# Haida Gwaii 'íináang | iinang Pacific Herring Rebuilding Plan:

## An Ecosystem Approach

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## Foreword

In 2009, Fisheries and Oceans Canada (DFO) developed A Fisheries Decision-Making Framework Incorporating the Precautionary Approach (PA Policy) under the auspices of the Sustainable Fisheries Framework. It outlines the departmental methodology for applying the precautionary approach (PA) to Canadian fisheries. A key component of the PA Policy requires that when a stock has declined to or below its limit reference point (LRP), a rebuilding plan must be in place with the aim of having a high probability of the stock growing above the LRP within a reasonable timeframe.

In addition, under section 6.2 of the Fish Stocks provisions (FSP) in the amended *Fisheries Act* (2019), rebuilding plans must be developed and implemented for prescribed major fish stocks that have declined to or below their LRP. This legislated requirement is supported by section 70 of the *Fishery (General) Regulations* (FGR), which set out the required contents of those rebuilding plans and establish a timeline for each rebuilding plan's development.

The purpose of this plan is to identify the main rebuilding objectives for Pacific herring in Haida Gwaii, as well as the management measures that will be used to achieve these objectives. This plan provides a common understanding of the basic "rules" for rebuilding the stock(s). This stock is prescribed in the *Fishery (General) Regulations* (section 69) and thus *is* subject to section 6.2 of the *Fisheries Act* and regulatory requirements.

The objectives and measures outlined in this plan are applicable until the stock(s) has reached its rebuilding target. Once the stock is determined to be at the target, the stock(s) will be managed through the standard Integrated Fisheries Management Plan (IFMP) or other fishery management process in order to fulfill the requirements of the FSP. Management measures outlined in this rebuilding plan are mandatory, and may be modified or further measures added if they fail to result in stock rebuilding.

**This rebuilding plan is not a legally binding instrument which can form the basis of a legal challenge. The plan can be modified at any time and does not fetter the Minister's discretionary powers set out in the *Fisheries Act*. The Minister can, for reasons of conservation or for any other valid reasons, modify any provision of the rebuilding plan in accordance with the powers granted pursuant to the *Fisheries Act*.**

Decisions flowing from the application of this rebuilding plan must respect the rights of Indigenous peoples of Canada recognized and affirmed by section 35 of the *Constitution Act* (1982), including those through modern treaties. Where DFO is responsible for implementing a rebuilding plan in an area subject to a modern treaty, the rebuilding plan will be implemented in a manner consistent with that agreement. The plan should also be guided by the 1990 *Sparrow* decision of the Supreme Court of Canada, which found that where an Aboriginal group has a right to fish for food, social and ceremonial purposes, it takes priority, after conservation, over other uses of the resource.

*The Honorable Diane Lebouthillier*
*Minister of Fisheries, Oceans and*
*the Canadian Coast Guard*

April 4, 2024
*Date of approval of rebuilding plan*

## Foreword by Haida Nation

This rebuilding plan is the result of five years of collaborative work by the Haida Nation and Canada. It focuses on 'íináang | iinang Pacific herring in Haida Gwaii. Iinang is a keystone species in the food web and k'aaw or herring spawn-on-kelp, is an important Haida traditional food and trade item. The Haida Nation has had concerns about the health of Haida Gwaii herring populations since the mid-1990s and commercial fisheries in the major stock area from Cumshewa to Louscoone Inlets have been closed for the past twenty years.

In 2018, both governments committed to developing a rebuilding plan for herring in the Gwaii Haanas Gina 'Waadluxan KilGuhlGa Land-Sea-People management plan. The plan reflects Haida values and responsibilities expressed in the Haida Constitution and related management plans and is a positive step in the direction of collaborative governance and management as envisaged in the 2018 Fisheries Resource Reconciliation Agreement between the Haida Nation and Canada.

The rebuilding plan outlines a mutually agreed framework for monitoring and assessing rebuilding and cautiously approaches the reopening of fisheries if targets are met. The plan takes an ecosystem approach, addresses herring throughout Haida Gwaii, incorporates Haida traditional knowledge, accounts for the lower impact of spawn on kelp fisheries relative to other fisheries, and recognizes finer spatial structure of Haida Gwaii herring by managing fisheries at a sub-stock level.

The rebuilding plan will remain in place until targets have been met and another collaborative management plan has been developed for Haida Gwaii.

December 19, 2023

Gaagwiis *Jason Alsop,* President of the Haida Nation

Date of Approval of the Rebuilding Plan

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| | | | |
|---|---|---|---|
| A2W | Area 2 West | MICE | Models of Intermediate Complexity |
| AAROM | Aboriginal Aquatic Resources and Ocean Management | MPA | Marine Protected Area |
| AFS | Aboriginal Fisheries Strategy | MSE | Management Strategy Evaluation |
| AMB | Archipelago Management Board | NPGO | North Pacific Gyre Oscillation |
| AOI | Arctic Oscillation Index | NPI | North Pacific Index |
| ATP | Allocation Transfer Program | NPP | Net Primary Productivity |
| BC | Province of British Columbia | OM | Operating Model |
| BCMCA | British Columbia Marine Conservation Analysis | oSOK | Open pond Spawn-on-Kelp |
| CC | Central Coast | PA | Precautionary Approach |
| CESD | Commissioner for Environment and Sustainable Development | PC | Parks Canada |
| CHN | Council of the Haida Nation | PDO | Pacific Decadal Oscillation |
| CMG | Cooperative Management Group | PMFA | DFO Pacific Fishery Management Area |
| C/S | Cumshewa/Selwyn (DFO management sections 23 and 24) | PICFI | Pacific Integrated Commercial Fisheries Initiative |
| cSOK | Closed pond Spawn-on-Kelp | PNCIMA | Pacific North Coast Integrated Management Area |
| DFO | Department of Fisheries and Oceans Canada | PRD | Prince Rupert District |
| EBM | Ecosystem-based Management | PWS | Prince William Sound |
| EwE | EcoPath with EcoSim | RoeGN | Roe Gillnet Fisheries |
| FRRA | Fisheries Resource Reconciliation Agreement | RoeSN | Roe Seine Fisheries |
| FSC | Food, Social and Ceremonial fisheries | RP | Rebuilding Procedure |
| GH | Gwaii Haanas | SAR | Stock Assessment Region |
| HCAM | Herring Catch Age Model | $SB_0$ | Unfished Spawning Stock Biomass estimate |
| HCR | Harvest Control Rule | SES | Social-ecological system |
| HDI | Highest Density Interval | SFF | Sustainable Fisheries Framework |
| HG | Haida Gwaii | SISCAH | Statistical Catch-at-Age Herring |
| HIAB | Herring Industry Advisory Board | SOK | Herring Spawn-on-Kelp |
| HMTK | Haida Marine Traditional Knowledge | SoG | Strait of Georgia |
| HR | Harvest Rate | SST | Sea Surface Temperature |
| IFMP | Integrated Fishery Management Plan | TAC | Total Allowable Catch |
| IHHPC | Integrated Herring Harvest Planning Committee | TRP | Target Reference Point |
| ISCAM | Integrated Statistical Catch Age Model | TWG | Technical Working Group |
| JP/S | Juan Perez/Skincuttle (DFO management sections 21 and 25) | UCP | Upper Control Point |
| LCP | Lower Control Point | USR | Upper Stock Reference |
| LRP | Limit Reference Point | WCVI | West Coast Vancouver Island |
| MaPP | Marine Plan Partnership for the North Pacific Coast | YOY | Young of Year |

## PREFACE

This plan for Haida Gwaii **'íináang | iinang** *herring* was co-developed by the Council of the Haida Nation (CHN), Parks Canada Agency (PC) and Fisheries and Oceans Canada (DFO), and provides an overview of Pacific Herring ecosystem attributes in Haida Gwaii and outlines a plan for rebuilding Haida Gwaii **'íináang | iinang** *herring*. Direction for the plan was provided by the Gwaii Haanas Archipelago Management Board (AMB) and the Haida Gwaii Cooperative Management Group (CMG) established under agreements between the Haida Nation and Canada. The plan was drafted by the Haida Gwaii Herring Rebuilding Plan Technical Working Group (TWG) under a Terms of Reference agreed upon by the AMB and CMG. The rebuilding plan utilizes a precautionary approach that corresponds to the Haida principle of **yahgudáng | yahguudang** *respect*, and takes an ecosystem-based management (EBM) approach, which are requirements of the Gwaii Haanas Gina 'Waadlu<u>x</u>an Kil<u>G</u>uhl<u>G</u>a Land-Sea-People Management Plan that guides management of Gwaii Haanas National Parks Reserve, National Marine Conservation Area Reserve, and Haida Heritage Site (hereafter Gwaii Haanas). This plan also contains the elements required by regulation under the *Fisheries Act* for Rebuilding Plans, and further extends beyond these elements to encompass broad aspects of the Haida Gwaii herring ecosystem, including culture, governance, management and socio-economic factors as a result of the additional governance and planning commitments associated with Gwaii Haanas as described above. Given the unique circumstances guiding development of this plan, this plan and the collaborative development process are not templates for future rebuilding plans required under the *Fisheries Act.* This plan was refined through consultation with herring harvesters, other stakeholders, other government agencies, Haida Gwaii communities and the general public.

## EXECUTIVE SUMMARY

Many of the **'íináang | iinang** *herring*[1] populations around Haida Gwaii have significantly declined over the past three decades and remain at low levels today. This decline is having cascading effects on the ecological, cultural, social and economic systems that depend on 'íináang | iinang, triggering the need for a plan to rebuild these herring populations. The potential causes of the decline and continuing low abundance are numerous, interconnected and difficult to disentangle. By considering the ecosystem and population dynamics, this plan outlines actions to support rebuilding.

This rebuilding plan for Haida Gwaii 'íináang | iinang *herring* was developed by the Council of the Haida Nation (CHN) and Canada (Parks Canada Agency (PC) and Fisheries and Oceans Canada (DFO)) and led by the Gwaii Haanas Archipelago Management Board (AMB) and the Cooperative Management Group (CMG) that are established under agreements between the Haida Nation and Canada. The plan was drafted by a Haida Gwaii Herring Rebuilding Plan Technical Working Group (TWG) under a Terms of Reference agreed upon by the AMB and CMG, and has been further refined through consultation with herring harvesters, other stakeholders, other government agencies, Haida Gwaii communities, and the general public. The rebuilding plan utilizes a precautionary approach that corresponds to the Haida principle of **yahgudáng | yahguudang** *respect* and takes an ecosystem-based management (EBM) approach. The herring rebuilding plan and an EBM approach are requirements of the Gwaii Haanas Gina 'Waadluxan KilGuhlGa Land-Sea-People Management Plan and a rebuilding plan is also required under the Fish Stocks Provisions of Canada's *Fisheries Act*, which states that any major fish stock that has declined to or below its limit reference point (LRP), then a plan shall be developed to rebuild the stock above that point in the affected area.

This rebuilding plan:

- Explores herring management issues and potential causes of decline of Haida Gwaii herring;
- Identifies ecological, cultural, social and economic, governance and management objectives and targets, including reference points for Haida Gwaii herring rebuilding and how they relate to the EBM Framework being developed for Gwaii Haanas fisheries;
- Defines what a 'rebuilt' Haida Gwaii herring ecosystem looks like, including ecological, cultural, social, economic, governance and management aspects;
- Reports on results of supporting analyses, including (1) a collaborative Management Strategy Evaluation (MSE) process for the Haida Gwaii Major stock assessment region (SAR), (2) an analysis of biomass and growth trends for sub-stocks throughout Haida Gwaii, and (3) an exploration of environmental drivers affecting herring productivity and production; and
- Outlines fishery management actions at various levels of biomass based on the supporting analyses, herring monitoring and research priorities for Haida Gwaii herring, areas of further collaborative work related to Haida Gwaii herring, and next steps for implementation.

A set of broad strategic and operational objectives guided the development of this rebuilding plan. The strategic objectives are:

[1] The two local dialects of the Haida language, **X̲aad kíl**, the **G̲aw Tlagée** *Old Massett* dialect, and **X̲aayda kil**, the **HlG̲aagilda** *Skidegate* dialect are incorporated throughout this document.

1. Rebuild and conserve herring populations and protect their habitat, related species, and key ecosystem features and processes, consistent with Section 6.2 of the *Fisheries Act*;
2. Sustain Haida traditional values and use of herring;
3. Collaborate to increase local social and economic opportunities related to herring;
4. Achieve collaborative governance that provides stability, transparency, and predictability in fisheries management;
5. Apply EBM principles and a collaboratively developed EBM framework (being developed concurrently by the governance partners) to manage and assess impacts of herring fisheries; and
6. Achieve successful fisheries in accordance with allocation priorities.

This document is presented in seven sections to align with these objectives; below are key highlights for each of these sections.

**Section 1: Introduction**

Herring in the Haida Gwaii Major SAR (Cumshewa Inlet to Louscoone Inlet) have been depressed for more than 25 years (five herring generations) and both the Haida Nation and Canada have called for a rebuilding plan. The rebuilding plan considers herring sub-stocks throughout Haida Gwaii (Figure 1), including those in the Major SAR, the Minor SAR (Port Louis to Tasu Sound), and Skidegate Inlet, Masset Inlet and Naden Harbour.

**Section 2: Guiding Principles and Knowledge Systems**

The rebuilding plan incorporates an ecosystem-based management approach and is informed by Haida Gwaii Ethics and Values and the Government of Canada's ongoing commitment to reconciliation. Several policies and initiatives have also informed the plan, including the Gwaii Haanas Gina 'Waadluxan KilGuhlGa Land-Sea-People Management Plan (2018) and Fish Stocks Provisions of Canada's *Fisheries Act* (updated 2021). The plan relies on both scientific and Haida traditional knowledge.

**Section 3: Management Issues and Causes of Decline**

Key management issues are described in this plan under five main themes: decision-making and governance; spatial variability and management; stock assessment and ecosystem-based management; fisheries closures; and the scope of Haida traditional fisheries. Historically, Haida knowledge was not used in stock assessment and management planning. The Major or Minor SARs of Haida Gwaii were assessed and managed as two aggregate stocks, potentially leading to local depletion; in contrast, Haida knowledge identifies a number of local herring spawning populations throughout Haida Gwaii. Annual stock assessments to date have been unable to address uncertainties, including accounting for ecosystem interactions in the Haida Gwaii system. Fishery closures in the area have had differential impacts on the **k'áaw | k'aaw** *spawn-on-kelp* (SOK)[2] harvesters who are unable to relocate when local herring populations are low.

[2] Herring eggs on kelp is **k'áaw** in Gaw Tlagée Xaad kíl and **k'aaw** in HlGaagilda Xaayda kil. Tone markers or accents are important for learning and pronunciation, and are becoming common in Xaad kíl. However, for purposes of readability, **k'aaw** will be used throughout the rest of the document, to represent both dialects, as it is a frequently used Haida word with already familiar pronunciation.

Traditional fisheries will not be limited by this rebuilding plan, and may occur in all areas of Haida Gwaii, subject to conservation concerns (see Section 2.2.2 for additional details).

Probable causes of decline and issues that influence rebuilding likely include past commercial fisheries catches such as during the reduction fishery (see Section 5.2.3.2 for additional details) period, and changing oceanographic and climatic conditions that have resulted in changes in prey quality, prey availability, and predation pressure.

## Section 4: Rebuilding Haida Gwaii Herring

A rebuilt herring system is one where herring are plentiful, diverse, productive, and resilient in the face of climate, ocean, and social change. The rebuilt system supports fisheries and contributes to human well-being while maintaining ecosystem needs. This vision is captured in the collaboratively developed objectives for rebuilding Haida Gwaii herring that address ecological, cultural, social and economic, governance and management aspects of the herring system.

## Section 5: The Haida Gwaii Herring Ecosystem

The plan describes Haida Gwaii herring ecosystem components using a conceptual model (Figure 2) that includes elements of herring habitat, climate and ocean, human activities, society and economy including Haida culture, governance, and management. Haida knowledge contributed to the approach and analyses through understanding about spatial dynamics, informing historical baselines and reference points, documenting climate and predator changes, and knowledge about the effects of and interactions among fisheries.

Recent herring population assessments estimate that populations in the Major SAR have been in a persistent low spawning biomass state since the 1990s and the increasing trend in the estimated natural mortality rate has largely absorbed any increases in annual production, inhibiting population growth. The last commercial roe and SOK fisheries in the Major SAR were in 2002 and 2004, respectively. Recent assessments of herring in the Minor SAR showed an increase in survey spawning biomass primarily in one sub-stock in 2019 and 2020 (DFO 2021). The mechanisms underlying the persistent low spawning abundances and low productivity state are likely complex and still poorly understood.

Herring populations outside the areas currently assessed by DFO, including Skidegate Inlet, Masset Inlet, and Naden Harbour, have only been monitored opportunistically. The population status for these smaller areas is largely unknown.

The characteristics of a rebuilt Haida Gwaii herring system are described according to the elements, objectives and attributes of the herring socio-ecological system. Characteristics are identified for ecological, cultural, social and economic, governance and management components of the system (Table 4).

Reference points for Haida Gwaii herring were identified by the TWG using an empirical approach. Reference periods of 1975-1985 and 1982-1992 were chosen for the Major SAR and for the Minor SAR, respectively, based on evidence of population recovery from a relatively low state back to relatively high abundance, for the purpose of defining healthy herring populations.

## Section 6: Modelling Approaches to Support Rebuilding

Differences in availability of survey data for the historically important spawning areas highlight the need to explore multiple modelling approaches in order to develop the best understanding of population status and rebuilding potential of Pacific Herring throughout Haida Gwaii. Analyses conducted during the development of this plan accounted for SOK fisheries, assumed a finer spatial structure for Haida Gwaii herring than the historic stock assessments (i.e., three sub-stocks in the Major SAR and five sub-stocks in the Minor SAR), helped identify short and long-term rebuilding targets, and highlighted the importance of decision-making processes with iterative management actions that could be implemented if environmental conditions were to improve and fisheries could be reopened without compromising recovery.

Three modelling approaches were used to support the rebuilding plan:

1) *Management Strategy Evaluation:* MSE analyses on the aggregate Major SAR indicated very low likelihood of herring rebuilding within 15 years, even without commercial fishing. Rebuilding performance appeared to be dominated by the population and ecosystem dynamics represented in the modelling scenarios rather than the impacts of the management procedures tested, including those with different fisheries allocations. As expected because of the herring use and operation size, the simulation results supported that SOK fisheries had the least impact on herring population growth and rebuilding out of all the fishing management procedures simulated. SOK fisheries also allowed for the greatest fishing opportunities.
2) *Spatiotemporal biomass dynamic and growth dynamic models:* Two models were used to reconstruct spatiotemporal trends in herring biomass and growth dynamics. Results from the spatiotemporal biomass dynamic model revealed some synchronicity in productivity and biomass between sub-stocks, but less abundant sub-stocks appear to be subject to more severe annual fluctuations in biomass with greater amplitude, prolonged periods of persistent collapse, with only short and unpredictable periods of sustained positive production. Results from the growth dynamic model showed synchrony in declining size-at-age trends between areas of Haida Gwaii and the rest of BC, in addition to overall larger herring in Haida Gwaii and the West Coast of Vancouver Island.
3) *Environmental drivers of productivity:* These exploratory analyses investigated spatiotemporal scales at which herring population productivity and production were correlated with environmental influences and evaluated the potential impact of specific biotic and abiotic environmental drivers. The analyses revealed negative temporal autocorrelation in productivity and production patterns indicating that the sub-stocks are unlikely to show smooth trends toward rebuilding. There was also some evidence that years with unfavourable environmental conditions may be becoming more common.

## Section 7: Management Measures and Implementation

Management measures under this rebuilding plan include:

### *Major Stock Assessment Region*

- Implementation of a cautious approach to management as herring population status changes, given that rebuilding above the limit reference point (LRP) is unlikely within three herring generations (15 years) under current natural mortality levels, recruitment (DFO 2020) and environmental conditions.
- Application of Rebuilding Procedures (RPs) that allow for commercial fisheries only once the aggregate herring population biomass shows clear signs of rebuilding above the LRP (Section 6).

- Use of short- ($0.75SB_{prod\text{-}avg}$) and long-term ($SB_{prod\text{-}avg}$) biomass targets in the strategy for rebuilding (Section 6).
- Implementation of a Rebuilding Procedure with open or closed pond SOK fisheries (Table 7) once the aggregate population biomass is in the rebuilding phase.
- Commitment to additional simulation analyses when aggregate population and sub-stocks show signs of rebuilding beyond that initially simulated, to assess the risks of potential management actions and plan for future fishing opportunities.

***Major and Minor Stock Assessment Regions (not including Tasu Sound and Skidegate Channel)***

- Management on a sub-stock basis, i.e., Cumshewa/Selwyn, Juan Perez/Skincuttle, Louscoone, Port Louis, Rennell Sound, and Englefield Bay (based on DFO management sections for data collection; Figure 4)
- Prioritization of fisheries with the lowest impact to rebuilding (i.e., SOK), during rebuilding to meet cultural, social, and economic objectives and promote viability of Haida traditional fisheries.
- Consideration of commercial seine roe fishery only once populations are rebuilt.
- Application of spatial management meta-rules to RPs in order to limit and distribute fisheries impacts when making annual fisheries management decisions.
- Setting of minimum biomass thresholds for multiple consecutive years after a low productivity signal and setting of low target harvest rates (e.g., 0, 5 and 10%).
- Observation of rebuilding signals over multiple years before determining rebuilding trends and stability, considering the volatility of sub-stocks particularly in the Minor SAR.
- Maintenance of high spawner biomass to sustain sub-stocks over years with poor environmental conditions, given that if rebuilding occurs, it may turn out to be fragile.

***Skidegate Inlet, Naden Harbour, Masset Inlet, Skidegate Channel and Tasu Sound***

Pacific Herring populations spawning outside the historical DFO stock assessment regions lack the consistent monitoring data required to assess status in these areas. Due to the lack of historical data, it is recommended that no commercial fisheries operate in areas lacking an established herring population monitoring program to assess population status, aligning with current DFO management policy.

***Timeframe for Rebuilding***

Management recommendations and actions are unlikely to achieve rebuilding of the Haida Gwaii herring system over the short-term (i.e., three herring generations (15 years) were simulated) due to population dynamics and ecosystem considerations outside the control of management actions. Population status and progress towards short- and long-term objectives will be assessed annually, and review of the rebuilding plan is expected to take place every five years, or sooner for exceptional circumstances.

The rebuilding plan process will remain in place until:

1. For the Major SAR, at least the short-term rebuilding target has been met for three consecutive years, and further simulation work and research has been completed;

2. For the Minor SAR, at least the rebuilding target has been met for three consecutive years for two of the three managed sub-stocks (Port Louis, Rennell Sound, and/or Englefield Bay), and a collaborative monitoring program has been initiated; and
3. For all Haida Gwaii sub-stocks, a collaborative fisheries management plan has been developed and implementation initiated.

***Future Work***

The plan identifies sets of research and monitoring priorities to guide future work towards rebuilding of the Haida Gwaii herring system. The governance partners will advance collaborative work related to governance, implementation plans, management and decision-making, ecosystem-based management, fisheries assessment and research, monitoring, policy reforms, communication, and conservation and protection related to rebuilding and management of Haida Gwaii herring.

*"One day the Herring People came dancing on their canoes. After landing at the village, they began to dance in a house. Rock Woman told a man to go behind the town, take a young hemlock bough, and put it into the corner of the house where the Herring People were dancing. When he pulled the hemlock bough out, it was covered thick with herring eggs, which he ate. (Tom Stevens, summarized from Swanton, 1905a, at p. 9-10")*

# 1 INTRODUCTION

**'íináang | iinang** *Pacific Herring*[3], *Clupea pallasii*, are an ecologically and culturally important forage fish along the west coast of Canada and North America, ranging from California to the Beaufort Sea. 'íináang | iinang populations spawn throughout Haida Gwaii and coastal First Nations have fished consistently for herring over at least the past 2500 years based on archaeological records (McKechnie et al. 2014), creating an inseparable linkage between culture and environment (HMTK 2011 and Box 1). As a forage fish, herring play a critical role in marine and coastal ecosystems, preying on plankton and providing food for a multitude of species from fishes and seabirds to marine mammals and people. When herring schools gather in coastal waters during the spring spawning season, humpback and grey whales, halibut and rockfishes, seabirds, eagles, and other predators congregate to feed. Likewise, the herring spawn attracts a plethora of foragers from bat stars to seabirds to black bears and many more. Herring populations are thought to be resilient because of their short-lived and fast-growing life histories, however these characteristics can also increase their vulnerability to collapse (e.g., Pinsky et al. 2011, Trochta et al. 2020), especially when overfishing occurs (Essington et al. 2015, Pinsky and Byler 2015). Despite being a significant and critical part of marine and coastal food webs and the ecosystem, many gaps in our knowledge still exist.

> *Box 1. Going to get herring is an experience that takes us onto the ocean, and it puts us in touch with nature by getting the herring. (Barbara 'Babs' Stevens, 2016)*
>
> *If we look at how we feel when things are askew, and then think of the earth and think of all parts of it, then how do we want to feel? We want to feel whole. How do we make ourselves feel whole? By making sure we are eating the right foods, and the right foods in our case are the foods that our ancestors ate. And how do we get that food? By making sure our creeks and our oceans and our lands are in good shape. (Barbara Wilson, 2016)*

Concerns around the herring populations in Haida Gwaii have been raised by the Council of the Haida Nation (CHN) since the Haida Fisheries Program was established in 1989. Haida Gwaii 'íináang | iinang populations were historically abundant (Box 2), but have been depressed or at critically low levels for the last three decades. In the Major Stock Assessment Region (SAR, Figure 1) the abundance estimates have often been below the 2021 estimate of the limit reference point (LRP), beginning in 1994 and consistently from 2000 to 2010, which signals when the stock fell into a critical stock status. The Major SAR has remained at low levels and has been fluctuating around the LRP since 2010. In response, little to no commercial herring

> *Box 2. [In the next twenty-five years,] I would love to see it like my parents saw it in Burnaby Narrows, where they could stand on the rocks and just get a rake and rake through like schools and schools of herring and just shake them off. I would love to see that whole area just plugged of herring again, just to witness that, and to see what kind of life is following that, phew, would be so amazing. (Judson Brown, 2016)*

[3] The two local dialects of the Haida language, **X̱aad kíl**, the **G̱aw Tlagée** *Old Massett* dialect, and **X̱aayda kil**, the **HlG̱aagilda** *Skidegate* dialect are incorporated throughout this document.

fisheries have occurred around Haida Gwaii for almost two decades. Key questions remain unanswered with respect to why herring populations have not rebuilt in Haida Gwaii (Section 7.4). Although finding answers to these questions will take time, it is equally important to take management actions to help rebuild Haida Gwaii herring over the shorter and longer term.

To inform Haida Gwaii herring rebuilding, collaborative research addressing the Haida Gwaii herring ecosystem condition and needs, including those of people, was conducted by members of the Ocean Modelling Forum (https://oceanmodelingforum.org/working-groups/pacific-herring/), led by a group of herring researchers including representatives from CHN, DFO and GH in 2015-16. Although many hypotheses exist about causes of Haida Gwaii herring decline and continued low abundance and productivity, ecosystem interactions are complex and difficult to disentangle; the exact causes are hard to pinpoint and are likely cumulative in their effects. However, results from modelling exercises (Section 6) indicated that the likely causes are some combination of past overfishing and changing environmental conditions. Regardless of the cause, the loss of access to herring and **k'áaw** | **k'aaw** *herring spawn-on-kelp*[4] has and continues to have profound cultural impacts on the Haida and socio-economic impacts on herring fisheries (Box 3).

*Box 3. Our future of our children is more important than making money in a couple years and putting it right back to the same, or worse. Because that's the last of the areas—where there's big spawn, is Skincuttle and Burnaby Narrows, and Section Cove area—that's the last area. It used to happen south and that all got fished out, so, you don't see spawns down there anymore. Plus the west coast, that too, there was quite a bit of spawn back in the day. And that's not that long ago too, it doesn't take much to—well it's been 14 years since they closed it, and you don't see a great big return yet. (Conrad Collinson, 2016)*

In response to the need for a cooperative approach between the Haida Nation and Canada to facilitate herring rebuilding, the Haida Gwaii Herring Rebuilding Plan Technical Working Group (TWG) was formed in 2018 to cooperatively develop a Haida Gwaii 'íináang | iinang *Herring* Rebuilding Plan. The Terms of Reference and Scoping Document for the working group are included in Appendix A.

Throughout this plan, the terms Haida Gwaii herring social-ecological system, ecosystem and system are used interchangeably to refer to the collective and interconnected components of the Haida Gwaii 'íináang | iinang *Pacific herring* system.

This rebuilding plan:

- Provides background information on the Haida Gwaii 'íináang | iinang herring ecosystem, including stock assessment and management of herring (Section 5.2).
- Explores management issues and potential causes of decline of Haida Gwaii herring (Section 3);
- Identifies objectives and targets including reference points for Haida Gwaii herring rebuilding; ecological, cultural, social and economic, governance and management aspects; and how these relate to the Ecosystem-Based Management Framework being developed for Gwaii Haanas fisheries (Sections 4 and 7);
- Defines what a 'rebuilt' Haida Gwaii herring system looks like including ecological, cultural, social and economic, governance and management aspects (Section 5.3);

[4] Herring eggs on kelp is **k'áaw** in G̲aw Tlagée X̲aad kíl and **k'aaw** in HlG̲aagilda X̲aayda kil. Tone markers or accents are important for learning and pronunciation, and are becoming common in X̲aad kíl. However, for purposes of readability, **k'aaw** will be used throughout the rest of the document, to represent both dialects, as it is a frequently used Haida word with already familiar pronunciation.

- Reports on results of analyses including a collaborative Management Strategy Evaluation process for Haida Gwaii Major SAR; an analysis of biomass and growth trends throughout Haida Gwaii; and an exploration of environmental drivers for productivity and production (Section 6); and
- Describes fishery management actions at various levels of biomass, and identifies monitoring and research priorities for Haida Gwaii herring, opportunities for further collaborative work related to Haida Gwaii herring, and next steps for rebuilding plan implementation (Section 7).

# 2 GUIDING PRINCIPLES & KNOWLEDGE SYSTEMS

## 2.1 HAIDA ETHICS AND VALUES

The CHN's Haida Marine Work Group identified Haida ethics and values (CHN 2007) based on Haida laws to guide marine planning initiatives and management plans that support decision-making processes in and around Haida Gwaii. These ethics, values, and laws were included with slight modifications in the Haida Gwaii Marine Plan (MaPP 2015), Gwaii Haanas Gina 'Waadluxan KilGuhlGa Land-Sea-People Management Plan (2018), and SGaan Kinghlas – Bowie Seamount Management Plan (2019). **Gaw Tlagée Xaad kíl** and **HlGaagilda Xaayda kil** are identified in blue and green, respectively:

> **Yahgudáng** | **Yahguudang** *Respect. Respect for each other and all living things is rooted in our culture. We take only what we need, we give thanks, and we acknowledge those who behave accordingly.*
>
> **K'uláagée** | **'Laa guu ga kanhllns** *Responsibility. We accept the responsibility passed on by our ancestors to manage and care for our sea and land. We will ensure that our heritage is passed onto future generations.*
>
> **Gin 'wáadluwan gud.ahl kwáagíidang** | **Gina 'waadluxan gud ad kwaagid** *Interconnectedness – Everything depends on everything else. The principle of interconnectedness is fundamental to integrated planning and management. This comprehensive approach considers the relationships between species and habitats, and accounts for short-term, long-term and cumulative effects of human activities on the environment. Interrelationships are accounted for across spatial and temporal scales and across agencies and jurisdictions.*
>
> **Agan t'ats'gang** | **Giid tlljuus** *Balance. Balance is needed in our interactions with the natural world. If we aren't careful in everything we do, we can easily reach a point of no return. Our practices and those of others must be sustainable.*
>
> **Ginn gán ga únsids kíl tla gudáng'wa** | **Gina k'aadang.nga gii uu tll k'anguudang** *Seeking Wise Counsel. Our elders teach us about traditional ways and how to work in harmony. Like the forests, the roots of our people are intertwined. Together we consider new ideas and information in keeping with our culture, values and laws.*

> **'Isda isgyaan diigaa isdii | Isda ad dii gii isda** *Giving and Receiving. Reciprocity is a respected practice in our culture, essential in our interactions with each other and the natural world. We continually give thanks to the natural world for the gifts that we receive.*

These Haida ethics and values correspond with ecosystem-based management principles described in scientific, planning, and management literature and also guide Haida herring practices that are further described in subsequent sections (Table 1).

Haida traditional knowledge (defined in Section 2.3.1) embedded in Haida stories and oral narratives provides important information not only about technological details and environmental conditions and changes, but also about ethical principles that guide management, including co-management of the marine environment (Box 4). These ethical principles provide a Haida vision for managing herring and other natural resources.

In addition to general responsibilities to caretake, Haida traditional knowledge describes specific considerations for herring and k'aaw, including to: respect the timing of the spawn and the importance of not interrupting reproduction to sustain herring populations; not take more than one needs and in particular avoid overfishing; protect key areas and close them to fishing or create buffers; monitor and manage local stocks of herring; limit fishing until there is robust recovery; distinguish between the different kinds of herring fishing and their varied impacts and benefit flows; and account for ecological factors within an ecosystem-based management context.

> *Box 4 … each Haida person has a responsibility and that responsibility is to take care of Haida Gwaii. And it's quite evident in many of us, we've done whatever it takes to protect—like Gwaii Haanas. It was our ancestors that set those down—the laws of respecting everything, the laws of not taking too much.* (Diane Brown, 2016)
>
> *It's our responsibility to look after these areas, the water and the land. No one knows it like we did or do—you know, maybe we've lost some of it, but we've been here a long time. We're not just talking to have our little share of it, you know, we are talking to protect it for the future too.* (Cindy Boyko, 2016)

## 2.2 POLICY DRIVERS AND CONTEXT

Several important policies and agreements have influenced the requirements and process utilized in the development of this Haida Gwaii 'íináang | iinang *Herring* Rebuilding Plan. These are briefly described in this section.

### 2.2.1 Gwaii Haanas Gina 'Waadluxan KilGuhlGa Land-Sea-People Management Plan

In November 2018, the Gwaii Haanas Gina 'Waadluxan KilGuhlGa Land-Sea-People Management Plan was signed by representatives from the Government of Canada and the Haida Nation, outlining the shared vision for the future of Gwaii Haanas and the direction for the Archipelago Management Board (AMB; described in Section 5.2) to manage both the terrestrial and marine areas of Gwaii Haanas. In this plan, a commitment was made by the parties to collaboratively develop a herring rebuilding strategy and implementation plan by 2020.
The Land-Sea-People Plan contains goals related to ecological integrity and ecologically sustainable use, which includes elements such as herring, eelgrass and kelp. A commitment was also made to develop an Ecosystem-Based Management Framework for fisheries in Gwaii Haanas. Herring are known to contribute extensively to the biodiversity of Haida Gwaii

ecosystems and therefore EBM has the potential to contribute to improving management of Haida Gwaii herring.

### 2.2.2 Reconciliation

Reconciliation is a top priority of the Government of Canada including recognition of Indigenous rights, and the Haida Nation is recognized as a leader in implementing reconciliation. While progress towards reconciliation is ongoing, some positive steps have been made, such as signing of the Gwaii Haanas Gina 'Waadluxan KilGuhlGa Land-Sea-People Management Plan (2018) by all management partners.

In March 2002, the Council of the Haida Nation initiated litigation against Canada and British Columbia, seeking a declaration that the Haida Nation has Aboriginal Title and Rights to Haida Gwaii, within the meaning of Section 35 of the *Constitution Act, 1982*. After an abeyance to allow for negotiations, the Haida Nation reactivated the litigation in early 2016; it remains active.

Canada recently committed to achieving reconciliation with Indigenous Peoples including the Haida Nation through a renewed, nation-to-nation and government-to-government relationship based on recognition of rights, respect, cooperation, and partnership as the foundation for transformative change (Canada Dept. of Justice 2018). The Haida Nation and Canada are engaged in reconciliation discussions on a variety of issues including fisheries. That process consists of a negotiating table comprised of representatives from the Haida Nation, federal government, and province of British Columbia. In July 2021, under the Fisheries Resources Reconciliation Agreement (FRRA) between DFO and eight First Nations, Canada and the Haida Nation committed to advancing a more collaborative, coordinated and efficient approach to governance and management of fisheries resources, including associated economic opportunities (https://www.canada.ca/en/fisheries-oceans/news/2021/08/government-of-canada-and-eight-coastal-first-nations-to-implement-community-based-fisheries-and-collaborative-fisheries-governance.html). Also in August 2021, the Haida Nation and Canada signed the **GayGahlda** *Changing Tide* Framework for Reconciliation agreement that sets out a process for negotiation of priority topics in an ongoing process of reconciliation (https://news.gov.bc.ca/releases/2021IRR0043-001601). Negotiation topics include Haida governance, Haida Gwaii marine management including fisheries and protected areas, environmental issues, social and community health and wellbeing, and economic wellbeing including commercial fisheries. The Changing Tide agreement allows negotiation and litigation to proceed in parallel, and for the scope of litigation to be narrowed if negotiations result in agreements.

In agreeing to and implementing this Rebuilding Plan, the Haida Nation is not agreeing that the collaborative management activities of the Haida Nation pursuant to this Rebuilding Plan necessarily constitute adequate accommodation of Haida interests in instances where Canada takes steps that in the opinion of the Haida Nation might prejudice the rebuilding of herring in Haida Gwaii.

### 2.2.3 Haida Nation Responsibilities

Haida Nation responsibilities are described in the Constitution of the Haida Nation (the "Haida Constitution") and Haida Ethics and Values (Section 2.1). The Haida Constitution defines Haida Gwaii and the surrounding waters as the mandate of the Haida Nation. The Haida Constitution and Haida citizens hold the Haida Nation responsible for establishment of land and resource policies consistent with nature's ability to produce, the regulation of access to resources to ensure self-sufficiency of the Haida Nation, and the perpetuation of Haida heritage and cultural identity. Specific to Haida Gwaii herring, the Haida Nation requested the completion of a herring management framework including the development of appropriate strategies for rebuilding herring as part of a court injunction that stopped the opening of the 2015 commercial herring fishery.

### 2.2.4 Canada Sustainable Fisheries Framework and Precautionary Approach

In 2009, DFO published the *Sustainable Fisheries Framework* (SFF) (https://www.dfo-mpo.gc.ca/reports-rapports/regs/sff-cpd/overview-cadre-eng.htm) and several associated policies which are summarized below.

A key policy under the SFF is *A Fisheries Decision-Making Framework Incorporating the Precautionary Approach* https://www.dfo-mpo.gc.ca/reports-rapports/regs/sff-cpd/precaution-eng.htm). In general, the precautionary approach in fisheries management is about being cautious when scientific knowledge is uncertain, and not using the absence of adequate scientific information as a reason to postpone action or failure to take action to avoid serious harm to fish stocks or their ecosystem. This approach is widely accepted internationally as an essential part of sustainable fisheries management.

Applying the precautionary approach to fisheries management decisions entails establishing a harvest strategy that: identifies three stock status zones – healthy, cautious, and critical – according to upper stock reference points (USRs) and limit reference points (LRPs); sets the removal rate at which fish may be harvested within each stock status zone; and adjusts the removal rate according to fish stock status variations (i.e., spawning stock biomass or another index/metric relevant to population productivity), based on pre-agreed decision rules.

The framework requires that a harvest strategy be incorporated into respective fisheries management plans to keep the removal rate moderate when the stock status is healthy, to promote rebuilding when stock status is low, and to ensure a low risk of serious or irreversible harm to the stock. A key component of the Precautionary Approach Framework requires that when a stock has declined to the Critical Zone, a rebuilding plan must be in place with the aim of having a high probability of the stock growing out of the Critical Zone within a reasonable timeframe.

### 2.2.5 Commissioner for Environment and Sustainable Development

In 2016, the Commissioner for Environment and Sustainable Development (CESD) performed an audit to determine, among other things, whether DFO had developed rebuilding plans for stocks in the critical zone. In the report, *Sustaining Canada's Major Fish Stocks – Fisheries and Oceans Canada* (https://www.oag-bvg.gc.ca/internet/English/parl_cesd_201610_02_e_41672.html), Haida Gwaii herring was identified as requiring a rebuilding plan but not having one in place, and the recommendation (2.28) was to set out priorities, targets, and timelines for putting rebuilding plans in place for those stocks that needed it. In response, DFO committed to developing a rebuilding plan for Haida Gwaii herring by the end of the 2020/2021 fiscal year (March 31, 2021), that is in line with DFO's *Guidance of the Development of Rebuilding Plans under the Precautionary Approach Framework: Growing Stocks out of the Critical Zone* (https://www.dfo-mpo.gc.ca/reports-rapports/regs/sff-cpd/precautionary-precaution-eng.htm).

### 2.2.6 Canada Fisheries Act: Fish Stocks Provisions

Under the *Fisheries Act*, DFO is responsible for managing Canadian fisheries resources, and for managing, conserving, and protecting Canadian fish and fish habitat. On June 21, 2019, with revisions to the *Fisheries Act,* new Fish Stocks Provisions (FSP) came into force to maintain major fish stocks at levels necessary to promote sustainability and develop and implement rebuilding plans for stocks that have declined to their critical zone. Guidelines to develop rebuilding plans that are consistent with the FSP are detailed in the document *Guidelines for writing rebuilding plans per the Fish Stocks Provisions and A Fishery Decision-making Framework Incorporating the Precautionary Approach* (https://www.dfo-mpo.gc.ca/reports-rapports/regs/sff-cpd/precautionary-precaution-eng.htm).

These provisions apply to stocks prescribed by regulation; Haida Gwaii herring in the Major SAR was the first Pacific Herring stock to be listed in regulation, and to which the FSP apply. The Haida Gwaii Major SAR has shown a few years of minor growth and the stock status in 2022 was above the LRP, however the stock remains below the incremental target (50%$SB_0$) identified within this plan (Section 5.3.6). This rebuilding plan, therefore, is consistent with the FSP requirements on rebuilding plans as a means of continuing to grow the stock to a sustainable level (to meet section 6.1 of the FSP).

The FSP formalized DFO's existing policies around sustainable fisheries, detailed in the *Sustainable Fisheries Framework* (section 2.2.4).

### 2.2.7 Canada Policy on New Fisheries for Forage Species

While herring fisheries in Haida Gwaii are existing fisheries that are not subject to the DFO *Policy on New Fisheries for Forage Species* (https://www.dfo-mpo.gc.ca/reports-rapports/regs/sff-cpd/forage-eng.htm), the principles and guidelines of this policy were reviewed and applied to develop objectives and guide future management measures. This policy recognizes the critical importance of forage fish species and outlines an approach to managing new forage species fisheries to ensure they are planned and conducted in ways that sustain ecosystem integrity. The *Policy on New Fisheries for Forage Species* has five primary objectives:

1. Maintain target, bycatch, and ecologically dependent species within the bounds of natural fluctuations in abundance;
2. Maintain ecological relationships (e.g., predator-prey and competition) among species affected directly or indirectly by the fishery within natural abundance fluctuations;
3. Minimize the risk of changes to species' abundances or relationships, which are difficult or impossible to reverse;
4. Maintain full reproductive potential of the forage species, including genetic diversity and geographic population structure; and
5. Allow opportunities to conduct commercially viable fisheries on forage species.

## 2.3 KNOWLEDGE SYSTEMS

### 2.3.1 Traditional Knowledge

The term 'traditional knowledge' is used in the context of this plan as a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment (*sensu* Berkes 1999). Haida marine traditional knowledge focuses on marine and maritime species, and the marine environment. In addition to ecological knowledge, traditional knowledge captures cultural, historical, economic, political, and societal information as it pertains to the marine environment. Due to the inherent importance of marine resources to the Haida, ecological knowledge is intertwined with other topics and broader observations about culture, society and economy, and is a reflection of cultural-social-ecological interconnectedness.

One of six goals in the Gwaii Haanas Gina 'Waadluxan KilGuhlGa Land-Sea-People Management Plan (2018) is to support the continuity of Haida culture. Another goal is to ensure ecologically sustainable fisheries by, in part, incorporating Haida traditional knowledge into decision-making processes (e.g., for Pacific Herring by 2020 and for all fisheries in Gwaii Haanas by 2023).

In this rebuilding plan, Haida traditional knowledge is incorporated into many aspects of herring management including the following elements:

- Contribute to understanding of the spatial dynamics such as finer stock structure and place-based, local-scale socioeconomic outcomes;
- Inform reference points and historical baselines for fisheries management, e.g., ecological, economic, sociocultural;
- Document ecosystem changes such as climate and predator changes that can inform understanding about herring population dynamics and development of ecosystem models;
- Improve understanding of herring biology, life history and ecology;
- Improve understanding about the effects of fisheries on herring populations and the Haida Gwaii ecosystem, e.g., SOK vs roe herring fisheries, ecosystem interactions, gear types and technology; and
- Support and inform co-management, decision-making and reconciliation processes.

Traditional knowledge in this plan was compiled from a variety of sources and is described in further detail in Appendix C:

- In the 1970s, information was gathered about knowledge and use of marine resources by Skidegate Haida that was included in several publications (Ellis and Wilson 1981; Jones and Lefeaux-Valentine 1991; Jones 1999).
- In 1998, interviews were conducted with seven Haida men about herring (Jones 2000; Jones 2007; HMTK 2011).
- Between 2007 and 2009, the Haida Marine Traditional Knowledge (HMTK) study was conducted and involved interviews with 54 Haida citizens regarding their knowledge and use of the marine environment around Haida Gwaii (HMTK 2011). Information was documented on marine charts, transcribed from audio and video recordings, and entered into a spatial database. Participants provided information on approximately 150 marine and maritime species. Herring was one of the focal species in the study.
- In 2016, 35 interviews with Haida citizens about cultural use, knowledge, harvest, environmental changes, governance, and well-being benefits of herring for the Gwaii Haanas Archipelago Management Board were conducted. This effort was part of the *Ocean Tipping Points (*http://oceantippingpoints.org/Haida-Gwaii) project to better understand human dimensions in a changing marine environment. Some individuals who were interviewed in 2016 had previously participated in the HMTK or earlier interviews.

**Limitations: Traditional knowledge information presented in this plan should not be considered complete and is only an indication of some of the Haida marine traditional knowledge that has been documented about herring and other species. Despite the fact that a substantial amount of information has been documented during the course of various studies, it is important to recognize that this work in no way represents the totality of Haida knowledge in regard to marine species and the marine environment.**

### 2.3.2 Scientific Knowledge

The best available scientific knowledge was used to inform this plan, including a review and summary of existing publications and data, and new modelling work using available scientific and traditional knowledge. DFO conducts annual spawning and biological surveys to support the annual stock assessment process for herring. The scientific approach used to assess stock status of Pacific herring populations was peer reviewed through the Canadian Science Advisory Secretariat (CSAS) which coordinates the scientific peer review of science advice for DFO. Scientific knowledge used to inform this plan includes work by DFO, academic institutions and environmental non-government organizations, with some studies conducted independently, and others in collaboration with the Haida Nation. New modelling work that supported this plan is detailed in Section 6, and in Appendices G, H and I.

# 3 MANAGEMENT ISSUES AND CAUSES OF DECLINE

This section describes challenges in Haida Gwaii herring management that have been identified by management partners represented by the TWG. This includes key issues identified in a workshop of Gwaii Haanas management partners in November 2012 (Appendix B) that are grouped into four themes: decision-making and governance, spatial variability and management, stock assessment and ecosystem-based management, and fisheries closures. We summarize potential causes of decline and issues that influence rebuilding considering the analyses and results drawn from various sections of the rebuilding plan.

## 3.1 DECISION-MAKING AND GOVERNANCE

As described in Section 2.2.2, the Haida Nation and Canada are involved in negotiation, as well as litigation, in an attempt to resolve issues concerning governance and decision-making regarding fisheries in Haida Gwaii, including herring. In 2014 and 2015 the Haida Nation disagreed with a DFO decision to open commercial herring fisheries in the Major SAR and obtained an injunction in 2015 that prevented the fishery from opening. This rebuilding plan attempts to bridge some of those disagreements regarding decision-making for herring populations and fisheries in Haida Gwaii.

A shared objective of the 2021 Fisheries Resource Reconciliation Agreement is to develop and enhance collaborative governance and management of fisheries resources but the process and structures for decision-making are still at an early stage of establishment and will take time to see results.

As well, DFO and the Haida have historically not had a common understanding of how to include Haida traditional knowledge in herring decision-making and governance, or how to prioritize Haida values related to Haida Gwaii herring. The management strategy evaluation (MSE) process and Gwaii Haanas management plan are steps towards incorporating different values but all parties recognize there is still a long way to go. As part of this larger herring rebuilding plan, incorporating traditional knowledge and recognizing Indigenous laws in decision-making can help to facilitate herring rebuilding and prevent declines in the future by facilitating a better understanding of the herring system and prioritizing fisheries that minimize herring mortality.

## 3.2 SPATIAL VARIABILITY AND MANAGEMENT

Haida Gwaii herring in the DFO Major SAR (southeast coast of Haida Gwaii), Minor SAR (west coast of Haida Gwaii) and Skidegate Inlet have been chronically low and spatially variable in abundance in recent decades. Haida traditional knowledge tells us that Haida Gwaii consists of a number of small herring spawning populations rather than a single population. Current DFO management considers the Major SAR on the east and south coasts of Haida Gwaii as an aggregate stock (i.e., one population) and does not consider managing by smaller herring populations due in part to the uncertainties around population structure and genetic diversity, possibly leading to overfishing of local sub-stocks. Up to this point, the Minor SAR on the west coast of Haida Gwaii has been managed as an aggregate area rather than by geographically distinct sub-stocks (e.g., Port Louis, Shields Bay, Seal Inlet and Kano Inlet). The aggregate management approach also means there are no established biomass targets or management goals for Haida Gwaii herring at the sub-stock level, potentially limiting rebuilding at finer geographic scales. Monitoring resources for the Major and Minor SARs are also variable, limiting the availability of stock assessment data at finer spatial scales. For the Major SAR, a biologically-based LRP has been defined by DFO; however, until this rebuilding plan, a collaboratively developed USR or target reference point (TRP) had not yet been identified. No reference points had been defined for the Minor SAR prior to this plan.

## 3.3 STOCK ASSESSMENT AND ECOSYSTEM-BASED MANAGEMENT

As a forage fish, herring play a vital role affecting many species in the ecosystem. The current DFO Pacific Herring stock assessment model is a single-species model which does not directly incorporate the needs of and interactions with other species in the ecosystem. Additionally, the stock assessment model has a high degree of uncertainty in estimates of recruitment and current and forecast spawning biomass, which are used to determine stock status, set annual total allowable catches (TACs), and inform management decisions. The large uncertainty in estimates often results in a realized harvest rate that is different than the target, highlighting the need for additional understanding of herring as part of the ecosystem.

The DFO coastwide cycle 1 MSE process was a step taken to further examine the impact of structural and biological uncertainties on conservation and harvest outcomes for Haida Gwaii herring, which indicated that the previous harvest policy (with a 20% harvest rate and cut-off biomass) was unsustainable and that the biomass was likely to remain low even under no fishing scenarios for the Haida Gwaii Major SAR (DFO 2020). An important next step to incorporating ecosystem considerations will be to conduct additional analyses to better understand how ecosystem processes and interactions are affecting herring rebuilding and recovery (e.g., changes in size-at-age, effects of cold and warm regimes, changing natural mortality and predation rates). Progress towards improved stock assessment and implementation of EBM for herring will require commitments to long-term stability in funding for herring stock assessment surveys and ecosystem-based research, and sufficient and timely data for in-season management.

In the short term, development of an EBM framework that draws upon Haida laws and knowledge remains a goal as has been committed to by the Council of the Haida Nation and Government of Canada in the Gwaii Haanas Gina 'Waadluxan KilGuhlGa Land-Sea-People Management Plan.

## 3.4 FISHERIES CLOSURES

Traditional fishery catches have been poor since the late 1990s due to low herring abundance and closure of commercial SOK fisheries. Fisheries closures have had a disproportionate effect on local commercial SOK fisheries because, unlike the roe herring fisheries, SOK operators are unable to relocate to other areas to fish. The Haida Gwaii Minor SAR has been open and supported a limited number of commercial SOK licences with larger vessels in recent years, but due to the harsh conditions and vessel safety considerations on the west coast of Haida Gwaii smaller operations have not been possible.

## 3.5 SCOPE OF HAIDA TRADITIONAL FISHERY

The Haida Nation and DFO have different understandings of the scope of the Haida traditional fishery in this rebuilding plan.

The Haida Nation defines Haida traditional fisheries as including an element of sale and trade based on historical and cultural practices. In 1998 the Haida Nation presented evidence to DFO for a Haida rights-based commercial SOK fishery as part of the Haida traditional fishery, but the issue has not been resolved (Galois, 1997). DFO defines First Nations' rights-based fisheries as food, social and ceremonial (FSC) fisheries or rights-based commercial fisheries consistent with court decisions protected under section 35 of Canada's Constitution. For the purpose of this plan, DFO defines Haida traditional fisheries as limited to FSC fisheries as described in DFO policies and fisheries management plans (IFMP 2022).

Haida traditional fisheries will not be limited by this rebuilding plan, and may occur in all areas of Haida Gwaii, subject to conservation. For management purposes, DFO sets an allocation level of 150 tons (136 tonnes) of herring for Haida FSC fisheries in the Major SAR, although this has not been agreed to by the Haida Nation. DFO does not recognize a Haida rights-based commercial fishery.

## 3.6 PROBABLE CAUSES OF DECLINE AND ISSUES THAT INFLUENCE RE-BUILDING

The many interacting environmental and anthropogenic factors that influence herring population dynamics, life stages, and ecological interactions make it challenging to definitively determine the underlying causes of herring population decline, continued low abundances of Haida Gwaii herring, and the specific role and relative importance of each contributing factor. However, based on current scientific and traditional knowledge, the potential causes likely include past commercial fisheries (e.g., during the reduction fishery period), oceanographic and climatic conditions causing changes such as prey quality and availability, predation pressure, Allee effects, and related effects on herring behaviour, recruitment, growth, and survival at different life stages, with many other potential ecosystem interactions. Less is known about the potential effects of competition, disease, invasive species, ocean condition change, and predator changes on herring populations. Although important in other parts of the BC coast, coastal development and habitat loss (e.g., loss or degradation of eelgrass and kelp) is not likely limiting the rebuilding of Haida Gwaii herring due to the remote and relatively undeveloped coastline where Haida Gwaii herring spawn.

As described above, management issues to address include governance systems, consideration of Haida traditional knowledge, variability in herring abundance and uncertainty in stock assessments, herring population dynamics including declines in herring size-at-age, identifying and accounting for spatial structure of stocks and migratory behaviour, and harvest rules including rebuilding targets.

Summaries of the key potential causes of decline in Haida Gwaii herring and related management issues are provided in the following sections and include:

- Herring predators (Sections 5.2.1.6.1 and 6.3)
- Herring prey (Section 5.2.1.6.3)
- Climate change and ocean conditions (Sections 5.2.1.7.1, 6.1 and 6.3)
- Commercial fisheries (Sections 5.2.3, 5.2.4, 6.1 and 6.2)
- Governance system and reconciliation (Section 5.2.5)
- Haida traditional knowledge (Section 5.2.2)
- Stock assessments (Sections 5.2.1.5, 6.1, and 6.2)
- Harvest rules (Sections 5.2.4, 6.1 and 7.1)
- Herring population dynamics (Section 5.2.1)
- Sub-stock structure (Section 5.2.1.2)
- Rebuilding targets (Sections 4.2, 7.1.2 and 7.1.3)

# 4 VISION AND OBJECTIVES FOR REBUILDING HAIDA GWAII HERRING

Overall, Haida Gwaii 'íináang | iinang *herring* have been depressed or at critically low levels over the past three decades, having cascading effects on the ecological and social systems that depend on 'íináang | iinang. Rebuilding the Haida Gwaii herring system will take time, and based on simulation results for Haida Gwaii from the MSE process, the probability of rebuilding within 15 years (three herring generations) is low given current trends in mortality and productivity (DFO 2020; discussed further in Section 6). Consequently, this rebuilding plan focuses on decision-making structures and processes with iterative management actions that would apply now and be further implemented if herring population trends and dynamics improve.

In this section, we provide a vision for a rebuilt Haida Gwaii herring ecosystem and ecosystem-based management approach to achieve that vision and define objectives for rebuilding Haida Gwaii herring.

## 4.1 VISION

A rebuilt Haida Gwaii 'íináang | iinang *herring* system is one where herring are plentiful, diverse, productive, and resilient in the face of climate, ocean, and social change. A rebuilt herring system would support successful annual traditional k'aaw *SOK* fisheries, present recreational fishing opportunities, and provide for a relatively consistent level of commercial fisheries while maintaining ecosystem needs. Herring would fulfill their role as a key element of a healthy and functioning ecosystem, including meeting Haida cultural, social, and economic needs (Box 5). Herring abundance, spatial distribution and population dynamics would be maintained in a healthy zone that supports ecological and human well-being. Applying a precautionary and adaptive management approach is a priority in order to account for dynamic and rapid climate, ocean, and social change.

> *Box 5. Where it's just like there is herring everywhere. It's consistently massive spawns, consistently seeing herring throughout the year. There's big salmon all over the place year-round, eagles are hanging around, the gulls are around year-round—like everything is just thriving, then you know it's in a good place.* (Judson Brown, 2016)

## 4.2 REBUILDING OBJECTIVES

Six overarching strategic objectives are defined to support the rebuilding of Haida Gwaii 'íináang | iinang *herring*. These objectives build on earlier collaborative work between DFO, CHN and Parks Canada for sea cucumber management that was approved by the Gwaii Haanas Archipelago Management Board and the CHN-DFO Cooperative Management Group. Use of the term 'Operational Objective' below is considered the equivalent of a 'Goal' in the DFO Management Strategy Evaluation process (more information on this process in Section 6.1). Given the Major SAR is unlikely to rebuild in the short-term (i.e., three herring generations (15 years)), some initial measurable objectives with performance metrics and timeframes are specified in Section 4.3, with additional measurable objectives to be added as implementation and work plans are developed and as Haida Gwaii herring begin to show signs of sustained rebuilding, as per the attributes, characteristics, and monitoring priorities identified in Table 4 and Table **25** to Table **29**.

### 4.2.1 Ecological Objectives

**Strategic Objective 1. Rebuild and conserve herring populations and protect their habitat to support related species and key ecosystem features and processes.**

Operational Objective 1.1. Rebuild and maintain natural productivity and spatial dynamics of herring populations to support ecosystem biodiversity at an appropriate scale.

Operational Objective 1.2. Incorporate uncertainties (such as climate change, habitat degradation, and food web alterations) and ecological risks of different fisheries (e.g., SOK vs. roe) into herring rebuilding to mitigate impacts.

Operational Objective 1.3. Increase opportunities to advance understanding of herring biology and ecology (e.g., ecosystem role of herring).

### 4.2.2 Cultural Objectives

**Strategic Objective 2. Sustain Haida traditional values and use of herring.**

Operational Objective 2.1. Foster Haida governance of traditional use and stewardship of herring on Haida Gwaii.

Operational Objective 2.2. Protect and maintain culturally important areas and other areas of concern for herring.

Operational Objective 2.3. Enable Haida traditional use of and cultural connections with herring, herring-related activities, and habitat.

### 4.2.3 Social and Economic Objectives

**Strategic Objective 3. Collaborate to increase local social and economic opportunities related to herring.**

Operational Objective 3.1. Increase local opportunities and participation in herring fisheries, and benefits from herring and herring fisheries to Haida Gwaii.

Operational Objective 3.2. Ensure sustainability of herring populations to support access for future generations.

Operational Objective 3.3. Increase economic benefits for Haida from herring fisheries-related activities.

Operational Objective 3.4. Foster economic viability of commercial herring fisheries.

### 4.2.4 Governance Objectives

**Strategic Objective 4. Achieve collaborative governance that provides stability, transparency, and predictability in herring fisheries management.**

Operational Objective 4.1. Support collaborative Haida-Canada process for herring rebuilding and fisheries management on Haida Gwaii, including the AMB process for Gwaii Haanas and other governance structures in place or as established.

Operational Objective 4.2. Increase collaborative work related to herring by employees and representatives of Gwaii Haanas partner organizations (CHN, DFO, and Parks Canada).

Operational Objective 4.3. Collaborate and coordinate on compliance and enforcement for herring fisheries.

### 4.2.5 Management Objectives

**Strategic Objective 5. Apply EBM principles and a collaboratively developed EBM framework to manage and assess impacts of herring fisheries.**

Operational Objective 5.1. Ensure use of the best available information to foster herring management that is sustainable, adaptive, ecosystem-based, and applied at appropriate spatial and temporal scales.

Operational Objective 5.2. Incorporate Haida traditional knowledge and recognize Haida laws in the herring management process.

Operational Objective 5.3. Foster collaborative long-term monitoring and research to assess ecological, cultural, social and economic effects of herring rebuilding, conservation and fisheries.

Operational Objective 5.4. Foster effective public engagement, including with stakeholders, in the herring fisheries management process.

Operational Objective 5.5. Foster safe operations in herring fisheries.

**Strategic Objective 6. Achieve successful fisheries in accordance with allocation priorities.**

Operational Objective 6.1. Manage fisheries to achieve priority of Haida traditional herring fishery after conservation.

Operational Objective 6.2. Manage fisheries to achieve successful commercial fisheries, including low-impact fisheries such as SOK during the rebuilding phase.

### 4.2.6 Measurable objectives

Using the strategic and operational objectives developed as part this plan (Section 4.2), several initial measurable objectives were identified to track progress towards rebuilding (Table 2). These measurable objectives are linked to performance metrics and timeframes, and are associated with management measures recommended in this plan (Section 7). Given that the MSE simulation analyses have indicated that the Haida Gwaii herring Major SAR is unlikely to rebuild over the short-term (three herring generations), these initial measurable objectives focus on rebuilding and maintaining natural productivity and spatial dynamics of herring populations, tracking social and economic contributions of herring fisheries to local Haida Gwaii and Haida communities, and supporting the prioritization and implementation of monitoring and research as they apply to all aspects of the Haida Gwaii 'íináang | iinang *herring* system. As work plans are developed and herring population conditions change, additional measurable objectives may be identified and included in updated MSE simulations as appropriate. The following ecological performance metrics addressing operational objectives 1.1 and 3.2 apply to the aggregate Haida Gwaii Major SAR only, with other measurable objectives applying to all parts of the Haida Gwaii herring system.

# 5 THE HAIDA GWAII HERRING ECOSYSTEM

The Haida Gwaii herring ecosystem is incredibly diverse and unique. In order to capture this diversity and support rebuilding, this plan takes into account interactions among a range of ecosystem components using an ecosystem-based management (EBM) approach. To implement an EBM approach, a conceptual model framework was developed for the Haida Gwaii herring ecosystem, based on the work of Levin et al. (2016). A review of this method and the initial work completed by Levin et al. (2016) is presented in Section 5.1. Section 5.2 expands the initial conceptual model to improve understanding of the Haida Gwaii herring ecosystem and address rebuilding objectives under ecological, cultural, social and economic, governance and management components (Sections 5.2.1 through 5.2.5). Section 5.3 further extends the conceptual model to identify characteristics of a rebuilt Haida Gwaii herring ecosystem.

