM	NoFish_FSC	84%	33%	0.00	0.14	–	–
DDM	HS30-60_HR10_Cap2	82%	27%	60.72	1.15	2.00	0.05
DDM	MinE30_HR05	82%	27%	59.45	1.01	1.87	0.05
DDM	HS50-60_HR10	82%	25%	89.73	1.28	3.73	0.10
DDM	HS30-60_HR15_Cap2	81%	27%	57.13	1.30	2.00	0.05
DDM	HS50-60_HR15	81%	23%	82.56	2.08	5.60	0.15
DDM	MinE30_HR10	80%	24%	75.21	1.87	3.74	0.10
DIM	NoFish_FSC	65%	17%	0.00	0.14	–	–
DIM	HS30-60_HR10_Cap2	63%	15%	71.81	0.79	2.00	0.05
DIM	MinE30_HR05	63%	15%	70.09	0.76	1.87	0.05
DIM	HS30-60_HR15_Cap2	62%	15%	80.94	0.83	2.00	0.05
DIM	HS50-60_HR10	62%	14%	96.54	0.72	3.73	0.10
DIM	MinE30_HR10	61%	13%	83.98	1.26	3.74	0.10
DIM	HS50-60_HR15	61%	12%	107.55	1.00	5.60	0.15

Table 34. Description and source for selected standardized pressure indicators and Pacific Herring responses (see Figure 18). Legend: SST is sea surface temperature, AVHHR is advanced very high resolution radiometer, DFO is Fisheries and Oceans Canada, CPUE is catch per unit effort, and IPHC is International Pacific Halibut Commission. Note that pressure indicators are for Hecate Strait and Queen Charlotte Sound, and responses are for Haida Gwaii (HG) Pacific Herring.

Variable	Description	Source
Physical environment		
Spring SST	March to May	AVHRR satellite
Summer SST	June to August	AVHRR satellite
Fall SST	September to November	AVHRR satellite
Winter SST	December to February	AVHRR satellite
Prey		
Mean boreal copepod abundance		M. Galbraith and R.I. Perry, DFO, pers. comm.
Mean boreal copepod biomass		M. Galbraith and R.I. Perry, DFO, pers. comm.
Mean southern copepod abundance		M. Galbraith and R.I. Perry, DFO, pers. comm.
Mean southern copepod biomass		M. Galbraith and R.I. Perry, DFO, pers. comm.
Mean subarctic copepod abundance		M. Galbraith and R.I. Perry, DFO, pers. comm.
Mean subarctic copepod biomass		M. Galbraith and R.I. Perry, DFO, pers. comm.
Mean total zooplankton abundance		M. Galbraith and R.I. Perry, DFO, pers. comm.
Mean total zooplankton biomass		M. Galbraith and R.I. Perry, DFO, pers. comm.
Predators		
Humpback Whale abundance	Interpolated using a 4% population growth rate (Ford et al. 2010; T. Doniol-Valcroze, DFO, pers. comm.)	Best et al. (2015) for 2008 estimate and DFO survey for 2018 estimate (B. Wright, DFO, pers. comm.)
Steller Sea Lion abundance	Interpolated from data every two to five years	S. Tucker, DFO, pers. comm.
Pacific Hake biomass	Hake stock assessment and acoustic trawl survey	S. Johnson, Landmark Fisheries Research, pers. comm.
Arrowtooth Flounder CPUE	Catch per unit effort from the IPHC	A. Edwards, DFO, pers. comm.
North Pacific Spiny Dogfish CPUE	Catch per unit effort from the IPHC	A. Edwards, DFO, pers. comm.
Pacific Cod CPUE	Catch per unit effort from the IPHC	A. Edwards, DFO, pers. comm.
HG Pacific Herring		
Median spawning biomass	Pacific Herring stock assessment	Boldt et al.[3]

Variable	Description	Source
Mean weight (age-3)	Pacific Herring stock assessment	Boldt et al.[3]
Mean female length-weight residuals	Double log-transformed length-weight regression	Boldt et al.[3]

Figures

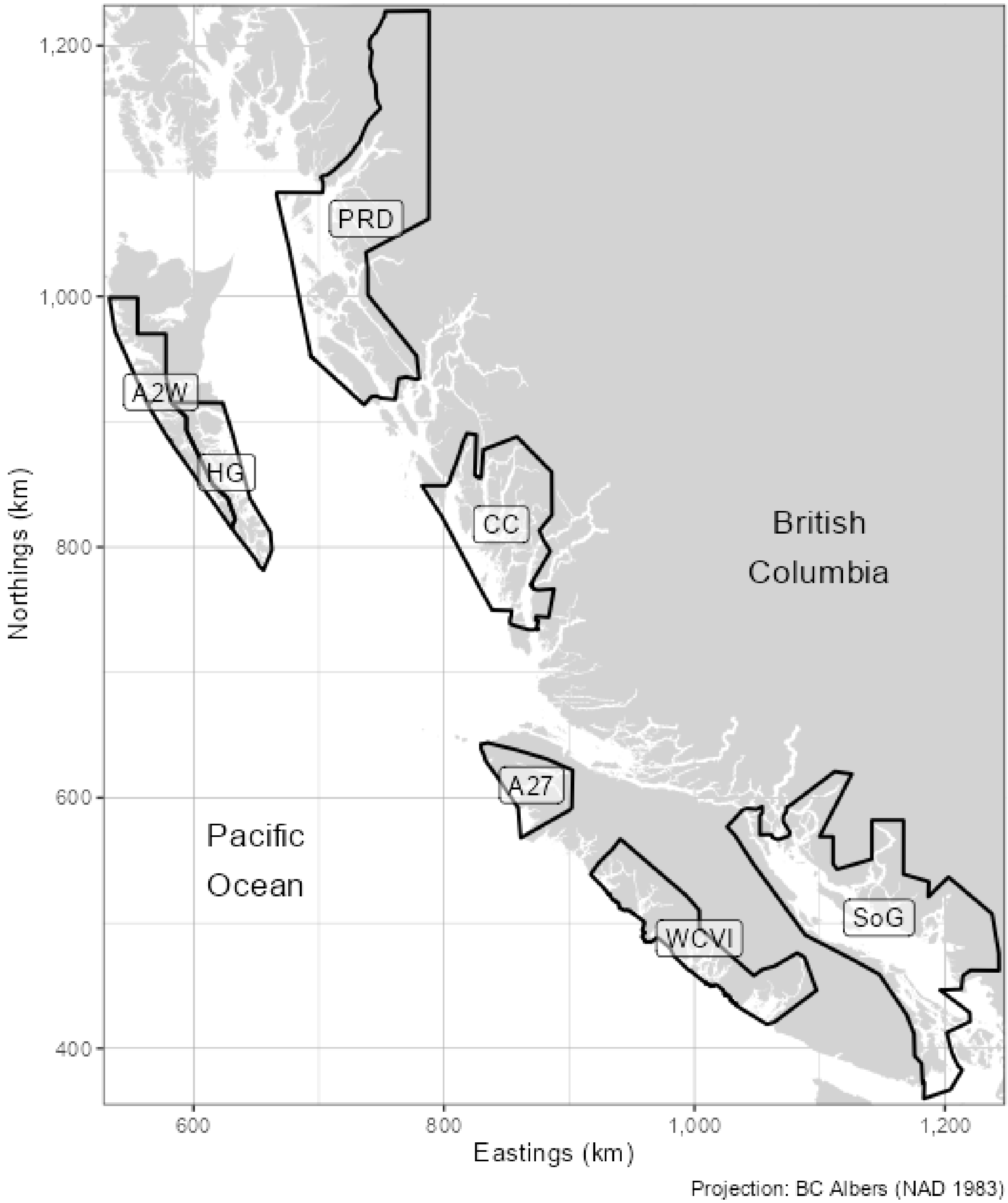

Figure 1. Boundaries for Pacific Herring SARs in British Columbia. The major SARs are Haida Gwaii (HG), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SoG), and West Coast of Vancouver Island (WCVI). The minor SARs are Area 27 (A27) and Area 2 West (A2W). Units: kilometres (km).

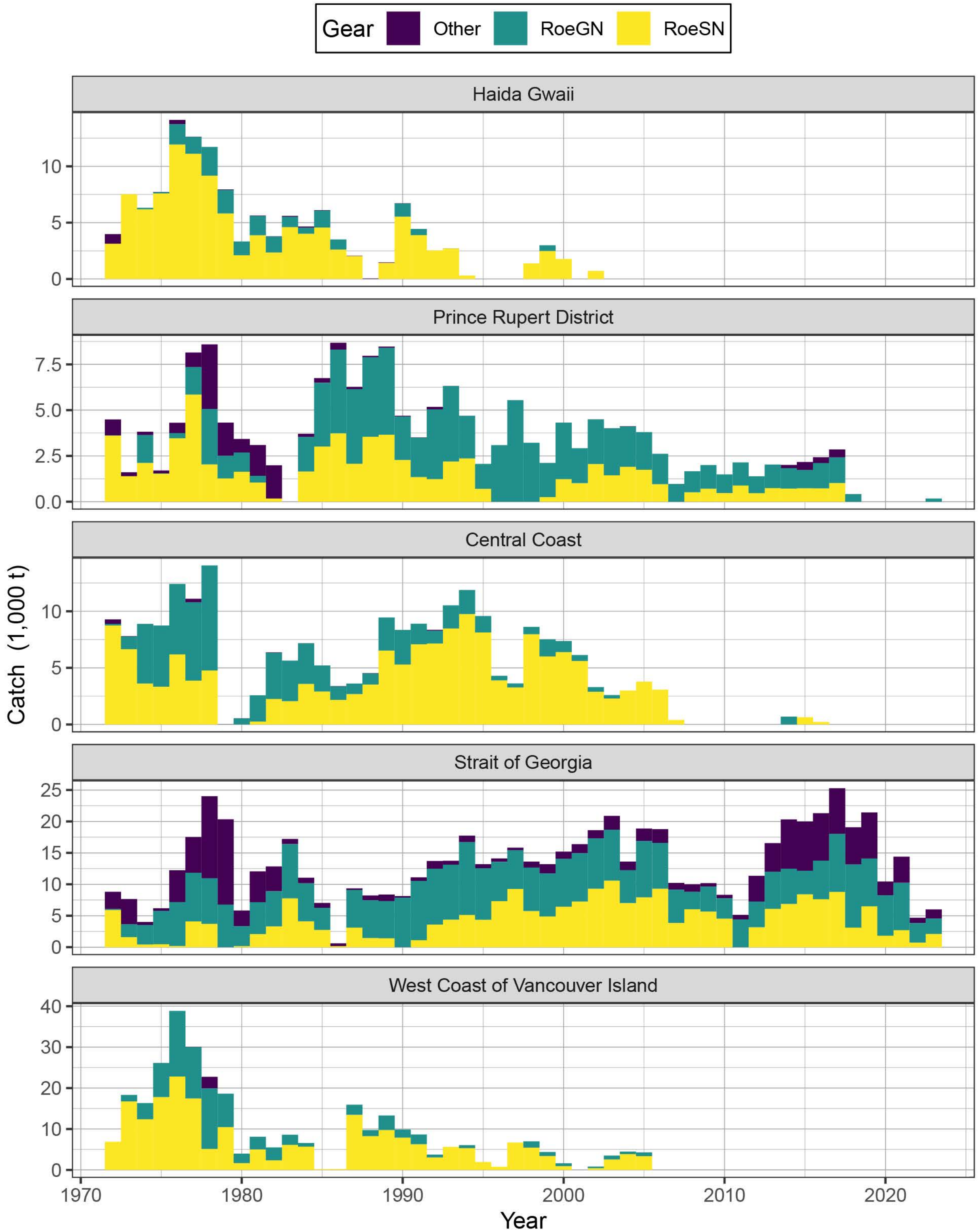

Figure 2. Total landed Pacific Herring catch in thousands of tonnes (t) from 1972 to 2023 in the major SARs. See Figures 9 to 14 for catches during the reduction period (1951 to 1971). Legend: 'Other' represents the reduction, the food and bait, as well as the special use fishery; 'RoeGN' represents the roe gillnet fishery; and 'RoeSN' represents the roe seine fishery.

