Fisheries and Oceans Canada | Pêches et Océans Canada
Ecosystems and Oceans Science | Sciences des écosystèmes et des océans

Pacific Region

Canadian Science Advisory Secretariat
Science Response 2026/006

# PRINCE RUPERT DISTRICT PACIFIC HERRING MANAGEMENT STRATEGY EVALUATION PROCESS FOR 2025-2027

## CONTEXT

Pacific Herring (*Clupea pallasii*) abundance in British Columbia is assessed using a spatially integrated statistical catch at age operating model framework, fit to spawn survey indices, fishery age composition data, and commercial catches. Simulations assess management procedure performance relative to the conservation objective and spawning stock biomass is assessed relative to biomass reference points including the limit reference point, candidate upper stock reference points, and $B_{MSY}$. A quota option is provided for the Prince Rupert District stock assessment region using a management procedure tuned to meet the conservation objective. This Science Response results from the Science Response Process of September 22, 2025 on

This Science Response results from the regional peer review meeting on September 22, 2025 on the Prince Rupert District Pacific Herring Management Strategy Evaluation Process for 2025-2027.

## SCIENCE ADVICE

### Status

- Spawning biomass, as represented by the operating model, is above the LRP with a 92% probability and has recently risen above the productive period candidate upper stock reference (USR) point of 39.38 kt (Table 1).
- The Prince Rupert District (PRD) major stock assessment region (SAR) is healthy.

### Trends

- Spawning biomass began declining in 1990 and approached the LRP in ~2003. The stock fluctuated at and above the LRP until ~2018, then increased the next several years, rising above $B_{MSY}$ and the USR in 2023.
- The operating model estimates spawning biomass to be above $B_{MSY}$ and above the productive period candidate USR for the past two years.

### Ecosystem and Climate Change Considerations

- An analysis of Herring data from 1988-2016 identified evidence of low biomass and low productivity states for 3 of 5 Pacific Herring major stocks (HG, CC, WCVI) and these states were used to define a limit reference point (LRP) of $0.3B_0$ for all 5 stocks (Kronlund et al. 2017). This LRP is implemented in Herring MSE using a conservation objective which states to “avoid the LRP with a high probability” (minimum 75%). For all 5 stocks, this LRP is more

conservative than the default LRP of $0.4 \cdot B_{MSY}$ identified in "DFO Sustainable Fisheries Framework" policy (DFO 2009).

- The Herring management framework incorporates density dependent mortality and time-varying recruitment into the Herring operating model, mechanistically accounting for predation mortality and ecosystem effects experienced by this mid-trophic level pelagic species. These effects are also included when simulating reference points and in evaluating management procedure performance.
- Additionally, each major SAR is modelled using regional life-history traits and regional ecosystem pressures.

### Stock Advice

- A quota option for 2026 of 3,367 metric tonnes is provided using the management procedure (MP) tuned to the conservation objective. This MP applies a maximum target harvest rate of 8% to the 2026 forecast spawning biomass.

## BASIS FOR ASSESSMENT

### Assessment Details

The Pacific Herring Prince Rupert District (PRD) stock assessment region (SAR) is one of the five major SARs. Advice for the other major and the two minor SARs is presented in DFO (In Prep.)[1] and DFO (In Prep.)[2]

Harvest strategies for PRD Pacific Herring are developed within a management strategy evaluation (MSE) process, intending to bring together First Nations and fishery stakeholders, their objectives, monitoring data, and quantitative models to generate harvest advice via repeatable and transparent decision rules. The technical core of an MSE is simulation testing which evaluates the performance of management procedures (MPs) against fishery management objectives. Simulations for PRD Herring are generated by the PRD Herring operating model (OM) implemented using the spatially integrated statistical catch-at-age Herring (SISCAH) modelling framework (DFO 2023a).

The SISCAH OM estimates PRD Herring biomass from 1951-2024 based on historical time series of spawn survey indices (Figure 1), biological and fishery age compositions, and commercial fishery data. Key operating model assumptions include: density dependent mortality (DDM), a spawn survey index that integrates (blends together) surface and dive survey observations, gear-specific commercial fishery timing and catch (Figure 2), and a likelihood function with correlated errors within age-composition data. Science advice supporting DFO's Ecosystem Approach to Fisheries Management (EAFM) is represented via density-dependent natural mortality and time-varying recruitment which aim to capture the net effect of ecosystem impacts on Pacific Herring mortality that are not directly observable (e.g., depensatory predation).

[1] DFO. In Prep. Stock Status Update with Application of Management Procedures for Pacific Herring (*Clupea pallasii*) in British Columbia: Status in 2025 and Forecast for 2026. DFO Can. Sci. Advis. Sec. Sci. Resp.

[2] DFO. In Prep. Strait of Georgia Pacific Herring Stock Status in 2025. DFO Can. Sci. Advis. Sec. Sci. Resp.

PRD stock responses to fishing under alternative MPs are generated via a single operating model. Future (projected) uncertainty in the underlying population dynamics and monitoring data are taken into account by sampling from operating model's joint Bayes posterior distribution for all estimated model parameters, while uncertainty in future recruitment is generated by simulating future recruitments from a $\log$-normal distribution around a Beverton-Holt stock-recruitment relationship. The joint Bayes posterior distribution for PRD model parameters includes the stock-recruitment model steepness $h$ parameter (i.e., productivity at low spawning biomass), which is not estimable in some SARs because these stocks have not gonethrough an extended low productivity state (e.g., SoG). Details of the operating model fit to data and its estimated quantities are described in Appendix A.

The operating model simulates herring population dynamics under candidate MPs over a 15-year projection period (2025-2039) to generate distributions of biomass and fishery yield outcomes and performance statistics related to fishery management objectives (Section "Fishery management objectives"). Here, we present an MP that is tuned to meet the conservation objective (i.e., $P(B_t \geq 0.3B_0) \geq 0.75$) to ensure MP compliance with the Herring LRP objective and with the 'DFO Sustainable Fisheries Framework' policy and 'A fishery decision-making framework incorporating the Precautionary Approach' policy as per the Terms of Reference.

#### Year Assessment Approach was Approved

The SISCAH operating model framework implemented here for PRD Herring was reviewed and approved by CSAS in June 2023 (DFO 2023a).

#### Assessment Type

Full assessment, MSE process, with update to the management procedure and harvest control rule.

#### Most Recent Assessment Date

Last Full Assessment: this document (2025).

#### Assessment Approach

1. Broad category: Full MSE process using a single stock operating model, every three years.
2. Specific category: Index-based, state-space, statistical catch-at-age model, with a Beverton-Holt stock-recruitment relationship and density dependent time varying natural mortality.

This SISCAH modelling framework (Johnson et al. 2024) estimates PRD Herring stock status and quota calculations for the 2025/2026 season using the MP tuned to the conservation objective.

## Stock Structure Assumption

The current assessment framework assumes BC has five discrete homogeneous SARs of Pacific Herring. This assumption is consistent with the findings of (Beacham et al. 2008) which assessed population structure using microsatellite variation and found little evidence for genetic sub-structure within the SAR.

More recent analysis of genomics data by (Petrou et al. 2021) show reproductive timing drives population structure in Pacific Herring and further research is now underway to further investigate spatial and temporal structure of BC Herring populations.

The current framework does not consider potential straying or movement between SARs, finer scale stock structure, or uncertainty in stock structure, however the finer scale dynamics of

herring stock structure are considered at an operational level in the on-grounds management of commercial fisheries, i.e., through gear restrictions and/or area closures (as described in the annual IFMP).

Herring in PRD spawn primarily in late March and early April, over multiple locations with variable timing (Figure 1). Most spawn occurs in Section 042 in the Big Bay area, and Section 052 in Kitkatla. Details of spawn timing and locations are described in the 2025 PRD data summary report.

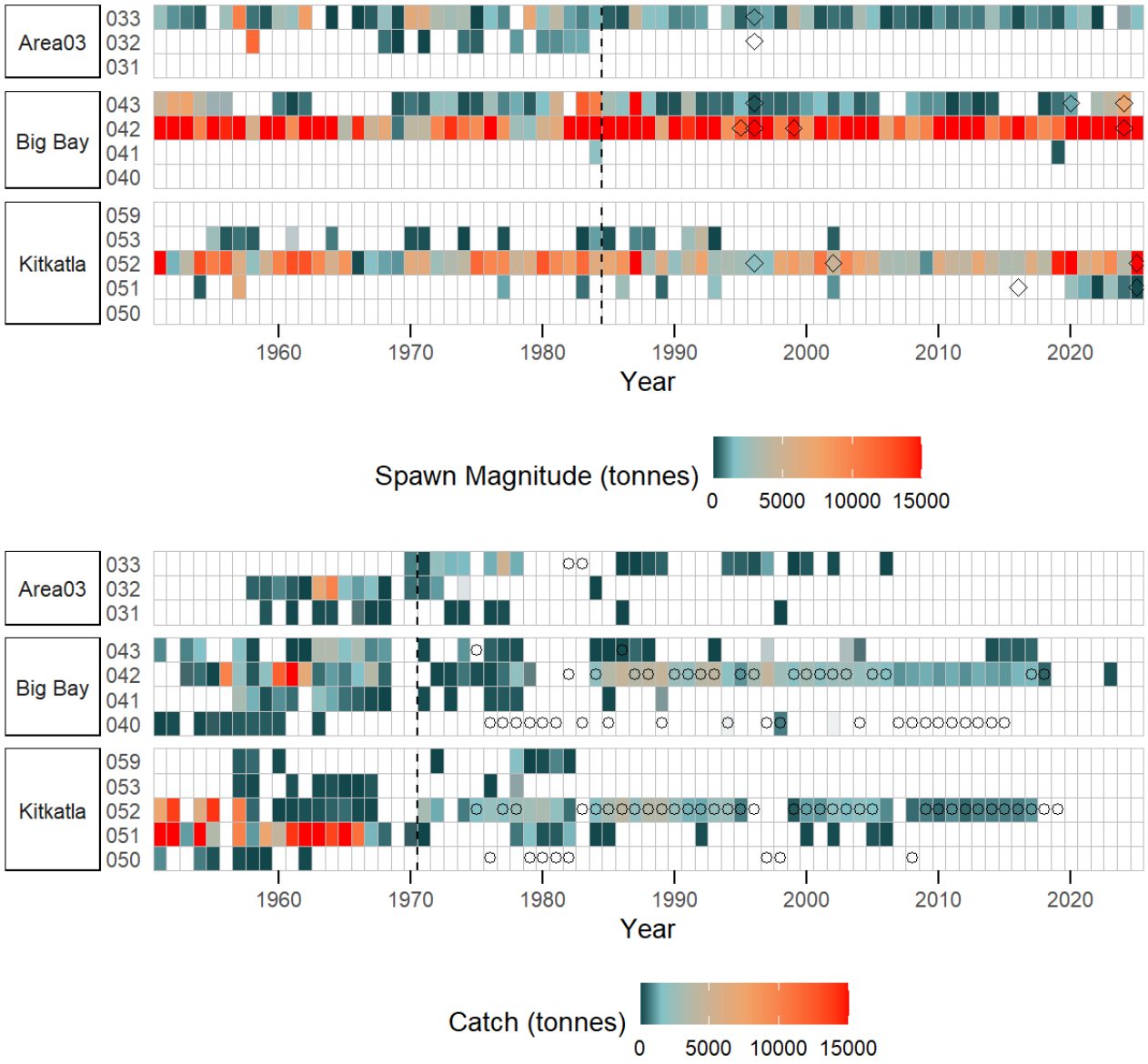


*Figure 1. Top: Spatial distribution of Herring spawn (blended index) in 1951 - 2025. Diamonds indicate incomplete survey of spawning event. Bottom: Spatial distribution of herring catch records in 1951 – 2025, where tonnes denotes catch from reduction, roe herring, food& bait, special use fisheries. Circles indicate spawn on kelp occurrences. Rows denote Herring Sections.*

Catch by seine and gillnet fleets has been in separate spatial areas since the mid-late 1990s (Figure 2). Both gear types have been used to fish in Big Bay and Kitkatla since that time, but since 2005 there are no sections where seine and gillnet fisheries have co-occurred. The majority of gillnet fishing is in Section 042 of Big Bay, and the majority of seine fishing is in Section 052 of Kitkatla; incidentally, 042 and 052 are the sections with the most spawn in Big Bay and Kitkatla, respectively (Figure 1).

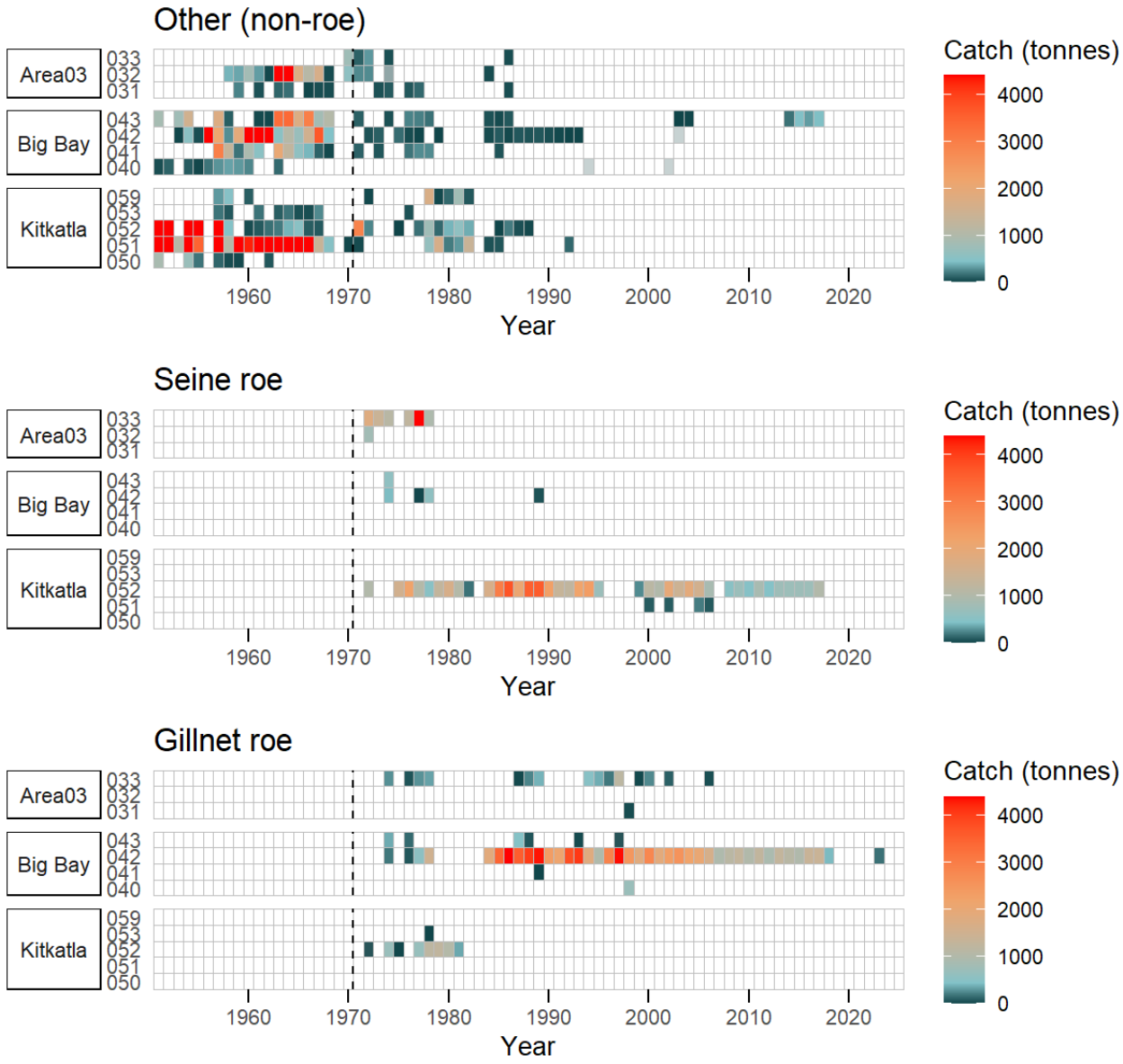


*Figure 2. Spatial distribution of herring catch records in 1951 – 2025, where tonnes denotes catch from reduction and FB/SU (top), seine roe (middle), and gillnet roe (bottom).*

## Reference Points

Biological reference points are used as the basis of some fishery objectives, and as performance metrics for MP evaluations. These include a range of proportions of $B_0$ (unfished spawning biomass) and $B_{MSY}$ (biomass at maximum sustainable yield). Figure 3 shows the

relative position of biological reference points for SISCAH operating model (Appendix A). The equilibrium yield curve assumes that yield is split among fisheries (i.e., seine, gillnet, food and bait, and/or spawn-on-kelp) using the average proportion of total catch landed by each fishery over the last 20 years with fishing. For areas with spawn-on-kelp fisheries (i.e., PRD), the catch is converted to whole fish equivalents (Johnson et al. 2024).

