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Science Response 2023/026

Maritimes Region

## STOCK STATUS UPDATE OF 4VWX HERRING FOR THE 2023 FISHING SEASON

### Context

Maritimes Fisheries and Oceans Canada (DFO) Resource Management has requested that DFO Science conduct a stock status update of the Northwest Atlantic Fisheries Organization (NAFO) Divisions 4VWX Atlantic Herring (*Clupea harengus*) (henceforth referred to as 4VWX Herring) in support of decision-making for the 2023 fishery. The last full assessment of 4VWX Herring was conducted in March 2022 (DFO 2022a). As defined in the Terms of Reference, the objectives for this update were as follows:

- Evaluate the indicators and assess the fishery with respect to the Limit Reference Point (LRP) for Southwest Nova Scotia/Bay of Fundy spawning component (SWNS/BoF).
- Update and review information on the other spawning components (Offshore Scotian Shelf, Coastal Nova Scotia, Southwest New Brunswick migrant juvenile fishery).
- Update and evaluate the candidate Management Procedures (MPs) on the Reference Set of Operating Models for the SWNS/BoF component.
- Advise on the probability of rebuilding above the LRP over the projection period for each candidate MP for the SWNS/BoF component.
- Assess whether exceptional circumstances are triggered for the SWNS/BoF component.
- Estimate  $T_{min}$ , where  $T_{min}$  is the time SWNS/BoF herring would take to rebuild above the LRP with a high probability in the absence of fishing ( $F=0$ ).
- Estimate the Probability of Preventable Decline from Year 3 to Year 8 in the projections for each MP.

The biological and fishery information for 4VWX Herring forms the basis for establishing harvest levels for the 2023 fishery, as required in the Integrated Fisheries Management Plan (IFMP). An assessment of biological and fishery information for 4VWX Herring is provided in this Science Response.

For the SWNS/BoF spawning component of 4VWX Herring, an assessment framework was conducted using a Management Strategy Evaluation (MSE) from 2019 to 2022 (Singh et al. 2020, Carruthers et al. 2023, Barrett In press). The stock status of the SWNS/BoF component is estimated by comparing the 3-year moving average of the acoustic index of spawning stock biomass for German Bank and Scots Bay to the Limit Reference Point defined in terms of the acoustic index (LRP, Clark et al. 2012), and also accounts for turnover of spawners at these grounds (DFO 2018). This science advice uses the 2022 assessment framework to identify candidate MPs that have a high probability of rebuilding the SWNS/BoF component above the LRP, evaluate trade-offs among other management objectives, and assess whether exceptional circumstances are triggered. This advice builds on the advice from 2022 (DFO 2022a) after which an MP was not selected.

For other spawning components of 4VWX Herring, indicators of relative status and landings are reported herein based on methodologies presented in the 2018 stock assessment (DFO 2018).

This Science Response Report results from the regional peer review of April 3, 2023, on Update of Stock Status for Herring in Northwest Atlantic Fisheries Organization Fishing Areas 4VWX.

## Background

Atlantic Herring (*Clupea harengus*) is a pelagic species found on both sides of the North Atlantic. Herring spawn in discrete locations to which they have a strong affinity. The majority of Herring in the 4VWX area are fall spawners. These Herring mature in 4VWX and first spawn at three or four years of age, then begin an annual pattern of spawning, over-wintering, and summer feeding. This often involves considerable migration and mixing with members of other spawning components and stocks. Fishing takes place on dense summer feeding, over-wintering, and spawning aggregations.

The 4VWX area contains a number of Herring spawning areas, separated to various degrees in space and time. For the purposes of evaluation and management, 4VWX Herring is divided into four stock components (see the Appendix [Figure A1] for a map of place names):

- Southwest Nova Scotia/ Bay of Fundy (SWNS/BoF) spawning component (includes German Bank, Scots Bay, Trinity Ledge, Spectacle Buoy, Seal Island, and Browns Bank),
- Offshore Scotian Shelf spawning component (includes The Patch and Western Hole),
- Coastal Nova Scotia (NS) spawning component (includes South Shore, Eastern Shore, and Cape Breton), and
- Southwest New Brunswick (SWNB) migrant juveniles (NB weirs).

Each component, except SWNB migrant juveniles, has several spawning areas, and there is mixing of fish among spawning components outside of the spawning period. The Total Allowable Catch (TAC) for SWNS/BoF was 23,450 tonnes (t) in 2022. The Offshore Scotian Shelf had an allocation of 12,000 t until 2021. The allocation was reduced to 8,000 t for the 2022 fishing season. The Coastal NS fishing areas have allocations based on the recent 5-year average of observed acoustic index of the Spawning Stock Biomass (SSB).

Historically, Georges Bank (NAFO area 5Z) has been included in the 4VWX Herring science update. Due to the absence of information in recent years, there is no basis for evaluating this component. There is an allocation of 20,000 t for the Georges Bank component, but no landings were reported for 2022.

In 2022, a discrepancy was identified in the methodology of how acoustic transects were analyzed. Edge transects for 2020 and 2021 were found not to have equal weighting as interior transects; a practice applied to the data from 1998–2019. Therefore, adjustments to acoustic index of SSB for all spawning components were made for years 2020 and 2021 to correct this discrepancy.

In 2012, a LRP for the SWNS/BoF Herring spawning component (German Bank and Scots Bay) was defined as the 2005–2010 average acoustic survey biomass; below this, there is risk of serious harm to the reproductive capacity of the stock (Clark et al. 2012). A 3-year moving average of German Bank and Scots Bay acoustic surveys is used to determine trends in spawning biomass of the SWNS/BoF Herring in relation to the LRP because of the variability in the annual acoustic point estimates (Clark et al. 2012). At the 2018 assessment, revisions to the method for estimating acoustic index of the SSB turnover on the German Bank and Scots Bay spawning grounds were presented and accepted (DFO 2018). The LRP for SWNS/BoF Herring spawning component used in this update is 317,846 t (DFO 2022a).

An assessment framework was conducted using MSE from 2019 to 2022 for the SWNS/BoF spawning component (Singh et al. 2020, Carruthers et al. 2023, Barrett In press). The last assessment (DFO 2022a) estimated whether, and to what extent, biomass could recover to above the LRP with a high probability using the MSE closed-loop simulations that evaluated various candidate MPs.

In 2023, it was identified that the projections used in DFO (2022) did not appropriately adjust the recruitment deviations as described in Barrett (In press). This has been corrected in the MP evaluations in this update.

Candidate MPs that rebuild the SWNS/BoF component above the LRP with a high probability in the simulations were identified using the MSE framework. The following conservation objective was defined by DFO Resource Management to be consistent with DFO's Precautionary Approach (PA) policy (DFO 2009) and serves as a minimum performance standard for MP selection. The stock must be above the LRP, with at least 75% probability in each year in years 10 to 15 of the projection period in the closed-loop simulations to meet this objective.

This update provides advice on which candidate MPs meet the conservation objective using closed-loop simulations that use the observed catches and acoustic index of SSB from 2021 and 2022.

## Analysis and Response

### Landings

Landings from the Herring fishery in 4VWX have always been dominated by purse seine (e.g., 81–99%, 1981–2021). Other gear types consist mainly of weir, gillnet, shutoff, and trap net. The landings for the period January 1, 2022, to December 31, 2022 (the 2022 quota year) were 23,284 t against a TAC of 23,450 t for the SWNS/BoF component (Table 1). Note that the quota year previous to 2020 was from October 15<sup>th</sup> of the preceding calendar year to October 14<sup>th</sup> of the current calendar year. The interim landings 4WX SWNS/BoF area from October 14<sup>th</sup>, 2018, to December 31<sup>st</sup>, 2019 were included in the 2019 quota year landings. Since 2020, the reported fishing season is now within a calendar year of January 1<sup>st</sup> to December 31<sup>st</sup>.

*Table 1. Reported landings (rounded to thousands of tonnes) and total allowable catch for 4VWX Herring from 2015 to 2022 with decadal averages from 1970 to 2019.*

Year	Avg. 1970– 79	Avg. 1980– 89	Avg. 1990– 99	Avg. 2000– 09	Avg. 2010– 19	2015	2016	2017	2018	* 2019	2020	2021	2022
4WX SWNS/BoF TAC <sup>1</sup>	106	106	112	69	48	50	50	42.5	42.5	35	35	35	23.45
4WX SWNS/BoF <sup>1</sup>	131	131	96	66	45	49	50	39	40	35	34	33	23
4VWX Coastal NS <sup>2</sup>	< 1	< 1	4	7	7	5	8	8	10	13	18	12	12
Offshore Scotian Shelf <sup>2</sup>	38	<0.1	13	6	4	2	1	4	3	6	< 0.1	< 0.9	2.5
SW New Brunswick <sup>2</sup>	26	24	24	15	5	< 0.2	4	2	12	5	6	4	3.3
Total Landings	172	155	137	93	60	56	63	53	65	53	56	48	41

1 – Quota year from October 15<sup>th</sup> of the preceding year to October 14<sup>th</sup>, 2019. \*An interim catch is reported from October 15<sup>th</sup>, 2019 to December 31<sup>st</sup> 2019 because in 2020 Quota year was changed to match calendar year (January 1<sup>st</sup> to December 31<sup>st</sup>).

2 – Calendar year from January 1<sup>st</sup> to December 31<sup>st</sup>.

Additional landings of 18,229 t were taken in the other components (outside the SWNS/BoF area) for a total of 41,513 t for all of 4VWX. The Coastal component had total landings of 12,395 t. Landings were 2,548 t for the Offshore Scotian Shelf which were below the 8,000 t allocation for the area. Landings for SWNB weirs and shutoffs were lower in 2022 (3,286 t) compared to 2021 (4,014 t).

## Southwest Nova Scotia/Bay of Fundy Spawning Component

### Age Structure

Age-structured data are presented herein using methodology developed for the 2019 to 2022 framework for the SWNS/BoF spawning component (Carruthers et al. 2023, Barrett In press). The 2020 fishery landings were dominated by Age 2 (50%) with Age 3 (10%), Age 4 (19%), Age 5 (9%), and Age 6 (8%) making up the majority of the age groups (Figure 1). The 2021 fishery landings were dominated by Age 2 (40%) with Age 3 (28%), Age 4 (7%), Age 5 (12%), and Age 6 (7%) making up the majority of the age groups. The 2022 fishery landings were dominated by Age 3 (48%), with Age 2 (13%), Age 4 (18%), Age 5 (4%), and Age 6 (9%) making up the majority of the age groups.

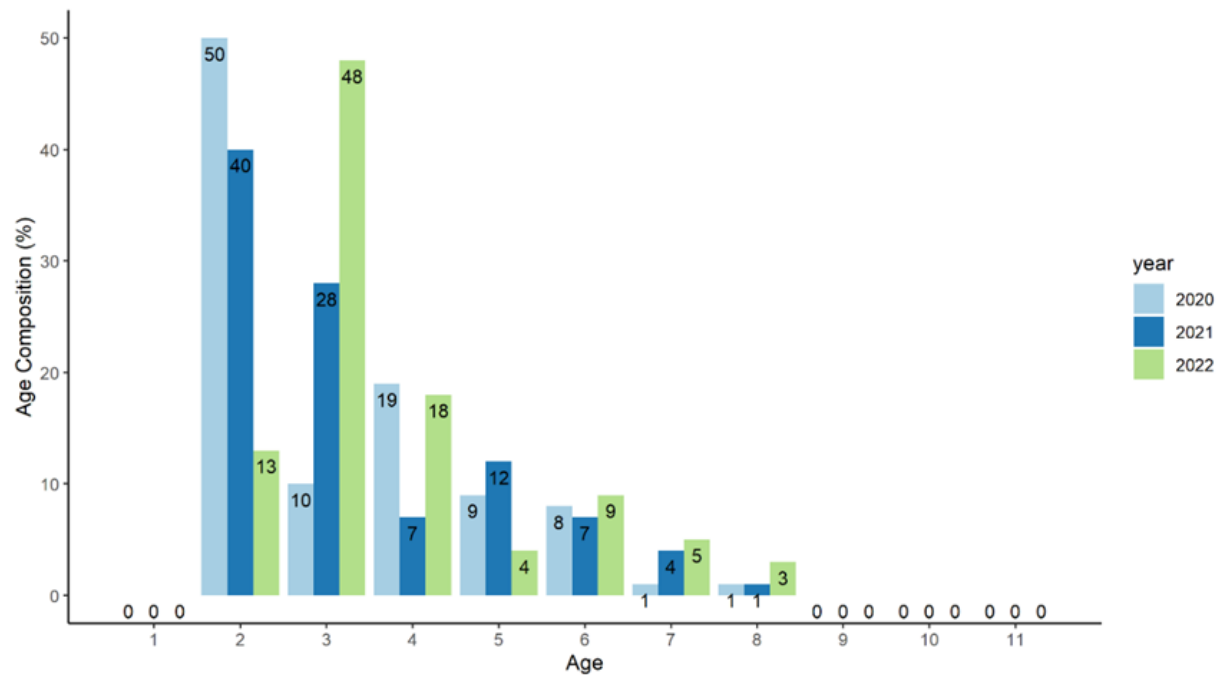


Figure 1. Commercial catch age composition (% catch by number) for Southwest Nova Scotia/Bay of Fundy spawning component for calendar years 2020, 2021, and 2022 from purse seine and gillnet gear.