## 5.1 ECOSYSTEM-BASED CONCEPTUAL MODEL

Conceptual models are a flexible way to describe systems that can incorporate multiple types and sources of knowledge, such as scientific, traditional and local knowledge. The conceptual model developed by Levin et al. (2016) describes several components of the Pacific Herring social-ecological system (SES; Figure 2, taken from Levin et al. 2016). This model frames the herring system in terms of key endpoints of herring and human well-being that encompass ecological, social, and economic outcomes that are influenced by system dynamics and potential management actions. The relationship between herring and human well-being was described in terms of the interactions among herring and major components of the SES including habitat, climate and ocean drivers, global economic and social drivers, Haida culture, human activities, governance, and management systems (Levin et al. 2016). A brief review of these elements and how they are connected in the Haida Gwaii 'íináang | iinang *herring* ecosystem is presented below.

### *Habitat*

Pacific Herring use a diverse range of coastal and offshore habitats, varying throughout their life cycle. In BC, the majority of herring occur as large schooling aggregations exhibiting seasonal migratory behaviour. Herring spawning mostly occurs in intertidal and shallow subtidal coastal inlets on kelp and other seaweeds, eelgrass, bedrock and other bottom substrates. Habitat and water quality in Haida Gwaii are generally good quality for herring spawning and rearing. Pollution is minimal except possibly sewage discharge in Skidegate and Masset Inlets. The extent of coastal development is small with limited impacts on most herring spawning areas that are associated with logging-related activities, harbours, and fishing lodge developments. Although habitat loss (e.g., loss of eelgrass) has been noted as a significant cause of herring population decline in other areas of BC (Frances and Lowry 2018), there is little evidence for this as a cause of decline on Haida Gwaii. Changes in spawning substrate type are thought to have relatively minor effects on herring egg mortality (Shelton et al. 2014), with lower mortality when eggs are in the mid-water (Keeling et al. 2017).

Kelp (e.g., **ngáal | ngaal** *giant kelp, Macrocystis pyrifera*) forests are important mid-water substrate for herring spawn in Haida Gwaii, and are likely at reduced levels following functional extirpation of sea otters by the early to mid-1800s, due to the maritime fur trade (Sloan and Dick

2012, Lee et al. 2016, 2018). The loss of this keystone species led to a shift in coastal ecosystems prior to industrial fishing. Without sea otter predation in the region sea urchin populations increased dramatically. Sea urchin grazing negatively impacts the distribution and abundance of kelps, which may also be exacerbated in recent years by warming sea water (e.g., Sloan 2004, Krumhansl et al. 2017).

Introduction and expansion of marine invasive species could have long-term effects on the quality of herring spawning habitat. The invasive European green crab was first discovered on Haida Gwaii in Skidegate Inlet in July 2020 and is considered in the early stages of invasion. In other places along the BC coast and elsewhere in the world, establishment of invasive green crabs has resulted in damage to and loss of eelgrass meadow habitat, which is an important spawning and potential rearing habitat for herring. Non-native invasive tunicates have also been found in several places around Haida Gwaii since 2015, mostly in and adjacent to areas of high marine vessel use (e.g., marinas, docks, communities) (L. Lee and S. Crawford, pers. comm.). Their potential impacts on survival of herring eggs to hatching remains unknown, but is likely to be minimal because the invasive tunicates currently known on Haida Gwaii are largely dormant during usual spring seawater temperatures and only reproduce at temperatures over 13°C. Although the impacts of these invasive species may not yet be measurable, long-term monitoring and research will be needed to understand their potential impacts on and connection to herring.

### *Climate and Ocean*

The effects of broad- (e.g., Pacific Decadal Oscillation and Northern Oscillation Index) and local-scale ocean conditions (e.g., ocean currents, temperature, prevailing winds, dissolved oxygen levels and pH) on the different life stages of herring are likely significant, yet not well understood. Marine heat waves and years of warmer than average sea water temperatures, such as ‘the Blob’ in 2014-16 and subsequent 2019-20 heat wave (Ross, Jackson and Hannah 2021), have likely changed the composition of zooplankton communities, which are prey for herring, from larger, lipid-rich northern copepod species to smaller and less lipid-rich southern species. Changes in ocean conditions are also causing range shifts in many marine species, including more frequent occurrence of more southern fish species in northern waters. These changes in marine food webs have widespread impacts on marine ecosystems and are potentially affecting herring through a variety of pathways (e.g., food supply, competition, predation pressure). Warmer waters are also associated with compressed timing of herring spawn and more frequent occurrence of fungal and/or bacterial mats covering herring eggs on Haida Gwaii in recent warmer years. Herring size-at-age has also decreased over the past three decades throughout the BC coast, and productivity of Haida Gwaii herring has been low over the past two decades; effects of climate change on ocean conditions are believed to be contributing factors (Schweigert et al. 2002, Hay et al. 2019). Cooler ocean temperatures are generally more favourable for herring production, therefore the trend in warming ocean temperature is likely detrimental to herring.

### *Human Activities*

Fishing continues to be the main human activity directly affecting herring in Haida Gwaii. Herring are a cultural keystone species for the Haida and provide important social, cultural and economic values and benefits. Although the traditional fishery occurs throughout Haida Gwaii, the focus is generally in Skidegate Inlet and the area from Selwyn Inlet south to Skincuttle Inlet (Box 6). Herring have sustained millennia-long traditional harvests (Shelton et al. 2014; McKechnie et al. 2014), supporting the Haida k'aaw fishery as a sustainable and comparatively low-impact part of the ecosystem.

In addition to the Haida traditional fishery, other fishing activities include the recreational fishery and commercial roe seine, some limited roe gillnet, and SOK fisheries. The Haida traditional fishery for k'aaw *herring SOK* is relatively small compared to historical commercial fisheries. Little is known about the amount of recreational fishing for Haida Gwaii herring, although the contemporary recreational catch is thought to be quite small for food and bait use. Commercial roe fisheries have been closed in the Major SAR since 2002. Most historical commercial roe fisheries have used seine nets, with gillnet fisheries occurring less frequently. Commercial herring SOK fisheries have been closed in the Major SAR since 2004. A few commercial SOK licenses have operated in the Minor SAR in recent years. Commercial SOK fisheries have mainly been closed ponds, with open ponding successful only in a few years when herring abundance was high. In the past, traditional gathering or ponding for traditional fishery harvest has occurred in the vicinity of commercial SOK ponds. Each of these fisheries has varying impacts on ecological, cultural and socio-economic components of the herring ecosystem that need to be considered, including impacts on herring, other fisheries and herring predators, the conditions that allow for successful fisheries, and the flow of benefits.

> *Box 6. … people used to go to Burnaby Narrows too. There used to be lots of k'aaw there. And when they start to spawn they don't allow anyone to row out that they excite the herring. They quit then. So they just leave it alone for a couple of days. (Jack Pollard, 1998)*
>
> *We used to set out buoys, we put a No-Go Zone, we'd set buoys out to make a boundary so people couldn't come in there and interfere in that natural process and possibly cause the herring—because if you bother them when they are spawning, it doesn't take much to cause them to stop spawning. And so we were very sensitive to that.* (Colin Richardson, 2016)

Shipping and vessel traffic has the potential to affect herring by way of physical disturbance, ocean noise, and potential marine spills of oil or other pollutants (Peng et al. 2015; Weilgart. 2018). Lack of knowledge about important rearing areas for Haida Gwaii herring make it difficult to assess the potential impacts on other potentially important habitat areas. Oil and other pollutant spills have potential to impact herring spawning areas and development of herring eggs and larvae, as well as potential effects on herring survival depending on the pollutant, timing, location, extent and duration of spills. Local vessel traffic on Haida Gwaii is generally limited to barges, tugs, fishing vessels, ferries, ecotourism charters, and small motor boats. Vessel traffic increases during the herring, salmon and other commercial fishery openings and during the ecotourism season.

***Society and Economy, including Haida Culture***

Herring have intrinsic value and are important for the well-being of coastal and marine ecosystems including people, seabirds, humpback and grey whales, salmon, eagles, sea lions, invertebrates and many more. Herring are important for Haida well-being (Box 7), including the following socio-cultural aspects of herring and k'aaw (M. Poe, pers. comm., 2017):

- Cultural continuity – a living Haida culture
- Food dimensions
- Opportunity to enjoy and experience places and marine environment
- Social connections and dynamics
- Traditional knowledge
- Commercial fishing
- Access to herring, k'aaw and their ecosystems

> *Box 7. It is a spiritual experience, to go out on the ocean and to be at one with the ocean and the food and the herring. And the silence of it all when you are done—sitting there. I am sure fishermen feel that when they go fishing out the west coast or wherever they go fishing.* (Barbara "Babs" Stevens, 2016)

- Governance

Many other people, particularly local Haida Gwaii residents, have connections to herring and ecosystems that contribute to human well-being. Protected areas and species also have value to the general public and visitors. Understanding the intrinsic and economic values of herring, k'aaw and herring roe fisheries to Haida and other local people is important to Haida Gwaii herring rebuilding.

***Governance and Management***

Governance is an important aspect of successful natural resource management, including the governance context of developing management plans and strategies. Failure to incorporate governance into management could lead to unexpected consequences when determining the risk of management choices, and mask the potential for undesirable social and ecological outcomes (Armitage et al. 2019). In general, Haida traditional fisheries have priority over commercial and recreational fisheries. The Haida assert a Haida commercial fishing right but this has not been agreed with Canada. Commercial SOK fisheries are managed using limited federal fishing licences that belong to Haida entities, Haida individual and other individuals or entities. Under current conditions, commercial seine and gillnet licences are required to fish in pools that are allocated a fixed roe herring quota for each pool. The cooperative role of the Haida Nation and Canada in management of fisheries is evolving. Cooperative governance of herring management including fisheries is part of the Haida Gwaii herring rebuilding plan.

Further details about these key components of the Haida Gwaii 'íináang | iinang *herring* ecosystem are described in Section 5.2. Characteristics of a rebuilt herring system including reference points for rebuilding are then described in Section 5.3.

## 5.2 CURRENT UNDERSTANDING OF THE HAIDA GWAII HERRING ECOSYSTEM

### 5.2.1 Ecology

Pacific Herring are a small mid-trophic level pelagic fish that play a key role in the marine ecosystem of Haida Gwaii (Box 8). Rebuilding herring populations in this area will require consideration of herring population dynamics and an understanding of the critical role herring play in ecosystem interactions under changing environmental conditions.

> *Box 8. Herring in my mind are the staple. If the herring go, the whole thing is going to collapse. They are absolutely crucial to the wellbeing of all those other resources that depend on them—whether they are humans, or sea lions, or spring salmon, or whatever it is—if we can't save that herring, we are in serious trouble.* (Colin Richardson, 2016)

With initiation of the Haida Gwaii herring rebuilding plan process, herring management discussions with DFO have shifted from focusing mainly on herring, to thinking more broadly about the impact of herring depletion on other species in the ecosystem (Jones 2000) and incorporating Haida traditional knowledge. Haida thinking about ecosystem relationships helped inform collaborative work with the University of British Columbia using ecosystem modelling (Ainsworth et al 2008; Pitcher et al 2016; Surma 2019) and Pacific Herring research of the Ocean Modelling Forum (MacCall et al. 2018; Punt et al. 2018; Voss et al. 2018; Armitage et al. 2019; Okamoto et al. 2019; https://oceanmodelingforum.org/working-groups/pacific-herring/). As well, Gwaii Haanas is currently developing an ecosystem-based management framework to evaluate fisheries sustainability that will include Haida traditional knowledge to guide fisheries management in Gwaii Haanas. While modelling to support this rebuilding plan focuses on herring response to environmental drivers, some of the analyses examined relationships between Haida Gwaii herring and other species (Section 6).

Several key ecological attributes have been identified as important to understand Haida Gwaii herring rebuilding, including spatial population structure, herring population size, productivity and condition, ecosystem health, climate and oceanographic conditions, and condition of herring spawning habitat.

#### 5.2.1.1 Habitat

Pacific Herring use a diversity of coastal and offshore habitats, varying throughout their life cycle from eggs to larvae, juveniles and adults. In BC, the majority of herring occur as large schooling aggregations exhibiting seasonal migratory behavior. Herring spawning mostly occurs in intertidal and shallow subtidal coastal waters on kelp and other seaweeds, eelgrass, bedrock and other bottom substrates, although deeper spawns down to 30 m have been reported on Haida Gwaii and elsewhere. Eggs hatch within three weeks and larvae are found largely in coastal nearshore areas. Once juveniles leave coastal habitats, little is known about their movements and distribution until they return to spawn along the coast, generally as 3-year old fish on Haida Gwaii. High juvenile abundance has been observed in locations such as the east coast of Gwaii Haanas and Skidegate Inlet during the fall and winter. Some Haida Gwaii herring are suspected to overwinter in Hecate Strait.

Spawning habitat and water quality in Haida Gwaii are generally in good condition and not thought to be limiting Haida Gwaii herring production. Persistent pollution is minimal, possibly from sewage discharge in Skidegate and Masset Inlets, and from on-going land-based leaching from past mining operations. Potential acute pollution from marine spills is an ongoing risk associated with marine vessel traffic. The extent of coastal development is small with limited impacts on most herring spawning areas that are associated with logging-related activities, harbours and fishing lodge developments. Little evidence of herring habitat loss (e.g., loss of eelgrass) has been noted on Haida Gwaii, although it can be a significant cause of herring population decline in other areas of BC (Francis and Lowry 2018). Changes in spawning substrate type are thought to have relatively minor effects on herring egg mortality (Shelton et al. 2014), with lower mortality when eggs are in the mid-water (Keeling et al. 2017).

Kelp are likely at reduced levels due to the loss of sea otters following the maritime fur trade. Reduced sea otter populations allowed their invertebrate prey, including grazing sea urchins, to increase dramatically in abundance. Sea urchin grazing negatively impacts the distribution and abundance of kelps, which may be exacerbated in more recent years by warming sea water, which also impacts kelp growth and recruitment (e.g., Sloan 2004, Krumhansl et al. 2017). Since 2015, sea star wasting disease, also associated with warming sea water (Harvell et al. 2019; Hamilton et al. 2021), may also be contributing to greater urchin abundance and increased grazing pressure on kelps (Burt et al. 2018). The recent natural return of sea otters to Haida Gwaii and their expected population growth and range expansion is expected to benefit nearshore habitats for herring. By foraging on urchins, sea otters can indirectly increase the abundance and depth of kelps (Watson and Estes 2011, Markel and Shurin 2015, Lee et al. 2016, 2018). Sea otter foraging activities have also been shown to increase the genetic diversity, biomass and resilience of eelgrass meadows (Hughes et al. 2013; Foster et al. 2021; Raymond et al. 2021), although their digging for clams may be reducing the extent of some eelgrass meadows in SE Alaska (Stephens et al. *in prep)*.

##### *5.2.1.1.1 Nearshore Habitat Conditions*

Local biogenic and physical site characteristics can influence different parts of the herring life cycle, including egg and juvenile survival. Eggs deposited on kelp in the middle of the water column receive more water circulation, less sedimentation, and possibly less predation, improving survival (Keeling et al. 2017). Historically, giant kelp (*Macrocystis pyrifera*) forests have provided this midwater substrate but contemporary kelp forests are likely reduced due to ecological extirpation of sea otters over a century ago (Sloan 2017, Keeling et al. 2017, Lee et al. 2016, 2018). In areas where re-introduced sea otters have grown and expanded in range, the areal extent of kelp increased 20-times, and the depth of kelp increased 4-times (Markel and Shurin 2015), generally increasing kelp abundance for herring spawning and rearing habitat. However, in Puget Sound, Washington, seabed characteristics and substrate type were experimentally found to have a relatively small effect on herring egg survival (Shelton et al. 2014), and giant kelp plants that have dense herring spawn tend to fall onto the substrate to lie on the bottom (L. Lee, pers. comm.) with unknown effects on herring egg survival.

#### 5.2.1.2 Spatial Structure of the Population

Herring are distributed throughout Haida Gwaii, with key spawning areas along all coasts. Many important spawning and harvesting locations were identified in interviews with Haida knowledge holders (further described in Appendix C). The locations identified by Haida coincide closely with DFO spawning location maps showing herring distribution in different management areas and sections (DFO 2021).

DFO currently uses five major and two minor geographical SARs in BC (Figure 3; DFO 2020), with the terms ‘Major’ and ‘Minor’ being used to describe relative differences in geographic distribution and abundance. The five Major SARs are Haida Gwaii, Prince Rupert District, Central Coast, Georgia Strait and West Coast Vancouver Island. The two Minor SARs are in Haida Gwaii (Area 2W) and the West Coast of Vancouver Island (Area 27). The boundaries for Major and Minor stocks attempt to capture the habitat range of relatively discrete migratory herring populations and are based on historical records of commercial catch and spawning locations. Each DFO SAR is comprised of several management ‘Statistical Areas’ that are further broken down into herring ‘Sections’ and then specific spawning ‘Locations’.

Heterogeneity in the distribution of herring within a SAR has been identified by Haida traditional knowledge and several studies examining stock structure through a variety of tagging and genetic methods. However, the degree to and spatial scale at which herring populations and sub-populations, or stocks and sub-stocks, return to spawn, is unknown. The mechanisms by which spatial structure occurs, such as the potential role of older fish leading younger fish (MacCall et al. 2018) and/or other herring behaviours, are also unknown. Some Haida reflected on the differences among herring populations in Haida Gwaii. Prior to population declines in the 1960s, especially large herring were known to be at Louscoone, Selwyn, Cumshewa and Skidegate Inlets (Figure 4). Several noted that even in times of abundance, herring in Naden Harbour tended to be smaller. Several Haida noted herring’s homing behaviour to spawning grounds and that different groups of herring can spawn in the same location. For example, Selwyn Inlet was described as having two different groups, with separate spawn times and sizes: one in February and one in late March/early April (Box 9).

*Box 9. (Selwyn.) Totally two different batches—that early one was getting big, I ended up getting it one year—it was just before they shut the islands down. […] We ran into some herring and dad was jigging them up and sounding on a great-big school and they were all real fat and full. (Conrad Collinson, 2016)*

Previous tagging studies suggested that herring generally return to the same large geographic region each year, but that they may not home to the same spawning beach or bay each year (Hay et al., 2001; Flostrand et al., 2009), leading to theories about mixing between the populations within each region. Beginning in the 1930s, BC Pacific Herring have been the subject of three tag-recovery studies. The first study employed internal belly tags (1936–1967), the second external anchor tags (1979–1992), and the third internal coded wire tags (1999–2006). The most recent analysis of data collected from the coded wire tag program indicated a wide range in fidelity across regions, from 53-90% (Flostrand et al., 2009), consistent with previous findings by Stevenson (1954), Hourston (1982), Ware et al. (2000), Hay et al. (2001), and Ware and Schweigert (2001).

Earlier genetic analyses by Beacham et al. (2008) examined genetic population structure of Pacific Herring in BC and adjacent regions using microsatellite variation. This research identified four stocks of Pacific Herring in BC (BC primary spawners, Southern BC late spawners, Northern BC late spawners, Mainland Inlet spawners), as well as genetically-distinct stocks in southeast Alaska, Washington, and California. These genetic studies also indicated genetic differentiation between Skidegate Inlet, Masset Inlet, and other Haida Gwaii herring populations (Beacham et al. 2008). In BC, differences in timing of spawning was identified as the main isolating mechanism among stocks. For example, Skidegate Inlet herring tend to spawn later in April than the Haida Gwaii Major SAR herring, and Masset Inlet herring tend to spawn even later in June and July. It is also recognized that geographic isolation of spawning populations may have some effect on genetic distinctiveness among populations.

> *Box 10. … herring comes back to certain areas to spawn… so what the Fisheries … were telling the fishermen is that they would preserve this stock over here and let the fisheries go into one area. And the fishermen would clean up… that whole bay, and the herring went back to that particular bay to spawn, and the Fisheries would open that area, and the fishermen would clean out that herring … and no herring would go back there … then they would move on to another area and do the same thing. Put a whole bunch of boats into a small area and they would clean up… the herring that's supposed to return to spawn*. (Reynold Russ, 2007)

Recent analyses that examined more spawning locations throughout BC and Washington indicated genetic differences on a finer scale than those identified in previous genetic studies (Petrou et al. 2021) and observed that differences were again tied to spawn timing. Haida traditional knowledge is also consistent with the more recent genetic studies that have identified potential finer-scale genetic structure based on spawn timing and geographic separation (Petrou et al 2021). While presence of genetic differentiation would provide evidence of low migration rates, the utility of genetic analyses is somewhat limited for the present context, since even small amounts of migration would be enough to result in apparent genetic homogeneity (Balloux and Lugon-Moulin 2002, Waples 1998). Much higher migration rates can still lead to demographic variation that affects trajectories of recovery and depletion in space. As a result, ignoring fine-scale spatial dynamics even in the face of modest migration can lead to erroneous expectations of homogeneity and resilience (Okamoto et al. 2020) and potentially bias estimates of population dynamics (Rogers et al. 2019, Punt et al. 2018, MacCall et al. 2018).

Many Haida assert that herring populations in different areas are distinct and should be managed as such, not at the large aggregated geographic scale of current management (HMTK 2011 and Box 10). Spatially refined management can direct attention to key areas of herring activity and could be supported by monitoring and protection of local sub-stocks, if required.

#### 5.2.1.3 Spatial Structure for Rebuilding

The TWG acknowledged the need for finer spatial scale management to support rebuilding of herring stocks in Haida Gwaii which led to the identification of sub-stock populations within the Major and Minor Haida Gwaii SARs for the rebuilding plan, based on Haida traditional knowledge, genetic studies noted above, distribution of herring spawn (Figure 4 and Figure 5; Appendix D), as well as differences in relative abundance and spawn timing. The DFO monitoring and data collection programs for Haida Gwaii herring were separated into geographic management 'Sections' and the sub-stocks were identified by individual or combined sections. Some sub-stocks reflect individual sections and others are made up of multiple sections primarily based on ecological considerations, modelling considerations and management of commercial fisheries.

The Major SAR of Haida Gwaii was divided into three sub-stocks, with approximately 80% of the annual herring spawning occurring in Juan Perez/Skincuttle and 10% in each of the other two sub-stocks (Figure 6):

- Cumshewa/Selwyn (C/S; DFO management sections 23 and 24)
- Juan Perez/Skincuttle (JP/S; DFO management sections 21 and 25)
- Louscoone Inlet (Lou; DFO management section 6)

The Minor SAR of Haida Gwaii was divided into five sub-stocks, with the latter two sub-stocks not recommended to be commercially fished due to significant data gaps:

- Port Louis (DFO management section 2)
- Rennell Sound (DFO management section 3)
- Englefield Bay (DFO management section 5)
- Skidegate Channel (DFO management section 4)
- Tasu Sound (DFO management section 1)

Several additional areas of Haida Gwaii have been identified as culturally important with geographically distinct herring populations. These areas also supported commercial fisheries in the past but have not been commercially fished in recent decades due to limited data and/or sustainability concerns:

- Naden Harbour (DFO management section 12)
- Masset Inlet (DFO management section 11)
- Skidegate Inlet (DFO management section 22)

For the purposes of this plan, current and future MSE analyses and other herring management investigations, the data are summarized at these finer spatial sub-stock scales. Knowledge of how distinct herring sub-stocks are and how much mixing may or may not occur between them are critical to a precautionary approach to rebuilding herring throughout Haida Gwaii.

#### 5.2.1.4 Population Status and Trends

Pacific Herring population abundance is dynamic on both large and small geographic scales. It is thought to be primarily driven by environmental changes that affect herring productivity, growth, recruitment, and mortality (Checkley et al., 2009; Peck et al., 2014; Trochta et al., 2020). Abundance of Haida Gwaii herring populations has also been heavily influenced by historical fishing activities (Trochta et al., 2020). Haida knowledge holders have described changes in herring spawns and predator abundance in several key areas of Haida Gwaii, including **K'iid Xyangs K'iidaay** *briefly known as Burnaby Narrows*[5] and Skidegate Inlet (Box 11). These types of observations are valuable in trying to recreate a picture of ecosystems before the onset of industrial fishing and changes to the ecosystem (Box 12).

> *Box 11. But I know that there were millions of tons of fish, because when they started moving through Burnaby Narrows it sounded like a big rainfall or something, at nighttime going through the Narrows. And then the sea lions and the killer whales right with them too. Hear the sea lions roaring all night going through the Narrows after the herring. When we go looking for k'aaw in the spring there's not nearly as much spawn [now]. And a few sea lions, maybe 20 or 30 sea lions passing through. But seals getting abundant every year. All along the beach here there are seals everywhere out here when the herring come into the inlet* (Percy Williams, 1998)
>
> *There used to be a lot of sea lion. Even k'yaaluu – cormorants. There used to be lots on both Islands (near Skidegate village). In the evenings you'd hear them. You'd hear them plainly. You don't see them now. No feed for them. No herring. Grey cod and tommy cods, they're edible but they're not there now. Soles, that's gradually disappearing too. We used to go out there and get lots, rowing just outside of Balance Rock. I've tried it a number of times in the past lately.* (Ernie Wilson, 1998)

> *Box 12. There's stories of Scudder Point for instance, where the old people used to say that after the spawning was over the eggs on the beach were as high as a human walking on the beach (Colin Richardson, 2016).*

As described in Jones (2000), changes in whale, sea lion, seal and seabird distribution may be either local effects or signs of longer-term trends. Grey whales began appearing in Skidegate Inlet in the late 1970s after decades of absence, and their presence in feeding and foraging activities disturb herring spawn. Traditional knowledge can also provide observations about historic fishing activities. For example, during the 1950s a large mobile fleet was fishing herring, locating schools with hydroacoustic depth sounders and using mercury lights to attract fish at night. Haida elders Ernie Wilson and Dempsey Collinson recalled this fishery occurring in Skidegate Inlet, describing the night fleet as looking like a "city of lights" on the water.

Haida Gwaii herring population status and trends are described below at the aggregate level for the Major and Minor SARs, as well as at the sub-stock level as defined in Section 5.5.2.1.3 where information is available. The status of each SAR and sub-stock has been assessed differently due to availability and quality of scientific data and availability of Haida traditional knowledge. For example, the formal stock assessment model is presently only applied to data rich areas such as the aggregate Major SAR. For the Minor SAR and sub-stocks with an annual spawn survey, a spawn index estimate is used to assess stock status. This plan relies on local Haida traditional knowledge to inform population status for other sub-stocks (Masset Inlet, Skidegate Inlet, Naden Harbour). Herring population status and trends have also differed likely because of different past management approaches and/or ecological and environmental influences on productivity in different areas.

The current assumption is that the spawn survey data is representative of the total actual extent of herring spawn distribution. For the Major SAR, spawn survey information currently includes:

[5] K'iid Xyangs K'iidaay is one of twelve Haida Gwaii place names to be formally restored in partnership with the CHN and BC Geographical Names Board. GIVING BACK NAMES | Council of the Haida Nation.

- Spawn timing: Start and end dates of each surveyed spawn event (spawn number) per year (Figure 7);
- Spawn duration: Total number of days each surveyed spawn event lasted each year. (Figure 8);
- Spawn amount per spawn event: Spawn index amount (t) for each surveyed spawn event per year (Figure 9);
- Annual spawn frequency: Total number of surveyed spawn events per year (Figure 10); and
- Spawn proportion by week: The proportion of the spawn index amount that occurred in each week of the year (Figure 11).

Further analyses and monitoring are needed to identify changes over time in spawn distribution and spawn timing throughout the Major and Minor SARs at the aggregate and sub-stock scales.

##### *5.2.1.4.1 Major Haida Gwaii stock assessment region*

Haida traditional knowledge and scientific knowledge both indicate that herring abundance and productivity were historically quite high in the Major SAR of Haida Gwaii compared to what is seen today (DFO 2020; Appendix C). The 2020 DFO assessment of the aggregate Major SAR population indicated that since the year 2000, the population has primarily been in a low biomass state, and until recently, below the LRP (30% of unfished spawning biomass; Figure 12). Most of these years also showed low productivity, which has precluded any significant population growth in this area (Figure 12; DFO 2020). In 2019 and 2020, the spawn survey index indicated an increase in abundance, estimates of age-2 recruitment were above average, and there was evidence of positive production. However, spawning biomass estimates in this area remain low relative to historical abundances and are below the incremental target (50% of unfished spawning biomass) despite the absence of commercial herring fisheries since 2005 (DFO 2020).

The Major SAR is assessed annually as an aggregate population using a statistical catch-at-age structured analysis that provides estimates for reference points and stock parameters, as well as other outputs (e.g., stock-recruitment relationships, reconstructed time series of spawning biomass, natural mortality and effective harvest rates) that are used to inform stock status (Cleary et al. 2019). Biological (numbers and size at age; Figure 13 and Figure 14) and catch data (Figure 15) are included in the model to incorporate growth and impacts of harvest on the population. Spawn surveys are conducted annually in the Major SAR at individual spawning locations using either surface or dive survey methods. A summary of spawn abundance from the last decade (2009-20) is shown in Figure 12a. Spawn surveys are conducted to estimate the spawn length, width, number of egg layers, and substrate type, and these data are used to estimate the relative index of spawning biomass (Grinnell et al. *In prep.*). In the stock assessment, the spawn index data is scaled to abundance by dividing the index value by an estimated scaling parameter, $q$. The aggregate assessment from 2020 estimates $q$ for the surface survey period (years 1951-1987) at 0.41 (5-95% range: 0.33-0.50; DFO 2020). For the dive survey period (years 1988-2020), $q$ is fixed at 1.0, which assumes that all spawn each year is observed by the survey.

The biological, catch and spawn index data for the Major SAR aggregate population can be disaggregated into the three sub-stock populations: Cumshewa/Selwyn, Juan Perez/Skincuttle, and Louscoone (Figure 16, Figure 17 and Figure 18). As part of rebuilding plan analyses, an attempt was made to estimate spawning biomass for each of these sub-stocks using the statistical catch-at-age model (Cleary et al. 2019); however, convergence of this model was only successful for the Juan Perez/Skincuttle sub-stock where 80% of the existing data is from. Instead, a time series of scaled abundance for each of the sub-stocks are presented in Figure

18, where survey indices by sub-stock were scaled using *q* estimated for the aggregate stock. Based on this data, all three sub-stocks show similar trends of decreased abundance over several decades and a lack of recovery despite the absence of fishing.

#### *5.2.1.4.2 Minor Haida Gwaii stock assessment region*

For approximately a decade, the Minor SAR of Haida Gwaii was assessed annually as an aggregate population by DFO using the same statistical catch-at-age analysis as the Major SAR (DFO 2016). In 2017, this analysis was discontinued due to data limitations and inconsistencies in monitoring and survey resources. Although spawn survey information has been collected in the Minor SAR since 1978, there were no spawn survey observations in 1995-1997 and 1999 due to limited spawn and/or lack of available resources and, in 2015, due to weather. In 1994, a roe seine fishery in the minor SAR was unable to catch a 1000t quota that was set based on the previous year's soundings, which was followed by a prolonged period of low biomass in the region. The majority of the spawn surveys that have been conducted in the Minor SAR were done by surface survey rather than by dive survey, which is thought to be a less accurate representation of the magnitude of a spawning event. Biological samples in the Minor SAR are collected from the annual test charter program and opportunistically from commercial SOK operations. The number of biological samples collected in this area has decreased slightly over the past decade due to limited monitoring resources (see Section 3.4.2). Recent survey effort has also been affected by a reduction in available resources and survey time (about a week), and are now largely focused in the northwest part of the Minor SAR, primarily Port Louis/Port Chanal and Seal Inlet/Rennell Sound/Kano Inlet (Figure 4 and Figure 19).

> *Box 13. It was pretty healthy, especially down in Port Louis […] I would set in there, and you get small fish and big fish mixed. We didn't get the real thick product out of it—and you know that's from fishing it too—you get different batches hanging out together after the stocks get smaller. [Juveniles] hanging out with the big ones. We operated in there and Port Chanel—Port Chanel's got a run in there too, and that one was pretty healthy—I was getting on good sets, made quite a few sets in there.* (Conrad Collinson, 2016)

Assessment of population status in the Minor SAR is limited to exploration of trends in the time series of spawn index information, spawn distribution and timing, commercial catches, and biological data including length and weight-at-age (Figure 20) and proportion-at-age. Port Louis, Rennell Sound and Englefield Bay were the main areas contributing to the spawn (Box 13). The most recent survey information for the Minor SAR showed an increase in spawning biomass in 2019 and 2020 compared to recent years where these observations occurred primarily in Port Louis (DFO 2021). Abundance of herring in some areas of the Minor SAR have declined substantially from historical levels (Box 14).

> *Box 14. There used to be a lot of herring there (Rennell Sound). See k'aaw drift up on the beaches; it used to be just piled up on the beach, like that. A foot or two high, piled up on the beach and way up the head… the eggs, yeah, the k'aaw. Even Dawson Harbour used to have a fairly good spawn. And that doesn't happen very much anymore. And Skidegate Narrows—on this side of Skidegate Narrows—there used to be spawn there. We used to get k'aaw there but not anymore… that was in March—late March or early April.* (Percy Williams,1998, HMTK 2011)

#### *5.2.1.4.3 Skidegate Inlet, Masset Inlet and Naden Harbour*

Although understanding the biological basis of distinct Pacific Herring populations is still evolving, several smaller, distinct sub-populations have been identified in the Haida Gwaii area including Skidegate Inlet, Masset Inlet and Naden Harbour (for more detail, see Appendix B, available on request). In the 1950s, Skidegate Inlet was identified as one of nine major herring populations in BC (Taylor 1964); the abundance has declined and is now similar to what is seen in some of the sub-stocks in the Minor SAR. Skidegate Inlet is adjacent to the north end of the Major SAR (Figure 4) and is recognized as an important area for k'aaw (traditional SOK) harvest due to its proximity for harvest by people in Skidegate (HMTK 2011). The Skidegate Inlet herring population was heavily impacted by the commercial reduction fishery that operated in the area until the fishery was closed coastwide in 1967-68 because of BC herring population collapse (Box 15).

> *Box 15. … there was such an abundance of [k'aaw] at the time, right out here {Skidegate Inlet], at the islands. But the past few years there hasn't been much … since that reduction wiped us out here, there was hardly any herring after that. But that's what we used to do out here—get enough roe on kelp for the winter, right out here … Everybody went out and loaded up.* (Dempsey Collinson, 1998, HMTK 2011)

No formal assessments are currently conducted on these sub-stocks, however herring fisheries catches in these areas have been recorded and spawn survey data has been collected opportunistically over the years (Figure 21). Northern Haida Gwaii has some of the earliest and latest herring spawning populations (Figure 22). Herring typically spawn in eelgrass in Naden Harbour between February and May, while those in Masset Inlet typically spawn later in June/July (HMTK 2011). The herring spawns of southern Masset Inlet provide an opportunity for the people of Masset to harvest SOK due to their close proximity to this area (HMTK 2011). Herring spawning events are distributed throughout the southern portion of Masset Inlet with larger spawn historically noted in Shannon Bay and off the mouth of the Awun River (HMTK 2011).

#### 5.2.1.5 Population Dynamics

Population dynamics are important drivers of the potential for fish stocks to rebuild from low abundance, although the specific attributes that contribute to the depressed condition of any particular fish population can be highly variable and largely unknown. Rebuilding of longer-lived, late maturing fish tends to take longer and be more challenging than shorter-lived, earlier maturing fish like herring; however, as evident in the case of Haida Gwaii herring, population rebuilding can still be challenging. The population dynamics of Pacific Herring have changed over recent decades including a reduction in size-at-age for all BC herring including Haida Gwaii, yet direct causes driving these observed changes remains unknown. Juvenile recruitment is also highly variable year-to-year, dependent on food availability, predation, environmental conditions, and competition that can be affected even by the number of juvenile herring and the number of egg layers deposited during spawning at each place. Additional monitoring, analyses, and dedicated effort in the context of this rebuilding plan will be beneficial to understand implications of population dynamics on the rebuilding potential of Haida Gwaii herring.

##### *5.2.1.5.1 Maturity, Age and Size Structure*

In northern BC, herring recruit to the spawning stock and are sexually mature predominantly at ages three or four with very few, if any, two-year-old recruits spawning (Taylor 1964). For Haida Gwaii, young-of-year herring appear to begin migrating offshore at the end of their first summer (Hourston and Haegele 1980). Pacific Herring are iteroparous and return to spawn each year after reaching maturity. Each female produces about 20-40,000 eggs and quite consistently about 100 eggs/g of female weight, with larger females producing more eggs than smaller or younger females (Hourston and Haegele 1980; Hay 1985). This species also has a relatively early age of sexual maturity and high rates of intrinsic population growth, which should make them resilient to large mortality events (Sadovy 2001, Hay 2019, Sanchez 2020). However, if age and size structure are altered (e.g., mortality concentrated mainly on older larger-sized fish cohorts and/or environmental conditions drastically changing), this can alter the spawning biology in terms of the relationship between age-at-maturity, fecundity, and egg viability

(Hutchings, 2000; Hixon et al., 2014, Hay et al 2019), and potentially spawning behaviour (e.g., inexperienced young fish, spot spawning, spawning in less suitable locations). Mortality focused on older and larger fish can also lead to genetic selection for smaller size-at-age within a population (Allendorf and Hard 2009). The loss of diversity in age and size-at-age structure can also be linked to lower resilience of herring populations to regimes shifts or large fluctuations in environmental conditions (Petrou et al. 2021). Additionally, if changes in age and size structure are the result of systemic ecosystem changes this may lead to biased estimates of future productivity and biomass that are based on historical trends.

Number, and size-at-age data are collected annually for all Major SARs in support of annual stock assessment (DFO, 2020). A seine test charter vessel funded by DFO is used to collect biological samples from main bodies of herring within the Major and Minor SARs of Haida Gwaii. The biological data collected annually include observed proportion, and number, weight, and length-at-age (DFO 2020). Samples from commercial fisheries are also included when and where available.

Trends in the size-at-age data have shown that all Major SARs in BC, including Haida Gwaii, have exhibited a decline in weight and length-at-age starting in the late 1970s until approximately 2010 when a slight increasing trend appeared to have begun through to the present (Figure 14; DFO 2020). Similar size structure trends have been observed at the sub-stock scale within the Major SAR as well as in the Minor SAR (Figure 16, Figure 20 and Figure 23). Declines in size-at-age can also be seen in a number of other herring populations including those in California (Therriault et al. 2009; Hay et al. 2012), Southeast Alaska (Hay et al. 2011; Cleary and Schweigert 2011), the Atlantic (Wheeler et al., 2009) and the Baltic (Rajasilta et al. 2015). Similar trends have been described for other commercial fish species as well, such as Pacific hake (*Merluccius productus*, King and McFarlane 2006), rockfishes (*Sebastes* genus, McGreer and Frid 2017) and halibut (*Hippoglossus stenolepis*, IPHC 2015). The synchronous decline in herring size-at-age coastwide and the lack of direct relationship to fishing pressure suggests these changes are not primarily driven by size-selective harvest. A number of other mechanisms have been identified that could also be contributing to the observed declines, including climate change effects, such as changes in zooplankton composition, sea surface temperatures, and pH levels of coastal waters, which can potentially lead to increased metabolic costs, and subsequent reduction of energy available for growth (Baudron et al. 2014).

#### *5.2.1.5.2 Juvenile Recruitment*

Pacific Herring spawner-recruit relationships indicate that herring recruitment is either strongly density-dependent and/or shaped by environmental variation (Zheng 1996). Density-dependence varies among forage fish species and operates at different life stages. For Pacific Herring, egg survival to larval hatching is strongly affected by egg density because of low oxygen conditions that occur at ≥8 layers of eggs on the spawning substrate (Taylor 1971). In Puget Sound, Washington, size of age-0 herring was predicted by herring abundance in the fall, but not in the spring, suggesting that newly hatched herring only show density-dependence after some months of growth (Reum et al. 2013). There is also some evidence in the Strait of Georgia for density-dependent growth: as herring spawning biomass increased, age-0 herring abundance increased but their body condition decreased (Boldt et al. 2018). The onset of this density-dependent growth may correspond to mid-summer habitat shifts from coastal inlets to pelagic habitats by young-of-year (YOY) herring, a process which may also be density-dependent and/or influenced by increasing intra- and inter-specific competition.

In the first few months of life, variation in juvenile herring mortality shaped by food availability and predation also affects recruitment success. For example, in the Strait of Georgia, low YOY herring abundance in September was generally followed by low recruitment of age-3 herring

(Schweigert et al. 2009; Boldt et al. 2018), and variation in fall abundance of YOY herring was associated with timing of herring spawn relative to the peak of plankton abundance that spring (Schweigert et al. 2013; Boldt et al. 2018). Survival of YOY herring in their first winter was also a major determinant of herring abundance in later year-classes (Sewall et al. 2019). In Prince William Sound, herring <75 mm in length by the onset of winter continue to grow in structural biomass, while larger herring can divert more energy to production of lipid energy storage (ibid). During the winter, herring that are actively growing may need to forage more, which could increase their vulnerability to predation; the potential benefit in the spring is that larger herring were more able to obtain higher quality euphausiid prey (ibid). Reduction in herring size-at-age over recent decades may be contributing to continuing low herring abundances, highlighting the importance of considering herring size-at-age and associated energetic trade-offs in management and population rebuilding.

#### 5.2.1.6 Other Species Interactions and Effects on Herring

Haida traditional knowledge of ecosystem health and species interactions highlights important connections between herring and other components of coastal and marine ecosystems, and can help re-create a picture of these ecosystems before the onset of industrial fishing (Jones 2000). A variety of different field, monitoring, laboratory, and modelling studies have more recently explored and compared the effects of different drivers of herring recruitment, survival, growth, and abundance, showing correlations between herring population dynamics and possible important factors on multiple spatial and temporal scales (Beamish et al. 2012, Sewall et al. 2021, Tanasichuk 2017, Ward et al. 2017). These studies and Haida traditional knowledge show that herring and their predators likely exert strong effects on one another’s abundance and distribution, that herring are strongly impacted by availability and amount of prey, and that physical environmental drivers also strongly affect herring, likely through impacts on herring prey.

### *5.2.1.6.1 Herring Predator Interactions*

Arrival of herring to spawn in spring is signaled by the arrival and congregation of many other species, making their presence predictable (Box 16). Sea lions, seabirds, whales, dolphins and many other sea creatures are drawn into the area during herring aggregation and spawning. Percy Williams observed that seabird nesting in Alliford Bay coincides with the timing of herring coming into Skidegate Inlet (HMTK 2011). Fishermen know to look for seagulls, cormorants, eagles and many other species when fishing herring. However, with the significant declines in Haida Gwaii herring populations, the number of predators coming in to prey on herring has likewise decreased.

> *Box 16. I remember seeing…you know, so many birds. Uncle Rufus, he'd see all the birds and say, 'You can't fool the birds.' When it came to the herring, eh? Then you'd see the whole shoreline would be white with the males' milt … miles of shoreline would appear white, like someone dumped cans of cream in there, and lots of it…* (Monte Stewart-Burton, 2007)
>
> *I think it takes so long for the herring to come back. And there's a lot of fish that eat that herring for survival. They don't think of that. There's spring salmon, cod, the whales. It is all food for them too. It's their food chain.* (James Young, 1998)
>
> *… [you get] lings, snappers, everything. You see everybody that did the roe on kelp down here, and guys that came down would all food-gather around here for their bottom fish … [it] usually … starts getting thick around the herring time, too. Halibut too, they move in… I think the spawns and everything drag them in. They get that smell… little halibut move in there. I imagine when the herring are spawning on the bottom … they do a lot of spawning in the deep too… and I think that's when the halibut get them … when they're letting go in the deep. The halibut just sit there and wait… feast on them.* (Conrad Collinson, Oct. 2008)

As a forage species, Pacific Herring play a key role in marine ecosystems throughout their life stages and are a food source for a diversity of species, ranging from jellyfishes to fishes to marine mammals (e.g., Ainsworth et al. 2008; Schweigert et al. 2010; Pitcher et al. 2016). Due to the multiple and diverse predators that eat herring at all stages of their life cycle, changes in predator diversity, population abundance, size and overall biomass, and timing, have the potential to affect herring population dynamics and potentially cause population declines (Surma et al. 2018; Godefroid et al. 2019). In recent decades, predation of herring larvae in nearshore spawning areas may be increasing due to populations of sea jellies which are now blooming earlier in the spring when herring are hatching; some jelly species can consume up to 95% of herring larvae at a single spawning site (Salish Sea Pacific Herring Assessment and Strategy Team 2018; Emry, unpublished data).

Studies have found that the abundance of predatory fish such as hake are associated with decreased herring recruitment or biomass in BC and elsewhere (Dreyfus-León and Chen 2007; Godefroid et al. 2019). Different predatory fish can have different site-specific effects, explaining some variation in herring abundance and distribution (Godefroid et al. 2019, Tanasichuk 2017). For example, Pacific cod are common in Hecate Strait and their abundance is negatively correlated with herring recruit abundance in Haida Gwaii (Tanasichuk 2017). Herring and other forage fish make up >25% of most piscivorous fish species' diets in Hecate Strait, although groundfish abundance is likely much reduced from historical levels (Pearsall and Fargo 2007). Hake, sablefish, and Pacific cod have been estimated to consume 29-54% of adult herring in the WCVI region (Ware and McFarlane 1986; Ware and McFarlane 1995), although the percentage may shift with fishing pressure, herring productivity, and/or abundance of predators. In Hecate Strait, the piscivores that rely on herring for the largest proportion of their diet are petrale sole, dogfish, arrowtooth flounder, and Pacific cod (Pearsall and Fargo 2007).

Herring fisheries often target the same age- and size-classes as many of their larger predators, and therefore are likely to also have an effect on predator populations. Even at lower levels of fishing, potential negative effects on herring include decreased stability in herring population growth parameters, sensitivity to bottom-up environmental effects, loss of demographic buffering by older individuals including migration route learning, increased metapopulation synchrony, and extirpation of individual sub-stocks at the small spatial and temporal scales at which many predators feed on herring (Pikitch et al. 2018; Anderson et al 2008; Shelton and Mangel 2011; Cameron et al. 2016; MacCall et al. 2018; Rogers et al 2018; Okamoto et al. 2020). Predators may be equally or more sensitive to distribution patterns of their herring prey (and the changes to this caused by local extirpations) than to region-wide prey abundance, given the small spatial scales on which many of them forage. Even fairly mobile predators such as Harlequin ducks limit how far they will travel from their wintering grounds to eat herring (Rodway et al. 2003).

Marine mammal and bird predation are likely significant (Box 17) but data often does not exist at the same local spatial and temporal scales as herring populations or specific to different parts of the herring life cycle. This mismatch in scale of data and sampling causes challenges in linking changes in predator populations to changes in herring populations (Trochta et al. 2020), particularly the specific role of large and/or wide-ranging predators such as cetaceans, pinnipeds and marine birds, in the decline and continued low abundance of Haida Gwaii herring. One study using time series data showed that humpback whale abundance may negatively affect the number of herring recruits in Haida Gwaii (Tanasichuk 2017). Another study in the Gulf of Alaska showed that humpback whale predation can have top-down effects on herring abundance; however, the relative importance compared to other environmental variables varied across sites and predation did not appear to be the main factor limiting herring population recovery (Moran et al. 2018).

> *Box 17. So one time I was asking my mum why they named Second Beach Kay. You know them rocks on this side? Along the highway? They used to be just covered with sea lions all the time—that's before the highway was put in—especially at this time of year when the herring start to come in, the sea lions used to come in and they used to just stay on the rocks there, where it's nice and handy to go in after the herring.* (Harvey Williams, 2007)
>
> *…especially in the roe on kelp…we started running into whales, I'd say in '98. And sometimes when we're through and we're heading south with our product, out in Hecate Strait …you could see whales as far as the eye could see. But not in the inlets; they were …out in the Hecate Strait. And I don't know if they eventually ended up in the inlets, but … that would be in the end of March, the early part of April … I would imagine [they were] feeding. I imagine … if the herring were in that volume in the inlets, they were probably out in the ocean also…* (Gary Russ, 2007)
>
> *There used to be a lot of sea lions, even the… k'yaaluu, cormorants. Yeah. There used to be lots on both islands. In the evening you would hear them—oohwoowoo, ohwoowoo—you could hear them plain as that. You don't see them now. No feed for them.* (Ernie Wilson, 1998)

Ecosystem models incorporating realistic diet proportions and mass-balance between predators and prey also show that predators can play a role in driving herring abundance (Ainsworth et al. 2008; Tanasichuk 2017; Surma et al. 2018). In Haida Gwaii, harbour seals are recovering from previous low abundances due to hunting and although they do eat herring, they may be more likely to feed on herring predators (Kumar et al. 2016), and therefore may reduce overall predation on herring. Using an ecosystem model, EcoPath with EcoSim (EwE), that looked at effects of herring on their predators and prey (Kumar et al. 2016; Pitcher et al. 2018; Surma 2019), predation effects were not able to fully explain herring declines and lack of recovery of Haida Gwaii herring (Surma 2019). The abundance of predators may also be positively correlated with herring biomass in space and time due to bottom-up or environmental effects that benefit both herring and their predators. Overall, differences in the scale of data collected for herring and their large predators, and the complex and intertwined interactions between species at different life stages, makes it difficult to directly link changes in place-based herring populations to overall changes in the population of specific and often highly mobile predators.

Although difficult to verify for specific places along the coast, in general, evidence suggests that herring maintained higher, but possibly just as variable, population levels in the pre-colonial past along with possibly higher levels of predation by some predators including salmon, cetaceans, and bears, and possibly lower predation by other predators such as pinnipeds (McKechnie et al. 2014; Surma and Pitcher 2015; Fox et al. 2015). Herring eggs deposited on coastal habitats during the spring spawning season feed a diverse array of marine species including invertebrates, fishes, seabirds, whales, and even coastal black bears. Observations in Prince William Sound suggest that sea otters opportunistically feed on herring roe on kelp (Lee et al. 2009). Sustainable traditional resource use by people, such as traditional use of herring and herring roe by Indigenous peoples, is also part of predator interactions in an ecosystem-based approach (Jones et al. 2000; Pinkerton et al. 2019). In this context it is important to note that harvesting of adult herring has a higher impact on herring populations overall than harvesting of herring eggs (Shelton et al. 2014).

#### *5.2.1.6.2 Herring Competitors*

Competitors of herring for food and resources have not been shown to play a consistent strong role in regulating herring population dynamics, although existing studies are not specific to Haida Gwaii. On the west coast of Vancouver Island (WCVI), models showed herring and their potential food competitors such as adult and juvenile pink and chum salmon did not preclude each other from coexisting at the same sites at the same times (Godefroid et al. 2019). However, in the Gulf of Alaska, high densities of hatchery released pink salmon have been shown to decrease herring feeding where they co-occur (Sturdevant 1999; Pearson et al. 2011). Off the WCVI continental shelf, sardine densities were suggested as a cause of low herring densities (Godefroid et al. 2019), and sardine abundance was positively associated with higher adult herring mortality (Schweigert et al. 2010), in spite of high euphausiid densities that provide food for both species. Other studies corroborate the absence of strong competitive interactions between herring and other potential competitor species that are not sardines or pink salmon. Abundance of young of the year pollock in Prince William Sound (PWS), Alaska, positively correlated with herring recruitment despite high dietary overlap, and herring recruitment had no significant relationship with juvenile pink salmon that consume similar prey (Sewall et al. 2018). Herring in PWS were also found to spatially partition by water depth from their walleye pollock competitors with herring generally shallower, thus reducing competition (Foy and Norcross 1998). This habitat segregation could be disrupted if herring are forced deeper due to warmer surface water temperatures (Cheung and Frolicher 2020), similar to what has been observed on the central coast of BC (Thompson 2017).

Strong relationships between time series of herring growth and survival and planktivorous competitors have not been observed in BC (Tanasichuk 2017). Biomass models have suggested that abundance of planktivorous fish increases with reduced herring abundance, indicating significant competition with herring (Surma et al. 2018). However, these models do not account for potential spatial-temporal habitat partitioning or intraspecific competition among herring themselves (Reum et al. 2013; Boldt et al. 2018). Sea jellies have been shown to negatively impact Atlantic herring via competitive effects (as well as predatory effects), suggesting the same may also exist between northwest Pacific jellies and Pacific Herring that also have high dietary overlap (Purcell and Sturdevant 2001; Lynam et al. 2005). Time series data on jellies are lacking in BC to assess these potential effects despite increases in sea jelly populations globally and overall shifts to environmental conditions favorable for jellies. Trends from existing studies on jelly abundances in the northwest Pacific are variable with increased numbers shown in Puget Sound (Greene et al. 2015), but lack of increasing trends observed in the Strait of Georgia (Li et al. 2013).

#### *5.2.1.6.3 Herring Prey*

Prey availability and abundance can explain significant variation in herring survival and individual growth and is likely a major determinant of population persistence and recovery across Pacific Herring populations (Pearson et al. 2011; Schweigert at al. 2013; Batten et al. 2016; Boldt et al. 2019). Pacific Herring larva generally eat plankton and zooplankton eggs (Megrey et al. 2007), as well as heterotrophic protists (Friedenberg et al. 2012). Juvenile herring eat larger but non-predatory zooplankton like copepods and their nauplii, then eat larger predatory zooplankton like euphausiids when they reach two years of age or older (Megrey et al. 2007). Gut content analyses and lab feeding experiments confirm the importance of euphausiids over copepods and other zooplankton in adult herring diets (Pakhomov et al. 2017; Friedenberg et al. 2012). Due to these life-stage specific diets, long-term surveys to track distribution and abundances of different zooplankton taxa over a significant time scale are important to relate zooplankton shifts to herring population dynamics, in order to better predict trends in herring populations (Batten et al. 2016).

Haida Gwaii herring population growth rates have been shown to be correlated with production of their phytoplankton and zooplankton prey (McQueen and Ware 2006; Ware, McQueen, and Barry 2006). More recently, herring survival has been found to be negatively correlated with the biomass of some southern species of zooplankton, suggesting that changes in ocean currents, and the resultant changes in BC's zooplankton community, may negatively impact the availability of preferred food for Pacific Herring (Schweigert et al. 2010). Climate change effects on plankton species, specifically warmer waters and observations of increasing southern zooplankton species in more northern waters, could therefore lead to reduced herring population growth rates and survival in Haida Gwaii. Conversely, top-down effects of herring on their zooplankton prey are thought to be very small. A dynamic bioenergetic model of herring coupled with a nutrient-phytoplankton-zooplankton model produced more accurate herring weight-age relationships, and lower long-term large and predatory zooplankton, than a model without feedbacks between the herring and plankton models; however, the effects of herring predation on plankton in these models via food consumption, egestion and excretion was small (Megrey et al. 2007).

#### *5.2.1.6.4 Herring Pathogens*

The overall effects of pathogens on herring population dynamics in BC are not well understood, although they have potential to dramatically affect both juvenile and adult mortality (Pearson et al. 2011; Hershberger et al. 2016). The impact of pathogens on herring can also be increased from interactions with other environmental stressors, such as poor nutrition exacerbating the impact of anthropogenic influences like nearby processing plants, resulting in locally-elevated infections. Some studies of the *Ichthyophonus* protist and hemorrhagic septicemia virus have shown effects on natural mortality and recruitment in Pacific Herring (Lovy et al. 2012; Marty et al. 2003), while other studies have not linked them to herring population dynamics in the wild; overall time series data for these pathogens is lacking throughout most of BC (Pearson et al. 2011; Sewall et al. 2018). *Ichthyophonus* is a protist that is a generalist parasite of fish spread from prey to predator through consumption and from predator to prey, such as from larger demersal fish to herring, through waterborne cells (Kocan 2019). *Ichthyophonus* is found at lower levels in Haida Gwaii herring than in other BC herring populations (Hershberger 2017). Hemorrhagic septicemia virus is a highly contagious virus that can be carried and spread by fish carrying even low parasite loads, and juvenile herring are particularly vulnerable (Lovy et al. 2012). Other parasitic infections that can be spread between herring and other fish include *Lepeophtheirus* and *Caligus* sea lice (Hemmingsen et al. 2020). Environmental disturbances such as pollution runoff may intensify the effects of parasites and other diseases, particularly in younger and smaller individuals (Hershberger et al. 2016). For example, long-term pollution effects of the oil spills on herring may reduce their fitness and reduce resilience to disease and parasites (Kennedy and Farrell, 2008). In recent years of warmer water in Haida Gwaii corresponding to years of marine heat waves in the mid-2010s, herring spawn was observed to have bacterial and/or fungal mats growing on their surface, presumably leading to reduced survival and likely death of those eggs before larval herring were able to hatch (L. Lee and D. McNeill, pers. comm.).

#### *5.2.1.6.5 Invasive Species*

Marine invasive species can have negative effects on herring spawning and rearing through habitat alteration, although overall effects on herring populations in BC are unknown at this time. Field experiments in Barkley Sound, WCVI, have shown that European green crabs (*Carcinus maenas*) can increase loss of eelgrass shoots by up to 81% compared to enclosures without green crabs (Howard et al. 2019), which can negatively affect herring that use eelgrass habitat for spawning and juvenile rearing. Invasive European green crabs were first reported in Haida Gwaii in Skidegate Inlet in July 2020 (C. Johnson Kendrick, pers. comm.), and a coordinated multi-agency effort to stop or slow their spread is underway. However, European green crabs have invaded many parts of the southern and central coasts of BC and their northward spread is continuing.

Rapidly growing invasive tunicates like chain (*Botrylloides violaceus*), star (*Botryllus schlosseri*), sea vomit (*Didemnum vexillum*), and grey (*Diplosoma listerianum*) tunicates have potential to dominate rocky and gravel seabed habitats (Kaplan 2017). However, these invasive tunicates tend to stop growing and go dormant over the winter, and thrive in warmer temperatures, so their effects on herring eggs during the spring spawning season is unknown. Chain tunicate is consistently at the Daajing Giids (formerly Queen Charlotte) and Masset docks and Bischof float camp in Gwaii Haanas. Star tunicate is at the Daajing Giids and Port Clements docks, and the grey tunicate is in Daajing Giids and Bischof float camp; these species were previously more abundant in southern BC (Clarke Murray et al. 2014), and are becoming increasingly abundant in Haida Gwaii. Chain tunicates have also been found on natural rocky habitats in Skidegate Inlet (S. Crawford and L. Lee, pers. comm.). Although studies in Puget Sound, Washington, have shown little to no effect of substrate type and seafloor characteristics on herring egg survival, compared to more substantial effects of oceanographic variables or land-based pollution (Shelton et al. 2014), the role of spawning substrate on herring egg survival remains understudied at a time when effects of invasive species are increasing. In BC, movement of recreational boats, shipping at commercial ports and marine industry developments, such as movement of barges and pile driving, are vectors for the spread of marine invasive species (Clarke Murray et al. 2014).

### 5.2.1.7 Environmental Conditions

Dynamic environmental conditions of pelagic and nearshore habitats, including oceanographic climate variability, sea surface temperature, ocean acidification, and coastal biogenic habitats, are known or expected to impact Pacific Herring populations and rebuilding potential through both direct and indirect effects.

#### *5.2.1.7.1 Climate Change and Ocean Conditions*

Local and basin-scale oceanographic and climatic variables are known to affect herring and have shown differing effects among BC herring stocks, yet the overall and sub-stock-specific impacts of many physical ecosystem variables are currently unknown. Models for Haida Gwaii suggested that the North Pacific Gyre Oscillation (NPGO) and downwelling-favourable winds were the most important oceanographic variables for explaining variation in the relative herring spawn index (Xu et al. 2019), along with the Pacific Decadal Oscillation (PDO), which is becoming increasingly synchronized with the NPGO (Joh and Di Lorenzo 2017). Downwelling-favorable winds showed a dome-shaped relationship with relative herring spawn index for Haida Gwaii, different from that relationship for other herring stocks (Xu et al. 2019). Additional oceanographic variables not included in this study may also be important predictors of herring spawn and other population parameters.

Oceanographic variables can have multiple, interacting, and variable effects on Pacific Herring at different scales via direct and indirect mechanisms. Warmer ocean temperatures can have negative direct effects on growth of herring larvae and juveniles (Stocker et al. 1985) due to temperature- and age-dependent respiration and other metabolic activity (Megrey et al. 2007), and models using data from the WCVI suggested that higher Pacific Herring recruitment was associated with cooler ocean temperatures (Dreyfus-León and Schweigert 2008). A BC-wide marine heat wave from 2014-16 caused sea surface temperatures to be higher than usual (Drever et al. 2018), with continuing warmer waters evident in the following years (Devred et al 2021) and another heat wave from 2019-20 (Ross, Jackson and Hannah 2021), suggesting negative effects on Haida Gwaii herring over recent years. High flooding and associated lower salinity waters were correlated with changes in decadal herring abundance in eastern mainland China (Li et al. 2019), suggesting that higher salinity conditions supported higher herring abundance, potentially by increasing mixing between ocean water layers to reduce stratification and increase productivity and availability of food for herring. Changes in physical ocean conditions can cause declines in the availability and/or diversity of food in existing herring feeding areas with direct effects on herring, potentially causing shifts in herring survival and distribution at different life stages. These changes may also alter predator-prey interactions with a cascading suite of direct and indirect positive and/or negative effects on herring populations and sub-stocks throughout the coast.

Regardless of mechanism, the preferred sets of oceanographic conditions for BC herring populations based on their current distributions are predicted to shift >20 km northward between now and 2100 (Cheung and Frolicher 2020). The preferred habitat of herring is also predicted to shift to deeper depths for Gulf of Alaska and California Current herring, though not for East Bering Sea herring (ibid).

#### 5.2.1.8 Relative Importance of Physical and Biological Environmental Factors

The relative importance of physical environmental variables compared to biological parameters for the prediction of herring population dynamics is not clear, as some models performed better when physical variables were included whereas others did not. A model for San Francisco Bay herring found that including a multivariate ocean climate index (based primarily on sea surface temperature (SST), sea level and air temperature) was most often less important to predictive accuracy than either including herring young-of-year biomass or spawning stock biomass (Sydeman et al. 2018). In contrast, other herring stock-recruitment models have performed significantly better when environment variables, such as air and water temperatures, are included (Williams and Quinn II 2000), and environmental variables may be specifically important in predicting years of low recruitment (Dreyfus-León and Schweigert 2008).

Changing physical environmental conditions are likely more important in driving continued low herring abundance than fluctuations in abundance of individual predator species because of a compensatory response from other predators. A spatial and temporal individual-based predator-prey model for the Strait of Georgia ecosystem found that herring abundance was generally unaffected by decreases in the harvest of individual herring predator species, such as hake, spiny dogfish, and seals, because other predator species would reciprocally increase in abundance (Fu et al. 2012). In contrast, both herring and their predators declined in abundance under simulated scenarios of lower phytoplankton and/or zooplankton abundance due to climate change.

The same ecosystem model for the Strait of Georgia found that decadal oscillations in copepod abundance had stronger effects on herring abundance than decadal oscillations in the phytoplankton (Fu et al. 2012). This means that environmental disturbances at different trophic levels in the food web differ in their severity of impacts on herring. Due to the short generation time of herring and relatively rapid responses to environmental change, harvest of herring during periods of low herring prey biomass could have negative effects on herring population recovery. A bioenergetics-based forecasting model showed that the effects of zooplankton production on herring were dependent on the abundance of herring relative to that of zooplankton (Megrey et al. 2007)[6]. Herring growth and weight-at-age responded to zooplankton growth and mortality, suggesting that climate change could impact herring size-at-age (ibid).