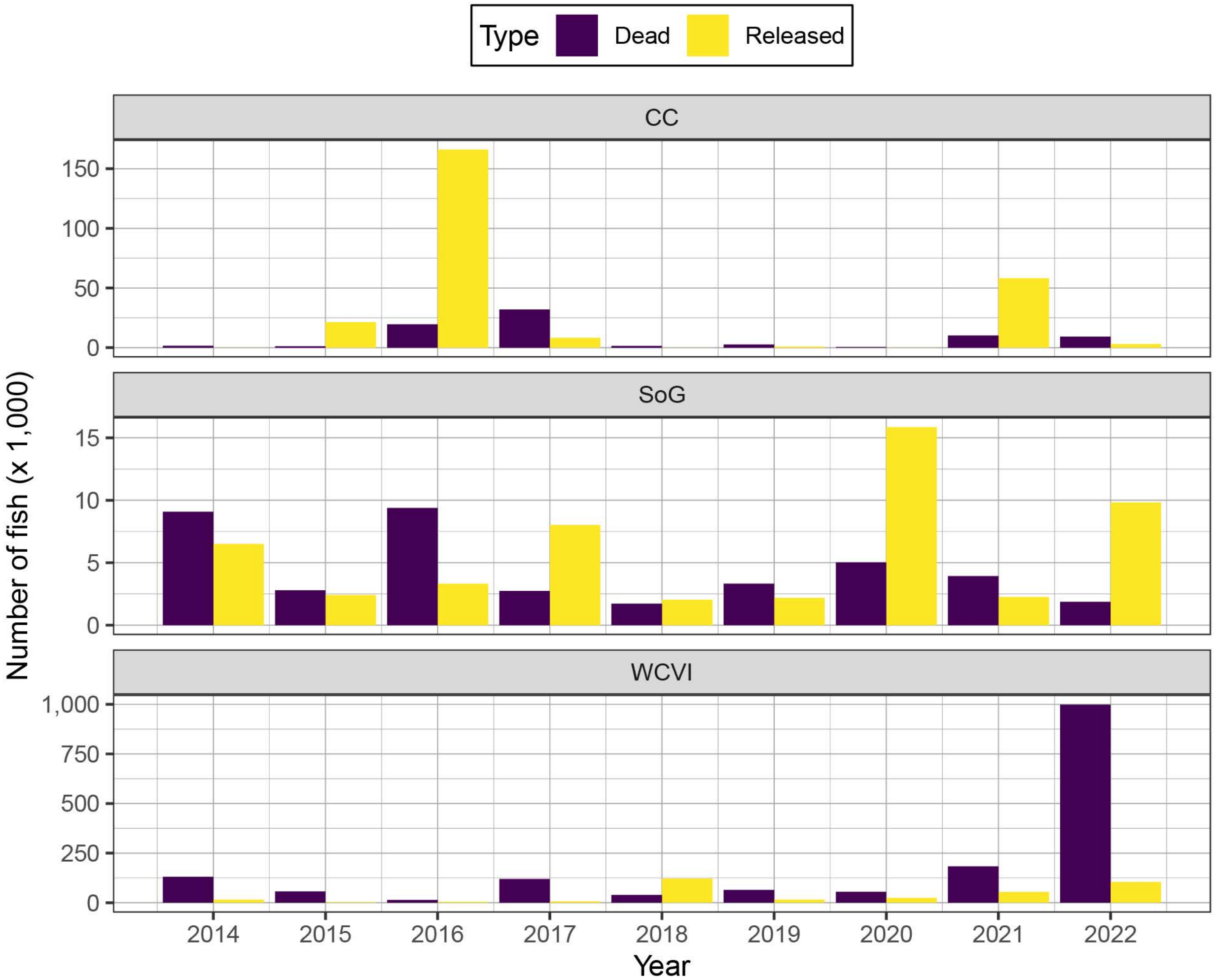

Figure 3. Incidental Pacific Herring mortality in aquaculture activities in thousands of fish from 2014 to 2022 in the major SARs. Notes: figure may include data outside SAR boundaries and figure excludes SARs with no reported incidental mortality.

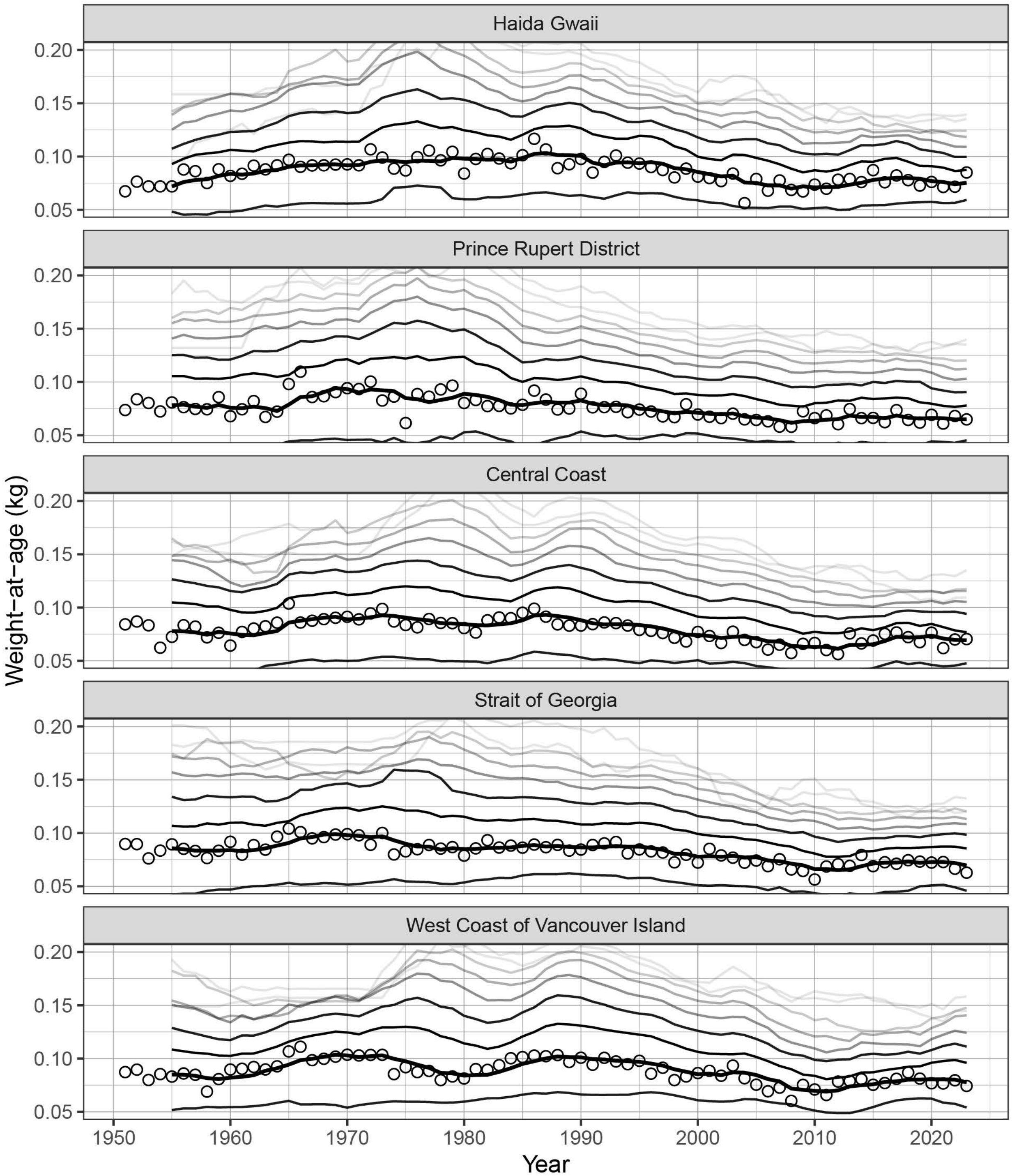

Figure 4. Mean weight-at-age for Pacific Herring in kilograms (kg) from 1951 to 2023 in the major SARs. Lines show 5-year running means for age-2 to age-10 herring, incrementing up from bottom line and shaded from darker to lighter, except thickest line shows age-3 herring. Circles show mean for age-3 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.

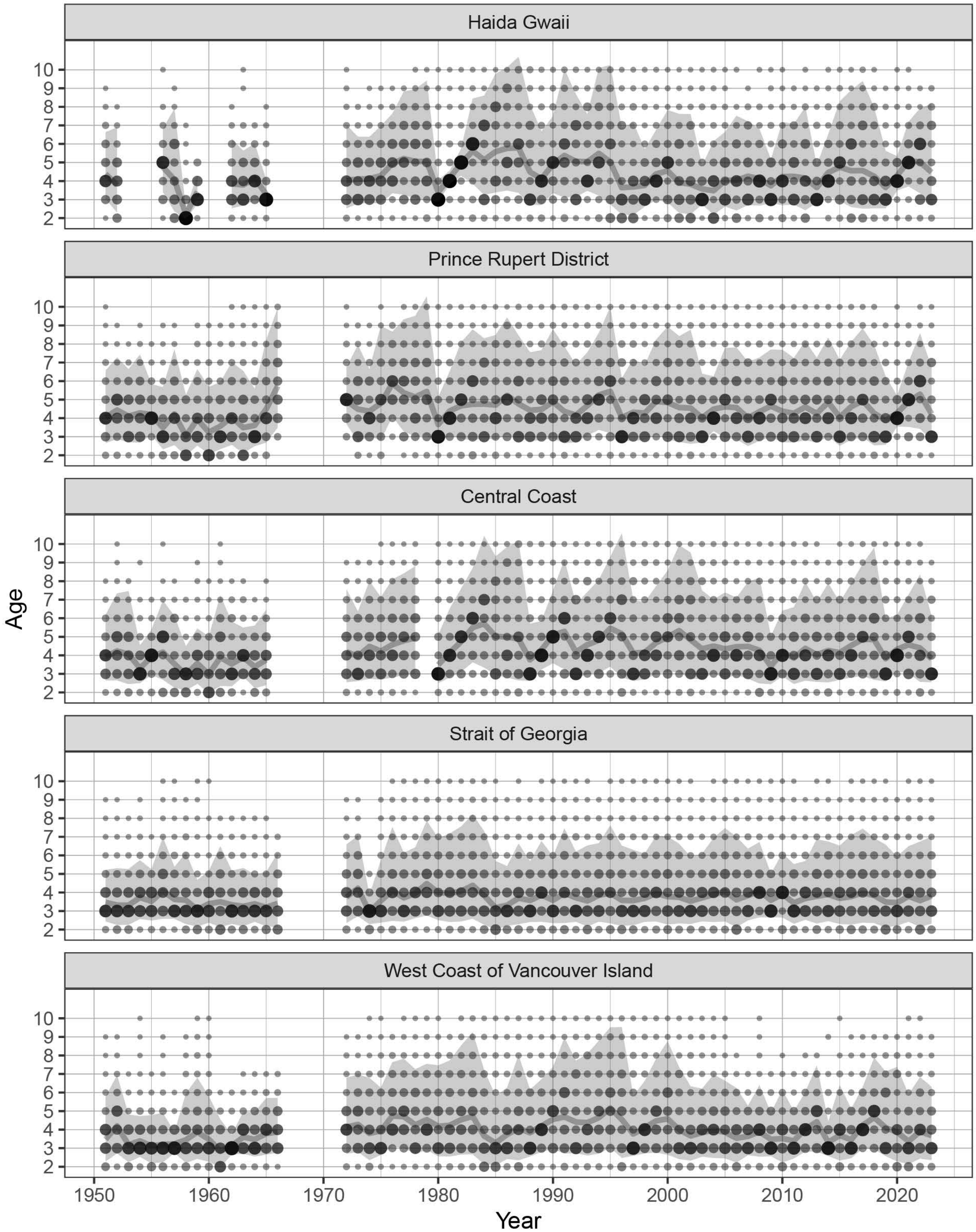

Figure 5. Proportion-at-age for Pacific Herring from 1951 to 2023 in the major SARs. Dot size and colour indicates age class proportion for the year; each year adds up to 1.0. The gray line is the mean age, and the shaded area is the approximate 90% distribution. Biological summaries only include samples 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.

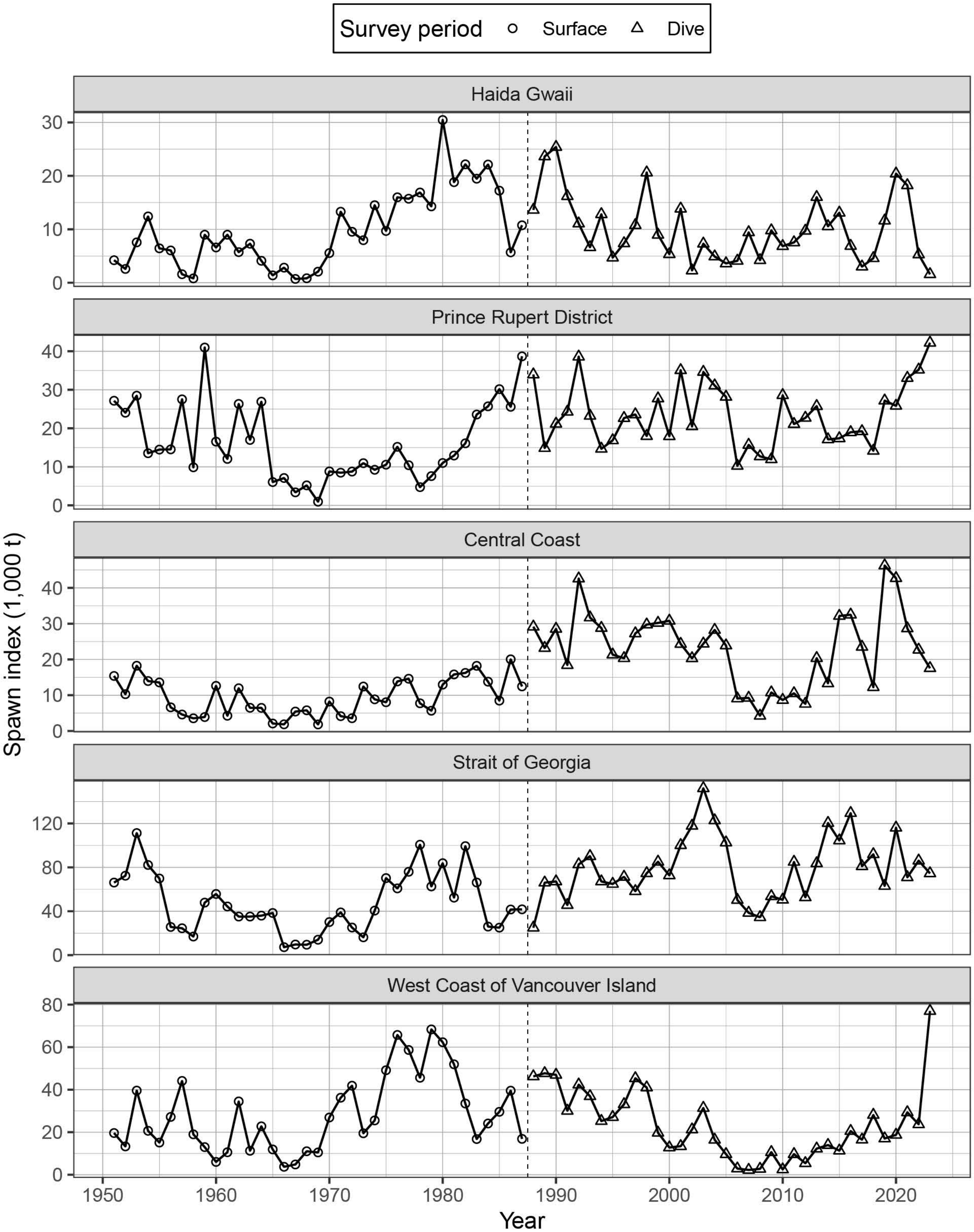

Figure 6. Spawn index in thousands of tonnes (t) for Pacific Herring from 1951 to 2023 in the major SARs. The dashed vertical line delineates between two periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2023). Note: the 'spawn index' is not scaled by the spawn survey scaling parameter q.