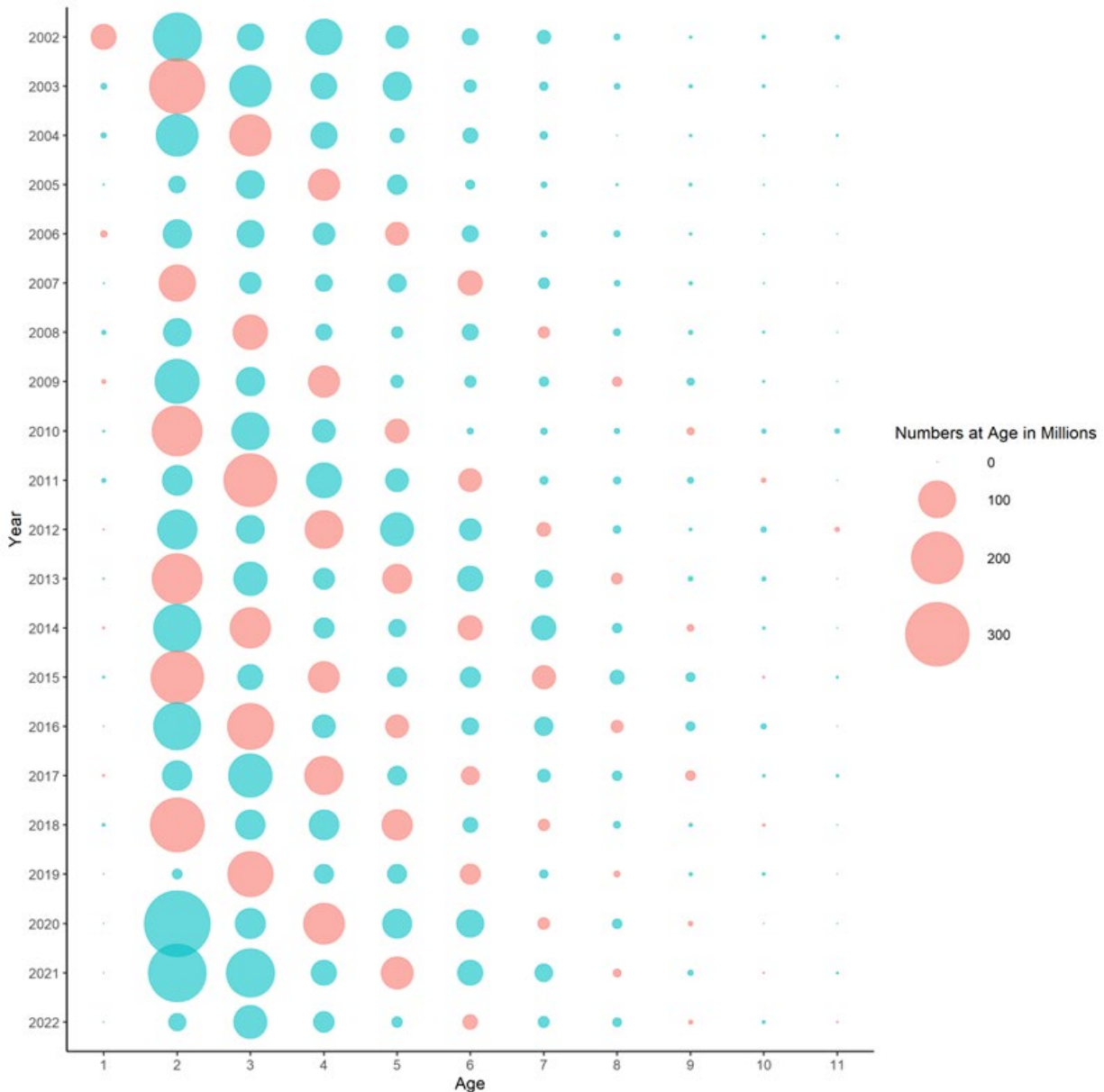


Figure 2. Numbers-at-age in the commercial landings for Southwest Nova Scotia/Bay of Fundy spawning component from 2002–2022 by quota year from purse seine and gillnet gear. The size of the bubble is proportional to the numbers by age. Selected cohort from 1998, 2005, 2007, 2011, 2013, and 2016 are shown in red.

Age 2 fish dominated the catch for the 2020 and 2021 fishing seasons, whereas Age 3 fish dominated the catch in 2022. Based on the age structure, the total number of fish removed by the fishery was estimated to be 319 million in 2020, 305 million in 2021, and 168 million in 2022 (Figure 2).

Since the 1970s, mean weight-at-age for Ages 4 to 11 declined and mean weight-at-age for Age 1 and Age 2 has increased (Figure 3). Declining trends in the older age classes in the commercial mean weight-at-age since 1970s have reduced the productivity of the stock. The mechanisms influencing changes in weight-at-age for SWNS/BoF component Herring are not well understood and require further study.

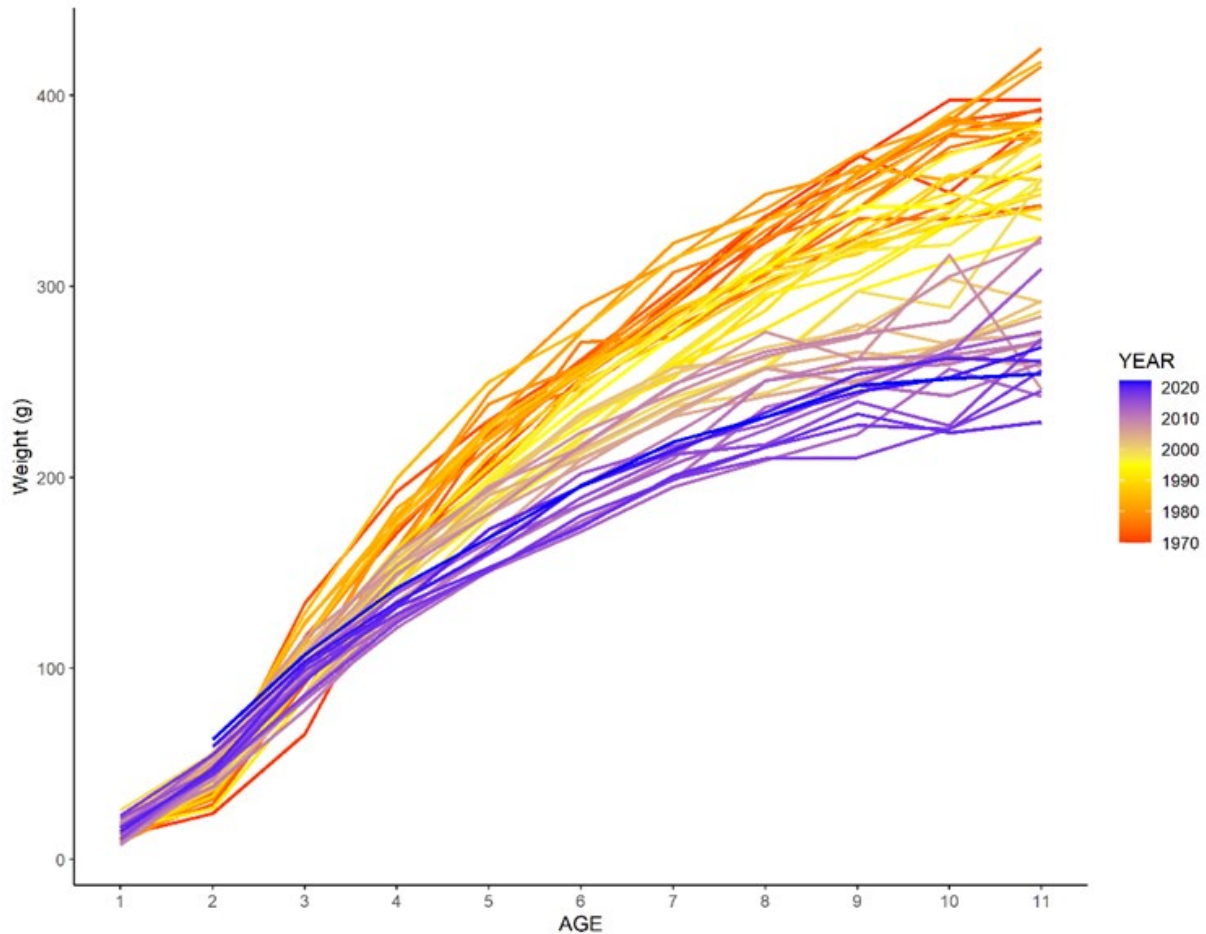


Figure 3. Fishery mean weight-at-age for the Southwest Nova Scotia/Bay of Fundy (SWNS/BoF) component from 1970 to 2022. Red lines indicate earlier in the time series and purple to blue lines are later in the time series.

### Acoustic Surveys

Industry-led surveys with automated acoustic recording systems deployed on commercial fishing vessels were used to estimate the distribution and abundance of mainly spawning Herring aggregations. Scheduled surveys were conducted approximately every two weeks (between late-May and early-November) on the main spawning grounds, and an acoustic index of SSB for each component was estimated by summing estimates across surveys (Table 2).

At the March 2013 Assessment meeting (DFO 2013), it was noted that fish abundance could be overestimated (double-counting) or underestimated (missing fish) using the acoustic survey approach employed. Methods were presented in Melvin et al. (2014) to account for double-counting. Mark-recapture methods were used to estimate the proportion of fish remaining on the spawning grounds relative to the elapsed time between surveys. These results were used to revise the acoustic index of the SSB estimates for the entire time series, including the LRP. This resulted in a change in the absolute magnitude of the LRP from 371,067 t to 316,313 t (DFO 2018), that was later revised to 317,846 t (DFO 2020). Consensus was reached during the 2018 assessment to use these revised estimates as the basis of the assessment and the advice. There was agreement to retain the current survey protocol of 10–14 days between surveys.

Table 2. Acoustic surveys spawning biomass index for Southwest Nova Scotia/Bay of Fundy spawning component average for 1999–2010 and biomass for 2011–2022 (rounded to thousands of tonnes).

Location	Avg. 1999–2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020 <sup>§</sup>	2021 <sup>§</sup>	2022	Avg. 2005–2010	Avg. 1999–2022
Scots Bay (inbox)	79	91	123	59	187	228	98	133	129	80	165	66	182	38	104
Scots Bay (outbox)	1	32	38	8	4	21	3	9	10	53	14	6	74	3	12
<b>Scots Bay total</b>	84	123	161	66	191	249	101	142	140	133	179	72	256	40	116
German Bank (inbox)	289	249	219	200	188	140	163	166	95	147	103	137	77	273	223
German Bank (outbox)	6	9	7	9	2	-	-	-	-	-	-	-	-	6	6
<b>German Bank total</b>	291	258	226	209	190	140	163	166	95	147	103	137	77	278	225
<b>German + Scots</b>	371	381	387	275	381	390	264	308	235	280	283	209	333	318	341
Trinity Ledge	7	7	3	1	5	1	1	14	7	20	14	4	17	6	7
Spec Buoy (spring)	1	0	-	-	-	-	-	-	-	-	-	-	-	1	1
Spec Buoy (fall)	44	-	-	-	-	-	-	9	10	23	13	23	16	-	22
<b>Overall Stock Area</b>	386	388	390	276	386	390	265	330	251	323	310	237	366	324	356
Seal Island	7	1	-	-	-	-	-	-	21	30	4	9	22	10	11
Browns Bank	26	-	-	-	-	-	-	-	-	-	-	-	-	8	26
<b>Total All Areas</b>	393	390	390	276	386	390	265	330	272	353	313	246	387	327	363

\* Note: Average 2005–2010 = Limit Reference Point (German Bank and Scots Bay total only). Numbers for German Bank and Scots Bay are adjusted for turnover.

§ Adjustments in estimated biomass were made in survey area from this report compared to the 2022 assessment report because edge transects did not have equal weighting as interior transects. This practice was applied to data from 1999–2019.

- = no data for that year in that category.

0 = surveys conducted but the numbers recorded were either 0 or less than 500 t (rounds to 0 thousand t).

The results of the 2022 acoustic surveys for the SWNS/BoF component are summarized in Table 2. Inbox and outbox refer to survey tracks within and outside the designated survey boxes, respectively. There were 10 surveys in Scots Bay, six on German Bank, six on Seal Island, five on Trinity Ledge, and five in the Spectacle Buoy area. A maximum biomass estimate value is taken when surveys on Trinity Ledge, Spectacle Buoy, and Seal Island are less than 10 days, and a single value is used in the reported biomass estimates.

The acoustic SSB estimates are interpreted as a relative index of biomass and not as an absolute index. The overall acoustic SSB estimate (Scots Bay, German Bank, Trinity Ledge, Spectacle Buoy, and Seal Island) was 387,481 t (95% C.I.: +/-140,000 t) in 2022, which is greater than the 245,813 t estimated in 2021 (Table 2). The overall acoustic biomass estimate in 2022 was 7% above the long-term average (1999–2021) of 363,134t. The 2022 Scots Bay acoustic SSB estimate was 76% above the long-term average (1999–2022) at 256,012 t (95% C.I.: +/- 135,165 t). The 2022 German Bank SSB estimate was 66% below the long-term average (1999–2022) at 76,558 t (95% C.I.: +/- 23,000 t). For a fifth year since 2018, surveys were completed on the Seal Island spawning area with an SSB estimate of 21,643 t (95% C.I.: +/- 5,543 t). The SSB estimate on Trinity Ledge increased from 3,597 t in 2021 to 17,475 t (95% C.I.: +/- 10,148 t) in 2022. The SSB estimate on Spectacle Buoy was 15,794 t (95% C.I.: +/- 25,826 t) in 2022 a decrease from 19,034 t in 2021.