Bioenergetics-based population dynamics models allow for estimating both direct temperature effects on herring growth and development, and indirect temperature effects on herring via lower trophic level effects on their zooplankton prey. The most recent literature suggests that the latter is more important but uncoupling these direct and indirect effects is challenging. Consistent with field observations, models showed that herring growth decreased with warmer ocean temperatures and varied directly with zooplankton abundance; the relative importance of each variable differed between sites (Rose et al. 2007). More recent models estimating variation in age-0 herring body condition with biotic and abiotic variables found an increase in condition at temperatures higher than 8°C, which was attributed to the relationship between temperature and food availability (Boldt et al. 2019). Atlantic herring embryos show accelerated muscle development and shortened embryonic development at 8°C compared to those at 5°C; however, higher temperatures also increased physical deformities (Johnston et al. 1998; Vieira and Johnston 1992). Higher temperatures of 12°C were also found to slow growth and increase larval mortality in herring, while negligible direct effects of acidification were detected (Sswat et al. 2018).

### 5.2.2 Culture

This section summarizes aspects of Haida culture that are important for this rebuilding plan, drawn from a more extensive report on Haida marine traditional knowledge about 'íináang | iinang *herring* (Appendix C).

[6] Warmer SST over the 2014-16 marine heat waves and El Nino were linked to lower phytoplankton abundance (Gómez-Ocampo et al. 2018). Corresponding declines in different copepod and euphausiid species were predicted to varying extents by both chlorophyll and temperature variables, suggesting that zooplankton prey of herring were affected directly and indirectly (through effects on primary productivity) by environmental disturbances due to reduced primary productivity and/or reduced smaller zooplankton prey (Lavaniegos et al. 2019).

#### 5.2.2.1 Haida Culture and Worldview

Culture includes roles in society, expectations about behaviour, beliefs, worldviews and the sense of well-being from belonging to a group. Haida culture and the Haida worldview are guided by Haida values, ethics and laws (described in Section 2.1). For example, the Haida worldview reflects the view that herring are "Herring People" equal to humans. The relationship between the Haida and the natural world is guided by fundamental Haida values and laws such as respect, responsibility, and reciprocity. Cultural well-being also involves self-efficacy and agency – and is supported by the Haida taking a pro-active approach to culture and taking care of each other, the Herring People, and the oceans. Haida traditional knowledge reflects Haida culture and worldviews (see Section 2.3).

**Harvest of k'aaw in Skidegate Inlet in 1897. Source: B.C. Provincial Museum PN355 Newcombe.**

Herring is a cultural keystone species. The X̲aayda kil word iinang, for herring, also means "plentiful". One Haida origin story tells of a **G̲andlaay Jaada** *Creek Woman*[7] who gave Haidas fish, and herring (Diane Brown, 2016). Another old story tells how the supernatural being, **Skil Jaada** *Luck or Wealth Woman*, brought herring to Skidegate Inlet so that Haidas would never have to worry about having enough food ("Captain Gold" Richard Wilson, 2016). Herring is both vital to coastal and marine food webs, and at the center of Haida cultural-ecological relationships (e.g., Jones et al. 2000, Okamoto et al. 2019). Herring plays a fundamental role in Haida cultural identity, foods, ceremonial use, and other cultural values (Box 18).

> *Box 18. [The supernatural laws] all pertain to the k'aaw, "Respect it," "Don't take too much," but something is amiss. Taking too much, not respecting, they were gifts for us to survive and we are getting too greedy and selling it.* (Diane Brown, 2016)

Important cultural attributes of herring and k'aaw that were identified through traditional knowledge interviews with Haidas, include:

- Cultural continuity as part of a living Haida culture;
- Traditional fishery dimensions, including food security, sharing, feasts and trade;
- Family and social relationships associated with the fishery;
- Traditional knowledge, including intergenerational transfer;
- Ceremonial use and spiritual importance;
- The Haida worldview of herring peoples, the oceans, and interconnectedness with the land;
- Connections to important places and the marine environment; and

[7] X̲aayda kil is included for place-based stories that are relevant to Skidegate and southern Haida Gwaii.

- Haida ethics, values, laws and co-governance.

Other attributes described in less detail include:

- Commercial fishing, including livelihoods and economic benefits; and
- Access to herring, k'aaw and their ecosystems, including physical, environmental, spatial and temporal dimensions, and management/policy.

Further details are in Appendix E.

K'aaw as food, the practice of harvesting, preserving, trading, and gifting, and its relationship to the marine environment, has a key role in Haida spiritual life and ceremonies. A supply of k'aaw is often kept or procured for ceremonies such as potlatches (Rollie Williams, 2016) and k'aaw "is at every feast – there's always a big bowl of boiled k'aaw." (Roberta Olson, 2016).

The ability to harvest, access and use herring and k'aaw is important to maintaining cultural continuity and a living Haida culture. Identity is a sense of individual self in relation to community – "Herring is part of the essence of who you are" (Barbara Wilson, 2016). In a marine ecosystem context, identity can include a sense of connection to marine life and to the practice of harvesting as a way of life, for example as expressed in the statement, "I am a fisherman." Heritage refers to generational connections to culture and place, which can include but is not limited to oral traditions and family stories; customary practices, knowledge, language, and laws; and archaeological and historical sites. As a living Haida culture, identity and heritage associated with k'aaw and herring are dynamic and continue to evolve through on-going relationships, engagements, practices, and intergenerational knowledge transfers.

Herring and the practice of harvesting provide opportunities for the Haida to connect to Haida worldview, culture, the ocean, traditional harvesting places, and marine life of Haida Gwaii. Not only marine food webs, but also k'aaw traditional activities, are tied to associated resources on land such as trees. The health of the land and sea is interconnected, and being connected with a healthy ocean and the cultural values of k'aaw is part of Haida well-being.

### 5.2.2.2 Haida Traditional Use and Stewardship

Traditionally, whole herring, k'aaw *herring spawn on kelp,* and herring spawn on branches or other substrates are harvested. Haidas use whole herring for bait, food, and oil, and k'aaw for food and trade. An origin story, **X̲uuya K̲aagang.ngas** *Raven who kept walking*, includes an account of how Haidas learned to gather k'aaw on hemlock branches (Box 19). Another account explains why herring are seldom seen while spawning (Box 20). Herring spawn was sometimes also picked from other substrate such as eelgrass and eaten on the spot. One Haida recalled his father – who was trained as a young man to carry on Haida oral history – describing use of herring as oil in Skidegate Inlet in the far-distant past (Box 21). Haida

*Box 19. "Afterwards, after he (Raven) had walked around for a while again, they say he came upon the Herring People dancing in a house. Even the sky above it was trembling [with the din]. He glanced inside and the Herring People spawned on his whiskers. He ate the roe. It tasted awful. They say he threw away his whiskers. Then he pushed in a branch which he broke off. He pulled it out. The roe was thick on it and he ate it. It was delicious. He invented this [manner of getting roe], they say." (Walter McGregor in Swanton, 1905a, at 135 as translated by Enrico 1991: 83)*

*Although I have never gone out and gathered it, you know, some people would go and stick a little hemlock tree in the sand or gravel there and let the herring spawn on it. (John Bennett, 2016)*

*Box 20. [Raven] went by canoe and came to where herring had been spawning. Raven filled the canoe with herring, dipped them out of the keel of the canoe and threw them toward the shore. Raven said to the herring people, "Future people will not see the place where you are", thereby explaining why the water is muddy and turbulent where herring spawn (John Sky, summary from Swanton, 1905a, at 128 and 149).*

use of herring is documented in archaeological sites. One site near **Daajing Giids** (formerly Queen Charlotte) was described as being "loaded with herring bones, … there was just thousands of little, tiny herring vertebrae" (Colin Richardson, 2016). Archaeological studies have documented the importance and consistent use of herring over millennia in Haida Gwaii and other locations throughout the Pacific Northwest Coast region (McKechnie et.al. 2014).

> *Box 21. I'll start off with before we got oolichan grease. Before they [the Haida] went over to the mainland. Before canoes. Herring was really thick in here. Outside South Bay [in Skidegate Inlet] there was great big herring there. You could use that herring for oil, its oil content, because we had no oolichan grease. You could get the oil out of there. You just put it up on a stick. You cut it open. I guess you gut it too. They were great big herring the size of humps (pink salmon). Then you put it by the fire and there's a container below it. The head up and the tail down and it just drips right into the container. (James Young, 1998)*

Herring management practices are based around the principle of **Yahgudáng | Yahguudang** which translates as respect (Section 2.2). An example of upholding this principle and law is not disturbing herring while they are actively spawning and waiting for a couple of days after to start the harvest. As described in Jones (2000), in the past, individual Haida lineages controlled such resource harvesting areas as salmon spawning streams, berry picking areas, halibut fishing grounds, hunting grounds for seal or sea otter, or shorelines where whales might wash up (Niblack 1973). Herring spawning grounds were similarly managed and would have limited resource exploitation and promoted local stewardship of resources. As well, quantities of herring spawn harvested would also have had natural limits, based on such factors as the amount that Haidas could have used fresh, the finite labor available for processing, and weather conditions conducive to drying product. Since mainly eggs were collected, most live adult herring were unharmed and could return to spawn again in following years.

Herring were caught using different methods. A story told by the chief of Tanu, and recorded by Swanton in 1901, tells about herring fishing with nets (Box 22). In the past, Haidas used stinging nettle and fireweed fibre to make cordage and nets (Turner 2004). Haida people also caught herring using a herring rake, a light pole six to eight feet in length with sharpened points driven through one end. Herring are used as bait for many other fisheries, including, halibut, salmon, blackcod, and dogfish. Larger herring used for food could be smoked, sun-dried or, in later years, even pickled (Box 23).

> *Box 22. "HlGaxiid town [an old village located at First Beach in Skidegate] was in existence they say. They say that sometimes the townspeople used to go out fishing for herring with nets. Sometimes they used to catch a porpoise in the net". (Chief Tanu, Swanton 1905b, at 234 and 236.)*

> *Box 23.… if the herring was too big, grandfather, all the guys would put it aside and they would … fillet it, take the bone out and put it in the smokehouse to smoke it. … I can't remember who it was but they were pickling a lot of the herring even after they took the … backbone out.* (Reynold Russ, 2007)

Collecting k'aaw is a seasonal activity that in the past, often involved travel to fishing camps, as Ernie Wilson recalled from the 1930s. At seasonal and permanent villages, if weather permitted, k'aaw was sun-dried on a gravel beach, or protected outdoor structures. If the weather was poor, it could be dried indoors. Dried kelp fronds with herring spawn were traditionally tied into bundles of about ten and stored in bentwood boxes. Dried k'aaw was susceptible to insect damage and could turn brown and lose flavour. It was eaten dried or soaked in freshwater, then dipped in boiling water or fried. K'aaw is often eaten with **satúu | taaw** *eulachon oil*.

Herring SOK is a common item that the Haida use for trade with other coastal First Nations, including the Tsimshian and Nisga'a (Box 24). For example, the Hudson's Bay journals recorded the following from August 1853: "The Kit-i-was traded a large quantity of dry Halibut, Herring Spawn & Sea Weed with the Chimsheans 'inside the Fort" (Galois 1997). Kit-i-was was the Tsimshian name for the Cumshewa people. These trading traditions continue into the modern era.

*Box 24. We used to go there [K'iid Xyangs K'iidaay briefly known as Burnaby Narrows] for drying k'aaw in April. There used to be about, oh, I'd say about eight, ten families there, they used to have houses. Oh, April is a poor time to try and dry k'aaw. Don't matter what you are doing, if you hear somebody let out a scream, drop everything, run like heck for the beach where you got it stretched out. Pick them up and bring them to a drying shed. Oh, boy. That was work. Everybody helps, nobody is excluded. When it's good they did fairly good. Only for 22 cents a pound. Dried up stuff. They used to sell it to Japanese right at Jedway. I don't think there is even any sign of the houses that used to be there. We used to come back in May, just to get ready for going to North Island, for trolling time too. And then from North Island they'd go across to Skeena. Dried, take it across and trade with the Indians over there for oolichans and oolichan grease and soapberries. (Ernie Wilson, 1998)*

Fishing methods for k'aaw include wild k'aaw harvest, open ponding where kelp is picked from local areas and strung from floats or logs in places where herring spawn, or closed ponding where herring is impounded in ponds where kelp is hung in lines. Closed and open ponding methods are sometimes used simultaneously.

Many people interviewed expressed joy and excitement when recounting traveling to fishing camps in spring. **K'áawdang | k'aawdang** *harvesting herring eggs on kelp* is described as a cooperative effort and an integral part of life. The development of commercial herring SOK ponding operations by the Haida are felt to be aligned with Haida values. Herring are released after spawning and most can return to spawn in future years.

#### 5.2.2.3 Food Security, Sharing and Trade

Herring SOK is an important food in the Haida seasonal round. It's one of the first foods of the spring. Marked by changing seasons and ocean food webs, k'aaw is thought to feed the spirit. It brings nutrients and adds to the subsistence foods that Haida harvest. It is "Haida food"; that is, culturally-important food and a key source of nutrition (Box 25).

*Box 25. [Herring] has always been a food of the Haida, it's been an important food. And we prepare it many different ways. And going to get herring is an experience that takes us onto the ocean, and it puts us in touch with nature by getting the herring—it's quite an experience, you have to be there to know it. The first taste of k'aaw, there's nothing like that.* (Barbara "Babs" Stevens, 2016)

*That's the reason why you have a potlatch is because you have the abundance of the marine resources. The marine resources are your form of money, and your form of wealth, and also your gift giving during the potlatch. ("Captain Gold" Richard Wilson, 2016)*

It's not only the herring and their roe, but also the kelp that make up the food value of k'aaw. Practicing the traditional food fishery has largely been a family-centered harvest activity. However, in some recent years the main harvest and access to k'aaw has been through a communal fishery sponsored by the Skidegate Band Council and/or the Council of the Haida Nation. For instance, from 2006-2008 a Haida seine vessel and crew were chartered to harvest k'aaw for the community. In addition to community food benefits, this provided livelihood benefits to fishermen and increased opportunities to monitor conditions in key spawning sites, and to connect with those places. These sponsored harvests distributed food to Haida households for whom it may be the only way to access k'aaw and created occasions for community celebrations and feasts.

Giving k'aaw during feasts and potlatches, and as food gifts, was described as an important cultural value. In particular, the importance of bringing k'aaw to family, elders, and community members as an avenue for distributing access to this traditional food.

Traditional harvesting and commercial SOK fishing are often combined. For instance, SOK fishermen were accustomed to bringing some k'aaw trimmings home for food. When product quality fell below market standards and if there were "peelers" and trimmings after assembling good market-quality product, these would not be wasted and instead would get used by fishermen as food for themselves and their families.

Trade networks have been important through the years for Haidas, both within Haida Gwaii and between families, as for example between Skidegate and Old Massett. That trade has been a key way for Haida families in Old Massett to get k'aaw. The access to k'aaw was described as improved after the road was built. Betty Richardson recalled sharing k'aaw with relatives on the mainland (Box 26).

> *Box 26. We used to send the herring on kelp to my husband's sisters. My husband had a sister in Port Edward, and one in Rupert. And you know, we would send them k'aaw whenever it came.* (Betty Richardson, 2016)
>
> *It's still our traditional and inherent right, we traded right—done it for thousands of years whether it was the abalone or anything like that—any kind of product [including spawn on kelp]."* (Sascha Jones, 2016)

Historical trade networks between Haida and other Nations on the mainland also existed. Sasha Jones described the trade interactions with the Nisga'a and other Nations on the mainland, who sought k'aaw or halibut from Haida Gwaii in exchange for elk, moose, or eulachon, among many goods (Box 26).

#### 5.2.2.4 Family and Social Relationships

Harvesting and processing k'aaw, and then sharing it through feasts and gifting, are among the important social benefits of herring to Haida families and close social relationships. It isn't just the benefit of food as nutrition, but also the social and community aspects of coming together and demonstrating Haida values (Box 27). Being generous and caring for each other, bringing k'aaw to elders and sharing in the community was described as the "Haida way" (Colin Richardson, 2016).

> *Box 27. I have a wonderful memory of k'aaw –it's one of my most favorite memories of childhood—was helping my mother as a little girl, take her k'aaw from the rowboat to the beach. … We packed the k'aaw up on our little arms and pile it on logs to drip dry. And our mother would call us and would be praising us and telling us how tough and wonderful we are for helping her. And that is my fondest memories of gathering k'aaw and how precious our k'aaw is to us and how much we love it.* (Isabel Brillon, 2016)

Everyone would play a role in harvesting and processing the spawn on kelp. Many of the adults who we interviewed recalled learning about k'aaw from their mothers, aunties, and grandmothers. Not simply acquiring traditional harvesting and conservation knowledge and laws, these times also held significance in strengthening family bonds, especially between children and their mothers and other women in their families.

Traditionally, it was primarily women who harvested k'aaw using row boats going to kelp beds not far from home. Diane Brown described learning that her ancestors pre-contact all had their own smaller food gathering canoes and at that time, the women would use these to go get k'aaw. The role of women as the primary k'aaw harvesters continued during her childhood and early adult years. These social relationships were especially important for women's friendships as they engaged in traditional k'aaw harvests: "it was just the joy of going out and being with all the women, the talking and laughter that would go on" (Diane Brown, 2016).

Gender roles may have changed over time as a photo from 1897 showed harvesting as a family activity (Figure 24). In recent decades, k'aaw harvests have been increasingly practiced primarily by Haida men, particularly by those involved in the SOK commercial fishery (Box 28). Fishing for SOK takes place in various bays and inlets throughout Haida Gwaii, and access to J-licenses and a power boat and having the time to get out to the fishing grounds are important enabling aspects of carrying out the fishery today. While many social changes have taken place in k'aaw fisheries and Haida life over the years, including gender-based changes, the significance of social ties across generations and among crew and family members remains. Similar social experiences and childhood memories were expressed by Haida men (Box 29).

> *Box 28. My earliest memories of the herring is probably going out with my dad when I was nine years old, or something like that. Going down to South Moresby to do up ponds and whatnot. I was doing that my whole life […] I started going down, '85 I started as a crew man […] my brothers and other crews that were down there doing the herring [pond fishery.]* (Conrad Collinson, 2016)

> *Box 29. We all just go to my uncle's house and he's got totes and we get all the stuff ready and then cut it up and then divide it up—but everybody helps right? All my sisters come and my cousins and everyone just chips in——whoever is around and then they take away what they need …you know enough for them.* (Jason Alsop, 2016)

#### 5.2.2.5 Intergenerational Knowledge Transfer

In addition to social relationships and strengthening family bonds, generational and traditional knowledge has been passed down within families from childhood. Traditional knowledge involves teachings and guidance on topics such as harvest and processing techniques; observing and reading the ecosystem for indicators of timing and location, as well as ecological relationships between herring and other marine life; learning about best quality and preparation; and Haida ethics, laws, and protocols.

> *Box 30. We have to really think about what's important and for me what's important is a clean, healthy world that can provide for the next thousand years and beyond of my descendants, so they can know what it's like to get k'aaw. Hopefully it won't be just a word then. But they will be able to eat k'aaw and dig clams and steam mussels and eat octopus and eat salmon. How does all that get passed on? It gets passed on by being respectful, it gets taken care of or made right by changing the way we view things as commodities—they are not commodities—if they are commodities, we are commodities.* (Barbara Wilson, 2016)

Among the traditional knowledge topics is learning conservation: learning to be respectful. Barbara Wilson described teaching about Haida ethics and spoke about the importance of stewardship and respectful practices (Box 30). Reflecting on how a respectful harvest should be practiced by not interrupting a spawn event, Diane Brown remarked on the lessons she learned from her grandparents and her mother (Box 31).

> *Box 31. Well nothing would ever harm the fish, like I said if we knew they were pregnant and around there, nobody went near them. You respected what was going on there. And when they got near the kelp they spawned on the kelp, and we never went near it for four days, and then once the milk went away, you can take. … Anything that disrupts the natural order of things is sort of like a sacrilege, 'cause we call those things, … Gund iina, I believe, it's sacred. Or it's taboo to do that, … it's sort of taboo to kill all the females.* (Diane Brown, 2016)

Informal caretakers and more formal guardians, such as those in the Haida Watchman programs, play important roles in monitoring and observing what takes place on the water, and in teaching protocols such as when is the right time and place to harvest k'aaw.

### 5.2.3 Social and Economic

Direct socio-economic benefits from herring in Haida Gwaii and BC are primarily generated by herring fisheries. Related activities include processing, sales and use of roe, roe products and herring meal that may be incorporated into aquaculture products. Additional benefits are generated by secondary activities such as marinas, transportation, and fishing supplies and services. Herring also have an existence value inherent in non-consumptive activities such as tourism including the use of protected areas.

Seven types of herring fisheries have occurred in BC and Haida Gwaii, and four are contemporary on Haida Gwaii: traditional Haida, recreational, commercial roe herring, and commercial SOK fisheries. The annual landed commercial catch of Haida Gwaii herring from each fishery has been reported since the 1950s for the Major SAR (Figure 15 and Figure 18), the Minor SAR (Figure 21) and Skidegate Inlet, Masset Inlet and Naden Harbour (Figure 21). The commercial dry salt fishery in Haida Gwaii ended around 1940, the reduction fishery in 1967 and bait fishery in about 1990. More detail on the historical commercial fisheries can be found in Appendix E.

#### 5.2.3.1 Haida Traditional fishery

Haida traditional fisheries provide important social, cultural, and economic value and benefits (see e.g., Box 32; described more in Section 5.2.2). For example, k'aaw is a staple food for Haida people and continues to be an important commodity for barter and trade.

> *Box 32… she'd (mother) go out and get cedar to tie up the k'aaw [into] little bundles, sitting out in the cold at night and all this cedar bark is in water and she'd, take pieces off and tie up her k'aaw.* (Pat Gellerman, 2016)

Haida traditional k'aaw fishery catch and effort was high in the late 1980s and 1990s. For example, DFO estimated that effort was more than 70 persons in 1993 and up to 66,000 lbs of k'aaw were estimated to be harvested in 1997. Some harvest was for trade and this was during a period when k'aaw market prices were high (up to $62.88/lb (2020$) in 1995; DFO fish slips). Traditional harvests have been relatively low since commercial SOK fisheries closed for a prolonged period in the Major SAR in 2005. Slightly higher traditional harvests occurred in 2006-08 and 2011 when Haida organizations chartered a vessel(s) to set up closed ponds in the Juan Perez–Skincuttle Inlet area. Skidegate Inlet, Selwyn Inlet, Juan Perez–Skincuttle Inlet, and the west coast of Haida Gwaii have varied in operation of the traditional fishery from year to year depending on a range of factors including the presence of commercial SOK operations in those areas.

Traditional fishery access to k'aaw has been provided to the Haida community in several ways in recent years. Individual harvesters who have the time and resources, such as a skiff to participate in the fishery, utilize methods that may involve wild harvest or open ponding in locations where kelp is not abundant in the usual spawning locations. Haida crew involved in commercial SOK operations will commonly gather wild k'aaw and bring it home for their extended families. Communal harvest occurs in some years, when the CHN, Skidegate Band Council and/or Old Masset Village Council charter a Haida vessel(s) to set up closed ponding operations, and for the resulting product to be distributed to the community. In addition, commercial SOK operations sometimes contribute SOK for distribution to Haida communities.

##### *5.2.3.1.1 Factors for Successful Traditional Fisheries*

Fisheries are often managed to achieve multiple objectives. Since traditional (food, social and ceremonial) fisheries have priority after conservation, management decisions can affect traditional fisheries. The major factors contributing to successful traditional fisheries include:

- Herring abundance, location, and spawn timing: The abundance of herring at traditional harvest places and consistency in the spawn timing affects the extent and intensity of spawn, availability, and quality of k'aaw, and opportunities for traditional harvest.
- Kelp abundance and quality: Generally, care is taken to harvest only the upper parts of individual fronds and not to damage the plant. Years of poor giant kelp abundance and/or quality impact success of the traditional harvest.
- Physical access: Harvesters need to be in the vicinity around the time of spawning and shortly after, which is difficult when herring spawn in places that are remote from communities.
- Minimal disturbance by commercial fishing and vessel traffic: Commercial fishing activities including gillnet and seine roe fisheries, and sometimes even commercial SOK, have been identified by the Haida as having negative impacts on traditional fisheries as well as Haida connections to the ocean and sense of place. Impacts occur through disturbance of herring and spawning behavior (R. Jones, pers. comm.), but could be mitigated by spatial separation of the fisheries.
- Capacity to harvest: Haida individuals require access to an adequate-sized boat and enough time to dedicate to harvest activities. Community food fisheries can mitigate limited fishery opportunities for individuals and yield benefits to Haidas including food distribution, cultural activities such as feasts, wages to fishermen, guardian activities, and monitoring, among other outcomes.
- Transfer of technical, ecological and cultural knowledge: Key knowledge is required for successful harvest. For example, knowledge to be able to read and interpret ecosystem observations about places and timing of herring spawns, places to gather kelp, and how to harvest and process k'aaw. Being able to continue annual traditional harvest of k'aaw facilitates knowledge transfer.
- Presence of commercial SOK fisheries: Traditional fishery harvest of k'aaw is often enhanced in the vicinity of commercial closed ponds as the closed ponds tend to attract herring spawners. Commercial SOK operations often have Haida crew and may provide opportunity for Haida individuals to harvest wild product nearby the ponds when the herring spawn or to keep trimmings from commercial product.

#### 5.2.3.2 Commercial Reduction Fisheries

Herring reduction fisheries operated in BC from about 1935 to 1967, when herring stocks collapsed (Houston and Haegle 1980). Herring were caught mostly by seine and delivered to processing plants where the fish were reduced into fishmeal and fish oil. The first reduction landings in Haida Gwaii were at a plant at Pacofi Bay in Selwyn Inlet that operated from 1938 to 1943, with the bulk of the catch occurring from January to March (Tester 1945). Summer seining was attempted at several locations in Haida Gwaii in 1938-39 but met with poor success. Tester states that, beginning in 1939, ‘a newly-discovered run in the vicinity of Burnaby Strait[8] contributed largely to the catch.’ The Pacofi plant was supplied consistently by two to three seine boats until it burned down in 1943: Taylor (1964) reported catches of 2,300, 7,800 and 2,500 tons from 1938-39 to 1941-42.

[8] The area briefly known as Burnaby Strait has had the X̲aayda kil place name G̲aysiiG̲as K̲'iidsii restored.

The herring fishery became increasingly mobile and by 1950, a large fleet was fishing the BC coast, locating schools with hydro-acoustic depth sounders, using mercury lights to attract fish at night, and packing fish to centrally located plants. The first major landings in Haida Gwaii of 10,200 tonnes were recorded in 1951-52 in the vicinities of Burnaby Island and Selwyn Inlet. Landings were low in 1952-53, due to a fishermen's union strike. Then a large stock of herring was located in Skidegate in the 1953-54 season, resulting in landings of about 24,100 tonnes in Skidegate Inlet over fourteen days between 25 February and 15 March (Taylor 1955). Taylor et al. (1956) remarked that in the third season of the fishery, it was closed on 1 February because of the large proportion of small fish, and that 'there was a marked decline in the catch for the second successive year; no spawning was reported for the third year in succession'. From February 5 to March 9, 1956, a catch of 77,650 tonnes was taken in the vicinity of Burnaby Island, the largest catch ever taken from a single area (Taylor et al. 1956: 52). Significant landings continued to be recorded from both Burnaby Island and Skidegate Inlet areas until the reduction fishery was closed coastwide in 1967-68. The average annual removal rate estimated for Haida Gwaii was 83% for three seasons from 1962-65 (Hourston 1980). Coastwide, reduction fishery catches on the BC coast peaked at about 240,000 tons in 1962-1963 (Stocker 1993).

The reduction fishery was different from current fisheries in several ways. First, the reduction fishery caught Pacific Herring of all sizes including age-1 fish, whereas modern-day herring fisheries target mature spawning fish which are mostly age-3 and older fish, with some early maturing age-2 fish also returning to spawn particularly in southern BC. Second, the quantity and location of reduction fishery catch was more uncertain, sometimes affecting the ability to accurately allocate catch to a specific stock assessment area or finer-scale sub-stock area; in contrast, the location and quantity of roe herring fisheries was better recorded including catch validation programs for the herring gillnet fishery since 1998 and roe seine fishery since 1999. Finally, the reduction fishery operated during winter months, whereas roe herring fisheries typically target spawning fish between February and April.

The reduction fishery ended in 1967 when the Pacific Herring stocks collapsed, and all large herring fisheries were closed. The timing of the decline varied among the stocks over a period of five years and, because the populations are made up of a mixture of stocks, the low period ranged from five to ten years for different populations. The BC north and central coast herring populations had not recovered to their former strength by 1977 (Hourston 1981).

#### 5.2.3.3 Commercial Bait Herring Fishery

A commercial bait herring fishery operated in Haida Gwaii from the 1950s to about 1990 and supplied bait for the commercial halibut fishery. Haida Gwaii bait ponds typically operated during April and May and closed for operators to participate in the commercial salmon fishery. Operators utilized seine boats to catch herring and tow them to the ponds. Locations of commercial bait ponds included Skidegate Inlet, K̲'iid Xyangs K̲'iidaay (*briefly known as Burnaby Narrows*), and Langara Island. During the 1967-71 herring fishery closure, small food and bait fisheries continued in BC (Hourston and Haegele 1980). From 1985 to 2002, several recreational service providers were allowed to pond up to three tons of herring for bait in DFO Pacific Fishery Management Area (PFMA) 1, including near Naden Harbour, but the extent of use is unknown. Haida Gwaii commercial bait operations became uneconomical in 1990 when the halibut fishery switched from a competitive fishery (lasting weeks to a few months), to an individual quota based fishery operating close to year-round.

Although little to no bait herring fishery has occurred in recent decades on Haida Gwaii or anywhere outside the Strait of Georgia, this situation could change. A food and bait herring fishery, generally occurring between November and February, has operated in the Strait of Georgia for many years and has increased over the past decade.

#### 5.2.3.4 Commercial Spawn-on-Kelp (SOK) Fishery

The DFO-licensed commercial herring SOK fishery began in 1972. It developed for the Japanese market, due in part to the initiative of a few Skidegate Haida who had experience operating herring bait ponds (Box 33). Most commercial SOK fisheries in Haida Gwaii occur using closed ponds in which herring are caught by seine and transferred to an enclosure made from a log frame and netting. **Ngáal | ngaal** *giant kelp* (*Macrocystis pyrifera*) is gathered and suspended from lines in the pond. Commercial SOK fisheries were initially restricted to impoundment of herring in closed ponds, but open ponding was allowed beginning in 1982. In open ponding, the kelp is suspended from floats and lines in locations where herring are expected to spawn. Open ponding was frequent in Haida Gwaii from 1983 to 1988 and is more successful when herring abundance is high.

> *Box 33. Well, we had to experiment quite a bit. I know so much now about the herring. I try to set as late as I possibly can and when I put them in the pond they'll spawn right away. We used to just put them in when they were still immature. Hopefully we have it down, and we don't hurt the herring. They're in perfect health, and we let them loose after they spawn. They have a six-, seven-year lifetime. So that's what we do. If you look after them then they come back to spawn again next year. (Chief Dempsey Collinson, 2008)*

The DFO-licenced SOK fishery started in 1975 after several years of experimental permits. Non-transferable licences were issued to individuals and Indigenous organizations. Currently 10 licences are allocated for Haida Gwaii including 4 held by Haida individuals, 3 by Haida organizations, and 3 by non-Haida individuals or companies.

Commercial SOK fishery operators are also required to obtain kelp harvesting permits from the Province of BC. With the signing of the Kunst'aa guu - Kunts'aayah Reconciliation Protocol between the Haida Nation and Province of BC in 2009, the Haida Gwaii Solutions Table began to advise on and jointly approve annual kelp harvesting permits. In Gwaii Haanas, the Haida Gwaii Solutions Table began to advise on joint approval of annual kelp harvesting permits, in the same process as for other parts of Haida Gwaii. However, kelp and other marine plant harvest permits in NMCARs are to be regulated by Parks Canada when NMCA regulations and policies are in place. For Gwaii Haanas, marine plant harvest permits will eventually be approved and issued by Parks Canada and the Council of the Haida Nation as cooperative management partners.

SOK operators in Haida Gwaii take advantage of local differences in the timing of spawn in the Major SAR which generally starts earlier in the south and moves northward. Historically, the earliest fishery occurred in Louscoone Inlet. The fishery then moved to the Juan Perez/Skincuttle area where most operators start their fishery by setting up ponds in Section Cove and/or Harriet Harbour. If they are unsuccessful, some operators later set up ponds in Selwyn Inlet, although this was discouraged by Haida traditional fishers. This means that many operators set up multiple ponds during the course of the season if their initial ponds were unsuccessful.

##### *5.2.3.4.1 Factors for Successful Commercial SOK Fisheries*

There is an important linkage between successful Haida traditional and commercial SOK fisheries. The major factors contributing to successful commercial SOK fisheries include:

- Fishery openings: When abundance allows, commercial SOK fisheries can operate. The Major SAR has been closed since the last fishery occurred in 2004; operators have had the option of moving to the Minor SAR on the west coast; however, it has not been suitable for many Haida operators and does not have the abundance to accommodate all licenses.
- Herring abundance and proximity to suitable ponding locations: Seiners need access to schools of herring that are maturing, within reasonable distance of suitable ponding locations (i.e., sheltered locations). These locations are limited and well-known by SOK operators, herring seine fishers, test boat operators, and managers.
- Lack of disturbance of herring: Disturbance of herring schools by roe or test fisheries may trigger spawning or movement of schools. Gillnet fisheries in particular disperse herring and reduce opportunities for an operator to set up a second closed pond if the first is unsuccessful.
- Availability of good quality kelp: Kelp is generally of good quality throughout the Major SAR, although this may be affected by climate change. Even still, kelp is often transported throughout the area. For instance, Flagstaff (north of Cumshewa), Porter Head, Ramsay Island, and Slim Inlet are known as areas with an abundance of good quality kelp that is picked and transported to other locations. Distance between kelp beds and spawning grounds affects operating costs (e.g., fuel and time for transport) but selection and transport of the best kelp is important for the quality of the final product.

#### *5.2.3.4.2 Commercial SOK Landings in British Columbia and Haida Gwaii*

Trends in commercial landings (1982-2020) for SOK in BC (Figure 26) show increases up to 2001, largely due to coastwide increases in the number of licences or quotas. In 1991, ten new licences were issued to Band Councils (including Skidegate Band Council). From 1997 to 1999, seven licences were provided to the Heiltsuk Nation (six open and one closed pond) in recognition of their court-determined Aboriginal right to sell SOK on a commercial basis (R. v. Gladstone 1996). In 2001, the Heiltsuk quota increased to 240,000 lbs with the conversion of three closed ponds to open ponds. Closure of Haida Gwaii SOK fisheries from 1994 to 1997 had a muted effect on coastwide catch as Haida Gwaii licences were allowed to move to other areas, provided consent was given by other First Nations in these areas. From 2005 to 2013, the catches in BC declined precipitously due to closures in Haida Gwaii, Central Coast and West Coast Vancouver Island. Licences were not allowed to relocate, other than movement of operators from the Haida Gwaii Major SAR to the Minor SAR. Production from Central Coast returned to pre-closure levels in 2014, but Haida Gwaii and West Coast Vancouver Island have remained closed. Catches in the Minor SAR in some years are considered confidential due to the DFO third party privacy rule and are only partially reported (Figure 27).

#### *5.2.3.4.3 Commercial SOK Prices and Landed Value*

Trends in average real landed prices of SOK in BC (Figure 25) started at $16-31 per pound[9] in the 1970s and reached a peak at $62.88 per pound in 1995. Prices in recent years have ranged from $11-14 per pound. Prices vary considerably depending on a number of factors including

[9] All values in this section in 2020$

the grade of the product, the time of fishing season, and/or other market-based or biologically driven factors.

Local socio-economic benefits arising from the influx of capital to local communities from the SOK fisheries were significant. Revenues contributed to the livelihood of the skipper and crew. The SOK fishery employed 3-6 persons per operation and the fishery could have employed up to 40 local persons.[10] The crew share varied depending on expenses from the fishing operation and the landed price of SOK. Local fishers typically supported a family and contributed to a cash inflow to the community. Spending by the local SOK operator as well as the crew and their families would have spilled over to other businesses in the community and other fisheries. The SOK operator and crew often participated in other fisheries at other times of the year.

The landed values in BC and Haida Gwaii were sensitive to variations in prices and increasing levels of production up to 2001. The effect of Haida Gwaii closures from 1994-96 and the long-term closure beginning in 2005 are strongly evident in coastwide and Haida Gwaii landed value trends (Figure 26).

#### *5.2.3.4.4 Commercial SOK Profitability, Markets and Competition*

At the height of SOK fishing on Haida Gwaii in 1988, the fishery directly contributed $9.1 million to the economy, with an average of $3.6 million annually from 1982-2008 (Minor SAR only after 2004; DFO fish slips). Roughly 60-73% of this value would have accrued to Haida licences and the benefits of commercial harvest would have mainly stayed in small coastal communities.[11]

DFO completed a cost and earnings survey of SOK operations in 2011 as part of a review of licence fees (DFO 2011). Economic returns were highly dependent on prices which were sensitive to international markets and currency exchange rates. DFO estimated that the breakeven price for the average SOK operation ranged from $6.57 to $7.55 per pound from 2008-2010 (DFO 2011). Expenses for operation in the Haida Gwaii Major SAR and more remote locations such as the Minor SAR would have been higher than the average. Profitability is affected by vessel ownership and whether a vessel is used in other fisheries.

Blewett's (2001) description of commercially sold SOK as a luxury food item with an uncertain outlook remains consistent with current market conditions. The main market is in Japan where SOK is primarily consumed in high-end restaurants or sold in the Japanese gift market. The Japanese SOK market is highly regional, concentrated in the Kanto region in and around Tokyo. Prices and markets are affected by global supply but are highly dependent on the Japanese economy and shifting consumer patterns such as young people being less invested in traditions than older generations. Haida Gwaii was originally a significant supplier of SOK but production in the rest of BC and Alaska has increased over time (Figure 28). BC accounted for the bulk of SOK imports to Japan up until 2008. Closure of fisheries in BC in the early 2000s was matched at first by an increase in production in Alaska. Production fell in Alaska when SOK prices bottomed out in approximately 2010.

#### *5.2.3.4.5 Social Differences Between K'aaw and Other Fisheries*

Ecosystem justice concepts (Jones 2000) can be used to assess the relative impact of different fishery sectors and gear types (see Pitcher et al. 2000). The concept of ecosystem justice in

[10] Based on 8 licences and an average of 5 crew each. The on-Reserve population in 1994 was 731 people in Skidegate and 626 people in Masset.
[11] The number of Haida owned licences varied from 8 out of 11 in the 1980s to 6 out of 10 at present.

fisheries is described as an ethical analysis that identifies ethical or other value components of the scientific, economic, and political decisions (e.g., interdependent species and habitat), and makes implicit value judgements explicit (Brunk and Dunham 2000).

The k'aaw herring *SOK* fishery has less potential to cause herring mortality than other commercial herring fisheries, therefore posing less risk to herring stocks than roe fisheries because most of the herring impounded for the SOK fishery are released alive to spawn the following year (Shelton et al. 2014). Herring SOK also has a higher value per ton of herring used in the fishery. Although the commercial SOK fishery has often been given preference in allocation over the roe fishery when stocks are low, it is also more seriously affected if the fishery has to be closed, given limitations on the ability of harvesters to move areas.

The Haida traditional fishery also suffers when stocks are low but has continued with a small fishery when other uses were prohibited. Harvest policies have an unequal impact on different fishery sectors because roe fishers can move to other areas when stock levels are low, while SOK fishers (both Haida traditional and commercial) are more intimately tied to local stocks and places. Trade-offs between fisheries, and between economic, ecological, and socio-cultural metrics are important to consider (Okamoto et al. 2019). This rebuilding plan has incorporated important aspects of k'aaw fisheries into the analyses to address these differences between k'aaw and roe herring or bait fisheries that were not previously accounted for in herring models and management.

#### 5.2.3.5 Commercial Roe Herring Fishery

The roe herring fishery is currently managed as a coastwide fishery in which seine and gillnet licence holders annually select a fishing area pre-season, depending on the forecast area openings and area quotas. Licences are personal and leasing of licences is common. Area licensing was first introduced in 1981 (Pearse 1983). Since 1998 for the roe herring gillnet fishery and 1999 for the roe herring seine fishery, each licence has been assigned a quota which was an equal portion of the total allowable catch in the area selected to fish. At the same time, a licence pooling system was established in each fishery (DFO 2019) with the objective of avoiding catch overages.

Social and cultural benefits of roe herring fisheries vary somewhat depending on the type of fishery participant. In general, active fishers will use or may develop knowledge about specific fishing places. Roe herring fisheries are mobile and of short duration and can move to other areas of the coast when local abundance is low.

Economic benefits for the Haida community will vary depending on opportunity and the level of participation, which is believed to be low, and depends on the fishing and profit-sharing arrangement. Currently, Haida may participate as licence owner-operators or as independent fishers using leased or company licences (including fishing for or leasing licences from an Indigenous organization obtained through DFO’s Allocation Transfer Program (ATP) or Pacific Integrated Commercial Fisheries Initiative (PICFI)).

##### *5.2.3.5.1 Factors for Successful Roe Herring Fisheries*

The current licensing system provides considerable flexibility for both seine and gillnet roe herring fisheries. Both select their fishing areas and licence pools annually depending on a pre-season determination of the fishing quota available in the fishing areas. Some vessels fish in several areas. Fishing in Haida Gwaii typically occurs from mid-March to mid-April. Factors contributing to successful roe herring fisheries in Haida Gwaii include:

- Herring abundance: Pre-season predictions in all areas including Haida Gwaii can vary considerably from actual returns. However, catches and quality are typically managed so that catches are relatively certain.
- Herring roe quality: Herring in Haida Gwaii typically include larger older herring than other areas which can result in higher prices. Generally, test sets are used to determine optimum roe content of the fish before the fishery progresses.

##### *5.2.3.5.2 Commercial Roe Herring Landings and Value in BC and Haida Gwaii*

Haida Gwaii supported significant roe fisheries up to 1994. Fisheries closures and low stock levels have limited fisheries since then (Figures 29 and 30) and the most recent roe herring fishery in Haida Gwaii occurred in 2002. Although DFO was prepared to open the Haida Gwaii fishery in 2014 and 2015, no roe fisheries occurred in 2014 due to an agreement between the Haida Nation and herring license holders not to fish and in 2015 due to a court injunction obtained by the Haida Nation.

Both the landed and wholesale value of the BC roe herring fishery peaked in the 1980s, was relatively high until the mid-1990s, dropped during the period from 1995-2005, and then again declined from 2008-present (Figures 31 and 32). There was a modest increase in value from 2016-18.

##### *5.2.3.5.3 Commercial Roe Herring Market Outlook and Competition*

Herring roe relies on export markets and is affected by international supply and demand and fluctuations in currency exchange rates. The roe fishery faces supply-based market pressures from the United States that produces larger quantities of roe in comparison to Canadian fisheries, even though BC generally produces a superior product compared to Alaska and processes most of its product before export (Carlson 2005). Market prices for seine and gillnet licences have been decreasing since the 2000s (Castlemain 2017). The primary market for herring roe products is in Japan.

#### 5.2.3.6 Processing

Value added from processing varies significantly among herring and spawn-on-kelp product. Roe herring and food and bait herring approximately triple in value after processing while spawn-on-kelp increases by about 15%.

The economic activity from processing is dominated by the roe herring fishery due to the amount of work needed to go from fish to finished product. Between 2016 and 2018, the processing of roe herring added over $29 million to the roughly $16 million in landed value. This represented over 85% of the processing value from all commercial herring harvest in those years. Often, herring roe processing fills processing line vacancies early in the fishing season when other species are not yet in season.

#### 5.2.3.7 Recreational Fishery

There is a minor recreational herring fishery for food and bait. Little information is collected about recreational catch of herring, but the catch is thought to be very small.

#### 5.2.3.8 Evaluations of Alternative Fishing Scenarios

Several researchers have investigated alternative scenarios for herring fisheries in Haida Gwaii. Lam et al. (2019) utilized an Ecopath with Ecosim (EwE) model and a value-based methodology to examine policy tradeoffs for 11 scenarios that were identified from the herring literature and discussions with Haida fishery managers. Poe, Marshall, Levin and team (2020) explored fishing scenarios using modifications to the EwE model and social benefits from Okamoto et al (2020) for Selwyn Inlet and Gwaii Haanas (i.e., Juan Perez-Skincuttle area).

Lam et al. (2019) applied the value-based methodology to four scenarios in separate workshops with groups of Haida, commercial fishers and other Haida Gwaii residents respectively. The scenarios included:

- No Fishing: the focal value was described as ecological. This was preferred by Haida Gwaii residents (including Haida, commercial fishers and residents). It was medium in terms of preference by herring industry representatives outside Haida Gwaii.
- Only Commercial SOK fishery: the focal value was cultural. This was either preferred or highly preferred by Haida Gwaii residents (including Haida, commercial fishers and residents). It was least preferable to herring industry representatives outside Haida Gwaii.
- Previous DFO harvest control rule (cut-off and 20% harvest rate (DFO 2020)): the focal value was described as socio-economic. This was least preferred by Haida Gwaii residents (including Haida, commercial fishers and residents). It was most preferred by herring industry representatives outside Haida Gwaii.
- Commercial roe herring and SOK fisheries managed separately with distinct harvest control rules: this involved a plurality of values. This had a medium preference by participant groups.

The methodology was aimed at making policy tradeoffs explicit, including ecological and socio-economic impacts and risks, and societal preferences. Based on the analysis, the authors recommended exploring the compromise option of managing the commercial roe herring and SOK fisheries separately with distinct harvest control rules.

In 2018, the Ocean Tipping Point team (see Poe et al. 2020) explored changes in the social-ecological system as a result of herring management. Through participatory workshops with Haida Gwaii residents, the research team elicited preferences from about 25 residents of Haida Gwaii about different types of herring fishing and the consequences to the local marine social-ecological system. The scenarios and their preferences are summarized here:

- Traditional Fishing only: Similar to the No Fishing scenario of Lam et al. (2019). Preferred for ocean connections; however, not preferred for food customs due to lack of access to k'aaw, particularly by older Haida women.
- Commercial SOK in Gwaii Haanas: Preferred scenario by the majority, especially for food customs by women.
- Commercial Roe Fishery (seine or gillnet) in Gwaii Haanas: Disliked in terms of both food customs and ocean connections.

The three fishing scenarios resulted in only modest differences in the marine food web but larger differences in social outcomes resulting from different types of herring fishing. In general, the scenario with Commercial SOK was preferred followed by Traditional Fishing only. The Commercial Roe Fishery was disliked. Participants perceived that the Commercial SOK scenario would yield the greatest conservation and sociocultural outcomes. Participants observed that current herring productivity is still too low to meet the socio-cultural practices and food needs of Haida.

Local participants in workshops and interviews identified additional policy and management considerations related to conservation, ecosystem benefits, equity, and rebuilding. These included:

- A need to have enough herring in the right places, such as traditional harvest places, before reopening fisheries.
- A need for a consistent recovery before reopening fisheries to avoid a repeat collapse, i.e., not just above a threshold one year, but multiple years.
- A need to see evidence of the ecosystem effects of recovered herring such as seeing a higher abundance of species dependent on herring including salmon, halibut, and seabirds.
- For some, the degree of acceptance of scenarios depended on the use of the herring (e.g., human food, bait, animal feed).
- A need for a better understanding of who benefits economically from the fishery.
- A desire for Haida and on-island priority for benefits from herring.
- A need for co-management of herring with decisions made by CHN together with Canada.

## 5.2.4 Management

Management measures and policies associated with herring fisheries in BC have changed over time. Measures and policies specific to each fishery are summarized below in addition to overall management resources, current management structures and spatial protection measures. Further information about the socio-economic components of each of the fisheries is described in Section 5.2.3 and Appendix E (available on request); additional information on the cultural significance of the Haida traditional fisheries is described in Section 5.2.2.

### 5.2.4.1 Management by Fishery Type

#### *5.2.4.1.1 Haida Traditional Fisheries*

Traditional fisheries will not be limited by this rebuilding plan, and may occur in all areas of Haida Gwaii, subject to conservation. DFO sets an allocation level of 150 tons (136 tonnes) of herring in the Major SAR annually for Haida traditional fisheries (Section 5.2.3.1), currently referred to as food, social and ceremonial (FSC) fisheries in DFO fisheries management plans (IFMP 2021) for management purposes (for additional details, see Section 3.5).

#### *5.2.4.1.2 Commercial Reduction Fisheries*

During the reduction fishery period, Haida Gwaii was initially identified as a single management area. Unlike some other areas of BC, most of the reduction fisheries in Haida Gwaii occurred mainly during the period when herring began to aggregate for spawning (Box 34). No fishing effort limits were in place during this period. In 1964, nine discrete major migratory populations, including Skidegate Inlet and K'iid Xyangs K'iidaay (*briefly known as Burnaby Narrows*), were identified based on tag recoveries (Taylor 1964). Taylor noted that little was known at that time about herring on the west coast of Haida Gwaii.

> Box 34. We used to get some (k'aaw) right in here (Skidegate Inlet). Until they had no quota in the Inlet, fished it out a couple of times and then [clap] no more fish in the inlet. Just been lacking off and on ever since, after they really cleaned it out. Ah, at nighttime, wintertime, you'd see it, like a big city out there, all these big seine boats with their lights. Just tons and tons, taking fish out, taking herrings out of here. It never really came back after they cleaned it out. [Fishing was] with a big seine, a real deep seine. Big boats, double-deckers. That was what was doing all the fishing. Yeah, there was no limit here at all so it didn't take long for them to clean it [out]. Ever since then it's never been the same. (Ernie Wilson, 1998)

Coastwide reduction catches peaked in 1962-63 and during this period, management measures included closed areas, closed seasons, catch quotas for some areas and mesh regulations (Stocker 1993, Hourston 1980). No catch quotas were in place for Haida Gwaii (Taylor 1964). Langara Island was noted as a closed area due to the commercial salmon troll fishery in that area. Fishing was also closed during the herring spawning period, with the fishing season generally extending from June 1 to March 10 or until quotas were reached (Taylor 1964).

The purpose of regulations during the reduction fishery was to maintain maximum sustained productivity (Taylor 1955 as cited by Stocker 1993). At the time it was believed that high harvest rates (75% or more) had limited effects on recruitment. The catch quotas set for some areas had limited effect on catches as extensions were frequently granted (Hourston 1980). Management proved ineffective to stop overfishing and led to the collapse of herring fisheries coastwide in the late 1960s. Hourston (1980) estimated that removal rates for lower Haida Gwaii during the reduction period were 44% before and 83% during the period of low abundance before the collapse. He pointed to poor recruitment over several years, increases in fishing efficiency to an extent that was not appreciated at the time, and inability of stock assessment procedures to detect the extent of the decline in spawning escapements, as the main factors causing the serious decline in eight herring populations including Haida Gwaii, while the upper east coast of Vancouver Island did not exhibit a decline (Hourston 1980).

#### *5.2.4.1.3 Commercial Bait Fisheries*

Commercial bait fisheries have represented a relatively small portion of commercial fisheries catches in Haida Gwaii to date. Up until about 1990, BC commercial bait operations were typically managed as permits with an allocation of 50 tons. Larger allocations were initially provided to a few companies or organizations in the Strait of Georgia and Prince Rupert areas.

Declining roe prices and market demand have led to a larger scale food and bait fishery in the Strait of Georgia. In both the Strait of Georgia and Prince Rupert areas, seine licence holders have been given the option of fishing food and bait instead of participating in the roe fishery since 2017 (DFO 2020). In the Strait of Georgia, the food and bait allocation increased in 2011/2012 and remained consistent for about a decade at approximately 6000 short tons per year. Food and bait allocations were then much reduced in 2021/2022 and 2022/2023 given the reduced overall permitted harvest rate (10% vs. 20%) in the Strait of Georgia. If a seine fishery is permitted in Haida Gwaii in the future, the fishery could experience changes similar to other areas (i.e., allocation changes from herring roe or bait).

Commercial bait is also harvested on a very small scale through Special Use Permits. From 1985 to 2002, several recreational service providers held commercial and sport bait licences (DFO Special Use Category ZY1 and ZY2) allowing impoundment of up to three tons of herring in PFMA 1, including near Naden Harbour. In recent years commercial and sport bait fisheries in other areas of the BC coast (Strait of Georgia and Prince Rupert) have occurred under a DFO Special Use Permit.

##### *5.2.4.1.4 Commercial Spawn-on-Kelp Fishery*

Successful experimental SOK operations in Haida Gwaii in 1972 and 1974 led to issuance of permits to 13 individuals in 1975, including two in Haida Gwaii. No commercial SOK operations have occurred in the Major SAR of Haida Gwaii since 2004. A limited number of operations have been permitted in the Minor SAR and since 2005 operated in 9 out of 16 years. Herring SOK licences are limited to a specific geographical area within the Major or Minor SARs.

The SOK fishery is managed using fishing quotas and limited entry, and presently occurs in four of the five Pacific Herring Major SARs: Haida Gwaii, Prince Rupert District, Central Coast, and the West Coast of Vancouver Island. It has not occurred in the Strait of Georgia since 1986 because of a lack of suitable kelp in the area. The fishery has also been active in the 2 Minor BC herring SARs (Area 2W and 27), and in Areas 10 and 12 which are outside the Major SARs.

Licensing in the SOK fishery is unique in that licenses provided for the commercial harvest of SOK within specific areas are issued to individuals or parties and are non-transferable. As such, SOK licenses cannot move areas if stocks decrease, nor can they be sold and transferred to another individual or party. Some exemptions have occurred as a result of legal challenges or through appeal board processes. This is in contrast to roe herring licenses which are transferable and have the opportunity to select a fishing area annually, when multiple areas are open.

SOK licences are quota-based licenses which have individual catch quotas that stipulate the maximum weight of spawn-on-kelp product that may be harvested. The base catch quota was 6 tons per licence from 1975-76, 10 tons in 1977 and 8 tons (16,000 lbs or 7,256 kg) from 1978 to present. There are also overage/underage provisions such that individual licence quotas varied from the base amount in most years. The number of SOK licences in BC gradually increased from 13 in 1975 to 46 at present (Table 3). In 1977, Haida Gwaii accounted for 11 of the 24 SOK licences in BC. Of those licences, five belonged to Haida individuals and two to Haida organizations. Following a closure and restrictions from 1995-1997, two of the Haida permits were moved to the mainland, leaving nine SOK licences on Haida Gwaii of which three belonged to Haida individuals and two to Haida organizations. The Council of the Haida Nation obtained a SOK licence around 1998 to bring the total number of licenses on Haida Gwaii to ten.

Increases in the number of SOK licences were the result of several policy initiatives. In 1989, ten new SOK licences were granted to Indigenous individuals or Nations, subject to retirement or making temporarily inactive either one seine or six gillnet roe herring licences. Then in 1996, the Supreme Court of Canada found in its Gladstone decision that the Heiltsuk First Nation had an Aboriginal right to commercially fish herring SOK. As a result, an additional seven new communal commercial licence eligibilities were negotiated with the Heiltsuk Nation. Until 2017 the Heiltsuk held nine SOK licences in the Central Coast SAR, equivalent to an annual quota of 240,000 lbs. In 2018, this was permanently increased by four SOK equivalent licences, or 64,000 lbs, to an overall quota of 304,000 lbs. DFO identifies the Heiltsuk fishery as a rights-based commercial fishery (DFO 2021). DFO licensing policy does not recognize Haida title or rights to commercial SOK fisheries, and overall, Haida commercial fisheries is an issue for reconciliation as described in Section 3.5.

Of the 46 current SOK licence eligibilities, 12 are communal commercial category ‘FJ’ licence eligibilities held by First Nations (three as a result of relinquishment through Allocation Transfer Program (ATP) and re-issuance as communal commercial and nine are unique Heiltsuk communal commercial licences). The remaining licenses are category ‘J’ commercial licence eligibilities issued to individual parties, which include First Nations individuals and bands.

Annual assessment and aggregate quotas for the commercial SOK and roe herring fisheries follow the same modelling and assessment procedures as described below for the roe herring fishery in Section 5.2.4.1.5.

##### *5.2.4.1.5 Commercial Roe Herring Fisheries*

As herring populations increased after the coastwide closure in the late 1960s, an experimental roe herring fishery began in 1971, and a limited entry roe herring licence was introduced in 1974. The fishery was initially a purse seine fishery, then gillnets assumed an increasing role, and by 1980 accounted for about half the coastwide catch. Gillnet fisheries did not occur every year a herring roe fishery was opened in Haida Gwaii. From 1972-1982, the roe herring fishery was managed through an optimum escapement policy (Trumble and Humphreys 1985). An optimum spawning escapement level was calculated for each management unit and biomass above that level was considered harvestable surplus (Hourston 1980). However, this approach led to large catches of roe herring during years of strong recruitment (Stocker 1993: 273). Additionally, there were difficulties in determining appropriate escapement targets and surpluses, leading to regularly exceeding catch targets (Schweigert 1995). Harvest rates in southern Haida Gwaii from 1972-77 averaged 44% (Hourston 1980). From 1972 to about 1982, the harvestable surplus was determined in-season on the fishing grounds for up to 35 individual management units in BC, including six in Haida Gwaii, to achieve spawning escapement goals (Hourston 1982; Stocker 1993). Three of the Haida Gwaii management sections were identified as major clusters of spawning grounds capable of supporting appreciable fisheries: Cumshewa, Burnaby Island and Louscoone (Hourston and Haegle 1980, Figure 4). The status of individual stocks was assessed in-season using catch, biological samples, spawn (Stocker 1993), and estimated biomass from soundings. Some fisheries occurred outside the assessed areas during the early period of the roe herring fishery, including Skidegate Inlet and Naden Harbour. Over time, Skidegate Inlet was no longer included in the assessment area.

In 1982, five aggregate herring management units were identified in BC. Finer-scale Haida Gwaii units were eventually aggregated into one Major SAR, extending from Cumshewa to Louscoone. DFO established a fixed harvest rate policy of 20% for Major SARs whereby the recommended yield was estimated pre-season from a forecast of the spawning stock biomass in assessment areas.

The Minor SAR on the west coast of Haida Gwaii, including herring sections from Tasu to Port Louis, was not officially included in the annual stock assessment process until 2007 (however, biomass records exist for most years dating back to 1973). Harvest levels were calculated by applying a harvest rate of 20% to the previous year’s soundings, roe fisheries were open in 8 of the 13 years from 1981-1993 (Figure 19). The spawning biomass declined in subsequent years and the fishery was not sustainable (Figure 19, Box 35). Following the 1994 fishery, the policy for the Minor SAR changed to a 10% harvest rate applied to spawning biomass estimates from spawn surveys in the previous year.

*Box 35. … one year before the closure [in 1995]… they fished every fish out of Rennell Sound and Inskip… to get their 1000 tons. And they didn't even get their 1000 tons. They quit at 800 tons because they couldn't find any more fish. … The fishermen finally shut it down themselves; the Fisheries didn't. They just finally knew that … if they catch every fish… they're not going to come back. (Vince Pearson, 1998)*

The number of coastwide licences in the roe herring fishery was not restricted until 1974 when a limited entry lottery fishery system was introduced. The original licence targets were 150 seine and 450 gillnet licences, however this was greatly exceeded and by 1987, there were 252 seine and 1,327 gillnet licences (Pearse 1982). The gillnet licences were since reduced and have remained static at 1,267 since 2014. Since 1981, eligible roe herring licences have selected a Major or Minor stock area to fish on an annual basis once roe herring allocations are determined (Sporer 2001). In 1983, pre-season quotas were introduced to regulate the catch (DFO 2008), to move away from setting quotas using in-season soundings, and to address the difficulty of managing a large fishing fleet. Since 1999, seine and gillnet licence holders have been required to fish in vessel pools. This was implemented to reduce fishing quota overages that had become common as a result of the fleet size and difficulty managing to a fixed catch quota.

Various stock assessment models have been used to forecast pre-season herring biomass and generate quotas by Major SAR however, a statistical catch-age model was introduced in 1983 (Haist and Stocker 1984) and is still in use today, with periodic updates and refinements. More detail on the catch-at-age model history can be found in the IFMP (DFO 2021b). Herring stock assessment data continues to be collected based on finer-scale herring sections identified when mapping work began in 1983 with some changes to boundaries and geographical names (Hay and McCarter 2013).

The maximum harvest rate of 20% of the preseason forecast for Pacific Herring was introduced in 1983 (e.g., Haist, Stocker and Schweigert 1985). In 1986, an operational reference point (referred to as the "cut-off") was defined at 25% of unfished spawning stock biomass ($0.25SB_0$). In cases where a forecast exceeded the cut-off, but a 20% harvest rate would result in a spawning biomass that is below the cut-off, the maximum available harvest was calculated using the difference between the forecast and the cut-off. This harvest control rule of a cut-off and maximum 20% harvest rate was in place for all BC Major SARs until 2017. At that time Haida Gwaii, Central Coast and West Coast of Vancouver Island were experiencing commercial fishery closures. Between 1986 and 2013, the frequency of closures for these areas was much higher than anticipated when the harvest control rules were developed; Haida Gwaii experienced closures 46% of the time while the expected frequency was 5% (Cox et al. 2019). This finding led to a review of the harvest policy in 2017.

An analysis of potential Limit Reference Points (LRPs) for the five major stocks of herring recommended a spawning-biomass based LRP of $0.3SB_0$ for the Central Coast, Haida Gwaii and West Coast of Vancouver Island populations (Kronlund et al. 2018). The results suggested that a persistent low production and low biomass state occurred at levels below $0.3SB_0$ for at least those three SARs. As a result of this analysis, $0.3SB_0$ was used as the LRP in all major SARs beginning in 2018. In 2018, technical operating models were developed to simulation test the performance of various management procedures against conservation, biomass, and yield objectives under three different natural mortality scenarios for SOG and WCVI SARs (DFO 2019; Benson et al. *In press*). In 2019, this simulation approach was applied to evaluate management procedures against similar objectives for Haida Gwaii, Prince Rupert District, and Central Coast (DFO 2019b). No management procedures tested in this analysis for Haida

Gwaii, including a no fishing procedure, could meet the conservation objective with at least 75% probability.

##### *5.2.4.1.6 Recreational Fishery*

Individual recreational fishers are allowed a maximum daily limit of 20 kg of herring on their personal saltwater fishing licenses. Recreational catch is not consistently or reliably monitored, therefore records are limited but the catch is thought to be minimal.

#### 5.2.4.2 Management Resources

Management resources in Haida Gwaii have included various types of patrol and charter vessels combined in past years with aerial overflights. The level of resources was relatively stable through the 1980s and early 1990s. The decline in resources began in 1995 with the retirement of dedicated DFO patrol vessels: M.V. Pillar Rock operated until 1995, Sooke Post until 1997, and Arrow Post until 2014 (Figure 33). Aerial reconnaissance surveys to locate herring spawn were replaced with vessel-based surveys in 2011 when a Haida Gwaii-based float plane became unavailable. The resources for the Minor SAR have been much lower than the Major SAR and have experienced a similar declining trend that began in the early-1990s (Figure 34).

#### 5.2.4.3 Marine Zoning and Marine Protected Areas

On Haida Gwaii, marine zoning is currently established in the Gwaii Haanas Gina 'Waadlu<u>x</u>an Kil<u>G</u>ulhl<u>G</u>a Land-Sea-People Management Plan (2018), and coastal heritage sites/conservancies established in the Haida Gwaii Marine Plan (2015). Areas of strict protection in Gwaii Haanas where commercial and recreational fishing are prohibited comprises approximately 40% of the marine area (Figure 5). Prior to that plan, some small fisheries closures were put in place in Gwaii Haanas with an interim management plan in 2013, which identified 3% of the marine area as strict protection zones, including the <u>K</u>'iid Xyangs <u>K</u>'iidaay (*briefly known as Burnaby Narrows*) area. The Gwaii Haanas management plan including zoning, can be found at: https://www.pc.gc.ca/en/pn-np/bc/gwaiihaanas/%20info/%20consultations/gestion-management-2018. Coastal conservancy areas outside of Gwaii Haanas have also been zoned with some restricted activities through the Haida Gwaii Marine Plan which can be found at: https://mappocean.org/haida-gwaii/haida-gwaii-marine-plan/.