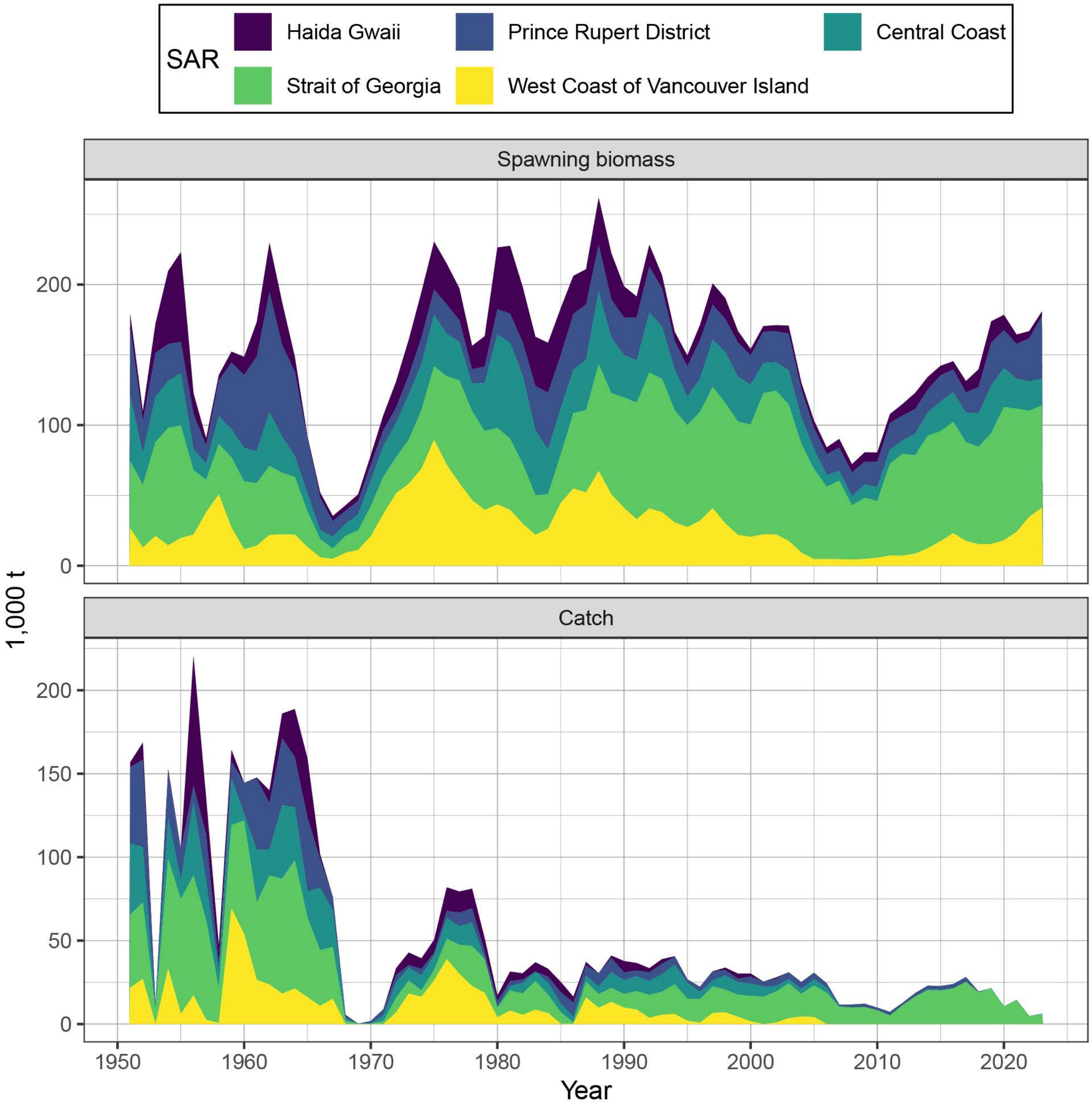

Figure 7. Spawning biomass and catch in thousands of tonnes (t) for Pacific Herring from 1951 to 2023 in the major SARs. Spawning biomass is represented by median posterior estimates.

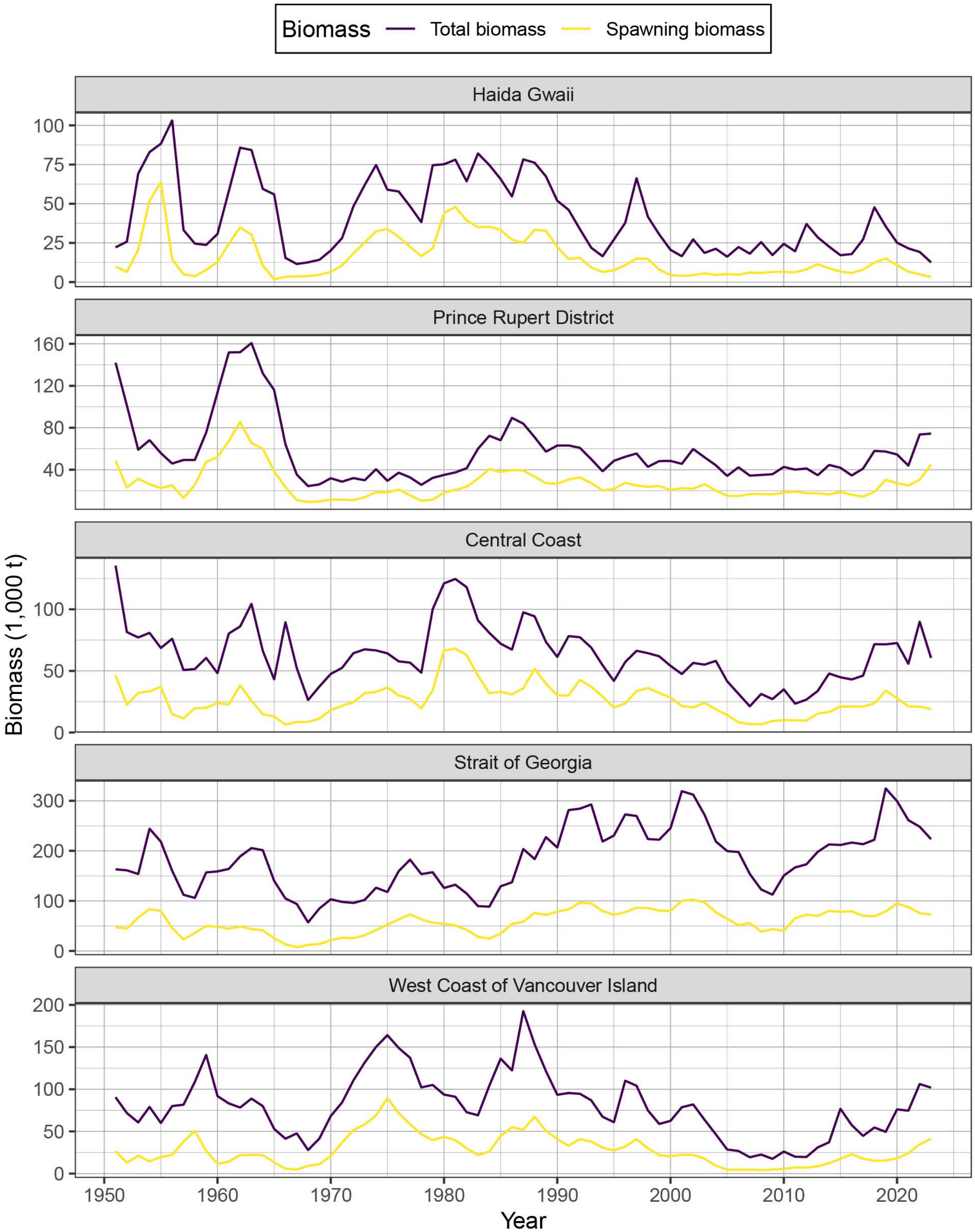

Figure 8. Total biomass and spawning biomass in thousands of tonnes (t) for Pacific Herring from 1951 to 2023 in the major SARs. Biomass is represented by median posterior estimates.

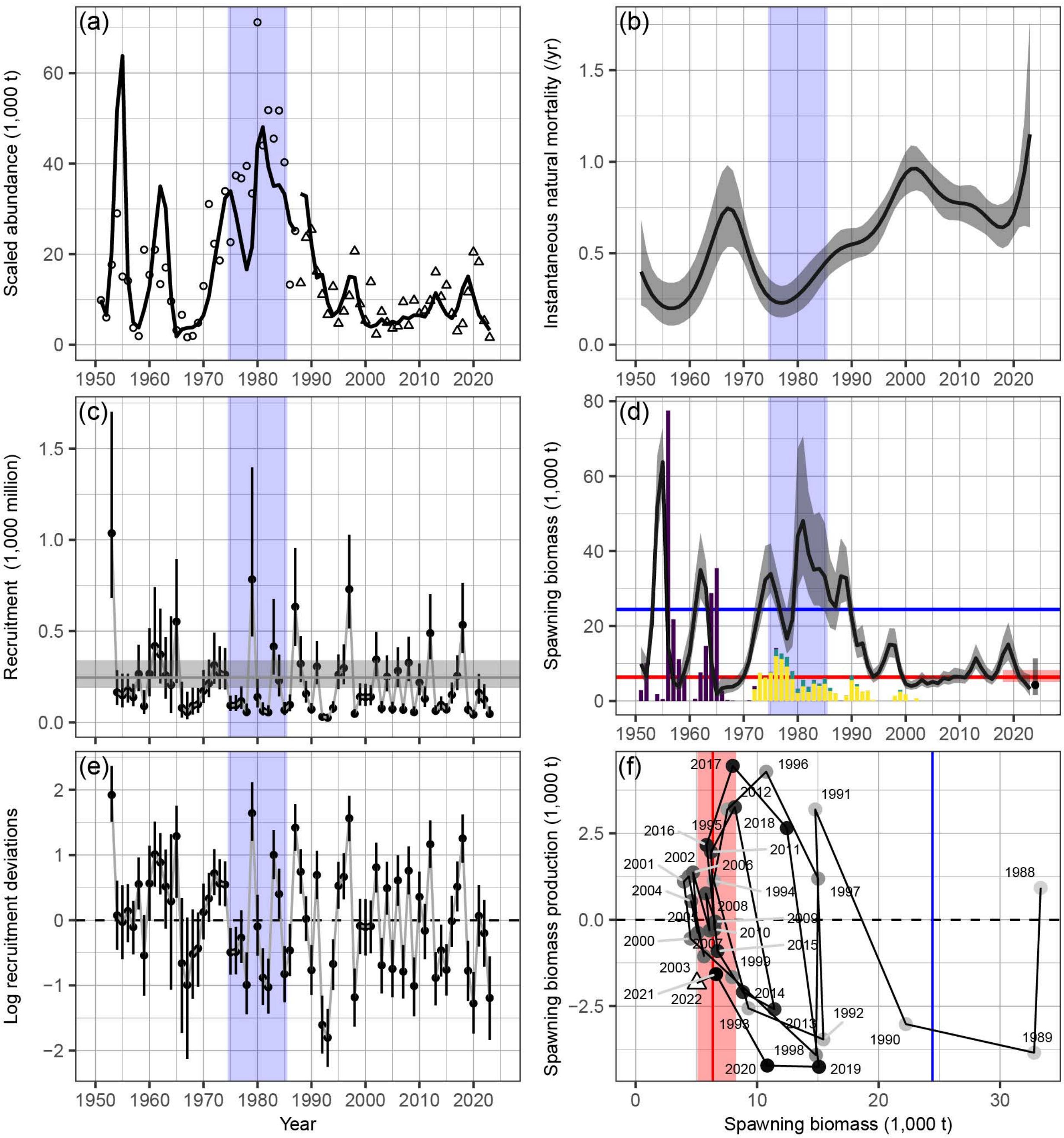

Figure 9. Haida Gwaii SAR: statistical catch-age model output for Pacific Herring from 1951 to 2023. ***Panel (a)****: Model fit (lines) to scaled abundance (points; Figure 6). Spawn index is scaled to abundance by the spawn index scaling parameter q.* ***Panel (b)****: Instantaneous natural mortality rate (year^{-1}).* ***Panel (c)****: Reconstructed number of age-2 recruits in thousands of millions from 1953 to 2023. Horizontal line indicates unfished age-2 recruitment R_0.* ***Panel (d)****: Spawning biomass (line), and forecast spawning biomass in 2024 in the absence of fishing (point). Coloured vertical bars indicate commercial catch (Figure 2).* ***Panel (e)****: Log recruitment deviations from 1953 to 2023.* ***Panel (f)****: Phase plot of spawning biomass production for the dive survey period (1988 to 2022). Points are chronologically shaded light to dark; triangle indicates 2022. 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; blue circles and shaded regions indicate a productive period (Table 29); blue lines indicate proportion of spawning biomass during a productive period 0.75 $\overline{SB}_{Prod}$; and red lines indicate the median limit reference point $0.3SB_0$, where SB_0 is estimated unfished spawning biomass.*