In 2022, an index of the relative exploitation rate for SWNS/BoF component estimated from total catch and acoustic index of the SSB (i.e., does not include juvenile fish) and landings was 7%, compared to a long-term (1999–2022) average of 15.6%.

The 2022 acoustic catch-at-age shows more Age 3 and Age 4 Herring compared to 2020 and 2021, suggesting more young spawners on the spawning grounds for 2022 (Figure 4, Figure 5). Whereas in 2021 older age classes (i.e., Age 6 and Age 7) dominate the age structure.

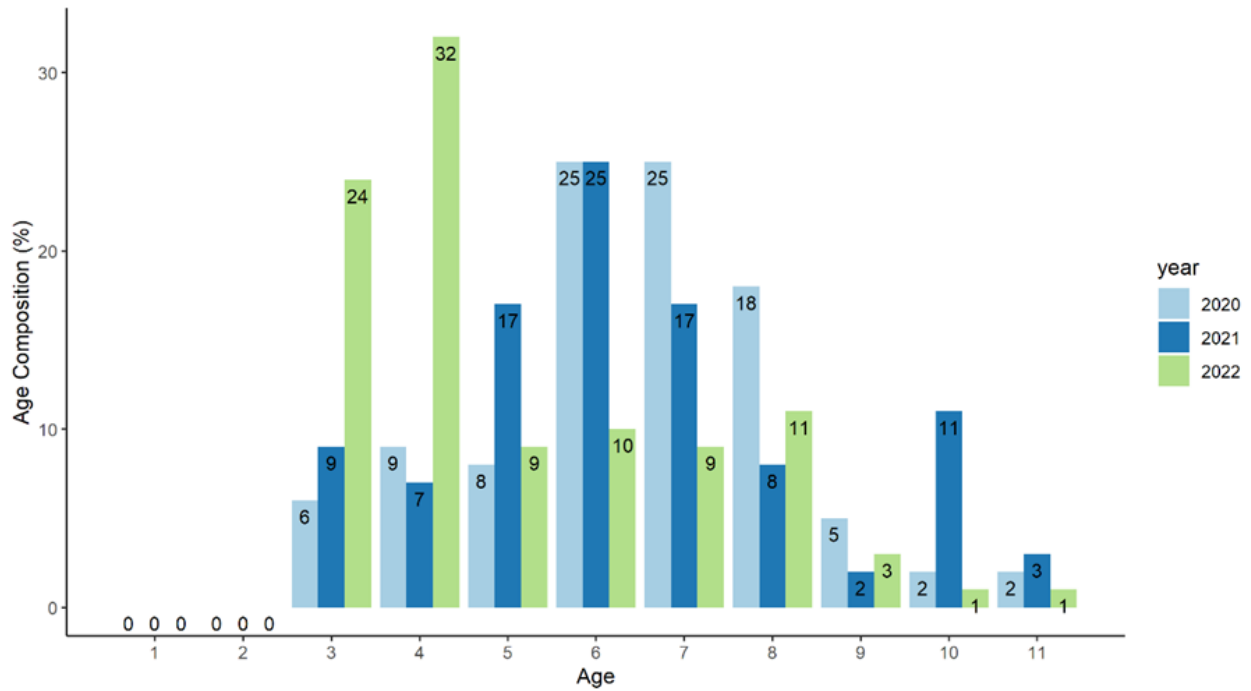


Figure 4. Acoustic survey age composition (% by number) for Southwest Nova Scotia/Bay of Fundy spawning component for German Bank and Scots Bay for calendar years (2020, 2021, and 2022) from purse seine gear.



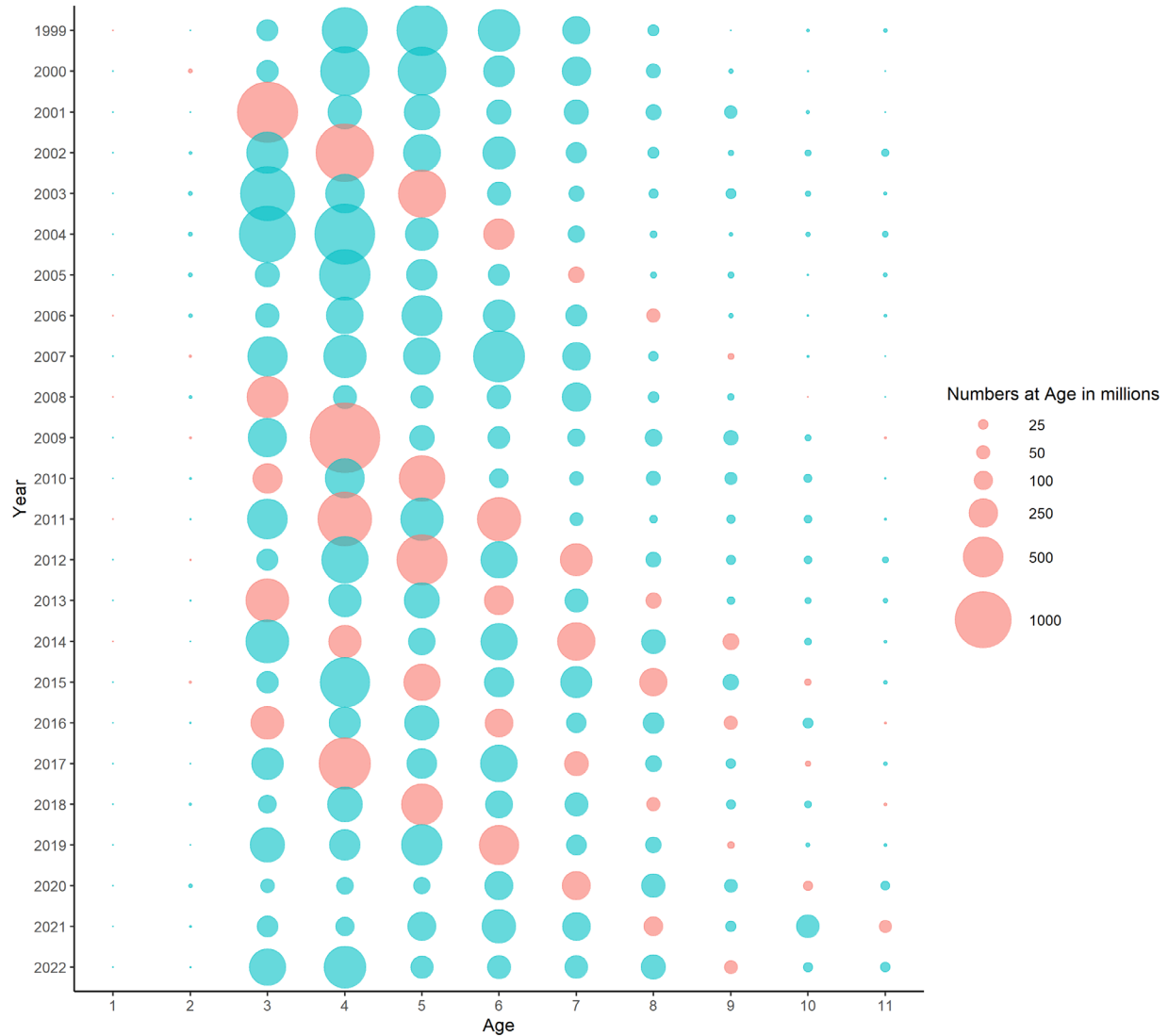


Figure 5. Acoustic survey relative numbers at age (denoted by circle size) for the German Bank and Scots Bay (main spawning areas in the Southwest Nova Scotia/Bay of Fundy (SWNS/BoF) spawning component from purse seine gear. The size of the bubble is proportional to the numbers by age. Selected year-classes 1998, 2005, 2007, 2011, and 2013 are shown in red.

### Stock Status

Though the annual acoustic index of the SSB estimates increased above the LRP in 2022, it has been at or below the LRP for the previous five years (Figure 6). The combined annual acoustic SSB estimate for German Bank and Scots Bay increased from 209,658 t in 2021, to 332,570 t in 2022 (Table 2). Despite this overall increase, the German Bank SSB is at the lowest it has been since 1999 (Figure 7).

The 3-year moving average (arithmetic mean) of the summed biomass in German Bank and Scots Bay is used to evaluate stock status relative to the LRP (Clark et al. 2012). Though, the 3-year moving average of German Bank and Scots Bay increased from 2021 (257,719 t) to 2022 (275,086 t), it still remains below the LRP, and the SWNS/BoF component is, therefore, considered in the Critical Zone (Figure 6). The DFO PA policy (DFO 2009) states that when a

stock is in the Critical Zone, productivity is sufficiently impaired to cause serious harm to reproductive capacity of the stock.

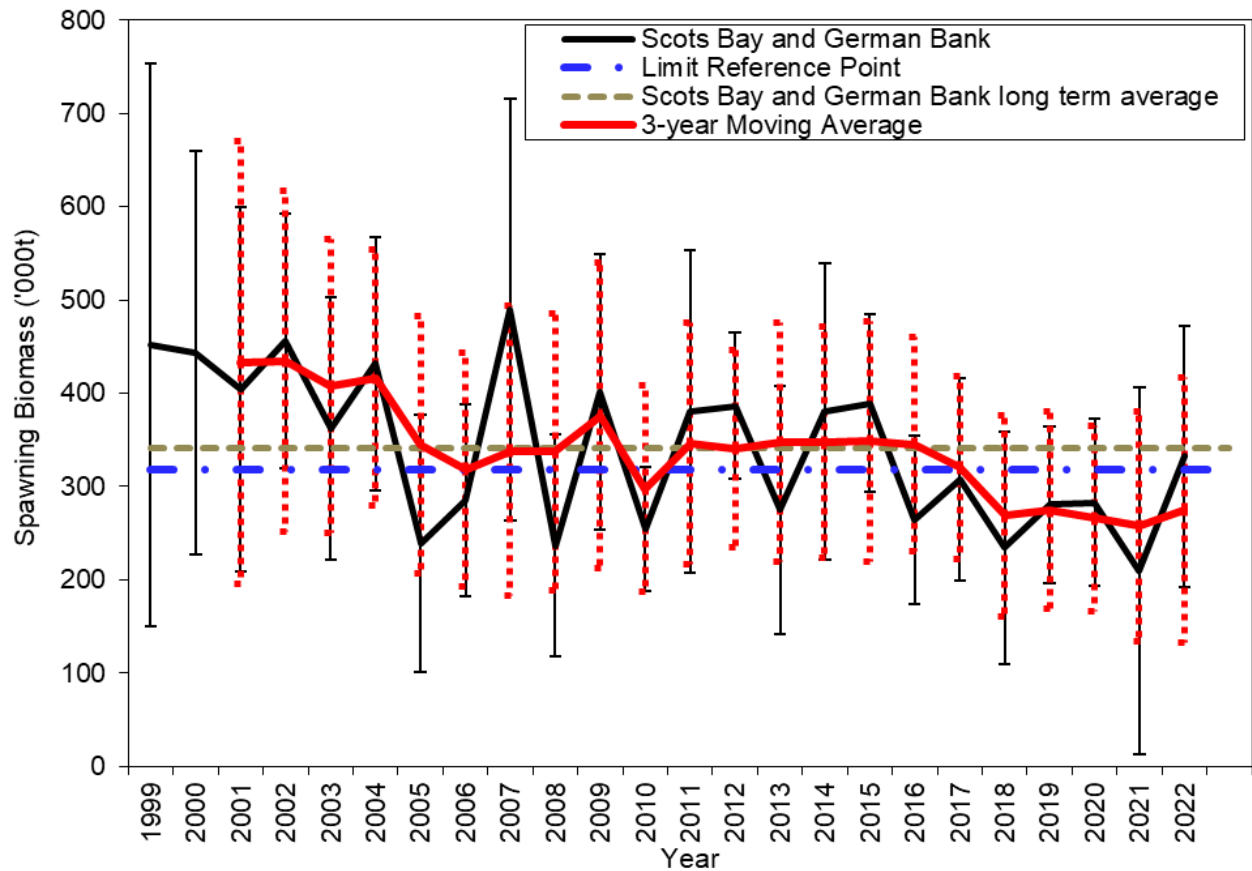


Figure 6. Acoustic index of SSB (in thousands of metric tons) (with 95% confidence intervals; black line), the 3-year moving average (red line), the overall average since 1999 (dashed brown line), and the Limit Reference Point for the Southwest Nova Scotia/Bay of Fundy spawning component (revised 2005–2010 German Bank and Scots Bay average; dashed blue line).