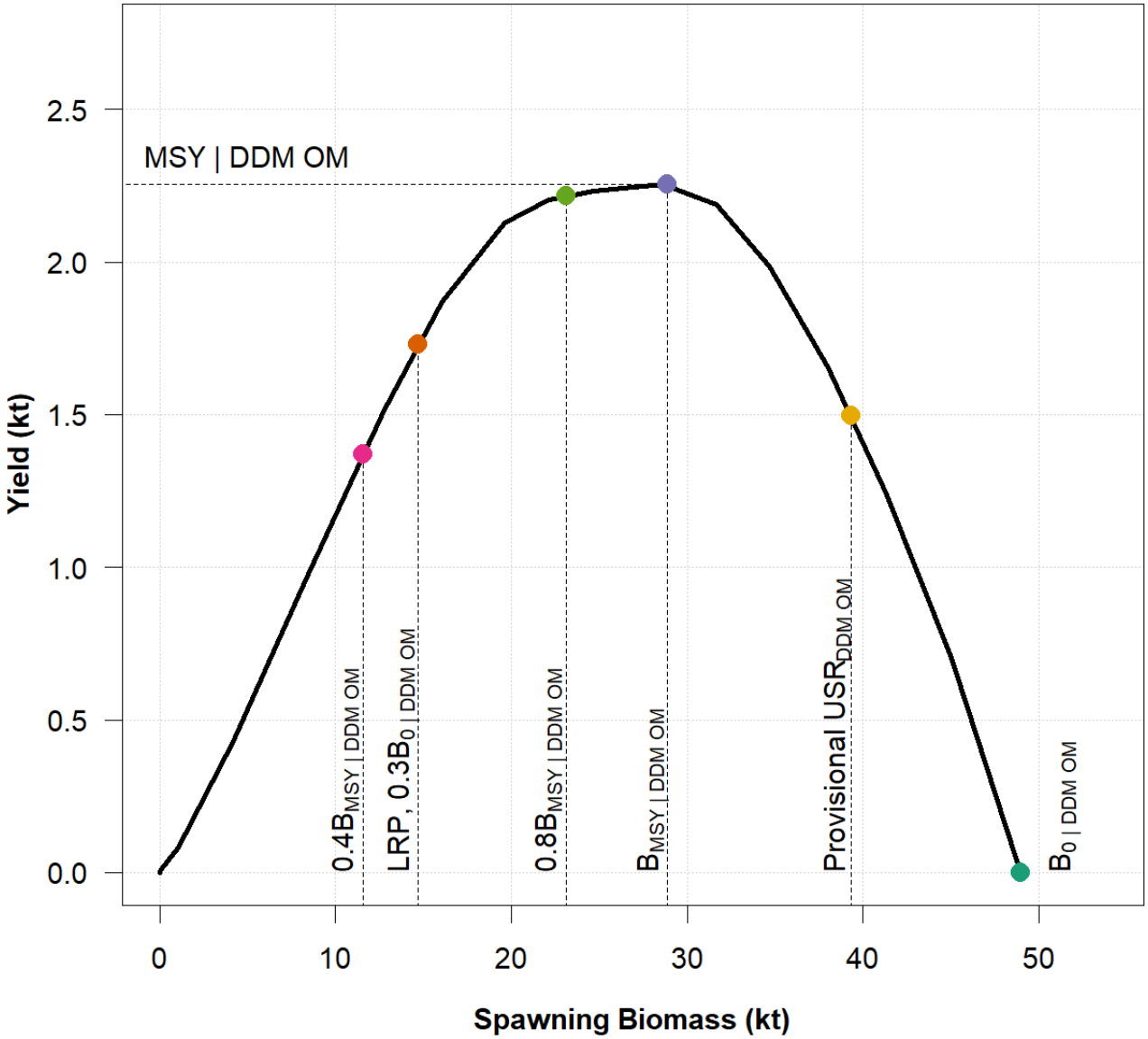


*Figure 3. Prince Rupert District Herring operating model equilibrium yield curve with respect to spawning stock biomass. The horizontal dashed line indicates the OM's estimate of maximum sustainable yield ($MSY$), while vertical line segments show biomass reference points including, from right to left, unfished biomass ($B_0$), the provisional upper stock reference ($\bar{B}_{1983:1992}$), optimal biomass producing $MSY$ on average ($B_{MSY}$), default USR from the DFO policy (80% of $B_{MSY}$), the Herring limit reference point (LRP = $0.3\ B_0$), and the default LRP from the DFO policy ($0.4B_{MSY}$).*

### Limit Reference Point (LRP)

The current LRP ($0.3\ B_0$), estimated using the SISCAH operating model, is 14.7 kt, where $B_0$ is the estimated long-term average unfished spawning biomass (Kronlund et al. 2017; Forrest et al. 2023) (Appendix A). This LRP is higher than the default LRP of $0.4\ B_{MSY}$ identified in "DFO Sustainable Fisheries Framework" policy (DFO 2009), and is a more conservative choice of limit.

### Upper Stock Reference (USR)

The current provisional USR ($\bar{B}_{1983:1992}$), estimated using the SISCAH operating model is 39.3 kt (Table 1; Figure 3). Candidate USRs were first introduced in Cleary et al. (2019) and a formal analysis of USR options was undertaken in 2022 (DFO 2023b). Following consultations, DFO Resource Management then selected and implemented $\bar{B}_{1983:1992}$ as a "provisional USR" beginning with the 2022/23 IFMP where the USR was included as a performance metric in the MP evaluations. Consultations are ongoing for selection of the PRD Herring USR, therefore we include 5 USR performance metrics in this analysis: $0.8B_{MSY}$ (newly estimated this year) and all four candidate USRs presented as $B_{MSY}$ proxies (DFO 2023b).

### Target Reference Point (TRP)

TRPs have yet to be defined for PRD Herring. A biomass target objective centered on the USR has been suggested within the Herring MSE process, however final selection of a USR for PRD Herring requires additional consultations.

### Removal Reference (RR)

The default maximum RR for commercially harvested fish stocks is $F_{MSY}$ DFO (2013). For PRD Herring, a maximum RR is not currently specified because the MSE process is used to select an MP that meets the conservation objective of avoiding the LRP with high probability, with a harvest rate at or below $U_{MSY}$.

### Ecosystem Reference Points

Ecosystem considerations are incorporated into the conservation objective for PRD Herring through:

1. A LRP of $0.3\ B_0$ based on an analysis of stock productivity (Kronlund et al. 2017). The LRP of $0.3\ B_0$ for the PRD operating model is approximately $0.5\ B_{MSY}$ (Appendix A). This is above the default LRP of $0.4\ B_{MSY}$ (DFO 2009) and incidentally is more like the conservative soft-limit of $0.5\ B_{MSY}$ implemented in New Zealand fisheries (Shelton and Sinclair 2008).
2. Including time-varying recruitment to account for changes in year-class strength and size-at-age.
3. Incorporating density dependent mortality to model predation mortality, representing the trophic level of Herring as a forage species.

Additional research is underway to identify evidence-based ecosystem indicators for BC Herring stocks for inclusion in the operating model framework (Boldt et al. 2025).

## Fishery Management Objectives

The primary fishery management objective (DFO 2020) is centered on the LRP and termed the conservation objective:

1. Maintain spawning biomass at or above the LRP with at least 75% probability over three Pacific Herring generations, or 15 years (i.e., avoid a biomass limit; $P(B_t \geq 0.3B_0) \geq 0.75$).

Three additional objectives are presented for consideration, once the LRP requirement is met:

2. Maintain spawning biomass at or above the USR with at least 50% probability over three Pacific Herring generations (i.e., achieve a target biomass; $P(B_t \geq B_{targ}) \geq 0.50$),
3. Maintain average annual variability (AAV) in catch below 25% over three Pacific Herring generations (i.e., minimize catch variability; AAV $< 0.25$), and
4. Maximize average annual catch over three Pacific Herring generations (i.e., maximize average catch).

DFO is also collaborating with coastal First Nations to develop area-specific objectives for Indigenous fisheries, and engages with the Herring industry, government, and non-government organizations to describe broader objectives related to conservation, economics, and access.

For PRD Herring, the following priorities have been stated by the Lax Kw'alaams, as communicated by the Lax Kw'alaams Fisheries Department:

1. Rebuild Herring stocks in areas that traditionally support SOK harvest.
2. Establish joint management of the fishery between the Lax Kw'alaams and DFO.
3. Identify major drivers of herring productivity (e.g., predators) and how those factors are expected to affect herring productivity in the future.

## Operating Model Stock Status

Stock status for the PRD SAR is derived from the SISCAH operating model, represented as a single operating model with uncertainty representing a range of productivity levels based on previous research (Appendix A).

The operating model stock status for 2024 is reported in Section "Assessment under MSE".

DFO Science, Pacific Region, will be updating the operating model for PRD Herring every three years, following recommendations of DFO (2023a), and as described in Table 3. In 2028 SISCAH will be fit to new PRD survey and fishery data (extending the historical time series) and MPs will be re-evaluated against fishery management objectives under the revised operating model(s). New hypotheses, objectives and performance metrics may also be added to the MSE process at this time.

In the interim years (2025, 2026, and 2027), the operating model and any values derived from it remain constant. The estimation model is used to generate interim estimates of unfished spawning biomass, the current spawning biomass, and the one-year-ahead spawning biomass projection which are all required as inputs to the MP HCR used to calculate an annual quota or total allowable catch (TAC).

## Harvest Decision/Control Rule

The Herring MSE produces sustainable harvest advice for PRD Herring using simulation tested MPs. Those simulations are used to identify the maximum target harvest rate for a MP that will meet the established conservation objective. MPs are evaluated using a 15-year projection period (three Pacific Herring generations) and simulated performance is measured against a suite of fishery metrics based on biological reference points and harvest outcomes. See Section "Projections" for a full description.

The harvest control rule (HCR) component of each simulation-test MP is a "hockey-stick" shaped function defined by lower and upper control points, and a maximum target harvest rate (Cox et al. 2013). Three control rules which differ in their control points and maximum target

harvest rates (Figure 4) are presented. These were chosen based on previous research which showed the harvest rate as the key factor governing conservation performance for Herring (Cleary et al. 2010).

Each rule is a ramp from no fishing at lower biomass levels to the maximum target harvest rate at higher biomass levels. The ramp progressively reduces target harvest rates as biomass declines in order to gradually close the fishery as biomass declines, intending to reduce the probability of declining below the LRP. Similarly, the ramp will gradually open the fishery as biomass increases, controlling fishing to be at low levels until stock biomass is higher. The ends of the HCR ramp are the lower and upper control points (LCP and UCP, respectively), which are biomass levels where the target harvest rate changes to the fixed values. At the LCP, PRD Herring HCRs have a 0% target harvest rate, and at the UCP the target harvest rate is set to the maximum level.

Sustainable harvest advice presented for PRD Herring for 2025/2026 is derived using the MP tuned to meeting the conservation objective. The HCR component of the MP has lower and upper control points at 30% and 60% of unfished spawning biomass, respectively, and a maximum target harvest rate (HR) of 8% for the selected MP (Figure 4); note that the maximum target harvest rate may be different for different MPs. HCR control points have been explored in the MSE process beginning in 2018, prior to defining provisional USRs for each SAR. The upper control point is not intended to represent the USR. The performance of MPs using the two alternative rules are presented in Appendix A for comparison.