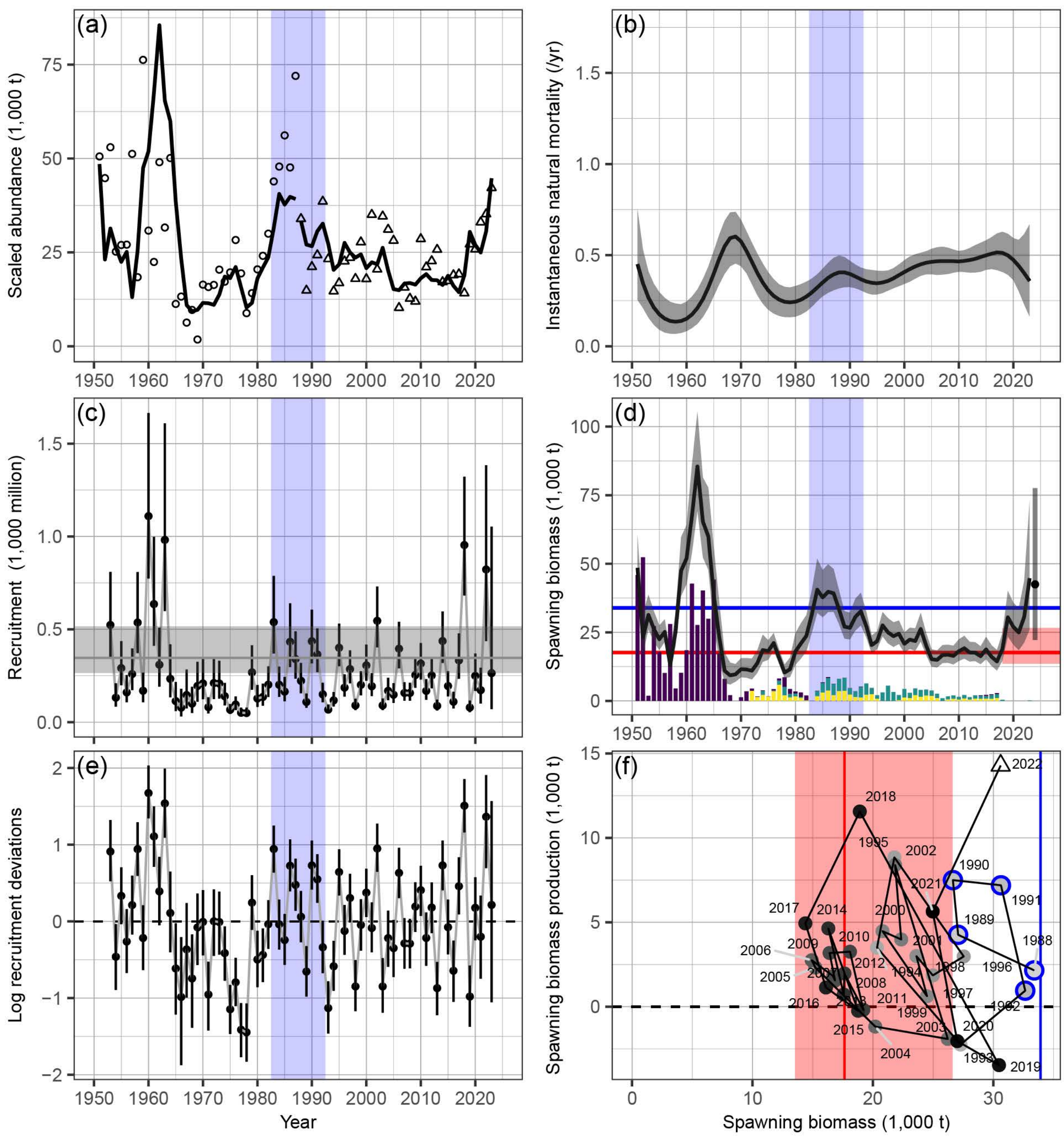

Figure 10. Prince Rupert District SAR: statistical catch-age model output for Pacific Herring from 1951 to 2023. ***Panel (a)****: Model fit (lines) to scaled abundance (points; Figure 6). Spawn index is scaled to abundance by the spawn index scaling parameter q.* ***Panel (b)****: Instantaneous natural mortality rate (year^{-1}).* ***Panel (c)****: Reconstructed number of age-2 recruits in thousands of millions from 1953 to 2023. Horizontal line indicates unfished age-2 recruitment R_0.* ***Panel (d)****: Spawning biomass (line), and forecast spawning biomass in 2024 in the absence of fishing (point). Coloured vertical bars indicate commercial catch (Figure 2).* ***Panel (e)****: Log recruitment deviations from 1953 to 2023.* ***Panel (f)****: Phase plot of spawning biomass production for the dive survey period (1988 to 2022). Points are chronologically shaded light to dark; triangle indicates 2022. 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; blue circles and shaded regions indicate a productive period (Table 29); blue lines indicate proportion of spawning biomass during a productive period $\overline{SB}_{Prod}$; and red lines indicate the median limit reference point $0.3SB_0$, where SB_0 is estimated unfished spawning biomass.*

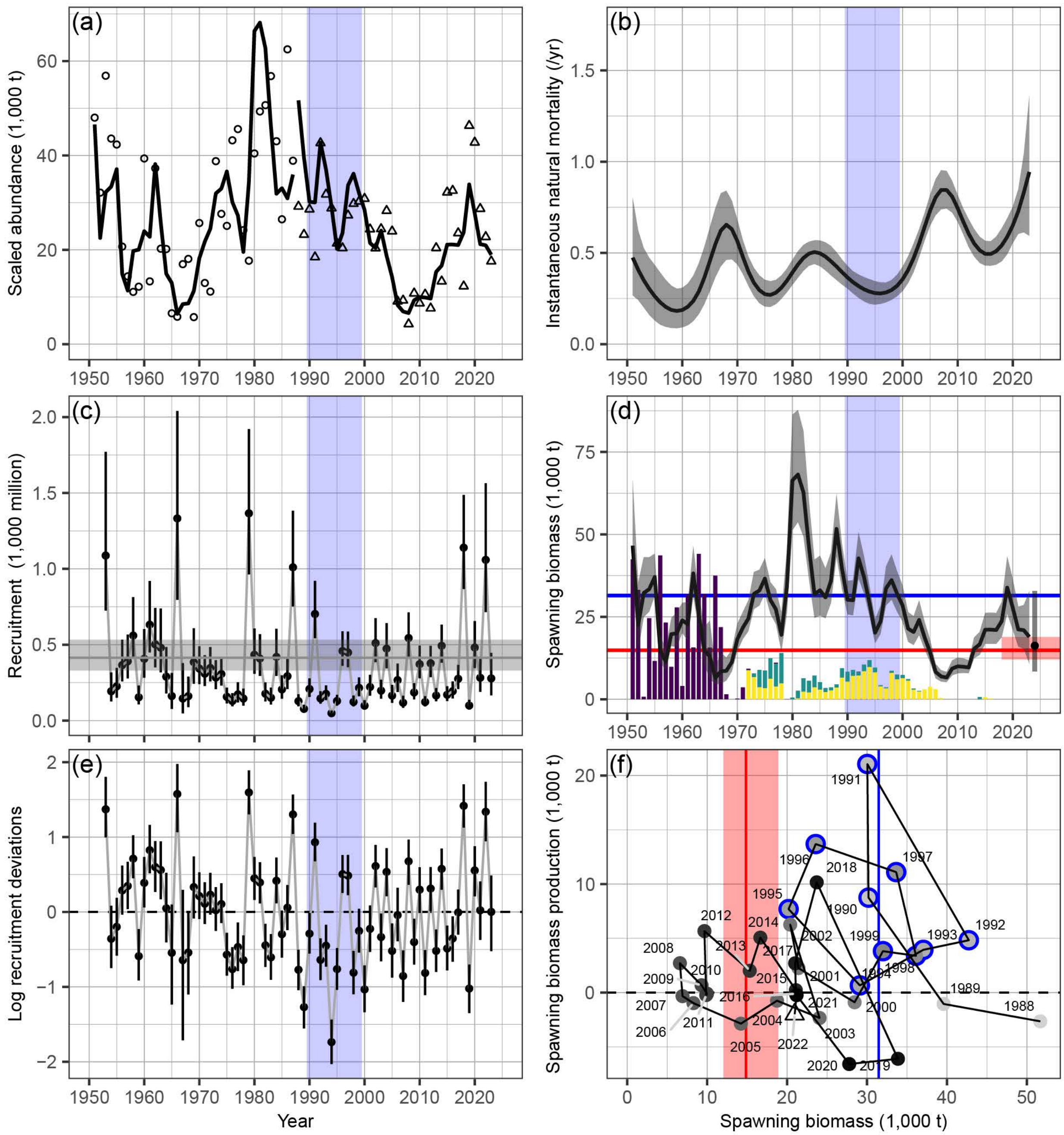

*Figure 11. Central Coast SAR: statistical catch-age model output for Pacific Herring from 1951 to 2023. **Panel (a)**: Model fit (lines) to scaled abundance (points; Figure 6). Spawn index is scaled to abundance by the spawn index scaling parameter q. **Panel (b)**: Instantaneous natural mortality rate (year^{-1}). **Panel (c)**: Reconstructed number of age-2 recruits in thousands of millions from 1953 to 2023. Horizontal line indicates unfished age-2 recruitment R_0. **Panel (d)**: Spawning biomass (line), and forecast spawning biomass in 2024 in the absence of fishing (point). Coloured vertical bars indicate commercial catch (Figure 2). **Panel (e)**: Log recruitment deviations from 1953 to 2023. **Panel (f)**: Phase plot of spawning biomass production for the dive survey period (1988 to 2022). Points are chronologically shaded light to dark; triangle indicates 2022. 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; blue circles and shaded regions indicate a productive period (Table 29); blue lines indicate proportion of spawning biomass during a productive period $\overline{SB}_{Prod}$; and red lines indicate the median limit reference point $0.3SB_0$, where SB_0 is estimated unfished spawning biomass.*

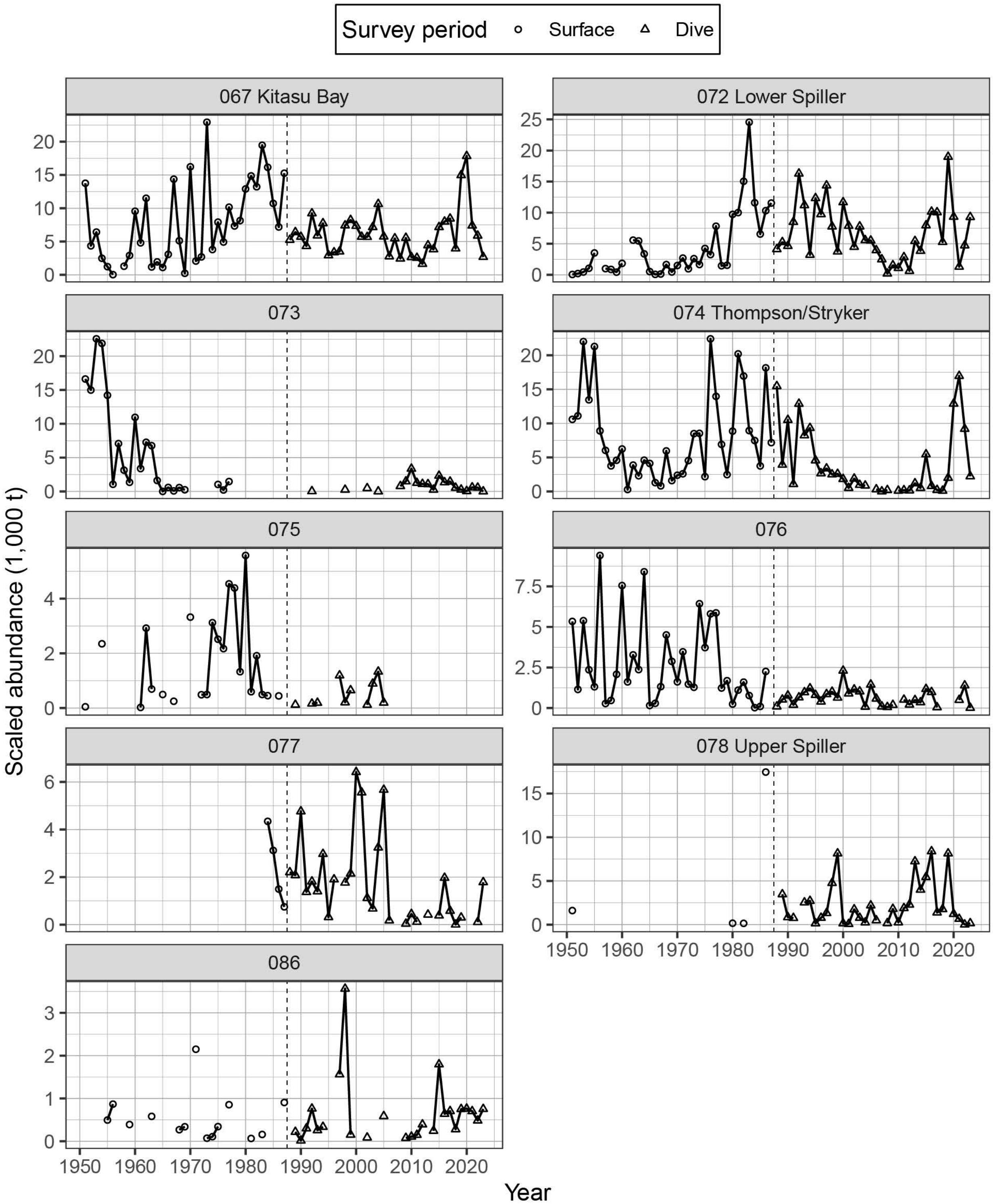

Figure 12. Central Coast SAR: scaled abundance in thousands of tonnes (t) of Pacific Herring in selected Sections from 1951 to 2023. The spawn index is scaled to abundance by the spawn survey scaling parameter q (median posterior estimate). The dashed vertical line delineates between two periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2023).