The Pacific North Coast Integrated Management Area (PNCIMA) Management Plan (2017) identified the MPA Network as one of five priorities for the Northern Shelf Bioregion. The Province of BC, the Government of Canada and 16 First Nations are working together to develop a marine protected area (MPA) network for the Northern Shelf Bioregion which extends from the top end of Vancouver Island (Quadra Island/Bute Inlet) to the Canada-Alaska border, including Haida Gwaii. The MPA network, once established, may provide additional protection for herring populations in Haida Gwaii. Conservation targets for Pacific Herring are based on conservation status, vulnerability, and ecological role, and range from medium (20-40% of a conservation feature) to high (40-60% of a conservation feature) depending on the analysis (DFO 2019). Target percentages are based on how much of a spatial feature (area, habitat, or species) should be protected. The governance partners endorsed a network action plan in February 2023 with milestones for MPA establishment by 2025 and 2030. More information on MPA Network Planning can be found at: http://www.mpanetwork.ca.

### 5.2.5 Governance

Natural resource governance is defined as the norms, institutions and processes that determine how power and responsibilities over natural resources are exercised, how decisions are made, and how organizations, groups, and individuals participate in and benefit from the management of natural resources (IUCN 2017).

The two primary partners in the governance of Haida Gwaii herring and their roles and responsibilities are:

- **Council of the Haida Nation** (CHN): An elected body representing Haida people who is responsible for protection of Haida Title and Rights and natural resource management according to the Constitution of the Haida Nation.
- **Government of Canada**: Includes Fisheries and Oceans Canada (DFO) and Parks Canada (PC). DFO is responsible for management of fisheries according to the Fisheries Act. In Gwaii Haanas, PC, working jointly with the CHN, is responsible for management of protected areas established under the National Parks Act (Gwaii Haanas terrestrial area) and the National Marine Conservation Areas Act (Gwaii Haanas marine area). An agreement on *The Role of the Archipelago Management Board in Gwaii Haanas Fisheries Management* was approved and accompanied the Gwaii Haanas Gina 'Waadluxan KilGulhlGa Land-Sea-People Management Plan (2018), committing CHN, PC and DFO to work together on fisheries management within Gwaii Haanas through the AMB.

Key structures for government-to-government planning, decision-making and/or consultations about Haida Gwaii herring include:

- **Archipelago Management Board** (AMB): Governs the planning, operations and management of Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve, and Haida Heritage Site. The AMB is comprised of three CHN, two Parks Canada and one DFO representative(s) and makes decisions by consensus. The Gwaii Haanas Marine Agreement (2010) outlines the roles and responsibilities of the AMB in management of activities in the Gwaii Haanas marine area, including fisheries. The Gwaii Haanas Gina 'Waadluxan KilGuhlGa Land-Sea-People Management Plan (described below) details how Canada and the CHN are working together to manage the Gwaii Haanas area, including herring.
- **Marine Management Council**: As part of the ongoing reconciliation discussion, CHN and Canada have supported, in principle, the establishment of a senior Marine Management Council for Haida Gwaii, with equal representation from both parties (CHN and Canada 2018). It is anticipated that the CHN and Canada, through further reconciliation discussions, will determine the relationship of the AMB to such a body with respect to fisheries management in Gwaii Haanas and Haida Gwaii more broadly.
- **Cooperative Management Group** (CMG): A process established by DFO and CHN in 1993 for discussion of fisheries issues. This process was initiated through an Interim Fisheries Agreement negotiated under DFO's Aboriginal Fisheries Strategy. The CMG is charged with discussion of fisheries policy and management issues and working through a joint technical committee to review, develop, and recommend fishery management plans and projects related to Haida Gwaii herring and other fisheries.
- **Haida Gwaii and Regional Fisheries Management Councils**: The amended Fisheries Resource Reconciliation Agreement (FRRA, 2021) commits to participation of the Haida Nation in a bilateral (Haida-Canada) Haida Gwaii sub-regional Management Council for

collaborative fisheries governance and a Bio-regional Fisheries Management Council with Canada and other First Nations in the Northern Shelf Bioregion. Under the FRRA, these collaborative governance bodies will operate through a model focused on consensus-building through joint science, technical, and management discussions, and not through delegated authority. Relationship to existing management structures is still to be determined.

- **Solutions Table**: A shared management body comprised of representatives from the Council of the Haida Nation and the Province of BC established under the Kunst'aa guu - Kunts'aayah Reconciliation Protocol. The Solutions Table reviews applications, conducts analyses, and provides informed input on land use authorization issues on Haida Gwaii, including kelp harvest applications. Briefing notes with recommendations for applications are sent to the Haida and provincial decision-makers for final approvals. The AMB currently uses the Solutions Table process for kelp harvest applications in Gwaii Haanas, although that may change in future.
- The **Gwaii Haanas Gina 'Waadlux̲an KilG̲uhlG̲a Land-Sea-People Management Plan** identifies guiding principles (Table 1) based on ethics and values from Haida law. They were adapted to support planning on Haida Gwaii and have been modified for the Gwaii Haanas context. They align with principles of ecosystem-based management described in scientific, planning and management literature.

DFO leads coastwide advisory processes that include an **Integrated Herring Harvest Planning Committee** (IHHPC), which provides cross-sectoral input and advice to DFO relating to Pacific Herring management planning and review. This is supported by a Herring Industry Advisory Board (HIAB) that provides advice regarding commercial roe, food and bait, and special use herring fisheries. There is also a newly developed process comprised of First Nations in all herring fishery areas (Tier II), which provides input and advice to DFO about all facets of Pacific Herring planning. IHHPC, HIAB, and Tier II advice contributes to the Integrated Fishery Management Plan (IFMP) for Pacific Herring that DFO develops annually. The IFMP describes the open fishery areas and harvest levels for herring in the Pacific Region each season, as well as the main objectives and requirements for the herring fishery, including management measures. The linkages between the coastwide advisory process and local Haida Gwaii processes is shown in Figure 33 (Jones 2016).

## 5.3 CHARACTERISTICS OF A REBUILT HAIDA GWAII HERRING SYSTEM

The following characteristics of a rebuilt Haida Gwaii 'íináang | iinang *herring* system are informed by past, present, and expected future uses and relationships with herring (Table 5). The 'íináang | iinang system includes herring in their various life stages, predators, prey, environmental influences, and human activities and uses, including fishing as well as the governance and management systems; these contribute to human and ecological well-being and are driven by cultural and social values and institutions (Levin et al. 2016; Figure 2). Herring provide ecosystem benefits to many other species as prey, and herring spawning provides a pulse of energy and nutrients to coastal areas that contributes to the well-being of numerous species including humans. This section provides a summary of characteristics and specific references are provided in Section 5.

### 5.3.1 Ecology

The vital role of herring as an ecological and cultural keystone species in the Haida Gwaii ecosystem is restored by a rebuilt herring system. The high energy content of herring contributes to their importance as a forage species for seabirds, other fishes and marine mammals. In recent decades, some herring predators, such as grey whales, humpback whales, sea lions, and harbour seals, have been increasing in numbers after low population abundance caused by historical culls and over-exploitation. Predation during the spawning season when herring aggregate in nearshore areas can be difficult to separate from estimates of overall natural mortality. Environmental conditions, including direct and indirect effects of climate and ocean change, are also affecting the herring system, impacting foodwebs and herring population dynamics. Together, these changes and sources of mortality are affecting herring rebuilding in multiple ways that are difficult to disentangle. When the system is rebuilt, herring will once again fully support the biodiversity and productivity of Haida Gwaii ecosystems at multiple spatial scales.

#### 5.3.1.1 Herring Abundance and Productivity

In a rebuilt system herring abundance and productivity are at levels that indicate healthy herring populations. When herring reach critically low abundances such as experienced in Haida Gwaii for the past two decades, they are susceptible to processes such as low reproductive success from Allee effects and predation pressure that keeps their abundance depressed and limits their ability to recover. Low herring abundances and changes in population dynamics have significant ecosystem effects, including impacts on human activities and well-being. Haida Gwaii is the smallest of the BC herring Major SARs and has more variable recruitment than the other major stocks. Strong recruitment has been infrequent in recent years, and high variability in productivity makes it challenging to determine whether short-term increases in productivity are persistent. Herring productivity varies at different scales from regional to local spawning sites. Some areas such as Juan Perez Sound and Skincuttle Inlet are known for their high abundance and productivity as reflected by higher average biomass and more consistent return of spawners. Skidegate Inlet was highly productive in the 1950s and 60s, but has been depressed since then. Haida Gwaii herring modelling analyses have shown a period of low productivity in the late 1970s which was likely driven by high harvest rates during the reduction fisheries period (1951-71), and another long-term period of low productivity that began in the mid-1990s. Changes in herring productivity may not be detectable over short time periods, and is impacted by environmental conditions and juvenile recruitment. To mitigate against lower productivity and foster rebuilding throughout Haida Gwaii, the best insurance is to maintain very low harvest rates, managed at the sub-stock or smaller scale, to maintain sub-stock biomass above minimum thresholds.

#### 5.3.1.2 Spatial Distribution

In a rebuilt system, herring are spatially distributed throughout Haida Gwaii, and spawn annually at self-sustaining levels in inlets and coastal areas where they were historically found. Most herring are migratory, spawning in nearshore areas and then moving offshore, while some herring may remain resident in inlets throughout the year (e.g., possibly herring in Englefield Bay). Haida traditional knowledge supports the management of herring at a finer spatial scale than is currently used to assess and manage Haida Gwaii herring populations (Box 36). Differentiation of the Major and Minor SAR populations into finer stock structure is further supported by recent genetic work, which links to geographic separation and differences in spawn timing. Traditional and scientific knowledge also distinguish Skidegate Inlet, Masset Inlet, and Naden Harbour as

> *Box 36. They're just like salmon, I think. They may travel a long way when they are not spawning. But I feel strongly that they go back to the same area to spawn, where they were born. But fisheries [DFO] think otherwise. They manage the whole area like they spread out and spawn in that whole area. We all know that they just spawn a little bit here and a little bit there. Wipe out these and it's gone. (Percy Williams, 1998)*

distinct sub-stocks. Naden Harbour is likely also distinct due to its geographic separation from other areas. Some areas of Haida Gwaii are the focus of higher cultural use, including Skidegate Inlet, Selwyn Inlet and Burnaby Island including Juan Perez Sound and Skincuttle Inlet. In practice, fisheries will occur on a much finer scale than the aggregate SARs, targeting sub-stocks with higher abundances in any given year. Taken together, the ecological evidence and management needs presented in Section 5.2.1.2 support finer-scale approaches to herring assessment and management to ensure continuity and resilience of all Haida Gwaii herring sub-stocks into the future. The spatial sub-stock structure that is used to assess rebuilding is described in Section 5.5.2.1.3.

#### 5.3.1.3 Age structure

Restoring and maintaining larger sizes and older age classes of herring is important in a rebuilt system. Haida Gwaii herring are known amongst fishers for their larger average size compared to other regions. Annual biological sampling of herring in Haida Gwaii show evidence of older age classes in Haida Gwaii, regardless of low biomass states, with higher proportions than are observed in other regions. This characteristic may support fidelity to spawning areas (MacCall et al. 2018) and increases the quality or value of Haida Gwaii herring products as larger herring produce more eggs. However, size-at-age of Haida Gwaii herring, particularly in the older age classes, has been declining since the 1970s, similar to other areas of the BC coast. Decreased size-at-age reduces herring fecundity and may also affect herring survival, yet this trend is outside of fisheries management control. Lack of understanding about the causes of this decline adds uncertainty to rebuilding assumptions. Once herring populations are rebuilt, supporting higher abundances of larger fish can generally be achieved by low herring harvest rates and avoiding size-selective fisheries unless there is clear evidence that they would not exacerbate declining size-at-age trends.

#### 5.3.1.4 Nearshore Habitat Conditions

Most nearshore herring spawning habitat in Haida Gwaii is relatively pristine and remains so in a rebuilt system. Contemporary urban or industrial development is minimal compared to many areas of BC, and largely outside known herring spawning areas; however legacy effects still persist from past mining, logging, and industrial activities. An emerging concern is the increasing occurrence of marine invasive species which have unknown, potentially negative impacts on herring spawning habitats and areas (Section 5.2.1.6.5). In a rebuilt system, continuing protection of herring spawning areas will foster resilience for sustaining herring populations, even in years when herring abundances are lower.

### 5.3.2 Culture

Herring is a cultural and ecological keystone species and thriving relationships with Haida are realized once again in a rebuilt system. Traditional k'aaw and commercial SOK fisheries are important for the continuity and interconnections of Haida culture, including food security and customs, sharing and trade, family and social relationships, intergenerational knowledge transfer, ceremonial use and spiritual importance, maintaining connections to important places, and practicing Haida ethics and values, particularly with regard to stewardship of herring ecosystems. Haida traditional fisheries have been constrained for several decades by low herring abundances in the traditional fishing areas on Haida Gwaii. Haida fishing culture has also been suppressed by closure of commercial SOK fisheries, which were an important social and economic activity in Haida communities, in addition to enhancing the success of traditional fisheries. As herring are rebuilt, Haida traditional fisheries, which have priority access over commercial and recreational fisheries, will thrive once again.

### 5.3.3 Social and Economic

When Haida Gwaii herring are rebuilt, local abundance of herring and spawn timing will again support successful commercial SOK fisheries and successful Haida traditional k'aaw fisheries, particularly on the east coast of Haida Gwaii. Herring provide many social and economic benefits, including healthy ecosystems, nutritious food, and fostering connections between humans and nature. A healthy ecosystem provides opportunities for education and raises public awareness about the value of ecosystem connections and protected areas, as well as providing ecological baselines for research. Traditional fisheries in Skidegate Inlet and throughout Haida Gwaii consistently support the needs of Haida communities, and social and economic relationships with herring are restored. Social and cultural benefits of traditional fisheries include connection to place, benefits to individuals, family and community, and continuity of traditional practices based on knowledge handed down from generation to generation. Recreational fisheries provide opportunities for Haida Gwaii residents and visitors to catch herring for food and/or bait for other fishing activities. Commercial SOK and roe herring fisheries support local employment and transfer of herring fishing knowledge within and among generations. In a rebuilt system, herring will again provide social benefits through thriving activities such as tourism, enjoyment of nature, traditional fisheries, recreational fisheries and commercial fisheries.

### 5.3.4 Management

Ecosystem-based management of herring will be collaborative and provide sufficient information about herring sub-stocks throughout Haida Gwaii. The EBM approach considers cultural, ecological, governance, management and social and economic well-being of Haida Gwaii communities. Monitoring the status of herring in all sub-stocks and monitoring the human aspects of the herring ecosystem will be required to determine rebuilding status in accordance with multiple rebuilding targets. As herring populations rebuild sufficiently to allow fisheries in accordance with rebuilding plan thresholds, they will be collaboratively monitored and managed consistent with agreements and processes developed by the Haida Nation and Canada. The best available information will be used to foster sustainable, adaptive, EBM at appropriate spatial and temporal scales. Long-term monitoring and research will assess herring rebuilding, and improve understanding of the herring system including conservation and fisheries according to an EBM framework. The herring management process will incorporate Haida traditional knowledge and recognize Haida laws in decision-making. The Haida Nation and Canada will foster effective stakeholder and public engagement in the management process and safe operations in herring fisheries.

### 5.3.5 Governance

Current fisheries governance systems involving the Haida Nation and Canada are evolving and adapting in response to reconciliation processes (see Section 2.2.2). Reconciliation is an important driver for changes in governance, management and decision-making related to Haida Gwaii 'íináang | iinang *herring*. This rebuilding plan was developed through a collaborative process involving the Haida Nation and Canada as represented by Gwaii Haanas Parks Canada and Fisheries and Oceans Canada. The Haida Nation and Canada will cooperate in monitoring herring populations and make joint decisions about the status of herring populations and management of fisheries consistent with the rebuilding plan. Decision-making structures and processes will be guided by reconciliation processes, agreements and plans. Moving forward, implementation of the Haida Gwaii herring rebuilding plan by the Haida Nation and Canada will continue to be coordinated with and integrated into collaborative governance and management processes, including the development of Integrated Fisheries Management Plans for Pacific Herring.

### 5.3.6 Reference Points

As part of this rebuilding plan and the overall DFO Sustainable Fisheries Framework for Canadian fisheries, reference points for defining rebuilt Haida Gwaii herring populations were identified that account for uncertainty and risk when implementing decision rules. Reference points are used in fisheries management to compare the current status of a population to benchmarks for healthy, cautious, and critical zones, and to evaluate the performance of harvest strategies.

For the Haida Gwaii Major SAR, the established LRP is 30% of unfished spawning biomass ($0.3SB_0$; Section 2.2.6) which signals the approximate uppermost limit of the critical zone for this population. This LRP was determined using the equilibrium concept of theoretical ecology, in which the unfished equilibrium spawning biomass ($SB_0$) and the minimum depletion levels, which the population recovered from during a period of low biomass and low productivity, are estimated. The equilibrium approach can be vulnerable to assumptions about productivity and growth dynamics and is limited to situations where data is adequate to support fitting population dynamics models. This LRP was also identified based on a single-species paradigm and did not consider ecosystem interactions.

The TWG adopted an alternative approach to determining reference points based on empirical methods to identify productive reference periods, which were used to set short- and long-term rebuilding targets. This approach provided a relative measure of the status of herring populations over time. It can also be applied to sub-stocks within the Major or Minor SARs using biomass estimates from population dynamics models where they exist, or abundance indices such the spawn index. Reference periods for the Major and Minor SARs are 1975-1985 and 1982-1992, respectively (Appendix F), chosen based on evidence of population recovery from a relatively low state back to a relatively high abundance. The Major SAR reference period was also based on a period of high abundance with successful SOK fisheries, including those using open-ponding techniques. Short and long-term rebuilding targets were identified for the Major SAR based on percentages of the average estimated abundance during the reference period in order to incorporate ecosystem considerations and uncertainties (Figure 12; Table 5). Long-term rebuilding targets were determined for some sub-stocks in the Minor SAR (Table 5), and no rebuilding targets have been identified for other Haida Gwaii sub-stocks due to data limitations. Major SAR reference points were incorporated into some of the modelling analyses (Section 6) and management recommendations (Section 7) to support Haida Gwaii 'íináang | iinang *herring* rebuilding.

# 6 MODELLING APPROACHES TO SUPPORT REBUILDING

Many hypotheses have been identified about the potential drivers of the continuing depressed state of Haida Gwaii 'íináang | iinang *herring*, such as environmental conditions, past overfishing, increased predation, and Allee effects (Section 5.2.1). The modelling approaches currently used to determine the status and management of Haida Gwaii herring are an annual assessment model of the aggregate population in the Major SAR (Section 5.2.1.4; DFO 2021a) and MSE simulations for the Major SAR (DFO 2019). Modelling results have identified that Haida Gwaii herring populations in the Major SAR have been in a persistent state of low spawning abundances and low productivity, however the mechanisms driving this persistent state remain largely unknown. The Minor SAR status is currently determined by examining trends in aggregate spawn biomass. Multiple interacting factors are likely contributing to persistent low Haida Gwaii herring abundance, with no evidence for any particular definitive cause(s) (see Section 3.6).

Several rebuilding objectives (Section 4.2) require support from additional modelling analyses and research in order to address uncertainties about the spatial structure of Haida Gwaii herring populations (e.g., Objective 1.1), the status of sub-stock populations (e.g., Objective 2.2), the relative impacts of different fisheries (e.g., Objective 3.3), and the environmental conditions affecting the populations (e.g., Objective 1.3). Initial steps to exploring these uncertainties taken by the rebuilding plan TWG included:

1. Extensions to the current DFO-led MSE process to focus on rebuilding and addressing herring in the Haida Gwaii Major SAR at a finer spatial scale, including consideration of multiple rebuilding objectives related to reference points, expected timeframe for rebuilding, social and economic considerations, and management procedures identified by the TWG;
2. Additional herring assessment modelling to explore spatial and temporal biomass dynamic and growth dynamics, applied broadly to all Haida Gwaii herring populations (Major and Minor SARs, Skidegate Inlet, Masset Inlet, and Naden Harbour); and
3. Initial steps to incorporate environmental factors by examining potential correlates of herring production and productivity in the Haida Gwaii area.

Details of these three analyses are described in Appendices G, H and I (available on request).

## 6.1 MANAGEMENT STRATEGY EVALUATIONS

Simulation evaluation techniques have become widely accepted tools in fisheries research to investigate the potential impacts of uncertainties on future stock status (Punt et al. 2016). DFO initiated a Management Strategy Evaluation (MSE) process for Pacific Herring across BC with the intent of simulation testing candidate management procedures at the major management area level (Haida Gwaii, Prince Rupert District, Central Coast, Strait of Georgia, and West Coast of Vancouver Island) to identify precautionary approaches to management. To date the process has resulted in a number of important findings, including identification of critical uncertainties that are not currently represented in the MSE operating models or management procedures (Benson et al. *In press*); these uncertainties include spatial disaggregation of data, smaller management units, fleet dynamics, and environment-stock interactions. From the first MSE simulation analyses for Haida Gwaii herring, no candidate management procedures, including no fishing (harvest rate = 0%), were able to meet the conservation objective under current natural mortality conditions (DFO 2019). This further confirmed the depressed state of Haida Gwaii herring, identified a need for considering alternative operating models to represent major uncertainties that are difficult to resolve, and to investigate management procedure performance under optimistic stock growth scenarios in order to evaluate rebuilding dynamics.

For this rebuilding plan, the specific goals of the second MSE simulation analysis were to:

a) Incorporate assumptions about finer spatial scales of stock structure; better represent fleet dynamics, including SOK removals; and additional natural mortality scenarios, including those linked to potential drivers of the current low productivity and low biomass state, as well as future stock growth assuming optimistic conditions;
b) Identify precautionary management procedures for the rebuilding phase;
c) Highlight potential trade-offs in population growth under the different management procedures;
d) Inform criteria for the long- and short-term rebuilding phases for Haida Gwaii herring;

e) Provide a priori understanding of the tradeoffs in population growth associated with different management procedures when the biomass levels are healthy; and
f) Inform management recommendations of this plan.

### 6.1.1 Approach

A step-wise approach was used to evaluate the expected performance of proposed rebuilding procedures, measured against biomass-based rebuilding objectives for Pacific Herring in Haida Gwaii (Cox et al. 2010):

1. Define and rank conservation and fishery objectives that rebuilding procedures must meet to be considered for application in Haida Gwaii (Table 6).
2. Define a range of rebuilding procedures by:
   (i) **data** types and precision;
   (ii) **assessment methods** for establishing stock status;
   (iii) **harvest control rules (HCRs)** for setting annual catch limits; and
   (iv) **meta-rules** for modifying annual catch limits given pre-defined constraints and conditions as required. Meta-rules might involve time intervals, constraints on fisheries, spatial and fishery allocation rules, and/or rules for revising the rebuilding procedures, as well as "exceptional circumstances" that provide trigger points and subsequent actions when rebuilding procedures are considered unreliable.
3. Specify operating models (OMs) to enable simulation of alternative plausible scenarios for Haida Gwaii herring population responses to fishing and data generation mechanisms. This step involves first fitting the OM to available data to estimate model parameters consistent with the stock history and structural assumptions of OM scenarios.
4. Project Haida Gwaii herring spatial sub-stock population dynamics and fishery harvests forward for three herring generation (15 years) from its current state for each management procedure under each alternative OM scenario. Each year and simulation replicate of the projection involves the following steps:
   (i) Simulate the data available for stock assessment and append to existing data sets;
   (ii) Apply the assessment method to the data to estimate quantities required by the HCR;
   (iii) Apply the HCR to generate a catch limit;
   (iv) Apply meta-rules such as area and fishery allocations;
   (v) Subtract the final catch limit from the simulated herring population as represented by the OM;
   (vi) If not in the final projection year, return to 4(i), otherwise go to 4(vii);
   (vii) Repeat steps 4(i)-4(vi) for 100 simulation replicates with independent random seeds.

### 6.1.2 Management Procedures for Rebuilding

Five candidate rebuilding procedures (RPs), including a no fishing procedure where harvest rate = 0%, were identified by the rebuilding plan TWG (Table 7). All RPs used the same historical data inputs and survey-based assessment method to generate 1-year ahead biomass forecasts in each of the three Major SAR sub-stocks and to determine stock status (See Appendix D for further details). A conservative ramped (hockey stick) HCR was used to determine the total allowable catch (TAC) in all RPs that allowed fishing. The lower control point was set at 30% of unfished biomass, below which the harvest rate was set at 0%. The upper control point was set at 100% of unfished biomass, above which the reference target harvest rate was 10%. The status quo no fishing procedure, where no fishing was allowed in any sub-stock, was also tested to highlight the impacts of environmental and biological assumptions in the OMs.

The aggregate Major SAR stock was separated by the rebuilding plan TWG into the three spatial sub-stocks (from north to south): Cumshewa/Selwyn (C/S), Juan Perez/Skincuttle (JP/S), and Louscoone (Lou; Figure 4). Based on the population trends in these sub-stocks and rebuilding objectives, several meta-rules were established and applied for all RPs. These meta-rules included limiting any simulated commercial seine roe fisheries to the JP/S sub-stock and restrictions on the maximum number of commercial SOK licenses in each sub-stock (8 in JP/S and 1 in each of C/S and Lou,Table 7). Each of the RPs was applied independently to each sub-stock, except for area-specific limits on seine roe fishing and the number of SOK licenses, and was evaluated under each of the OM scenarios described below.

### 6.1.3 Operating Models

A large component of the on-going DFO MSE process for Pacific Herring has been the development of OMs to investigate potential impacts of critical uncertainties in the assessment and management of Pacific Herring. The Spatially Integrated Statistical Catch-at-Age Herring (SISCAH) OM is an age-structured model with multiple biologically independent sub-stocks that has been developed as a base OM with the flexibility to accommodate numerous scenarios about Pacific Herring and commercial fishery dynamics, including SOK (Appendix G).

The SISCAH OM is applied to each of the sub-stocks independently assuming no mixing and the aggregate stock status is estimated by summing across the sub-stocks. In addition to increased spatial resolution, the SISCAH operating model also incorporates closed-pond and open-pond SOK fisheries. For closed-pond fisheries in Haida Gwaii, fish are captured via purse-seines and then towed to and subsequently transferred into a closed net-pen (pond), within which herring will spawn on blades of kelp placed in the pen (usually *Macrocystis pyrifera*) (Schweigert et al. 2018). In the OM the closed-pond fisheries are modelled in the historical and projection (when applicable) periods by removing ponded fish from the spawning stock biomass for a portion of the fishing year (April 15$^{th}$-June 30$^{th}$), and then releasing them to the main population, after losses due to a ponding-induced mortality. The ponding-induced instantaneous mortality rate for closed pond SOK fisheries was fixed at 0.315/yr in the historical period, based on an average observed loss of 27% of ponded biomass (Shields and Kingston 1982). In reality, the true value of ponding induced mortality can be highly variable and dependent on environmental factors, general stock health, tow distance, pond density, and operator handling (Shields and Kingston 1982; Schweigert et al. 2018). To account for uncertainty in the ponding-induced mortality, we tested an alternative higher rate in simulations, with 1.05/yr, corresponding to 65% mortality of ponded biomass (Schweigert et al. 2018). In an open-pond fishery, herring are not impounded but are attracted to a site where kelp is laid out to collect spawn, or alternatively, frames strung with kelp are towed to sites where herring are already spawning. Open-pond SOK harvesting induces lower mortality on mature fish, and its impact on the stock is primarily through egg loss (Shelton et al. 2014). Historical data for open-pond SOK fisheries are not available, therefore open-pond SOK fisheries are only modelled in the projection period. To simulate an open-pond SOK fishery in the projections, the fish necessary to generate the harvest were removed from the spawning stock biomass, but no ponding-induced mortality rate was applied. The biomass vulnerable to the seine roe fishery was set equal to the total mature spawning biomass because there is no impounding and associated gear selectivity.

From the base SISCAH OM, a total of 72 OM scenarios were defined for Haida Gwaii herring, combining 18 historical scenarios with four projection hypotheses (Table 8, Appendix G). The historical scenarios represented multiple hypotheses about age-1 natural mortality rates, stock productivity (stock-recruit steepness), and whether the projected time-varying mortality random walk deviations were identical or correlated among the three sub-stocks. The projection scenarios included uncertainties about the future trends in age 2+ natural mortality rates and closed-pond SOK ponding mortality rates.

### 6.1.4 Main Findings to Support Haida Gwaii Herring Rebuilding Plan

Main findings from the MSE simulation evaluation analyses for the Haida Gwaii 'íináang | iinang *herring* in the Major SAR indicated that:

1. Rebuilding performance of Haida Gwaii 'íináang | iinang *herring* populations was dominated by the population and ecosystem dynamics represented in the operating model scenarios, and not by the impacts of fisheries allocation scenarios simulated in the analyses. Very little difference was found in stock growth towards short- and long-term rebuilding targets between the no fishing scenario and the conservative ramped (hockey stick) HCR RP;
2. Change in natural mortality was the main driver of herring biomass dynamics in the MSE, as has also been shown in the annual stock assessments and ongoing Pacific Herring MSE OM development;
3. SOK fisheries had less of an impact on population rebuilding compared to the commercial seine roe fishery; and
4. SOK fisheries allowed for more fishing opportunities than the commercial seine roe fishery due to the assumption of a minimum TAC requirement (300 t) for opening the herring seine roe fishery.

Several results from the simulation analyses indicated that operating model dynamics were the main drivers of recovery (or lack thereof), rather than the choice of fishery allocation under the same empirical forecast or HCR. First, no RP met the conservation objective when performance was averaged over the full OM grid and the variation in conservation performance was quite small across all rebuilding procedures (Table 9. Rebuilding procedure (RP) performance for the aggregate Haida Gwaii 'íináang | iinang *herring* population with respect to biomass metrics, averaged over the full grid of 72 operating models assuming an equal weighting. RPs are ordered by performance with respect to the conservation objective, i.e., $\boldsymbol{P\ B_{t\geq}0.3B0}$. Growth rates are provided in percentage points, and biomass values are in kt.). The no fishing (NoFish) procedure exceeded the LRP in 49.8% of simulated years and replicates, while the RPs that allowed fishing ranged from 49.6% for the open-pond SOK fishery (oSOK) to 48.3% for the seine roe fishery (SR), all within 3.1% of the NoFish performance. This result was observed at both the aggregate population level and at the disaggregated sub-stock level (Table 10).

Second, when OMs were examined individually, the conservation performance for the NoFish procedure was almost perfectly correlated with 2019 stock status for the 18 historical OMs (Table 11). For example, the least (Table 12) and most optimistic (Table 13) natural mortality projection scenarios both showed that OMs with higher stock status (higher $SB_{2019}$ /$SB_0$ values) had higher probabilities of being above the LRP ($P(SB_t \geq 0.3SB_0)$) after the 15-year projection period. The improvements in stock status and conservation performance were driven by lower estimated unfished biomass values rather than higher estimates of 2019 biomass, because 2019 biomass is tightly constrained by the informative prior on dive survey catchability ($q$ = 1). The improved stock status to begin the projections (i.e., biomass near or above the LRP) indicated that biomass was nearer to the portion of the stock-recruitment curve where, on average, recruitment was at its density-dependent maximum. As expected, the most pessimistic natural mortality projection scenario OMs that estimated large $SB_0$ and low stock-recruit steepness were unable to rebuild in the 15-year projection under any scenario and RP. Furthermore, when future age-2+ mortality rates were slow to return to the average historical level (rw15, Table **12**), biomass continued to decline for the first part of the projection under the two time varying natural mortality historical scenarios because mortality exceeded the low average recruitment in the early projection period associated with the low biomass and stock-recruit steepness.

Finally, a conservative ramped HCR was used in all the RPs with fisheries (harvest rate > 0%) to allow population growth while still allowing for some fishing opportunities (Figure 36). The operational control points of the HCR were scaled to the estimated unfished spawning biomass averaged across the full OM grid for the aggregate population ($\overline{SB}_o$ = 50.76 kt), which was higher than the $SB_0$ estimates from 11 of the 18 individual historical aggregate OM scenarios (Table 11). The lower control point of 0.3$\overline{SB}_o$ (15.23 kt) was theoretically achievable under the majority of OMs, as the biomass estimates in the final projection year ($SB_{2034}$) were typically higher than 15.23 kt. The upper control point, however, was not achieved in any of the OM scenarios (Table 11), and the reference maximum harvest rate of 10% was on average not applied. For all OMs the $SB_{2034}$ estimates were lower than 50.76 kt, indicating that target harvest rates were likely to be low, falling somewhere on the ramp of the HCR. The minimal fishing impacts allowed by the conservative HCR chosen further supported that OM dynamics were the main drivers of recovery (or lack thereof), and not the choice of RP simulated.

The major findings from the simulation analyses were related to fisheries impacts and fishing opportunities during a rebuilding phase. As expected, results supported previous understanding that SOK fisheries have lower impacts on herring population growth and rebuilding than seine roe fisheries (Table 9 and Table 10). The simulation results indicated that for closed-pond SOK fisheries there was negligible difference in RP performance under the low versus the higher ponding induced mortality projection scenarios, given that the amount of fish ponded was low. Results also showed that SOK fisheries allowed for greater fishing opportunities, with fewer seine roe fishing opportunities because of the minimum 300 t TAC required to open the fishery in the simulations (Table 14).

The DFO Precautionary Approach (PA) Policy indicates that a reasonable timeframe for a stock to grow above its LRP should be between one and a half to two generations. However, for Pacific Herring a longer timeframe (three herring generations; 15 years) was recommended to be examined in the MSE process due to the species short life span and volatility in productivity. Simulations for a longer timeframe were not recommended for this analysis due to the added uncertainty about the species state dynamics (stochastic recruitment, natural mortality and growth). Due to this the timeframe in which the stock is expected to rebuild is uncertain beyond 15 years.

## 6.2 SPATIAL AND TEMPORAL DYNAMICS

### 6.2.1 Context

Pacific Herring population dynamics can vary dramatically, which can influence temporal trends in abundance at small spatial scales. Such complexity can have different implications for access to herring by different fishing communities and predators. Of the many challenges related to Haida Gwaii 'íináang | iinang *herring* rebuilding, this analysis focused on the following:

1. Quantifying herring population dynamics and distribution of spawning biomass at a finer spatial scale than the aggregate scale used historically for management and data

collection for Haida Gwaii herring stock assessment (DFO 2021a). The Major and Minor SARs were identified as being comprised of multiple sub-stocks with boundaries defined by the rebuilding plan TWG (Section 5.2.1.2).

2. Understanding changes in herring growth rates that can affect biomass productivity, stock assessment accuracy, and population viability through changes in somatic growth, fecundity and/or life history characteristics (i.e., size-at-maturity and size-specific fecundity). All major herring stocks in BC have exhibited substantial declines in growth parameters. Although the mechanisms causing this broad-scale decline are still unknown, they may be occurring at both local and regional scales and may vary among life stages.

These challenges require spatiotemporal analyses at both the broad- and fine-scale for comparison of regional, stock, sub-stock, and within sub-stock trends to assess how different management approaches may impact herring at different scales.

Two different modelling approaches were used to characterize spatiotemporal trends in biomass and growth dynamics. The first model used a delay difference biomass production model to simultaneously estimate: a) trends in biomass dynamics at the sub-stock level, b) historical harvest rates, c) spatial covariance among sub-stocks of trends in productivity, and d) spatiotemporal trends in the distribution of sub-stock biomass. The second model estimated spatiotemporal trends in growth anomalies to assess the degree of synchrony in growth trends between areas in Haida Gwaii and elsewhere in BC. Both were hierarchical Bayesian models that explicitly accounted for spatial structure in the time series of data.

### 6.2.2 Approach

#### 6.2.2.1 Bayesian Hierarchical Spatiotemporal Biomass Dynamics Models

To characterize biomass dynamics in space and time at the sub-stock scales, a three-tiered Bayesian hierarchical delay-difference biomass model was developed in a spatially explicit, state-space framework to estimate: (1) synchrony and variation among sub-stocks in biomass trends, and (2) variation in biomass distribution within sub-stock areas. A biomass dynamics model was used rather than an age-structured (i.e., statistical catch-at-age model) because of sparse and intermittent age-composition sampling at the spatial scales of interest, especially for the Minor SAR sub-stocks. A spatial model was used within each sub-stock because observations were recorded at finer spatial scales than the sub-stock delineations, and a core objective was to estimate the degree of inertia and variation in spatial distribution of spawn. For the purpose of supporting this rebuilding plan, analyses focused mainly on results from estimates of synchrony, sub-stock scale biomass trends, and inertia in spawning biomass distribution in space.

In brief, the model estimated biomass dynamics by allowing shared distributional properties among sub-stock parameters (i.e., a fully hierarchical model), allowing the unique trends in sub-stock productivity to co-vary in space, and assuming measurement error occurred at the scale of individual spawning locations. To link observations across scales, the model combined estimates of spatiotemporal variation in proportional biomass distribution among locations within each sub-stock with total sub-stock level biomass estimates. At the broadest scale, the model assumed that sub-stock parameters were constrained by distributional properties hierarchically; in other words, the individual sub-stock parameters were estimated with both shared and individual information by estimating overall mean parameters and constraining sub-stock scale parameters by that mean and an estimated among sub-stock variance. Biomass in any given year was modelled as a function of the prior year's biomass, and anomalies were allowed to co-vary with other sub-stocks.

Within each sub-stock, the proportional distribution of biomass was assumed to be correlated in time and space. The model estimated pre-spawn biomass production in space and time, average and sub-stock-specific productivity parameters, spatial and temporal covariance in productivity trends, harvest rates, and spatial and temporal covariance in biomass distribution in space. The Bayesian hierarchical structure, combined with a model of observation error that assumes a lower probability of detecting spawn at low abundances, is resilient to variability in survey effort and related data quality issues to some degree. However, as with the models used in 6.1, systematic reduction in survey effort over time and/or space would need to be explicitly accounted for to avoid bias in biomass estimates. The model used only vague Bayesian priors (i.e., allowed the data to drive the parameter estimates), except in the case of $q$ (spawn survey scaling), where informative priors were essential because the data itself contained little information about $q$. Locations of biomass observations and clustering into sub-stocks are shown in Figure 37. The full model is described in Appendix H.

#### 6.2.2.2 Bayesian Hierarchical Spatial Stage Specific Growth Models

To characterize spatial and temporal trends in growth dynamics, a hierarchical Bayesian spatiotemporal growth model was used to estimate trends within and among Haida Gwaii management sections, and to compare those trends across BC in space and time. A hierarchical structure was used because average growth parameters at individual sections were expected to exhibit variation around a consistent overall mean set of parameters. A spatiotemporal model structure was used because individual spawn sections were expected to exhibit temporal trends and variation in size-at-age that co-vary in space. Specifically, drivers of change in size-at-age were likely to vary in spatial scale, from being shared along the coast (e.g., due to regionally similar climatic effects), to exhibiting smaller-scale patterns of spatial covariance (e.g., changes in food supply, predator distribution, or movement of fish among adjacent sections or sub-stocks), to varying at finer-spatial scales (e.g., differing conditions for larvae or juveniles among small sections of coastline that propagate to older age classes).

In brief, the model estimated an overall mean growth dynamics model for all of BC and for each section while simultaneously estimating spatial and temporal variation in anomalies around those expectations. The model assumed growth anomalies differed by age 2 and age 3+ fish. Because the model separated mean growth expectations for each section from the spatial and temporal anomalies from those expectations, the trends were directly comparable for analyses. Specifically, the model directly used data from hundreds of thousands of individual fish from each section to account for variation in sample sizes and observation errors, and teased the spatiotemporal signal from these noisy samples. The model used only vague Bayesian priors. Using these model estimates, we directly illustrated how growth dynamics have changed over time throughout BC, and how trends in Haida Gwaii sections compared with each other and with sections elsewhere in BC. Locations of biosample observations throughout BC are shown in Figure 36. The full model equations are described in Tables 15 to 17.

### 6.2.3 Main Findings

#### 6.2.3.1 Biomass dynamics

Biomass dynamics of herring sub-stocks throughout Haida Gwaii exhibited volatility (i.e., experienced changes in biomass over short periods, meaning they were somewhat unpredictable) with periods of severe depletion (i.e., below roughly 100 tonnes cumulative biomass; Figure 36). For example, Naden Harbour, Englefield, Louscoone, Rennell Sound, Skidegate Inlet, Tasu Sound, and Port Louis have all exhibited collapses that were intermittent and/or persistent; some of these collapses followed periods of intense harvest while others occurred in the absence of documented harvests. These sub-stocks were prone to frequent or prolonged periods of extremely low biomass, and as a result, the scale of change in biomass tended to be two to three times that of sub-stocks in the Major SAR. Similar levels of volatility were observed during a few periods of severe depletion at Cumshewa/Selwyn and Juan Perez/Skincuttle (Figure 37). In general, however, sub-stocks within the Major SAR exhibited less volatility and fewer periods of severe depletion compared to those outside of the Major SAR.

Sub-stocks outside the Major SAR specifically exhibited low predictability when biomass lingered in depleted states. Rennell Sound experienced a short recovery from low biomass in the early 1980s, followed by a brief two-year collapse following modest harvest, then a brief recovery and another collapse following several years of significant harvest. The Rennell Sound sub-stock remained severely depleted until mounting a brief recovery in 2000 followed by decline, notably in the absence of harvest, to a persistently depleted state where it remains. Englefield Bay, and Louscoone Inlet in the Major SAR, exhibited similar patterns of recovery in the early 1980s, when intense harvest was followed by a brief period of low abundance in 1983, recovery thereafter, and intense harvest was again followed by persistent low abundance, where both sub-stocks remain. Port Louis exhibited similar trends in the early 1980s, with harvest and collapse in 1990, followed by persistently depleted biomass until showing recovery in 2000, with annually variable spawn indices in 2016 (negligible), 2017 (high), 2018 (negligible), and 2019 (high), leading to uncertainty in biomass estimates. Like most sub-stocks, Skidegate Inlet was subject to large removals and high harvest mortality during the reduction fishery period, followed by low production in the 1960s and early 1970s, with trace detections of spawning and low estimated biomass in the years since then. Overall, trends in biomass productivity for sub-stocks outside the Major SAR did not fluctuate synchronously, and sub-stocks in the Minor SAR experienced episodic periods of harvest that exceeded the current target 10% harvest rate for the stock (Figure 37). Although the scale of estimated biomass and magnitude of estimated harvest rates described in the patterns above depended on parameter uncertainty, especially with regards to *q,* the trends in biomass dynamics remained consistent when models were estimated with different assumptions (priors) about *q*.

#### 6.2.3.2 Spatial distribution of spawning biomass

The spatial distribution of spawning biomass within sub-stock areas is relatively consistent in terms of the proportion of spawning biomass at a given site, but that spatial trend can also vary through time (as indicated by the autoregressive coefficient, $\phi$ = 0.70 (0.67 – 0.73 95% HDI)). In other words, how spawn is distributed in space, proportionally, tends to be similar among years that are close together in time. Thus, hierarchical, spatially explicit models of biomass distribution at fine scales may provide tools that can project where biomass is likely to occur given observations in recent years, or to assess how biomass distributions change over time relative to environmental covariates.

#### 6.2.3.3 Growth Anomalies

Pacific Herring in BC have experienced dramatic, and persistent decays in growth rates of both recruits and returning adults since 1970. On average, Haida Gwaii herring grow faster and larger than in many, but not all, sections of the coast (Figure 39). Specifically, estimated mean maximum length ($L_{\infty}$) varied spatially, where for a given age and time period, herring were generally (but not exclusively) larger for a given age in exposed, western-most sections (WCVI and west coast of Haida Gwaii) and substantially smaller in sections along the BC mainland coast (e.g., some eastern sections with the Central Coast and Prince Rupert). Despite the spatial variation in mean size parameters, on average, the rates of decline in growth rates have been similar and synchronous across the coast.

Importantly, growth dynamics of Pacific Herring appear to exhibit different patterns for age-2 and age-3+ fish, where both the temporal patterns and spatial patterns differ among these stages. For both groups, growth anomalies declined consistently over time across all of BC, leading to an approximate 10% decline in annual growth rate over the time series (Figure 39). However, trends in growth anomalies for age-2 fish exhibited more region-specific synchrony than for age-3+ fish. Specifically, spatial synchrony in growth of age-3+ fish remained high (r ~ 0.75-0.90), even for sites distant from Haida Gwaii. Synchrony in growth of age-3+ declined only slightly with distance from sites in Haida Gwaii (Figure 40). In contrast, synchrony in growth for age-2 fish declined more rapidly with distance from Haida Gwaii, levelling off at mean correlation with distant sites of roughly r ~ 0.6, while within the west or east coast of Haida Gwaii sections, synchrony among neighbouring sites was approximately r ~ 0.8. Moreover, trends for age-2 fish exhibited low-period fluctuations and strong serial correlation (1st order autoregressive parameter of $\phi = 0.64$, 95% uncertainty interval: 0.57-0.70). In contrast, age-3+ fish exhibited synchronous, near linear decline with no serial correlation in the growth anomalies after accounting for the linear trend ($\phi = 0.01$, 95% uncertainty interval: 0.00-0.02) with a notable substantial decline in 2019.

Overall, the analyses results showed clear evidence for shared drivers of change in herring growth over time and space across the BC coast, with different responses among age-2 and age-3+ fish over time. Specifically, location specific factors may be contributing to greater variability for age-2 fish given the decline in covariance with distance, indicating (1) some variation in growth specific to areas of Haida Gwaii, and/or (2) shared sources of variation such as sampling effects. These differences in growth among age classes may arise from differences in diet, variation in where fish overwinter, the proportion of males versus females maturing at age-2 versus -3, or other characteristics.

### 6.2.4 Key Considerations for Management

#### 6.2.4.1 Sub-stock approach and reference points for the Minor SAR

Numerous recent studies have indicated the potential conservation risks of ignoring sub-stock level dynamics in Pacific Herring (Benson et al. 2015, Okamoto et al. 2020a, b, Rogers et al. 2018, MacCall et al. 2018, Stier et al. 2020). Specifically, harvest rates can appear appropriate at the aggregate scale, but inequitably burdensome for some sub-stocks at smaller scales. We provide estimates of sub-stock scale reference points for the Minor SAR SOK fisheries (analogous to that of the aggregate reference points) based on the mean of the estimated annual sub-stock biomass across the reference time period of 1982-1992 (Table 18). For Englefield, the mean of estimated annual biomass was 1,393 tonnes (80% probability interval 883-1,720 tonnes), Rennell Sound was 2130 tonnes (80% probability interval 1,538-2,511 tonnes) and Port Louis was 2,583 tonnes (80% probability interval 1,650-3,238 tonnes).

For a sub-stock approach to management in the Minor SAR, target harvest rates (e.g., 5%) may be applied to projections from these or similar biomass production models where integrated statistical catch-at-age models are not feasible or not useful because of data deficiencies. It is important to note that these biomass-specific reference points will shift with assumptions of *q* and other parameter estimates that affect scaling, and should be used only when comparing similar scaling expectations (i.e., a change in assumptions about *q* should lead to a commensurate change in the reference points). Thus, these reference points should only be used with similar assumptions about biomass scaling.

The analyses presented here highlight the extreme volatility of sub-stocks in the Minor SAR, suggesting that reopening based on short-term forecasted or observed recoveries may generate challenges for roe harvests. Specifically, forecasting future biomass within these sub-stocks based on a short-term recovery may prove challenging or erroneous as years of relatively high productivity are generally short-lived, unpredictable, and followed by collapse, even in the absence of harvest.

#### 6.2.4.2 Considering trends in volatility for rebuilding targets

For sub-stocks outside of the Major SAR, shifting to sustained, rather than short-term, production as a pre-requisite for rebuilding may be necessary to attain and maintain rebuilding targets. For example, a shift into a high productivity regime might temporarily support harvest, but a shift into a demonstrably stable, high productivity regime, away from episodic volatility or persistent collapses, may provide a more robust alternative. Simulation models could be used to assess how such volatility affects performance metrics in context of proposed reference points and HCRs and to determine what improvements in productivity or reductions in volatility would be sufficient to generate acceptable performance metrics.

#### 6.2.4.3 Additional field and spawn survey data to support stock assessment

Annual collection of age composition data at finer spatial scales may help characterize whether pulses of production and collapse are a result of single cohort inputs without sustained recruitment, or changes in natural mortality, or both. Over the long-term, such data would facilitate use of age-structured models for stock assessment that are challenging with the current data gaps.

Additional metadata on spawn index survey effort may also improve estimates when biomass is low. Specifically, one challenge these models experience is separating true zeros in spawn indices from zeros that result from insufficient survey effort. The model currently assumes a very low probability of observing a spawn below a specific low tonnage of spawn deposition, which transitions to a very high probability above that threshold. More consistency in data collection and metadata on survey effort for spawn metrics should help improve model estimates.

#### 6.2.4.4 Drivers of growth and implications for herring life histories

Declines in growth rates and size-at-age represent substantial risks for productivity of herring populations, leading to declines in fecundity, commercial yields, and ability to achieve sufficient SOK yields. Research focused on drivers of growth dynamics at both the BC-wide and sub-stock scale may provide effective data for understanding how current trends and future oceanographic conditions may impact biomass productivity in Pacific Herring. In addition, analyses that ignore the effects of changing growth rates over space and time may lead to biased estimates of productivity and biomass, since life history characteristics such as mass-specific fecundity (which determines spawn index conversions), age-at-maturity, and fishery-independent mortality rates, are likely to change with declines in growth. Therefore, identifying factors that affect both coastwide and Haida Gwaii specific variation in growth of age-2 and age-3+ fish, as well as any impacts on stock assessment assumptions, should remain a high research priority.

## 6.3 ENVIRONMENTAL DRIVERS OF PRODUCTIVITY

### 6.3.1 Context

Lack of understanding of the potential environmental drivers leading to herring decline and recovery remains a core knowledge gap in developing a rebuilding strategy for Haida Gwaii herring. Climate change, which is increasingly taking ecological systems outside the range of historical parameters, further limits our ability to understand how the system is likely to respond in the future. Improved understanding of the potential factors driving herring productivity and mortality can aid future model development and inform management about likely future scenarios. Key research questions include:

- What can we learn about potential environmental drivers that affect Haida Gwaii herring from the spatiotemporal patterns evident in the herring data?
- Which environmental factors are potential drivers of Haida Gwaii herring recruitment and/or mortality?
- Are relationships between environmental variables and herring characteristics different for individual sub-stocks, or for the east vs. west coasts of Haida Gwaii?
- Are these relationships linear? Is there evidence of potential thresholds and/or tipping points?
- What are some potential implications of environmental drivers for herring recovery and recovery strategies?

Using Section 5.2 as a guide for prioritizing selection of potential environmental drivers to include in this study, data was compiled on predators, competitors, and oceanographic indicators that capture aspects of variability in ocean conditions thought to affect herring through food availability or predator prevalence (Table 19 and Table 20); see Appendix I for further details on selection and interpretation of environmental driver time series). Where possible, environmental indicators were compiled for each of the BC Marine Conservation Analysis oceanographic regions surrounding Haida Gwaii (Figure 41) to gain a better understanding of spatiotemporal variation in the indicators and support analyses of local versus regional relationships.

Correlation analysis based on Pearson correlation coefficients and single-variable linear regression was used to gain a rough estimate of the magnitude of potential effects of each environmental driver under consideration. Exploratory visualization techniques, including stratified scatter plots and histograms, residual plots, and spline interpolation were also used to look for evidence of non-linear relationships and tipping points.

Herring response was assessed at the sub-stock level, using outputs from the spatiotemporal models described in Section 6.2 as the primary source of spawner biomass estimates, augmented with catch and age structure information. Raw spawn index data was used for sensitivity analyses, since the structural assumptions made in the Section 6.2 analyses could result in potentially spurious correlations. Production and productivity were the two primary indicators of herring response defined as follows:

- Production was calculated as pre-harvest spawner biomass in year t - post-harvest spawner biomass in year t-1, representing the change in spawning stock biomass occurring over the course of the year due to losses from natural mortality and gains from recruitment; and

- Productivity was calculated as pre-harvest biomass of age-3s in year t / spawner biomass in year t-3, reflecting the fact that juveniles recruit to the spawning biomass predominantly at age-3 for Haida Gwaii herring.

Unfortunately, limitations inherent in the age structure data make it difficult to construct an index that specifically captures changes in adult mortality. However, since production captures effects of both changes in recruitment and adult mortality, while productivity focuses specifically on recruitment, comparison of results obtained for these two indices can help to tease out potential differences in how recruitment and adult mortality respond to environmental drivers. Since environmental conditions would be expected to have the most immediate influence during the three years prior to t, environmental indicators were aligned with production and productivity at one-, two-, and three-year lags for all analyses.

Time series for productivity and production are shown in Figures 42 and 43. Skidegate Inlet, Masset Inlet, and Naden Harbour sub-stocks were excluded from these analyses due to limited data availability.

### 6.3.2 Main Findings

#### 6.3.2.1 Spatiotemporal patterns of herring productivity and production

Haida Gwaii herring productivity exhibited correlation among sub-stocks, more strongly for sub-stocks in the Minor SAR (0.45-0.79) than the Major SAR (0.23-0.55, Figure 44). Presence of synchronicity in productivity across Haida Gwaii suggested drivers that influenced all sub-stocks in similar ways, whereas lower synchronicity for stocks on in the Major SAR indicated a stronger influence of more localized drivers, a more complex response to regional drivers, and/or potential inconsistencies in the spawn data time series (noted in Section 6.2). An important consequence of higher synchronicity in productivity for rebuilding is that the 'portfolio effect' that would be provided by a set of sub-stocks with 'out-of-sync' recruitment is more limited. Thus, results indicated a higher risk of volatility and potential for recruitment failures due to unfavorable environmental conditions for the Minor SAR than the Major SAR.

Herring production was less synchronous than productivity, in that correlations were weaker and dropped off more quickly with spatial distance (Figure 44). Correlation between production and productivity (0.31-0.62, Figure 44) suggested that changes in age-3 recruitment were an important driver of changes in production; however, the moderate correlation suggested that age-2 recruitment and/or adult mortality (signals of which are only captured in production, but not productivity) may also play an important role. The finding that production was less synchronous than productivity (correlations ranged from 0.12-0.79 for productivity vs. -0.03-0.55 for production, Figure 44) suggested that drivers of age-2 recruitment and/or adult mortality were likely acting at finer spatial scales than drivers of age-3 recruitment. An important management implication of this relative lack of synchronicity in production dynamics is that extrapolation of data from surveyed to unsurveyed areas would have high uncertainty. This result highlights the importance of maintaining a consistent survey protocol that covers all areas, even where areas largely share similar recruitment dynamics.

Years of high productivity were often followed by years of low productivity, and vice versa, a pattern that was also present for production but to a lesser extent (Figures 42 and 43). This suggested either the presence of density-dependent interactions or environmental drivers of productivity that exhibited a similar on-off pattern. It also indicated that sub-stocks were unlikely to exhibit smooth trends, either in phases of growth or decline, which needs to be considered in designing recovery metrics and targets.

#### 6.3.2.2 Relationships between environmental drivers and production/productivity

Relationships with environmental drivers were mostly similar for production and productivity indices. No systematic differences in correlations for production and productivity were found that would be consistent with hypotheses about adult mortality being subject to different drivers than those driving age-3 recruitment (e.g., negative correlations for predators that are only observed for production; Figure 45). This result could indicate that environmental drivers predominantly act on the processes captured in both indicators (i.e., those affecting age-3 recruitment). However, the relative predominance of local pattern (i.e., relatively low synchronicity) in the production index suggested that distinct drivers are affecting production through adult mortality and/or age-2 recruitment, and that these drivers are acting at a more local scale than drivers of age-3 recruitment. Most of the environmental driver data were available only at a broad-scale, and thus more likely to miss the influence of local, sub-stock specific drivers that would require finer spatial scales data (e.g., predator presence during spawning in specific locations). Therefore, an alternative explanation for the similarity in results for production and productivity is that analyses were unable to capture drivers of mortality and/or age-2 recruitment at an appropriate scale.

Declines in productivity were associated with positive anomalies in the Arctic Oscillation Index (AOI), as well as positive anomalies in sea surface temperature (SST) for Major SAR sub-stocks and positive anomalies in the North Pacific Index (NPI) for Minor SAR sub-stocks in the preceding year (Figure 45). These relationships were weak (correlations <0.3 for SST and NPI, and <0.4 for AOI), but consistent across sub-stocks within each SAR, making it less likely that correlations were spurious. Systematic differences between the Major and Minor SARs in the relationship with SST and NPI suggested that herring response to large-scale environmental drivers may differ, and that conclusions drawn from analyses focused only on the Major SAR cannot necessarily be extrapolated to other sub-stocks. The declines in productivity with positive AOI and higher SST anomalies may be of particular concern for rebuilding, since both conditions have become more common in recent years, possibly indicating that environmental conditions are becoming less favourable for herring.

Analyses of correlations with potential biological drivers were hampered by short data series and lack of local-scale data, particularly for humpback whales. While this makes it difficult to draw more than tentative conclusions, the evidence suggests potentially complex relationships that warrant further exploration. Interestingly, net primary productivity (NPP, as estimated from satellite-derived chlorophyll concentration) exhibited negative temporal autocorrelation reminiscent of that present in the productivity time series. Reduced productivity was weakly associated with low NPP for the fall of the 1$^{st}$ and 3$^{rd}$ life years of new recruits; however, this correlation was not consistent across sub-stocks and was reversed for the fall of the 2$^{nd}$ year through to the spring of the 3$^{rd}$ year. Both production and productivity were also negatively associated with hake biomass at lags 1 and 3, but not lag 2. Evidence further suggested negative association with production for Sitka Sound humpback whale counts, primarily for Minor SAR sub-stocks, as well as negative association of production with Steller sea lion counts from both Haida Gwaii and mainland rookeries. The latest available Steller sea lion counts indicated that while populations on the mainland are still rebounding, population size seemed to have stabilized for Haida Gwaii (Appendix I). The Sitka Sound data suggested that the humpback population was still expanding as of 2011, the last year for which data was available. Hake abundance around Haida Gwaii appeared to fluctuate substantially, but showed no clear time trends, although hake biological characteristics suggest that warming oceans may favour a northward expansion of this predator species. These findings support further research into the role of predators in shaping Haida Gwaii 'íináang | iinang *herring* population dynamics to better understand the relative contribution of different predators to overall herring mortality rates, as well as the herring biomass required to support potentially expanding predator populations.

# 7 MANAGEMENT MEASURES AND IMPLEMENTATION

A multi-year implementation plan supported by annual work plans will be required to implement this rebuilding plan and will be collaboratively developed by the management partners within one year of finalizing the rebuilding plan. This work plan will identify priority activities for each Haida Gwaii area and sub-stock, and include annual tracking of progress towards meeting rebuilding objectives, monitoring and research priorities, and funding needs.

## 7.1 MANAGEMENT MEASURES DURING REBUILDING

The following sections present SAR and sub-stock scale management recommendations, informed by the main findings of the three modelling approaches with linkages to annual stock status (Section 5.2.1.2), Haida traditional knowledge (Section 2.3.1), cultural importance and social and economic considerations (Section 5.2.3), such as criteria for successful SOK fisheries. The annual stock status will be determined based on the current spawning biomass estimated from the stock assessment model for the Major SAR (not the projected biomass estimate) and from the spawn index for the Minor SAR.

### 7.1.1 Management measures for the Haida Gwaii Major stock assessment region

Simulations conducted in the first MSE cycle indicate a low probability of maintaining the stock above the LRP over the 15-year simulation period (three herring generations) under current or historical natural mortality trends, even in the absence of fishing (DFO 2020). Given this, management recommendations for the Major SAR are designed to foster signs of rebuilding while providing some fishing opportunities to meet cultural and social and economic objectives when stock status allows. Management measures for the Haida Gwaii Major SAR are as follows:

- Manage at the sub-stock level, using both aggregate and sub-stock reference points in decision-making;
- Implement short- and long-term rebuilding targets based on biomass levels relative to the average biomass from 1975-1985 (at 75% and 100%, respectively) for all sub-stocks;
- Gradually phase in SOK fisheries as biomass increases relative to these rebuilding targets;
- Maintain fisheries closures until the aggregate and/or sub-stocks have been above the critical zone for two consecutive years, at which point limited open- or closed-pond SOK operations up to a maximum allocation of 105 tons can proceed at the beginning of the third consecutive year;
- Allow open- and/or closed-pond SOK up to a maximum 5% harvest rate when the stock is in the first two years of the rebuilding phase, defined as when the status has been above the LRP for two or more consecutive years and is greater than $0.5SB_0$ but less than the short-term rebuilding target of $0.75\overline{SB}_{75:85}$;
- Allow open- and/or closed-pond SOK up to a maximum 10% harvest rate when the stock has been in the rebuilding phase for two or more consecutive years;

- Conduct additional analyses to determine appropriate management procedures, such as those that incorporate roe fisheries, once the stock has exceeded the short-term rebuilding target for two consecutive years, given that this falls outside the range of biomass simulated in this MSE process;
- Allow Haida traditional fisheries in this and other areas of Haida Gwaii, subject to conservation (this rebuilding plan will not limit Haida traditional fisheries; see Section 3.5 for additional details); and
- Continue recreational fisheries access at current levels, given minimal harvests.

A summary of how the main findings from the three modelling approaches were considered in rebuilding measures is provided in Table 21. More detailed description of management measures for the different population status levels, as informed by the modelling approaches, and how they relate to the measurable objectives are outlined in Table 22.

### 7.1.2 Management measures for the Haida Gwaii Minor stock assessment region

The Haida Gwaii Minor SAR herring populations currently have no biological reference points to define the status of the herring populations, including no established LRP at either the aggregate or sub-stock scales. Management actions are based on biomass levels relative to a rebuilding target, and include changing the existing management approach of applying a 10% harvest rate to the spawn index or spawning biomass estimate (DFO 2020). Management measures for the Haida Gwaii Minor SAR are as follows:

- Implement a long-term rebuilding target of the average biomass from 1982-1992, $\overline{B}_{82:92}$, for all sub-stocks, based on this historical period of higher herring biomass (Figure 19);
- Allow only open- and/or closed-pond commercial SOK fisheries while the Minor SAR is rebuilding;
- Open SOK fisheries in accordance with sub-stock effort limits (spatial meta rules) at a 5% harvest rate when the biomass of a sub-stock is above $0.25\overline{B}_{82:92}$,
- Allow increase to a 10% harvest rate if the biomass has been above the $0.25\overline{B}_{82:92}$ level for two consecutive years;
- Maintain fisheries closures for Tasu and Skidegate Channel sub-stocks as these areas have only small herring populations that lack consistent monitoring and assessment data;
- Allow Haida traditional fisheries in this and other areas of Haida Gwaii, subject to conservation (this plan will not limit Haida traditional fisheries; see Section 3.5 for additional details).
- Continue recreational fisheries at current levels, given minimal harvests.

Management recommendations for the Minor SAR herring populations are supported by the main findings from the three modelling approaches used to support rebuilding (Section 6, Table 23), and include changes to the existing management approach (Table 24).

### 7.1.3 Management measures for areas outside the Haida Gwaii stock assessment regions (e.g., Skidegate Inlet, Masset Inlet, Naden Harbour)

Haida Gwaii 'íináang | iinang *herring* populations spawning outside the Major and Minor SARs lack the consistent monitoring data required to assess sub-stock status in these areas. Due to the lack of historical data, no commercial fisheries are recommended in areas where survey programs to assess population status have not been established, aligning with current DFO management policy.