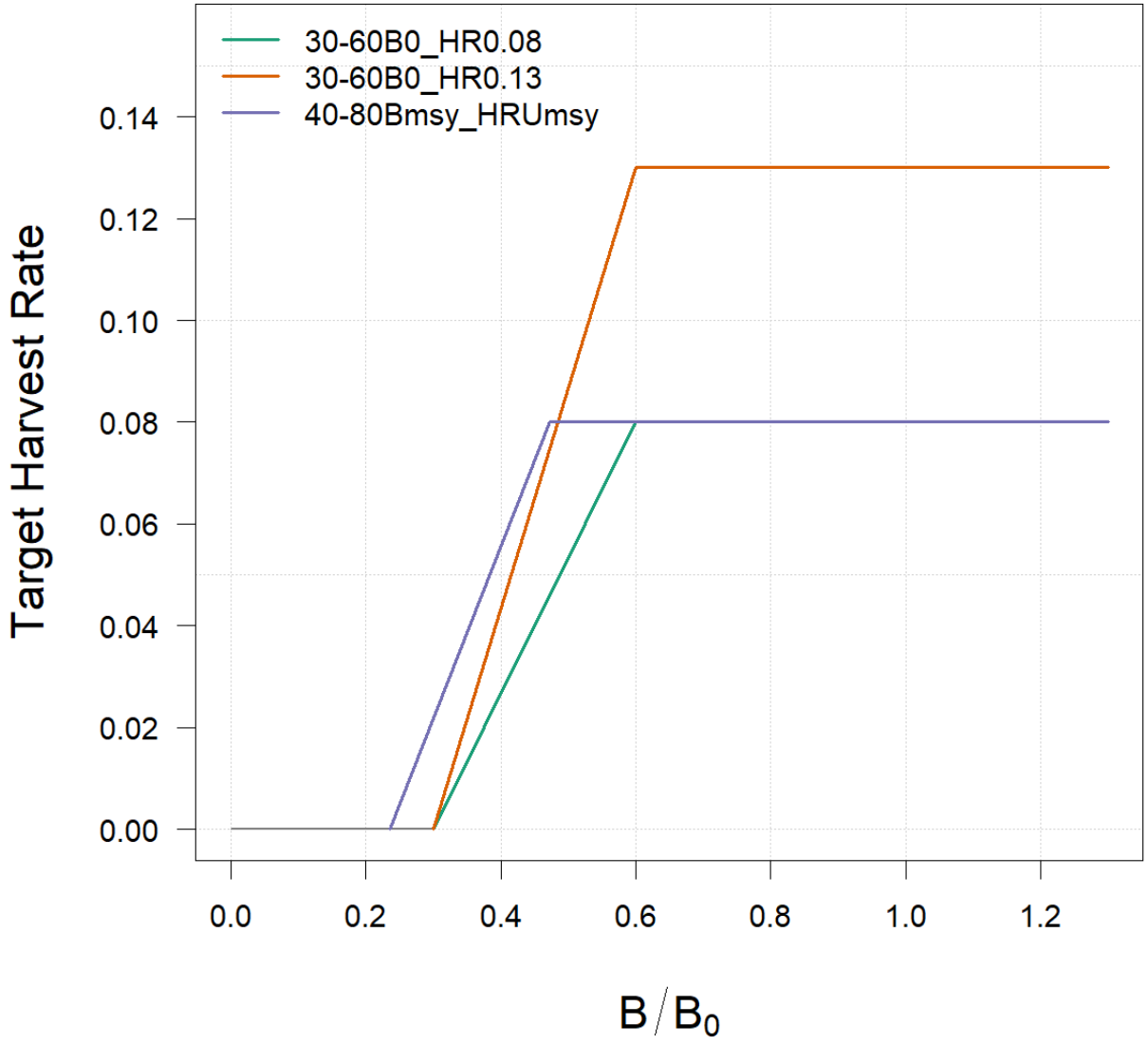


*Figure 4. Three harvest control rules for PRD management procedures (MPs). The green line represents the MP tuned to meet the conservation objective over a 40-year projection period for the operating model (with density dependent natural mortality) and maximum target harvest rate (HR) of 8%. The orange line denotes an additional hockey-stick shaped rule with the realized (20-year average) maximum target harvest rate of 13% and the purple line shows the DFO default harvest control rule with maximum target harvest rate set at $U_{MSY}$ and control points at $0.4B_{MSY}$ and $0.8B_{MSY}$.*

## Performance Evaluation for Interim Years and Exceptional Circumstances

For each interim year three indicators: the realized catch, survey index, and estimation-model-derived spawning biomass, will be examined and compared to the range of values simulated in the operating model in order to identify exceptional circumstances. Any unusual deviations from the operating model range of uncertainty would be investigated for severity and potential impacts on the performance of the MP, and consideration given to re-examining operating models and reevaluating MPs through simulation in interim years. For example, if the previous

year's realized catch far exceeds the TAC prescribed by the MP or if the survey index is far below the projected index this would be an indication of an exceptional circumstance requiring consideration. Additional criteria for exceptional circumstances will be considered on a case-by-case basis. For example, if the survey data required to implement the MP are not available in a given year this would also be a form of exceptional circumstances that would need to be examined.

### Data

There are three types of input data used for the Pacific Herring stock assessment: catch data, biological data, and a fishery independent survey index. The survey index is made up of two classes of surveys, surface and dive. Combining the surveys into a blended index properly accounts for years in which these survey types co-occur and is a feature of the new SISCAH model.

PRD data are described in full in the 2025 PRD data summary report.

## ASSESSMENT UNDER MSE

Stock status and trends for PRD Herring are represented by the operating model, using the historical time series (1951-2024) and 6 indicators (Figure 5). Operating model trends are similar to those presented for PRD Herring in previous stock assessments (DFO 2024), with near-identical data sources and choice of indicators. Step wise comparisons are found in Johnson et al. (2024).

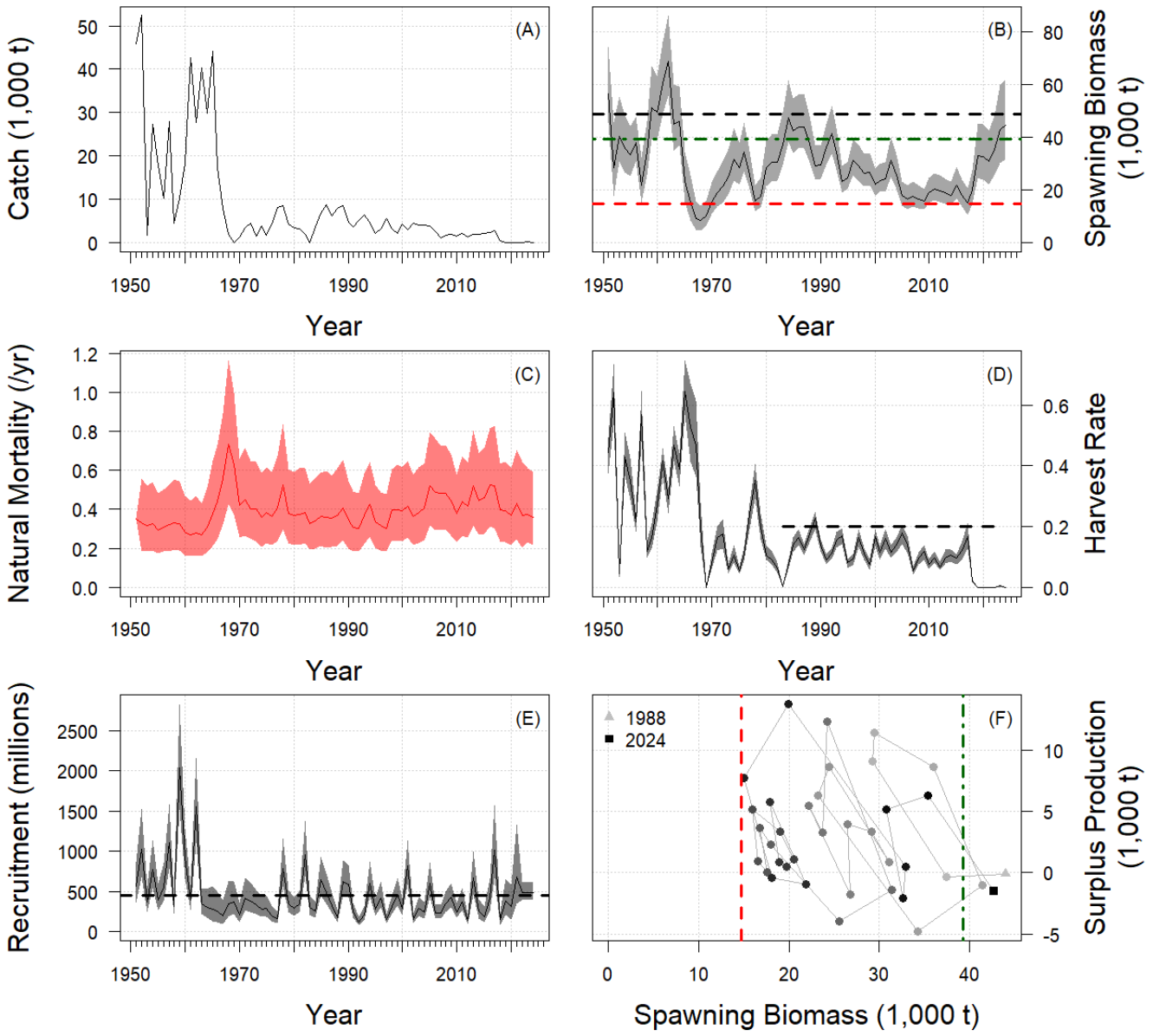


*Figure 5. Estimated stock status indicators for Pacific Herring in the Prince Rupert District (PRD) major stock assessment region (SAR) from 1951 to 2024, as estimated by the operating model. All lines indicate posterior median values, and where applicable, shading indicates 95% credibility intervals. (A) Catch (x 1,000 t). (B) Estimated spawning stock biomass (x 1,000 t) with limit reference point (LRP; dashed red line), productive period upper stock reference (USR; dashed green line), and unfished spawning biomass ($B_0$; dashed black line). (C) Estimated natural mortality rate ($M$ /yr; red line). (D) Estimated harvest rate ($U_t$, black trend line), with dashed horizontal line at 20% for 1983-2022. (E) Recruitment of age-1 fish, with historical average shown as a black dashed line. (F) Estimated surplus production (vertical axis) vs. spawning biomass (horizontal axis) for 1988 (triangle) though 2024 (square) with lighter points representing earlier years. Vertical dashed lines (left to right): LRP (red), productive period USR (green), and $B_0$ (black).*

## Historical and Recent Stock Trajectory and Trends

### Spawning Biomass and Status Relative to Reference Points

The estimated spawning biomass in 2024 ($B_{2024}$) is 45.2 kt, the unfished spawning biomass ($B_0$) is 48.95kt, and the stock status ($B_{2024}/B_0$) is 0.91 (posterior medians). Spawning biomass in 2024 is estimated to be above the LRP with a % probability in the operating model.

The operating model estimates spawning biomass to be above $B_{MSY}$ and provisional USRs (Figure 5B).

### Recruitment and Natural Mortality

Fluctuations in estimated PRD herring spawning biomass are driven by a combination of natural mortality and recruitment. There are longer-term trends in natural mortality and spawning biomass that are inversely correlated, where mortality declines as biomass increases and vice-versa (Figure 5B-C). Such behaviour is expected given the Density-Dependent $M$ formulation. The more volatile inter-annual changes are driven by the recruitment trends, which show periods where they vary around the mean such as 1978 - 1995, but also have periods where there are consistently below average recruitments, such as the 1960s, 1970s, and 2000s (Figure 5E). Persistent periods of low recruitment can have different effects, related to trends in harvest rates around the same time (Figure 5D). For example, despite low recruitment in the post-collapse period of the 1960s and 1970s, the stock was able to recover towards the end of the 1970s, driven in part by the closure of the fishery and a lower average harvest rate. Notably, the recovery falters as harvest rates increase in 1979, leading to another closure in 1981. On the other hand, the below-average recruitment in the 2000s holds the stock near the limit reference point, when harvest rates are close to the recent average of 13% in most years. Again, recovery occurs after the catches are reduced to near zero after 2017.

### Spawn Biomass Production

Estimated spawning biomass production was high in 2019 and then declined each of the next three years to 2023 (Figure 5F), while spawning biomass started to increase. This is fairly normal as a stock approaches levels above $B_{MSY}$ and surplus production is replaced with a standing stock (Figure 5C).

## Ecosystem and Climate Change Considerations

Stock assessment models for Pacific Herring incorporate ecosystem and climate change indirectly via estimates of time-varying natural mortality ($M$) and recruitment, which are the foundations of historical stock productivity. This implicit approach allows productivity estimates to reflect a changing climate and/or ecosystem without needing to describe the exact ways in which those changes affet recruitment and mortality, as many of those pathways are not directly observable.

Over the years, scientists and First Nations expressed the need to examine the role of ecosystem changes in driving variation and trends in these processes, especially considering the importance of future productivity in evaluating harvest management procedures (i.e., as part of the MSE process). This also aligns with DFOs commitment to advance Ecosystem Approaches to Fisheries Management.

First Nations-led research conducted since 2020 in WCVI examining ecosystem impacts on Pacific Herring productivity found relatively large changes in predator populations since the 1990s. The direction and magnitude of potential consumption of Pacific Herring by these predators generally align with natural mortality trends estimated in stock assessment models.

Although the role of predation and ecosystem change varies among Pacific Herring stock assessment regions, there are shared processes and commonalities among regions in how ecosystems and climate affect productivity. The following section summarizes insights from these studies and their implications for future management of PRD Pacific Herring fisheries, and explains how this research supports/further corroborates the use of a depensatory function to model natural mortality for PRD Herring.

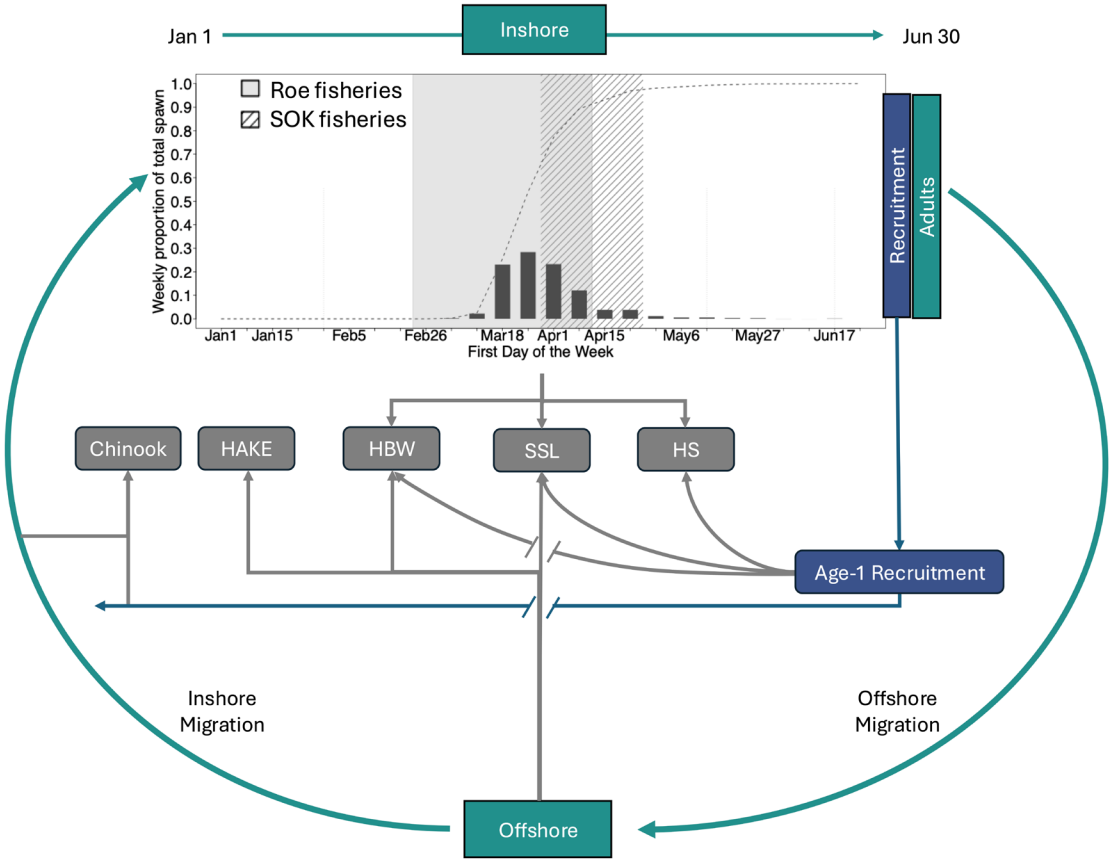


*Figure 6. Conceptual model of the annual life cycle of Pacific Herring, including predation mortality in inshore and offshore regions, spawn timing (January–June), recruitment, and fisheries. Arrows to predator boxes (grey) indicate losses due to predation mortality from Pacific Hake (HAKE), Humpback Whales (HBW), Steller Sea Lions (SSL), Harbour Seals (HS), and Chinook Salmon (Chinook). Spawning occurs at the end of each year on June 30th. Arrows from recruitment boxes (blue) to indicate recruitment of juveniles hatched from eggs deposited during the previous year's spawning events. Recruits do not migrate offshore during the feeding season but are subject to inshore predation before mixing with age-2+ herring returning from the offshore (green arrow on far left) during the spawning season. The top panel shows average weekly (vertical bars) and cumulative (dashed line) proportion of spawn for inshore spawning grounds, along with timing for roe and SOK fisheries.*

### Changing predation regimes

Ecosystem effects are included in Herring population dynamics models by linking historical (and future) predator consumption estimates to observed natural mortality (Doherty et al. 2024). Predators in PRD include Humpback Whales (*Megaptera novaeangliae*), Harbour Seals (*Phoca vitulina*), Steller Sea Lions (*Eumetopias jubatus*), Pacific Hake (*Merluccius productus*), and Chinook Salmon (*Onchorynchus tshawytscha*) that all prey on multiple life stages of Herring during most of their annual life cycle (Figure 6).