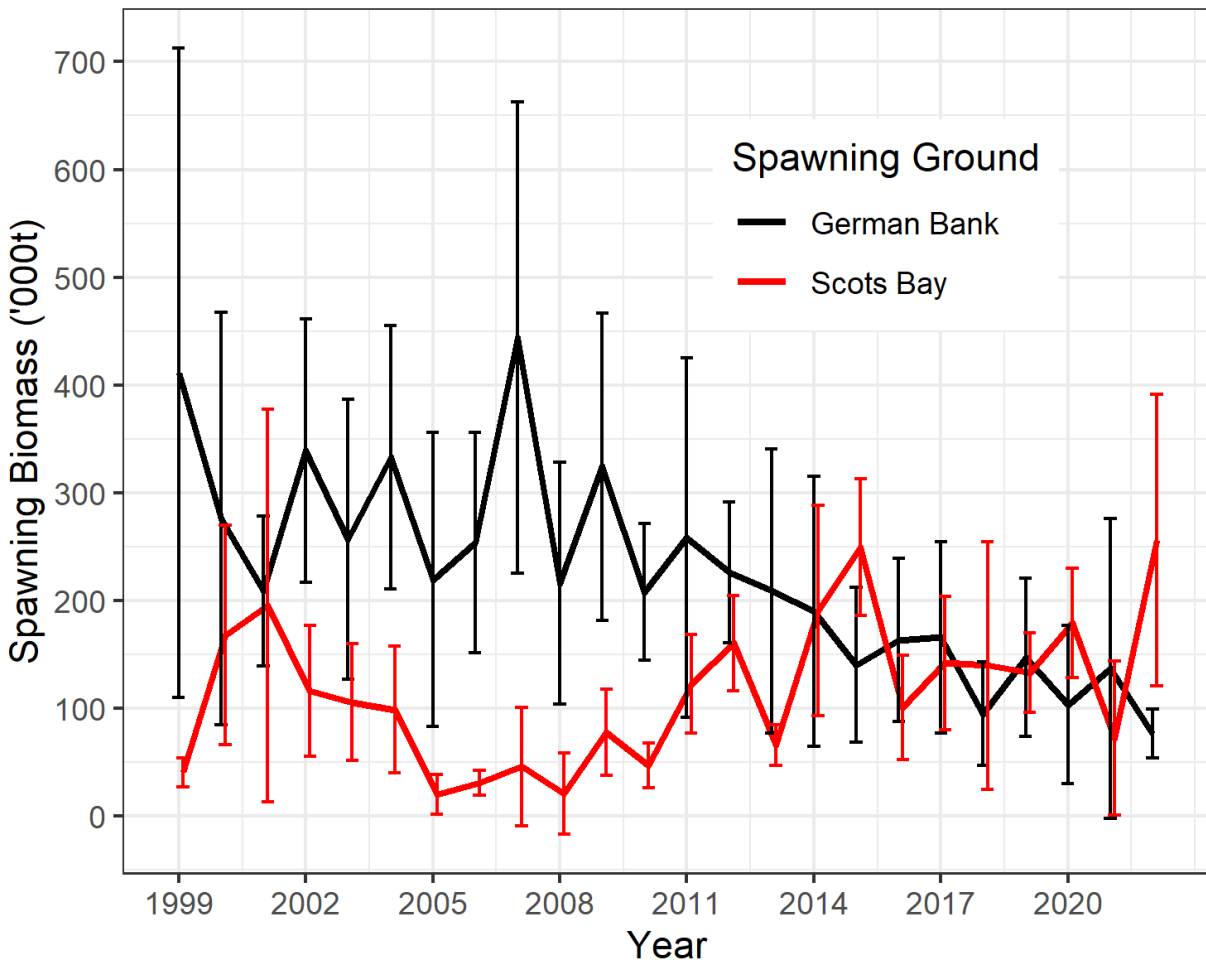


Figure 7. Acoustic index of SSB from 1999 to 2022 (in thousands of metric tonnes) for German Bank (black) and Scots Bay (red) (with 95% confidence intervals; error bars).

### Evaluation of Candidate Management Procedures

An analytical modeling framework using closed-loop simulation to evaluate the performance of candidate MPs was developed from 2019 to 2022 for the SWNS/BoF spawning component (Singh et al. 2020, Carruthers et al. 2023, Barrett In press). Candidate MPs that enable the rebuilding of the SWNS/BoF component above the LRP with a high probability were identified in the MSE framework. The following conservation objective was defined by DFO to be consistent with DFO's PA policy (DFO 2009) and serves as a minimum performance standard for MP selection:

1. Maintain the stock above the LRP with at least 75% probability in each year in years 10 to 15 of the projection period for each Operating Model (OM) in the reference set.

Other performance metrics rank the relative performance of MPs and are used to evaluate trade-offs among MPs. The performance metrics for objectives 2 to 6 are as follows:

2. Maintain SSB above a target biomass in the long-term (years 16–25).
3. Maximize short-term yield (years 1–5).
4. Maximize long-term yield (years 6–25).

5. Minimize variability in catch (years 1–25).
6. Limit the removal of small fish (years 1–15).

Discussions of trade-offs between candidate MPs occurred with industry and other partners and stakeholders over the course of the MSE, including at a March 2022 meeting of the Scotia-Fundy Herring Advisory Committee. However, while preferences were put forward by some committee members, there was no consensus reached, and ultimately an MP was not selected. Instead, the implementation of the MSE was delayed, and a one-year TAC was set for 2022.

For this update, a suite of MPs is presented that meets Objective 1 and that uses catch data from 2021 and 2022 to inform the projected SSB within each simulation, and trade-offs among other management objectives are re-evaluated.

MPs selected for this evaluation and passing Objective 1 were references of no harvest beginning in 2021 (NFref) and no harvest beginning in 2023 (NFref\_FY22), fixed TACs, fixed harvest rates (based on the annual acoustic index, three-year moving average index, and annual index while controlling the removal of small fish), a step function for TAC based on the annual acoustic index, hockey stick functions (Figure 8), and a harvest control rule (nALT\_f11; Figure 9) combined with a rule to limit the variability in TAC based on an industry proposal (Figure 10). In all cases, aside from NFref, fisheries removals (i.e., catch) and the estimated acoustic index in 2021 and 2022 (i.e., projection year 1 and 2 in the closed-loop simulation framework) were accounted for in the projections.

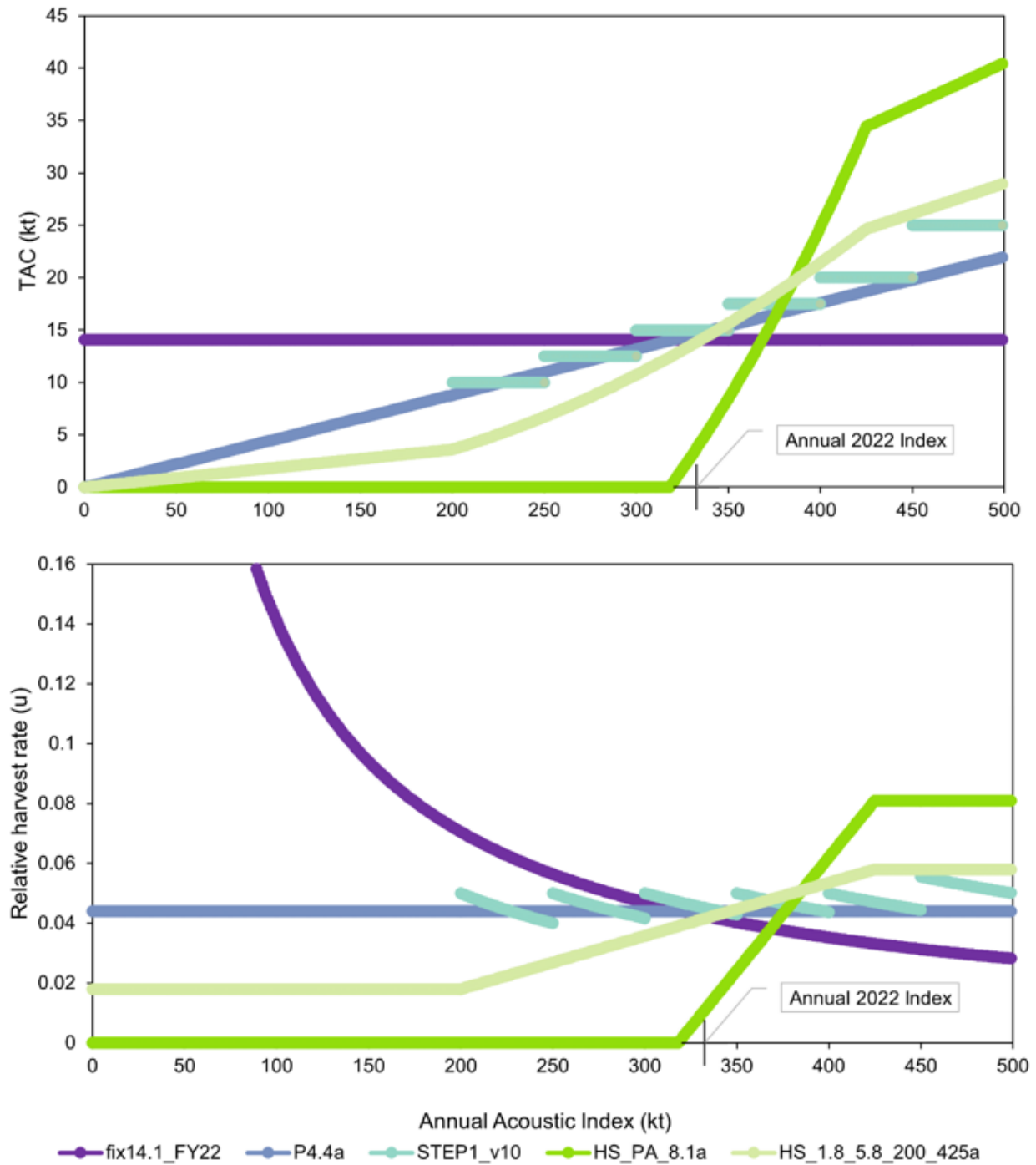


Figure 8. Summary of Management Procedures (MP) using the annual acoustic index of spawning stock biomass (SSB) (kt) that met Objective 1. Each MP used the annual acoustic index (kt) to inform total allowable catch (TAC) (kt) (top panel) and relative harvest rate (u) in units of the index (bottom panel). The pink hashed area denotes the Limit Reference Point and below, and the enlarged x-axis tic mark denotes the annual acoustic index for 2022.

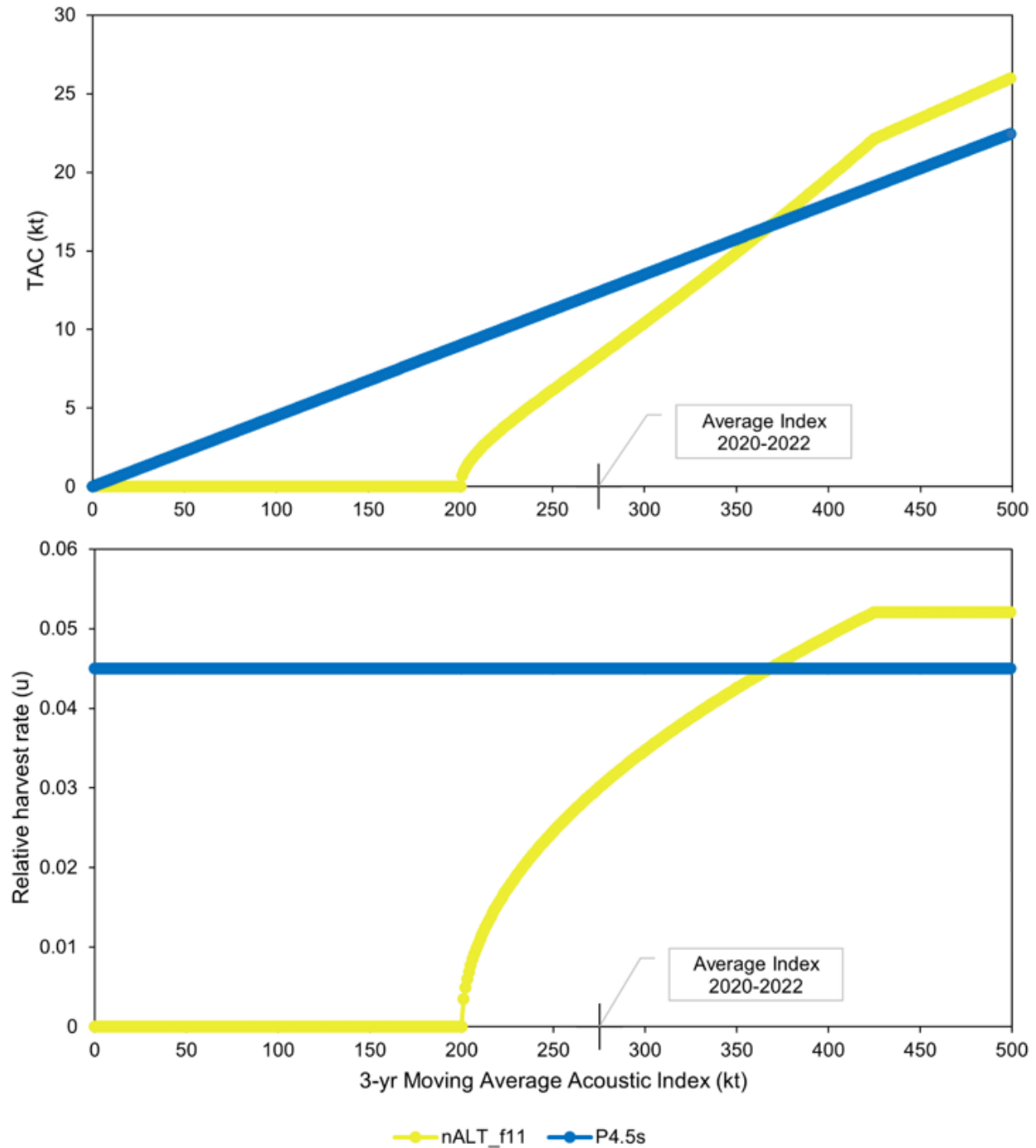


Figure 9. Comparison between a fixed harvest rate ( $u$ ) Management Procedure (MP) and a multi-step MP using the three-year moving average acoustic index of spawning stock biomass (SSB) (kt) to assess the total allowable catch (TAC) (top panel) and the relative harvest rate ( $u$ ) (bottom panel). MP nALT\_f11 applied from an industry proposal to meet Objective 1 and is shown without the TAC adjustment reductions (step decrease function; Figure 10) that are applied to form the MP nALT\_f11\_d5\_5\_35u20. Enlarged x-axis tic mark denotes the average acoustic index from 2020–2022.