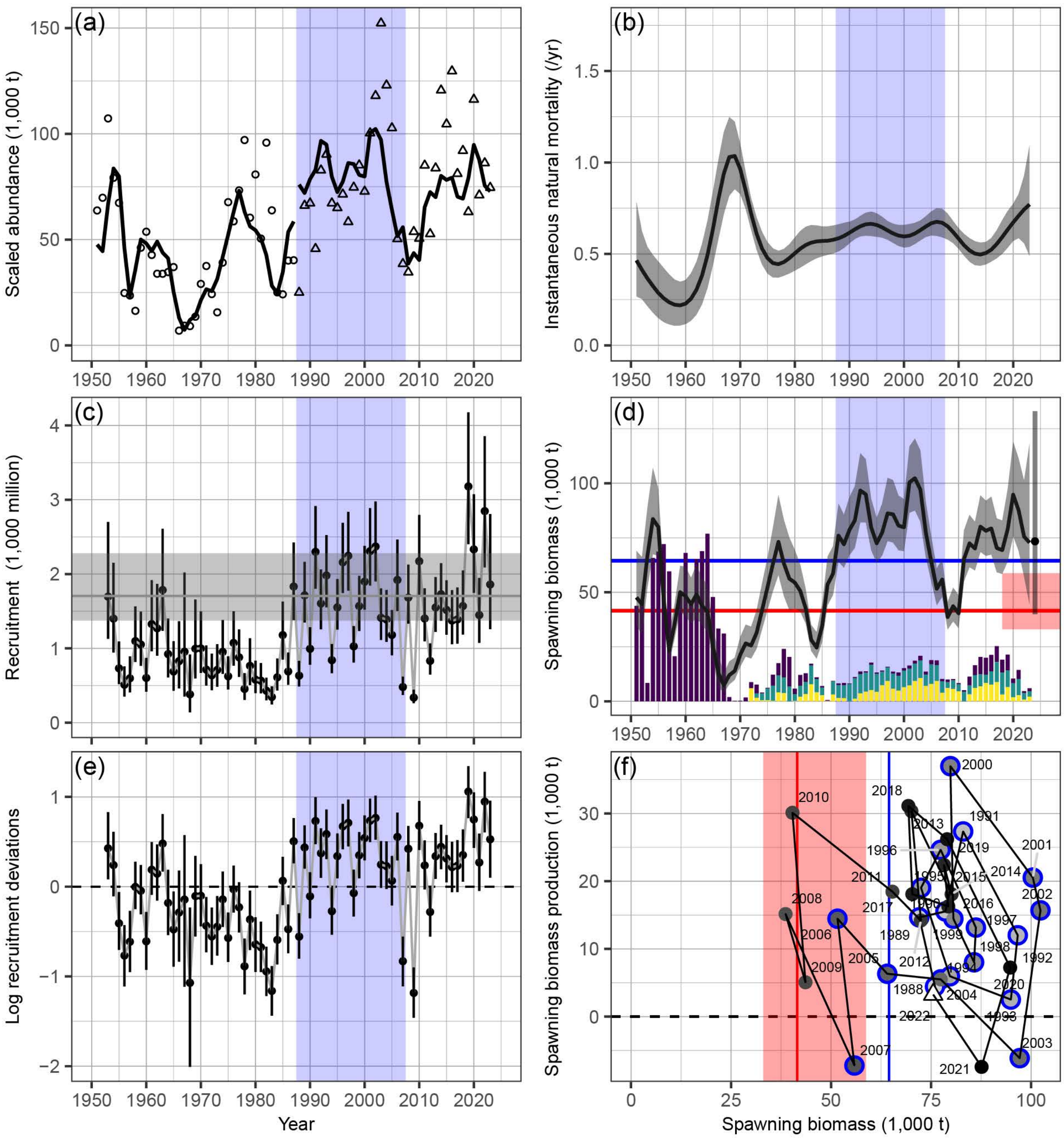

*Figure 13. Strait of Georgia SAR: statistical catch-age model output for Pacific Herring from 1951 to 2023. **Panel (a)**: Model fit (lines) to scaled abundance (points; Figure 6). Spawn index is scaled to abundance by the spawn index scaling parameter q. **Panel (b)**: Instantaneous natural mortality rate (year^{-1}). **Panel (c)**: Reconstructed number of age-2 recruits in thousands of millions from 1953 to 2023. Horizontal line indicates unfished age-2 recruitment R_0. **Panel (d)**: Spawning biomass (line), and forecast spawning biomass in 2024 in the absence of fishing (point). Coloured vertical bars indicate commercial catch (Figure 2). **Panel (e)**: Log recruitment deviations from 1953 to 2023. **Panel (f)**: Phase plot of spawning biomass production for the dive survey period (1988 to 2022). Points are chronologically shaded light to dark; triangle indicates 2022. 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; blue circles and shaded regions indicate a productive period (Table 29); blue lines indicate proportion of spawning biomass during a productive period 0.8 $\overline{SB}_{Prod}$; and red lines indicate the median limit reference point $0.3SB_0$, where SB_0 is estimated unfished spawning biomass.*

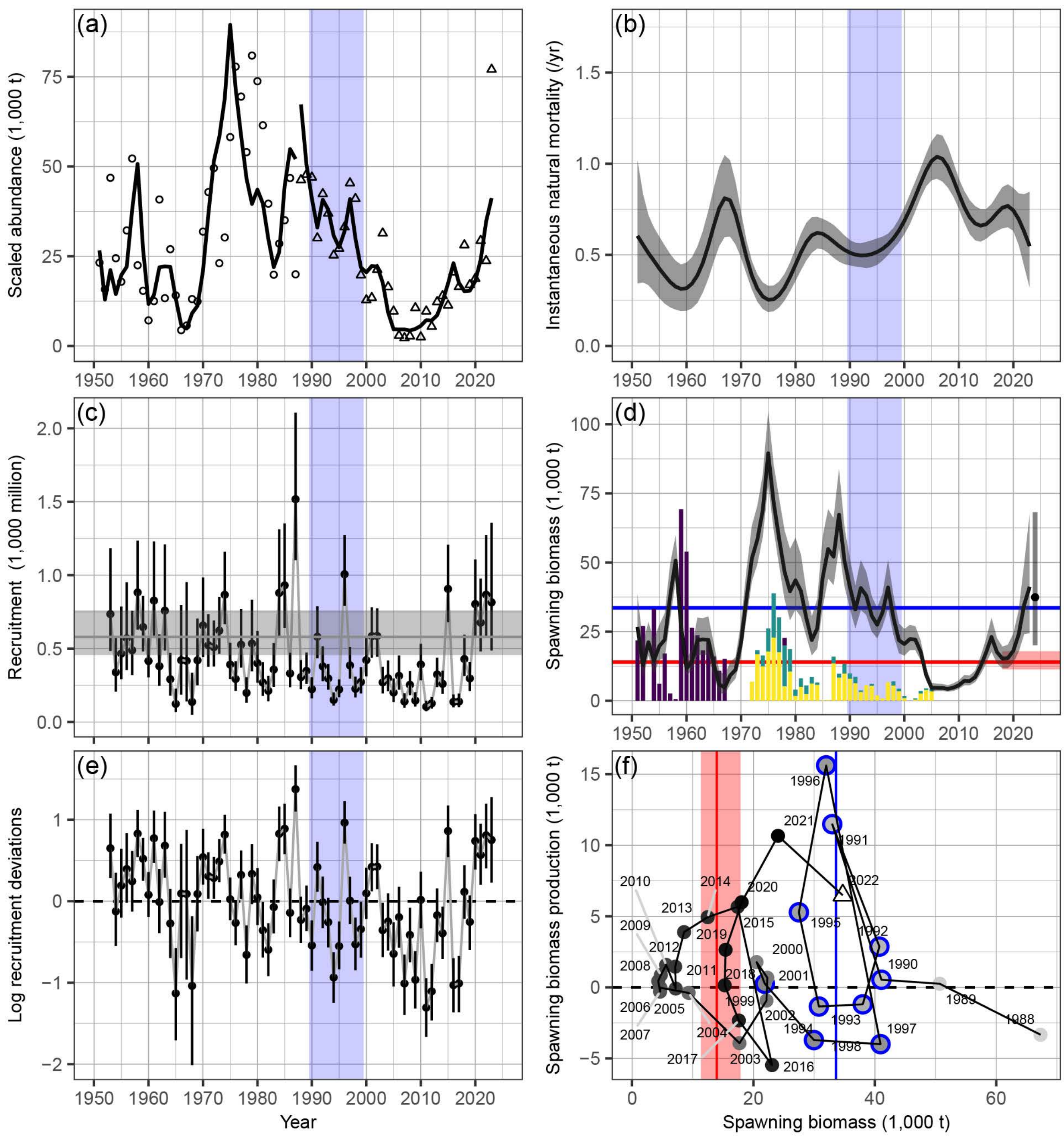

Figure 14. West Coast of Vancouver Island SAR: statistical catch-age model output for Pacific Herring from 1951 to 2023. ***Panel (a)****: Model fit (lines) to scaled abundance (points; Figure 6). Spawn index is scaled to abundance by the spawn index scaling parameter q.* ***Panel (b)****: Instantaneous natural mortality rate (year^{-1}).* ***Panel (c)****: Reconstructed number of age-2 recruits in thousands of millions from 1953 to 2023. Horizontal line indicates unfished age-2 recruitment R_0.* ***Panel (d)****: Spawning biomass (line), and forecast spawning biomass in 2024 in the absence of fishing (point). Coloured vertical bars indicate commercial catch (Figure 2).* ***Panel (e)****: Log recruitment deviations from 1953 to 2023.* ***Panel (f)****: Phase plot of spawning biomass production for the dive survey period (1988 to 2022). Points are chronologically shaded light to dark; triangle indicates 2022. 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; blue circles and shaded regions indicate a productive period (Table 29); blue lines indicate proportion of spawning biomass during a productive period $\overline{SB}_{Prod}$; and red lines indicate the median limit reference point $0.3SB_0$, where SB_0 is estimated unfished spawning biomass.*

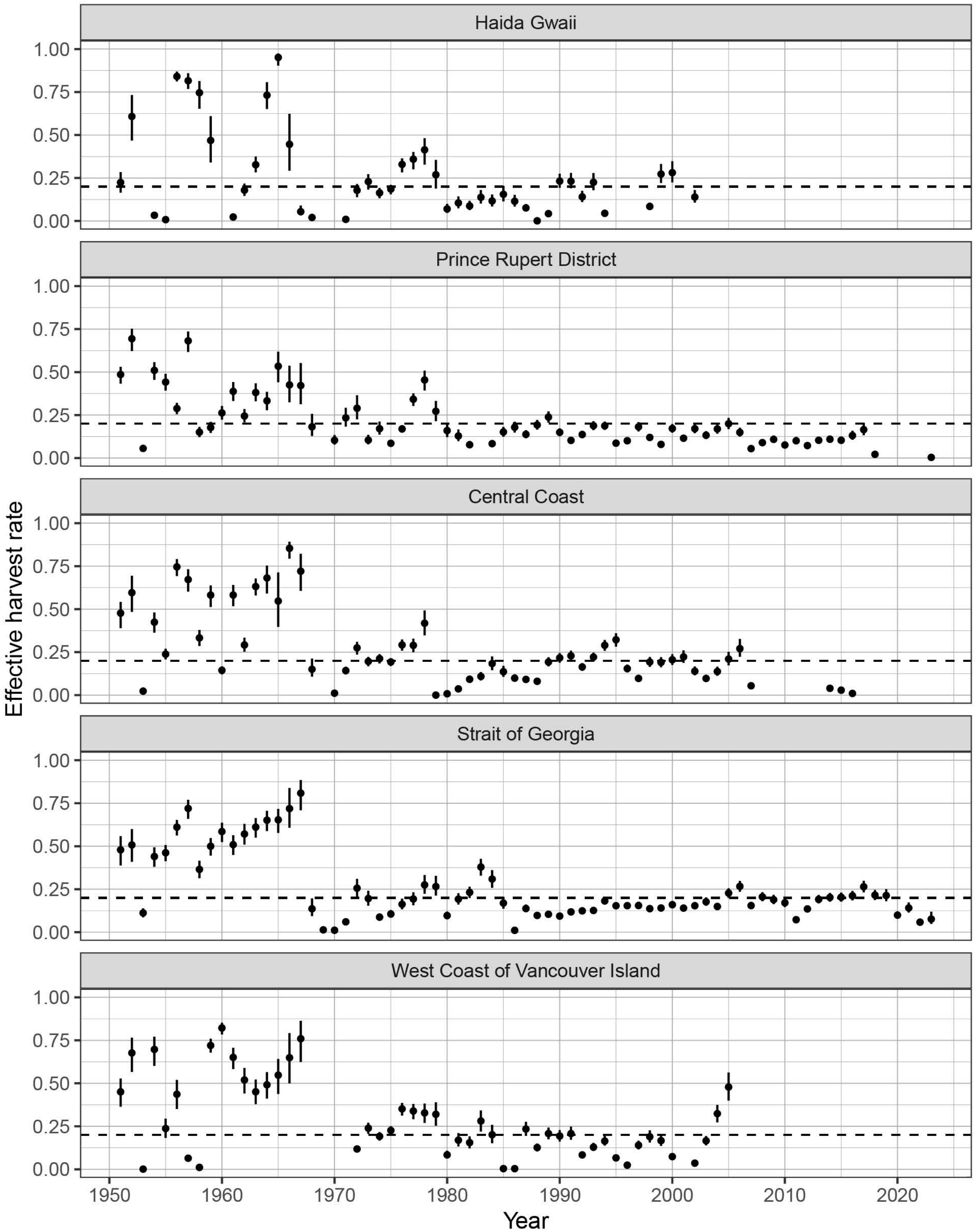

Figure 15. Effective harvest rate U_t for Pacific Herring from 1951 to 2023 in the major SARs. Effective harvest rate is $U_t = C_t/(C_t + SB_t)$ where C_t is catch in year t, and SB_t is estimated spawning biomass in year t. Points and vertical lines indicate medians and 90% credible intervals for U_t, respectively. Horizontal dashed lines indicate $U_t = 0.2$.