## 7.2 TIME FRAME FOR REBUILDING

Management recommendations and actions are unlikely to achieve rebuilding objectives for the Haida Gwaii 'íináang | iinang *herring* system over the short-term, due in large part to population dynamics and ecosystem considerations outside the control of possible management measures. The DFO PA Policy indicates that a reasonable timeframe for a stock to grow above its LRP should be between one and a half to two generations. However, for Pacific Herring a longer timeframe (three herring generations; 15 years) was recommended for analyses due to the species short life span and volatility in productivity. Simulations for a longer timeframe were not recommended for the analyses in this rebuilding plan due to the added uncertainty about the species state dynamics (stochastic recruitment, natural mortality and growth). Analyses conducted in support of this plan suggested that the time needed for rebuilding will likely extend beyond three herring generations or 15 years, even in the absence of fishing (Section 6.1; Appendix G). Simulations for a longer timeframe were not analyzed due to the added uncertainty past this 15-year period and therefore there is no predicted timeline for rebuilding.

Population status and progress towards rebuilding objectives will be evaluated annually, and the rebuilding plan will be reviewed at least every five years, with more frequent updates should:

1. Significant new information become available that could impact herring rebuilding, fishing, or management; or
2. The stock status increases to a biomass level outside the range of uncertainty that was simulated in the MSE analyses for the Major SAR (specified in Table 11), triggering new simulations and analyses.

The rebuilding plan process will remain in place until:

1. For the Major SAR, at least the aggregate short-term rebuilding target has been met for three consecutive years, and further simulation work and research has been completed;
2. For the Minor SAR, at least the rebuilding target has been met for three consecutive years for two of the three managed sub-stocks (Port Louis, Rennell Sound, and/or Englefield Bay), and a collaboratively developed monitoring program has been initiated; and
3. For all Haida Gwaii sub-stocks, a collaborative fisheries management plan has been developed and implementation initiated.

Given that the Haida Gwaii Major SAR herring population has been in a prolonged state of very low biomass since the early 2000s, it is difficult to specify rebuilding time frames to achieve cultural and social and economic objectives, though greater understanding will be likely once rebuilding is underway. As such, rebuilding timelines for meeting these objectives (Table 2 and Table **6**, Section 4.2) will be added to the rebuilding plan as herring populations approach rebuilding targets.

## 7.3 MONITORING AND EVALUATION

Priority monitoring metrics were identified to measure success of ecological, cultural, social and economic, governance, and management objectives (Table 25 to Table 29). These were based on the characteristics and attributes of a rebuilt Haida Gwaii 'íináang | iinang *herring* system described in Section 5.3, and organized according to the objectives in Section 4.2. Many of these monitoring programs are currently in place for herring-related ecological and economic priorities, with some additional work required to augment existing programs; some new metrics are needed to ensure that performance against all rebuilding objectives can be tracked.

While not all new monitoring activities can be undertaken over the short-term due to limitations in funding and capacity, the TWG will develop an implementation plan supported by annual work plans that identify and implement key monitoring priorities from the comprehensive list in Table 25 to Table 29. Priority monitoring needs specific to different areas and sub-stocks of Haida Gwaii will be identified. Moving forward, design of a Haida Gwaii 'íináang | iinang *herring* ecosystem monitoring program should include current, additional, and new priority metrics identified in Table 25 to Table 29, with timelines for work.

### 7.3.1 Monitoring recommendations for the Major stock assessment region

Population status of Haida Gwaii 'íináang | iinang *herring* in the Major SAR will continue to be assessed annually at the aggregate and sub-stock levels using methods reviewed and adopted for the DFO stock assessment process or Haida Gwaii fisheries management processes approved by the management parties engaged in herring rebuilding and fisheries management for Haida Gwaii. Spawning biomass will be assessed relative to the LRP, the rebuilding phase, and the short- and long-term rebuilding targets, as outlined in Section 7.1. In addition, spawn trends and distribution will be assessed using survey and empirical methods, as well as traditional and local knowledge, for the three sub-stocks to assess changes in status. As noted in Section 7.3, specific priorities for the Major SAR and associated sub-stocks will be addressed. All key information will be reviewed at least annually by members of a Haida Gwaii 'íináang | iinang *herring* rebuilding working group and members will report to management bodies annually on progress against the rebuilding objectives.

### 7.3.2 Monitoring recommendations for the Minor stock assessment region

Spawn trends and distribution will be assessed annually at the aggregate and the sub-stock levels for the Minor SAR using appropriate empirical and statistical methods, as well as traditional and local knowledge, given the limitations of historical data collection and the lack of previously established reference points for these areas (Section 5.2.1.4.2). The aggregate assessment should not include Tasu and Skidegate Channel, which only have small herring populations that lack consistent monitoring data and are not recommended to be open in any future commercial fisheries. As noted in Section 7.3, specific priorities for the Minor SAR and associated sub-stocks will be addressed. Key information will be reviewed annually by members of a Haida Gwaii 'íináang | iinang *herring* rebuilding working group and members will report to management bodies annually on progress against the rebuilding objectives.

### 7.3.3 Monitoring recommendations for areas outside the stock assessment regions (e.g., Skidegate Inlet, Masset Inlet, Naden Harbour)

Skidegate Inlet continues to be an important area for Haida traditional harvest and continues to be a Haida Nation priority for catch monitoring. Spawns should also be documented using surface survey or dive methods, consistent with historical monitoring. Naden Harbour and Masset Inlet support early and late spawners, respectively, and traditional harvest is infrequent. Any reported spawns should be assessed if resources are available. Herring management bodies should encourage local residents, operators and/or fishers to report any spawning observations. Each of these areas should be specifically included in post-season traditional harvest interviews. If opportunities arise to collect herring samples for research during spawning, these should be collected using low intensity methods such as cast nets, herring jigs or small gillnets.

## 7.4 DATA GAPS AND AREAS OF FUTURE RESEARCH

### 7.4.1 Areas of Future Research

The TWG identified priority areas of research that should be addressed for 'íináang | iinang *Pacific Herring* in Haida Gwaii. Potential research questions were developed and prioritized based on three criteria:

1. How important is this for better understanding of and supporting herring rebuilding in Haida Gwaii?
2. How feasible is the question to answer in the next ten years?
3. To what degree does this research question advance ecosystem-based management for herring?

After assessing research questions against the criteria, 20 priority research questions were identified, and are listed below in no particular order of priority. Timelines for addressing these questions will be identified through the development of the implementation plan and associated annual work plans. Rating of the research questions as high, medium, or low relative to the criteria can be found in Appendix J. Some questions may be more relevant to specific sub-stocks.

**Prioritized Research Questions:**

***Ecological***

1. What are the key environmental factors and trends, including climate change and marine heat waves (e.g., the “Blob”), that are driving Pacific herring population dynamics and behaviour (i.e., recruitment, mortality, growth, and spawner distribution)?
2. How has herring size structure (e.g., size-at-age or weight-at-length) changed at different spatial and temporal scales, and what are the causes and consequences (e.g., reproductive dynamics and fishing methods) of these changes?
3. Are herring vital rates (e.g., recruitment, mortality) density-dependent? Have these relationships changed over time?
4. What is the population/stock structure of herring in Haida Gwaii? What is the best method for determining this structure (e.g., genetic differences between spawning sites, geographic separation of spawning sites, temporal characteristics of spawning events, etc.)?
5. How important is mixing among identified sub-stock areas in Haida Gwaii and what are the factors or mechanisms driving any mixing?
6. How are the abundance, size and diversity of the suite of herring predators changing over space and time? How are these related to key herring rearing and spawning areas in Haida Gwaii (e.g., sea lions, hake, humpback whale, sea birds)?

7. What factors, including diet, food availability and temperature, affect distribution and survival of herring eggs, larvae, and young-of-the-year?
8. How has herring habitat changed around Haida Gwaii, including potential impacts from invasive species (e.g., European green crab, colonial tunicates) and recovering species (e.g., sea otter and grey whale effects on eelgrass habitat)?

***Cultural, Social and Economic***

9. How does herring spawning abundance vary spatially and temporally in critical areas for Haida traditional k'aaw fisheries (using spawn surveys, traditional knowledge, etc.)? How can thresholds for commercial SOK fisheries help to maintain higher productivity at the sub-stock level (e.g., Cumshewa/Selwyn sub-stock including spawning locations in Cumshewa, Selwyn and Atli Inlets; and early and late spawn timing sub-stocks)?
10. What have been the main sources of k'aaw for the Haida community and how might this change (e.g., individual wild harvest, communal harvest, Bella Bella product, distribution by commercial SOK, design of future Community Based Fishery, redesign of commercial fisheries)? What are the benefits associated with k'aaw distributed through the Haida community, and how might this change in future?
11. What are the main factors affecting development of past and future commercial SOK and roe herring fisheries in Haida Gwaii and how have cultural and socio-economic conditions in the community changed as a result (e.g., commercial SOK and roe fisheries, markets and prices, licencing and allocation systems, new community-based fisheries opportunities, compare to Heiltsuk rights-based SOK fishery)?

***Governance***

12. How can herring policies and management strategies be changed to better account for Indigenous rights and Haida governance, values, and laws, including addressing the spatial and temporal components of herring ecology and fishing?

***Management***

13. How can surface, dive, hydroacoustic and/or other survey methods (e.g., drop camera, towing diver) best be combined and used to provide an accurate assessment of past, current and future herring biomass and distribution, including assumptions around spawn missed by surveys (i.e., scaling factor, q)?
14. What additional priority monitoring activities and/or programs, including traditional knowledge and community monitoring, are needed to contribute to our understanding of ecosystem interactions and relationships (and therefore EBM) and how technically feasible are they?
15. How can alternative models (e.g., Ecopath, Ecospace, Ecosim, MICE, bioenergetics, bioeconomics) help advance our understanding of ecosystem interactions and relationships?

16. What are best practices for defining reference points, including biomass, and other ecological, cultural, social and economic reference points? How might traditional knowledge, values, and laws alter definitions of overfishing thresholds and levels of sustainable use?
17. What are the ecological, cultural, social, and economic costs and benefits of alternative fisheries management strategies (e.g., traditional fishery only, SOK or roe fishery only, current SOK priority with roe fishing, sub-stock specific fisheries)?
18. What are the pros and cons of different temporal and spatial scales for herring fisheries management and decision-making (e.g., current sub-stock scale vs. finer scale, variations in local spawn timing)?
19. What are appropriate alternative methods for forecasting abundance (e.g., "same as last year", average of 2-3 years, delay difference biomass dynamics models (Section 6.2))?
20. What are the implications of using harvest rates that are based on forecasts of older (age-4+) herring only in MSE simulation analyses, with the understanding that all ages would be susceptible to the fishery (related to 19)?

## 7.5 COLLABORATIVE GOVERANCE, MANAGEMENT AND STEWARDSHIP

The governance partners will work together to implement the Haida Gwaii 'íináang | iinang *Herring* Rebuilding Plan using a collaborative governance and management approach. Work will be led by evolving governance structures and take place in the spirit of commitments outlined in the Gwaii Haanas Gina 'Waadlux̲an KilG̲uhlG̲a Land-Sea-People Management Plan (2018), Fisheries Resource Reconciliation Agreement (2021), and where appropriate, Reconciliation Framework Agreement for Bioregional Oceans Management and Protection (2018). These agreements seek to facilitate transformative change in the collaborative governance of fisheries and support application of the precautionary approach in rebuilding and recovery plans. The corresponding Haida law and principle for the precautionary approach is Yahgudáng | Yahguudang which translates as “respect” (Section 2.1). In this section, we briefly describe how we will advance our collaborative work related to governance, implementation plans, management and decision-making, ecosystem-based management, fisheries assessment and research, monitoring, policy reforms, communications, and conservation and protection, related to rebuilding of Haida Gwaii herring.

**Governance**. The partners will utilize governance structures established through existing agreements (Section 5.2.5) to implement the rebuilding plan, including the AMB, the CMG or new structures such as Haida Gwaii Management Council(s). A Haida Gwaii 'íináang | iinang *Herring* Rebuilding Plan Working Group will be established, made up of representatives of the governance partners, which will be responsible for developing an implementation plan and associated annual work plans that include regular assessments of the status of Haida Gwaii herring rebuilding and development of priorities with timelines. Stakeholders will be engaged through processes led by the governance partners, including the Haida Gwaii Integrated Advisory Committee and the DFO Integrated Herring Harvest Planning Committee.

**Implementation Plan and Associated Annual Work Plans.** Implementation of this plan will be included in long-term strategic and operational planning by the governance partners. Resources for implementation of the rebuilding plan will be coordinated and identified through a longer-term implementation plan and annual work plans. Funding contributions are expected from all governance partners.

**Management Plans and Decision-Making**. Rebuilding plan measures will be incorporated into fisheries management plans including the Integrated Fisheries Management Plan (IFMP) for Pacific Herring, and other fisheries management and conservation plans as appropriate (e.g., action plan for herring in Gwaii Haanas). The Fisheries Resource Reconciliation Agreement established herring as a priority species for the 2023-24 fiscal year. Rebuilding of Haida Gwaii herring will also be incorporated into Haida Nation work plans through the Aboriginal Fisheries Strategy (AFS) and Aboriginal Aquatic Resource and Oceans Management (AAROM) programs, and for Pacific North Coast Integrated Management Area (PNCIMA) implementation, as appropriate. Best available information will be incorporated into decision-making processes including Haida traditional knowledge.

**Ecosystem-based Management**. Management processes will seek to advance ecosystem-based management of Haida Gwaii 'íináang | iinang *herring*, which includes ecological, cultural, social and economic, governance, and management objectives as identified in this rebuilding plan (Section 4.2). A related goal is to ensure ecological integrity and ecologically sustainable use, which includes elements of the 'íináang | iinang system, including herring, eelgrass and kelp. Assessment and reporting will also be adapted to align with the Gwaii Haanas Ecosystem-Based Management Framework as it is developed and finalized.

**Fisheries Assessment and Research**. Haida Gwaii 'íináang | iinang *herring* will continue to be assessed using aggregate and sub-stock modelling approaches as described in the rebuilding plan, as well as other potential analyses. Research programs will be aimed at advancing understanding of Haida Gwaii 'íináang | iinang *herring*, fisheries, and ecosystem relationships, including mitigating and adapting to the effects of climate change and sea otter return.

**Monitoring**. The partners support long-term monitoring programs to maintain and improve datasets and knowledge related to rebuilding objectives, using existing relationships and exploring new partnerships to support long-term monitoring. Monitoring of the Haida traditional fishery will continue to be a priority for the Haida Nation. If and when commercial fisheries re-open, they will be carefully monitored with respect to herring use and practices.

**Policy Reforms**. Governance partners are seeking to effect transformative change in collaborative governance of fisheries through the Fisheries Resource Reconciliation Agreement and commitments through the Gwaii Haanas Gina 'Waadlu<u>x</u>an KilGuhlGa Land-Sea-People Management Plan (2018). Changes will be effected through policy review and development, as agreements are negotiated and implemented, and will result in the creation of new community-based fisheries, and increased Haida participation in commercial fishing. The partners will be exploring new models for herring fisheries to better achieve objectives of this rebuilding plan over the short- and long-term.

**Communications**. The partners will engage and regularly communicate with fisheries participants about the status of Haida Gwaii 'íináang | iinang *herring* and progress on implementation of the rebuilding plan.

**Conservation and Protection**. Surveillance and enforcement by the governance partners will continue, related to habitat protection, traditional fisheries, any community-based fisheries as a result of the implementation of the FRRA, and commercial fisheries. These activities will be coordinated by the partners and are expected to include participation from DFO Fisheries Officers, Haida Fisheries Guardians, Parks Canada Wardens, Haida Watchmen, and fisheries charter skippers and crews.

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# TABLES

Table 1. Guiding Principles and associated Ecosystem-Based Management Principles identified in the Gwaii Haanas Gina 'Waadluxan KilGuhlGa Land-Sea-People Management Plan signed by the parties in November, 2018. Xaad kíl is shown in blue, and Xaayda kil is shown in green.

| GUIDING PRINCIPLES | ECOSYSTEM BASED MANAGEMENT PRINCIPLES |
|---|---|
| **Yahgudáng** \| **Yahguudang** *Respect* | Precautionary approach |
| **K'uláagée** \| **'Laa guu ga kanhllns** *Responsibility* | Inclusive and participatory |
| **Ginn 'wáadluwan gud .ahl kwáagíidang** \| **Gina 'waadluxan gud ad kwaagid** *Interconnectedness; Everything depends on everything else* | Integrated management |
| **Agan t'ats'gang** \| **Giid tlljuus** *Balance* | Sustainable use |
| **Ginn gán ga únsids kíl tla gudáng'wa** \| **Gina k'aadang.nga gii uu tll k'anguudang** *Seeking Wise Counsel* | Adaptive management |
| **'Isda isgyaan diigaa isdii** \| **Isda ad dii gii isda** *Giving and Receiving* | Equitable sharing |

Table 2. Initial measurable objectives and performance metrics to support Haida Gwaii 'íináang | iinang herring rebuilding.

| Measurable Objective | Description | Performance Metric / Frequency of measurement |
|---|---|---|
| *Operational Objective 1.1a*<br><br>Conservation target (LRP) | Avoid the LRP of $0.3SB_0$ with a high probability (>75%) over three herring generations (15 years). | Probability that current SSB is greater than LRP. Measured annually in the stock assessment. |
| *Operational Objective 1.1b*<br><br>Spawning biomass targets | Maintain spawning stock biomass at or above the incremental spawning biomass target ($0.5SB_0$) with at least 50% probability over three herring generations (15 years) to enter and stay in the rebuilding phase. | Probability that current SSB is greater than incremental spawning biomass target. Measured annually in the stock assessment. |
| | Maintain spawning stock biomass at or above short-term rebuilding target (USR; greater of 75% average spawning biomass from 1975-85 and $SB_0$) with at least 50% probability over three herring generations (15 years) to demonstrate progress towards rebuilding and allow for additional harvesting options. | Probability that current SSB is at or above short-term rebuilding target. Measured annually in the stock assessment. |
| *Operational Objective 1.1c*<br><br>Spawning stock growth | Maximize annual spawning stock biomass growth over short- (one herring generation, 5 yrs), medium- (two herring generations, 10 yrs) and long- (three herring generations, 15 yrs) term growth. | Median percentage growth rate of spawning biomass over the time interval from $t_0$ to $t_1$. Measured every five years, in stock assessment. |
| *Operational Objective 3.2a*<br><br>Target biomass reference point | Maintain spawning stock biomass at or above the target biomass reference point (long-term rebuilding target; 100% of average spawning biomass from 1975-1985) with at least 50% probability over three herring generations. | Probability that the current stock status is at or above the reference point. Measured annually in the stock assessment. |
| *Operational Objective 3.3a*<br><br>Benefits to Haida community | Support herring fishery contributions to Haida community (e.g., landed value, local income/employment) | Proportion of annual landed value (CAD$) of Haida Gwaii herring commercial fisheries that went to the Haida community. Annual number, types, work days, and approximate value of Haida employment opportunities associated with each commercial fishery type. Evaluated every five years as part of rebuilding plan review. |
| *Operational Objective 3.4a*<br><br>Economic viability | Support economic viability of fisheries in years of suitable abundance, based on a phased-in approach that observes rebuilding signals over multiple years. | Number of years commercial fisheries were opened when abundance-based phased-in approach was applied; herring fisheries landed value (CAD$). Measured every five years as part of rebuilding plan review. |

| Measurable Objective | Description | Performance Metric / Frequency of measurement |
|---|---|---|
| *Operational Objective 5.3a*<br><br>Monitoring and compliance | Define and prioritize key new monitoring activities in an implementation plan by January 2025. Review progress on the implementation plan every five years. | Implementation plan developed by January 2025 that includes priority monitoring activities. Measured once. Plan is reviewed by working group every five years. |
| *Operational Objective 5.3b*<br><br>Knowledge gaps | Define and prioritize timelines on priority research questions in an implementation plan by January 2025. Review progress on the implementation plan every five years. | Implementation plan developed by January 2025 that includes addressing priority research questions. Measured once. Plan is reviewed by working group every five years. |

Table 3. Number of spawn-on-kelp (SOK) licenses per area (as of 2021).

| Area | Number of Licences |
|---|---|
| Haida Gwaii (including Area 2W) | 10 |
| Prince Rupert District | 10 |
| Central Coast | 15 |
| Area 10 | 3 |
| Area 12 | 1 |
| Strait of Georgia | 0 |
| West Coast Vancouver Island | 4 |
| Area 27 | 3 |
| **Total** | **46** |

Table 4. Summary of the attributes and characteristics of a rebuilt Haida Gwaii 'íináang | iinang *herring* system.

| System Elements & *Strategic Objectives* | Attributes | Characteristics |
|---|---|---|
| **ECOLOGICAL**<br><br>*Rebuild and conserve herring populations and protect their habitat, related species, and key ecosystem features and processes* | • Herring population size and productivity<br><br>*(At multiple spatial scales, including aggregate populations in Major and Minor SARs and sub-stock populations)* | • Herring abundance (biomass estimates and/or abundance indices)<br>• Recruitment and natural mortality<br>• Productivity and surplus production |
| | • Herring population condition<br><br>*(At multiple spatial scales, including aggregate populations in Major and Minor SARs and sub-stock populations)* | • Spatial and temporal coverage of spawn<br>• Size and age structure |
| | • Species interactions and ecological health | • Biodiversity<br>• Herring predator and competitor trends<br>• Primary and zooplankton production trends<br>• Invasive species trends |
| | • Environmental conditions<br><br>*(Climate and ocean change and nearshore habitat condition)* | • Ocean temperature, pH, currents, light and salinity<br>• Environmental variability and resilience (e.g., regime shifts)<br>• Water quality and spawning substrate availability and quality |
| **CULTURAL**<br><br>*Sustain Haida traditional values and use of herring* | • Respect priority of Haida fishery<br>• Cultural continuity<br>• Food security, sharing and trade<br>• Intergenerational knowledge transfer<br>• Ceremonial use and spiritual importance<br>• Connections to place and environment | • Success of traditional fishery<br>• Opportunities to fish and Haida participation in fishery<br>• Satisfaction with fishery<br>• Resolution of management issues<br>• Haida access, use of catch and sharing |
| **SOCIAL AND ECONOMIC**<br><br>*Collaborate to increase local, social, and economic opportunities related to herring* | • Reconciliation<br>• Community benefits from adjacent fisheries<br>• Access for future generations<br>• Fishing opportunities<br>• Tourism<br>• Supporting infrastructure | • Policy objectives<br>• Local fishery benefits<br>• Long-term sustainability<br>• Spawn-on-kelp fisheries<br>• Herring roe fisheries (MSE analysis required if conditions change)<br>• Interactions between fisheries<br>• Kelp access, availability and quality |

| System Elements & *Strategic Objectives* | Attributes | Characteristics |
|---|---|---|
| | | • Annual visitors and local spending (indirect effects) |
| **GOVERNANCE**<br>*Achieve collaborative governance that provides stability, transparency and predictability in fisheries management* | • Reconciliation<br>• Relationships<br>• Planning and policy development e.g., rebuilding plan or management plan<br>• Decision-making | • Government-to-government approach<br>• Collaborative policy development, planning and management<br>• Consensus decision-making<br>• Engagement with stakeholders and interest groups |
| **MANAGEMENT**<br>*Apply EBM principles and a collaboratively developed EBM framework to manage and assess impacts of herring fisheries*<br>*Achieve successful fisheries in accordance with allocation priorities* | • Ecosystem-based management approach<br>• Management planning and programs<br>• Reconciliation<br>• Traditional knowledge<br>• Data and information management<br>• Monitoring herring and ecosystem status<br>• Research planning and implementation<br>• Compliance and enforcement<br>• Communications and engagement | • Policy objectives<br>• Capacity and resources<br>• High quality information from multiple knowledge systems<br>• Timeliness<br>• Transparency<br>• Incorporation of Haida perspective |

Table 5. Major and Minor SAR reference points for Haida Gwaii 'íináang | iinang *herring*. For the Major SAR estimates are taken from the 2022 stock assessment statistical model and for the Minor SAR estimates are from the 2022 spawn index.

| Reference point description | Reference point | 2022 Estimate (t) |
|---|---|---|
| Major SAR (based on aggregate status) | | |
| Limit reference point | $0.3SB_0$ | 6,839 |
| Incremental spawning biomass target (start of rebuilding phase) | $0.5SB_0$ | 11,399 |
| Short-term rebuilding target / Upper stock reference | Greater of $0.75\overline{SB}_{75:85}$ and $SB_0$ | 24,399 and 22,798, respectively |
| Long-term rebuilding target | $SB_{75:85}$ | 32,532 |
| Minor SAR (based on sub-stock status) | | |
| Cut-off biomass level | $0.25\overline{SB}_{82:92}$ | Aggregate: 855<br>Sub-stocks<br>Port Louis: 440<br>Rennell Sound: 235<br>Englefield Bay: 158 |
| Incremental spawning biomass target (start of rebuilding phase) | $0.5S\overline{B}_{82:92}$ | Aggregate: 1,710<br>Sub-stocks<br>Port Louis: 881<br>Rennell Sound: 471<br>Englefield Bay: 315 |
| Long-term rebuilding target | $S\overline{B}_{82:92}$ | Aggregate: 3,419<br>Sub-stocks<br>Port Louis: 1761<br>Rennell Sound: 942<br>Englefield Bay: 631 |

Table 6. Description of MSE-related measurable objectives and performance metrics for the herring rebuilding plan considered and calculated for each management procedure/scenario combination. All performance statistics are calculated over 3 generations from the first year of the projections (2020-34). The indicator function $\mathbf{1}(\boldsymbol{X})$ takes value 1 when the statement X is true, and zero otherwise. "High probability" is defined as 75-95%. Q2 is a statistical representation for median.

| Objective | Description | Performance Metric | Definition |
|---|---|---|---|
| DFO MSE Conservation (LRP) Objective | Avoid the LRP of $0.3SB_0$ with high probability (>75%) over three herring generations (15 years) | Proportion of projection years where spawning biomass exceeds $0.3SB_0$. | $P(SB > .3SB_0) = \frac{1}{100 \cdot 15}\sum_{i=1}^{100}\left[\sum_{2020}^{2034} 1(SB_{i,t} > .3SB_{i,0})\right]$ |
| Spawning Biomass Target | Maintain spawning stock biomass at or above $0.5SB_0$ (start of rebuilding phase) with at least 50% probability over three herring generations. | Proportion of projection years where spawning biomass exceeds $0.5SB_0$. | $P(SB > .5SB_0) = \frac{1}{100 \cdot 15}\sum_{i=1}^{100}\left[\sum_{2020}^{2034} 1(SB_{i,t} > .5SB_{i,0})\right]$ |
| | Maintain spawning stock biomass at or above $SB_0$ (short-term target) with at least 50% probability over three herring generations. | Proportion of projection years where spawning biomass exceeds $SB_0$. | $P(SB > SB_0) = \frac{1}{100 \cdot 15}\sum_{i=1}^{100}\left[\sum_{2020}^{2034} 1(SB_{i,t} > SB_{i,0})\right]$ |
| Target biomass reference point | Maintain spawning stock biomass at or above a target biomass level equivalent to the median spawning biomass from 1975-85 (long-term rebuilding target), with at least 50% probability over three herring generations. | Proportion of projection years where spawning biomass exceeds the median spawning biomass and 50% of the median spawning biomass from 1975-1985. | $P(SB > \overline{SB_{75-85}}) = \frac{1}{100 \cdot 15}\sum_{i=1}^{100}\left[\sum_{2020}^{2034} 1(SB_{i,t} > \overline{SB_{i,75-85}})\right]$ |
| | Maintain spawning stock biomass at or above a target biomass level equivalent to 50% of the median spawning biomass from 1975-1985 | Proportion of projection years where spawning biomass exceeds 50% of the median spawning biomass from 1975-1985. | $P(SB > .5\overline{SB_{75-85}}) = \frac{1}{100 \cdot 15}\sum_{i=1}^{100}\left[\sum_{2020}^{2034} 1(SB_{i,t} > .5\overline{SB_{i,75-85}})\right]$ |

| Objective | Description | Performance Metric | Definition |
|---|---|---|---|
| | (short-term target), with at least 50% probability over three herring generations. | | |
| Spawning stock growth | Maximize annual spawning stock biomass growth over short (one herring generations, 5 yrs), medium (two herring generations, 10 yrs) and long (three herring generations, 15 yrs) term growth | Median percentage growth rate of spawning biomass over the time interval from $t_0$ to $t_1$ | $\Gamma(t_0,t_1) = Q2\left[exp\left(\frac{logSB_{i,t_1} - logSB_{i,t_0}}{t_1 - t_0}\right) - 1\right]$ |
| SOK fisheries | | Median number of years when SOK fisheries are open | $\overline{N}_{SOK} = Q2\left(\sum_{2020}^{2034} 1(P_{i,t} > 0)\right)$ |
| | | Median of the average annual SOK licenses for years when the fishery is open | $\overline{L}_{SOK} = Q2\left(\frac{1}{15}\sum_{2020}^{2034} 1(L_{i,t} > 0) \cdot L_{i,t}\right)$ |
| | | Median of the average annual SOK product for years when the fishery is open | $MAK = Q2\left(\frac{1}{15}\sum_{2020}^{2034} 1(K_{i,t} > 0) \cdot K_{i,t}\right)$ |
| | | Median of the average annual ponded fish for years when the fishery is open | $MAP = Q2\left(\frac{1}{15}\sum_{2020}^{2034} 1(P_{i,t} > 0) \cdot P_{i,t}\right)$ |
| | | Median of average annual absolute change in the landed catch | $AAV(P_t) = Q2$ |
| Seine roe fishery | | Median number of years when the fishery is open | $\overline{N}_{SR} = Q2\left(\sum_{2020}^{2034} 1(C_{i,t} > 0)\right)$ |
| | | Median of the average annual catch for years when the fishery is | $MAC = Q2\left(\frac{1}{15}\sum_{2020}^{2034} 1(C_{i,t} > 0) \cdot C_{i,t}\right)$ |

| Objective | Description | Performance Metric | Definition |
|---|---|---|---|
| | | open | |
| | | Median of average annual absolute change in the landed catch | $AAV(C_t) = Q2$ |
| | | Median of the average annual landed catch, including years where the fishery is closed | $\overline{C}_t = Q2\left(\frac{1}{15}\sum_{2020}^{2034} C_{i,t}\right)$ |
| | | Proportion of projection years where catch is less than 650 t | $P(C_t < 650) = \frac{1}{100 \cdot 15}\sum_{i=1}^{100}\left[\sum_{2020}^{2034} 1\left(C_{i,t} < 650\right)\right]$ |
| All fisheries | | Proportion of projection years where harvest rate exceeds 10% | $P(U_t > 0.1) = \frac{1}{100 \cdot 15}\sum_{i=1}^{100}\left[\sum_{2020}^{2034} 1\left(U_{i,t} > 0.1\right)\right]$ |
| | | Median of the expected annual harvest rate in years that the harvest rate exceeds 10% | $E(U_t \mid U_t > 0.1) = Q2\left(\frac{\sum_{2020}^{2034} 1\left(U_{i,t} > 0.1\right) \cdot U_{i,t}}{\sum_{2020}^{2034} 1\left(U_{i,t} > 0.1\right)}\right)$ |

Table 7. Summaries of each rebuilding procedure (RP) tested against the full grid of 72 operating model scenarios. The major difference between each fishing RP is the allocation of TAC among either open-pond SOK (oSOK), closed pond SOK (cSOK), commercial seine-roe (SR) fisheries, or a combined fishery (cSOK+SR). The harvest control rule to determine the TAC (HS30-100) and reference maximum harvest of 10% (HR0.1) were identical among RPs. Max SOK Licenses shows the maximum number of licenses able to be activated in each sub-stock when TAC allows for expected ponding-induced mortality. In the combined closed-pond SOK and seine-roe fishery, TAC* indicates that seine-roe TAC is allocated once the maximum number of SOK licenses were activated in the JP/S sub-stock. The harvest control rule had control points based on the OM grid average unfished sub-stock *p* biomass ($\overline{\boldsymbol{B}}_{\boldsymbol{0,p}}$), with a lower control point (LCP) of 30% of unfished biomass, below which the target harvest rate was set to zero, and an upper control point (UCP) of 100% of unfished biomass, above which the target harvest rate was the maximum reference harvest rate of 10%, with harvest rates linearly interpolated between the two control points.

| Rebuilding Procedure | SOK ponds | Max SOK Licenses | | | Seine-Roe Catch | | | LCP | UCP | HR |
|---|---|---|---|---|---|---|---|---|---|---|
| | | C/S | JP/S | Lou | C/S | JP/S | Lou | | | |
| NoFish | - | 0 | 0 | 0 | 0 | 0 | 0 | - | - | 0 |
| cSOK_HS30-100_HR0.1 | Closed | 1 | 8 | 1 | 0 | 0 | 0 | $0.3\overline{B}_{0,p}$ | $\overline{B}_{0,p}$ | 0.1 |
| oSOK_HS30-100_HR0.1 | Open | 1 | 8 | 1 | 0 | 0 | 0 | $0.3\overline{B}_{0,p}$ | $\overline{B}_{0,p}$ | 0.1 |
| cSOK+SR_HS30-100_HR0.1 | Closed | 1 | 8 | 1 | 0 | TAC* | 0 | $0.3\overline{B}_{0,p}$ | $\overline{B}_{0,p}$ | 0.1 |
| SR_HS30-100_HR0.1 | - | 0 | 0 | 0 | 0 | TAC | 0 | $0.3\overline{B}_{0,p}$ | $\overline{B}_{0,p}$ | 0.1 |

Table 8. Operating model scenario factors, factor levels, and their descriptions for both historical and projection operating model scenarios. The full operating mode grid is a fully factorial experimental design across both historical and projection factors, with scenarios defined by taking one level from each factor.

| ***Historical operating model scenarios*** | | |
|---|---|---|
| **Factor** | **Level** | **Description** |
| Age-1 M | **a1Mmean** | Age-1 natural mortality rate is set to the time-averaged natural mortality rate for each sub-stock |
| | **a1M1.25** | Age-1 natural mortality rate is set to 1.25 in all sub-stocks |
| | **a1M1.64** | Age-1 natural mortality rate is set to 1.64 in all sub-stocks |
| Stock-recruit Steepness | **sr0.5** | Stock-recruit steepness is set to 0.5 for all sub-stocks |
| | **sr0.67** | Stock-recruit steepness is set to 0.67 for all sub-stocks |
| | **sr0.8** | Stock-recruit steepness is set to 0.8 for all sub-stocks |
| Time-varying M correlation | **identM** | Time-varying random walk deviations in age-2+ natural mortality $M_{2+,p,t}$ are assumed to be identical (100% correlated) among sub-stocks for the history and projection |
| | **diffM** | Time-varying random walk deviations in age-2+ natural mortality $M_{2+,p,t}$ are assumed to be independent (0% correlated) among sub-stocks for the history, and generated in the projections with correlations empirically derived from historical deviations |
| ***Projection operating model scenarios*** | | |
| **Factor** | **Level** | **Description** |
| Return to average M | **rw5** | Natural mortality return to the historical average over the first 5 projection years (2020-2024) |
| | **rw15** | Natural mortality return to the historical average over the 15 projection years (2020 – 2034) |
| Post-ponding mortality | **loPondM** | Average ponding induced mortality set to $\overline{M}_{SOK} = 0.315$, corresponding to a 73% survival rate |
| | **hiPondM** | Ponding induced mortality set to $\overline{M}_{SOK} = 1.05$, corresponding to a 35% survival rate |

Table 9. Rebuilding procedure (RP) performance for the aggregate Haida Gwaii **'íináang | iinang** *herring* population with respect to biomass metrics, averaged over the full grid of 72 operating models assuming an equal weighting. RPs are ordered by performance with respect to the conservation objective, i.e., $\boldsymbol{P(B_t \geq 0.3B_0)}$. Growth rates are provided in percentage points, and biomass values are in kt.

| **Rebuilding Procedure** | $P(B_t \geq .3B_0)$ | $P(B_t \geq .5B_0)$ | $P(B_t \geq B_0)$ | $P(B_t \geq .5B_{75:85})$ | $P(B_t \geq B_{75:85})$ | $\Gamma(2019,2024)$ | $\Gamma(2019,2029)$ | $\Gamma(2019,2034)$ | $B_{2034}$ |
|---|---|---|---|---|---|---|---|---|---|
| NoFish | 0.50 | 0.27 | 0.05 | 0.04 | 0 | 5.1 | 5.5 | 4.3 | 17.7 |
| oSOK_HS30-100_HR0.1 | 0.50 | 0.27 | 0.05 | 0.04 | 0 | 5.1 | 5.5 | 4.2 | 17.5 |
| cSOK_HS30-100_HR0.1 | 0.49 | 0.26 | 0.05 | 0.04 | 0 | 4.9 | 5.3 | 4.2 | 17.3 |
| cSOK+SR_HS30-100_HR0.1 | 0.48 | 0.25 | 0.04 | 0.03 | 0 | 4.7 | 5.0 | 4.0 | 16.8 |
| SR_HS30-100_HR0.1 | 0.48 | 0.25 | 0.04 | 0.03 | 0 | 4.6 | 5.0 | 4.0 | 16.7 |

Table 10. Rebuilding procedure (RP) performance in individual spatial sub-stocks with respect to biomass metrics, averaged over the full grid of 72 operating models assuming an equal weighting. RPs are ordered by performance with respect to the conservation objective in the aggregate stock, i.e., $\boldsymbol{P(B_t \geq 0.3B_0)}$. Growth rates are provided in percentage points, and biomass values are in kt. Note that C/S and Lou areas do not allow seine-roe fishing and no metrics were included for SR_HS30-100_HR0.1 and cSOK+SR_HS30-100_HR0.1 RPs in those areas.

| Rebuilding Procedure | $P(B_t \geq .3B_0)$ | $P(B_t \geq .5B_0)$ | $P(B_t \geq B_0)$ | $P(B_t \geq .5B_{75:85})$ | $P(B_t \geq B_{75:85})$ | $\Gamma(2019,2024)$ | $\Gamma(2019,2029)$ | $\Gamma(2019,2034)$ | $B_{2034}$ |
|---|---|---|---|---|---|---|---|---|---|
| **C/S** | | | | | | | | | |
| NoFish | 0.45 | 0.25 | 0.07 | 0.14 | 0.02 | 7.3 | 6.8 | 5.6 | 2.8 |
| oSOK_HS30-100_HR0.1 | 0.45 | 0.25 | 0.07 | 0.14 | 0.02 | 7.3 | 6.8 | 5.6 | 2.8 |
| cSOK_HS30-100_HR0.1 | 0.44 | 0.25 | 0.06 | 0.14 | 0.02 | 7.2 | 6.7 | 5.6 | 2.8 |
| cSOK+SR_HS30-100_HR0.1 | - | - | - | - | - | - | - | - | - |
| SR_HS30-100_HR0.1 | - | - | - | - | - | - | - | - | - |
| **JP/S** | | | | | | | | | |
| NoFish | 0.44 | 0.24 | 0.06 | 0.05 | 0.00 | 3.4 | 5.5 | 4.2 | 12.8 |
| oSOK_HS30-100_HR0.1 | 0.44 | 0.24 | 0.06 | 0.05 | 0.00 | 3.4 | 5.5 | 4.1 | 12.7 |
| cSOK_HS30-100_HR0.1 | 0.44 | 0.23 | 0.06 | 0.04 | 0.00 | 3.3 | 5.4 | 4.0 | 12.5 |
| cSOK+SR_HS30-100_HR0.1 | 0.43 | 0.22 | 0.05 | 0.04 | 0.00 | 3.1 | 5.1 | 3.8 | 12.0 |
| SR_HS30-100_HR0.1 | 0.42 | 0.22 | 0.05 | 0.04 | 0.00 | 3.0 | 4.9 | 3.7 | 11.8 |
| **Lou** | | | | | | | | | |
| NoFish | 0.63 | 0.44 | 0.18 | 0.22 | 0.05 | 5.7 | 4.2 | 4.0 | 2.1 |
| oSOK_HS30-100_HR0.1 | 0.63 | 0.43 | 0.18 | 0.22 | 0.05 | 5.7 | 4.1 | 4.0 | 2.1 |
| cSOK_HS30-100_HR0.1 | 0.62 | 0.43 | 0.18 | 0.21 | 0.04 | 5.4 | 4.0 | 3.9 | 2.0 |
| cSOK+SR_HS30-100_HR0.1 | - | - | - | - | - | - | - | - | - |
| SR_HS30-100_HR0.1 | - | - | - | - | - | - | - | - | - |

Table 11. The full grid of 18 historical operating model (OM) scenarios, showing unfished biomass ($SB_0$, kt), 2019 biomass ($SB_{2019}$, kt) and 2019 biomass depletion ($SB_{2019}/SB_0$) - all for the aggregated Haida Gwaii population - and negative log likelihood difference ($\boldsymbol{\Delta}(-\boldsymbol{logL})$) relative to the OM scenario with the minimum negative log likelihood. Historical OM scenarios are arranged in ascending order of 2019 biomass depletion relative to unfished. For reference, grid mean biomass values are $\boldsymbol{SB_0 = 50.7}$ kt, and $\boldsymbol{SB_{2019} = 9.3}$ kt.

| **OM Scenario** | $SB_0$ | $SB_{2019}$ | $SB_{2019}/SB_0$ | $\Delta(-\log L)$ |
|---|---|---|---|---|
| a1M1.64_sr0.5_identM | 117.4 | 7.7 | 0.07 | 41.50 |
| a1M1.64_sr0.5_diffM | 87.9 | 7.3 | 0.09 | 10.22 |
| a1M1.64_sr0.67_identM | 81.7 | 8.8 | 0.11 | 35.43 |
| a1M1.64_sr0.67_diffM | 72.4 | 9.4 | 0.13 | 6.32 |
| a1M1.64_sr0.8_identM | 67.5 | 8.8 | 0.13 | 35.03 |
| a1M1.25_sr0.5_identM | 56.4 | 8.1 | 0.14 | 36.95 |
| a1M1.64_sr0.8_diffM | 61.8 | 10.1 | 0.16 | 2.12 |
| a1M1.25_sr0.5_diffM | 50.4 | 8.8 | 0.18 | 8.03 |
| a1M1.25_sr0.67_identM | 47.5 | 9.4 | 0.20 | 36.12 |
| a1M1.25_sr0.8_identM | 42.9 | 9.8 | 0.23 | 35.74 |
| a1M1.25_sr0.67_diffM | 42.6 | 9.9 | 0.23 | 4.31 |
| a1M1.25_sr0.8_diffM | 39.6 | 10.6 | 0.27 | 1.97 |
| a1Mmean_sr0.5_identM | 25.0 | 8.8 | 0.36 | 36.26 |
| a1Mmean_sr0.5_diffM | 23.6 | 9.2 | 0.39 | 5.41 |
| a1Mmean_sr0.67_identM | 24.1 | 10.2 | 0.42 | 34.95 |
| a1Mmean_sr0.8_identM | 23.7 | 10.5 | 0.45 | 34.69 |
| a1Mmean_sr0.67_diffM | 23.2 | 10.6 | 0.46 | 1.23 |
| a1Mmean_sr0.8_diffM | 20.7 | 10.1 | 0.48 | 0.00 |

Table 12. Summary of historical operating model (OM) dynamics for the aggregate Haida Gwaii population in the absence of fishing under the most pessimistic future $\boldsymbol{M}$ trend scenario rw15. Operating models are arranged by performance with respect to the conservation objective, i.e., $\boldsymbol{P(B_t \geq 0.3B_0)}$. Growth rates are provided in percentage points, and biomass values are in kt.

| OM Scenario | $P(B_t \geq .3B_0)$ | $P(B_t \geq .5B_0)$ | $\Gamma(2019{,}2024)$ | $\Gamma(2019{,}2029)$ | $\Gamma(2019{,}2034)$ | $B_0$ | $B_{2019}$ | $B_{2019}/B_0$ | $B_{2034}$ | $B_{2034}/B_0$ |
|---|---|---|---|---|---|---|---|---|---|---|
| a1M1.64_sr0.5_identM_rw15 | 0.002 | 0.000 | -5.6 | -1.7 | -0.6 | 117.4 | 7.7 | 0.07 | 8.0 | 0.07 |
| a1M1.64_sr0.5_diffM_rw15 | 0.015 | 0.001 | -4.2 | -1.3 | 0.2 | 87.9 | 7.3 | 0.09 | 8.2 | 0.10 |
| a1M1.64_sr0.67_identM_rw15 | 0.035 | 0.002 | 1.8 | 3.7 | 3.7 | 81.7 | 8.8 | 0.11 | 15.3 | 0.19 |
| a1M1.25_sr0.5_identM_rw15 | 0.107 | 0.020 | -0.4 | 2.0 | 2.4 | 56.4 | 8.1 | 0.14 | 12.8 | 0.22 |
| a1M1.64_sr0.67_diffM_rw15 | 0.123 | 0.012 | 3.3 | 3.9 | 3.6 | 72.4 | 9.4 | 0.13 | 16.7 | 0.23 |
| a1M1.64_sr0.8_identM_rw15 | 0.141 | 0.019 | 3.6 | 5.0 | 5.0 | 67.5 | 8.8 | 0.13 | 17.6 | 0.26 |
| a1M1.25_sr0.5_diffM_rw15 | 0.227 | 0.051 | -0.2 | 0.7 | 3.0 | 50.4 | 8.8 | 0.18 | 13.9 | 0.28 |
| a1M1.64_sr0.8_diffM_rw15 | 0.253 | 0.049 | 4.5 | 5.8 | 4.7 | 61.8 | 10.1 | 0.16 | 19.3 | 0.31 |
| a1M1.25_sr0.67_identM_rw15 | 0.373 | 0.095 | 3.9 | 5.1 | 5.0 | 47.5 | 9.4 | 0.20 | 18.0 | 0.38 |
| a1M1.25_sr0.67_diffM_rw15 | 0.438 | 0.119 | 2.1 | 4.2 | 4.1 | 42.6 | 9.9 | 0.23 | 17.8 | 0.42 |
| a1M1.25_sr0.8_identM_rw15 | 0.508 | 0.141 | 4.4 | 6.0 | 4.7 | 42.9 | 9.8 | 0.23 | 18.8 | 0.44 |
| a1M1.25_sr0.8_diffM_rw15 | 0.643 | 0.225 | 5.3 | 5.5 | 4.4 | 39.6 | 10.6 | 0.27 | 20.2 | 0.50 |
| a1Mmean_sr0.5_identM_rw15 | 0.750 | 0.381 | 3.3 | 4.6 | 4.6 | 25.0 | 8.8 | 0.36 | 16.0 | 0.64 |
| a1Mmean_sr0.5_diffM_rw15 | 0.789 | 0.449 | 2.8 | 4.1 | 3.9 | 23.6 | 9.2 | 0.39 | 16.5 | 0.70 |
| a1Mmean_sr0.67_identM_rw15 | 0.911 | 0.591 | 5.4 | 6.2 | 4.4 | 24.1 | 10.2 | 0.42 | 19.2 | 0.79 |
| a1Mmean_sr0.67_diffM_rw15 | 0.914 | 0.615 | 4.9 | 5.0 | 4.3 | 23.2 | 10.6 | 0.46 | 19.6 | 0.85 |
| a1Mmean_sr0.8_identM_rw15 | 0.923 | 0.614 | 5.6 | 5.4 | 4.7 | 23.7 | 10.5 | 0.45 | 19.5 | 0.83 |
| a1Mmean_sr0.8_diffM_rw15 | 0.938 | 0.682 | 4.6 | 5.9 | 4.5 | 20.7 | 10.1 | 0.48 | 18.1 | 0.87 |

Table 13. Summaries of historical operating model (OM) dynamics for the aggregate Haida Gwaii population in the absence of fishing under the most optimistic future $\boldsymbol{M}$ trend scenario rw5. Operating models are arranged by performance with respect to the conservation objective, i.e., $\boldsymbol{P(B_t \geq 0.3B_0)}$. Growth rates are provided in percentage points, and biomass values are in kt.

| OM Scenario | $P(B_t \geq .3B_0)$ | $P(B_t \geq .5B_0)$ | $\Gamma(2019{,}2024)$ | $\Gamma(2019{,}2029)$ | $\Gamma(2019{,}2034)$ | $B_0$ | $B_{2019}$ | $B_{2019}/B_0$ | $B_{2034}$ | $B_{2034}/B_0$ |
|---|---|---|---|---|---|---|---|---|---|---|
| a1M1.64_sr0.5_identM_rw5 | 0.01 | 0.00 | -0.3 | 1.8 | 1.7 | 117.4 | 7.7 | 0.07 | 11.1 | 0.09 |
| a1M1.64_sr0.5_diffM_rw5 | 0.02 | 0.00 | 0.4 | 3.0 | 2.8 | 87.9 | 7.3 | 0.09 | 10.9 | 0.13 |
| a1M1.64_sr0.67_identM_rw5 | 0.10 | 0.01 | 6.5 | 6.7 | 4.8 | 81.7 | 8.8 | 0.11 | 18.3 | 0.22 |
| a1M1.64_sr0.67_diffM_rw5 | 0.20 | 0.03 | 8.3 | 6.9 | 5.1 | 72.4 | 9.4 | 0.13 | 20.0 | 0.27 |
| a1M1.25_sr0.5_identM_rw5 | 0.22 | 0.04 | 5.6 | 6.3 | 4.2 | 56.4 | 8.1 | 0.14 | 16.4 | 0.29 |
| a1M1.64_sr0.8_identM_rw5 | 0.25 | 0.04 | 10.3 | 8.9 | 5.8 | 67.5 | 8.8 | 0.13 | 19.8 | 0.29 |
| a1M1.25_sr0.5_diffM_rw5 | 0.35 | 0.09 | 3.2 | 4.9 | 4.6 | 50.4 | 8.8 | 0.18 | 17.7 | 0.35 |
| a1M1.64_sr0.8_diffM_rw5 | 0.39 | 0.08 | 10.1 | 8.1 | 5.5 | 61.8 | 10.1 | 0.16 | 21.3 | 0.34 |
| a1M1.25_sr0.67_identM_rw5 | 0.55 | 0.17 | 9.1 | 8.1 | 6.0 | 47.5 | 9.4 | 0.20 | 20.6 | 0.43 |
| a1M1.25_sr0.67_diffM_rw5 | 0.62 | 0.22 | 7.9 | 8.0 | 5.0 | 42.6 | 9.9 | 0.23 | 20.6 | 0.48 |
| a1M1.25_sr0.8_identM_rw5 | 0.70 | 0.26 | 11.5 | 8.8 | 5.4 | 42.9 | 9.8 | 0.23 | 20.6 | 0.48 |
| a1M1.25_sr0.8_diffM_rw5 | 0.79 | 0.36 | 10.1 | 8.3 | 5.0 | 39.6 | 10.6 | 0.27 | 21.8 | 0.55 |
| a1Mmean_sr0.5_identM_rw5 | 0.89 | 0.58 | 8.0 | 8.8 | 5.6 | 25.0 | 8.8 | 0.36 | 19.1 | 0.77 |
| a1Mmean_sr0.5_diffM_rw5 | 0.90 | 0.64 | 7.6 | 7.5 | 5.0 | 23.6 | 9.2 | 0.39 | 19.7 | 0.83 |
| a1Mmean_sr0.67_identM_rw5 | 0.96 | 0.74 | 10.4 | 8.3 | 5.2 | 24.1 | 10.2 | 0.42 | 20.9 | 0.86 |
| a1Mmean_sr0.8_identM_rw5 | 0.96 | 0.80 | 11.1 | 8.5 | 5.1 | 23.7 | 10.5 | 0.45 | 21.0 | 0.89 |
| a1Mmean_sr0.67_diffM_rw5 | 0.96 | 0.78 | 10.0 | 8.0 | 5.3 | 23.2 | 10.6 | 0.46 | 21.5 | 0.93 |
| a1Mmean_sr0.8_diffM_rw5 | 0.98 | 0.82 | 9.9 | 7.7 | 5.0 | 20.7 | 10.1 | 0.48 | 19.3 | 0.94 |

Table 14. Rebuilding procedure (RP) performance for individual spatial sub-stocks with respect to fishery metrics, averaged over the full grid of 72 operating models assuming an equal weighting. RPs are ordered by performance with respect to the conservation objective in the aggregate stock, i.e., $\boldsymbol{P(B_t \geq 0.3B_0)}$. Spawn on kelp landings (MAK) are given in thousands of lbs, and ponded fish (MAP) and seine-roe catch (MAC) are given in tonnes. Note that C/S and Lou metrics will be the same for the SR_HS30-100_HR0.1 and NoFish RPs, and for cSOK_HS30-100_HR0.1 and cSOK+SR_HS30-100_HR0.1 RPs, as those areas do not allow seine-roe fishing.

| **Rebuilding Procedure** | $\overline{N}_{SOK}$ | $\acute{L}_{SOK}$ | $MAK$ | $MAP$ | $AAV(P_t)$ | $\overline{N}_{SR}$ | **MAC** | $AAV(C_t)$ | $P(U_t > .1)$ | $E(U_t \vee U_t > .1)$ |
|---|---|---|---|---|---|---|---|---|---|---|
| **C/S** | | | | | | | | | | |
| NoFish | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | - |
| oSOK_HS30-100_HR0.1 | 2.5 | 0.9 | 14.5 | 95.1 | 88.6 | 0.0 | 0.0 | 0.0 | 0.00 | - |
| cSOK_HS30-100_HR0.1 | 1.4 | 0.8 | 13.2 | 86.0 | 84.5 | 0.0 | 0.0 | 0.0 | 0.00 | - |
| cSOK+SR_HS30-100_HR0.1 | - | - | - | - | - | - | - | - | - | - |
| SR_HS30-100_HR0.1 | - | - | - | - | - | - | - | - | - | - |
| **JP/S** | | | | | | | | | | |
| NoFish | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | - |
| oSOK_HS30-100_HR0.1 | 3.2 | 6.4 | 102.4 | 676.4 | 110.7 | 0.0 | 0.0 | 0.0 | 0.03 | 0.122 |
| cSOK_HS30-100_HR0.1 | 2.6 | 4.7 | 74.4 | 491.0 | 113.1 | 0.0 | 0.0 | 0.0 | 0.01 | 0.119 |
| cSOK+SR_HS30-100_HR0.1 | 2.6 | 4.6 | 73.8 | 486.9 | 114.2 | 0.5 | 389.7 | 57.7 | 0.06 | 0.182 |
| SR_HS30-100_HR0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.6 | 782.1 | 110.5 | 0.06 | 0.180 |
| **Lou** | | | | | | | | | | |
| NoFish | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | - |
| oSOK_HS30-100_HR0.1 | 4.2 | 0.9 | 15.2 | 100.3 | 104.7 | 0.0 | 0.0 | 0.0 | 0.02 | 0.120 |
| cSOK_HS30-100_HR0.1 | 2.8 | 0.9 | 14.7 | 97.1 | 100.9 | 0.0 | 0.0 | 0.0 | 0.01 | 0.117 |
| cSOK+SR_HS30-100_HR0.1 | - | - | - | - | - | - | - | - | - | - |
| SR_HS30-100_HR0.1 | - | - | - | - | - | - | - | - | - | - |

Table 15. Equations for the biomass dynamics model. See Table 17 for symbol descriptions.

| | Formula | Description |
|---|---|---|
| Eq. 1 | $B_{y,s} =$ | Estimated total pre-harvest biomass; year *t*, sub-stock *s* |
| Eq. 2 | $logp + \left[logI_{y,s,l} - \left(logb_{y,s,l} + logq_y\right)\right]^2 / 2\,\sigma^2 - log\left(\sqrt{2\pi}\sigma I \middle\| y,s\right)$ | Observation log-likelihood $(I_{y,s,l} > 0$ |
| Eq. 3 | $logp$ | Observation log-likelihood $(I_{y,s,l} = 0$ |
| Eq. 4 | $p = 1/\left(1 + exp\left[-\left(\left[logb_{y,s,l} + logq_y\right] - a_1\right)/a_2\right]\right)$ | Observation probability |
| Eq. 5 | $b_{y,s,l} = \left(B \middle\| y,s - C_{y,s}\right) \frac{exp\,(\epsilon \| y,s,l)}{\left(1 + \sum_l^{L-1} exp\epsilon_{y,s,l}\right)}$ | Spatial biomass distribution |
| Eq. 6 | $\varepsilon$MVT) | Process error in biomass productivity (spatial-temporal covariance) |
| Eq. 7 | $\epsilon_s$MVT) | Process error in logit spatial distribution (spatial-temporal covariance) |
| Eq. 8 | $\alpha, \beta, \gamma$ ~ LN(0,1) | Hyperprior for the mean productivity hyperparameters |
| Eq. 9 | $[\alpha_s, \beta_s, \gamma_s]'\mathrm{LN}\left([\alpha,\beta,\gamma]', \Sigma_p\right)$ | Hierarchical prior for sub-stock productivity parameters |
| Eq. 10 | $\rho, \tau, \sigma, \sigma_\epsilon, \sigma_\varepsilon \mathrm{N}(0,1); > 0$ | Priors for various scale parameters |
| Eq. 11 | $qln(\log(1),0.05)$ or $ln(\log(0.75),0.05)$ | Prior for q |
| Eq. 12 | $f(D_{i,j}) = \begin{cases} \left(1 + \frac{\sqrt{5}\|D_{i,j}\|}{\rho} + \frac{\sqrt{5}\|D_{i,j}\|^2}{3\rho^2}\right) \Big/ \left(\frac{e^{\sqrt{5}\|D_{i,j}\|}}{\rho}\right) & i \neq j \\ 1 + \tau & i = j \end{cases}$ | 5/2 Matérn covariance kernel with nugget $\tau$ |
| Eq. 13 | $t(D_{i,j}) = \phi^{\|D_{i,j}\|}$ | AR(1) covariance kernel |

Table 16. Equations for the growth dynamics model.

| | Formula | Description |
|---|---|---|
| Eq. 14 | $\mu_{y,s,a} = \begin{cases} e^{K_s}\left(-L_{\infty_s} + e^{K_s}L_{\infty_s} + A_{0_s}\right)e^{e_{y,s,g}} & a = 2 \\ e^{K_s a}\left(-L_{\infty_s} + e^{K_s a}L_{\infty_s} + A_{0_s}\right)e^{e_{y,s,g}} & a > 2, y = 1 \\ e^{K_s}\left(-L_{\infty_s} + e^{K_s}L_{\infty_s} + \mu_{y-1,s,a-1}\right)e^{e_{y,s,g}} & y > 1 \end{cases}$ | Annual growth equation |
| Eq. 15 | $e_{y,g,s}$MVT)<br>(See Eq. 12, Eq. 13, ⊗ = Kronecker product) | Annual and section specific growth anomalies |
| Eq. 16 | $log\left[K_s, L_{\infty_s}, A_{0_s}\right] = MVN(log[K, L_\infty, A_0], \Sigma); \Sigma$ ~ LKJ(2)<br>$K, L_\infty, A_0 ln(log0.5,0.3)$ | Site specific and mean LVB parameters |
| Eq. 17 | $\left[logL_{y,s,a,i} - log\mu_{y,s,a}\right]^2/2\,\sigma^2 - log\left(\sqrt{2\pi}\sigma logL_{y,s,a,i}\right)$ | Observation likelihood |
| Eq. 18 | $\sigma_e$,$\sigma$, ρ, $\phi$ ~ N(0,1); >0 | Scale parameters |

Table 17. Key observed variables, estimated state variables, and estimated parameters.

| Symbol | Description | Model |
|---|---|---|
| $\boldsymbol{B_{t,s}}$ | Estimated total biomass in year *y* at sub-stock *s* | Biomass Dynamics |
| $\boldsymbol{C_{t,s}}$ | Catch in year *y* at sub-stock *s* | |
| $\boldsymbol{I_{y,s,l}}$ | Observed biomass in year *y*, sub-stock *s*, location *l* | |
| $b_{y,s,l}$ | Estimated biomass in year *y*, at sub-stock *s*, location *l* | |
| $q_y$ | Spawn fraction observed in year *y* (three groups, <78, <88, >=88) | |
| $\epsilon_{y,s,l}$ | Logit-scale proportion of biomass in year *y*, at sub-stock *s*, location *l* | |
| $L_{y,s,a,i}$ | Observed length of the ith fish in year *y*, section *s*, at age *a* | Growth Dynamics |
| $\mu_{y,s,a,i}$ | Estimated length of the fish in year *y*, section *s*, at age *a* | |
| $K_s, L_{\infty_s}, A_{0_s}$ | Section specific LVB growth parameters | |
| $e_{y,g,s}$ | Section, year, and group (age 2 or 3+) growth anomalies | |

Table 18. Estimated biomass reference points (tonnes) for selected sub-stocks for chosen periods. The posterior uncertainty intervals represent the highest density intervals (HDI). Note that the estimates and uncertainty reflect posterior estimates for q, which is estimated separately for intervals <1977 (posterior mean = 0.65), 1978-1988 (posterior mean = 0.70), and >1988 (posterior mean = 0.71) using a prior mean of 0.75 in the model. Changes to assumptions and uncertainty in q will alter these reference points directly. For visualizations of the time series see Figure 36.

| Sub-stock | Reference Period | Posterior Mean | Posterior Median | Uncertainty Intervals (HDI) | |
|---|---|---|---|---|---|
| | | | | 95% | 80% |
| Port Louis | 1982-92 | 2,583 | 2,455 | 1,363 – 3,987 | 1,650 – 3,238 |
| Rennell Sound | 1982-92 | 2,130 | 2,071 | 1,438 – 3,037 | 1,538 – 2,511 |
| Englefield | 1982-92 | 1,393 | 1,327 | 770 – 2,157 | 883 – 1,720 |
| Louscoone | 1975-85 | 2,740 | 2,635 | 1,805 – 3,846 | 2,018 – 3,245 |
| Skincuttle/Juan Perez | 1975-85 | 31,153 | 30,769 | 24,500 – 38,543 | 25,870 – 35,082 |
| Cumshewa/Laskeek | 1975-85 | 4,908 | 4,823 | 3,512 – 6,441 | 3,876 – 5,716 |

Table 19. Indicators of ocean conditions and atmospheric circulation patterns.

| Indicator | Details |
|---|---|
| Pacific Decadal Oscillation (PDO) | Leading principal component of North Pacific (poleward of 20 degree latitude) monthly sea surface temperature variability. NCEI PDO index is based on NOAA's extended reconstruction of SSTs (ERSST). Annual PDO index is calculated as mean of monthly anomalies.<br>Positive phase: sea surface temperature warm<br>Negative phase: sea surface temperature cool<br>Data coverage: full analysis period (1959-present) |
| North Pacific Gyre Oscillation (NPGO) | 2nd dominant mode of SSH variability in the Northeast Pacific. Captures changes in the intensity of the North Pacific Gyre Oscillation. Closely correlated with nutrient availability and chlorophyll concentration in the California Current and Line P. Annual NPGO index is calculated as mean of monthly anomalies.<br>Positive phase: increases in circulation, salinity, nutrients, and chlorophyll.<br>Negative phase: decreases in circulation, salinity, nutrients, and chlorophyll.<br>Data coverage: full analysis period (1959-present) |
| Arctic Oscillation Index (AOI) | Mean 1000mb height anomalies poleward of 20° latitude, projected onto leading EOF mode. Primarily an index of winter conditions, calculated as seasonal mean for Jan - March.<br>Positive phase: jet stream primarily loops north, and outflow conditions are more common.<br>Negative phase: jet stream is primarily at mid-latitude - ‘typical wet winter weather’ with strong western storm track predominates.<br>Data coverage: full analysis period (1959-present) |
| North Pacific Index (NPI) | Area-weighted sea level pressure over 30°N-65°N, 160°E-140°W. Captures changes in the intensity of the Aleutian Low. Primarily an index of winter conditions. Annual index calculated as Nov - March average.<br>Positive phase: more active storm track, increased likelihood of extreme weather events<br>Negative phase: less active storm track<br>Data coverage: full analysis period (1959-present) |
| Southern Oscillation Index (SOI) | ENSO index, based on the pressure difference between Tahiti and Darwin. Annual SOI index calculated as mean of monthly anomalies.<br>Positive phase: La Nina<br>Negative phase: El Nino<br>Data coverage: full analysis period (1959-present) |
| Sea Surface Temperature (SST) | Met Office Hadley Centre reconstructed SST 1 degree global grid. Annual SST indices calculated for BCMCA regions as mean of monthly anomalies.<br>Data coverage: full analysis period (1959-present) |