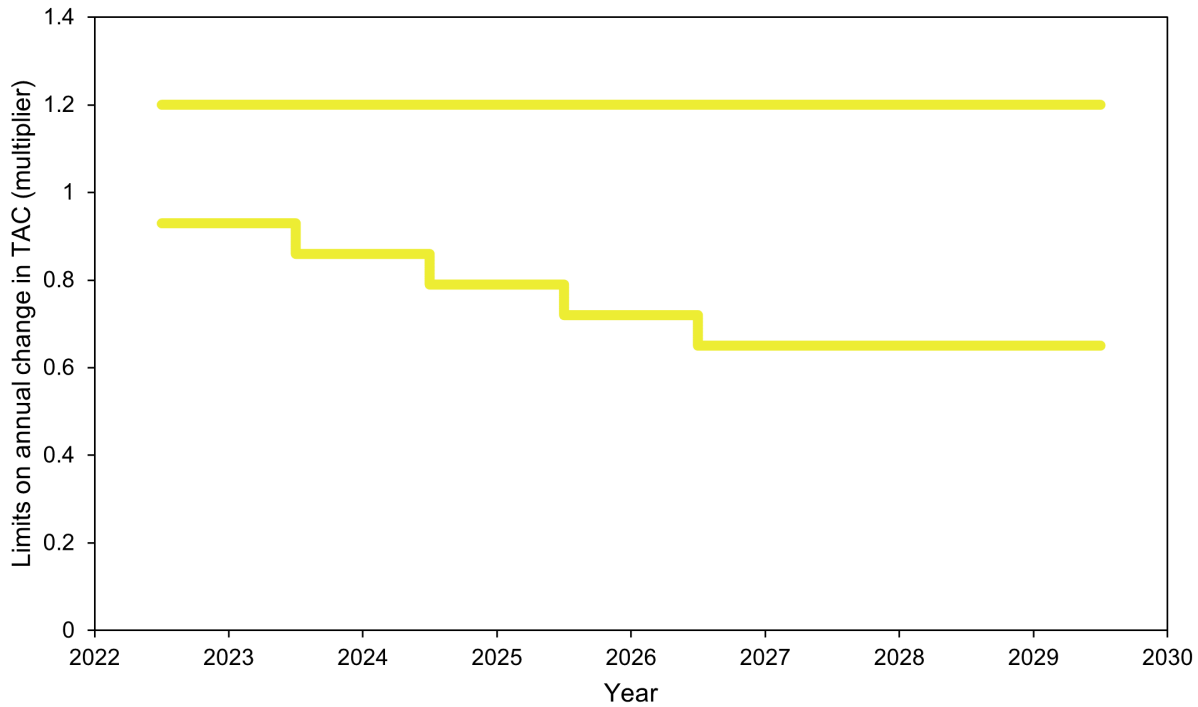


Figure 10. The limits on annual change in total allowable catch (TAC) multiplier combined with the harvest control rule  $nALT\_f11$  (Figure 9) to form the Management Procedure (MP)  $nALT\_f11\_d7\_35\_7u20$ . The multipliers were modified from an industry proposal to meet Objective 1 and are shown without the harvest control rule to highlight the percent change in TAC advised by the MP.

Table 3. Candidate Management Procedures (MPs).

MP	MP Description: All relative harvest rates ( $u$ ) are defined in terms of the annual acoustic index of SSB ( $I$ ) or three-year average acoustic index of SSB ( $I_3$ )
NFref	No fishing reference ( $u=0$ ), beginning in 2021 (projection year 1)
NFref_FY22	No fishing reference ( $u=0$ ), with catch in 2021 & 2022
Fix14.1_FY22	Fixed TAC of 14.1kt
P4.4a	Fixed relative $u$ of 4.4% of $I$
P4.5s	Fixed relative $u$ of 4.5% of $I_3$
P4.8a_20_80	Fixed relative $u$ of 4.8% of $I$ , 20% of purse seine TAC for juvenile fish; 80% for adult fish as described in (Barrett In press)
STEP1_v10	Step function with ( $I$ , TAC in kt) line segments joining points: (0,0) to (200,0), (200,10) to (250,10), (250,12.5) to (300,12.5), (300,15) to (350,15), (350,17.5) to (400,17.5), (400,20) to (450,20), and (450,25) to ( $\infty$ ,25)
HS_PA_8.1a	Hockey stick with ( $I$ , $u$ ) control points at (0,0%), (318, 0%), (425, 8.1%), and ( $\infty$ , 8.1%)
HS_1.8_5.8_200_425a	Hockey stick with ( $I$ , $u$ ) control points at (0,1.8%), (200, 1.8%), (425, 5.8%), and ( $\infty$ , 5.8%)

MP	MP Description: All relative harvest rates ( $u$ ) are defined in terms of the annual acoustic index of SSB ( $I$ ) or three-year average acoustic index of SSB ( $I_3$ )
	$u = 0$ when $I_3 < 200$ kt $u = [1 - \exp(-0.11)]/2 * [(I_3 - 200)/(425 - 200)]^{0.5}$ when $200 \text{ kt} \leq I_3 \leq 425$ kt $u = [1 - \exp(-0.11)]/2$ when $I_3 > 425$ kt with restriction on TAC adjustments as: maximum decrease in TAC for 2023: 7% maximum decrease in TAC for 2024: 14% maximum decrease in TAC for 2025: 21% maximum decrease in TAC for 2026: 28% maximum decrease in TAC for 2027 and later: 35% maximum increase in TAC: 20%
nALT_f11_d7_35_7u20	

The control points for all candidate MPs were tuned, to meet the minimum performance standard of having probability of  $SSB > SSB_{2005-2010}$  above 0.75 in each year for years 10–15 of the projections.

In the previous evaluation of MPs (DFO 2021), MPs that used the annual acoustic index had a higher short-term and long-term yield compared to MPs that use the 3-year moving average acoustic index. Therefore, the focus of the MP evaluation for this update was primarily on MPs that used the annual acoustic index (Figure 11, Figure 12, Figure 13, and Figure 14). Interannual variability of yield (%) was assessed across MPs (Figure 15). See Figure A2 and A3 for worm plots of variability in yield (kt) within selected simulations for MPs.

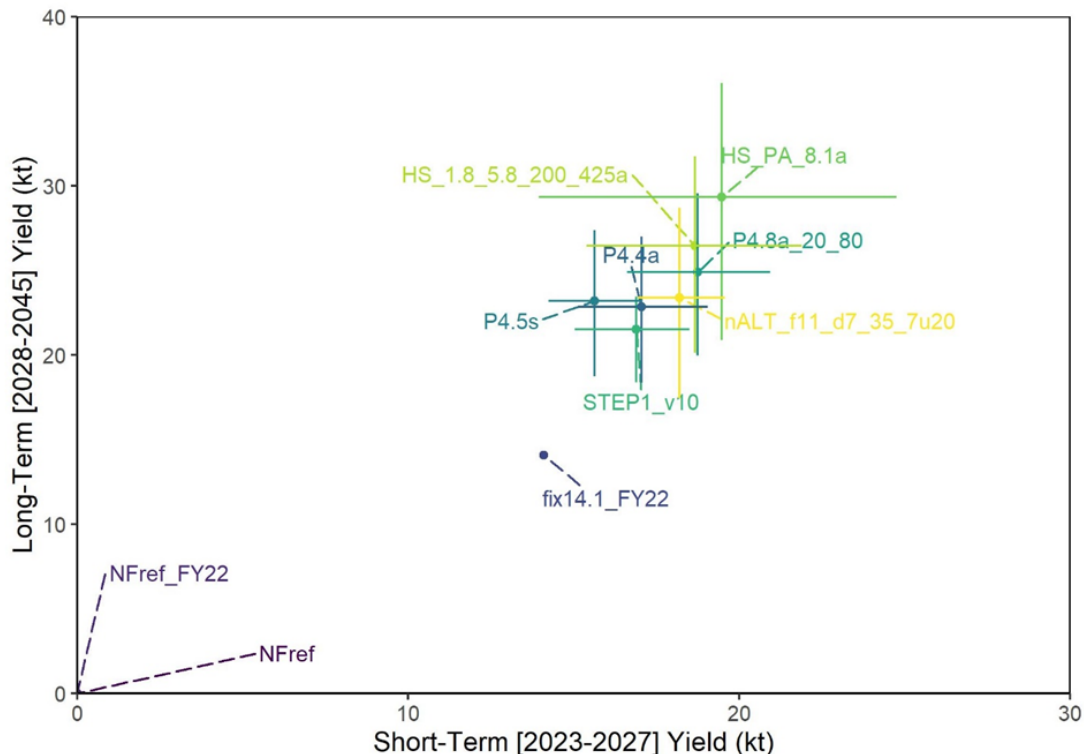


Figure 11. Trade off in performance of Management Procedures (MPs) for long-term (2028–2045) and short-term (2023–2027) yield (kt). Across the 12 Operating Models (OMs) the median is represented as a point and the minimum and maximum values are the error bars.



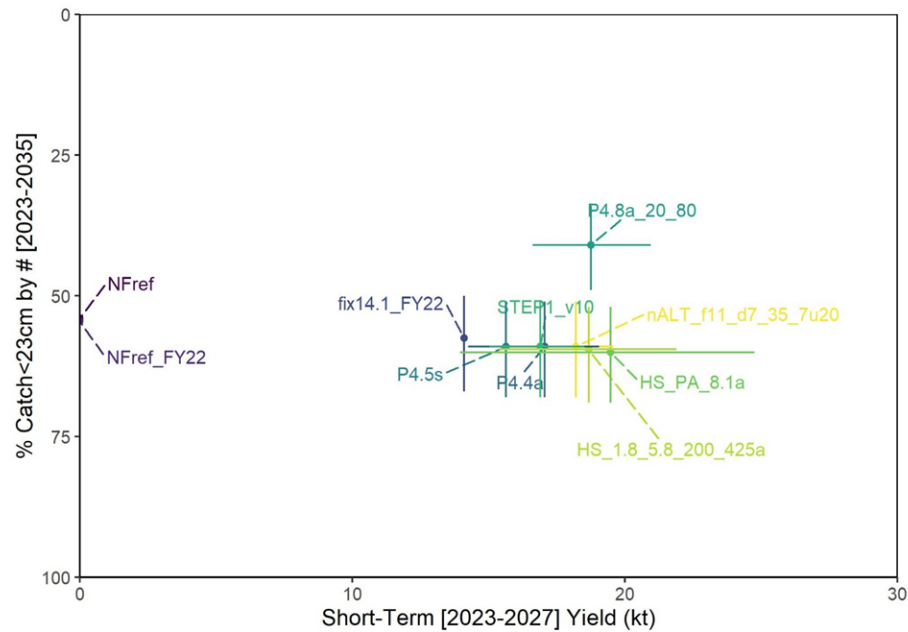


Figure 12. Trade off in performance of Management Procedures (MPs) for limiting the removal (%) of small (< 23 cm) fish by 2023–2035) and short-term (2023–2027) yield (kt). Across the 12 Operating Models (OMs) the median is represented as a point and the minimum and maximum values are the error bars.

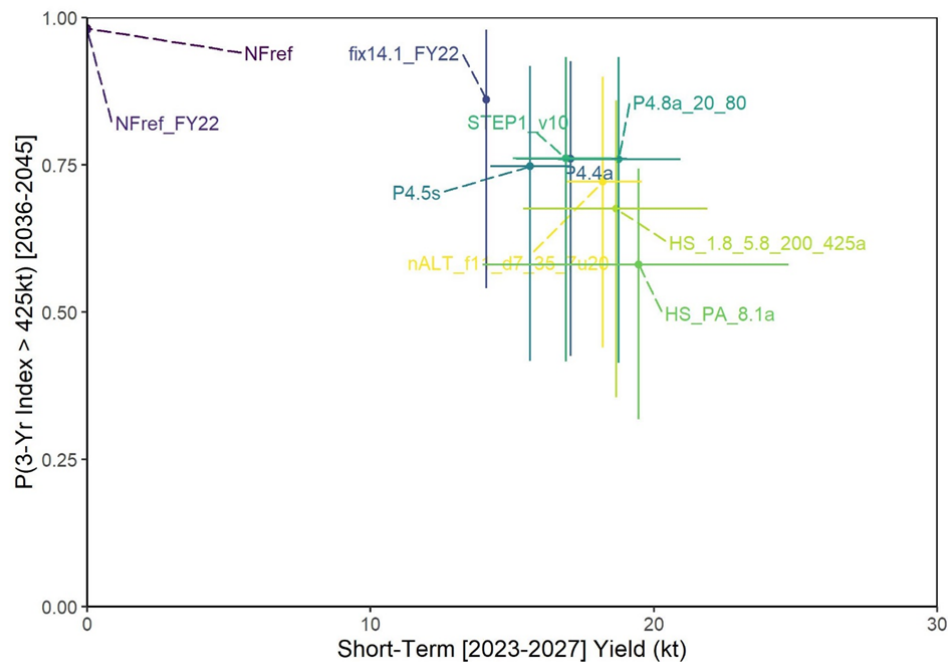


Figure 13. Trade off in performance of Management Procedures (MPs) assessing the probability that the three-year moving average of acoustic SSB is greater than 425 kt (2036–2045) and short-term (2023–2027) yield (kt). Across the 12 Operating Models (OMs) the median is represented as a point and the minimum and maximum values are the error bars.