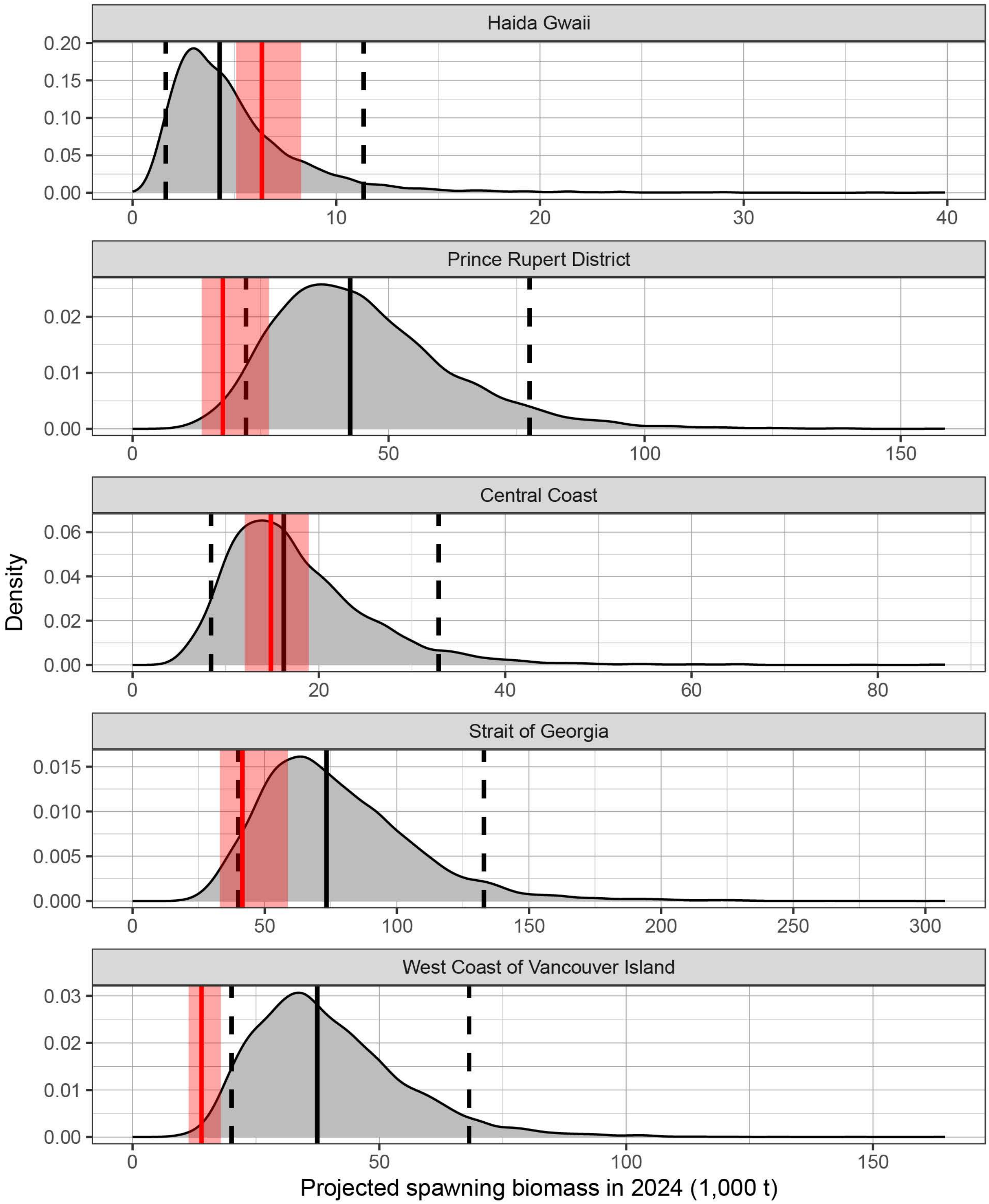

Figure 16. Projected spawning biomass of Pacific Herring assuming no fishing in 2024 SB_{2024} in thousands of tonnes (t) in the major SARs. Solid and dashed black lines indicate median posterior estimate and 90% credible intervals for SB_{2024}, respectively. Vertical red lines and shaded red areas indicate medians and 90% credible intervals for the limit reference point $0.3SB_0$, respectively, where SB_0 is estimated unfished spawning biomass.

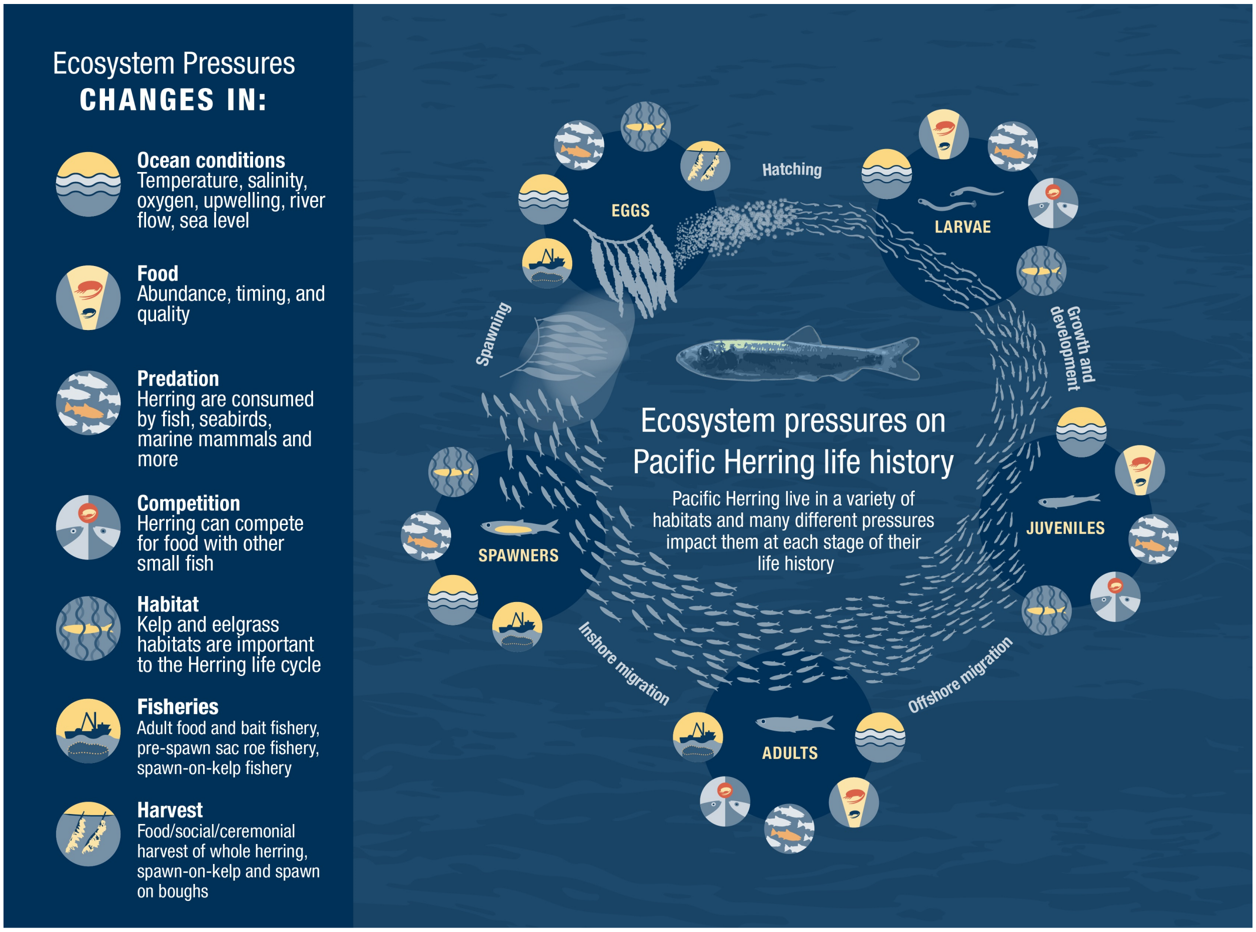

Figure 17. Depiction of some pressures that can affect different life history stages of Pacific Herring. Diagram copied with permission from DFO (2022b).

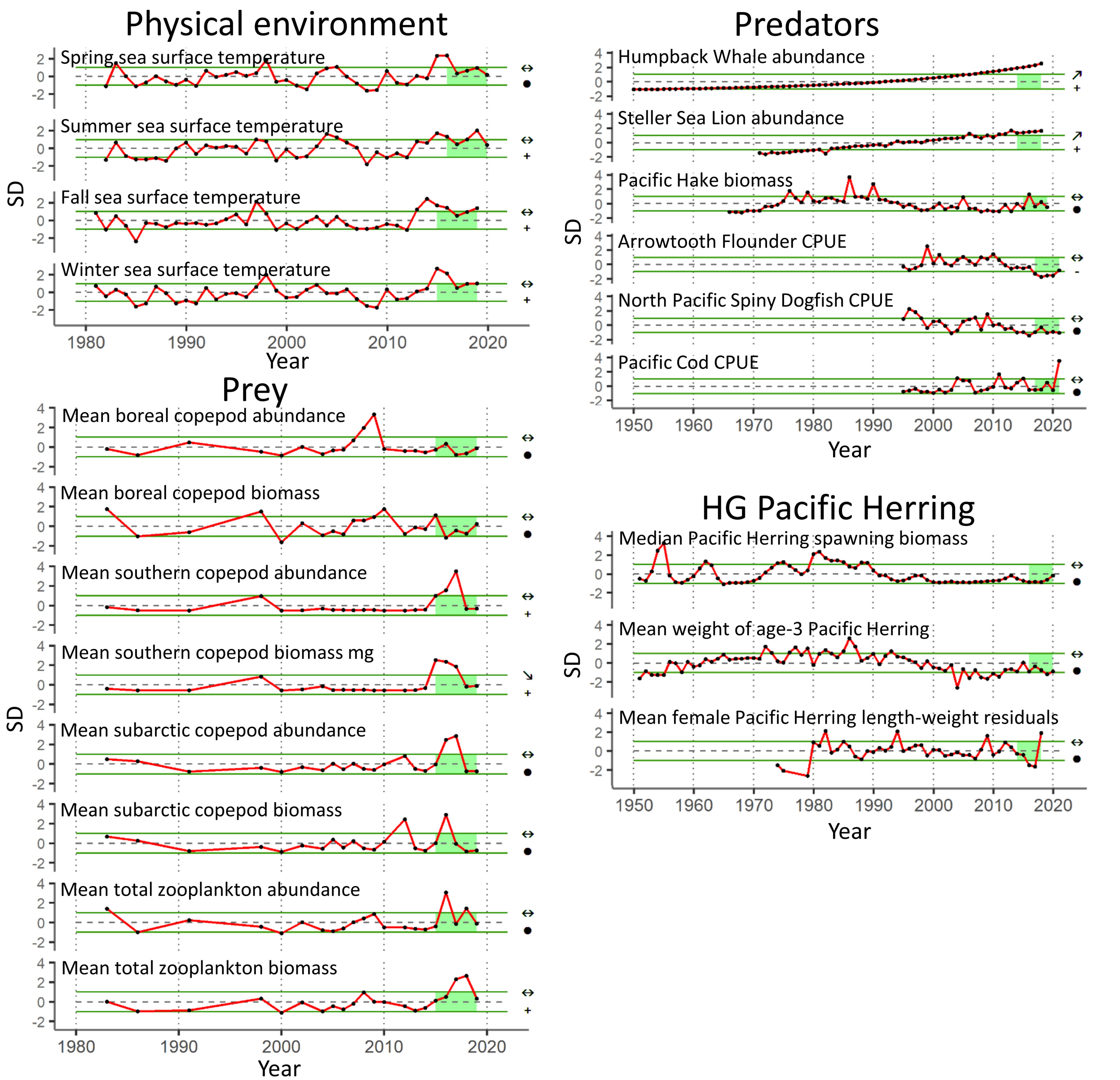

Figure 18. Selected standardized pressure indicators and Pacific Herring responses (e.g., status and trend) in the last five years. Solid green lines are within one standard deviation (SD); the most recent five years are highlighted in green. Symbols on the right indicate trend (top) and status (bottom). Trend indicates a significant increase (up arrow), decrease (down), or neither (horizontal) in the last five years, where there are more than two years of data. Status indicates if recent average values are greater than one SD above (plus), below (minus), or neither (dot) the time series average. Note that pressure indicators are for Hecate Strait and Queen Charlotte Sound, and responses are for Haida Gwaii (HG) herring. See Table 34 for description.

Contributors

Contributor	Affiliation	Role
Jaclyn Cleary	DFO Science, Pacific	Author
Sarah Power	DFO Science, Pacific	Author
Matthew Grinnell	DFO Science, Pacific	Author
Jennifer Boldt	DFO Science, Pacific	Author (Ecosystem section)
Chris Rooper	DFO Science, Pacific	Author (Ecosystem section)
Thomas Doniol-Valcroze	DFO Science, Pacific	Data (Ecosystem section)
Andrew Edwards	DFO Science, Pacific	Data (Ecosystem section)
Moira Galbraith	DFO Science, Pacific	Data (Ecosystem section)
Ian Perry	DFO Science, Pacific	Data (Ecosystem section)
Strahan Tucker	DFO Science, Pacific	Data (Ecosystem section)
Brianna Wright	DFO Science, Pacific	Data (Ecosystem section)
Sam Johnson	Landmark Fisheries Research	Data (Ecosystem section)
Katherine Middleton	DFO Science Advisor, Ottawa	Infographic (Ecosystem section)
Bryan Rusch	DFO Fisheries Management, Pacific	Client
Marisa Keefe	DFO Fisheries Management, Pacific	Client

Approved by

Andrew Thomson
Regional Director
Science Branch, Pacific Region
Fisheries and Oceans Canada
September 25, 2023

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Appendix

Minor stock assessment regions

DFO does not conduct formal analyses of stock trend information for the two Pacific Herring minor SARs: Area 27 (A27) and Area 2 West (A2W). However, DFO does provide landed commercial catch (Figure 19), incidental mortality in finfish aquaculture activities (Figure 20), biological data including weight-at-age (Figure 21) and proportion-at-age (Figure 22), as well as spawn index (Figure 23) from 1978 to 2023. DFO also provides the spawn index and proportion of spawn index by Section from 2014 to 2023 for A27 and A2W (Tables 35 and 36, respectively). For Area 27, spawn index by Section from 1978 to 2023 is also provided (Figure 24).