Table 20. Biological indicators.

| Indicator | Details |
|---|---|
| Net Primary Productivity (NPP) | Composite of estimates derived from SeaWiFS and MODIS Aqua sensor data processed using the standard VGPM algorithm, obtained from Oregon State University Ocean Productivity website. Seasonal (spring, summer, fall) averages of NPP indices calculated for each BCMCA region of interest.<br>Data coverage: 1997-present; poor data quality in winter due to cloud coverage. |
| Pacific Hake (*Merluccius productus)* | Kriged biomass grid from joint Pacific Hake survey. Annual hake index calculated for BCMCA regions by averaging over grid points within each region.<br>Data coverage: 1995 - present; at semi-regular multi-year intervals. |
| Steller Sea Lion (*Eumetopias jubatus*) | 'Non-pup' summer rookery counts from aerial surveys. 'Index rookeries' selected based on data continuity. Haida Gwaii index is sum of counts from Cape St. James and Reef Island rookeries. Mainland index is sum of counts from Bonilla and North Danger Rocks rookeries. Alaska index is sum of counts from Forrester Island rookeries.<br>Data coverage BC: 1971 - 2014, at semi-regular multi-year intervals.<br>Data coverage AK: 1982 - present, at semi-regular multi-year intervals. |
| Humpback Whale (*Megaptera novaeangliae*) | Mark-recapture estimates from BC and Sitka Sound (AK).<br>Data coverage BC: annual from 1992 - 2005<br>Data coverage AK: annual from 1981 - 2011, some data gaps. |

Table 21. Summary of main findings from modelling approaches and rebuilding considerations for the Haida Gwaii **'íináang | iinang** *herring* Major stock assessment region (SAR). RP = rebuilding procedure, HCR= harvest control rule, LRP = limit reference point.

| Source | Main Finding | Consideration for Rebuilding |
|---|---|---|
| SISCAH model (Section 6.1) | Context: Rebuilding time frame<br>The time frame for rebuilding is expected to be greater than 15 years (under current ecosystem conditions). Simulation evaluation results indicated little difference in stock growth toward rebuilding targets and the expected timeline for rebuilding under the no fishing procedure when compared to the rebuilding procedures that allowed fishing. This suggests that rebuilding performance of Haida Gwaii Herring populations is dominated by the population and ecosystem dynamics represented in the operating model scenarios, not the impacts of the fisheries allocations simulated in the analysis. | Rebuilding above the LRP is unlikely at current natural mortality levels (DFO 2020).<br>It is recommended that fishing RPs are applied only once aggregate stock biomass shows clear signal of rebuilding (Section 5).<br>Rebuilding plan should include short- and long-term biomass targets (Section 5). |
| SISCAH model (Section 6.1) | Context: Fishery type<br>Spawn on kelp (SOK) fisheries had a slightly reduced impact on population rebuilding compared to the commercial seine roe fishery (Table 9 and Table 10). | Once aggregate stock biomass is in the rebuilding phase, implement RP with open or closed pond SOK (Table 7). |
| SISCAH model (Section 6.1) | Context: Socio-economic considerations<br>SOK fisheries allowed for more fishing opportunities within the rebuilding phase than the commercial seine roe fishery, due to the higher minimum TAC requirements for the commercial seine roe fishery leading to more frequent closures. | Assess acceptable tradeoffs during rebuilding between population growth rates and fishing opportunities.<br>Prioritize SOK fisheries during rebuilding to meet cultural and socio-economic objectives.<br>Introduce seine roe fisheries only once populations rebuilt. |
| SISCAH model (Section 6.1) | Context: Spatial resolution<br>Spatial structure of Haida Gwaii herring still remains a major source of uncertainty and may be different than the resolution analyzed in the simulations. Sub-stocks were assumed to be independent in the analysis and results showed some correlation in recruitment and natural mortality between sub-stocks, indicating that this current assumption may be incorrect.<br>Increasing spatial resolution led to a reduction in available data for each sub-stock, which increased bias and decreased precision in parameter estimates. | Fisheries concentrated in areas with larger abundance may impact the smaller neighbouring areas in ways not accounted for in the simulation modelling.<br>Apply spatial management meta-rules to RPs in order to limit and distribute fisheries impacts.<br>The relative impacts of the different types of fisheries do not appear to be sensitive to assumptions about the spatial population structure. |

| | | |
|---|---|---|
| | Simulation analysis results showed the same relative order of ranking of the performance of rebuilding procedures when applied at the sub-stock level compared to the aggregate level. | |
| Spatial and temporal models (Section 6.2) | Context: Sub-stock productivity and biomass<br>Analysis revealed some synchronicity in productivity and biomass between sub-stocks, but smaller sub-stocks appear to be subject to more severe fluctuation in biomass with greater amplitude, prolonged periods of persistent collapse, with only short and unpredictable periods of sustained positive production. | Set minimum biomass thresholds for multiple consecutive years after a low productivity signal and set low maximum target harvest rates. |
| Environmental correlation models (Section 6.3) | Context: Sub-stock productivity and production<br>Negative temporal autocorrelation in productivity and production patterns indicates that the sub-stocks are unlikely to show smooth trends. | Rebuilding signals will need to be observed over multiple years before determining rebuilding trends and stability. |
| Environmental correlation models (Section 6.3) | Context: Expected environmental conditions<br>Some evidence that years with unfavourable environmental conditions may be becoming more common. | If rebuilding occurs, it may turn out to be fragile, therefore aim to maintain high spawning biomass to sustain sub-stock over years with poor environmental conditions. |

Table 22. Management measures for the Haida Gwaii **'íináang | iinang** *Herring* Major stock assessment region (SAR) as informed by the stock status, modelling approaches and rebuilding considerations. All fishing rebuilding procedures (RPs) apply spatial meta-rules to distribute commercial fishing effort to the three sub-stocks: Open and closed spawn on kelp (oSOK and cSOK): Juan Perez/Skincuttle (JP/S) - max 10 licences, Cumshewa/Selwyn (C/S) & Louscoone Inlet (Lou) - max 1 licence, permitted only when estimated sub-stock biomass (based on best available information) >500t; Seine roe (SR) is only permitted in JP/S (See Section 6.1.3 for details; subject to further simulation analyses as rebuilding progresses). When commercial cSOK is permitted, oSOK is also permitted. Minimum total allowable catch (TAC) rules are also applied in all fishing RPs: oSOK, minimum 31.7t (35 short tons) TAC required per licence; cSOK, minimum 90.7t (100 short tons) TAC required per licence; and SR, minimum TAC of 300t required to open. LRP = limit reference point ($0.3SB_0$), USR = upper stock reference ($\mathbf{0.75\overline{SB}_{75:85}}$, HR = harvest rate, $SB_t$ = current spawning biomass, $SB_0$ = unfished equilibrium spawning biomass, $\mathbf{\overline{SB}_{75:85}}$ = estimated average median spawning biomass from 1975-85, *P* = probability, RP = rebuilding procedure, short-term rebuilding target = greater of USR and $SB_0$, long-term rebuilding target = greater of $\mathbf{\overline{SB}_{75:85}}$ and $1.5SB_0$. Also see Figure 47 for a flow chart representation of recommendations presented here.

| Assessed status | Description | Rebuilding procedure (RP)[12] | Justification/Linkage to modelling analysis & objectives |
|---|---|---|---|
| $SB_t \leq$ LRP ($0.3SB_0$) ($P \geq 25\%$) | Stock in critical zone | HR = 0 | Implement NoFish RP as prescribed by the PA Framework (Section 6.1, Table 7); maintain access for Haida traditional fisheries and existing recreational fisheries; measure will support objective 1.1a, as no commercial fishing will be permitted below the LRP. |
| LRP < $SB_t$ < $0.5SB_0$ ($P \geq 50\%$) | Stock above critical zone and below rebuilding phase ***years 1 and 2*** | HR = 0<br>***<u>Year-2 decision making:</u>*** identify which RP to be applied in year 3 (+) based on projected $SB_{t+1}$ | Maintain NoFish RP for the first 2 consecutive years of $SB_t$ being above the LRP (intended to avoid premature signal of exceeding the LRP with P ≥ 75%, measure supports objective 1.1a) |

[12]Haida traditional fisheries will not be limited by assessed aggregate stock status and may occur in all areas of Haida Gwaii, subject to conservation. Traditional fisheries are primarily open ponding (oSOK) but may be augmented by 1-2 closed ponds.

| | | | |
|---|---|---|---|
| | Stock above critical zone and below rebuilding phase<br>***years 3 (+)*** | (1) Max 105 t; oSOK or cSOK<br><br>Open pond SOK operations limited to 3 (max) or closed pond SOK operation limited to 1 (max) and requires a partnership agreement to support the traditional fishery approved by CHN | Allow a maximum of 105t harvest which is equivalent to a max of 3 open pond operations or 1 closed pond SOK in the Major SAR:<br>(1) oSOK RP with max target HR of 10% performed nearly identically to NoFish RP in simulations. Max target HR of 5% would have minimal impact on growth of the stock and still provide traditional fishing opportunities. Measure supports objective 1.1c to maximize stock growth (by opening fisheries that have low impact to stock); objective 3.4a to promote economic viability when stock begins to show signs of rebuilding |
| $0.5SB_0 < SB_t <$ short-term rebuilding target (greater of USR ($0.75\overline{SB}_{75:85}$) and $SB_0$)<br>($P \geq 50\%$) | Stock in rebuilding phase when status has been above the LRP for 2 (+) years<br>***years 1 and 2*** | ****If status has not been above the LRP for 2(+) years HR = 0***<br>(1) oSOK_HS30-100_HR0.05<br>(2) cSOK_HS30-100_HR0.05<br><br>Target max HR = 0.05<br>Open and closed pond SOK; number of licences determined by RP and spatial meta-rules.<br><br>***<u>Year-2 decision making:</u>***<br>Identify which SOK RP to be applied in year 3 (+) based on projected $SB_{t+1}$ | Apply SOK RPs with max target HR of 5%:<br>(1) oSOK RP with max target HR of 10% performed nearly identically to NoFish RP in simulations. Max target HR of 5% would have less impact on growth of the stock and still provide traditional fishing opportunities.<br>(2) cSOK RP with max target HR of 10% performance metrics differed from NoFish RP performance by no more than 0.1% at the aggregate (with HR = 10%; Table 9, cols |

| | | | |
|---|---|---|---|
| | | | 1:4) and sub-stock (Table **10**) scales. Max target HR of 5% would have less impact on growth of the stock and still provide traditional fishing opportunities. Measure supports objective 1.1b as it protects stock growth above the rebuilding target. |
| | Stock in rebuilding phase ***years 3 (+)*** | (1) oSOK_HS30-100_HR0.1<br>(2) cSOK_HS30-100_HR0.1<br><br>Target max HR = 0.10 | Apply one of the two simulation tested RPs or a combination of cSOK and oSOK (See Section 6.1). Measure supports: objective 1.1c to maximize stock growth (by opening fisheries that have low impact to stock); objective 3.4a to promote economic viability. |
| Short-term rebuilding target < $SB_t$ < long-term rebuilding target (greater of $\overline{SB}_{75:85}$ and $1.5SB_0$) ($P \geq 50\%$) | Stock out of initial rebuilding phase but below long-term rebuilding target ***years 1 and 2*** | (1) oSOK_HS30-100_HR0.1<br>(2) cSOK_HS30-100_HR0.1<br><br>Target max HR = 0.10<br>***<u>Year-2 analysis:</u>***<br>- Conduct additional simulation analysis (new MSE cycle) to update RP evaluation for assessed population status that is approaching the long-term rebuilding target.<br>- Consider alternative RPs (i.e., cSOK+SR_HS30-100_HR0.05).<br>- Identify which RP to be applied in year 3 (+) based on updated MSE cycle and projected $SB_{t+1}$. | Apply one of the two simulation tested RPs (intended to avoid premature signal of exceeding USR with P >50%). This may be the same RP as applied in the previous stage.<br><br>Measure supports objective 1.1b as protects growth above short-term rebuilding target. |
| | Stock out of initial rebuilding phase but | Apply RPs identified in updated simulation analyses in previous phase | Apply simulation tested RPs. Measure supports objective 3.4a to |

| | | | |
|---|---|---|---|
| | below long-term rebuilding target<br>***years 3 (+)*** | | promote economic viability. |
| Long-term rebuilding target (greater of $\overline{SB}_{75:85}$ and 1.5$SB_0$) ($P \geq 50\%$) < $SB_t$ | Stock in long-term rebuilding phase<br>***years 1 and 2*** | Apply RPs identified in updated simulation analyses in previous phase<br>***<u>Year-2 analysis</u>***:<br>- Conduct additional simulation analysis (new MSE cycle) to update RP evaluation when the assessed population status is approaching the long-term rebuilding target.<br>- Consider alternative RPs.<br>- Identify which RP to be applied in year 3 (+) based on updated MSE cycle and projected $SB_{t+1}$. | Apply simulation tested RPs identified in the updated MSE cycle in the phase above.<br>This may be the same RP as applied in the previous stage.<br><br>Measure supports objective 3.2a to maintain stock above the long-term rebuilding target (unlikely in the 15 year projection period) |
| | Stock in healthy phase<br>***years 3 (+)*** | Apply RPs identified in updated simulation analyses in previous phase | Apply simulation tested RPs identified in the updated MSE cycle. |

Table 23. Summary of main findings from modelling approaches and rebuilding considerations for the Haida Gwaii Minor stock assessment region (SAR). RP = rebuilding procedure, HCR = harvest control rule.

| Source | Main finding | Consideration for rebuilding |
|---|---|---|
| Sections 6.2-6.3 | *Context: Portfolio diversity*<br>The portfolio of the Minor SAR sub-stocks has become less diverse than in previous decades. Specifically, persistent collapses of multiple sub-stocks without commensurate increases in productivity in adjacent sub-stocks. | Risk of overharvesting at the sub-stock level due to uncertain abundance estimates and evidence of volatility. |
| Section 6.2-6.3 | *Context: Sub-stock productivity and biomass*<br>Some synchronicity in sub-stock productivity and biomass was identified but smaller sub-stocks appear to be subject to more severe fluctuation in biomass, with greater amplitude, prolonged periods of persistent collapse, with only short and unpredictable periods of sustained positive production. | Set high minimum thresholds over a minimum number of consecutive years before opening commercial fisheries, and set harvest rates by sub-stock. |
| Section 6.2 | *Context: Trends in size-at-age*<br>Continual slowing of growth rates of adult fish is largely synchronous with the rest of BC herring sections, with trends differing slightly by age-2 and age-3+ fish, and may pose a challenge to rebuilding. | Continued sampling and monitoring for herring size-at-age is important to maintain and expand to other areas as needed. |
| Section 6.2 | *Context: Monitoring and data availability*<br>There is insufficient data available in Minor SAR to conduct an age-structured statistical analysis. Therefore, spawn index information, without estimation of uncertainty, is currently used to provide the basis for evaluating status and management options in the Minor SAR. Alternative models (i.e., biomass-based forecast models including consideration of environmental covariates) should be evaluated for efficacy. | Continued monitoring of the Minor SAR sub-stocks with sufficient effort will be required to maintain time series for spawn index that is comparable to historical data. |

Table 24. Management measures for the Haida Gwaii **'íináang | iinang** *Herring* Minor stock assessment region (SAR) as informed by the best available information about population status and rebuilding considerations. All fishing rebuilding procedures (RPs) apply spatial meta-rules to distribute open and closed spawn on kelp (SOK*)* fishing effort to the sub-stock areas within the Minor SAR: Port Louis - max 3 licences, Rennell Sound - max 4 licence and Englefield – max 1 licence (See Section 6.2 for further details). No fishing is recommended for Skidegate Channel and Tasu Sound sub-stocks. Minimum total allowable catch (TAC) rules are also applied in all fishing RPs: oSOK, minimum 35t TAC required per licence; cSOK, minimum 100t TAC required per licence; and SR, minimum TAC of 300t required to open. $SB_t$ = best available estimate of spawning biomass (e.g., spawn index for the previous year or determined using the best available modelling method), $\overline{SB}_{82:92}$ = estimated average spawning biomass from 1982-92, HR= harvest rate, rebuilding target = $\overline{SB}_{82:92}$. Also see Figure 48 for a flow chart representation of recommendations presented here.

| Assessed status of sub-stocks | Description | Recommended rebuilding procedures (RPs) for the Minor SAR sub-stocks[13] | Justification/Linkage with modelling analysis and objectives |
|---|---|---|---|
| No data available (e.g., No fishing is recommended for Skidegate Channel and Tasu Sound sub-stocks due to lack of historical data) | No assessment data available for a sub-stock area within the Minor SAR | HR = 0 | Implement NoFish RP; maintain access for Haida traditional and existing recreational fisheries. |
| $SB_t \leq 0.25\overline{SB}_{82:92}$ | Current biomass is less than 25% of the target reference point for a sub-stock area | HR = 0 | Implement NoFish RP; maintain access for Haida traditional and existing recreational fisheries; intended to establish a minimum biomass threshold before opening a commercial fishery. |
| $0.25\overline{SB}_{82:92} < SB_t < 0.5\overline{SB}_{82:92}$<br><br>***Status must have been above the $0.25\overline{SB}_{82:92}$ for 2 years to enter this phase or 2 out of 3 years if data is missing for $SB_{t-1}$** | Current biomass is between 25-50% of target reference point for a sub-stock area ***years 1 and 2*** | (1) oSOK<br>(2) cSOK<br>Target max HR = 0.05<br>Open and closed pond SOK, maximum number of licences available in each sub-stock area determined by spatial meta-rules | Allow SOK operations including spatial meta rules.<br>Currently no peer reviewed biological reference points and patchy time series data, thus it is recommended to continue with SOK only but with a 5% harvest rate for the first 2 years at this status. |

[13]Haida traditional fisheries will not be limited by assessed aggregate stock status and may occur in local areas at any abundance. Traditional fisheries are primarily open ponding (oSOK) but may be augmented by 1-2 closed ponds.

| | | | |
|---|---|---|---|
| | ***years 3 (+)*** | (1) oSOK<br>(2) cSOK<br>Target max HR = 0.1<br>Open and closed pond SOK, maximum number of licences available in each sub-stock area determined by spatial meta-rules | Allow SOK operations including spatial meta rules.<br>Currently no peer reviewed biological reference points and patchy time series data, thus it is recommended to continue with SOK only with a 10% harvest rate in years 3 (+) at this status. |
| $\overline{SB}_{82:92} < SB_t$<br><br>***Status must have been above the $0.25\overline{B}_{82:92}$ for 2 (+) years to enter this phase or 2 out of 3 years if data is missing for $SB_{t-1}$** | Previous year index observation is greater than 100% of rebuilding target | (1) oSOK<br>(2) cSOK<br>Target max HR = 0.1<br>Open and closed pond SOK, maximum number of licences available in each sub-stock area determined by spatial meta-rules. | Allow SOK operations including spatial meta rules.<br><br>Currently no peer reviewed biological reference points and patchy time series data, thus it is recommended to continue with SOK only with a 10% harvest rate. |

Table 25. Ecological monitoring priorities to measure rebuilding progress for Haida Gwaii **'íináang | iinang** *herring*.

| Operational Objectives | Attributes | Characteristics | Monitoring Priorities to address objectives | Status | | |
|---|---|---|---|---|---|---|
| | | | | Current work | Additional work | New work |
| • Rebuild and maintain natural productivity and spatial dynamics of herring populations and ecosystem biodiversity at an appropriate scale<br>• Increase opportunities to advance understanding of herring biology and ecology (e.g., ecosystem role of herring) | • Herring population size and productivity<br>*(At multiple spatial scales, including: Aggregate populations in the Major and Minor SARs and sub-stock populations)* | • Herring abundance (Biomass estimates and/or abundance indices) | • Annual estimates of spawning biomass and trends in abundance | ✓ | | |
| | | | • Annual abundance relative to reference points (e.g., LRP, productive period biomass), probability biomass > reference points, proportion of years biomass is below reference points, proportion of years population abundance was below reference points, and annual deviations of abundance biomass from reference points (e.g., sum of squares (SSQ) calculation) | | ✓ | |
| | | • Recruitment and natural mortality | • Annual estimates of recruitment (Age 2/3) | | ✓ | |
| | | | • Annual estimates and trend of abundance of older fish (age 4+) | | | ✓ |

| Operational Objectives | Attributes | Characteristics | Monitoring Priorities to address objectives | Status | | |
|---|---|---|---|---|---|---|
| | | | | Current work | Additional work | New work |
| | | | • Annual estimates and trend of natural mortality estimate | ✓ | | |
| | | • Productivity and surplus production | • Annual estimates of productivity and surplus production | ✓ | | |
| | • Herring population condition<br><br>*(At multiple spatial scales, including: Aggregate populations the Major and Minor SARs and sub-stock populations)* | • Spatial and temporal coverage of spawn | • Annual length, width, area, and egg layers of each spawn event | | ✓ | |
| | | | • Annual spawn index (t) for each spawn location | ✓ | | |
| | | | • Annual frequency of spawn events by spatial scale area | ✓ | | |
| | | | • Start and end dates of spawn events | ✓ | | |
| | | | • Number of days each spawn lasts | ✓ | | |
| | | | • Proportion of spawn index (t) by date or period (Julien calendar) | ✓ | | |
| | | | • Quality and coverage of survey, including comparison to previous years | | ✓ | |
| | | • Size and age structure | • Annual length- and weight-at-age | ✓ | | |
| | | | • Annual proportion of fish-at-age | ✓ | | |
| | | | • Annual proportion of older fish (Age 4+) | | ✓ | |

| Operational Objectives | Attributes | Characteristics | Monitoring Priorities to address objectives | Status | | |
|---|---|---|---|---|---|---|
| | | | | Current work | Additional work | New work |
| | • Ecosystem health | • Biodiversity | • Surveys (baseline and 5-year minimum frequency) and calculation of biodiversity at scale to be determined (e.g., species richness, Shannon's diversity, abundance of keystone species, introduced species) | | | ✓ |
| | | | • Zooplankton community and diversity comparisons | | ✓ | |
| | | • Trends in primary production | • Annual plankton biomass or index of abundance | | | ✓ |
| | | | • Annual and seasonal trends in abundance and timing of Chlorophyll a production | | | ✓ |
| | | | • Annual and seasonal net primary productivity | | | ✓ |
| | | • Herring predators, competitors and invasive species trends | • Surveys (5-year minimum frequency Major and Minor stocks and sub-stocks as data and methods allow) and annual observations of abundance of predator and competitor species (e.g., hake, humpback whale, sea lions, sea birds, sandlance, etc.) | | | ✓ |
| | | | • Presence, spatial distribution, and relative | | ✓ | |

| Operational Objectives | Attributes | Characteristics | Monitoring Priorities to address objectives | Status | | |
|---|---|---|---|---|---|---|
| | | | | Current work | Additional work | New work |
| | | | abundance of invasive species (e.g., tunicates, European green crab) | | | |
| • Incorporate uncertainties and ecological risks of different fisheries (e.g., spawn-on-kelp vs. roe) into herring rebuilding to mitigate impacts, including climate change, habitat degradation, and food web alterations | • Climate and oceanographic trends and habitat condition | • Ocean conditions | • Annual and seasonal measures of sea surface temperature (SST), dissolved oxygen, pH, salinity, conductivity, currents, light and water clarity in herring spawning sites | | ✓ | |
| | | • Environmental variability and resilience (e.g., Regime shifts) | • Detection of climate-change impacts, including regime shifts and persistent trends | | | ✓ |
| | | | • Risk assessments and response capacity for major catastrophic events (e.g., drift groundings, oil spills) | | ✓ | |
| | | • Water quality and spawning substrate availability/ quality | • Annual measure of water quality index in spawning sites | | | ✓ |
| | | | • Toxin levels in spawning habitats (e.g., baseline such as DFO sediment surveys and after any spill event) | | ✓ | |
| | | | • Area and proportion of herring habitat degraded/undisturbed by urban development, | | ✓ | |

| Operational Objectives | Attributes | Characteristics | Monitoring Priorities to address objectives | Status | | |
|---|---|---|---|---|---|---|
| | | | | Current work | Additional work | New work |
| | | | fishing, or other human activities | | | |
| | | | • Presence of and damage to critical herring spawning substrate by invasive species (e.g., tunicates, European green crab) | | | ✓ |

Table 26. Cultural monitoring priorities to measure rebuilding progress.

| Operational Objectives | Attributes | Characteristics | Monitoring Priorities to address objectives | Status | | |
|---|---|---|---|---|---|---|
| | | | | Current work | Additional work | New work |
| • Foster Haida governance of traditional use and stewardship of herring on Haida Gwaii.<br>• Protect and maintain culturally important areas and other areas of concern for herring.<br>• Enable Haida traditional use of and cultural connections with herring.<br>• Haida laws, ethics and values recognized in governance and management (summarize how) | • Respect priority of Haida fishery<br>• Cultural continuity<br>• Food security, sharing and trade<br>• Intergenerational knowledge transfer<br>• Ceremonial use and spiritual importance<br>• Connections to place and environment | • Success of traditional fishery<br>• Opportunities to fish and Haida participation in fishery<br>• Satisfaction with fishery<br>• Resolution of management issues<br>• Haida access, use of catch and sharing | • Traditional fishery catch and effort by location and date (annual survey) according to community protocols | | ✓ | |
| | | | • Source and use of k'aaw e.g., quantity exchanged, gifted or traded by Haida fisher and/or household (baseline survey and follow-up every 2-3 yrs) according to community protocols | | | ✓ |
| | | | • Satisfaction by type of fisher and community e.g., type of fishery, days fished, relative success, cost of fishing, sharing of traditional foods (survey every 2-3 yrs, include demographic variables) | | | ✓ |
| | | | • Extent of intergenerational interaction about herring e.g., fishing or other marine activities such as Haida watchmen, cultural camps, or school programs (survey every 2-3 yrs)<br>• Interviews with commercial fishers to capture knowledge | | | ✓ |

Table 27. Social and economic monitoring priorities to measure rebuilding progress.

| Operational Objectives | Attributes | Characteristics | Monitoring Priorities to address objectives | Status | | |
|---|---|---|---|---|---|---|
| | | | | Current work | Additional work | New work |
| ***Social***<br>• Increase local opportunities, participation in, and benefits from herring and herring fisheries to Haida Gwaii<br>• Ensure sustainability of herring populations to support access for future generations | • Reconciliation<br>• Community benefits from adjacent fisheries<br>• Access for future generations | • Policy objectives<br>• Increase local fishery benefits<br>• Long term sustainability | • Collaborative decision-making for Haida Gwaii herring fisheries according to agreements (see Governance for details) | | ✓ | |
| | | | • Prioritization of traditional SOK fishery | | ✓ | |
| | | | • Satisfaction with opportunities to work in herring-related jobs; Why? (e.g., Training, Seasonality; align with periodic surveys below) | | | ✓ |
| | | | • # of herring/SOK commercial licenses and/or amount of quota held locally/non-locally; by Haidas/other Haida Gwaii residents; by community | | ✓ | |
| ***Economic***<br>• Increase economic benefits for Haida from herring fisheries-related activities | • Fishing opportunities<br>• Tourism<br>• Supporting infrastructure | • Spawn on kelp fisheries<br>• Herring roe fisheries (MSE analysis required | • Commercial spawn on kelp fishery openings in Haida Gwaii and catch and effort by location and date (as reported) | ✓ | | |
| | | | • Commercial herring roe fishery openings in | ✓ | | |

| Operational Objectives | Attributes | Characteristics | Monitoring Priorities to address objectives | Status | | |
|---|---|---|---|---|---|---|
| | | | | Current work | Additional work | New work |
| • Foster economic viability of commercial herring fisheries | | if conditions change)<br>• Interactions between fisheries<br>• Kelp availability and quality<br>• Annual visitors and local spending (indirect effects) | Haida Gwaii (see conditions in Section 7) | | | |
| | | | • Community benefits from commercial herring fisheries including fishing, processing, marketing, and management (e.g., #, types, and value of wages or jobs for Haida/other Haida Gwaii residents and companies; Baseline survey to be repeated periodically or as fisheries reopen) | ✓ | | |
| | | | • Relationship between commercial SOK fisheries and traditional SOK fisheries e.g., agreements between operators and Haida communities including any product transfers | | | ✓ |
| | | | • Is existing infrastructure sufficient to support herring-related opportunities? Yes/No and Why or why not? | | | ✓ |
| | | | • Trends in non-consumptive uses (e.g., marine tourism) | | | ✓ |

Table 28. Governance monitoring priorities to measure rebuilding progress.

| Operational Objectives | Attributes | Characteristics | Monitoring Priorities to address objectives | Status | | |
|---|---|---|---|---|---|---|
| | | | | Current work | Additional work | New work |
| • Support collaborative Haida-Canada process for herring rebuilding and fisheries management on Haida Gwaii, including the AMB process for Gwaii Haanas and other governance structures in place or as established.<br>• Increase collaborative work related to herring by employees and representatives of Gwaii Haanas partner organizations.<br>• Collaborate and coordinate on compliance and enforcement for herring fisheries. | • Reconciliation<br>• Relationships<br>• Planning and policy development e.g., rebuilding plan or management plan<br>• Decision-making | • Government-to-government approach<br>• Collaborative policy development, planning and management<br>• Consensus decision-making | • Tier 1, 2 and 3 structures supported through agreements (Yes/No) and functioning well (Yes/No or Ranking; Why or why not?). Baseline and annual changes documented. | | | ✓ |
| | | | • Status of reconciliation or rights recognition agreements including for herring fishery management and rights-based commercial Haida fishery | | | ✓ |
| | | | • Working relationships between partner organizations (DFO, CHN, Gwaii Haanas) | ✓ | | |
| | | | • Agreed-upon rebuilding and management plans and collaborative processes for management decision-making in place? Yes/No or Ranking; Why or why not? | | | ✓ |

| Operational Objectives | Attributes | Characteristics | Monitoring Priorities to address objectives | Status | | |
|---|---|---|---|---|---|---|
| | | | | Current work | Additional work | New work |
| | | | • Number of consensus decisions; Number of unresolved decisions each year; Reasons for disagreements | | ✓ | |
| | | | • Management issues and success of efforts to resolve them (re: traditional and commercial fisheries in Haida Gwaii) from interviews with local fishery managers and fishers and/or review of meeting records, documents and reports, etc. | | | ✓ |
| | | | • Do other organizations play a role in herring monitoring and management? List of organizations, people and roles and responsibilities (e.g., Herring Conservation and Research Society, CoastWatch) | | | ✓ |

Table 29. Management monitoring priorities to measure rebuilding progress.

| Operational Objectives | Attributes | Characteristics | Monitoring Priorities to address objectives | Status | | |
|---|---|---|---|---|---|---|
| | | | | Current work | Additional work | New work |
| • Ensure use of the best available information to foster herring management that is sustainable, adaptive, ecosystem-based, and applied at appropriate scales<br>• Incorporate Haida traditional knowledge into the herring management process<br>• Foster collaborative long-term monitoring and research to assess ecological, cultural, social, and economic effects of herring rebuilding, conservation and fisheries<br>• Foster effective public engagement, | • Ecosystem-based management approach<br>• Management planning and programs<br>• Traditional knowledge<br>• Data and information management<br>• Monitoring herring and ecosystem status<br>• Compliance and enforcement<br>• Research planning and conduct<br>• Communications and engagement | • Capacity and resources<br>• High quality information<br>• Timeliness<br>• Transparency<br>• Incorporation of Haida perspective | • Is a collaboratively developed ecosystem-based and adaptive fisheries management framework in place? Yes/No or Ranking; Why or why not? | | | ✓ |
| | | | • Is the framework ensuring sustainability of herring populations to potential stressors? Yes/No or with Ranking; Why or why not? | | | ✓ |
| | | | • Is a collaboratively developed monitoring plan in place to monitor fisheries and ecosystem status using appropriate methods? Yes/No or Ranking; Why? | | | ✓ |
| | | | • Is Haida traditional knowledge incorporated into decision-making as appropriate? Yes/No or Ranking; Why or why not and how? | | | ✓ |
| | | | • Are management actions consistent with | | | ✓ |

| Operational Objectives | Attributes | Characteristics | Monitoring Priorities to address objectives | Status | | |
|---|---|---|---|---|---|---|
| | | | | Current work | Additional work | New work |
| including stakeholders, in the herring fisheries management process<br>• Foster safe operations in herring fisheries<br>• Manage fisheries to achieve priority of Haida traditional herring fishery after conservation<br>• Manage fisheries to achieve successful commercial fisheries, including spawn-on-kelp during the rebuilding phase | | | the rebuilding plan. Yes/No, if no, why not? | | | |
| | | | • Is there localized overfishing of herring sub-stocks or specific spawning sites? Yes/No with locations and issues | | | ✓ |
| | | | • Annual amount of management resources relative to target (e.g., vessel-days, overflights, dive charter days, hydroacoustic survey days) | | | ✓ |
| | | | • List of proposed and supported/not supported research proposals each year | | ✓ | |
| | | | • Are agreed-upon compliance and enforcement programs in place? Yes/No or ranking; Why or why not?; # of incidents per year; List of organizations, people and roles and responsibilities | | | ✓ |

| Operational Objectives | Attributes | Characteristics | Monitoring Priorities to address objectives | Status | | |
|---|---|---|---|---|---|---|
| | | | | Current work | Additional work | New work |
| | | | • Are all relevant agencies and organizations effectively coordinated to respond to emergencies related to fisheries activities? Yes/No or Ranking; Why or why not? | | ✓ | |
| | | | • Is updated information on herring and any future fishery available via Gwaii Haanas and CHN communications materials? Yes/No and/or Ranking? | | | ✓ |
| | | | • Are fishers satisfied that communication with the management system is effective, and that their interests are considered in management processes? Why or why not? | | | ✓ |
| | | | • Are fisheries successful? (see social and economic monitoring priorities) | | | ✓ |

## FIGURES

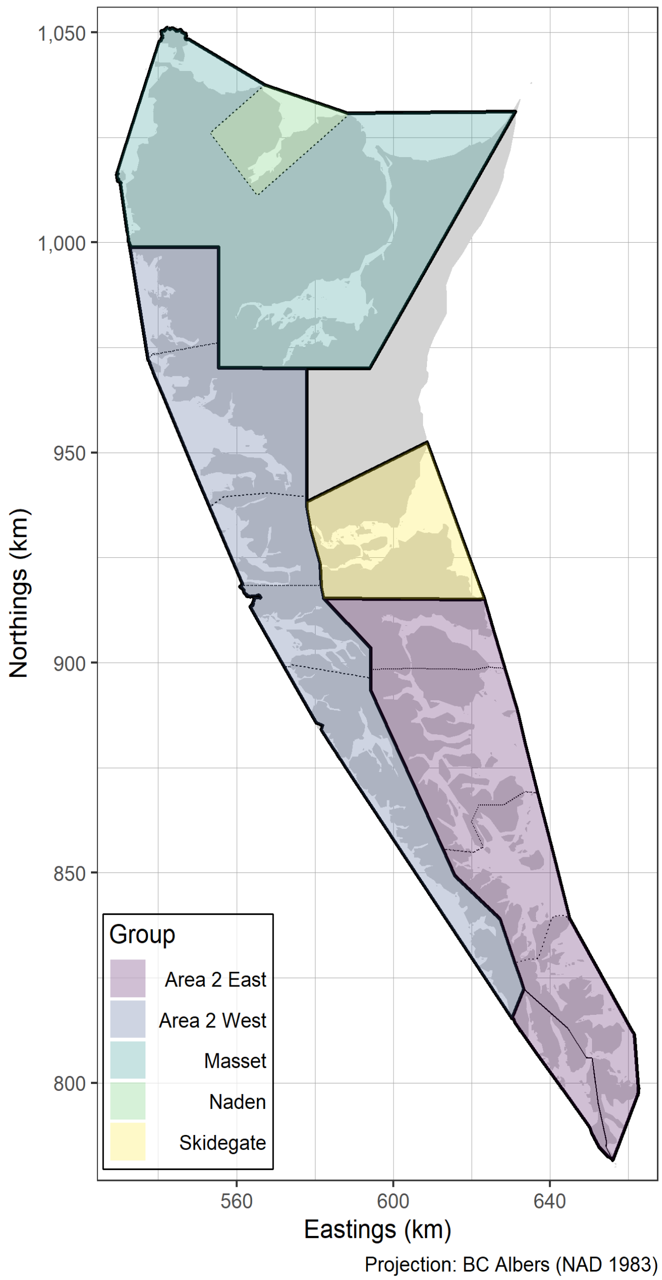



Figure 1. Pacific **'íináang | iinang** *herring* populations in Haida Gwaii are described as five main groups: Haida Gwaii Major stock assessment region (SAR; Area 2 East), Skidegate Inlet, Masset Inlet, Naden Harbour, and Haida Gwaii Minor SAR (Area 2 West).

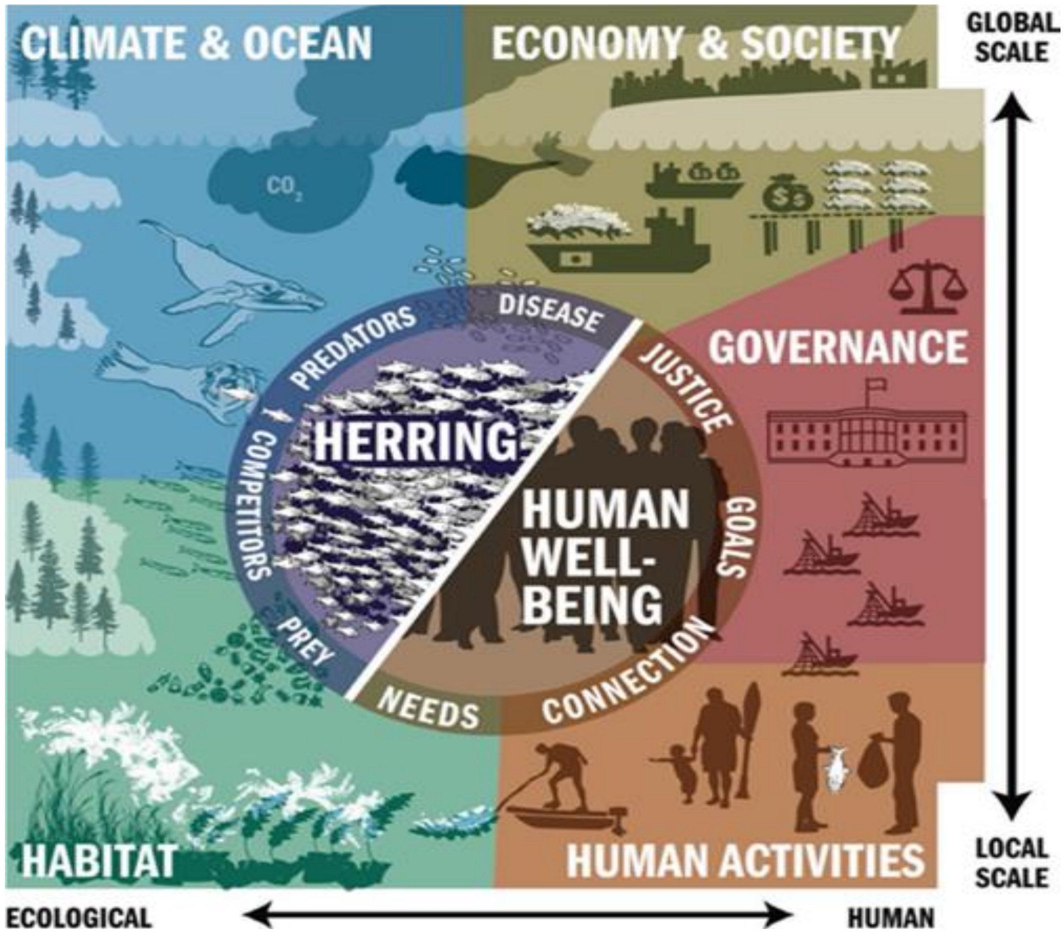



Figure 2. Conceptual model of the Pacific Herring social-ecological system developed by Levin et al. (2016)

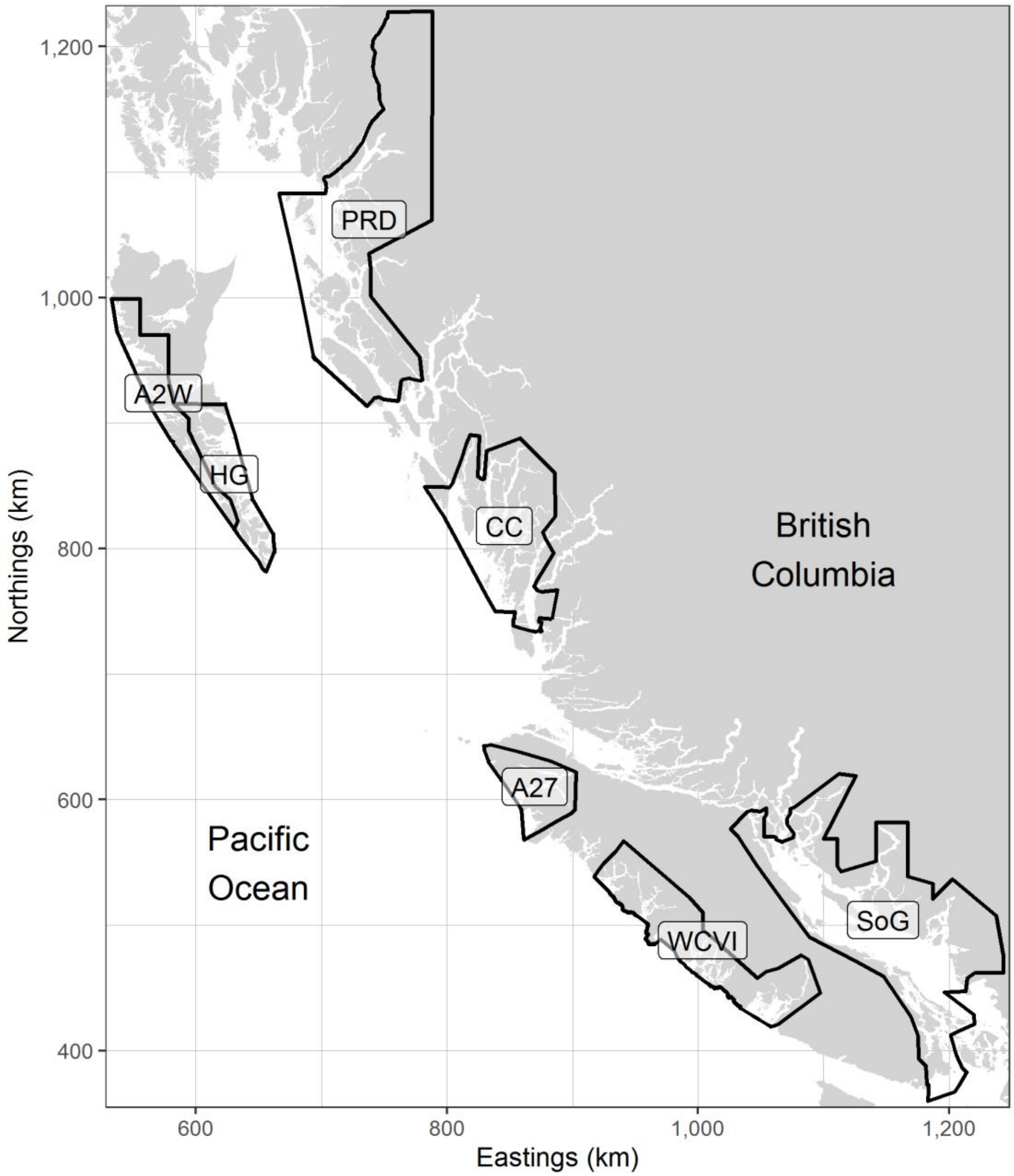



Figure 3. Boundaries for the Pacific Herring stock assessment regions (SARs) in British Columbia. There are 5 Major SARs: Haida Gwaii (HG), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SoG), and West Coast of Vancouver Island (WCVI). There are 2 Minor SARs: Area 27 (A27) and Area 2 West (A2W). Units: kilometres (km).

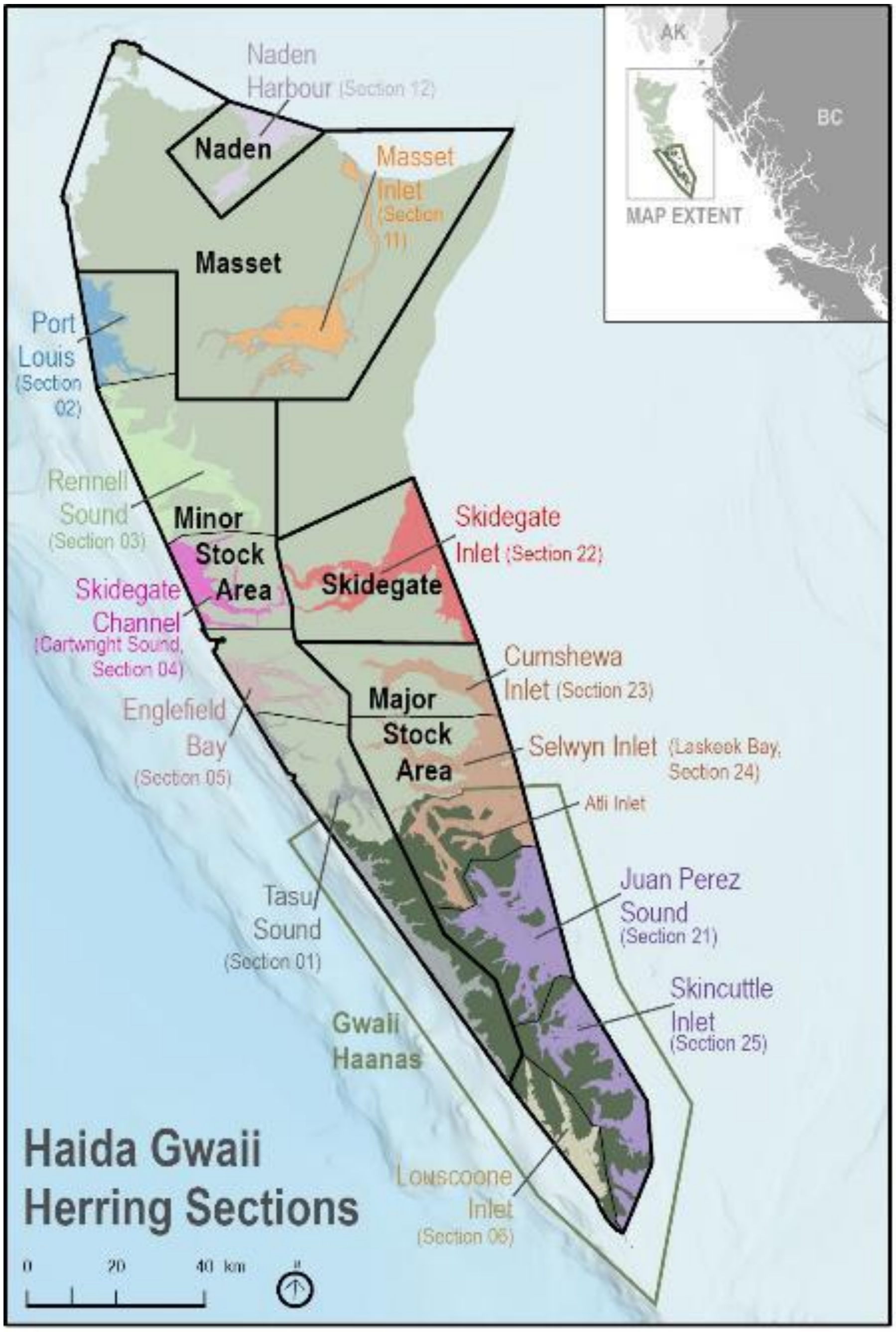



Figure 4. Map of Haida Gwaii 'íináang | iinang *herring* spawning populations. DFO management sections shown in brackets: Section 006 is Louscoone, Section 021 is Juan Perez, Section 023 is Cumshewa, Section 024 is Selwyn, and Section 025 is Skincuttle.

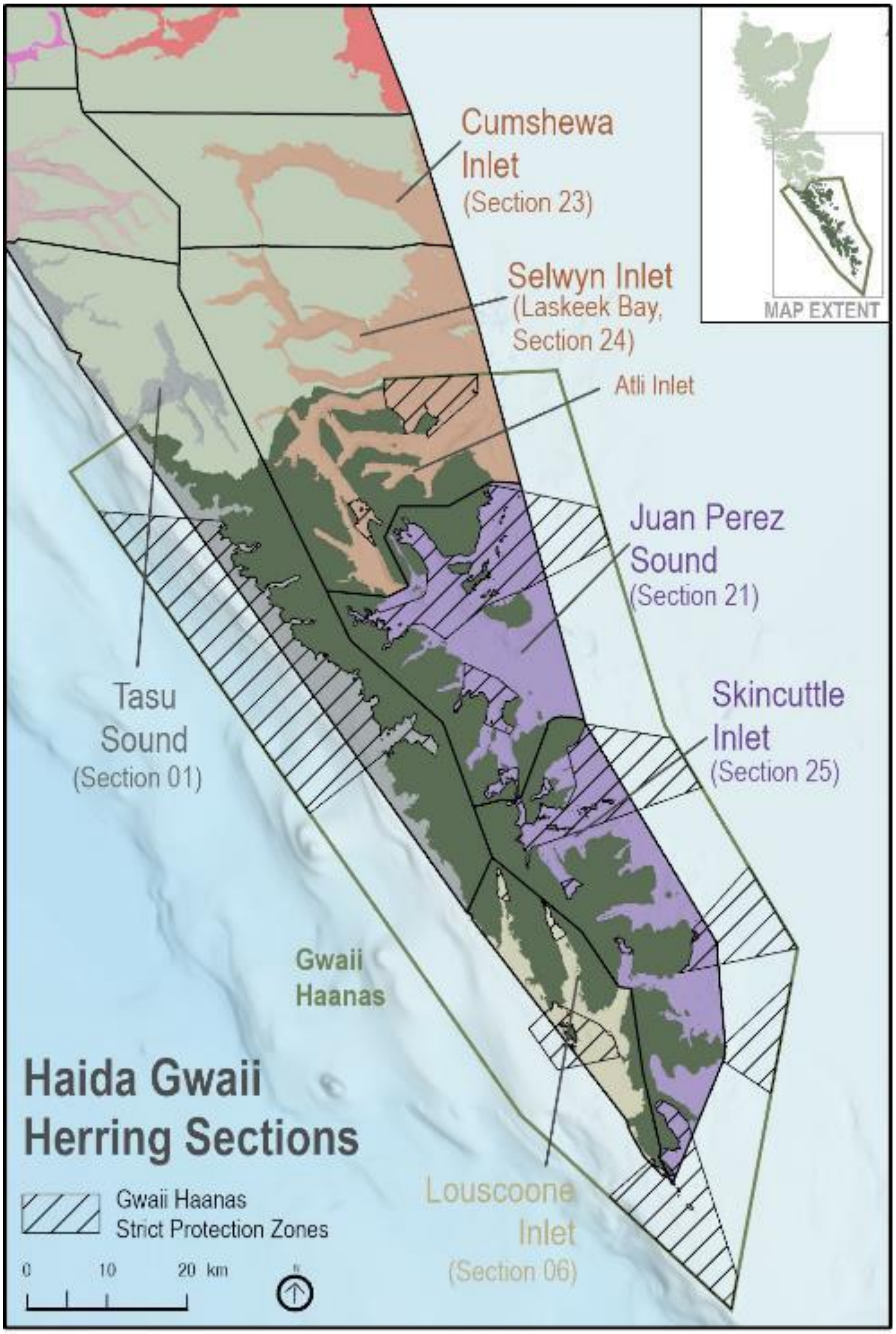



Figure 5. Strict Protection Zones within Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve, and Haida Heritage Site as defined in the Gwaii Haanas *Gina 'Waadluxan KilGuhlGa Land-Sea-People Plan* (2018) in relation to herring sub-stocks and sections.

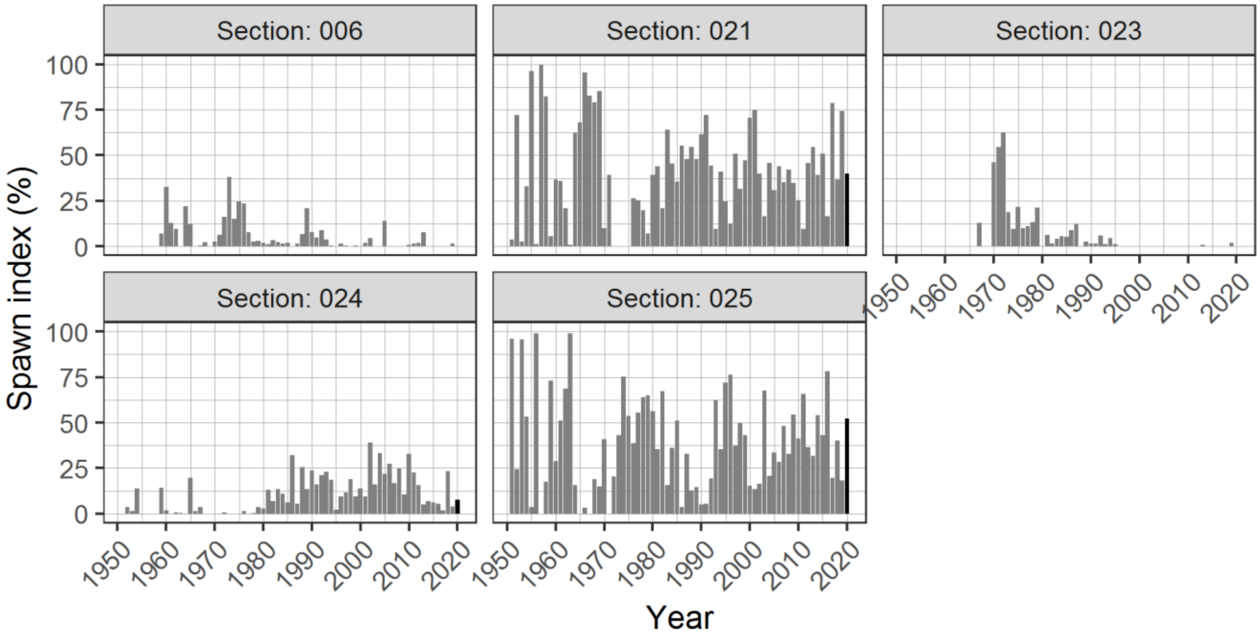



Figure 6. Time series of percent of spawn index by Section for Pacific Herring from 1951 to 2020 in the Haida Gwaii Major stock assessment region. The year 2020 has a darker bar to facilitate interpretation. The spawn index has two distinct periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2020). The spawn index is not scaled by the spawn survey scaling parameter, *q*. Section 006 is Louscoone, Section 021 is Juan Perez, Section 023 is Cumshewa, Section 024 is Selwyn, and Section 025 is Skincuttle.

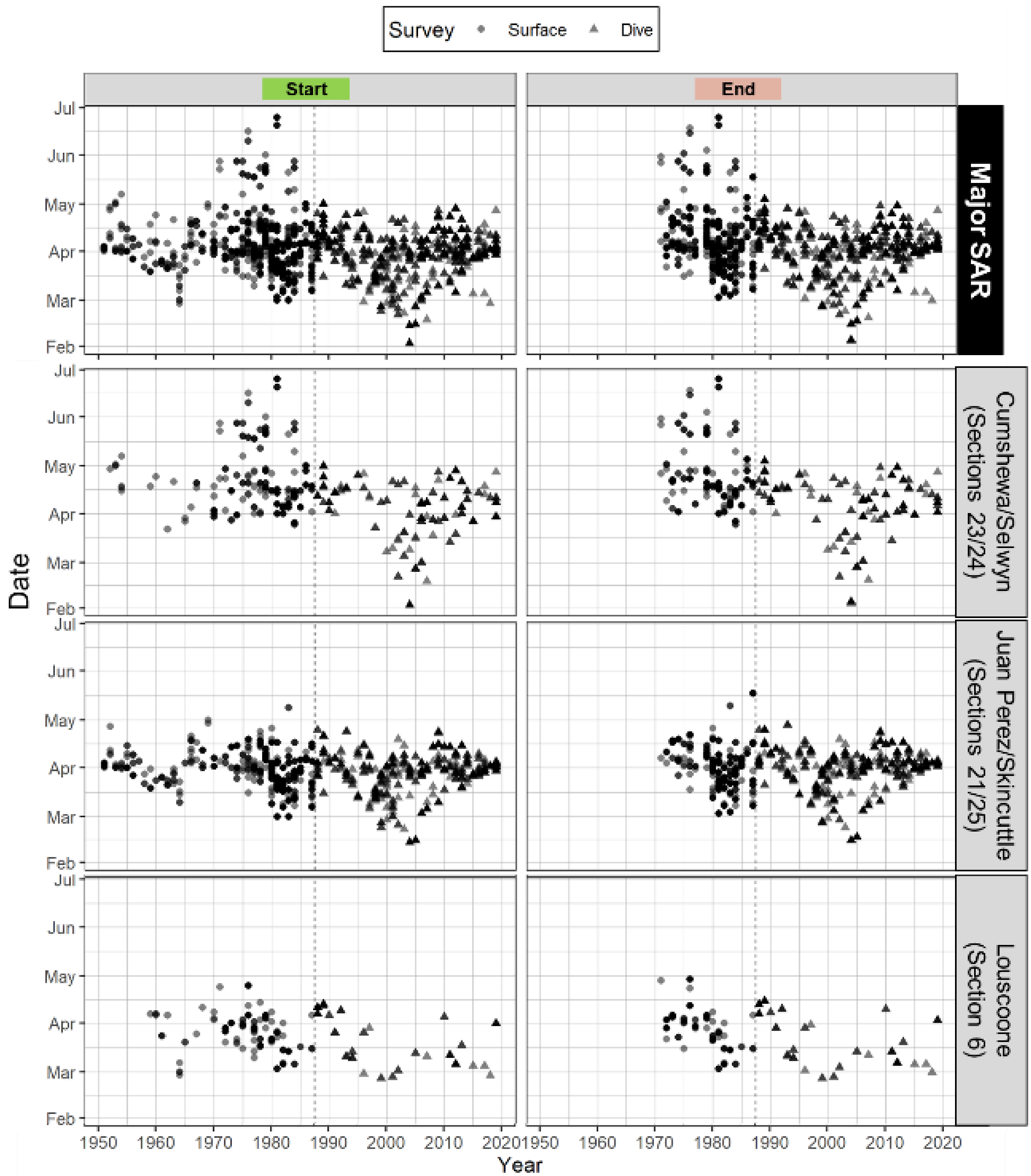



Figure 7. Start dates of each surveyed herring spawning event in the Major stock assessment region (SAR) of Haida Gwaii at the aggregate scale and disaggregated into the three sub-stocks, Cumshewa/Selwyn (DFO Sections 023/024), Juan Perez/Skincuttle (DFO Sections 021/025), and Louscoone (DFO Section 006). Multiple spawns can occur at a single spawning location throughout the year. The darker points indicate more than one independent spawning event started during a single day.

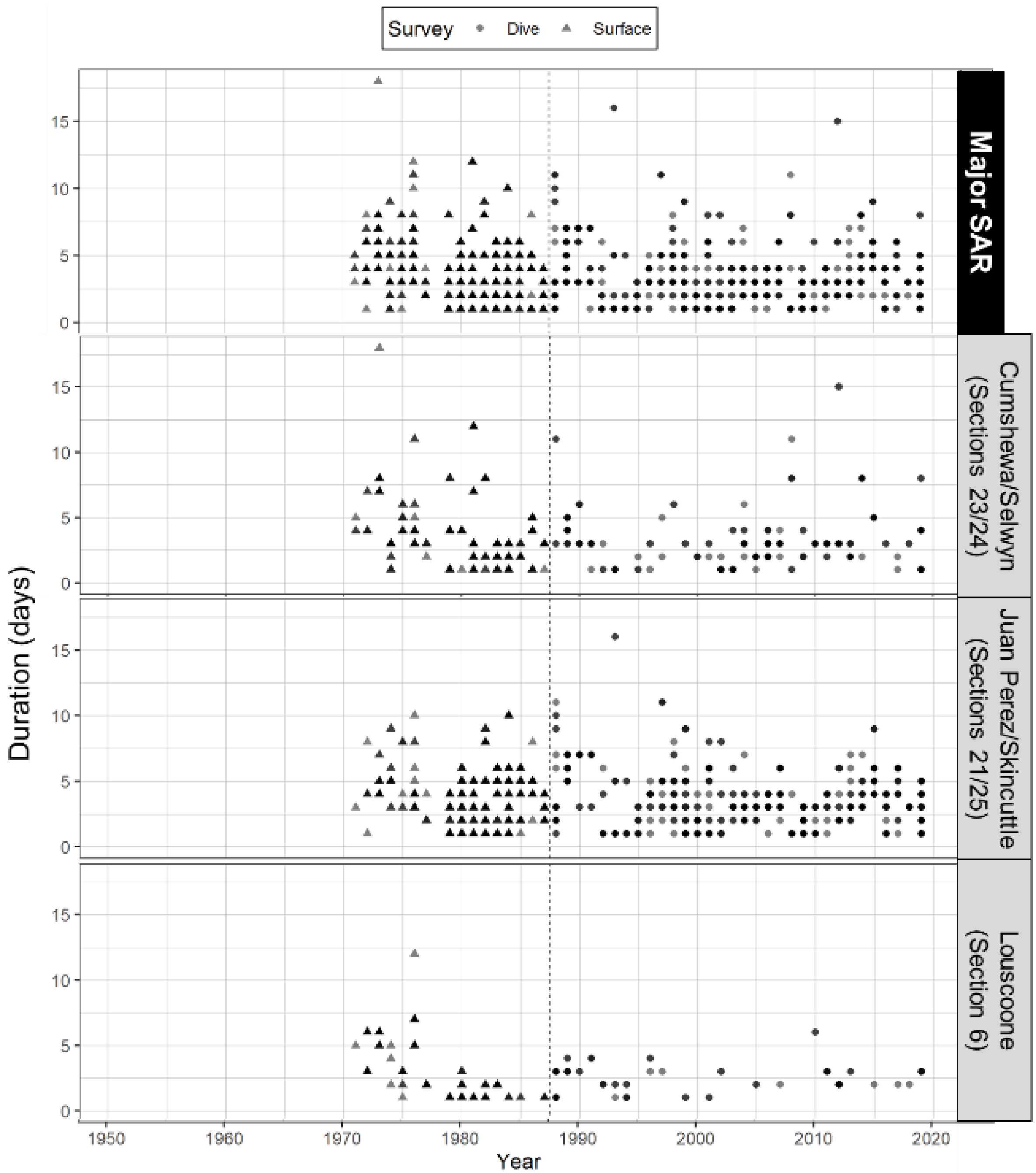



Figure 8. Number of days each surveyed herring spawning event lasted in the Major stock assessment region (SAR) of Haida Gwaii at the aggregate scale and disaggregated into the three sub-stocks: Cumshewa/Selwyn (DFO Sections 023/024), Juan Perez/Skincuttle (DFO Sections 021/025), and Louscoone (DFO Section 006). Multiple spawns can occur at a single spawning location throughout the year. The darker points indicate more than one independent spawning event lasting the same number of days.