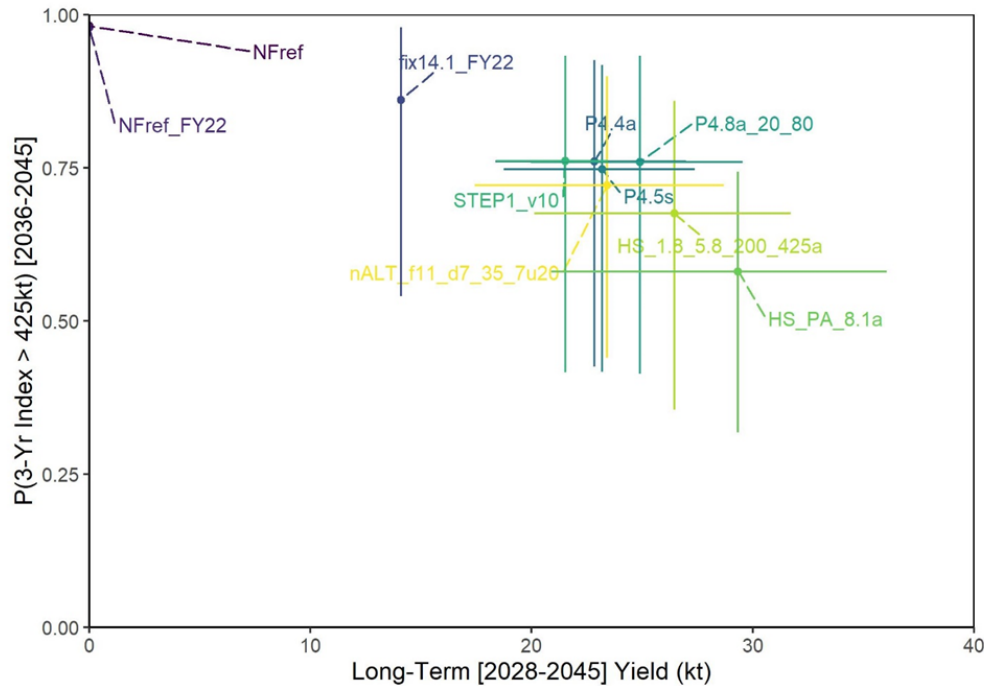


Figure 14. Trade off in performance of Management Procedures (MPs) assessing the probability that the three-year moving average of acoustic SSB is greater than 425 kt (2036–2045) and long-term (2028–2045) yield (kt). Across the 12 Operating Models (OMs) the median is represented as a point and the minimum and maximum values are the error bars.

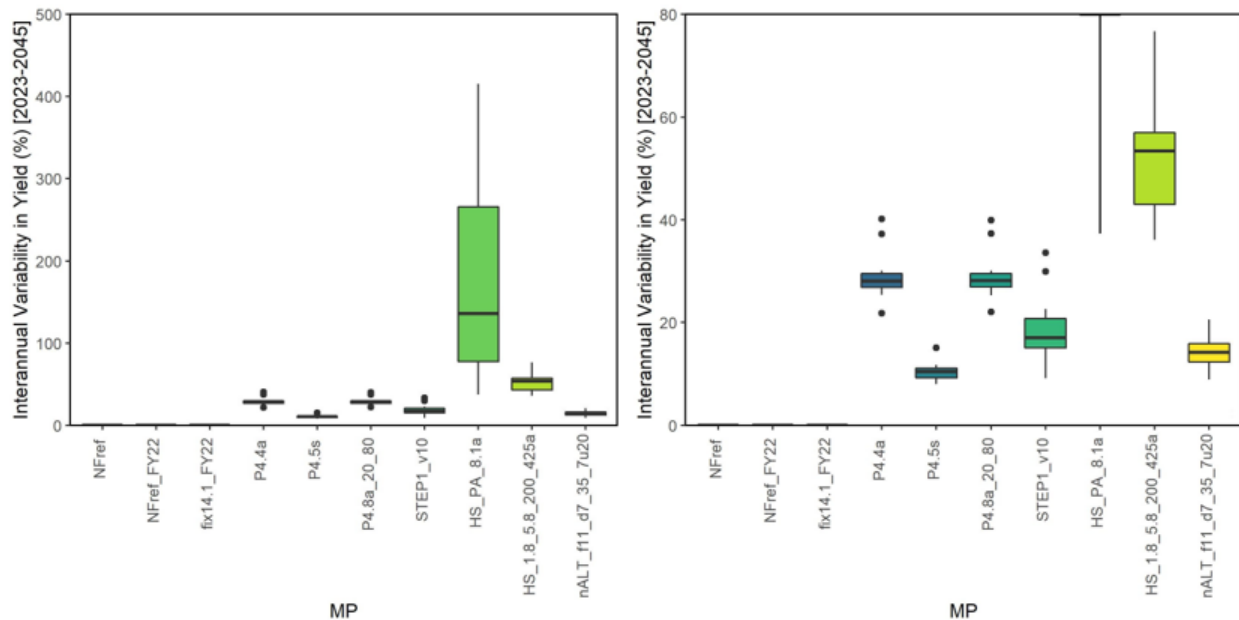


Figure 15. Performance of Management Procedures (MPs) for the reference set of Operating Models (OMs) for objective 5. Left panel shows the full range of variability among MPs while the right panel shows the same plot, but the y-axis is scaled to visualize the relatively smaller values. The boxplots display the minimum, 25<sup>th</sup>, 50<sup>th</sup>, and 75<sup>th</sup> percentiles, and maximum values across the 12 OMs. Values more than the 1.5 times the interquartile range beyond 25<sup>th</sup> and 75<sup>th</sup> percentiles are plotted as individual values.

### Assessing Rebuilding and Preventable Decline in the Absence of Fishing

As part of this update, DFO Science was asked to estimate  $T_{min}$  (the time required to rebuild the stock above the LRP with a high probability in the absence of fishing) in the closed-loop simulation projections year 3 to year 8 across MPs and to estimate the Probability of Preventable Decline for each candidate MP. These considerations did not form part of the original MSE framework (Barrett In press) and stem from requirements under the Department's new *Guidelines for writing rebuilding plans per the Fish Stocks Provisions and A Fishery Decision-making Framework Incorporating the Precautionary Approach* (DFO 2020b).

The value of  $T_{min}$ , defined as the number of years required for the stock to have a  $P(SSB > SSB_{2005-2010}) > 0.75$  in the absence of fishing was estimated for each OM. Since fishing occurred in 2021 and 2022,  $T_{min}$  was calculated using projection year 3 (2023) as the first year of rebuilding. The estimate of  $T_{min}$  ranged between 2 to 4 years across OMs (Table 4).

*Table 4.  $T_{min}$  estimates across all Operating Models (OMs) for Southwest Nova Scotia/Bay of Fundy (SWNS/BoF) herring, where  $T_{min}$  is defined as the time period for the model estimated SSB to rebuild above the mean SSB from 2005–2010 with probability greater than 0.75 for each OM.*

OM	$T_{min}$ in Years	$P(SSB > SSB_{2005-2010})$
1	2	0.772
4	2	0.785
7	4	0.823
10	4	0.827
13	2	0.878
16	2	0.874
19	3	0.856
22	3	0.867
25	2	0.787
28	3	0.760
31	2	0.876
34	3	0.872

A method to estimate the probability of preventable decline was presented in the update meeting; however, multiple different approaches could be used and the scope of this term of reference was deemed to be beyond that for a Science Response and a separate peer-review meeting would be needed to review these methods. No advice is therefore provided on the probability of preventable decline.

### Evaluation of Exceptional Circumstances

Exceptional circumstances are commonly defined in MSE frameworks to address situations outside the range for which MPs were simulation-tested or when the data required to apply MPs are not available. The exceptional circumstance protocols defined within the 2022 MSE framework (Barrett In Press) set "Science considerations" for each exceptional circumstance. Exceptional circumstances are evaluated annually or when new data become available.

Within this update, the exceptional circumstances were evaluated for the 2022 fishing season, and include fishery catch data for 2021 and 2022, and the acoustic index of SSB for SWNS/BoF for 2021 and 2022. No exceptional circumstances were triggered from the 2022 data. Results are reported below for each of the established exceptional circumstances for this update:

1. The observed acoustic index of SSB is outside the 90% prediction interval (5<sup>th</sup> and 95<sup>th</sup> percentiles) for all OMs in the reference set in a single year.

The observed index in 2022 (332.57 kt) is within the 90% prediction interval for the projected index in 2022 for all OMs. The 90% prediction interval for the projected index in 2022 is (166 kt–468 kt) for OM10 (most pessimistic OM) and (181 kt–509 kt) for OM31 (most optimistic OM).

2. Mean weight-at-age for Age 3, 4, 5, 6, or 7 is above/below the upper/lower 98% (2-tailed) prediction interval for the predicted weight-at-age for growth scenario Binv/B.

Observed mean weight-at-age in 2022 for Age 3 to 7 fish were within the lower/upper 98% (2-tailed) prediction interval for the growth scenario B/Binv. The mean weights-at-age were 107 g, 142 g, 161 g, 196 g, 216 g for Age 3, 4, 5, 6, and 7 Herring, respectively. Note that as the projection year advances the uncertainty in the predicted lower and upper weight-at-age decreases and increases, respectively.

*Table 5. Upper and Lower 98% prediction intervals for mean weight-at-age (g) for 2022 (projection Year 1) compared to observed mean weight-at-age taken from commercial catch samples in 2021.*

Age	Predicted Lower	Predicted Upper	Observed mean 2022
3	76	115	107
4	113	148	142
5	140	170	168
6	160	202	195
7	184	223	219

3. New Brunswick southwest weir/shutoff landings > 50% of the SWNS/BoF TAC.

In 2022, New Brunswick southwest weir/shutoff landings were 14.0% of the TAC.

4. Evidence that the catch for quota fisheries for the SWNS/BoF stock area > 10% more than TAC.

There is no evidence to suggest that these fisheries exceeded the quota in 2022.

5. DFO Science identifies new data to suggest that data inputs or model assumptions are no longer valid.

The MSE framework was recently (2022) peer-reviewed and there is no evidence to suggest that that model assumptions are no longer valid. The MP evaluations were updated for this update, applying observed catch and estimated acoustic index of SSB for 2021 and 2022 to account for these new data.

6. The acoustic index of SSB is not available or is insufficient to apply the MP.

The acoustic index of SSB was available through sufficient surveys conducted by industry vessels. With these surveys, the acoustic index of SSB for 2022 fishing year could be successfully estimated.

7. Acoustic estimate of SSB on the spawning grounds outside of German Bank and Scots Bay greater than the 90<sup>th</sup> percentile of the overall historical observation error on the index (30.9%) for two consecutive years.

The total combined biomass of spawning grounds outside of German Bank and Scots Bay (i.e., Trinity, Spectacle Buoy, and Seal Island) was 54,911 t in 2022. The acoustic index in 2022 was 332,570 t giving a trigger for this exceptional circumstance of 102,764 t, for which 54,911 t is well below.

### Offshore Scotian Shelf Component

In 2022, offshore landings were 2,548 t (Table 1). These landings are less than 50% of the allocation limit of 8,000 t. Since 1996, a fishery has occurred on aggregations on the offshore banks, primarily in May and June, with catches ranging from 20,261 t in 1997 to 37 t in 2020. Recent landings have been low, less than the 12,000 t annual allocation, from 2012 to 2021. The allocation was updated to 8,000 t for the 2022 fishing season. Landings from the offshore component are subject to market, weather, offshore fish availability, and relative quota in SWNS/BoF herring component. No acoustic surveys were conducted on the Offshore Scotian Shelf during the years 2015–2022.

### Coastal Nova Scotian (South Shore, Eastern Shore and Cape Breton) Spawning Component

Allocations for the Coastal NS spawning component are based on the recent 5-year average of observed acoustic index of the SSB, where available. Landings in the Little Hope/Port Mouton area were 6,900 t against the 2022 allocation of 8,595 t. The 2022 landings were greater than landings in 2021 at 6,355 t but less than the landings in 2020 at 10,747 t (Table 6). In the Eastern Shore area, landings were 5,495 t in 2022 against the allocation of 5,699 t. The 2022 landings were less than the maximum annual landings in 2020 at 6,871 t (Table 6). In Glace Bay, landings of 0 t were reported in 2022, and have been between 0 t to 9 t since 2018, yearly. The Bras d'Or Lakes area remained closed to Herring fishing.