Special areas

As is the case for the minor SARs, DFO does not conduct formal analyses of stock trend information for the Pacific Herring special area, Area 10 (A10; Figure 25). However, DFO provides biological data including weight-at-age (Figure 26) and proportion-at-age (Figure 27), as well as spawn index and proportion of spawn index by Section (Figure 28,Table 37) from 1978 to 2023, where available. Note that Area 10 is a subset of the Central Coast and is outside the SAR boundary. In addition, note that there is no landed commercial catch or incidental mortality in finfish aquaculture activities in Area 10 from 1978 to 2023.

Tables

Table 35. Area 27 SAR: spawn index in tonnes for Pacific Herring and proportion of spawn index by Section from 2014 to 2023. See Table 4 for description.

		Proportion			
Year	**Spawn index**	**271**	**272**	**273**	**274**
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
2023	13,511	0.000	0.000	1.000	0.000

Table 36. Area 2 West SAR: spawn index in tonnes for Pacific Herring and proportion of spawn index by Section from 2014 to 2023. See Table 4 for description.

		Proportion				
Year	**Spawn index**	**001**	**002**	**003**	**004**	**005**
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
2023	1,191	0.000	1.000	0.000	0.000	0.000

Table 37. Area 10 special area: spawn index in tonnes for Pacific Herring and proportion of spawn index by Section from 2014 to 2023. See Table 4 for description.

		Proportion		
Year	**Spawn index**	**101**	**102**	**103**
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	34	0.000	1.000	0.000
2023	NA	0.000	0.000	0.000

Figures

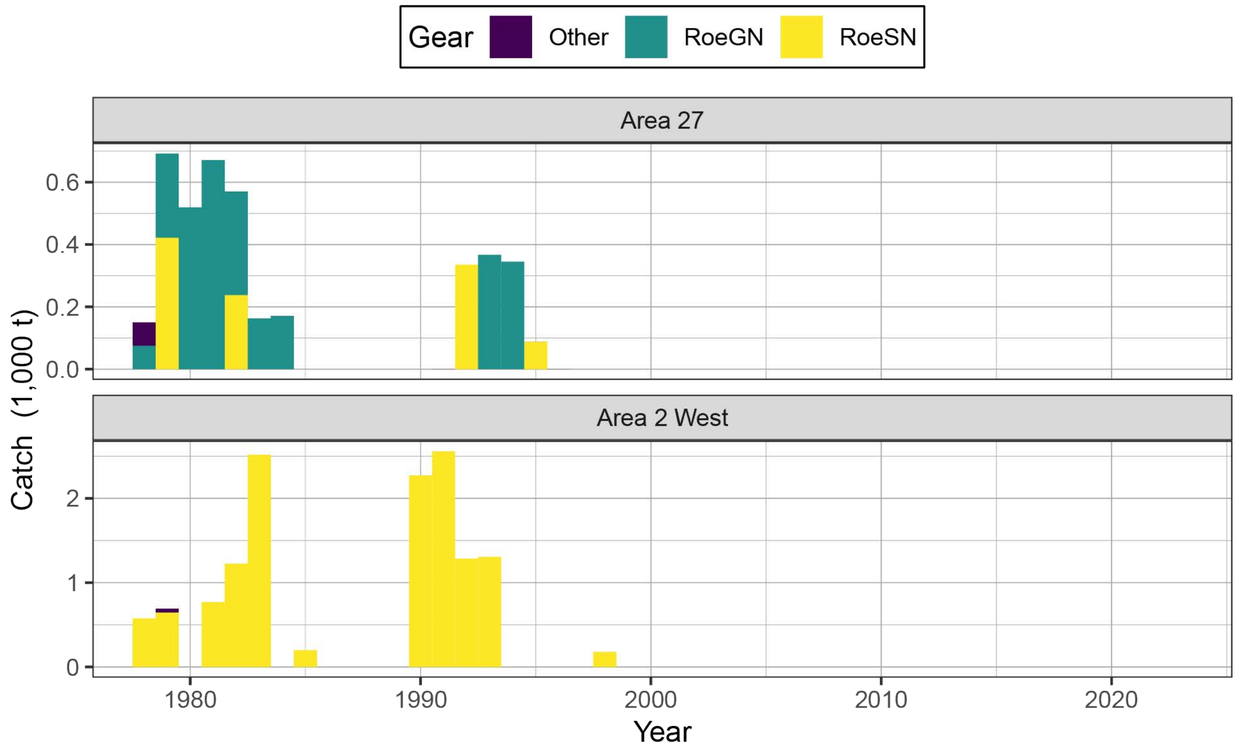

Figure 19. Total landed Pacific Herring catch in thousands of tonnes (t) from 1978 to 2023 in the minor SARs. See Figure 2 for description.

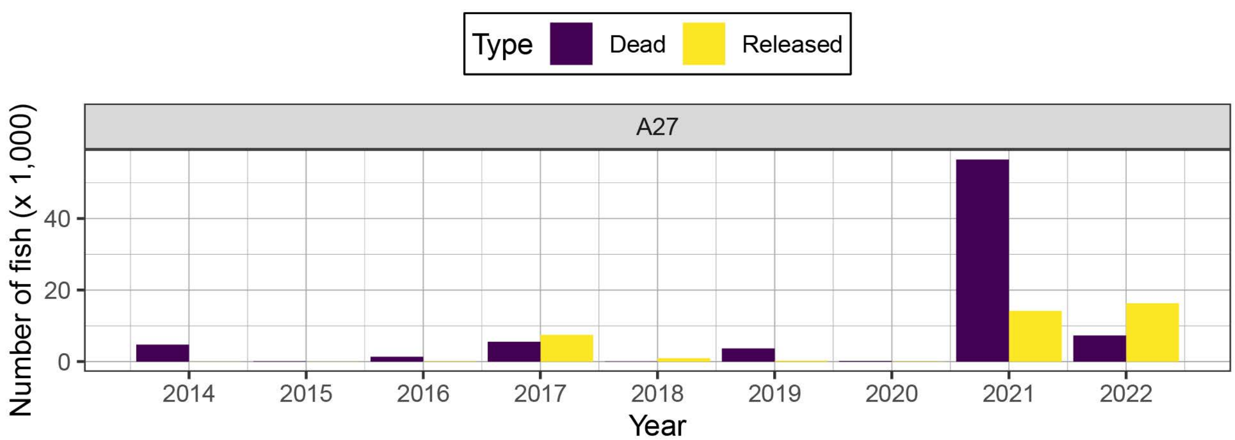

Figure 20. Incidental Pacific Herring mortality in aquaculture activities in thousands of fish from 2014 to 2022 in the minor SARs. See Figure 3 for description.

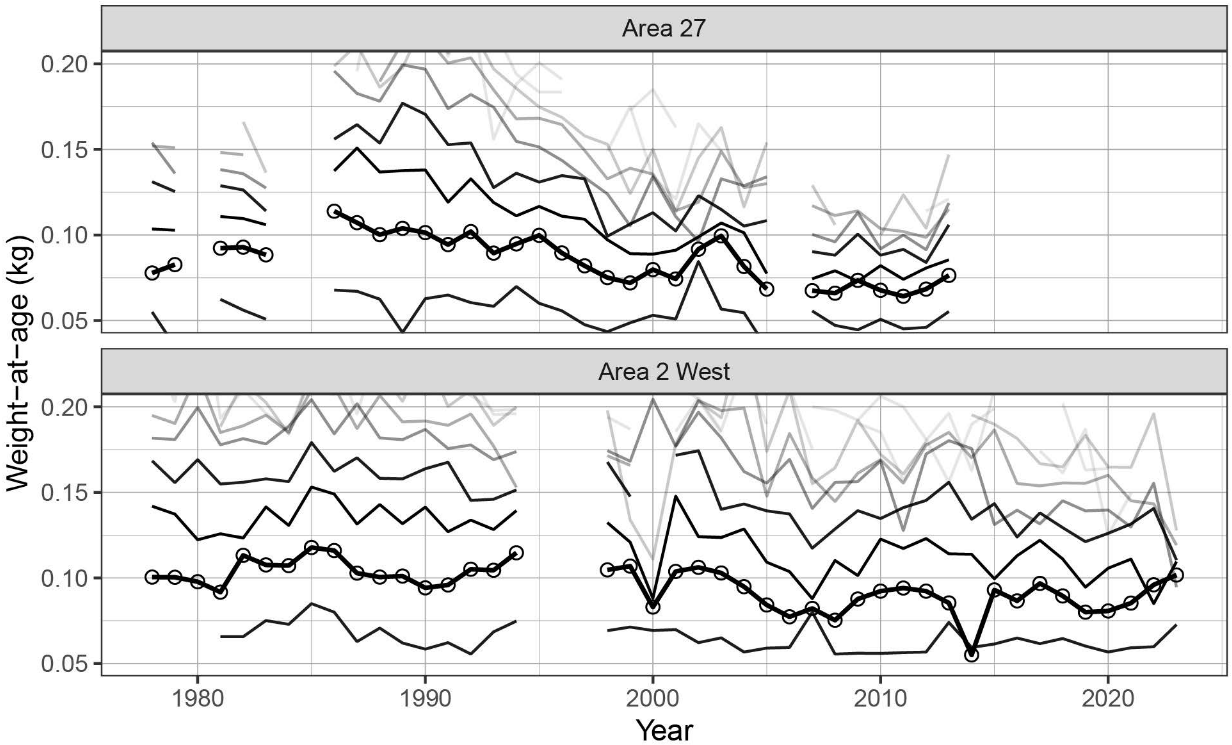

Figure 21. Mean weight-at-age for Pacific Herring in kilograms (kg) from 1978 to 2023 in the minor SARs. Circles show mean for age-3 herring. Lines show means for age-2 to age-10 herring, incrementing up from bottom line and shaded from darker to lighter. The thick line shows age-3 herring. Biological 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.

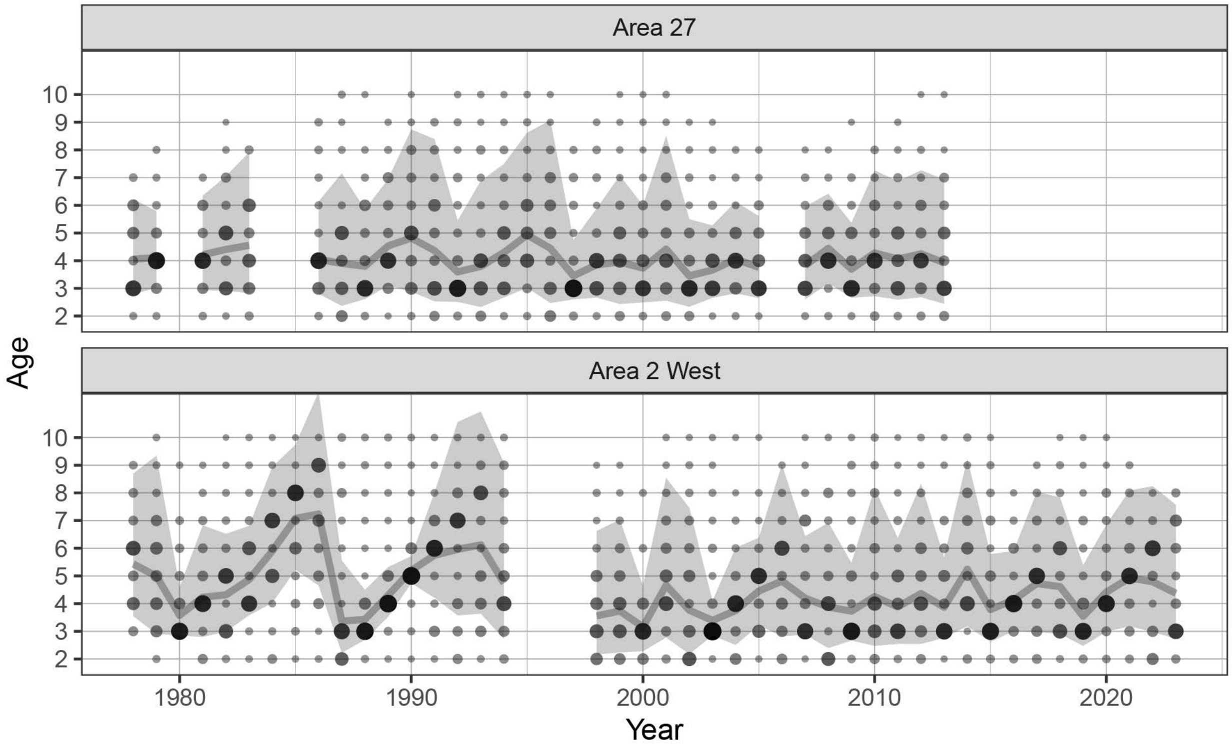

Figure 22. Proportion-at-age for Pacific Herring from 1978 to 2023 in the minor SARs. See Figure 5 for description.