Consumption of Pacific Herring by each predator is estimated via bio-energetics modeling (Chasco et al. 2017; Doherty et al. 2024), accounting for predator body size, estimated predator abundance, size selectivity, foraging days, diet composition, and the energy content of Pacific Herring (Doherty et al. 2024). Estimates of stock biomass and historical total natural mortality derived from these ecosystem based models are consistent with corresponding estimates from this stock assessment (Figure 7).

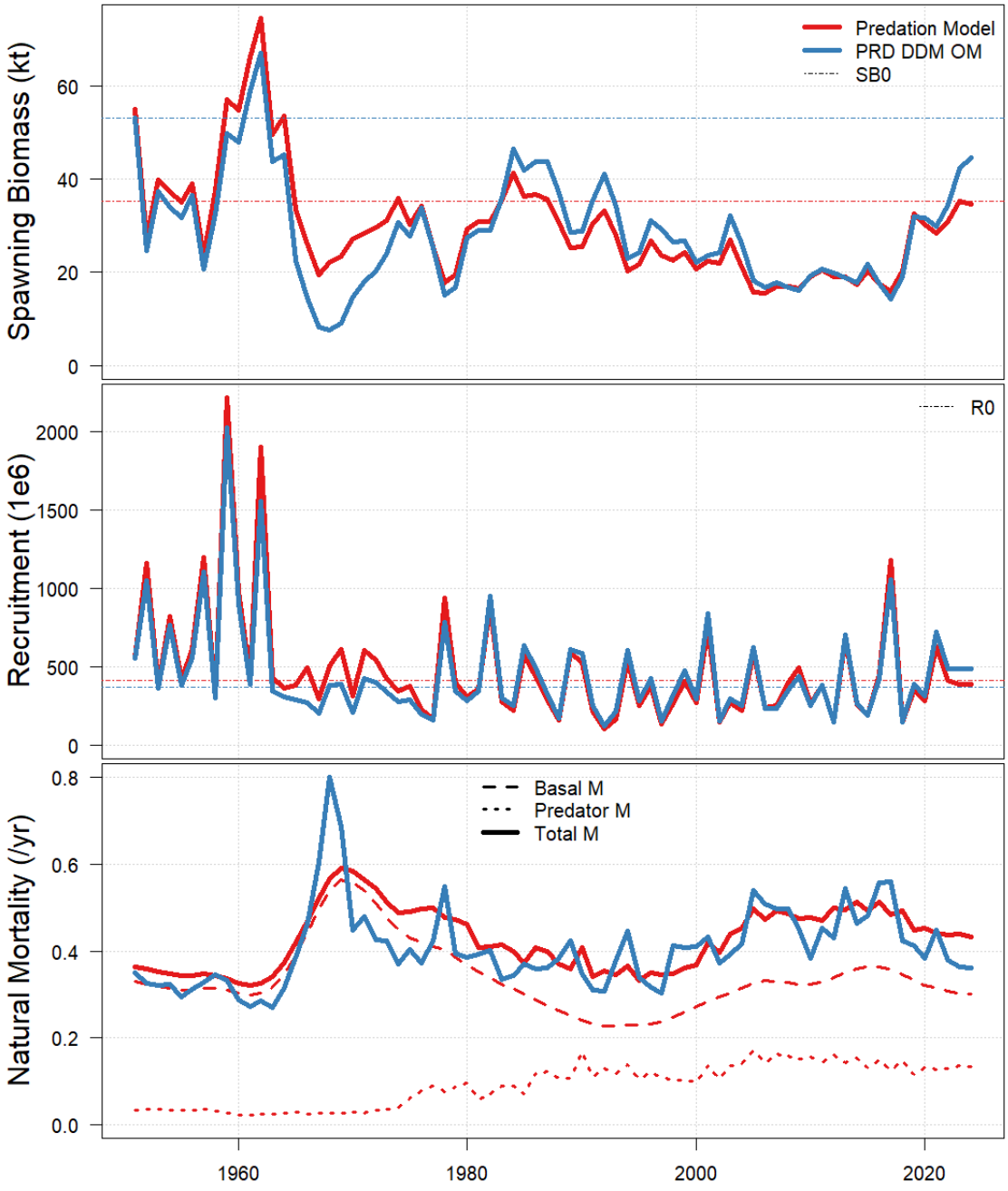


*Figure 7. Comparison of Prince Rupert District (PRD) maximum likelihood estimates of spawning stock biomass (top), age-1 recruitment (middle), and age-2 natural mortality rate (bottom) from the Predation Model (red) and PRD SISCAH Density Dependent Mortality Operating Model (DDM OM, blue).*

While estimates of historical biomass, mortality, and recruitment derived from predation models are similar to corresponding estimates from the SISCAH framework used in this assessment, expectations for future biomass and productivity differ because of expected future changes in predation regimes. For example, over the last 20 years consumption of herring by predators has increased by around 25%, driven primarily by growth in Humpback Whales and Steller Sea

Lions within the PRD SAR. At the same time, consumption by Hake and Chinook Salmon has varied depending on the stock and/or run size, with Hake consuming more herring between the mid 1970s and mid 1990s when Hake stocks were larger, and Chinook Salmon consuming more herring over the 1980s - 2010s (Figure 8) when Chinook runs were larger. Estimates of unfished biomass levels based on these more recent predation mortality rates are about 10% lower than estimates from time-varying $M$ models, suggesting that future productivity may be negatively impacted by predator consumption.[3]

Note that a 2024 Lax Kw'alaams Pacific Herring Traditional Use study (unpublished), indicated that birds were a potential significant source of mortality for PRD Herring. Preliminary evaluations of the top 7 bird predator species (gulls, eagles, surf scoters, merganser) showed a small impact, relative to marine mammals on spawning biomass and expectations for future Herring productivity.

The key difference between the time-varying $M$ approach and explicitly modeling $M$ via predation lies in their implications for future trends in natural mortality. Projecting $M$ via the implicit approach requires strong assumptions about the trends in $M$, while the predation approach involves modeling future trends in predator populations for which we have reasonable data and models. In general, some of these key predators may increase further in the future as the continue to recover from historical over-exploitation.

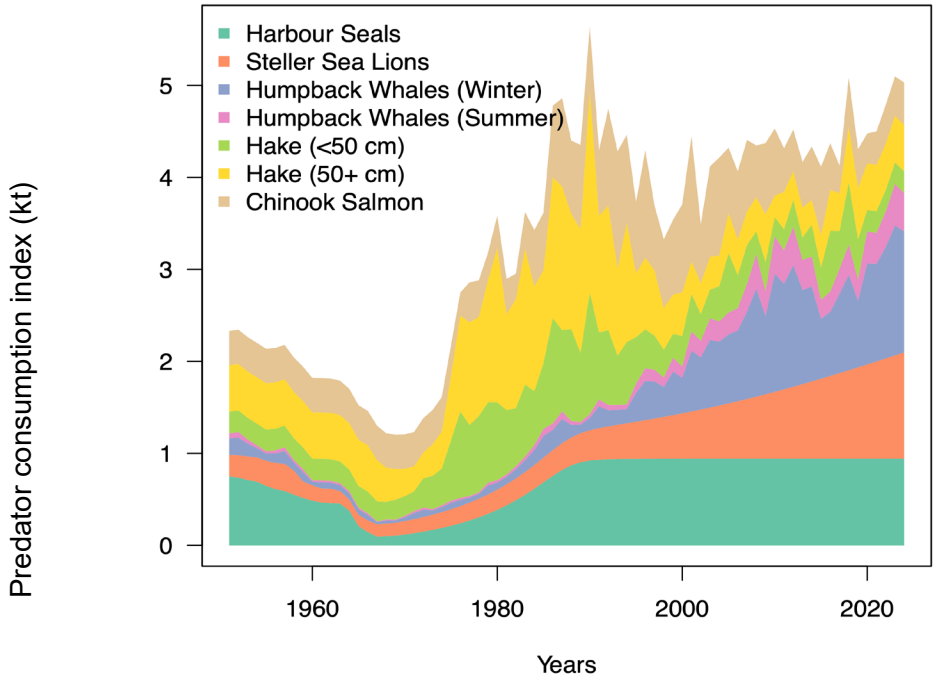


*Figure 8. Estimated predator consumption of PRD Herring from 1951 – 2024. Predators consume herring of all ages to varying degrees, depending on their size preference. Consumption is estimated in thousands of tonnes for each species, with Hake and Humpback Whales broken into feeding groups, which for Hake differ in size (and therefore size preference), and for Humpback Whale differ in size preference and spatio-temporal overlap with PRD Herring.*

[3] Johnson, S.D.N., Doherty, B., Wang, S., Benson, A. J. B., Cox, S. P., and Cleary, J.S. In prep. Marine mammal and fish predation effects on Pacific Herring natural mortality in the Strait of Georgia and Prince Rupert District.

### Spatial dynamics and spawn distribution

The historical distribution of PRD Herring spawn abundance shows relatively consistent core areas within StatArea 03, StatArea 04 (Big Bay) and StatArea 05 (Kitkatla; Figures 1, 9). The core area in Big Bay is Section 042, which has consistently had a large amount of spawn observed in most years since 1951. The core area for Kitkatla is Section 052, which has several larger than average spawn observations but also several low spawn years. Section 033 is the core spawning area in StatArea 03, which has less total spawn on average relative to the core areas in Big Bay and Kitkala, but within a much smaller area. More investigation is needed to understand if these core areas have some degree of connectivity, and how to include any spatial trends in spawn distribution in future models.

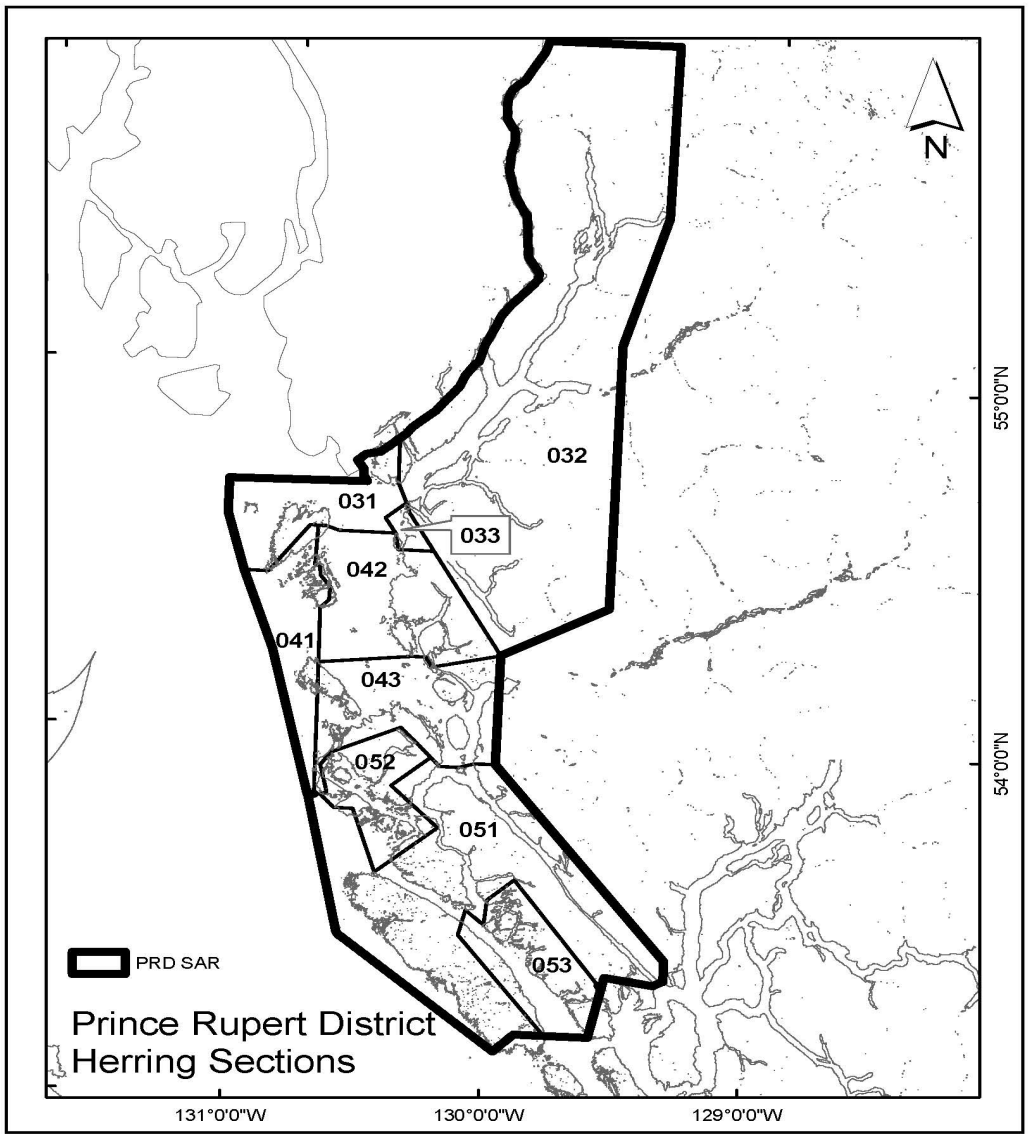


*Figure 9. Map of Prince Rupert District Herring Sections.*

### Implications for science advice

Changing ecosystems and climate are implicitly represented in historical science advice for Pacific Herring; however, their impact on future Herring productivity is of most importance for management. Changes in natural mortality and recruitment are neither random nor independent of Pacific Herring or predator abundance (Doherty et al. 2024). This finding should be integrated into the MSE process.