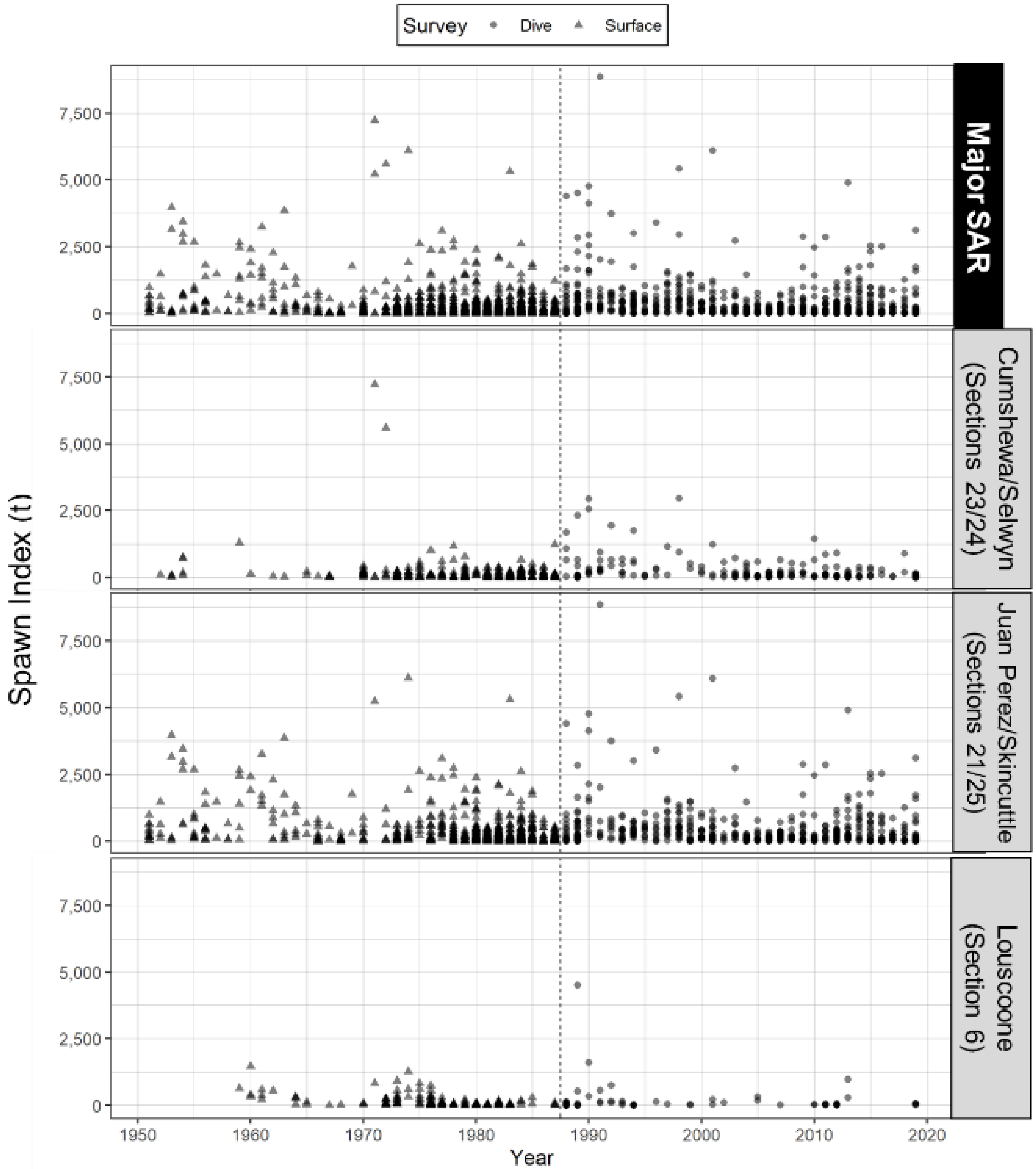



Figure 9. Spawn index amount (t) for each surveyed herring spawning event in the Major stock assessment region (SAR) of Haida Gwaii at the aggregate scale and disaggregated into the three sub-stocks: Cumshewa/Selwyn (DFO Sections 023/024), Juan Perez/Skincuttle (DFO Sections 021/025), and Louscoone (DFO Section 006). Multiple spawns can occur at a single spawning location throughout the year. The darker points indicate more than one independent spawning event with the same amount of spawn in a year.

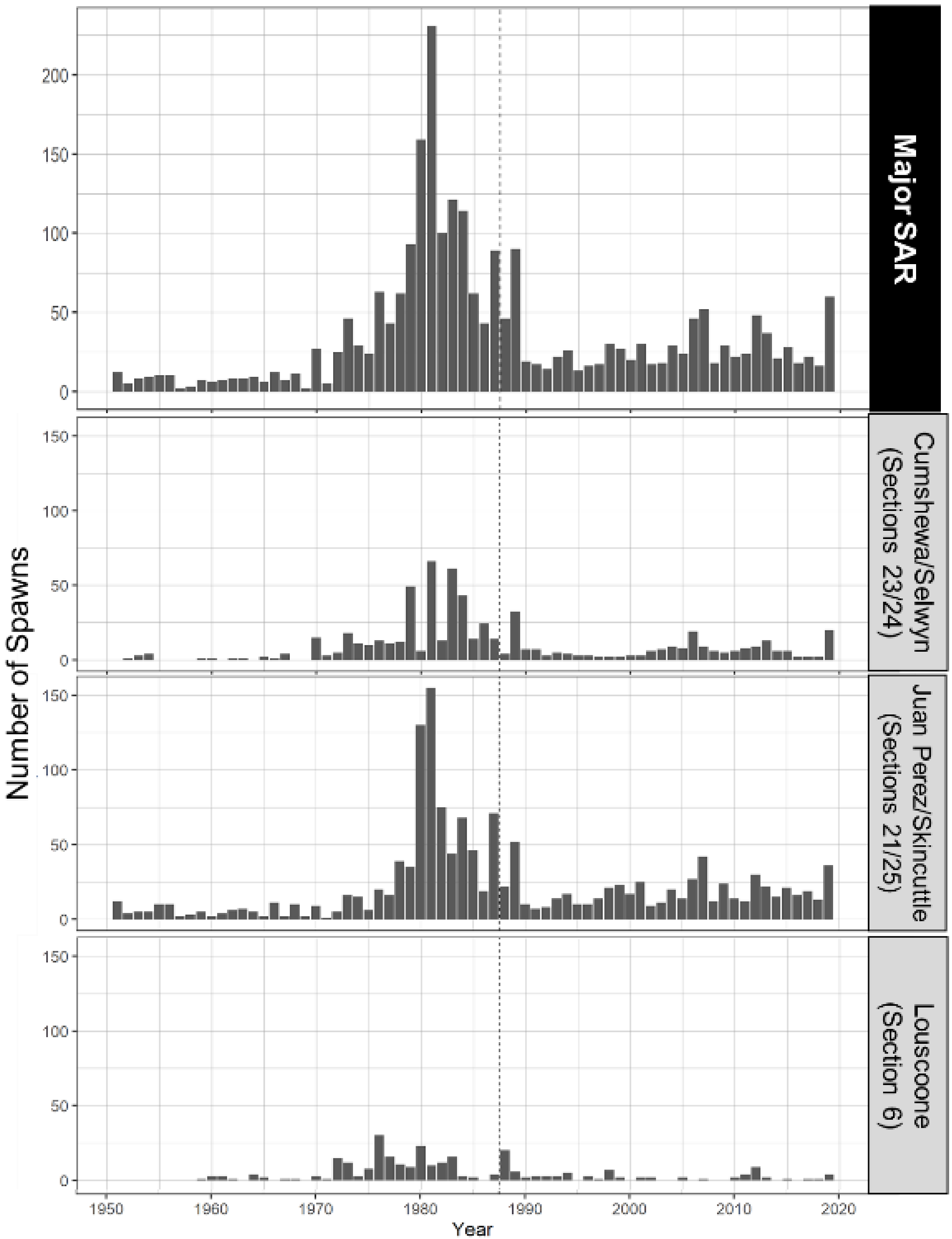



Figure 10. Total number of surveyed herring spawning events per year in the Major stock assessment region (SAR) of Haida Gwaii at the aggregate scale and disaggregated into the three sub-stocks: Cumshewa/Selwyn (DFO Sections 23/24), Juan Perez/Skincuttle (DFO Sections 21/25), and Louscoone (DFO Section 6).

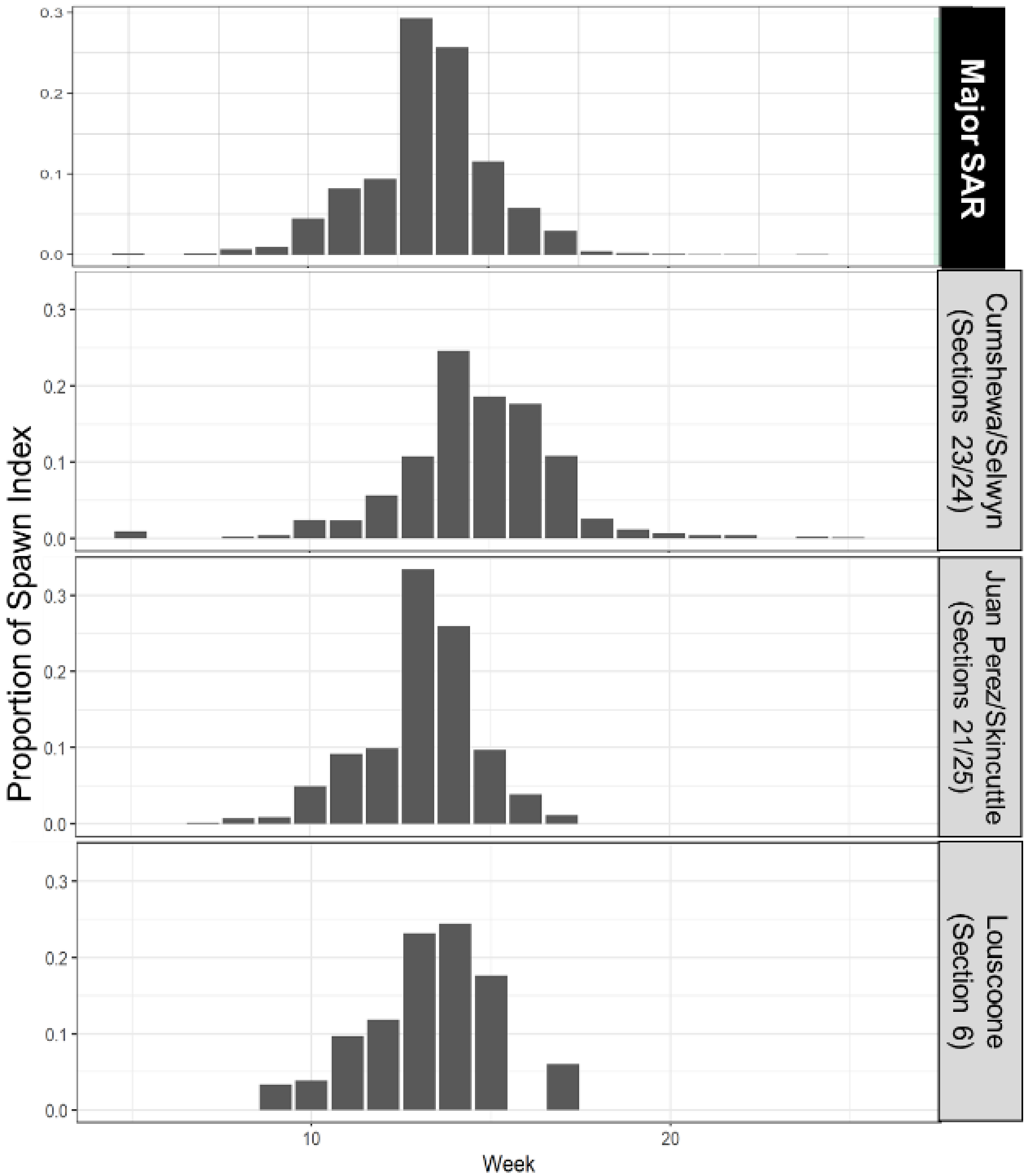



Figure 11. The proportion of the surveyed herring spawn index amount that occurred in each week of the year in the Major stock assessment region (SAR) of Haida Gwaii at the aggregate scale and disaggregated into the three sub-stocks: Cumshewa/Selwyn (DFO Sections 23/24), Juan Perez/Skincuttle (DFO Sections 21/25), and Louscoone (DFO Section 6).

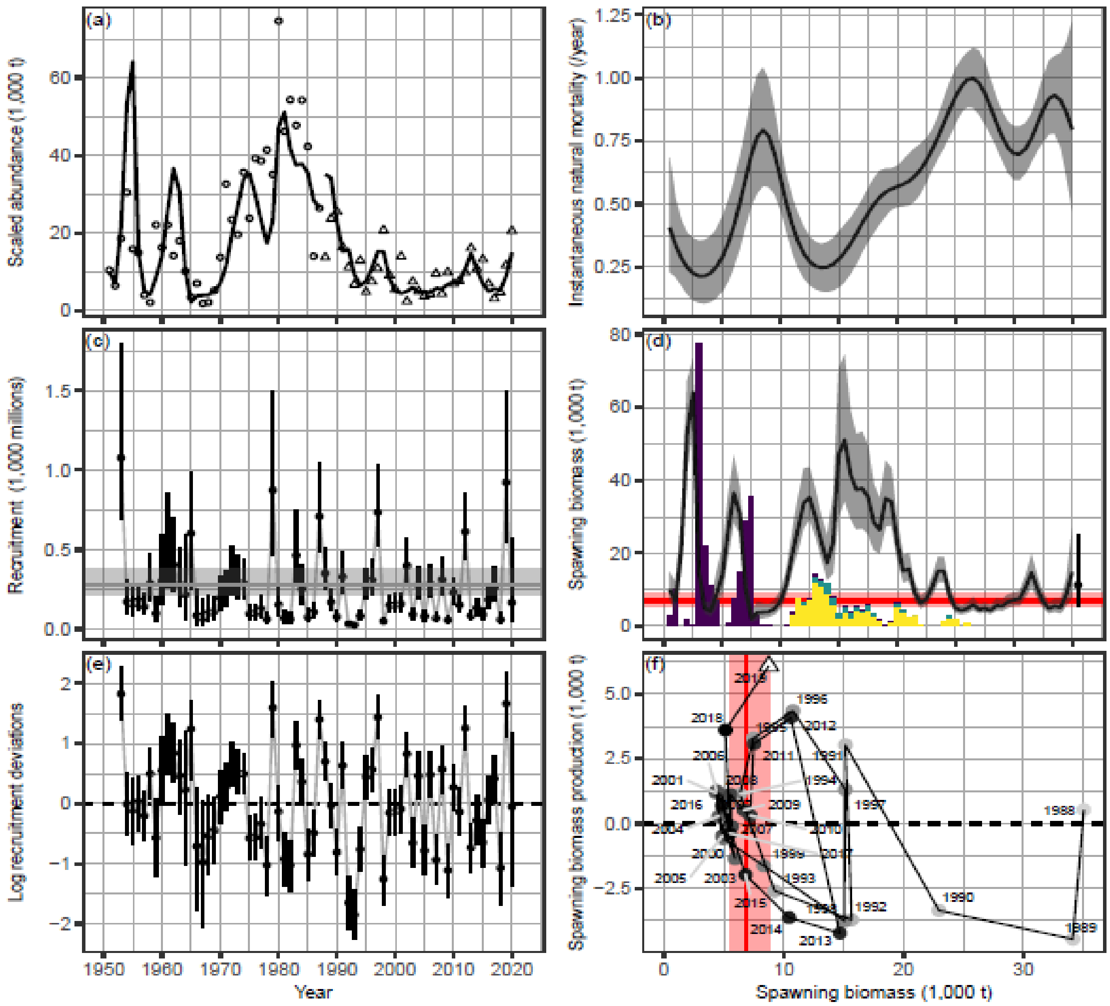


Figure 12. Time series of model output for the Pacific Herring statistical catch-at-age model from 1951 to 2020 in the Haida Gwaii Major stock assessment region. Panel (a): model fit (median posterior estimate; lines) to scaled spawn survey data (points). Spawn survey data (i.e., spawn index) is scaled to abundance by the spawn survey scaling parameter q (median posterior estimate). Panel (b): posterior estimates of instantaneous natural mortality rate (year-1). Panel (c): reconstructed number of age-2 recruits in thousands of millions. Horizontal line and shaded area indicate median and 90% credible interval for unfished age-2 recruitment $R_0$, respectively. Panel (d): posterior estimate of spawning biomass. Circle and vertical line indicate the median and 90% credible interval, respectively, of forecast spawning biomass in 2021 in the absence of fishing. Vertical bars indicate commercial catch, excluding spawn-on-kelp. Panels (b & d): lines and shaded areas indicate medians and 90% credible intervals, respectively. Panel (e): log recruitment deviations. Panels (c & e): time series start in 1953; circles and vertical lines indicate medians and 90% credible intervals, respectively. Panel (f): phase plot of spawning biomass production for the dive survey period (1988 to 2019; median posterior estimates). Grey shading becomes darker in chronological order; the triangle indicates 2019. Panels (d & f): red lines and shading indicate medians and 90% confidence intervals, respectively, for the limit reference point $0.3SB_0$, where $SB_0$ is estimated unfished spawning biomass. Panels (e & f): horizontal dashed lines indicate zero. Note: biomass and catch are in thousands of tonnes (t). *Reproduced from DFO 2020.*

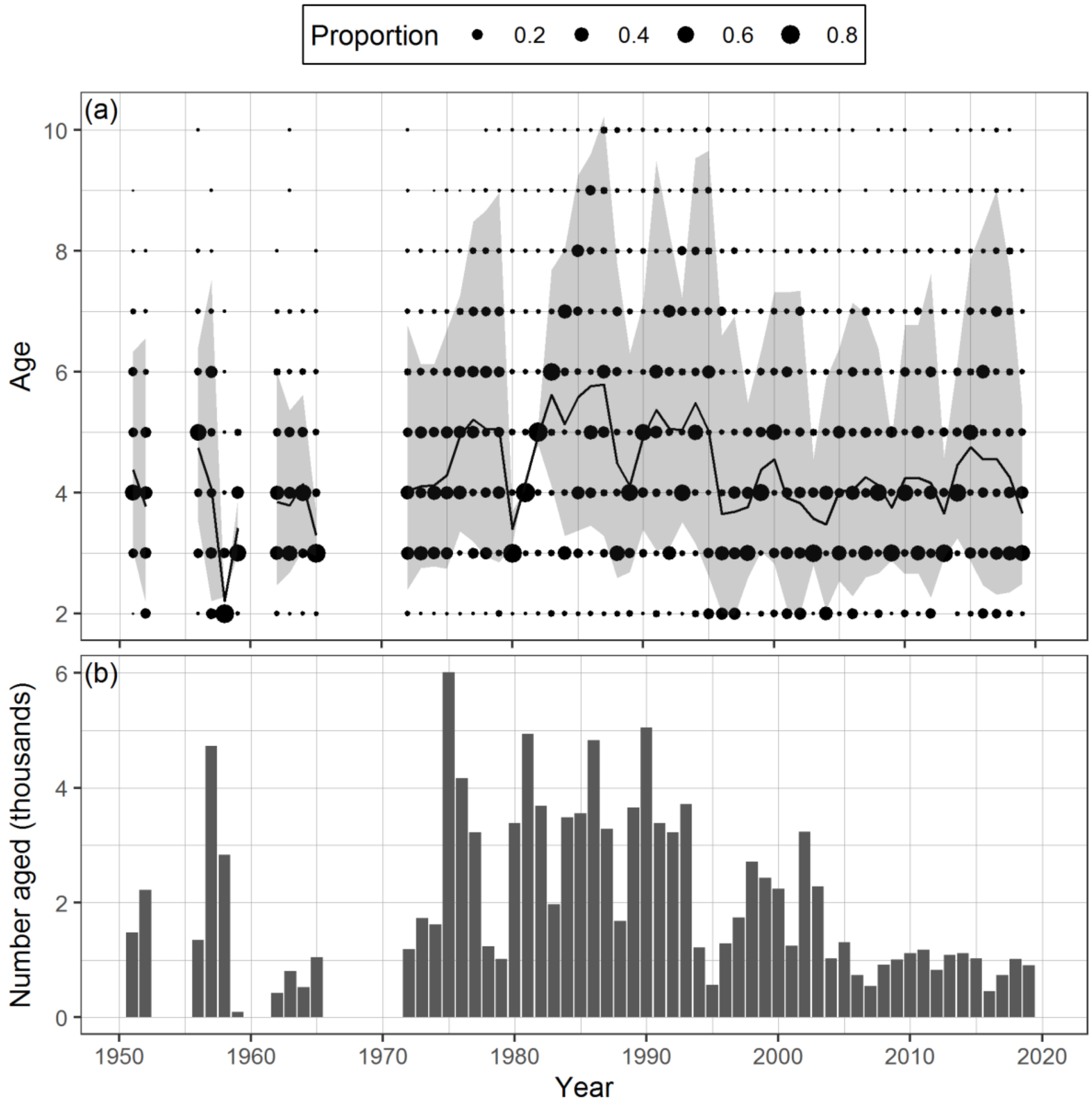



Figure 13. Time series of (a) observed proportion-at-age and (b) number aged in thousands of Pacific Herring from 1951 to 2020 in the Haida Gwaii Major stock assessment region (SAR). The black line is the mean age, and the shaded area is the approximate 90% distribution. Biological summaries only include samples collected using seine nets (commercial and test) due to size-selectivity of other gear types such as gillnet. The age-10 class is a ‘plus group' which includes fish ages 10 and older.

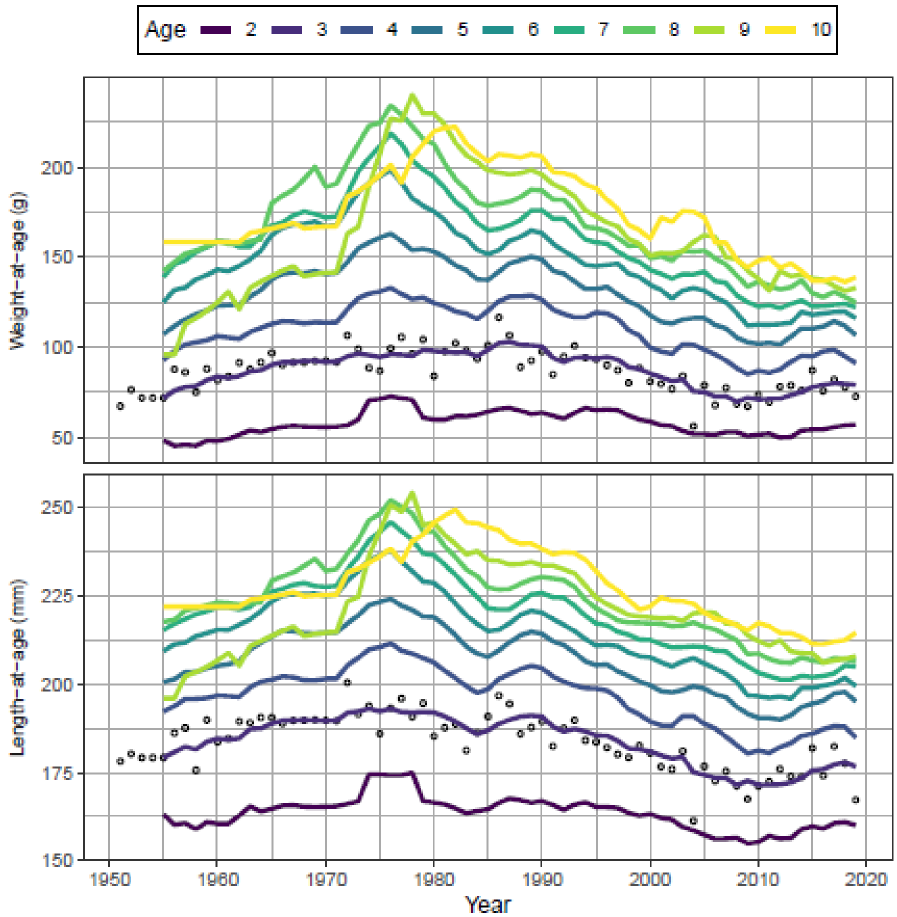



Figure 14. Time series of weight-at-age in grams (g) and length-at-age in millimeters (mm) for age-3 (circles) and 5-year running mean weight- and length-at-age (lines) for Pacific Herring from 1951 to 2019 in the Haida Gwaii Major stock assessment region (SAR). Missing weight- and length-at-age values (i.e., years with no biological samples) are imputed using one of two methods: missing values at the beginning of the time series are imputed by extending the first non-missing value backwards; other missing values are imputed as the mean of the previous 5 years. 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 is a ‘plus group’ which includes fish ages 10 and older.

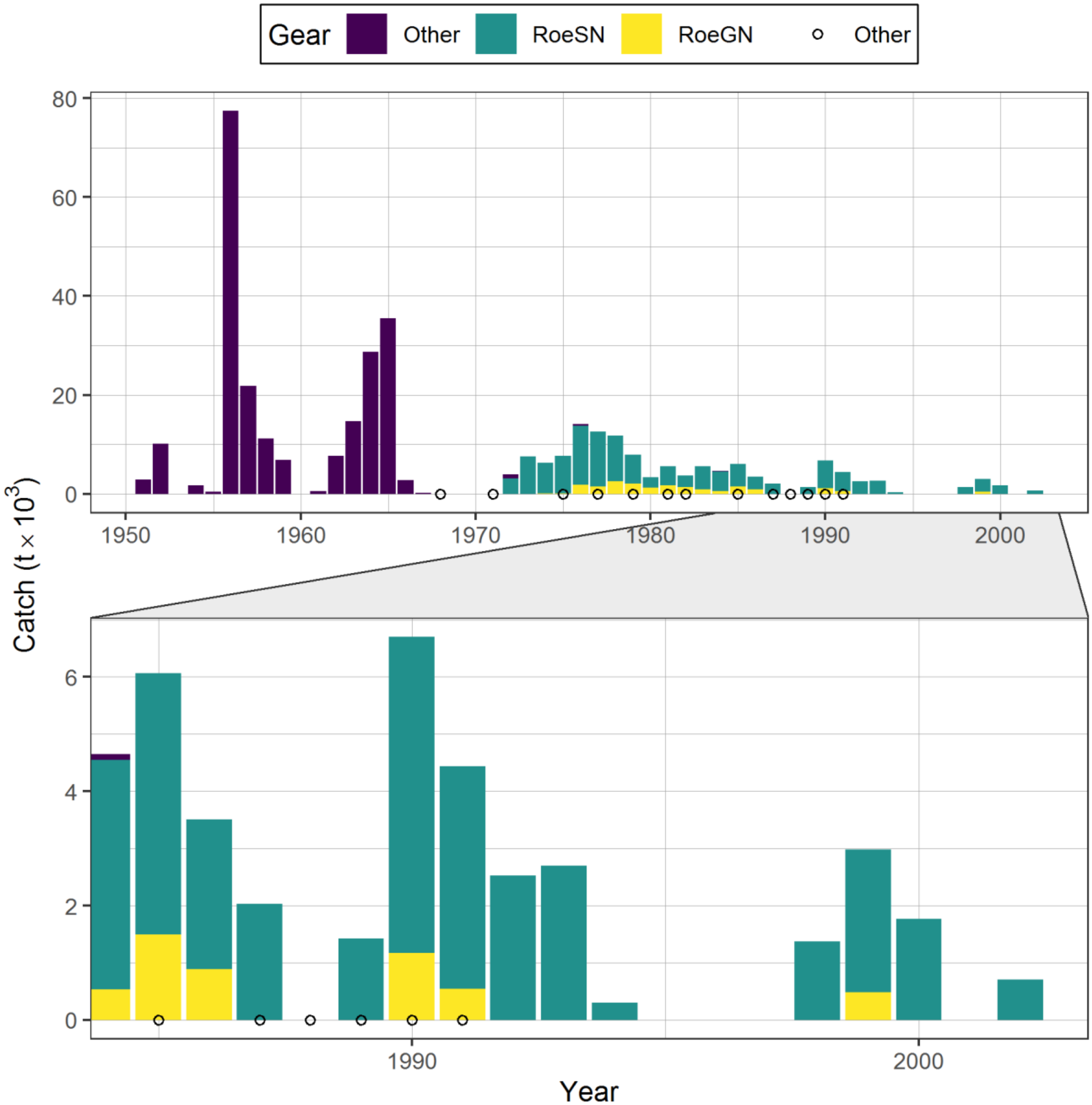



Figure 15. Time series of total landed catch in thousands of metric tonnes (t x $10^3$) of Pacific Herring by gear type from 1951 to 2020 in the Haida Gwaii **Major** stock assessment region (SAR). Legend: ‘Other' represents the reduction, the food and bait, as well as the special use fishery; ‘RoeSN' represents the roe seine fishery; and ‘RoeGN' represents the roe gillnet fishery. Data from the spawn-on-kelp (SOK) fishery are not included. Note: symbols indicate years in which some catch by gear type (i.e., Other, RoeSN, RoeGN) is withheld due to privacy concerns.


Figure 16. Time series of weight-at-age in grams (g) and length-at-age in millimeters (mm) for 5-year running mean weight- and length-at-age (lines) for Pacific Herring from 1951 to 2019 in the **sub-stocks** (Cumshewa/Selwyn (DFO Sections 023/024), Juan Perez/Skincuttle (DFO Sections 21/ 25) Louscoone Inlet (Section 6)) in the **Major** Haida Gwaii stock assessment region (SAR). Missing weight- and length-at-age values (i.e., years with no biological samples) are imputed using one of two methods: missing values at the beginning of the time series are imputed by extending the first non-missing value backwards; other missing values are imputed as the mean of the previous 5 years. 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 is a `plus group' which includes fish ages 10 and older.

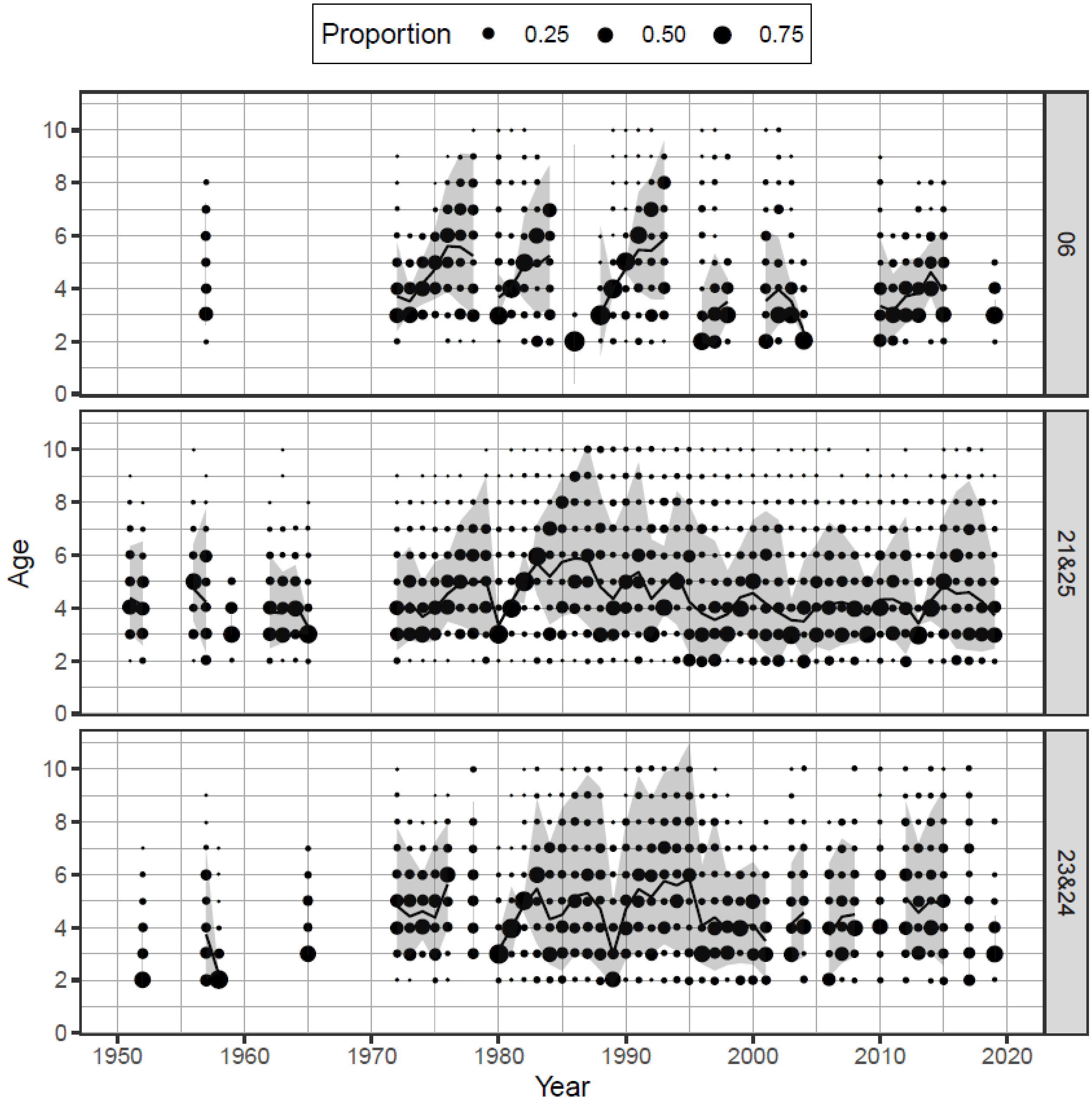



Figure 17. Time series of observed proportion-at-age of Pacific Herring from 1951 to 2019 in the three **sub-stocks** (Cumshewa/Selwyn (DFO Sections 23/24), Juan Perez/Skincuttle (DFO Sections 21/ 25) Louscoone Inlet (Section 6)) in the **Major** Haida Gwaii stock assessment region (SAR). The black line 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 class is a `plus group' which includes fish ages 10 and older.

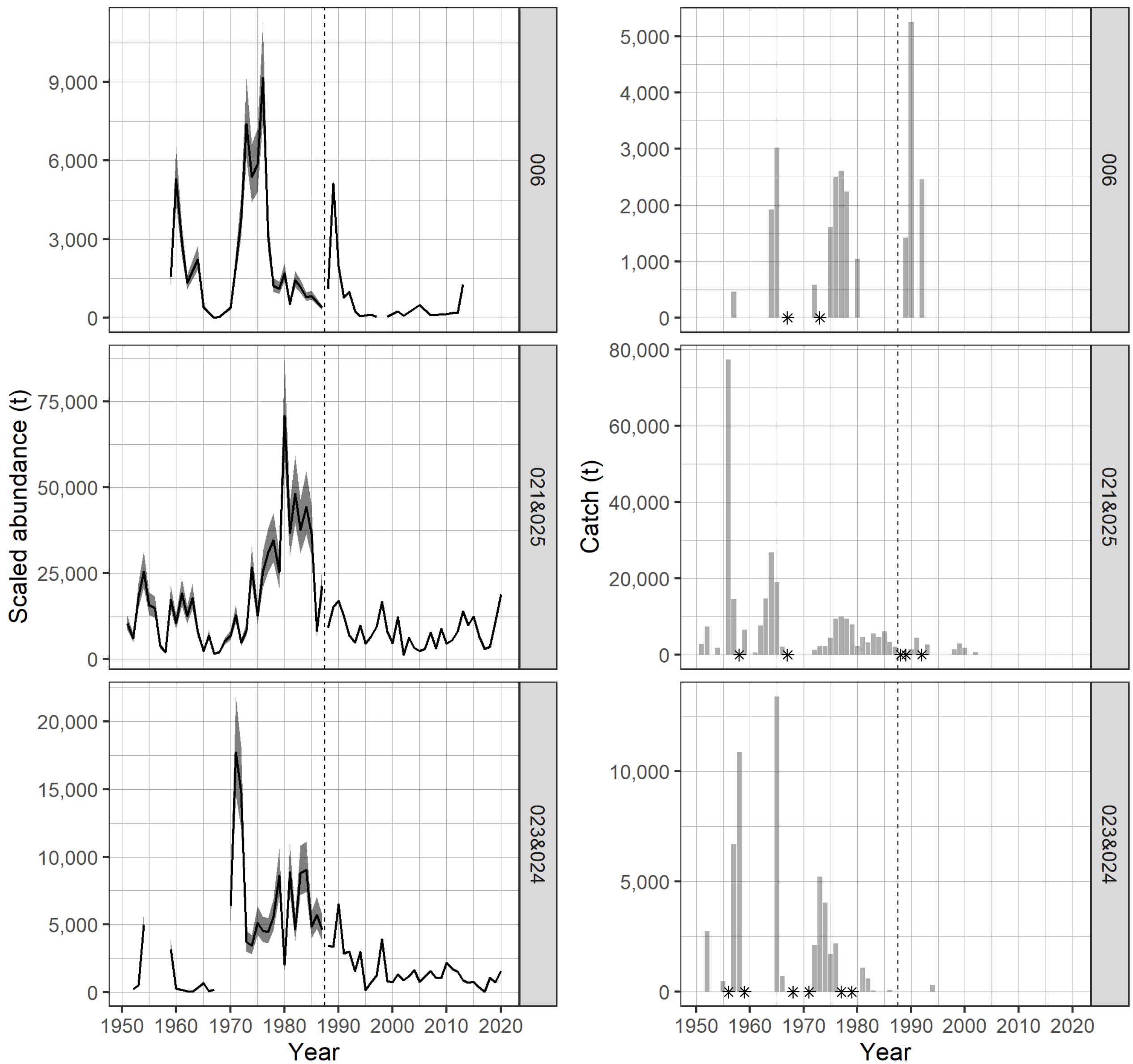



Figure 18. Time series of scaled abundance (spawn index/*q*) and catch for the three **sub-stocks** (Cumshewa/Selwyn (DFO Sections 23/24), Juan Perez/Skincuttle (DFO Sections 21/25) Louscoone Inlet (Section 6)) in the **Major** stock assessment region (SAR) of Haida Gwaii. Scaled abundance is calculated using *q* estimated for the aggregate (median 0.41, 5-95% range: 0.33-0.50). Note the y-axis scales differ among panels. Asterisks in the catch time series denote years where catch data are not releasable due to the three-party privacy rule. All these removals are less than 100 tonnes.

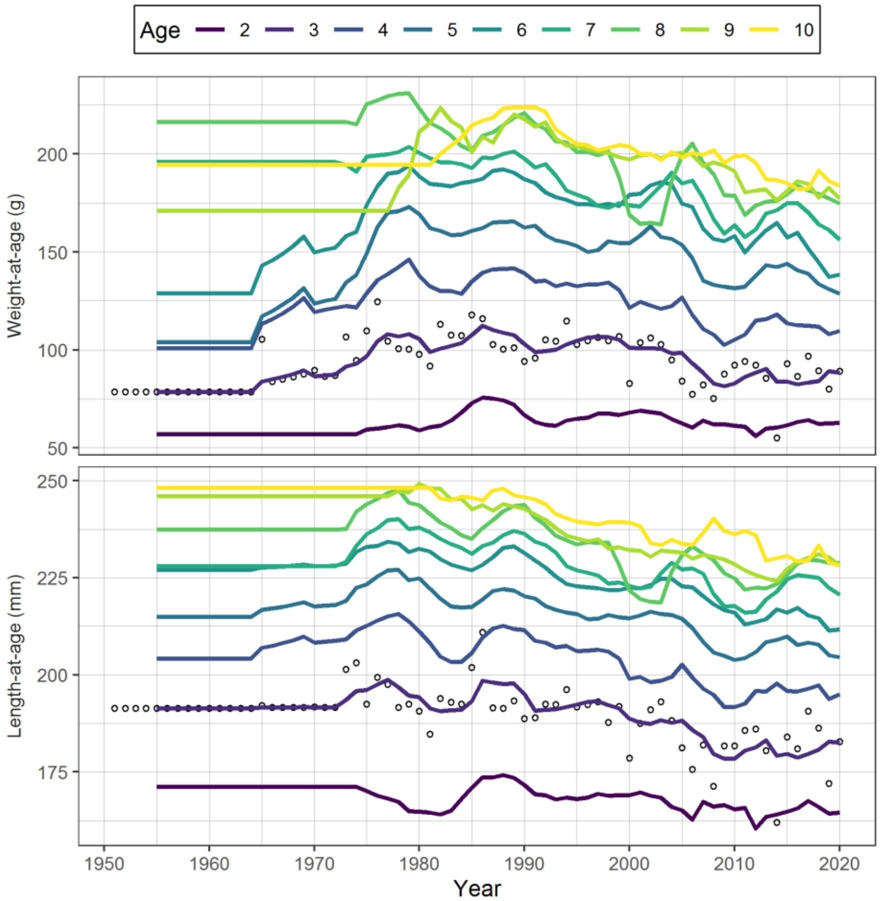



Figure 19. Time series of weight-at-age in grams (g) and length-at-age in millimeters (mm) for age-3 (circles) and 5-year running mean weight- and length-at-age (lines) for Pacific Herring from 1951 to 2019 in the **Minor** stock assessment region (SAR) of Haida Gwaii. Missing weight- and length-at-age values (i.e., years with no biological samples) are imputed using one of two methods: missing values at the beginning of the time series are imputed by extending the first non-missing value backwards; other missing values are imputed as the mean of the previous 5 years. 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 is a `plus group' which includes fish ages 10 and older.

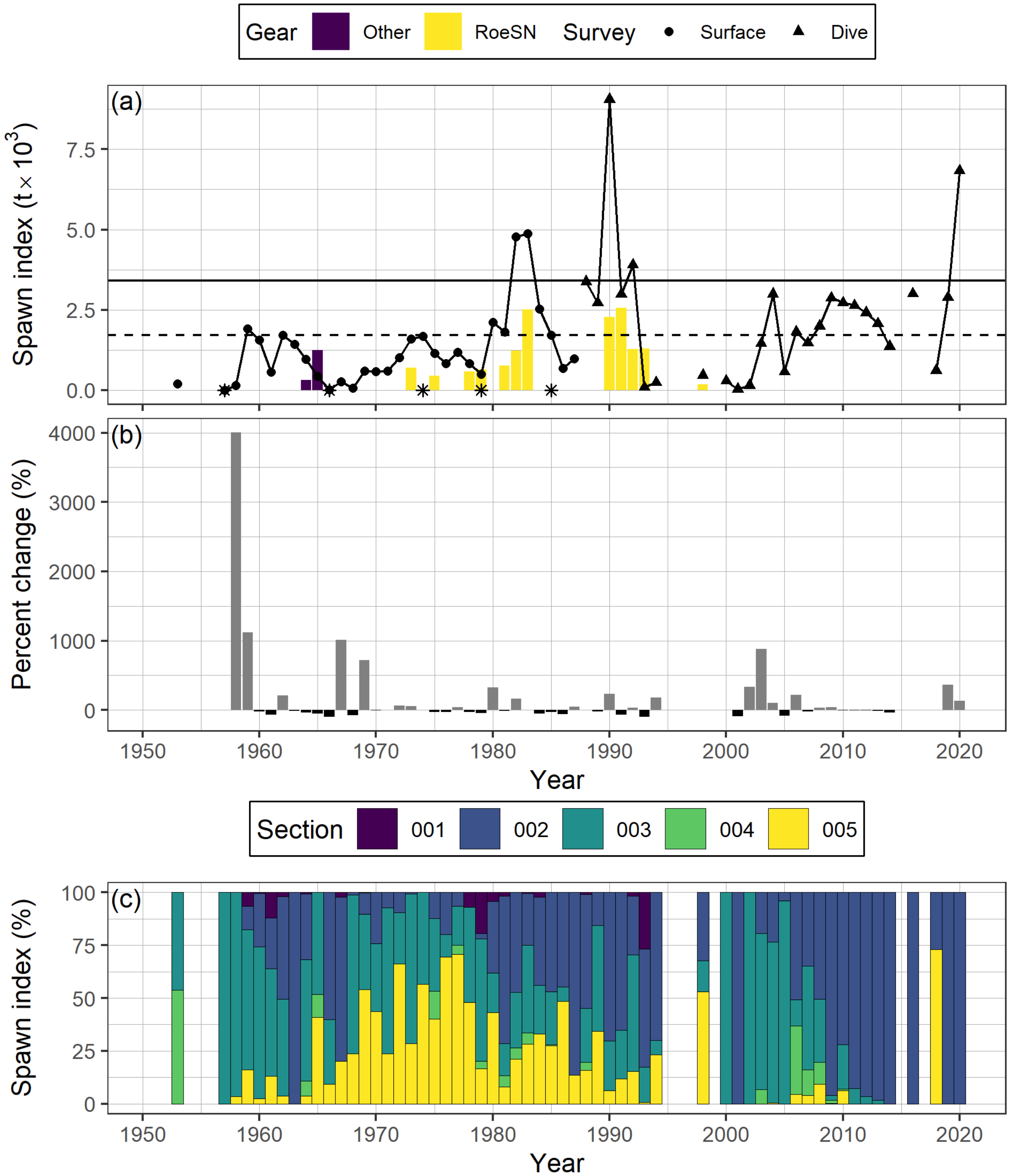



Figure 20. Time series of spawn index in thousands of metric tonnes (t x$10^3$) for Pacific Herring from 1951 to 2020 in the Haida Gwaii **Minor** stock assessment region (SAR; panel a), percent change in spawn index from the previous year (panel b) and percent contributed by DFO management section (Section 1 (Tasu Sound), Section 2 (Port Louis), Section 3 (Rennell Sound), Section 4 (Skidegate Channel) and Section 5 (Englefield Bay); panel c). The spawn index has two distinct periods defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2019). The `spawn index' is not scaled by the spawn survey scaling parameter, q.

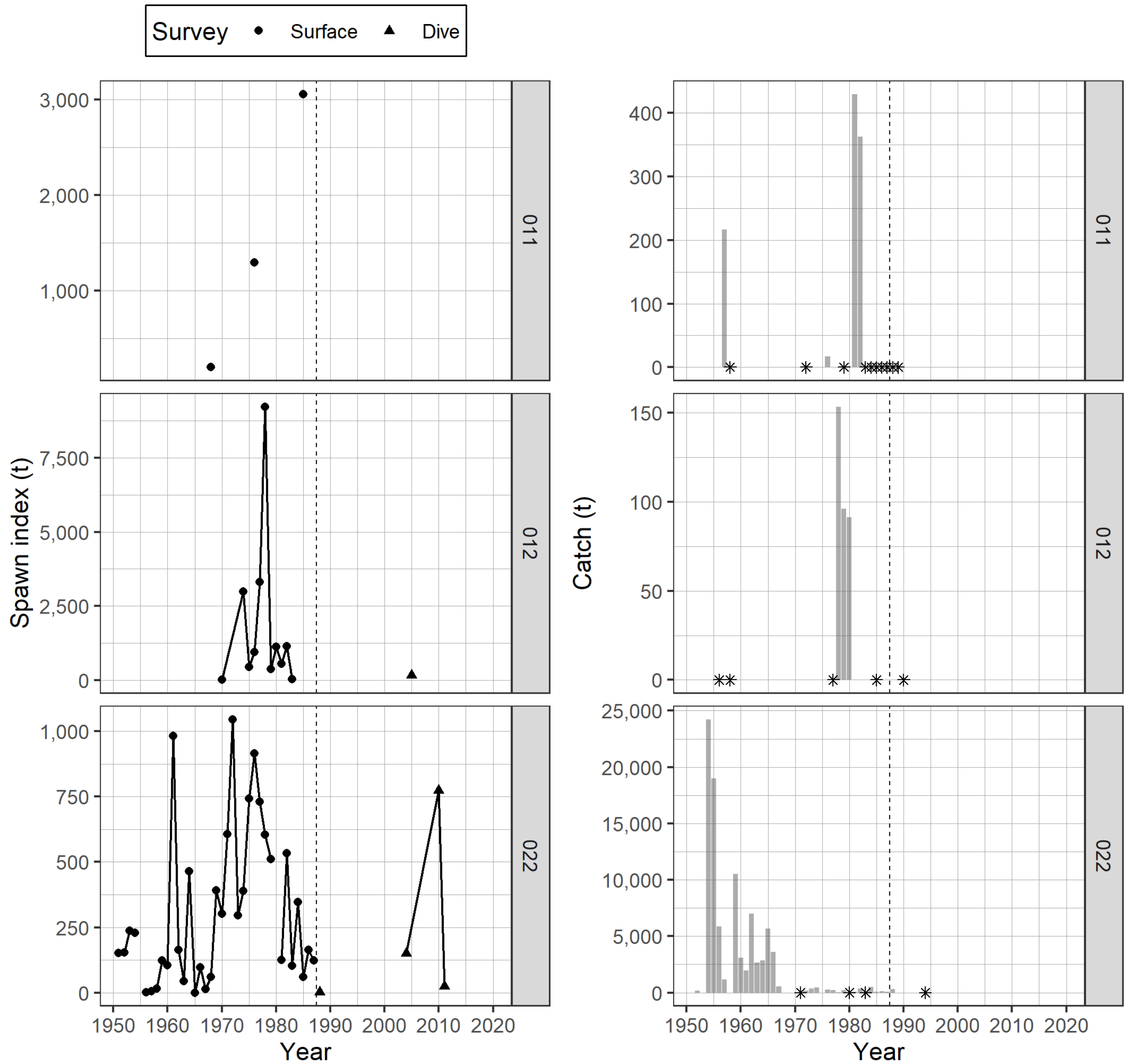



Figure 21. Time series of spawn index and catch for sub-stocks in Masset Inlet (Section 011), Naden Harbour (Section 012) and Skidegate Inlet (Section 022). The spawn index has two distinct periods (separated by the dashed vertical line) defined by the dominant survey method: surface surveys (1951 to 1987), and dive surveys (1988 to 2019). The `spawn index' is not scaled by the spawn survey scaling parameter, q. Note the y-axis scales differ among panels. Asterisks in the catch time series denote years where catch data are not releasable due to the three-party privacy rule.

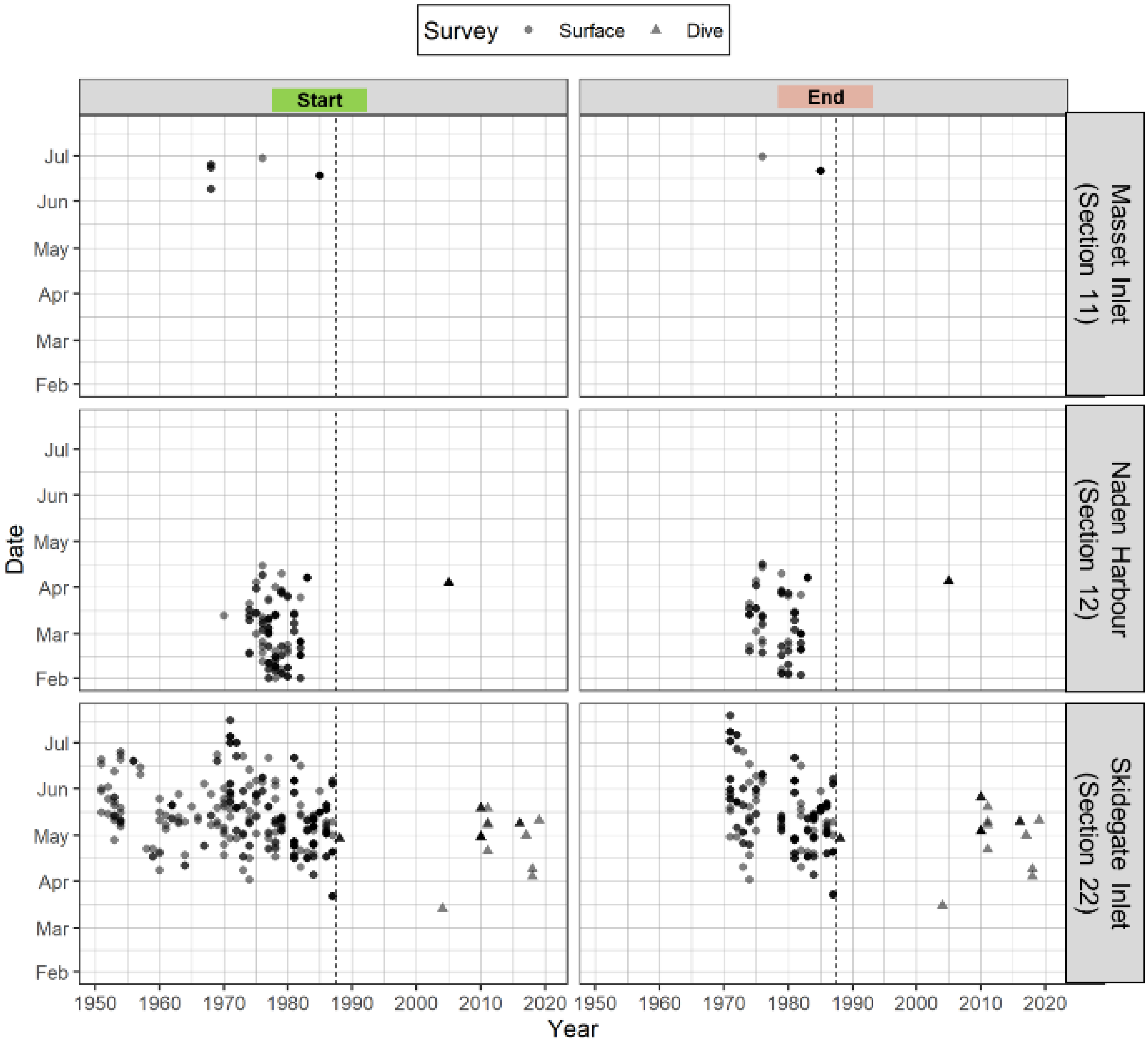



Figure 22. Start and end dates of each surveyed herring spawning event for herring sub-stocks in Masset Inlet (Section 11), Naden Harbour (Section 12) and Skidegate Inlet (Section 22). Multiple spawns can occur at a single spawning location throughout the year. The darker points indicate more than one independent spawning event started during a single day.

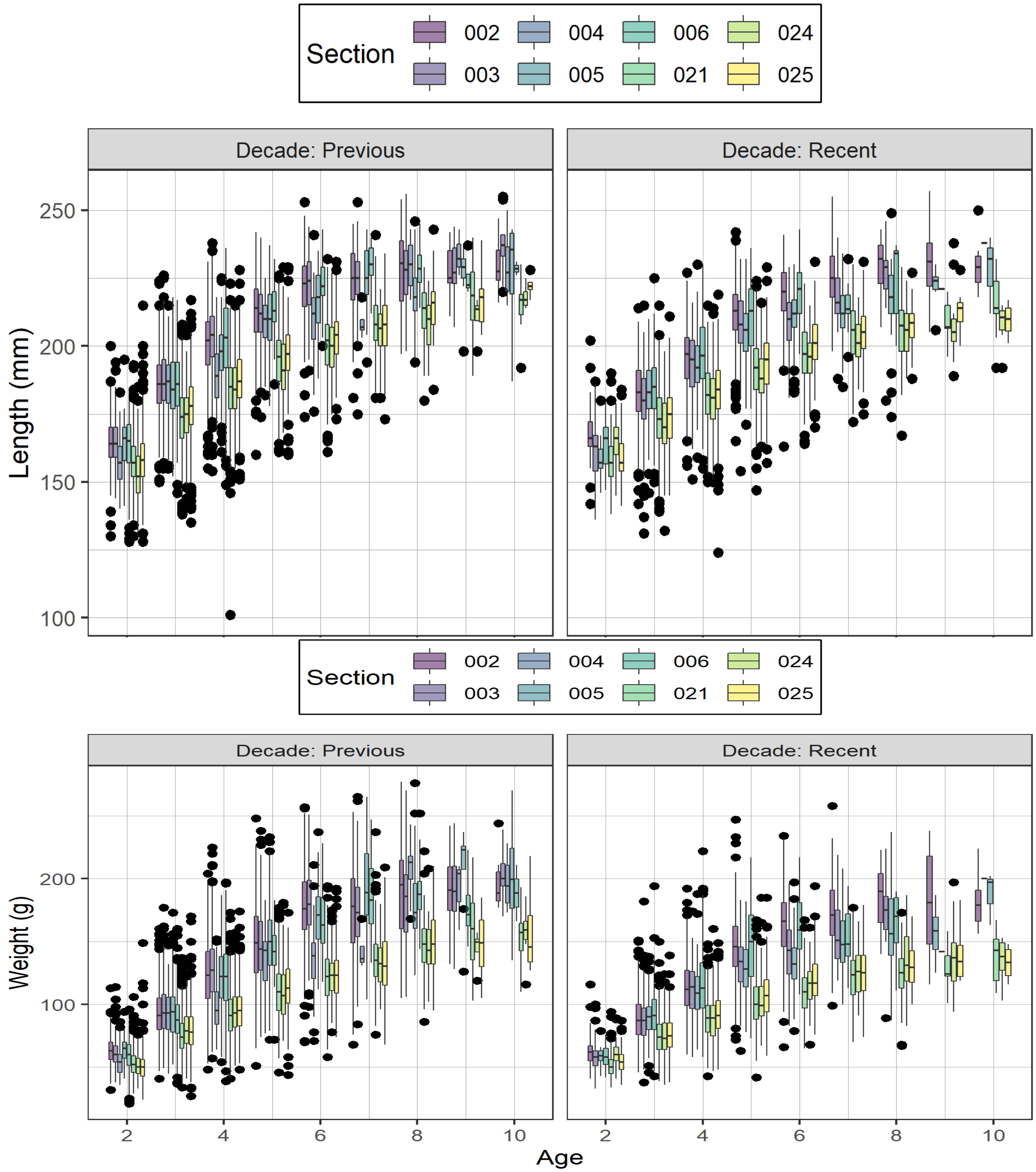



Figure 23. Weight-at-age in grams (g) and length-at-age in millimetres (mm) of Pacific Herring in the Haida Gwaii Major and Area 2 West Minor stock assessment regions by Section in the most recent decade (2011 to 2020), and the previous decade (2011 to 2010). The outer edges of boxes indicate 25th and 75th percentiles, and middle lines indicate 50th percentiles (i.e., medians). Whiskers extend to 1.5 x IQR, where IQR is the distance between the 25th and 75th percentiles, and dots indicate outliers. 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 is a 'plus group' which includes fish ages 10 and older.

Figure 24. Harvest of k'aaw in Skidegate Inlet in 1897. Source: B.C. Provincial Museum PN355 Newcombe.

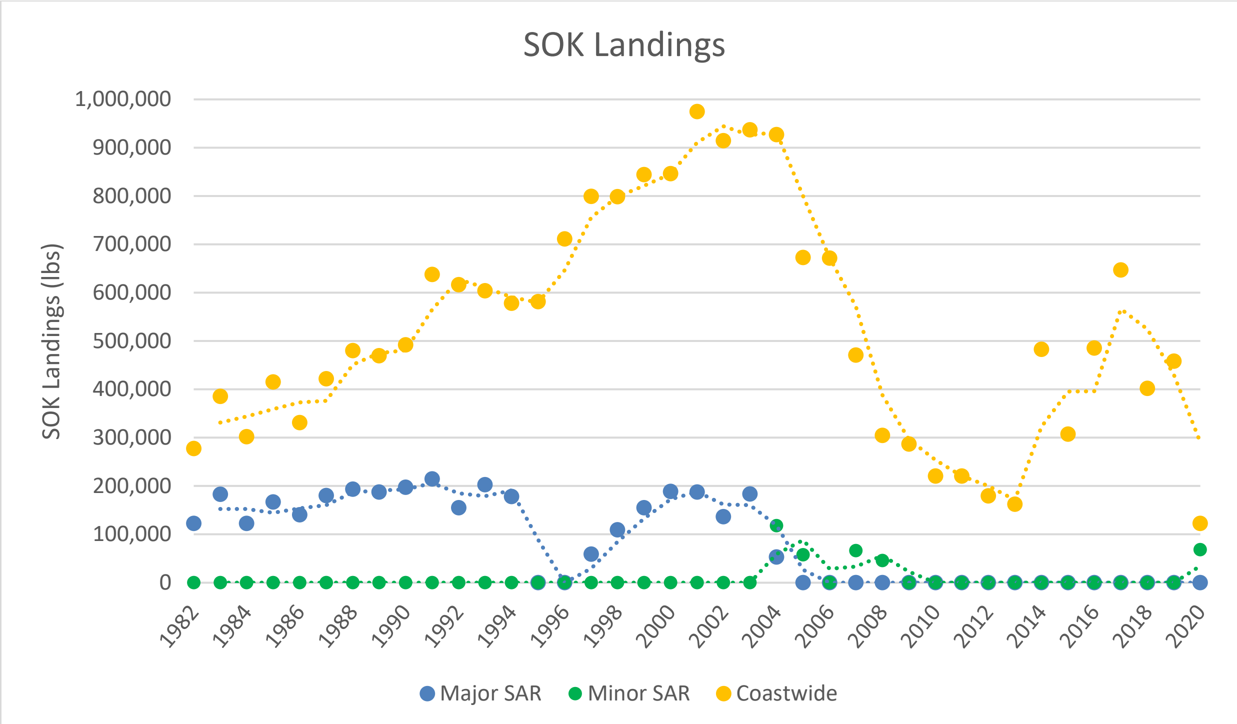



Figure 25. Commercial spawn-on-kelp landings in British Columbia (coastwide; yellow) and Haida Gwaii, in the Major Stock Assessment region (2E; blue) and the Minor stock assessment region (2W; green). Source: DFO landings from fish slips.

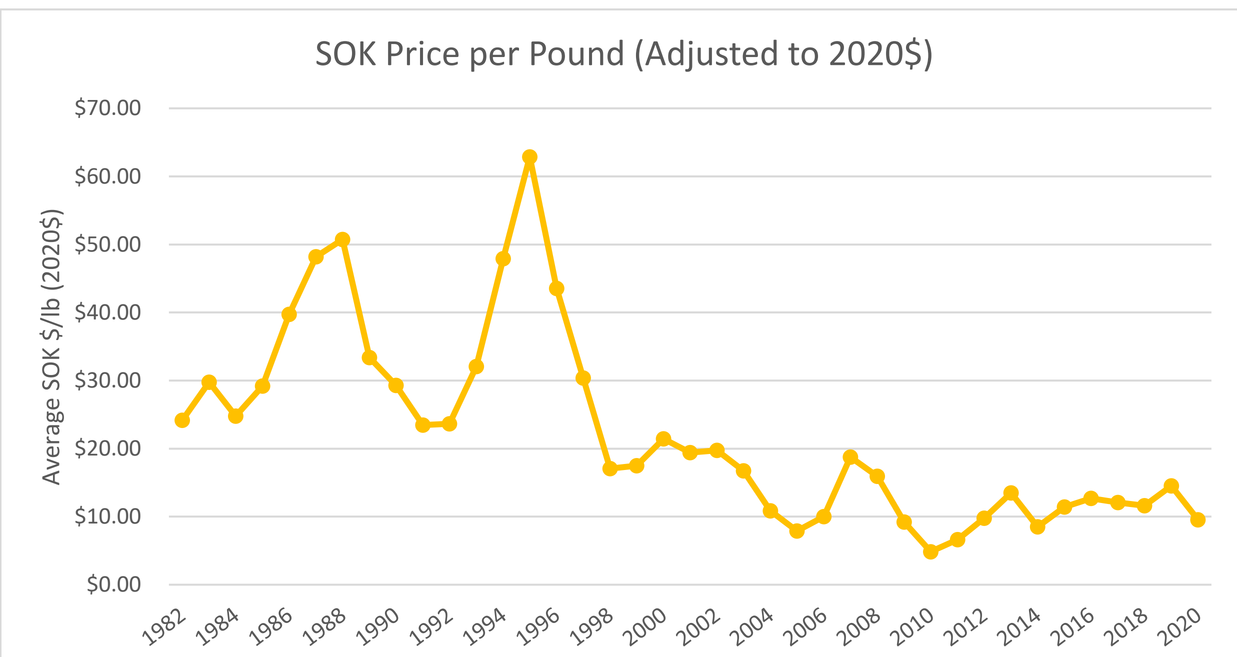



Figure 26. Average coastwide (British Columbia) per pound for commercial herring SOK. The fishery was closed in Haida Gwaii between 1994-1997 and 2005-2013. Source: coastwide prices from DFO fish slips.