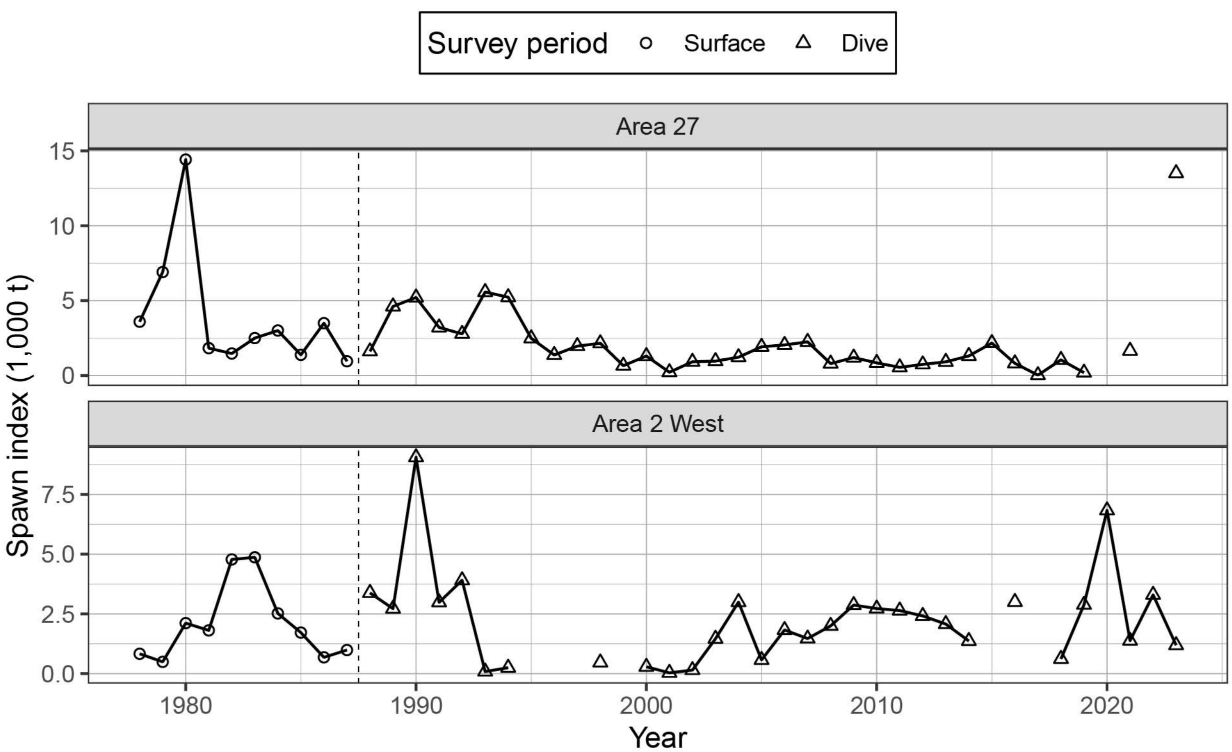

Figure 23. Spawn index in thousands of tonnes (t) for Pacific Herring from 1978 to 2023 in the minor SARs. See Figure 6 for description.

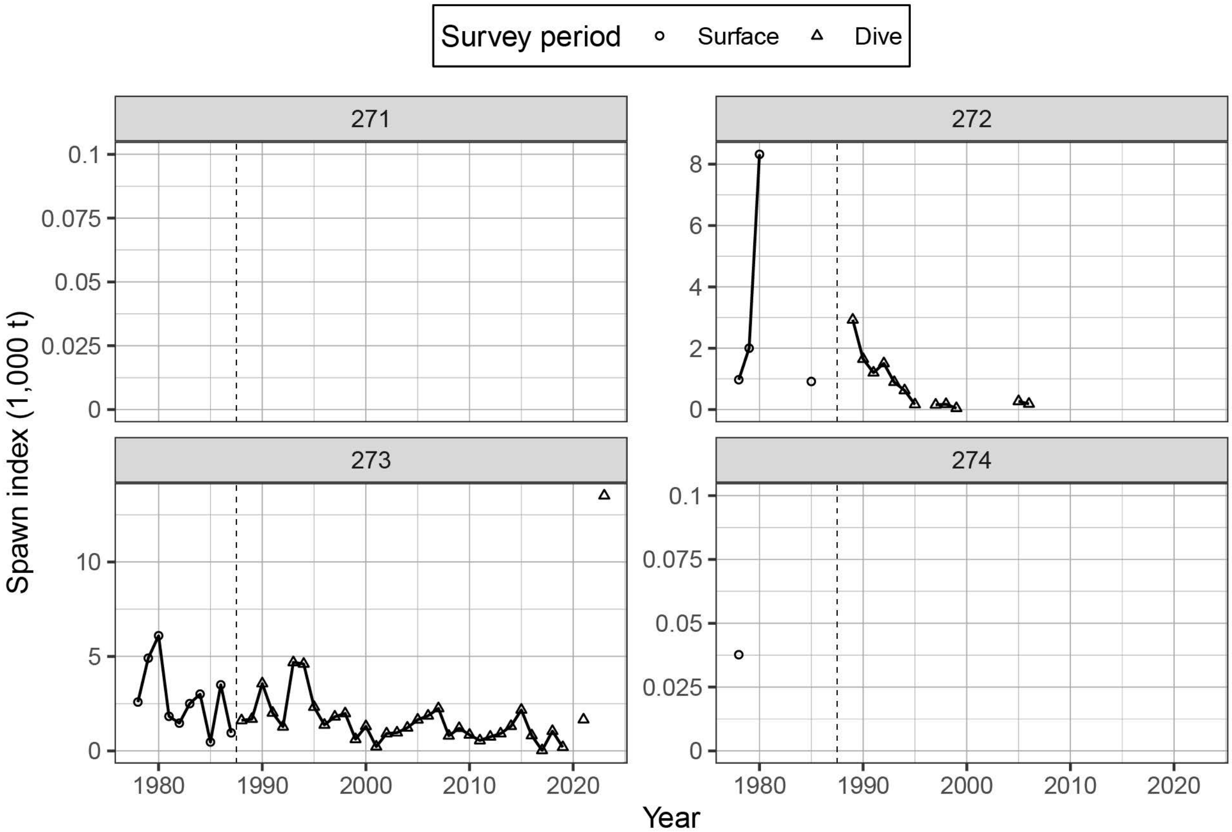

Figure 24. Area 27 SAR: spawn index in thousands of tonnes (t) of Pacific Herring by Section from 1978 to 2023. The dashed vertical line delineates between two periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2023). Note: the 'spawn index' is not scaled by the spawn survey scaling parameter q.

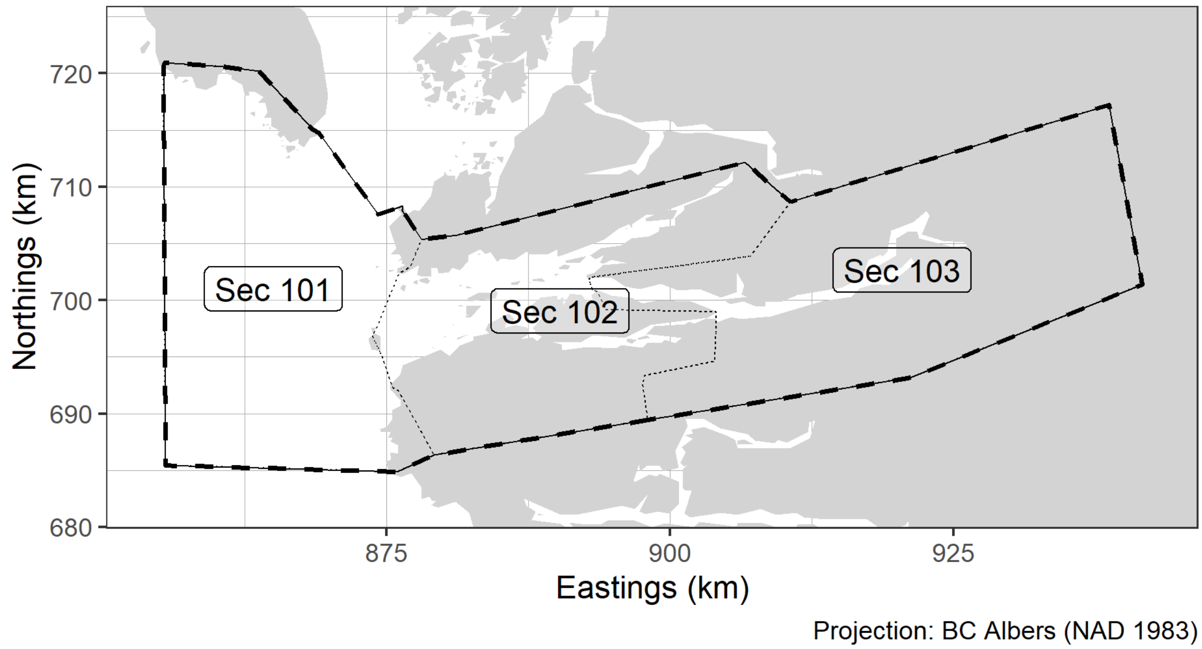

Figure 25. Sections (Sec) included in the Pacific Herring special area, Area 10 (A10). Note that special areas are not stock assessment regions (SARs); therefore they are excluded from regular monitoring and analyses. In addition, note that A10 is a subset of the Central Coast Sections that are outside the SAR boundary. Units: kilometres (km).

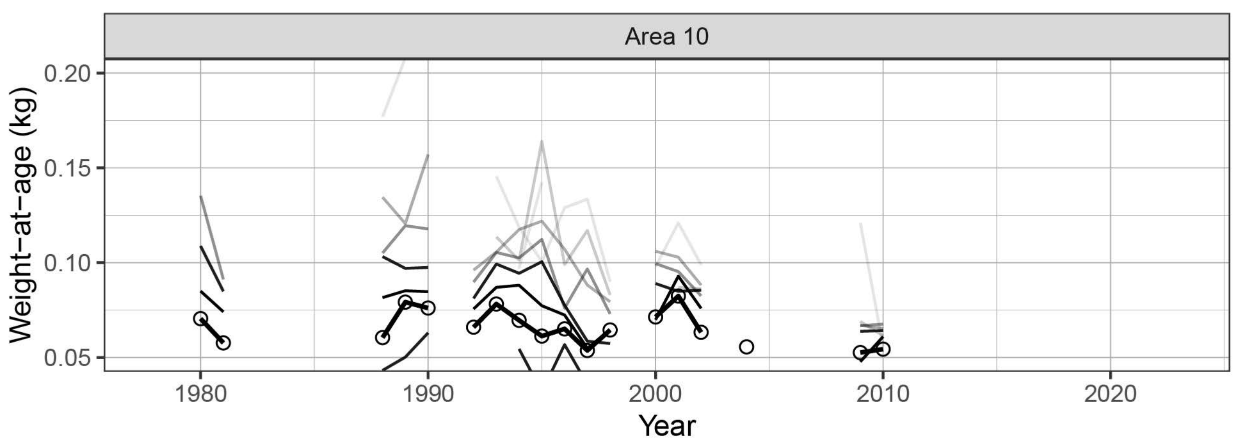

Figure 26. Mean weight-at-age for Pacific Herring in kilograms (kg) from 1978 to 2023 in the special area, Area 10. See Figure 21 for description.

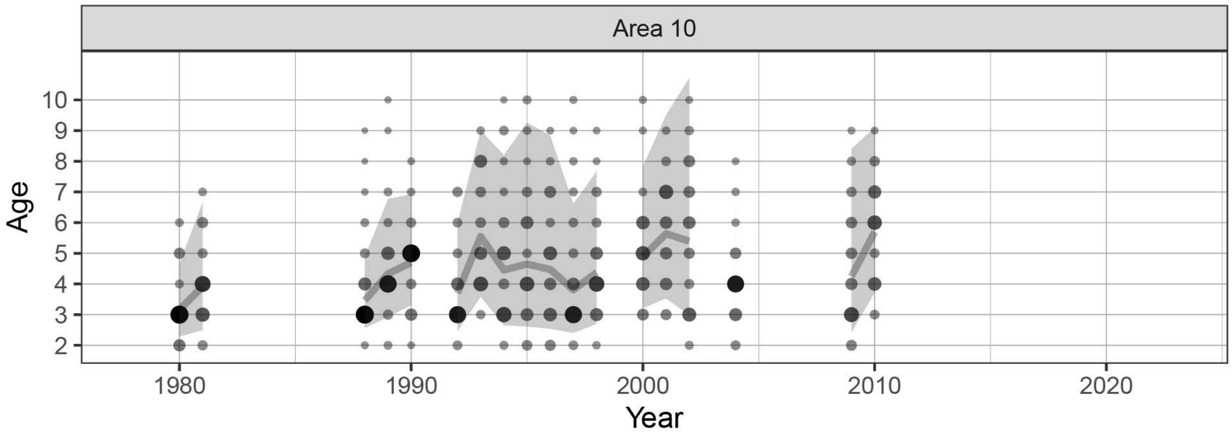

Figure 27. Proportion-at-age for Pacific Herring from 1978 to 2023 in the special area, Area 10. See Figure 5 for description.

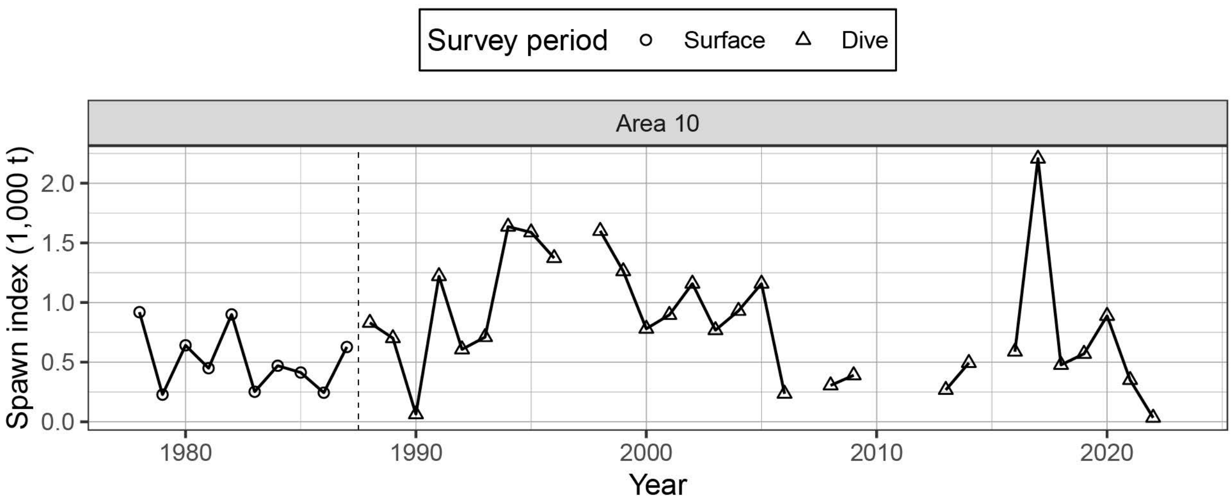

Figure 28. Spawn index in thousands of tonnes (t) for Pacific Herring from 1978 to 2023 in the special area, Area 10. See Figure 6 for description.

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Nanaimo, BC V9T 6N7

E-mail: DFO.PacificCSA-CASPacifique.MPO@dfo-mpo.gc.ca
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