Historical and future changes to Pacific Herring ecosystems imply a need to modify expectations for future biomass and fisheries, and to account for this in the choice of management objectives. For example, biomass targets (or upper stock reference points) recently proposed for BC Pacific Herring were based on a productive period in the recent history (DFO 2023b). In the PRD region, the proposed objective is to maintain spawning stock biomass at or above a target biomass level equivalent to the average biomass from 1983-1992, with at least 50% probability over three herring generations. Such target objectives based on periods with different ecosystem conditions may not be achievable under current or future predator regimes. The MP presented herein for PRD Herring approaches this proposed objective (p = 0.47; Table 2). Future MSE analyses should include scenarios with forecasted future predation that may inhibit the stock's ability to return to historical periods of peak biomass, which occurred during periods with fewer marine mammals.

## History of Management

A maximum target harvest rate of 20% was defined for PRD Herring in 1983. However, the 20% maximum was rarely implemented in the IFMP, and the realized harvest rate has averaged around 13% in the 20 most recent years with annual fishing (Figure 5, panel D).

## Projections

### Interim Year Update for 2025

For 2025, the estimation model estimates spawning biomass, $\hat{B}_{2025}$, = 42.13 kt (maximum likelihood estimate), with stock status ($\hat{B}_{2025}/\hat{B}_0$) = 0.88. Time series of maximum likelihood estimates from the estimation model are presented in Figure 18.

### Application of MP for 2026

We simulation tested three MPs, each with hockey-stick shaped harvest control rules (Figure 4). The MP 30-60B0_HR0.08 with lower and upper control points at 30% and 60% of unfished spawning biomass $B_0$, respectively, and a maximum target HR of 8% meets the conservation objective and is compliant with both the "DFO Sustainable Fisheries Framework" policy and the "Precautionary Approach" (DFO (2009)), as per the Terms of Reference.

In the absence of fishing, spawning biomass in 2026 is estimated to be $\hat{B}_{2026} = 42.09$ kt (maximum likelihood estimate), with stock status ($\hat{B}_{2026}/\hat{B}_0$) = 0.88. Given that the spawning biomass is above the harvest control rule's upper control point of $0.6B_0$, the maximum target harvest rate of 8% is recommended by the MP, resulting in a total allowable catch of 3.37 kt.

This is shown graphically in Figure 10.

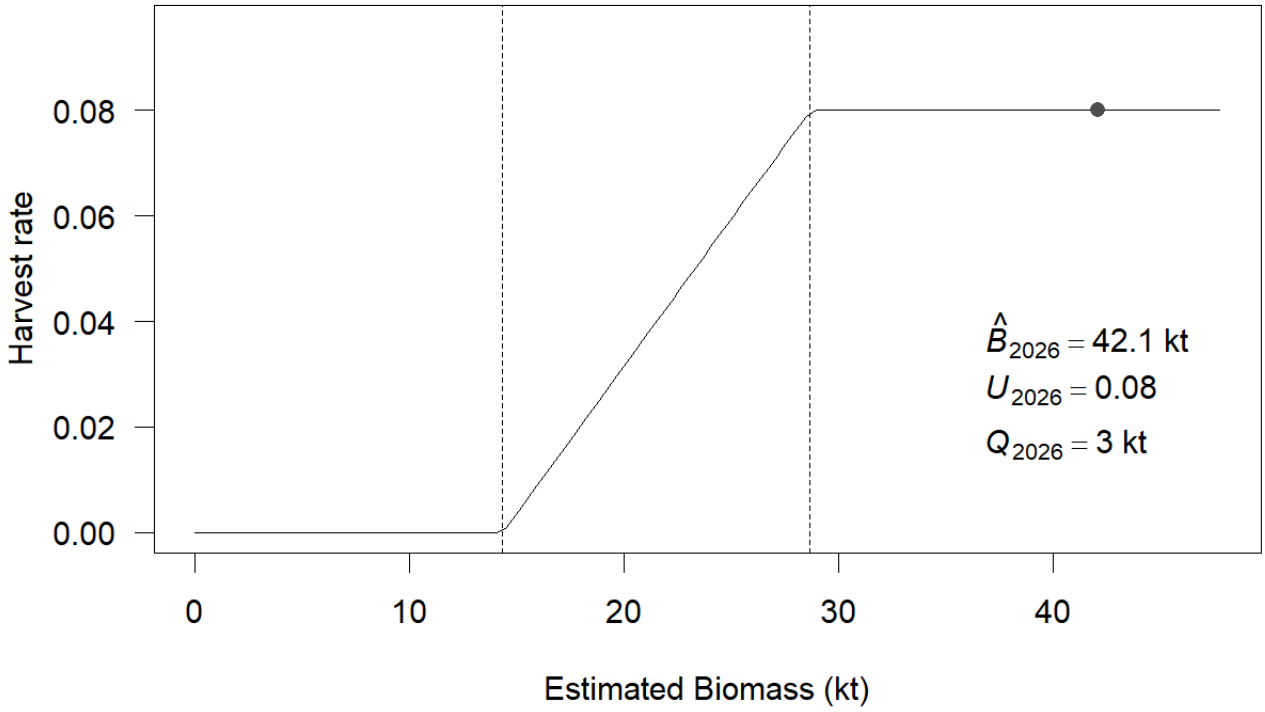


*Figure 10. Prince Rupert District (PRD) Pacific Herring management procedure harvest control rule (HCR; line), showing forecast spawning biomass (kt) in 2026 ($\hat{B}_{2026}$, point), and associated harvest rate $U_{2026}$ and total allowable catch (TAC (kt); $Q_{2026}$) for the 2025/2026 fishing season.*

## Performance Evaluation for Interim Years and Exceptional Circumstances

There is no indication of operating model misspecification (Figure 11), which is evaluated visually by comparing catch and spawn index values within the central 95% of the simulations.

All routine forms of Herring fishery monitoring data were collected in 2025 and show the population is behaving within operating model expectations. The most recent spawn index falls within the range of uncertainty that was simulated in the MSE projections starting in 2024 (Figure 11). While catch is outside of the range of uncertainty in 2025 in the MSE projections (i.e., from the MP tuned to meet the conservation objective), this is because of very low quotas (i.e., zero catch in some years) since the 2017/18 season.

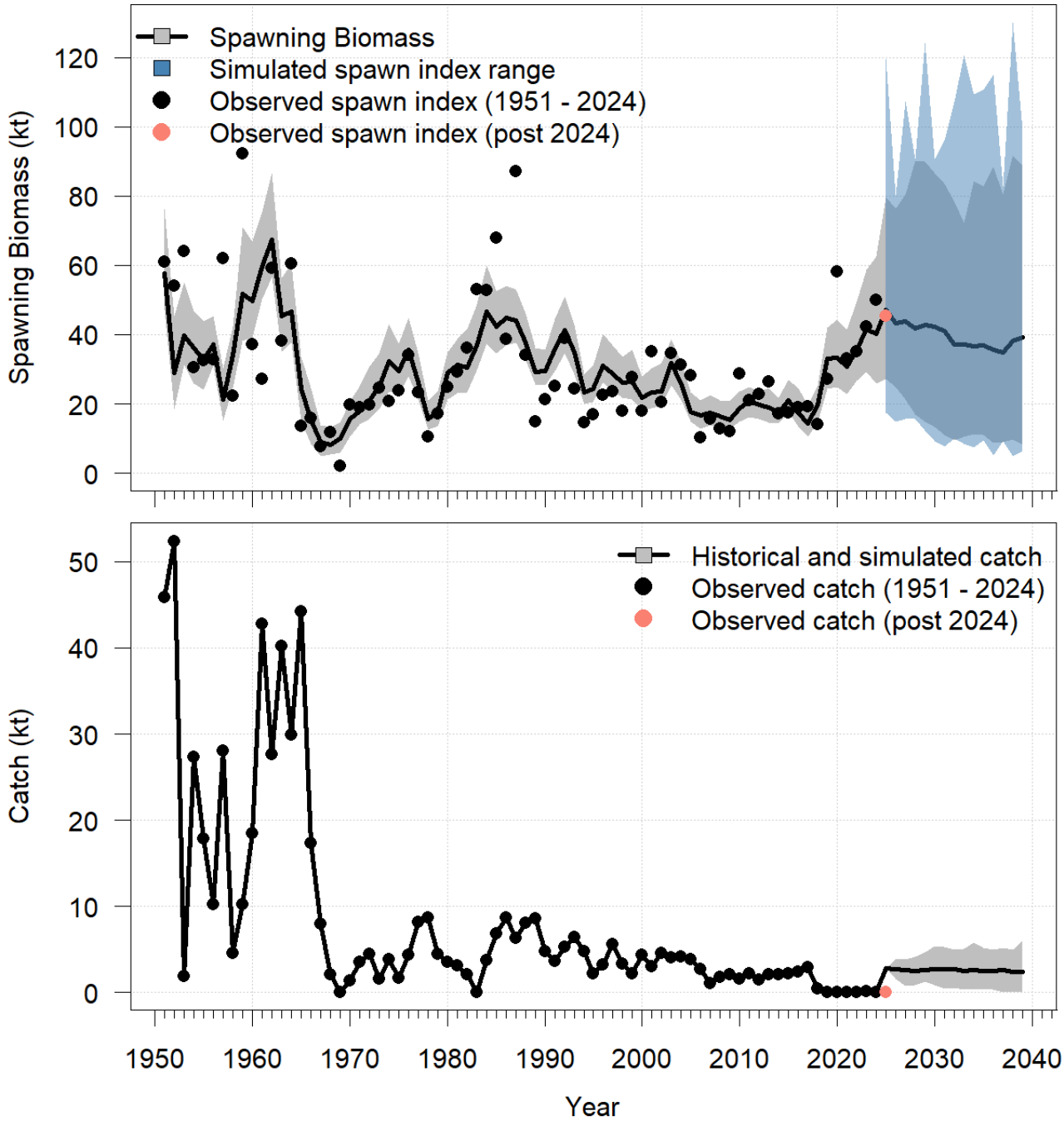


*Figure 11. Evaluation of exceptional circumstances and operating model misspecification: graphical comparison of simulation envelopes from the operating model (1951-2024) and catch and spawn index data from interim year (2025). Panels show the central 95% of projected simulated data, including spawn index data (top) and catch (bottom) from the 2024 PRD operating model. Forward projections in time (15-years) represent the 30-60B0_HR0.08 MP. Realised data are overlaid as points for the history (black) and projection years (red).*

# BYCATCH

Some fisheries and aquaculture activities in BC cause incidental mortality to Pacific Herring. Similar to FSC and recreational catch, data on incidental mortality is not directly included in the assessment process however it is indirectly accounted for in annual estimates of natural mortality and is considered minor relative to commercial harvest.

# PROCEDURE FOR INTERIM YEAR UPDATES

Once a harvest control rule is chosen through the MSE process, that harvest control rule defines the maximum possible removal rate that meets management objective(s) until the next MSE cycle. The recommended MP for the PRD SAR is model-based with a harvest control rule that depends on annual estimates of projected spawning biomass ($\hat{B}_{Y+1}$) and unfished spawning biomass ($\hat{B}_0$). These estimates are obtained using an estimation method (EM) and for PRD Herring, the EM is the spatially integrated statistical catch at age Herring (SISCAH) model with density independent $M$ (DIM SISCAH). This EM was selected because its performance was similar to the DDM formulation and it is less computationally intensive for interim updates.

Exceptional circumstances criteria will be examine each interim year and if no exceptional circumstances are identified then the 2023 status relative to reference points and objectives would carry forward indicating that the MP was working as intended.

# SOURCES OF UNCERTAINTY

Sources of uncertainty include those surrounding both the data and the model estimations. That being said, Herring operating models are built on a data rich environment and uncertainty is well-accounted for in the model. See also Appendix A.

## Research Recommendations

Future research could look into developing better priors for the depensatory density dependent $M$ (DDM) model. Currently, there is a large amount of uncertainty in the depensation rate $m_1$ parameter, and the model breaks down when exploring the range of the $M_b$ (asymptotic lower limit on $M$) parameter. There are several reasons why there is high uncertainty in both of these parameters, including the fact that the effects of the parameters are not directly observable, and that the data used to estimate the parameter is not very informative. Identifiability is also an issue, as several combinations of $m_1$ and $M_b$ can produce similar results, especially with annual mortality process errors adding flexibility to the historical period for model fitting.

# LIST OF MEETING PARTICIPANTS

| Name | Affiliation |
|---|---|
| Jaclyn Cleary | DFO Science |
| Matthew Grinnell | DFO Science |
| Samuel Johnson | Landmark Fisheries Research |
| Roger Kanno | DFO Science |
| Marisa Keefe | DFO Resource Management |

| Name | Affiliation |
|---|---|
| Bryan Rusch | DFO Resource Management |
| Sarah Hawkshaw | DFO Science |
| Chris Rooper | DFO Science |
| Jessica Finney | DFO Science |
| Miriam O | DFO Science |

## SOURCES OF INFORMATION

Beacham, T.D., Schweigert, J.F., MacConnachie, C., Le, K.D., and Flostrand, L. 2008. Use of microsatellites to determine population structure and migration of pacific herring in british columbia and adjacent regions. Transactions of the American Fisheries Society 137: 1795–1811.

Boldt, J.L., Rooper, C.N., Cleary, J.S., Fu, C., Edwards, A.M., Hourston, R.A.S., Pena, R.A.S., and Perry, R.I. 2025. Incorporating ecosystem information into science advice for fisheries management—a case study for Haida Gwaii Pacific Herring. Can. J. Fish. Aquat. Sci. 2025/82: 1–26.

Chasco, B.E., Kaplan, I.C., Thomas, A.C., Acevedo-Gutiérrez, A., Noren, D.P., Ford, M.J., Hanson, M.B., Scordino, J.J., Jeffries, S.J., Marshall, K.N., and others. 2017. Competing tradeoffs between increasing marine mammal predation and fisheries harvest of chinook salmon. Scientific reports 7(1): 15439. Nature Publishing Group.

Cleary, J.S., Cox, S.P., and Schweigert, J.F. 2010. Performance evaluation of harvest control rules for Pacific Herring management in British Columbia, Canada. ICES Journal of Marine Science 67: 2005–2011.

Cleary, J.S., Hawkshaw, S., Grinnell, M.H., and Grandin, C. 2019. Status of B.C. Pacific Herring (*Clupea pallasii*) in 2017 and forecasts for 2018. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/028. v + 285p.

Cox, S.P., Kronlund, A.R., and Benson, A.J. 2013. The roles of biological reference points and operational control points in management procedures for the sablefish (*anoplopoma fimbria*) fishery in british columbia, canada. Environmental Conservation 40(4): 318–328.

DFO. 2009. A fishery decision-making framework incorporating the precautionary approach.

DFO. 2013. Guidance for the development of rebuilding plans under the precautionary approach framework: Growing stocks out of the critical zone. Sustainable fisheries framework (SFF): A fishery decision-making framework incorporating the precautionary approach.

DFO. 2020. Evaluation of management procedures for Pacific Herring (*Clupea pallasii*) in Haida Gwaii, Prince Rupert District and the Central Coast management areas of British Columbia. DFO Can. Sci. Advis. Sec. Sci. Resp. 2020/003.