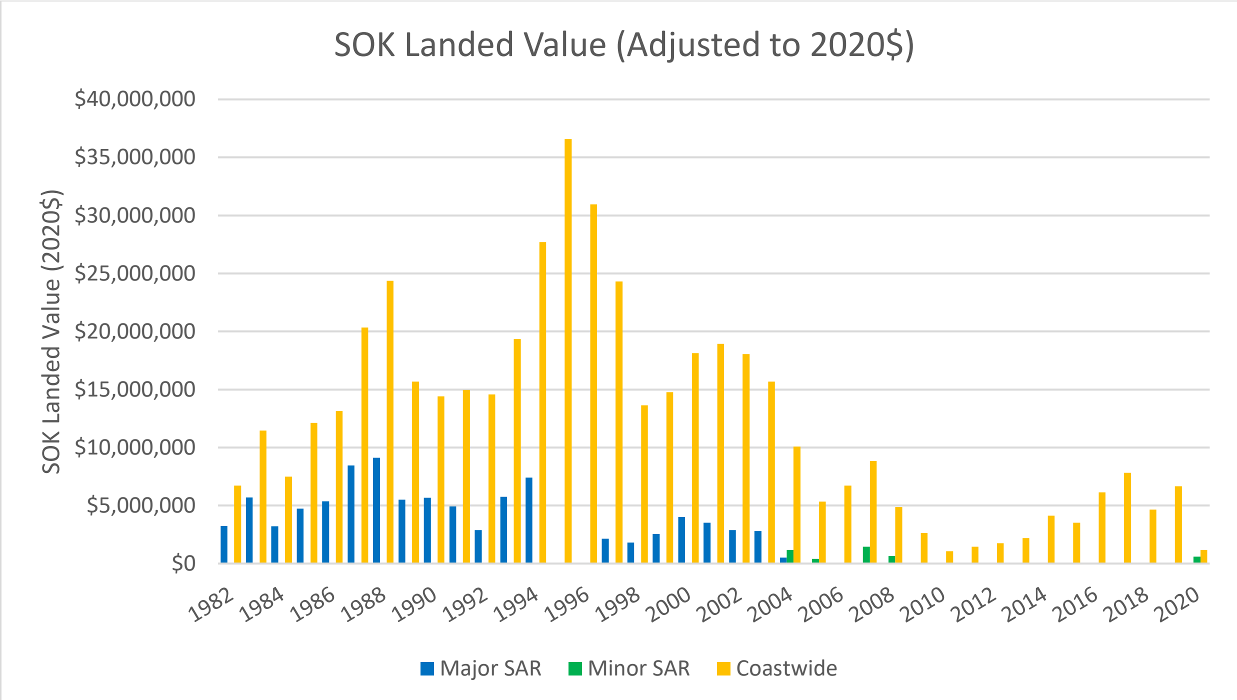



Figure 27. Commercial spawn-on-kelp nominal landed value trends in British Columbia (coastwide; yellow) and Haida Gwaii Major stock assessment region (SAR) (2E; blue), and Minor SAR (2W; green). Fishery was closed in Haida Gwaii between years 1994-1997 and again 2005-2013. Source: DFO landed value from fish slips.

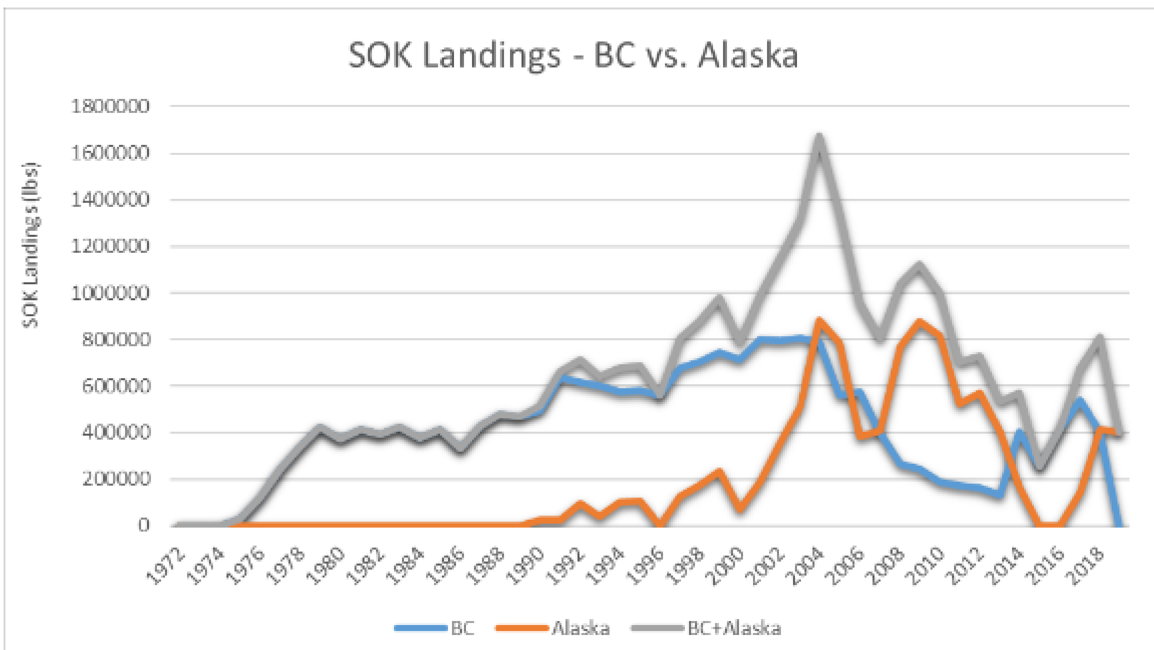



Figure 28. Spawn-on-kelp landings (lbs) in British Columbia and Alaska. Source: DFO and Alaska Department of Fish & Game report (2019).

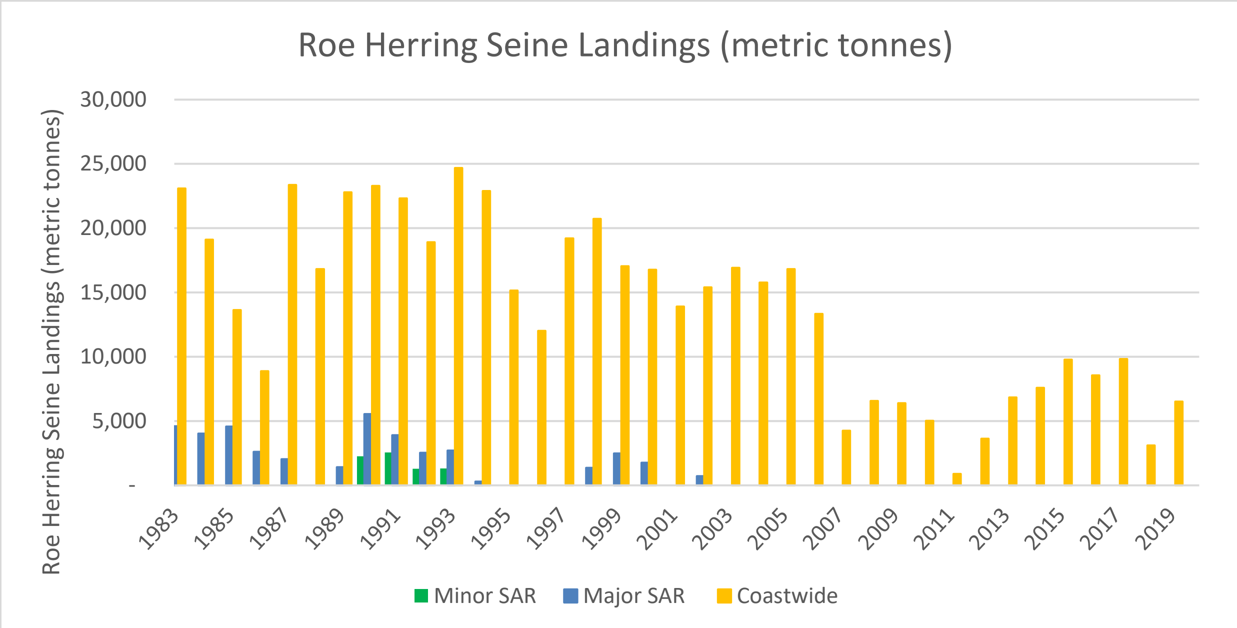



Figure 29. Seine roe catch trends in British Columbia (coastwide; yellow) and Haida Gwaii Major (2E; blue), and Minor (2W; green) stock assessment regions (SARs)). Source: coastwide landings from DFO fish slips, Major and Minor stock assessment regional landings from DFO Stock Assessment Database.

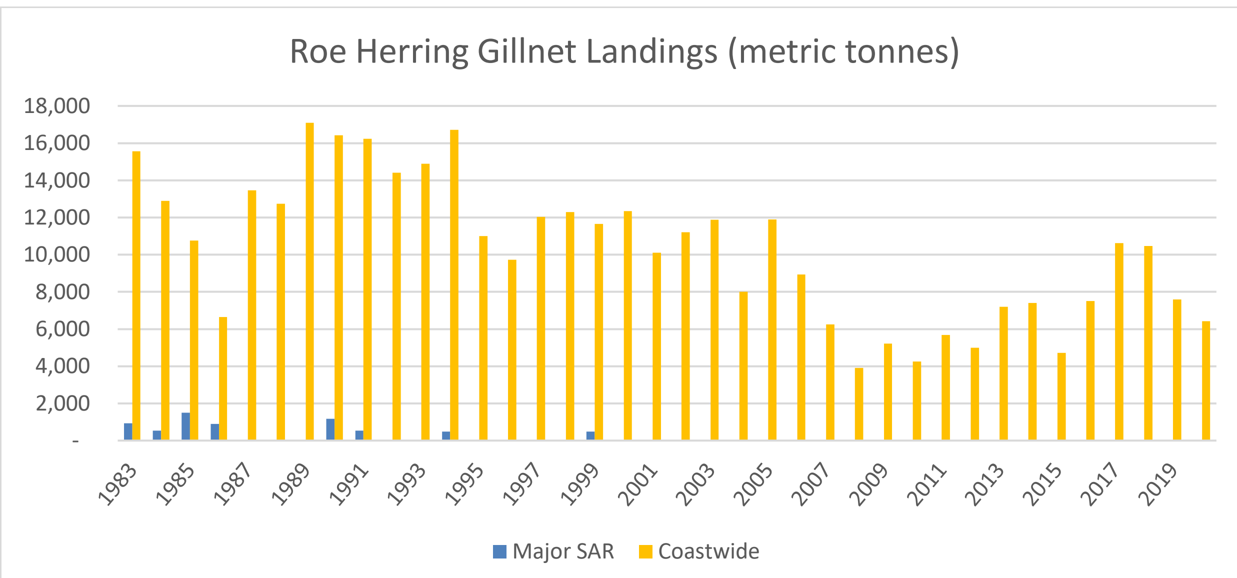



Figure 30. Gillnet roe catch trends in British Columbia (coastwide; yellow) and Haida Gwaii Major Stock Assessment Region (2E; blue). Source: coastwide landings from DFO fish slips, Major and Minor stock assessment regional landings from DFO Stock Assessment Database.

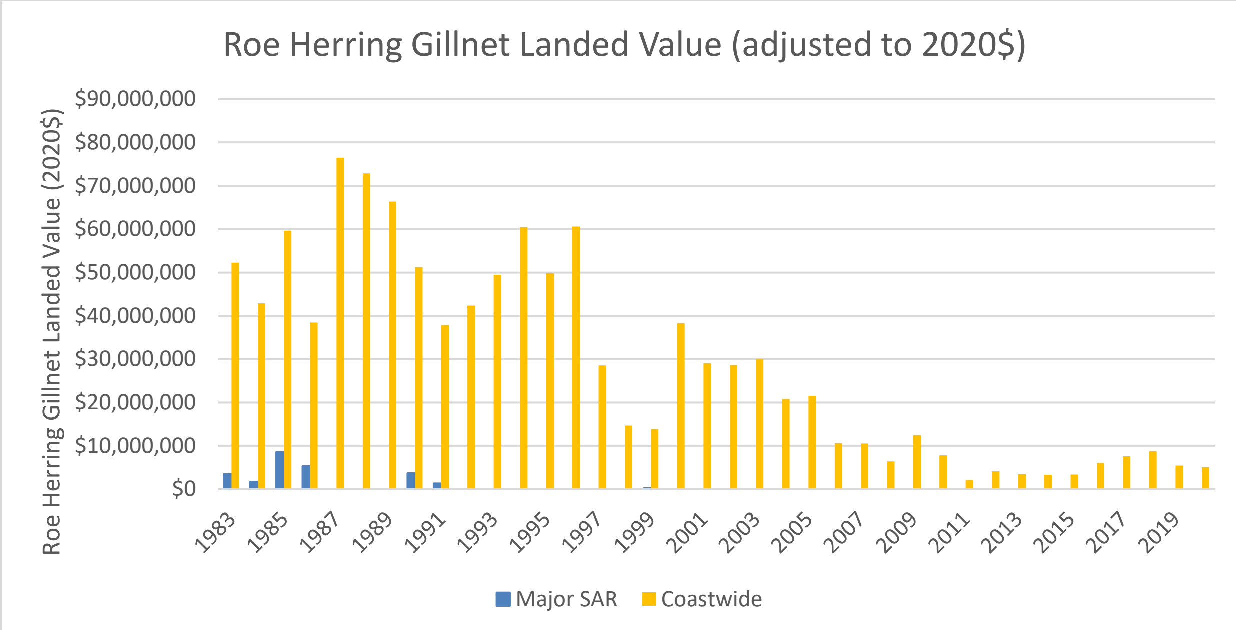



Figure 31. Commercial roe gillnet landed value trends in British Columbia (coastwide; yellow) and Haida Gwaii Major SAR (2E; blue) gillnet. The roe gillnet fishery has been closed in Haida Gwaii since 1995. Source: DFO fish slips.

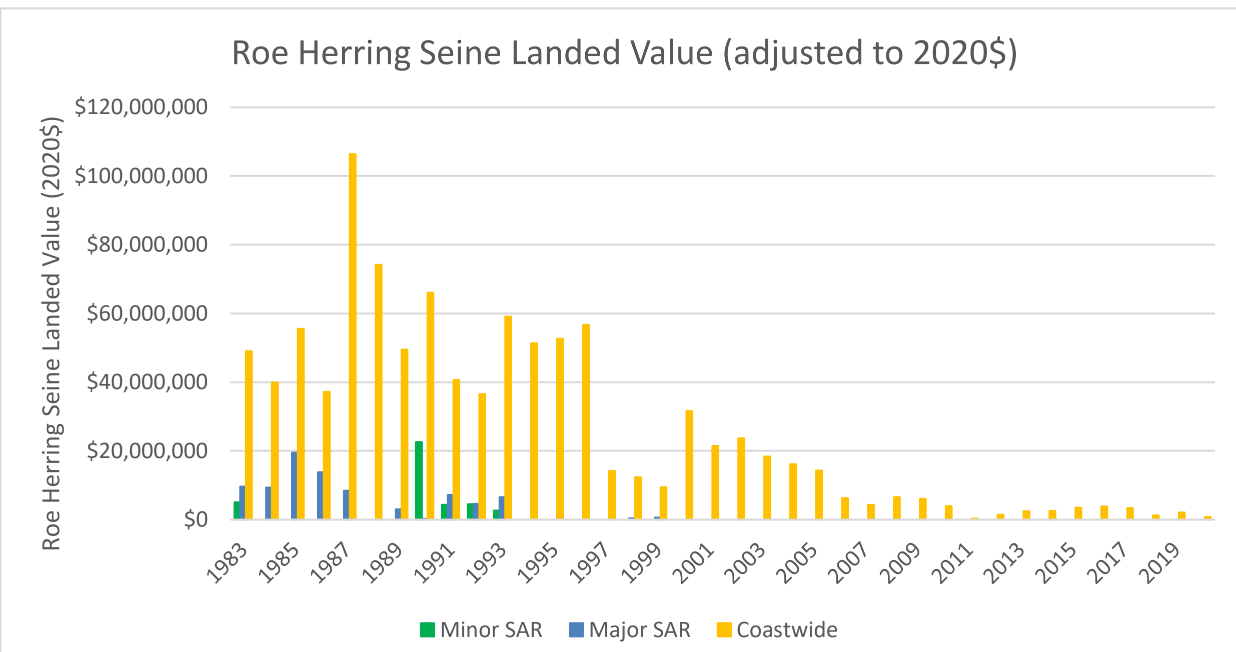



Figure 32. Commercial roe seine landed value trends in British Columbia (coastwide; yellow) and Haida Gwaii Major (2E; blue), and Minor (2W; green) stock assessment regions (SARs)). The roe seine fishery has been closed in Haida Gwaii since 2002. Source: DFO fish slips.

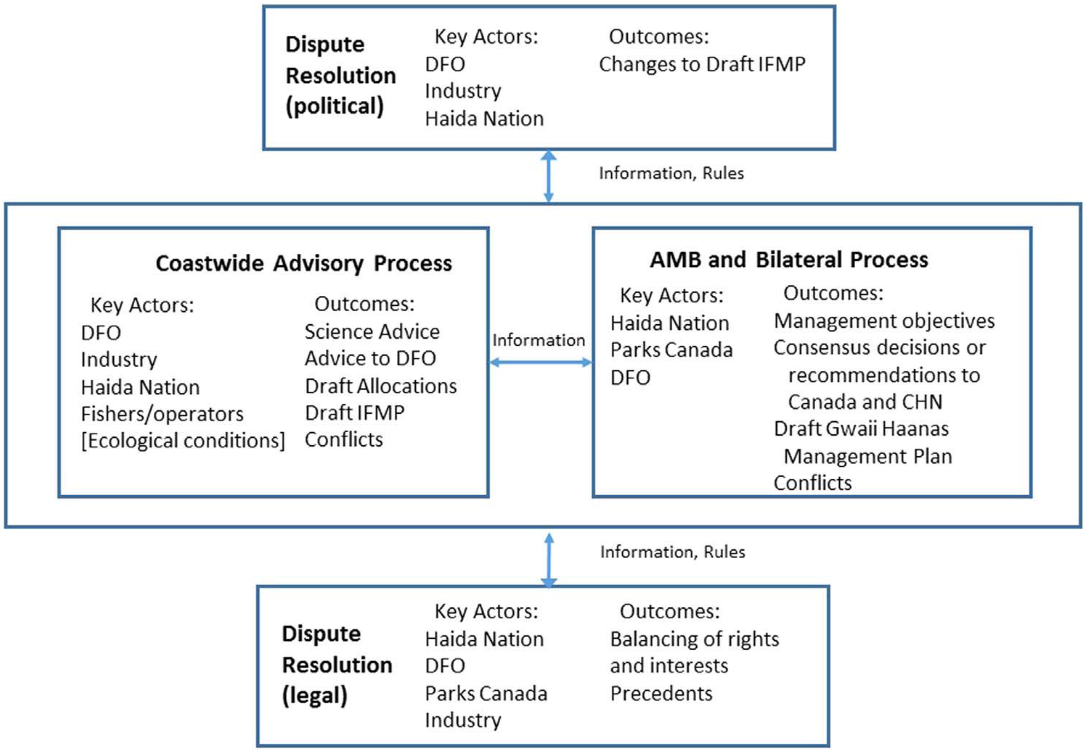



Figure 33. Adjacent action situations related to Haida Gwaii herring fishery conservation rules. IFMP = Integrated Fishery Management Plan produced by DFO with advice from other actors; AMB = Archipelago Management Board. The box around the coastwide and local processes indicates that these processes occur in parallel ahead of attempts at dispute resolution but that outcomes of dispute resolution may affect future rules in the fishery (from Jones et al. 2016)

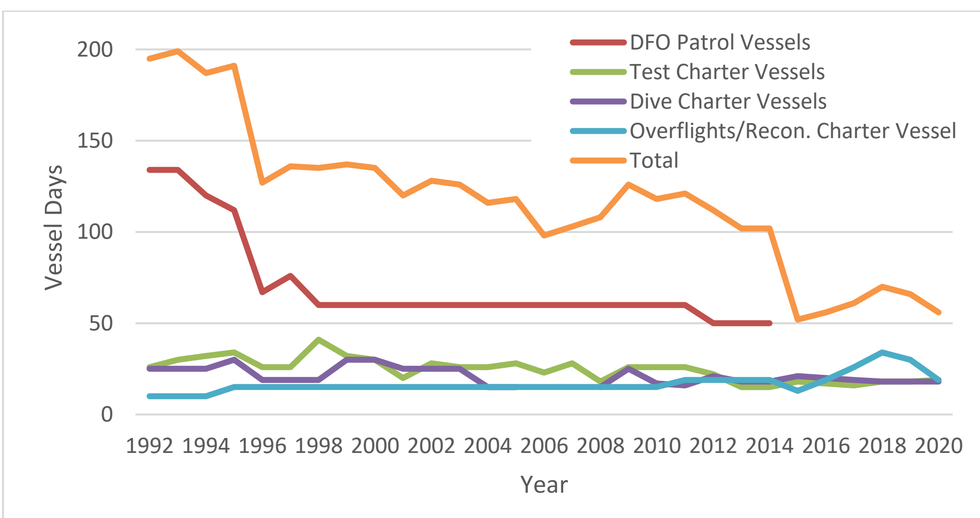



Figure 34. Management resources from 1992-2020 in the Major Haida Gwaii stock assessment region (SAR). Notes: from 1991-1993 there was also an additional 35 vessel days per year allocated as part of the Free Trade Agreement not shown above. From 1991-2010, overflights were used, and changed in 2011 to spawn reconnaissance charter vessels after the local charter flight operation closed. Aerial overflight days were shared between the Major and Minor

SARs so actual days in in the Major SAR are less than indicated. In 2006 and 2007, the dive charter vessels were cancelled due to lack of ‘payment of fish’ funds.

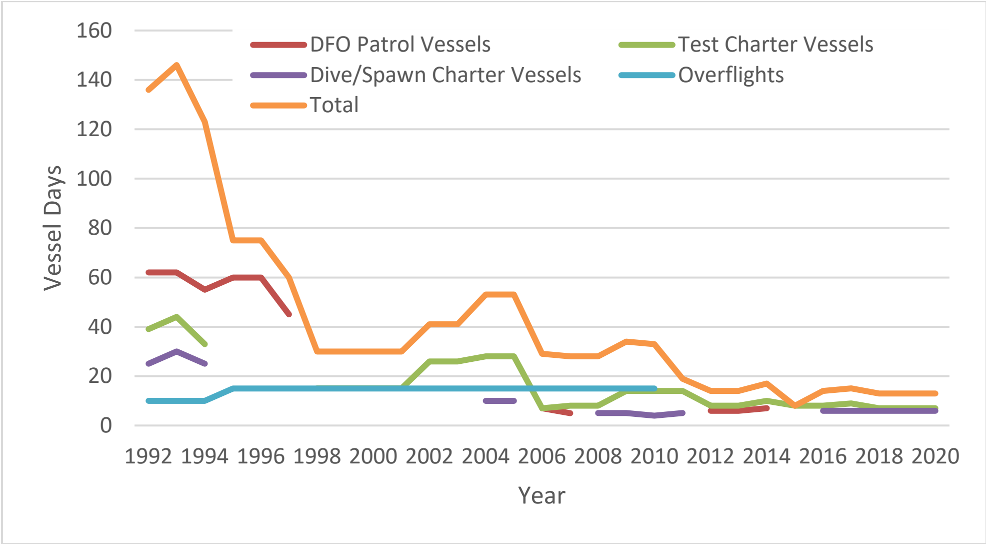



Figure 35. Management resources from 1992-2020 in the Minor Haida Gwaii stock assessment region (SAR). Notes: from 1991-1993 there was also an additional 35 vessel days per year allocated as part of the Free Trade Agreement not shown above. From 1992-2015, dive charters were used, and changed in 2016 to surface spawn charters due to funding limitations. Aerial overflight days were shared between the Major and Minor SARs so actual days in the Minor SAR are less than indicated. In 2006 and 2007, the dive charter vessels were cancelled due to lack of ‘payment of fish’ funds, so the DFO patrol vessels conducted surface surveys those years.

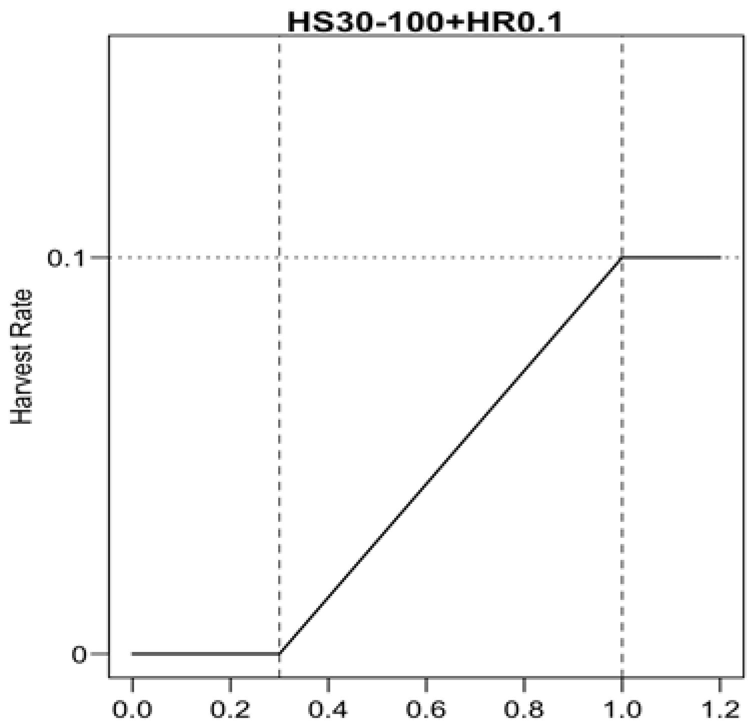



Figure 36. Harvest control rules, showing harvest rate as a function of estimated stock status, that were used for setting TACs in each sub-stock under different RPs in the rebuilding evaluation (HS30-100+HR0.1). Vertical dashed lines show the lower and upper control points, and the horizontal dashed line shows the reference maximum harvest rate.

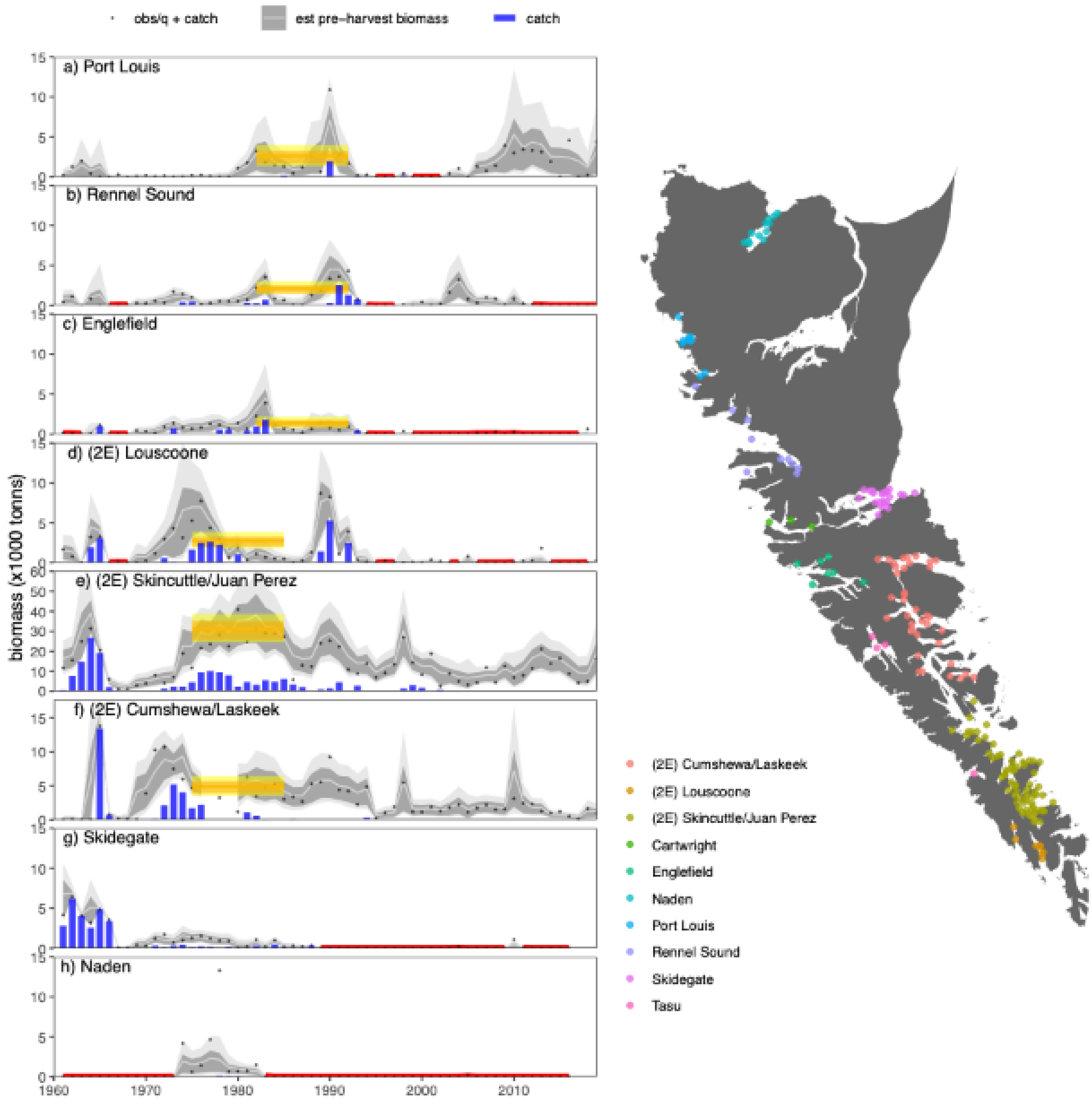



Figure 37. Left: Estimated pre-harvest biomass trends (mean with 95% and 80% and posterior credible intervals as light and dark grey bands, respectively) along with observed harvest (blue lines) and spawn observations (black points). Note that the observations are adjusted for posterior mean “q” without uncertainty but the estimated trends include uncertainty in “q”, which is estimated separately for intervals <1977 (posterior mean = 0.65), 1978-1988 (posterior mean = 0.70), and >1988 (posterior mean = 0.71) estimated using a prior mean of 0.75. The red line at the axis margin indicates regions where biomass falls below 200 tonnes in multiple consecutive years, and the orange/yellow band represent 80%/95% the posterior mean intervals for the biomass reference points for the relevant years (1975-1985 for Major SAR, 2E and 1982-1992 for Minor SAR, 2W). Right: Map of spawn locations that represent the time series used to estimate the model. Tasu and Cartwright are not shown due to minimal spawn deposition.

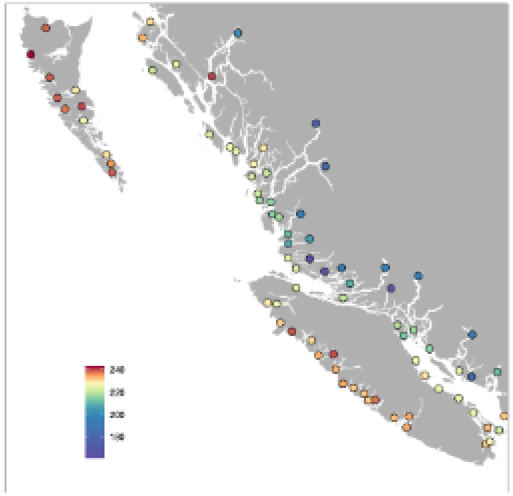


Figure 38. Estimated mean maximum size ($L_\infty$) from the spatiotemporal growth model by herring spawn section. Note that the mean maximum size estimate is the time-averaged estimated mean asymptotic size, but does not reflect any specific year.

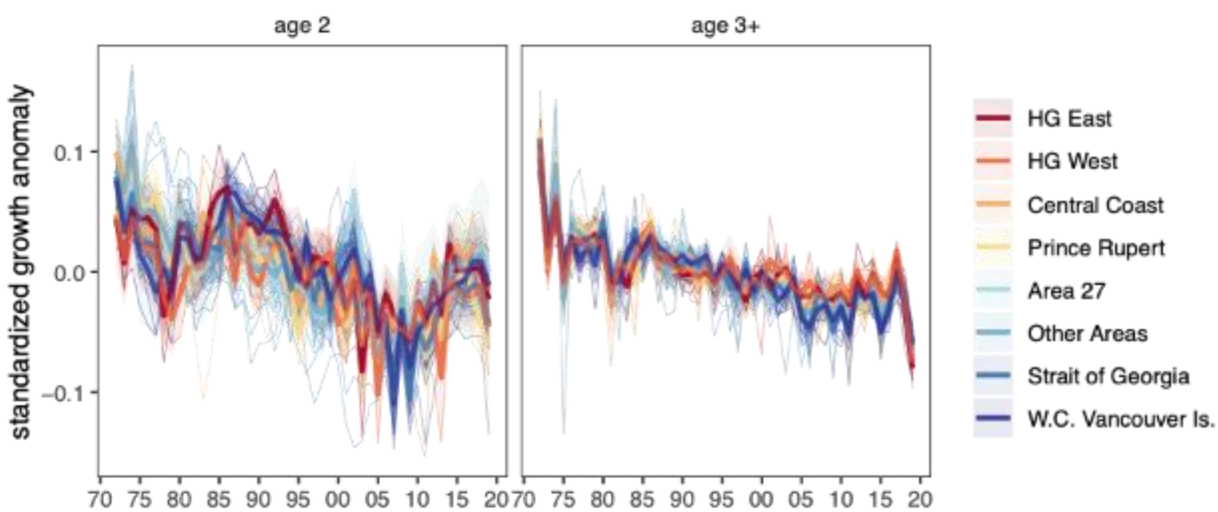



Figure 39. Estimated trends in log-scale growth anomalies for 1972-2019 by spawning sections by group (age-2 or age-3+) from the spatiotemporal growth model. Thick lines represent mean estimated trends within each region, and thin lines represent section specific estimates. Growth anomalies are estimated as the deviation from expected growth after accounting for site-specific von Bertalanffy growth and prior years' deviations for the prior age class at each given site. The von Bertalanffy growth parameters were estimated in a hierarchical framework, with anomalies estimated with separable temporal (AR(1)) and spatial (5/2 Matérn isotropic covariance by linear distance) correlation structure for each group.

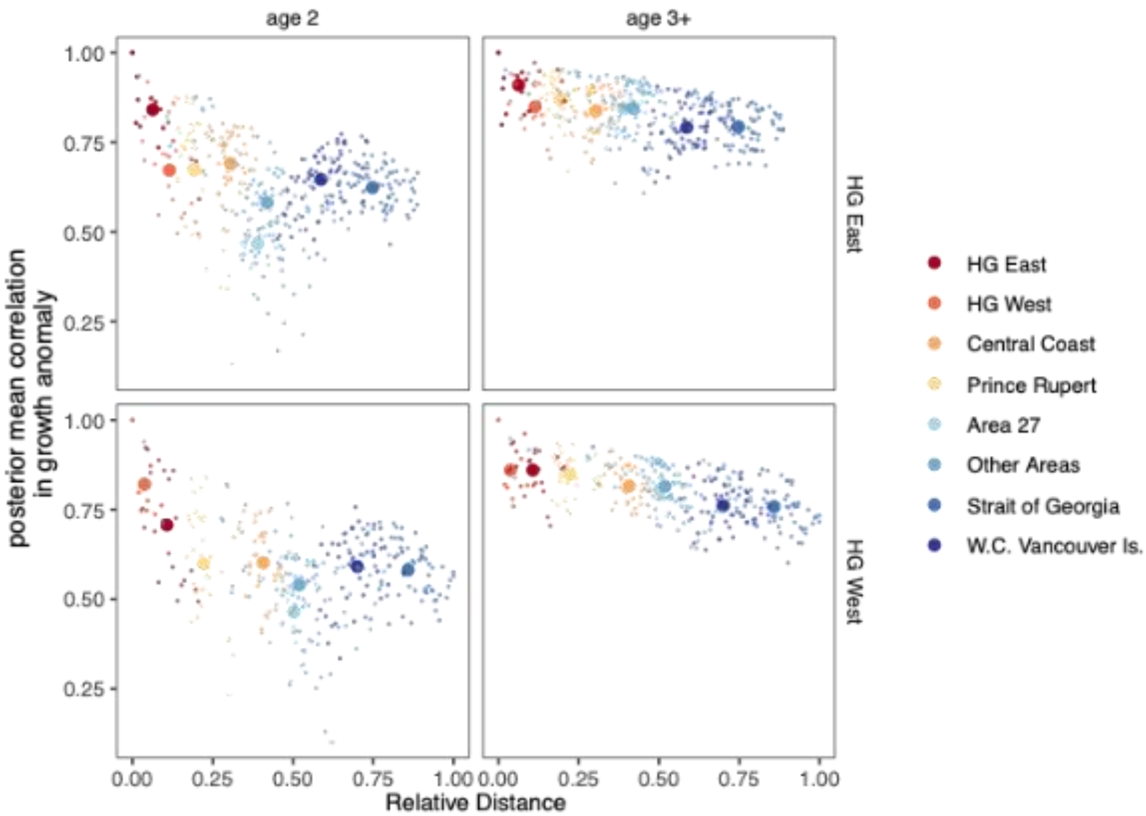



Figure 40. Pairwise correlations in trends in estimated growth anomalies between spawning sections by group (age-2 or age-3+) and by geographic area (west and east side of Haida Gwaii, where Skidegate, Masset, and Naden are not included and Louscoone is included in the east) by relative distance compared to all other sections in all other assessment regions. Note that correlations remain high despite overall mean differences in size-at-age. Large points represent mean correlations and distances. A map of all sections is shown in Figure 38.

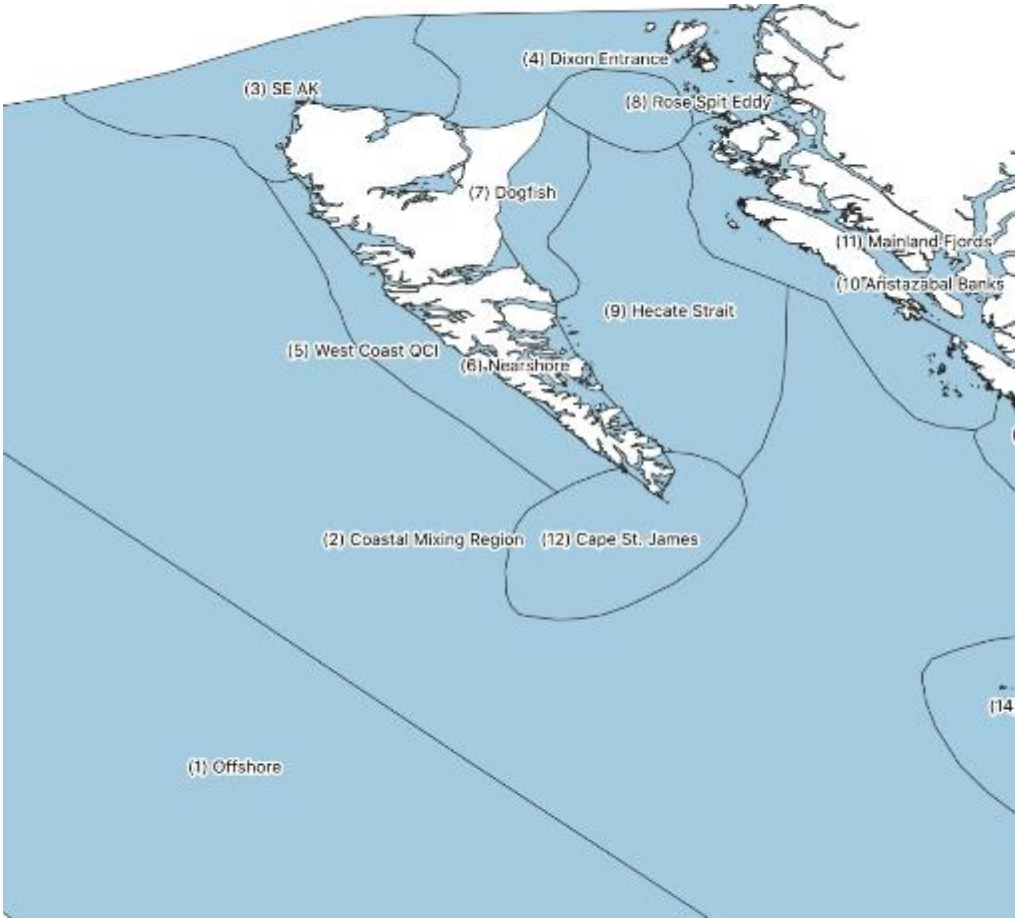



Figure 41. BCMCA oceanographic regions.

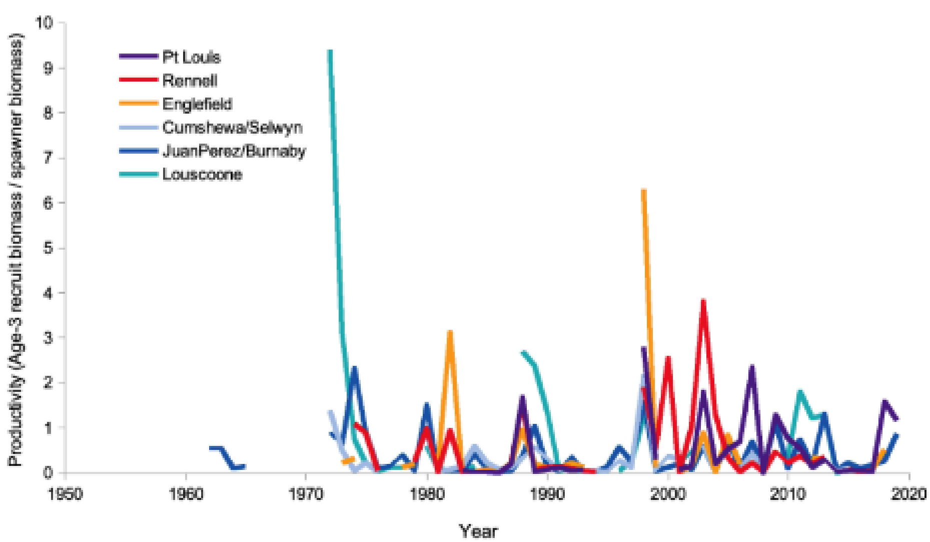



Figure 42. Productivity time series for the Haida Gwaii Major SAR (Cumshewa/Selwyn, Juan Perez/Burnaby, and Louscoone) and Minor SAR (Port Louis, Rennell, and Englefield) sub-stocks. Data gaps are due to lack of age data.

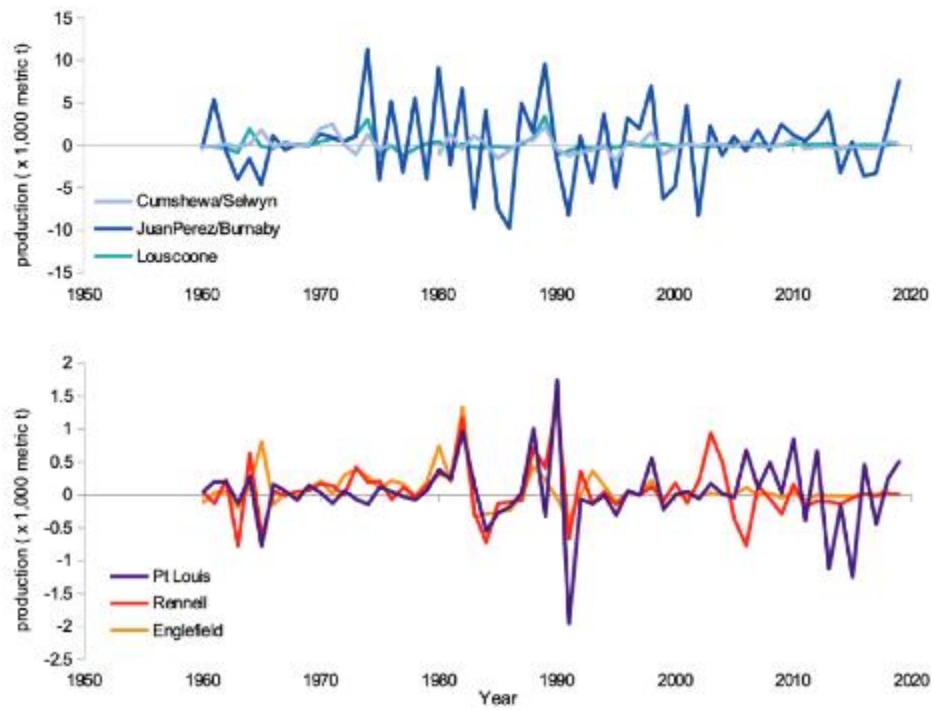



Figure 43. Production time series for the Haida Gwaii Major SAR (Area 2E; top) and Minor SAR (Area 2W; bottom) sub-stocks.

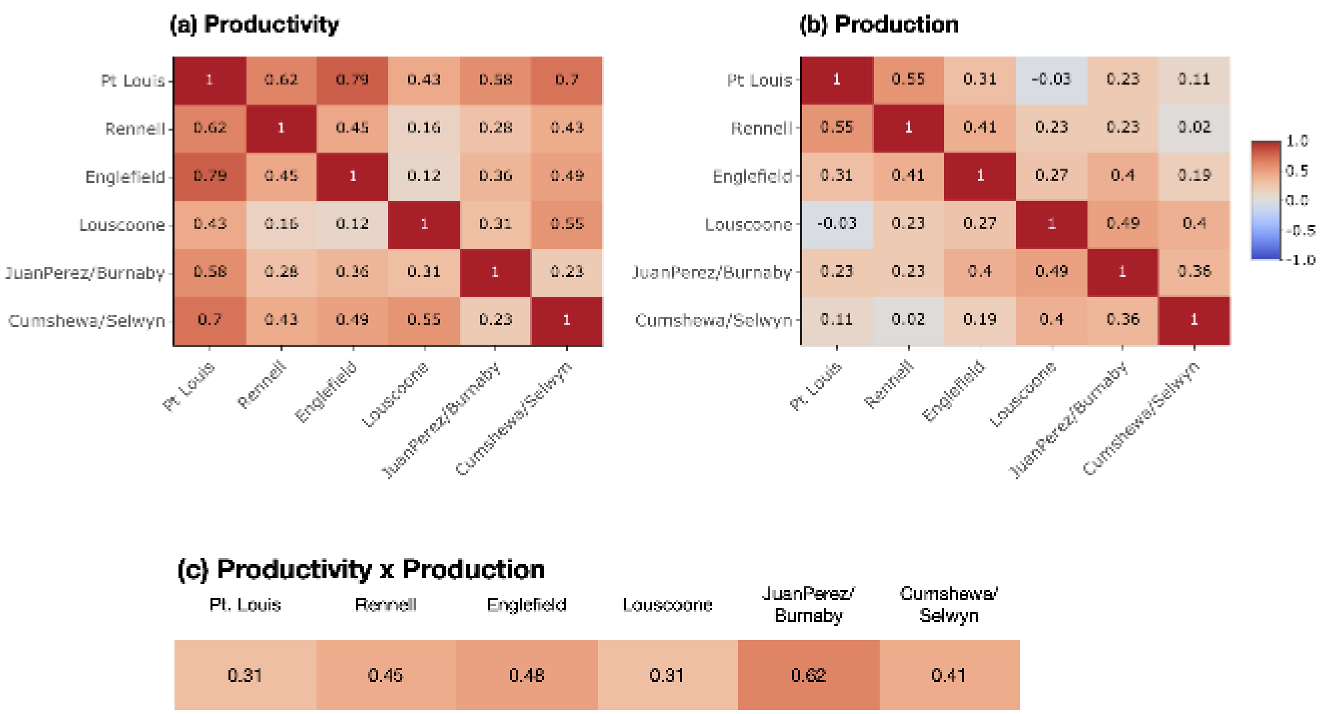



Figure 44. Correlation between sub-stock specific time series for (a) productivity and (b) production, and correlation between productivity and production for each sub-stock.

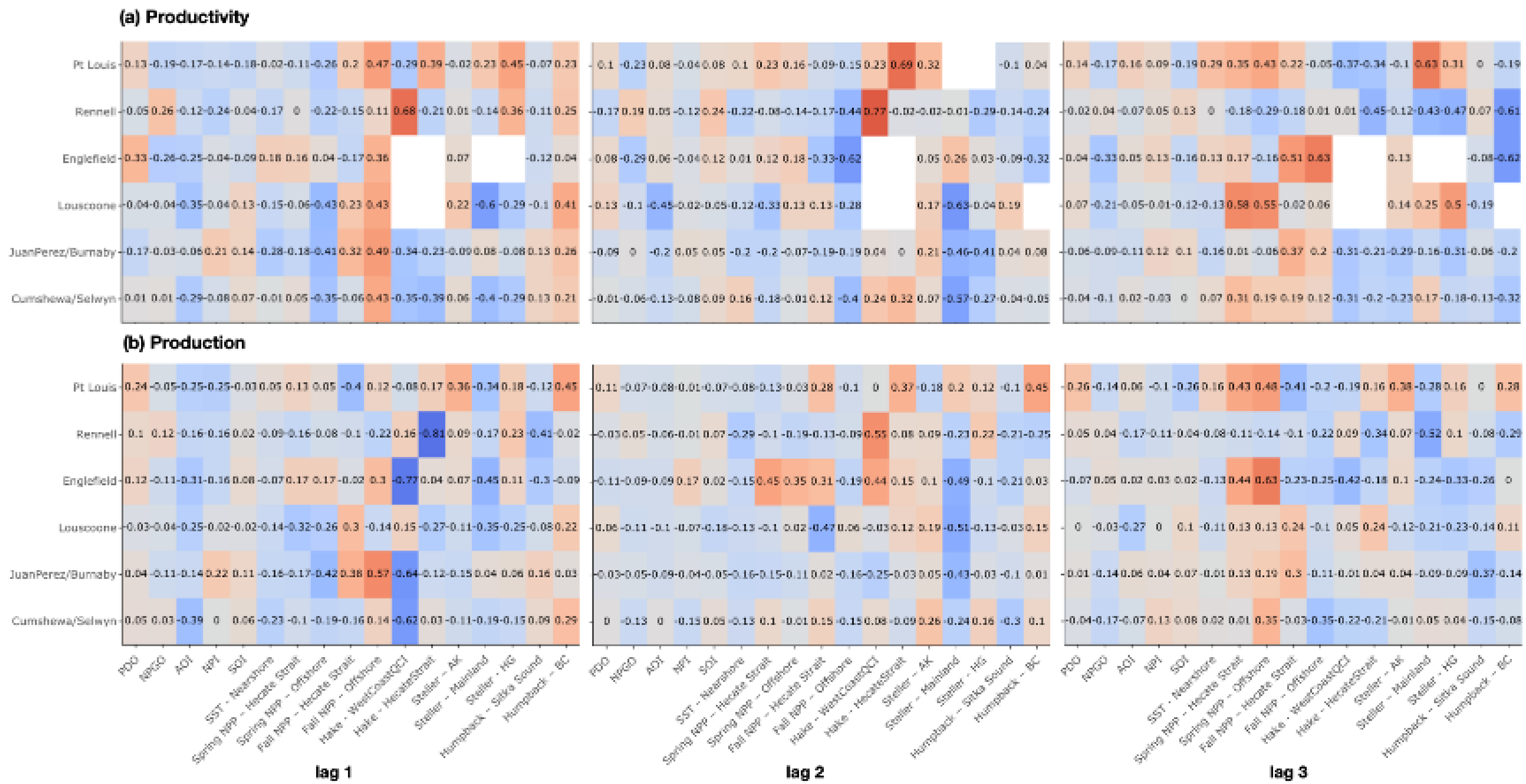



Figure 45. Correlation with environmental indicators for (a) productivity and (b) production at multiple lags for each sub-stock in Haida Gwaii Major SAR (Area 2E) and Minor SAR (Area 2W). For brevity, indicators were included only for a few select oceanographic regions in this summary representation. Blank cells indicate that correlations were not calculated because there were fewer than 8 overlapping data years.

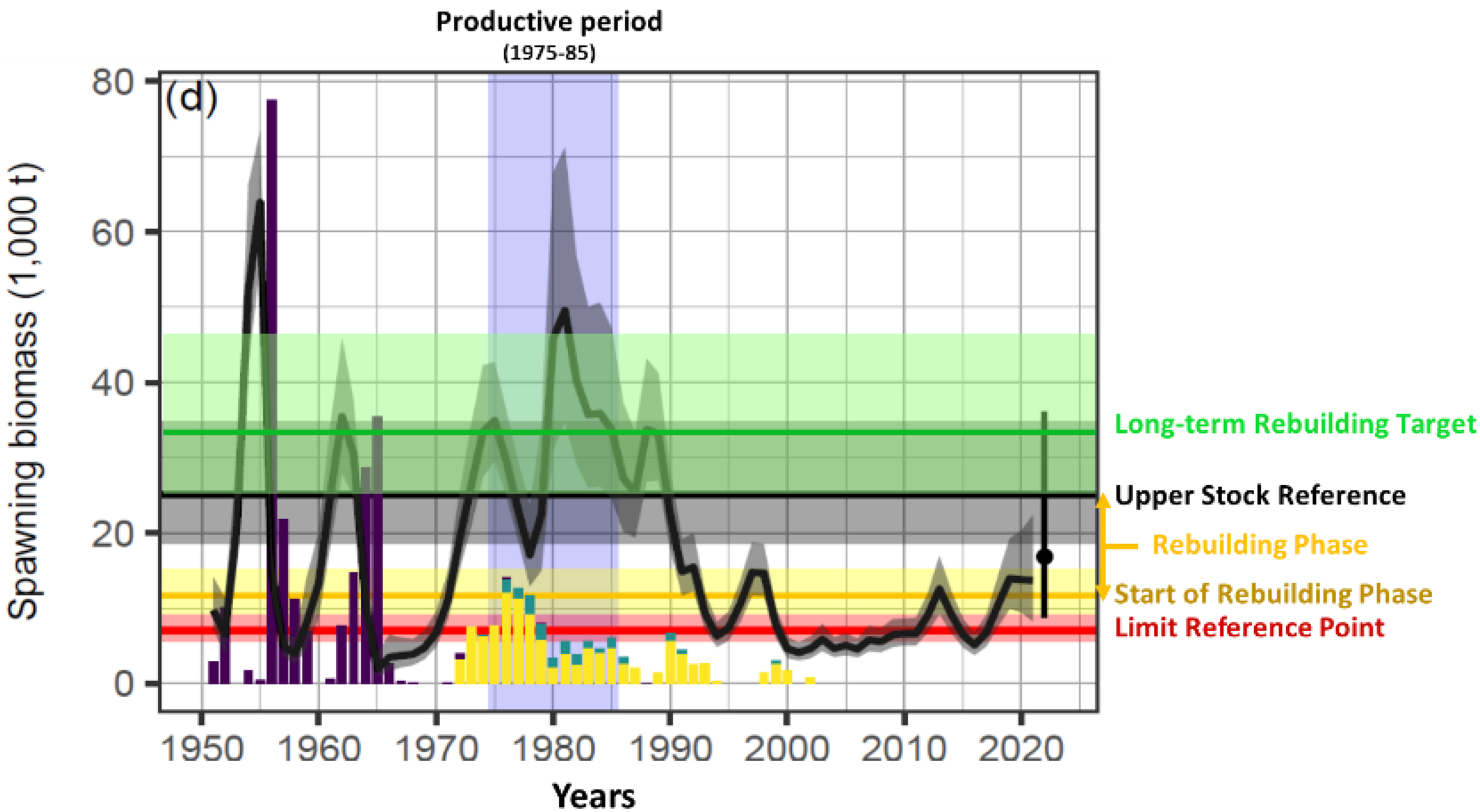



Figure 46. Annual statistical catch-at-age model output for Pacific Herring for the Major stock assessment region of Haida Gwaii from 1951 to 2021. Median posterior estimates of annual spawning biomass are shown by the black trendline, with 90% credible intervals represented by grey bands. The dot and vertical line indicate the median and 90% credible interval, respectively, of forecast spawning biomass for 2022 in the absence of fishing. Coloured vertical bars indicate commercial catch (reduction fishery in purple; gillnet roe fishery in green and seine roe fishery in yellow). Rebuilding reference points identified by the technical working group are represented by the straight colored horizontal lines and their 90% credible intervals represented by shaded bands.

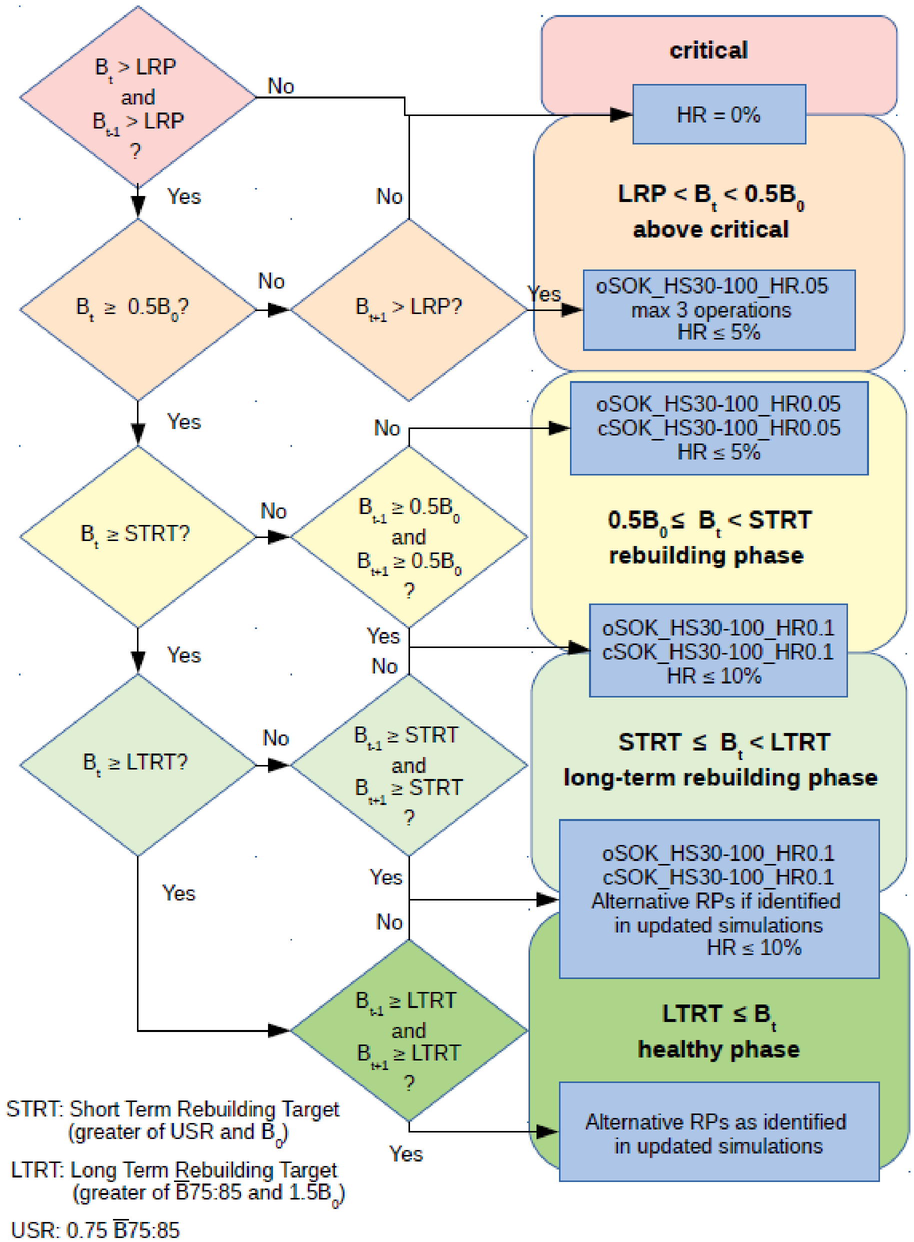
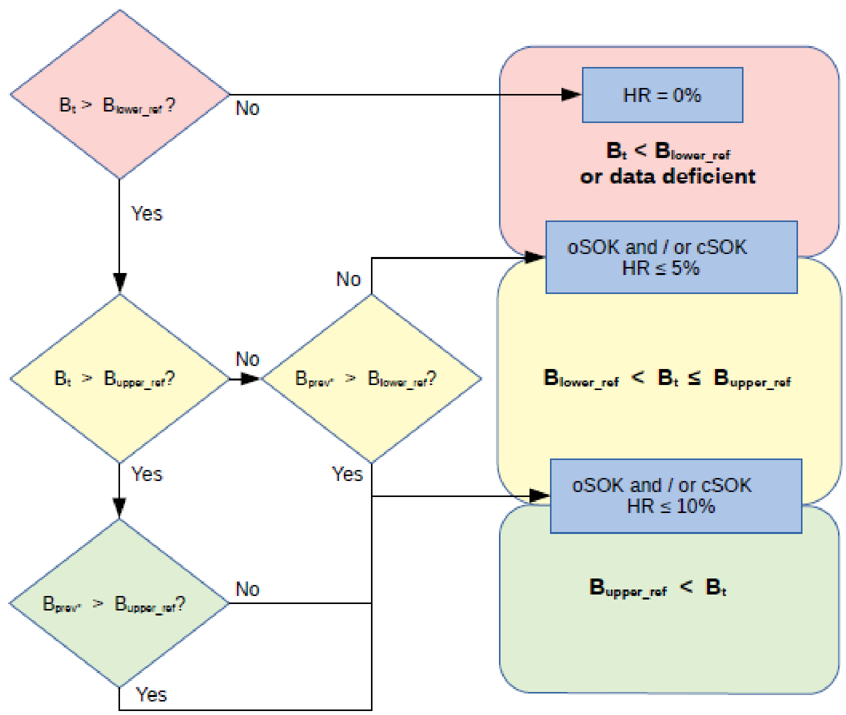



Figure 47. Flow chart of management measures for the Haida Gwaii Major stock assessment region (SAR).




$B_{lower\_ref}$: greater of 500t and $0.25\overline{B}_{82:92}$

$B_{upper\_ref}$: $\overline{B}_{82:92}$ (rebuilding target)

$B_{prev^*}$: $B_{t-1}$, t, or $B_{t-2}$ if data missing for $B_{t-1}$

$B_t$: estimated as $I_t$ or using best available method

Figure 48. Flow chart of management measures for the Haida Gwaii Minor stock assessment region (SAR).