For acoustic surveys in Little Hope/Port Mouton and Eastern Shore that occurred less than 10 days apart, no matter where in the allocation box a single, maximum biomass estimate was used in the report. Little Hope/Port Mouton had conducted a total of 5 surveys where 4 were used in the estimate. Eastern Shore conducted a total of 10 surveys and 3 were used in the biomass estimate.

The acoustic index of the SSB for the Little Hope/Port Mouton area decreased to 41,383 t in 2022 from 82,297 t in 2021 and is below the 5-year average of 83,041 t (Table 7).

The acoustic index of the SSB for the Halifax/Eastern Shore area increased to 20,313 t in 2022 from 18,341 t in 2021 and is below the 5-year average of 49,694 t (Table 7). As in previous years, caution is warranted in applying the acoustic index of the SSB as an absolute tonnage of Herring in the water.

Since 2013, no survey has been completed in Glace Bay.

*Table 6. Recorded landings and allocations (tonnes) of Herring from major gillnet fisheries on the Coastal Nova Scotia spawning component average for 1998 to 2012 and biomass for 2013–2022. Landings reported are from the MARFIS database and include Herring landed outside of the allocation season.*

Landings and Allocations (t)		Avg. 98–12	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Little Hope/Port Mouton	Catch	2,558	2,499	3,596	4,160	5,943	5,557	7,353	8,707	10,747	6,355	6,900
	Allocation	2,487	2,387	3,577	3,772	6,151	6,803	7,884	9,757	10,676	8,622	8,595
Halifax/Eastern Shore	Catch	2,596	1,390	1,163	1,001	1,837	2,259	2,553	4,544	6,871	5,635	5,495
	Allocation	3,359	2,427	1,959	1,066	1,884	2,856	3,960	4,671	7,303	6,649	5,699
Glace Bay	Catch	1	2	1	0	4	0	9	1	2	0	0
Bras d'Or Lakes	Catch	0	0	0	0	0	0	0	0	0	0	0

Table 7. Estimated acoustic index of the Herring spawning stock biomass (tonnes) average for 1998–2012, biomass for 2013 to 2022 and recent 5-year average for the Coastal Nova Scotia spawning component areas.

Acoustic index of SSB (t)	Avg. 98–12	2013	2014	2015	2016	2017	2018	2019	2020*	2021*	2022	Avg. last 5 years
Little Hope (SSB)	25,244	73,992	46,077	145,395	61,408	66,815	168,164	92,019	35,739	82,297	41,383	83,920
Allocation	2,487	2,421	3,577	3,772	6,151	6,803	7,884	9,757	10,676	8,622	8,595	
Halifax (SSB)	29,994	6,870	9,586	68,562	54,312	58,681	42,416	141,198	26,205	18,341	20,313	49,694
Allocation	3,359	2,630	2,240	1,066	1,884	2,856	3,960	4,671	7,303	6,649	5,699	
Glance Bay	7380	-	50	-	-	-	-	-	-	-	-	-
Bras d'Or Lakes	300	-	-	-	-	-	-	-	-	-	-	-

"-" = no survey

\* Adjustments in estimated biomass were made in survey area in this report compared to DFO 2022a because edge transects did not have equal weighting as interior transects.

### Southwest New Brunswick Migrant Juveniles Component

The southwest New Brunswick weir and shutoff fisheries have relied, for over a century, on the aggregation of juvenile Herring (Ages 1–3) near shore at the mouth of the Bay of Fundy. Herring landed from southwest New Brunswick weir and shutoff fisheries are conventionally considered to originate from NAFO Subarea 5 spawning component. Therefore, DFO Resource Management have excluded these landings from the SWNS/BoF quota.

Landings from the New Brunswick weir and shutoff fishery were 3,286 t in 2022, which is lower than the 4,014 t in 2021 (Figure 16). In 2020, 2021 and 2022, Age 2 dominated the fishery with 98% and 94% in the landings, respectively (Figure 17).

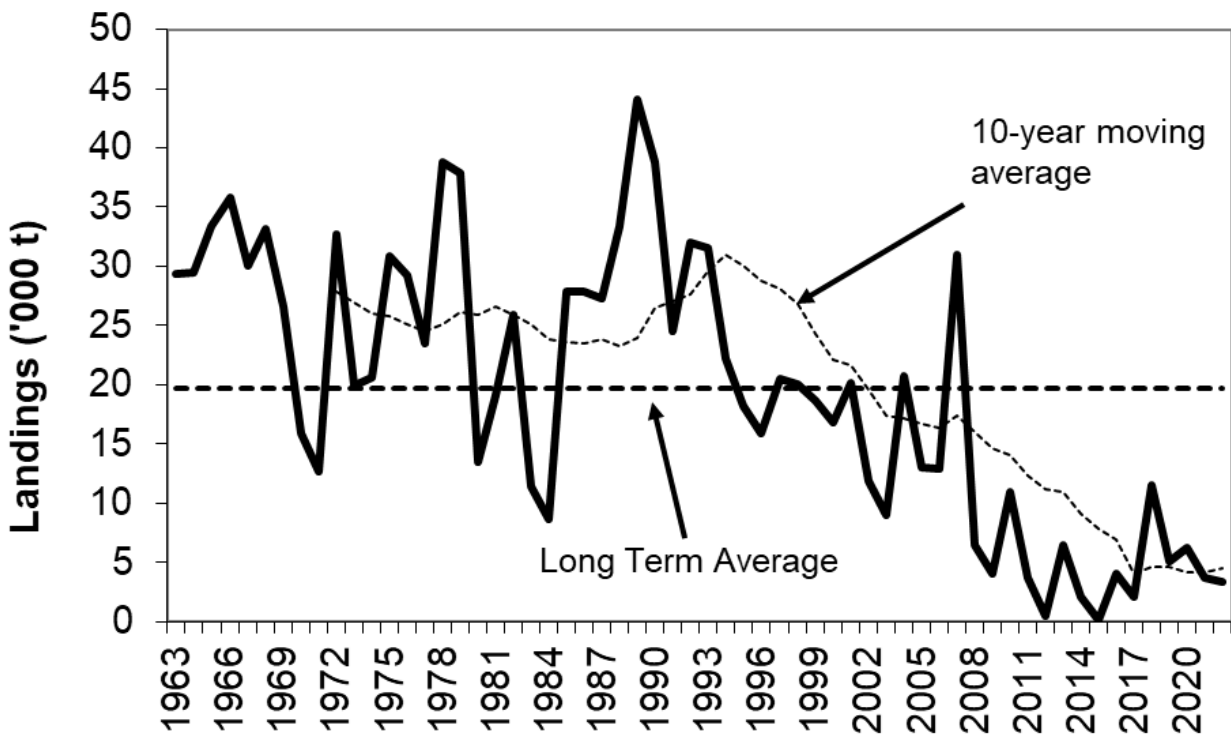


Figure 16. Herring landings (in thousands of metric tonnes) from the New Brunswick weir and shutoff fishery for 1963–2022.

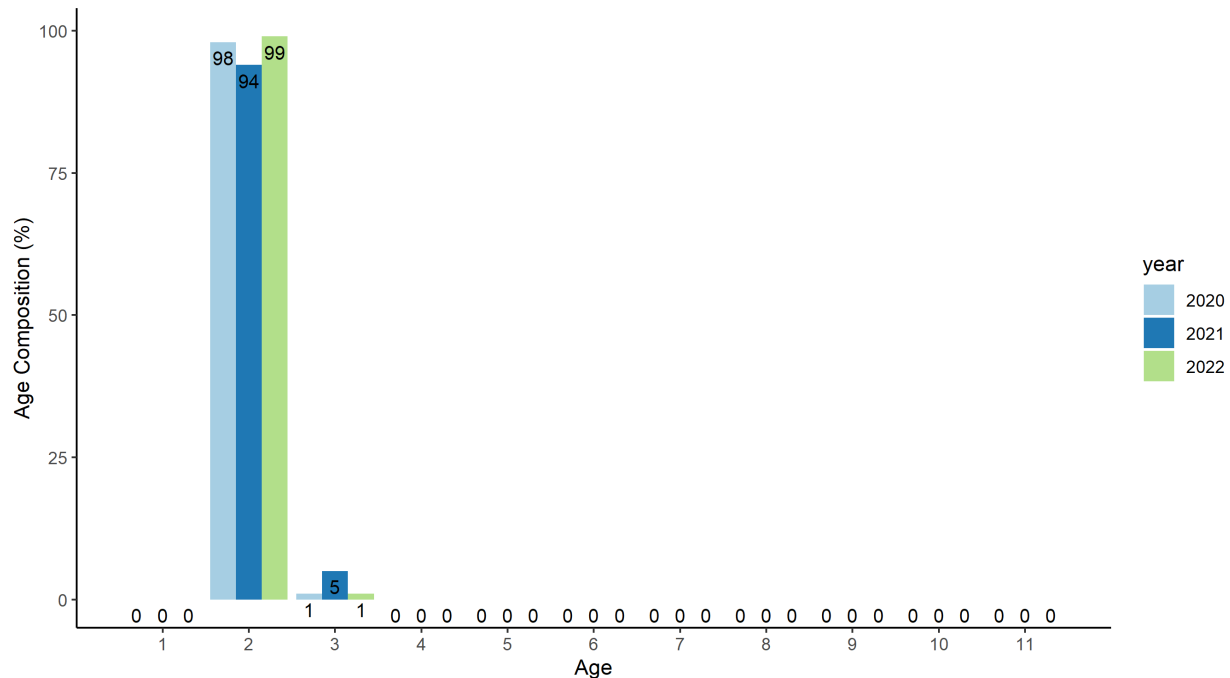


Figure 17. Age composition (% by number) for the SWNB migrant juveniles (weir and shutoff gear) for calendar years (2019, 2020, and 2021).

For the time series presented, current NB weir and shutoff landings are at or near the lowest observed values. Landings for this fishery are highly variable and are not indicative of abundance because catches are susceptible to market, effort, and fish availability.

## Conclusions

### Southwest Nova Scotia/Bay of Fundy Spawning Component

The 2022 German Bank SSB was 66% below the long-term average (1999–2022) making it the lowest this area has been since 1999 (Figure 7). Despite this decrease, the overall annual acoustic index of the SSB for the SWNS/BoF spawning component increased by 36.6% in 2022 compared to 2021. Although the increase in the index is notable, there is an overall decreasing trend in the acoustic index since 1999 to present that is evident for the two remaining major spawning grounds, German Bank and Scots Bay, which are used to assess the relative stock status of the SWNS/BoF component. The 3-year moving average (arithmetic mean) of the summed SSB in German Bank and Scots Bay is used to determine trends in the acoustic index of SSB and is compared to the LRP (Clark et al. 2012). The 3-year moving average SSB of German Bank and Scots Bay increased from 2021 (257,719 t) to 2022 (275,086 t), and remains below the LRP, and the SWNS/BoF component is considered in the Critical Zone (Figure 6). The DFO PA policy (DFO 2009) states that when a stock is considered in the Critical Zone, productivity is sufficiently impaired to cause serious harm.

The acoustic index of biomass for Trinity Ledge increased from 4,098 t in 2021 to 17,475 t in 2022. The acoustic index of biomass for Seal Island, was 21,643 t in 2022, which is the second highest estimate observed since consecutive surveys began in 2018. Despite increases in biomass from 2021 to 2022 for these spawning grounds, caution is still warranted for these spawning components due to the variation in annual observation. These spawning components were historically, large-spawning grounds, so further increases in future years would provide better evidence these components are recovering.

The HS\_PA\_8.1a MP had the highest long-term (2028–2045) and short-term (2023–2027) yields (Figure 11) but also had the highest interannual variability in yield (Figure 15). This interannual variability is high due to no fishing occurring before an annual acoustic SSB of 318 kt followed by a steep increase in TAC between an annual acoustic SSB of 318 kt and 425 kt (Figure 8). The MPs with higher yields have a lower probability of the 3-year moving average acoustic index being above a target biomass of 425 kt in the long-term (Figure 13 and Figure 14). The HS\_1.8\_5.8\_200\_425a MP had higher long-term and short-term yield compared to nALT\_f11\_d7\_35\_7u20 (Figure 11) but at the expense of higher variability in yield (Figure 15). The lower variability in yield for nALT\_f11\_d7\_35\_7u20 is achieved by using the 3-year moving average acoustic index as well as the limits on the annual change in TAC (Figure 10). The MP with a fixed harvest rate of the annual acoustic index had lower yields compared to those that have larger reductions in the TAC at low biomass (Figure 11). The MPs with similar structure that attempt to reduce the variability in yield compared to P4.4a were the STEP1\_v10 MP and the fixed harvest rate MP that used the 3-year moving average acoustic index (P4.5s). A lower short-term yield for P4.5s and a lower long-term yield for STEP1\_v10 (Figure 11) are achieved to obtain the lower variability in yield (Figure 15). Reducing the proportion of small fish in the catch (MP 4.8a\_20\_80) increases the harvest rate (4.8 compared to 4.4) to achieve the conservation objective thereby increasing yields (Figure 11), reducing the percentage of the catch below 23 cm (Figure 12) while maintaining a relatively high probability of the 3-year moving average acoustic index being above a target biomass of 425 kt in the long-term (Figure 13 and 14). MP 4.8a\_20\_80 is the only MP that changes future selectivity so all other MPs have similar percentage of the catch below 23 cm (Figure 12). The fixed TAC MP allows a catch while keeping variability in yield as zero, thus has lower yields compared to the other MPs (Figure 11) and higher probability of the 3-year moving average acoustic index being above a target biomass of 425 kt in the long-term (Figure 13 and Figure 14).