DFO. 2023a. Application of a new modelling framework for the assessment of Pacific Herring (*Clupea pallasii*) major stocks and implementation in the management strategy evaluation process. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2023/040.

DFO. 2023b. Management strategy evaluation update and evaluation of upper stock reference point options for Pacific Herring (*Clupea pallasii*) in British Columbia, Canada. DFO Can. Sci. Advis. Sec. Sci. Resp. 2023/002.

DFO. 2024. Stock status update with application of management procedures for Pacific Herring (*Clupea pallasii*) in British Columbia: Status in 2023 and forecast for 2024. DFO Can. Sci. Advis. Sec. Sci. Resp. 2024/001.

Doherty, B., Johnson, S.D.N., Benson, A.J., Cox, S.P., Cleary, J.S., and Lane, J. 2024. Predation by marine mammals explains recent trends in natural mortality of Pacific Herring (*clupea pallasii*) and changes expectations for future biomass. ICES Journal of Marine Science.

Forrest, R.E., Kronlund, A.R., Cleary, J.S., and Grinnell, M.H. 2023. An evidence-based approach for selecting a limit reference point for pacific herring Clupea pallasii) stocks (*Clupea pallasii*) in British Columbia, canada. Can. J. Fish. Aquat. Sci. 80: 9–26.

Johnson, S.D.N., Cox, S.P., Cleary, J.S., Benson, A.J., Power, S.J.H., and Rossi, S.P. In press. Application of a New Modelling Framework for the Assessment of Pacific Herring (*Clupea pallasii*) Major Stocks and Implementation in the Management Strategy Evaluation Process. DFO Can. Sci. Advis. Sec. Res. Doc. 2024/066.

Kronlund, A.R., Forrest, R.E., Cleary, J.S., and Grinnell, M.H. 2017. The selection and role of limit reference points for Pacific Herring (*Clupea pallasii*) in British Columbia, Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/009. ix + 125p.

Martell, S.J., Schweigert, J.F., Haist, V., and Cleary, J.S. 2011. Moving towards the sustainable fisheries framework for Pacific Herring: Data, models, and alternative assumptions; stock assessment and management advice for the British Columbia Pacific Herring stocks: 2011 assessment and 2012 forecasts. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/136. xii + 151p.

Petrou, E.L., Fuentes-Pardo, A.P., Rogers, L.A., Orobko, M., Tarpey, C., Jiménez-Hidalgo, I., Moss, M.L., Yang, D., Pitcher, T.J., Sandell, T., Lowry, D., Ruzzante, D.E., and Hauserr, L. 2021. Functional genetic diversity in an exploited marine species and its relevance to fisheries management. Pro. R. Soc. B. 288: 20202398.

Shelton, P.A., and Sinclair, A.F. 2008. It's time to sharpen our definition of sustainable fisheries management. Can. J. Fish. Aquat. Sci. 65: 2305–2314.

# APPENDIX A

This appendix summarises closed loop simulations evaluating candidate management procedures for the Prince Rupert District (PRD) Herring fishery. PRD Herring is the second BC Herring region to use the new Spatially Integrated Statistical Catch-at-Age Herring Operating Model (SISCAH-OM) Framework. There are several features that differ between SISCAH-OM and the previous Herring assessment and operating models, the main po is that SISCAH-OM is the ability to model density dependent mortality (DDM), where natural mortality is higher when biomass is lower (Johnson et al. 2024).

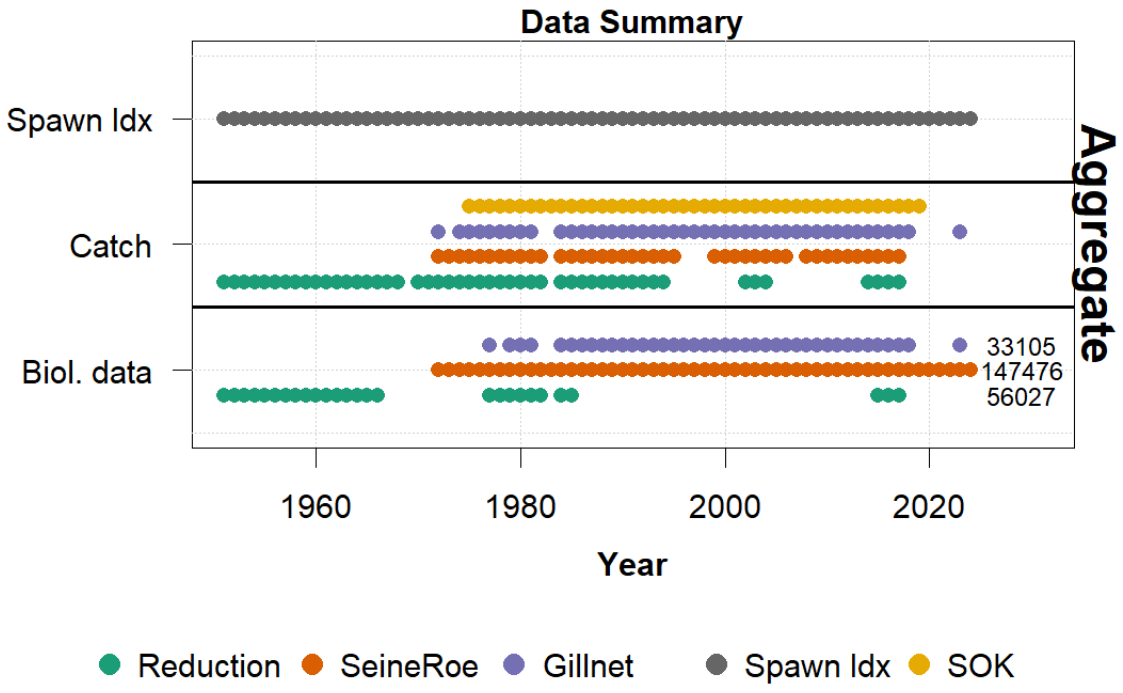


*Figure 12. Summary of data used in the Prince Rupert District (PRD) Herring operating model (1951-2024). Closed circles are plotted by model season and indicate that fishery monitoring data for the labeled source exists in the associated season. Sample sizes for biological data are shown on the right-hand end.*

## Simulation approach

### Operating model

The PRD Herring operating model incorporates uncertainty in stock responses to fishing when evaluating management procedures. Unlike other areas that use an approach to integrate a range of plausible assumptions regarding stock productivity at high and low stock sizes, the PRD region uses a single operating model to represent a similar level of uncertainty.

Uncertainty in productivity at low stock sizes is provided by the stock-recruitment relationship's steepness parameter $h$, which is the ratio of average recruitment at 20% of unfished biomass to the average unfished recruitment $R_0$. The amount of information contained in fishery data for estimating $h$ is limited, and the PRD OM estimates a posterior distribution for $h$ based on an

informative prior. The posterior distribution includes steepness values ranging from 0.2 - 0.95 (Figure 13), capturing all plausible values for steepness and their effect on productivity at low stock sizes in a single operating model.

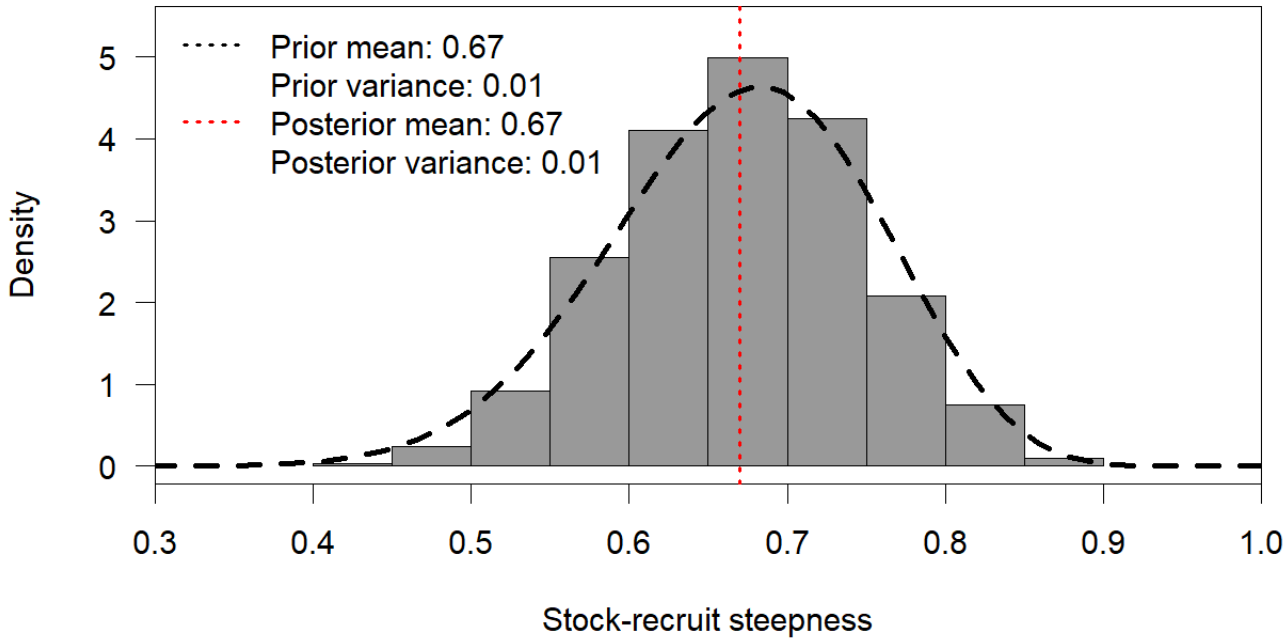


*Figure 13. PRD SISCAH model marginal Bayes posterior (rectangles) and prior (dashed curve) distributions for stock-recruitment steepness. Dashed vertical lines show the prior mean (black) and posterior mean (red), with the prior and posterior variance given in the legend.*

Productivity at high stock sizes is influenced by $M_b$, the lower limit of average mortality at high stock sizes. The PRD OM uses a fixed, maximum likelihood estimate of $M_b = 0.35$, which was found via a likelihood profile approach. We defined a grid of $M_b$ values spaced evenly at 0.05 intervals from 0.3 to 0.6, and the likelihood profile is obtained by fitting the SISCAH model to PRD data for each $M_b$ value in the grid and plotting the negative log likelihood values at each grid point. The maximum likelihood estimate is the minimum value (i.e., the value most in agreement with the data), which occurs when $M_b = 0.35$ (Figure 14).

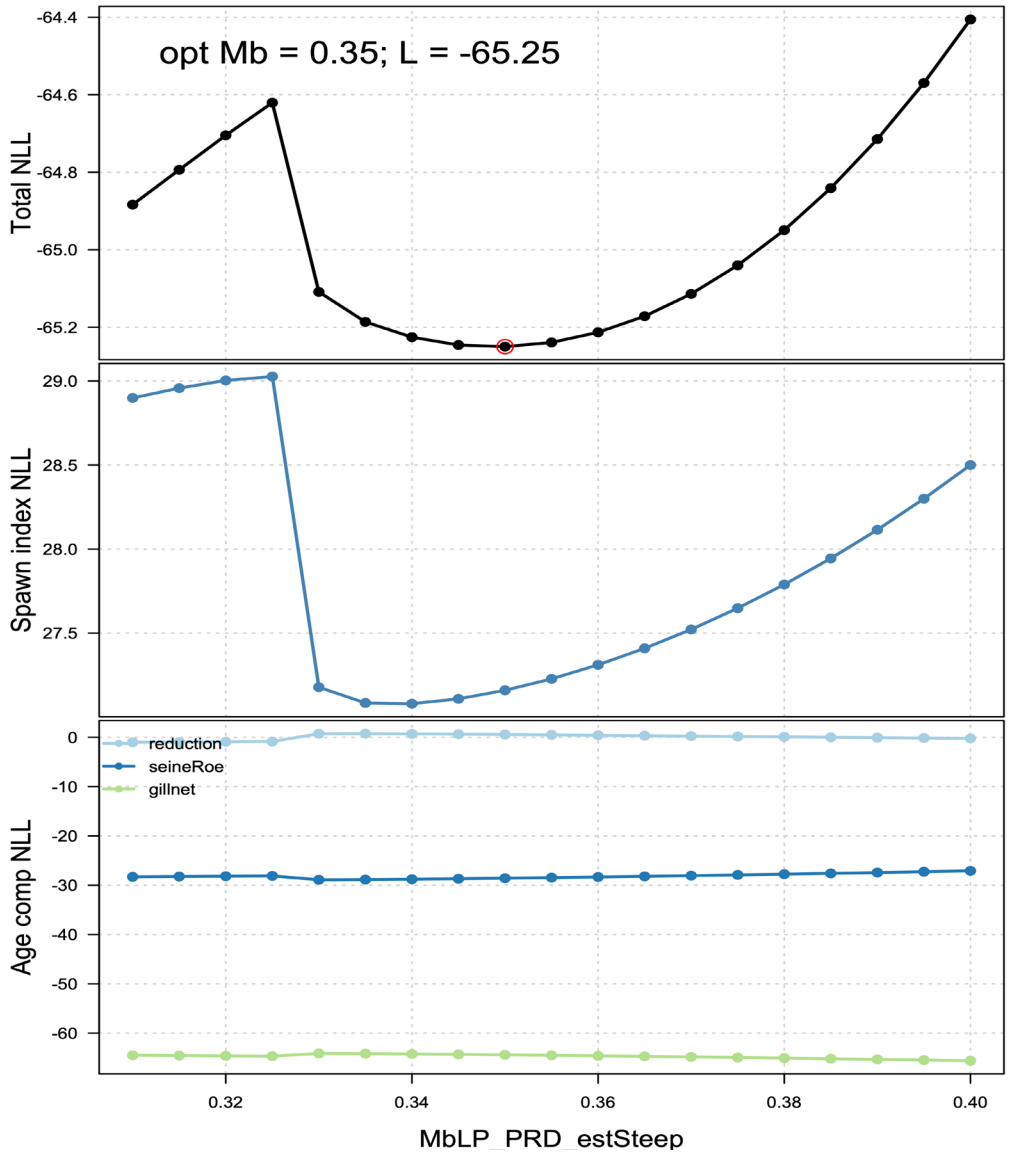


*Figure 14. Data likelihood function profiles over a range of natural mortality asymptotic lower limit ($M_b$) parameter values, with the maximum likelihood estimate indicated by the red point.*

PRD uses a single $M_b$ value, instead of a grid of plausible values, because the lower limits of the grid show some erratic behaviour. While this does limit the lower range of average natural mortality rates the stock can reach at high stock sizes, there is still a large amount of uncertainty in the range of unfished natural mortality ($M_0$) and the density dependent mortality rate ($m_1$) quantities (Table 1). In particular, the posterior distribution of $m_1$ estimates provide a wide range of natural mortality rates at intermediate stock sizes (Figure 15).

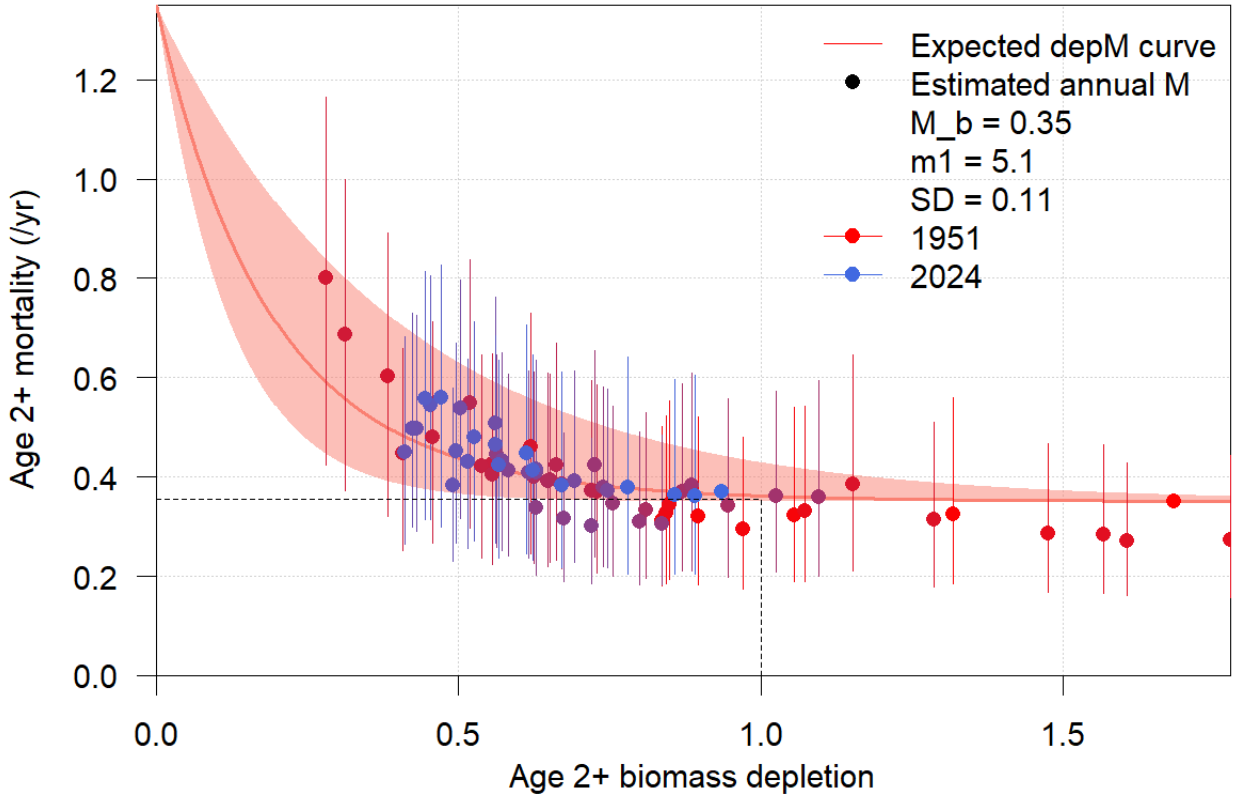


*Figure 15. PRD SISCAH model posterior estimate of the density dependent relationship between age-2+ biomass and age-2+ natural mortality. The median relationship is shown by the red curve, with the posterior 95% credibility range shown by the shaded region. Individual annual $M_t$ estimates with process error are shown as points (posterior median) and vertical line segments (central 95% credibility interval), with the year indicated by point/segement colour. The parameters shown are: $M_b$ = asymptotic lower limit of density dependent mortality; $m_1$ = depensation rate; and $SD$ = the effective standard deviation of the annual natural mortality process deviations.*

We report leading OM parameters, current biomass, current stock status relative to the limit reference point, and $MSY$ based reference points (Table 1).

*Table 1. PRD SISCAH-OM life-history and management parameter values from the operating model. Posterior mean values are shown for stock-recruit steepness (h), asymptotic lower limit on depensatory M ($M_b$, /yr), unfished biomass ($B_0$, kt), unfished recruitment ($R_0$, 1e6), unfished mortality ($M_0$, /yr), mortality depensation rate ($m_1$), time-averaged mortality ($\bar{M}$, /yr), surface survey design catchability ($q_s$), spawning biomass in 2024 ($B_{2024}/B_0$), stock status ($P(B_{2024} > 0.3\ B_0)$), spawning biomass at maximum sustainable yield ($B_{MSY}$, kt), harvest rate targeting maximum sustainable yield ($U_{MSY}$), maximum sustainable yield (MSY), upper stock reference (USR, kt), harvest rate targeting the upper stock reference ($U_{USR}$), equilibrium yield at the upper stock reference ($Y_{USR}$), harvest rate associated with negative production and higher risk of extirpation ($U_{Crash}$). Uncertainty is shown as the 95% credible interval where estimates could be drawn from posterior samples (indicated by two parenthetical values), or half the interquartile range where estimates were drawn from 200-year simulations (one parenthetical value).*

| **Parameter** | **DDM_discF_SOK** |
|---|---|
| *h* | 0.67 (0.52, 0.82) |

| **Parameter** | **DDM_discF_SOK** |
|---|---|
| $M_b$ | 0.35 |
| $M_0$ | 0.36 (0.35, 0.43) |
| $m_1$ | 5.3 (2.54, 8.29) |
| $\bar{M}$ | 0.4 (0.37, 0.43) |
| $q_s$ | 0.45 (0.36, 0.55) |
| $q_d$ | 1 (1, 1) |
| $q_{blend}$ | 0.72 (0.67, 0.77) |
| $R_0$ | 405.24 (322.67, 510.82) |
| $B_0$ | 48.95 (17.15) |
| $B_{2024}$ | 45.19 (31.83, 61.88) |
| $B_{2024}/B_0$ | 0.84 (0.52, 1.35) |
| $P(B_{2024} > 0.3\ B_0)$ | 1 |
| $B_{MSY}$ | 28.88 (6.42) |
| $U_{MSY}$ | 0.081 (0.053) |
| $MSY$ | 2.282 (1.799) |
| $U_{USR}$ | 0.041 (0.053) |
| $USR$ | 39.38 (34.21, 45.6) |
| $Y_{USR}$ | 1.509 (1.916) |
| $U_{Crash}$ | 0.131 (0.088) |

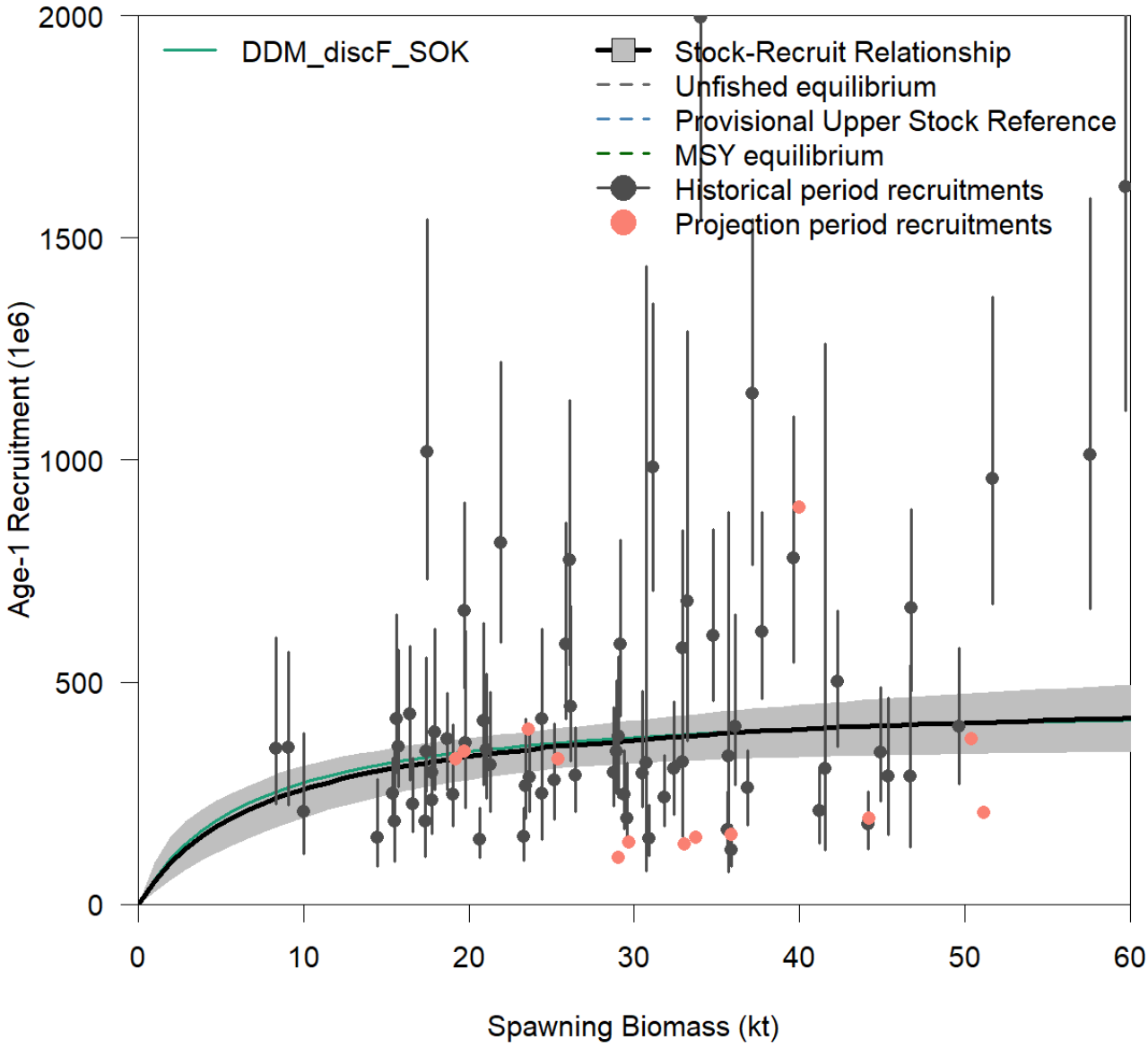


*Figure 16. Stock-recruitment relationships and age-1 recruitment for the PRD Herring operating model. Relationships are shown for the operating model with uncertainty (black curve and grey shaded region) and the posterior median relationships for individual operating models (coloured lines). Annual age-1 recruitments are also shown with uncertainty for the historical 1951 - 2024 period (grey points with vertical segments) and for a single possible future in the 2025 - 2039 projection period (pink points). Finally, dashed lines show average biomass and recruitment levels for fishery reference points including unfished biomass (grey), the provisional upper stock reference (blue), and biomass at maximum sustainable yield (MSY, green).*

## Management Procedures

MPs are a repeatable algorithmic method of setting catch limits. They comprise a set of regularly collected fishery monitoring data, a biomass estimation method (EM), and a harvest control rule (HCR). The EM estimates biomass and the resulting estimates are passed to the HCR to produce TAC advice.

MPs are evaluated via closed loop simulation, whereby the SISCAH operating model (OM) simulates the population dynamics of PRD herring in 15 year (three herring generation) projections. Simulations include realistic effects of fishing, natural mortality, and recruitment variability on the stock, and generate realistic fishery monitoring data. Each simulation year, simulated data are provided to an MP, and then the resulting TAC advice is applied to the stock as fishing mortality. The resulting operating model outcomes (e.g., spawning biomass, effective harvest rates) are used to generate performance metrics related to fishery objectives, which are used for evaluating MPs. Closed loop simulations testing MPs are recommended to occur every three years, or sooner if required under an exceptional circumstance.

For PRD herring, the estimation model (EM) is a simplified SISCAH model using a density-independent $M$ (DIM) random walk formulation. The EM estimates the input signal to the HCR for calculating the annual TAC (DFO 2023b).

The DIM EM is similar to the previous model used for Herring assessments and setting TACs prior to 2024 (Martell et al. 2011), except that the previous model used a spline with 16 nodes instead of a simple random walk to estimate time-varying $M_t$. The EM provides annual estimates of unfished spawning biomass and a 1-year ahead forecast of spawning biomass. It is worth noting that a model-based EM is not a full stock assessment, and rather, it should be considered as an algorithm that generates the inputs to the HCR. As such, a simpler DIM EM is appropriate for setting TACs in an MSE context, allowing more computational resources to be focused on evaluating population dynamic complexities in the OM realm.

TAC advice is estimated from the EM estimates via the HCR. For PRD Herring, the HCR is a "hockey-stick" shaped function defined by lower and upper control points, and a maximum target harvest rate (Cox et al. 2013). When biomass is estimated to be below the lower control point the rule sets the harvest rate to zero. Between control points, the harvest rate is a linear ramp from zero to the maximum harvest rate, and above the upper control point the rule sets harvest rates to the maximum target harvest rate.

This report shows results for three MPs with the maximum target harvest rate set to either the currently recommended 8% (tuned to meet the conservation objective), the formerly applied 13%, or $U_{MSY}$( Figure 4, Table 2).

Finally, after the three year cycle (e.g., in 2028, Table 3) the operating model is fully updated with new data and hypotheses and the comprehensive performance evaluation of MPs is repeated.

## Performance metrics

First, MPs are quantitatively evaluated against the conservation objective (the primary management objective):

1. $P(B_t > 0.3B_0) \geq 0.75$, or avoid the limit reference point (LRP) with high probability over three Herring generations.

Next, MP performance is examined using additional metrics of biomass and yield, which reflect three additional objectives described in Section "Fishery management objectives".

To help fishery managers understand trade-offs among biomass and yield, additional quantitative performance metrics are estimated. These metrics do not have a minimum or target value like objectives, but give greater detail on biomass and yield outcomes of each MP over the 15-year simulation.

2. $P(B_t > B_{MSY})$: The probability that biomass is above $B_{MSY}$.
3. $P(B_t > 0.6B_0)$: The probability that biomass is above $(0.6B_0)$
4. $P\left(B_t > \overline{B}_{prod}\right)$: The probability that biomass is above $\left(\overline{B}_{prod}\right)$, also called the provisional $USR$.
5. $AAV$: Average annual variation in catch, or the mean percentage difference in catch from year-to-year.
6. $\overline{C}$: Median (over replicates) of the average (over years) total landings.
7. $P(U_t > U_{MSY})$: The probability that the effective harvest rate is above $U_{MSY}$.
8. $\overline{B_t/B_0}$: Average biomass depletion from 2025 - 2039.
9. $B_{2039}/B_0$: Median biomass depletion in 2039.
10. $B_{2039}$: Median biomass in 2039.

Performance metrics are estimated via the following closed loop feedback simulation algorithm:

1. Initialize a pre-conditioned simulation model for the period 1951 to 2024 based on a random draw from the operating model posterior distribution;
2. Project the PRD Herring DDM operating model into the future one year at a time. For each year in the projection, apply the following:
    a. Update the time series of commercial catch, catch-at-age, and blended spawn survey data up to time-step $t$ for the stock assessment component of the MP;
    b. Use an estimation model (a statistical catch age model with density independent $M$) to produce a 1-year ahead forecast of spawning biomass depletion;
    c. Determine the target harvest rate associated with the forecast depletion using a harvest control rule;
    d. Using this target harvest rate calculate the total allowable catch from the 1-year ahead biomass forecast;
    e. Update the simulated DDM operating model Herring population with incoming recruitment from the DDM stock-recruit curve with recruitment process errors; density dependent natural mortality; and fishing mortality corresponding to the total allowable catch in the previous step.
    f. Repeat steps 2.i - 2.v until the projection period ends (2027).
3. Repeat Step 1. and Step 2. 99 more times;
4. Calculate quantitative performance statistics across all 100 replicates.