The MPs shown in this update are a subset of MPs with different shapes for which the control points were tuned to meet the minimum performance standard of having a probability of  $SSB > SSB_{2005-2010}$  above 0.75 in each year for years 10–15 of the projections. Harvest rates and TACs can be further reduced to achieve other management objectives.

### Offshore Scotian Shelf Component

There was an increase in the landings from the offshore banks from 921 t in 2021 to 2,548 t in 2022, below the annual allocation limit of 8,000 t. In the absence of recent information about stock status, there is no basis for evaluating the current catch allocation. Structured acoustic surveys are needed to obtain data on the stock in the offshore area.

### Coastal Nova Scotian (South Shore, Eastern Shore and Cape Breton) Spawning Component

From 2018 to 2022, landings in the Little Hope/Port Mouton area have ranged from 6,355 t to 10,747 t, and have been near or above the allocation in some years (from –2,267 t to +71 t).

From 2018 to 2022, landings in the Eastern Shore area have ranged from 2,553 t to 6,871 t, and are generally within the allocation (from –1,407 t to –127 t).

Landings were minimal for Glace Bay since the last assessment (DFO 2018), with 9 t reported in 2018, 1 t in 2019, 2 t in 2020, and none in 2021 and 2022.

The Bras d'Or Lakes area remained closed to Herring fishing. No Herring surveys have been conducted in the Bras d'Or Lakes since 2000. It has been noted since 1997 that the status of Herring in the Bras d'Or Lakes is cause for concern. In the absence of current abundance information, there is no information upon which to recommend a change to the management approach for the Bras d'Or Lakes.



Individual spawning groups within the Coastal component are considered vulnerable to fishing because of their relatively small size (biomass) and proximity to shore. For this reason, a large effort increase in new areas has potential to markedly reduce abundance in the absence of information about the status of the specific spawning group.

### Southwest New Brunswick Migrant Juveniles Component

Landings in the New Brunswick weir and shut-off fishery decreased to a historic low in 2015 of 146 t, increased to 4,060 t in 2016, and decreased to 2,102 t in 2017. It is notable that in 2007 landings were 30,944 t, the highest in nearly 20 years and higher than the long-term average of 20,680 t. From 2018 to 2021, weir landings decreased from 11,574 t to 2,663 t. Landings for this fishery are highly variable and are not indicative of abundance because catches are variable and are susceptible to market, effort, and fish availability. Age 2 fish dominated the fishery in 2020, 2021, and 2022.

Abundance of Herring available to the weirs is unknown and there is very little research being conducted to investigate local Herring abundance.

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## Appendix

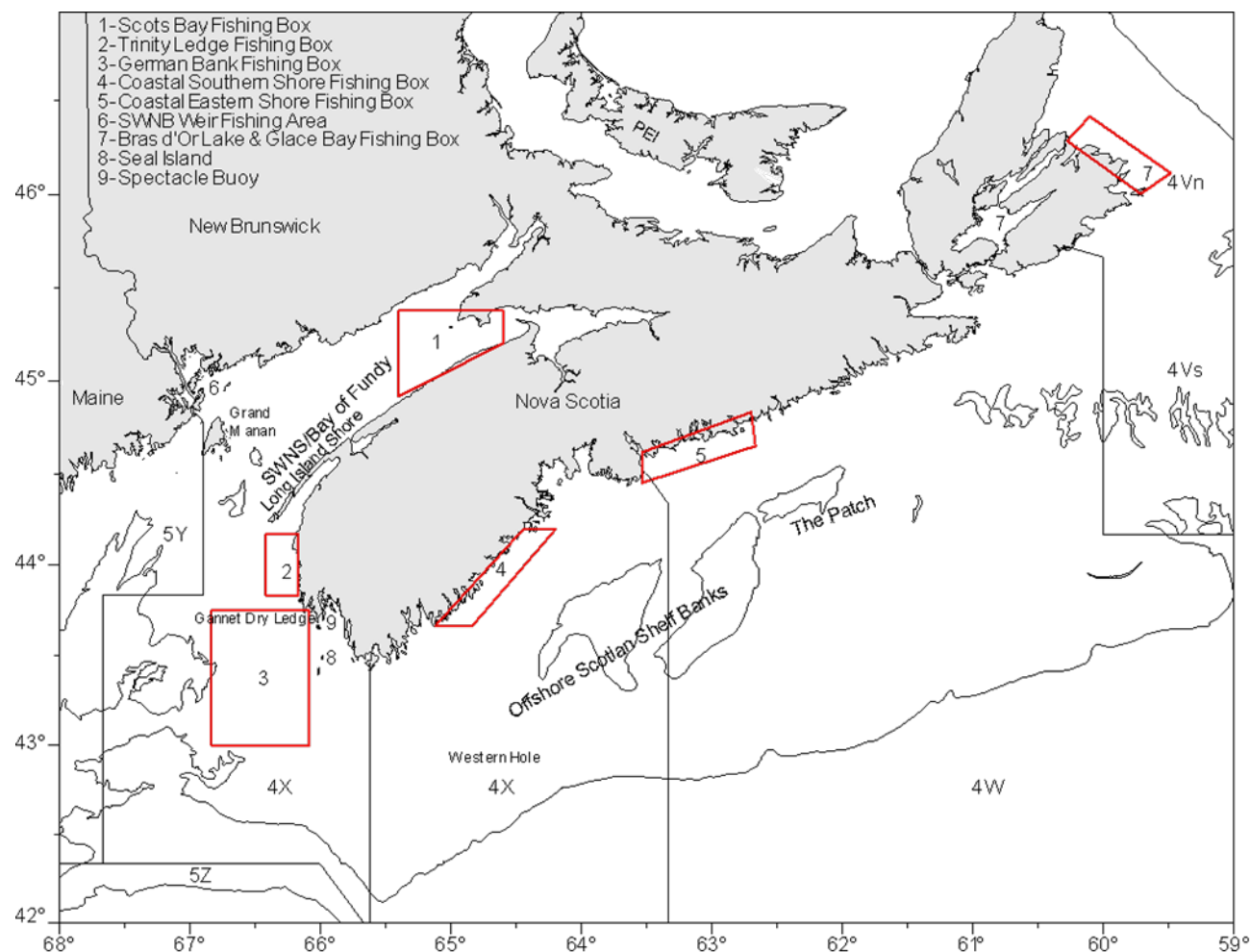


Figure A1. Place names and fishing locations for Southwest Nova Scotia/Bay of Fundy, Coastal NS (South Shore, Eastern Shore, Cape Breton), Offshore Scotian Shelf, and SWNB weirs. The vertical line between the two 4X labels indicates the outer boundary of the Southwest Nova Scotia/Bay of Fundy (SWNS/BoF) stock component.

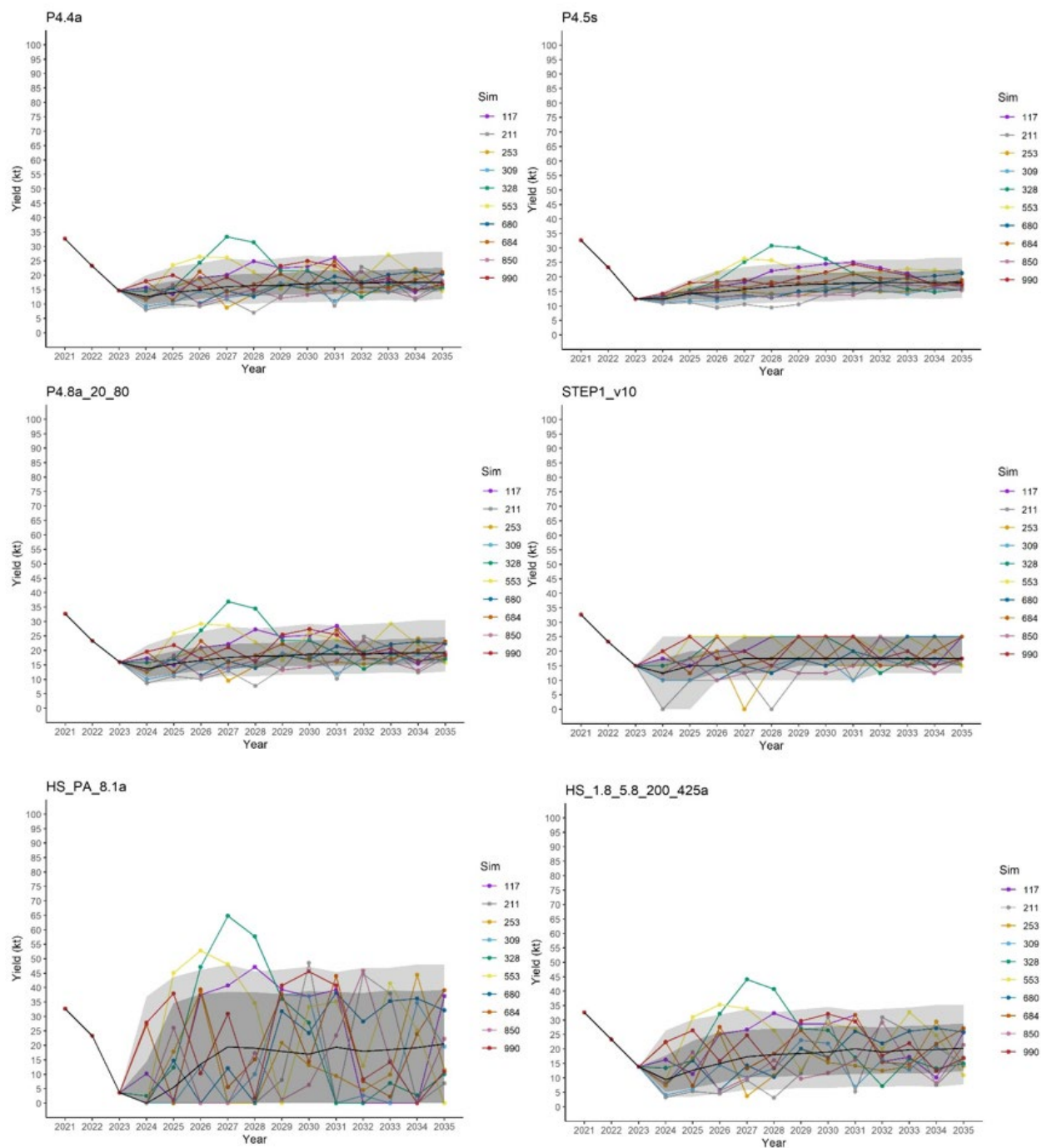


Figure A2. Worm plots showing the variability in yield (kt) within each simulation of OM10 for Management Procedures (MPs) P4.4a, P4.5s, P4.8a\_20\_80, STEP1\_v10, HS\_PA\_8.1a, and HS\_1.8\_5.8\_200\_425a. Coloured lines represent individual simulations. The black line represents the median and the shaded areas denote the 10<sup>th</sup>, 25<sup>th</sup>, 75<sup>th</sup> and 90<sup>th</sup> percentiles.

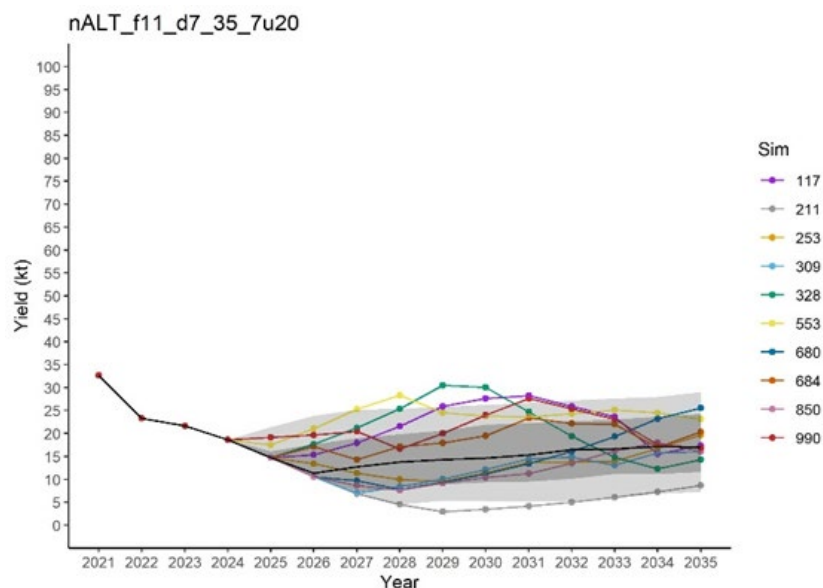


Figure A3. Worm plot showing yield (kt) per year from individual simulations of OM10 using the *nALT\_f11\_d7\_35\_7u20* Management Procedure (MP) which was modified from an Industry proposal. Coloured lines represent individual simulations. The black line represents the median and the shaded areas denote the 10<sup>th</sup>, 25<sup>th</sup>, 75<sup>th</sup> and 90<sup>th</sup> percentiles.

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