## Discussion

Long-term tuning showed the target harvest rate is around $U_{MSY} = 8\%$ to avoid the LRP with high probability (75% or more). This is due to the LRP being set at a higher level, roughly 50% of $B_{MSY}$ estimated from the operating model (Table 1, Figure 17). For comparison, the default

LRP in Canadian fisheries policy (DFO (2009)) is 40% of $B_{MSY}$ or some proxy, although this is largely applied to longer lived groundfish species with less variable recruitment and lower predation pressures.

The tuning simulations for MP selection use a 40 year projection, which is a longer than the 15 years used in the SoG area. More time is necessary because PRD herring productivity is higher at the currently high stock sizes than in SoG, given the higher $m_1$ value and lower $M_0$ value (Table 1). Higher productivity means that the PRD stock declines from its current biomass more slowly than SoG herring, so finding the equilibrium outcomes for a given target harvest rate requires a longer simulation period.

The selected MP has an average yield of around 2.7 kt (Table 2, Figure 17). Although the other two MPs also meet the conservation objective, the target harvest rates of these MPs approach or exceed $U_{MSY}$ making them less desirable under DFO Sustainable Fisheries Framework policy (DFO 2009). Based on the performance of the 30-60B0_HR0.08 MP, any MP with a maximum target harvest rate at or below 8% will achieve the conservation objective.

Although additional fishery objectives are presented in Section “Fishery management objectives”, only the LRP objective is used for tuning. Despite this, the recommended MP meets any of the candidate target objectives across all USRs. This is partially based on the low target harvest rate (relative to other regions) of 8% that both meets the LRP objective and is roughly equal to $U_{MSY}$, but also related to the current stock status, which is close to an unfished state ($0.91\ B_0$) given that there has been very little fishing since 2017. As a result, the operating model infers biomass available for harvest, and given the estimates of stock productivity for PRD, the operating model expects the effects of harvest at the 8% target rate to be quite gradual and to maintain the spawning biomass above all USR candidates with at least 50% probability.

The EM implements a density independent $M$ model and appears to overestimate biomass in the 1-year ahead forecast. This positive bias can result in an effective harvest rate that exceeds the maximum target harvest rate (Figure 17, bottom row). However, this is accounted for in the simulation. Harvest that occurs as a result of the overestimated projected biomass is subtracted from the simulated actual biomass. Thus the MP is simulation-tested with this known positive bias and the probabilities reflect the likelihood of the MP being able to meet the conservation objective.

*Table 2. Performance statistics for MPs indicated in column 1. Objectives that are met by an MP are indicated by 'Y', otherwise 'N'. $\bar{B}$ is the average biomass from 1951 to 2024. Subscript t indicates the years 2025 - 2039. Biomass B and Harvest Rate U metrics (columns 2 -8) are the probability that Bt or Ut respectively is greater than the value indicated in the header. Average catch $\bar{C}t$ and final biomass B2039 are in biomass units (kt), and final year B2039/B0 and average projection year $\bar{B}t$/B0 stock status is biomass depletion relative to unfished biomass. For PRD, Bprod is calculated as the average spawning biomass during the productive period, B1983:1992.*

| ***Management Procedure*** | ***0.3 $B_0$*** | ***$B_{MSY}$*** | ***0.4 $B_0$*** | ***0.5 $B_0$*** | ***0.6 $B_0$*** | ***$\bar{B}_{prod}$*** | ***$\bar{B}$*** | ***$U_{MSY}$*** | ***$\bar{C}_t$*** | ***AAV*** | ***$\bar{B}_t/B_0$*** | ***$B_{2039}/B_0$*** | ***$B_{2039}$*** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30-60B0_HR0.08 | Y | 0.69 | 0.86 | 0.77 | 0.67 | 0.47 | 0.67 | 0.38 | 2.66 | 17.3 | 0.81 | 0.76 | 37.33 |
| 30-60B0_HR0.13 | Y | 0.56 | 0.76 | 0.66 | 0.55 | 0.36 | 0.54 | 0.81 | 3.88 | 20.4 | 0.70 | 0.61 | 29.74 |
| 40-80Bmsy_HRUmsy | Y | 0.68 | 0.85 | 0.75 | 0.67 | 0.47 | 0.66 | 0.43 | 2.72 | 16.3 | 0.81 | 0.75 | 36.80 |

*Table 3. Implementation of the SISCAH operating model framework for Pacific Herring major stocks: MSE update schedule for 2023-2029 (subject to evaluation of exceptional circumstances criteria and available resources).*

| SAR | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 |
|---|---|---|---|---|---|---|---|
| SOG | CSAS review of SISCAH OM framework | SISCAH transition and MP evaluations | Interim update | Interim update | OM review and full MSE update | Interim update | Interim update |
| PRD | CSAS review of SISCAH OM framework | - | SISCAH transition and MP evaluations | Interim update | Interim update | OM review and full MSE update | Interim update |
| HG | CSAS review of SISCAH OM framework | - | - | SISCAH transition and MP evaluations | Interim update | Interim update | Interim update |
| CC | CSAS review of SISCAH OM framework | - | - | SISCAH transition and MP evaluations | Interim update | Interim update | Interim update |
| WCVI | CSAS review of - SISCAH OM framework | - | - | SISCAH transition and MP evaluations | Interim update | Interim update | Interim update |

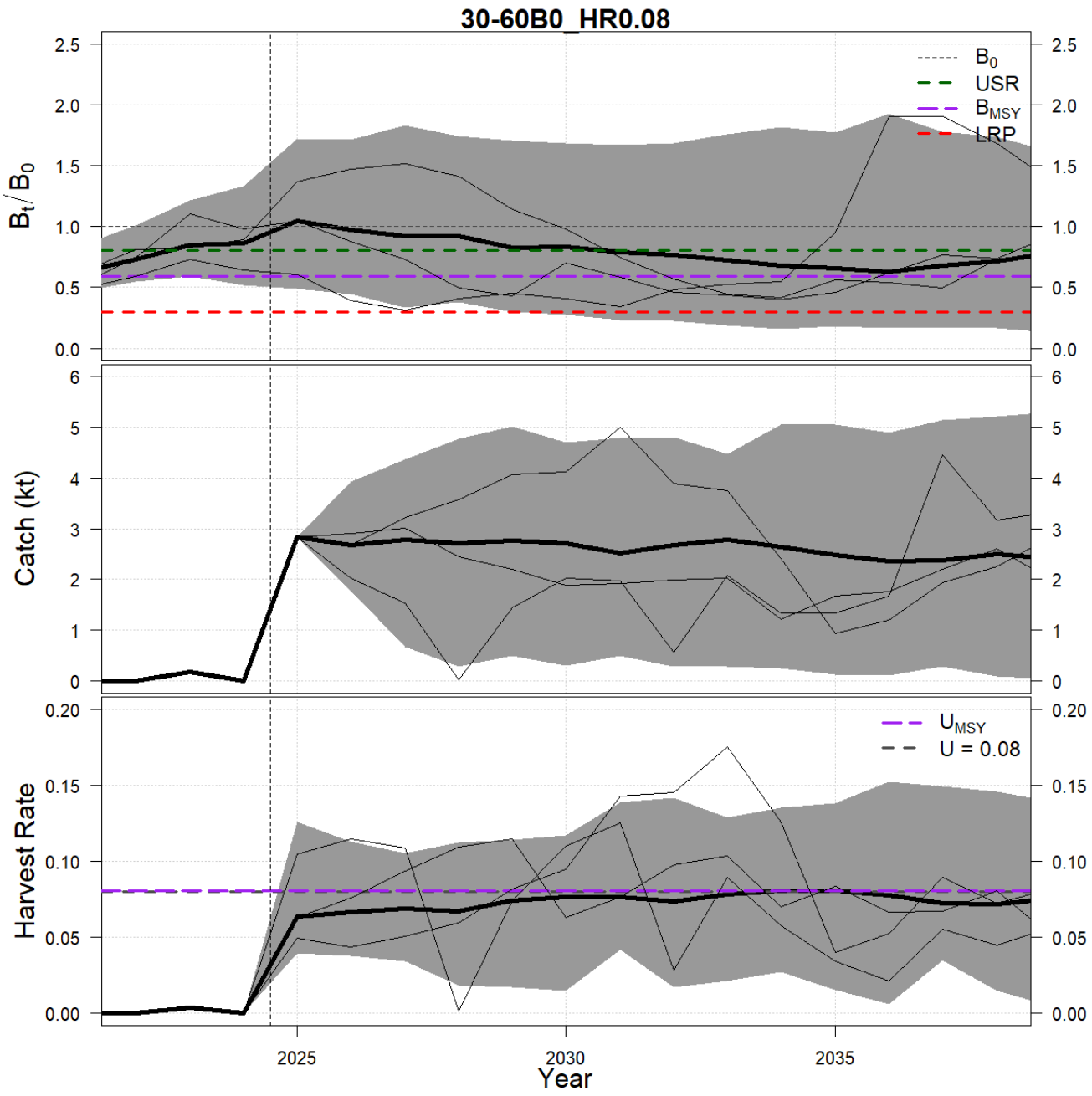


*Figure 17. Simulated time series of projected spawning biomass (top), catch (middle), and harvest rate (bottom) for the MP tuned to the conservation objective (30-60B0_HR0.08). Median values are shown by the thick black lines, the grey shaded region shows the central 95% of each simulation envelope, and three randomly selected individual replicate traces are shown as thin black lines. The dashed vertical line represents the last year of the historical data, 2024, and the dashed horizontal line in the bottom panel represents 8% maximum target harvest rate.*

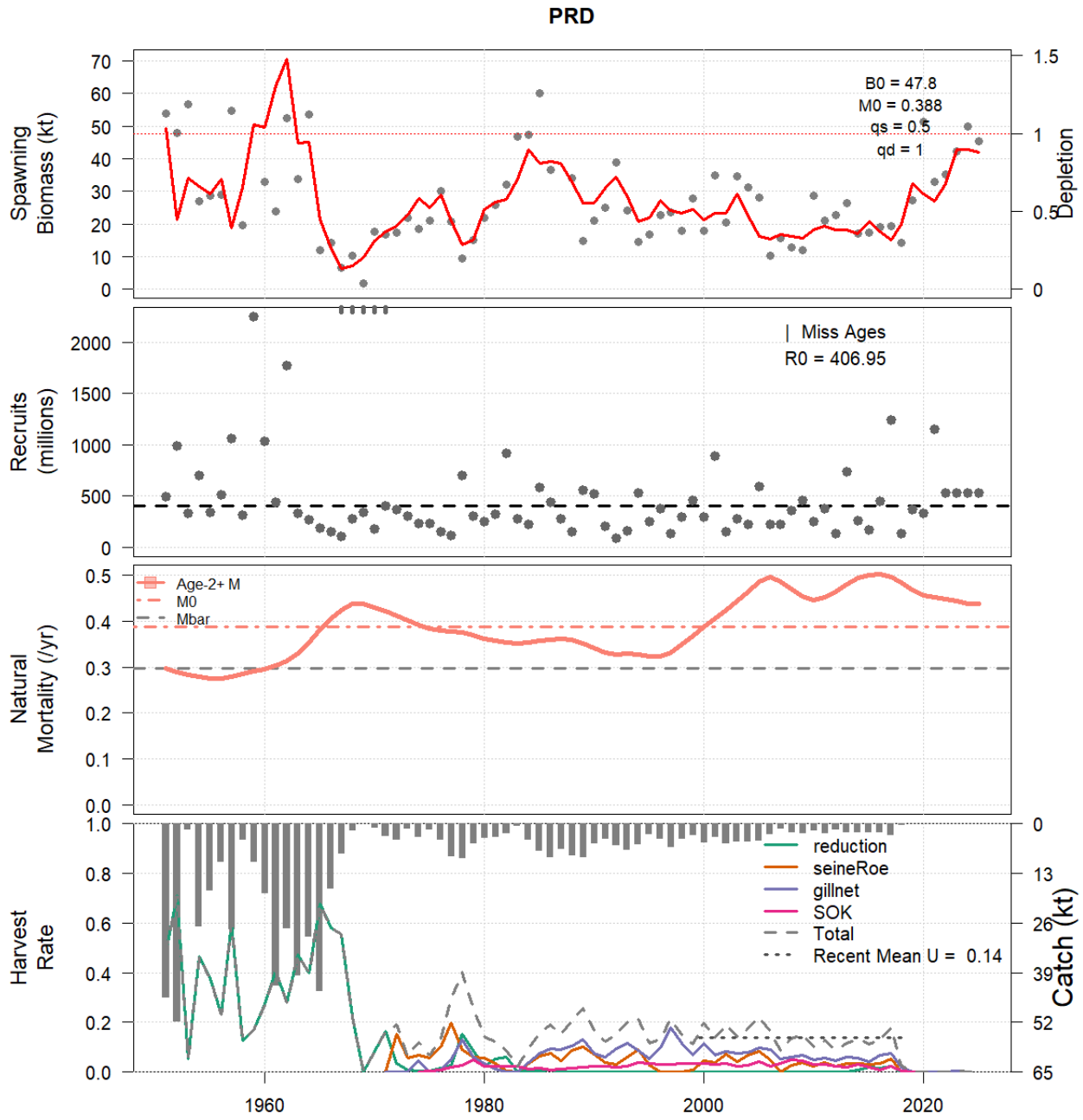


*Figure 18. Time series (1951-2025) of maximum likelihood estimates from the estimation model (top to bottom): blended spawn index (circles, kt) and spawning biomass (kt) and depletion (red trend), recruitment in millions of fish (Miss Ages denotes years with no age composition data), estimated natural mortality (density independent formulation), and harvest rate (trend lines), and catch (kt, vertical bars).*

## THIS REPORT IS AVAILABLE FROM THE:

Center for Science Advice (CSA)
Pacific Region
Fisheries and Oceans Canada
3190 Hammond Bay Rd.
Nanaimo, BC V9T 6N7

E-Mail: DFO.PacificCSA-CASPacifique.MPO@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

ISSN 1919-3769
ISBN 978-0-660-98154-3 Cat. No. Fs70-7/2026-006E-PDF


Correct citation for this publication:

DFO. 2026. Prince Rupert District Pacific Herring Management Strategy Evaluation Process for 2025-2027. DFO Can. Sci. Advis. Sec. Sci. Resp. 2026/006.

*Aussi disponible en français:*

*MPO. 2026. Processus d'évaluation des stratégies de gestion du hareng du Pacifique du district de Prince Rupert pour 2025 à 2027. Secr. can. des avis sci. du MPO. Rép. des Sci. 2026/006.*