Fisheries and Oceans Canada | Pêches et Océans Canada
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Canadian Science Advisory Secretariat
Maritimes Region **Science Response 2024/030**

STOCK STATUS UPDATE OF 4VWX HERRING FOR THE 2024 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 the 2024 fishery. The last full assessment of 4VWX Herring was conducted in March 2022 (DFO 2022). 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 (SWNS/BoF) spawning component.
- Update and review information on the other spawning components (Offshore Scotia 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 (OMs) for the SWNS/BoF component.
- Advise on the probability of rebuilding above the LRP over the projection period (2021–2045) for each candidate MP for the SWNS/BoF component.
- Assess whether exceptional circumstances are triggered for the SWNS/BoF component.

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 LRP defined in terms of this acoustic index (Clark et al. 2012). It also accounts for turnover of spawners at these grounds (DFO 2018). For the SWNS/BoF 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 2023). The science advice for 2024 uses the 2022 assessment framework to evaluate whether candidate MPs 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. The analytical model was accepted for peer-review for the 2022 assessment (DFO 2022). However, Total Allowable Catch (TAC) advice for 2022 and 2023 was not based on an implemented MP, instead, one-year TACs were set for 2022 and for 2023. 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 March 20, 2024, on the Stock Status Update of Herring in Northwest Atlantic Fisheries Organization (NAFO) 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 with 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 TAC for SWNS/BoF was 21,000 t in 2023. 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, and was further reduced to 4,000 t for the 2023 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 landings and survey information in recent years, there is no basis for evaluating this component. A larger Canadian-directed fishery on Georges Bank for Herring has not occurred since the mid-1970s (Stephenson et al. 1987). Herring catches have occurred on Georges Bank in 1996 to 2004 (16 t to 3,317 t annually); however, aside from 2021 when 23 t of Herring were harvested, Herring catches on Canadian portion of Georges Bank have not been reported. There was an allocation of 20,000 t for the Georges Bank component until 2022, in 2023 the allocation was changed to 1,000 t.

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 (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 2022).

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

Candidate MPs were evaluated using the MSE framework to determine whether they rebuild the SWNS/BoF component above the LRP with a high probability in the simulations. 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 each year in years 10 to 15 of the projection period in the closed-loop simulations to meet this objective.

This update identifies in a projection period (1 to 25 years) which candidate MPs meet the conservation objective of being above the LRP in years 2030 to 2035 using closed-loop simulations that include the observed catches and acoustic index of SSB from 2021, 2022, and 2023.

Analysis and Response

Landings

Landings from the Herring fishery in 4VWX have been greatest by purse seine (e.g., 81–99%, 1981–2023). Other gear types consist mainly of weir, gillnet, shutoff, and trap net. The landings for the period January 1, 2023, to December 31, 2023 (the 2023 quota year) were 20,705 t against a TAC of 21,000 t for the SWNS/BoF component (Table 1). Note that the quota year previous to 2020 was from October 15th of the preceding calendar year to October 14th of the current calendar year. The interim landings 4WX SWNS/BoF area from October 14th 2018 to December 31st, 2019 were included in the 2019 quota year landings. Since 2020, the reported fishing season is now within a calendar year of January 1st to December 31st.

Table 1. Reported landings (rounded to thousands of tonnes) and total allowable catch for 4VWX Herring from 2015 to 2023 with decadal averages from 1970 to 2019.

Year	Avg. 1970–79	Avg. 1980–89	Avg. 1990–99	Avg. 2000–09	Avg. 2010–19	2016	2017	2018	2019	2020	2021	2022	2023
4WX SWNS/BoF TAC[1]	106	106	112	69	48	50	42.5	42.5	35	35	35	23.45	21
4WX SWNS/BoF[1]	131	131	96	66	45	50	39	40	35	34	33	23	21
4VWX Coastal NS[2]	< 1	< 1	4	7	7	8	8	10	13	18	12	12	12
Offshore Scotian Shelf[2]	38	< 0.1	13	6	4	1	4	3	6	< 0.1	< 0.9	2.5	0.8
SW New Brunswick[2]	26	24	24	15	5	4	2	12	5	6	4	3.3	0.9
Total Landings	172	155	137	93	60	63	53	65	53	56	48	41	35

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

Additional landings of 13,806 t were taken in the other components (outside the SWNS/BoF area) for a total of 34,511 t for all of 4VWX. The Coastal NS component had total landings of 12,118 t. Landings were 781 t for the Offshore Scotian Shelf. Landings for SWNB weirs and shutoffs were lower in 2023 (907 t) compared to 2022 (3,286 t).

Southwest Nova Scotia/Bay of Fundy Spawning Component

Age Structure

Age-structured data are presented herein using an age-length key methodology specified by year and season developed for the 2019 to 2022 framework for the SWNS/BoF component (Carruthers et al. 2023, Barrett 2023). The 2021 landings were greatest for Age 2, whereas Age 3 were greatest for the 2022 and 2023 landings (Table 2, Figure 1). Based on the age

structure, the total number of fish removed by the fishery was estimated to be 305 million in 2021, 168 million in 2022, and 158 million in 2023 (Figure 1).

Table 2. Commercial catch age composition (% catch by abundance) for Southwest Nova Scotia/Bay of Fundy spawning component for calendar years 2021, 2022, and 2023 from purse seine and gillnet gear.

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9
2021	0%	40%	28%	7%	12%	7%	4%	1%	0%
2022	0%	13%	48%	18%	4%	9%	5%	3%	0%
2023	0%	28%	32%	19%	4%	9%	4%	4%	1%

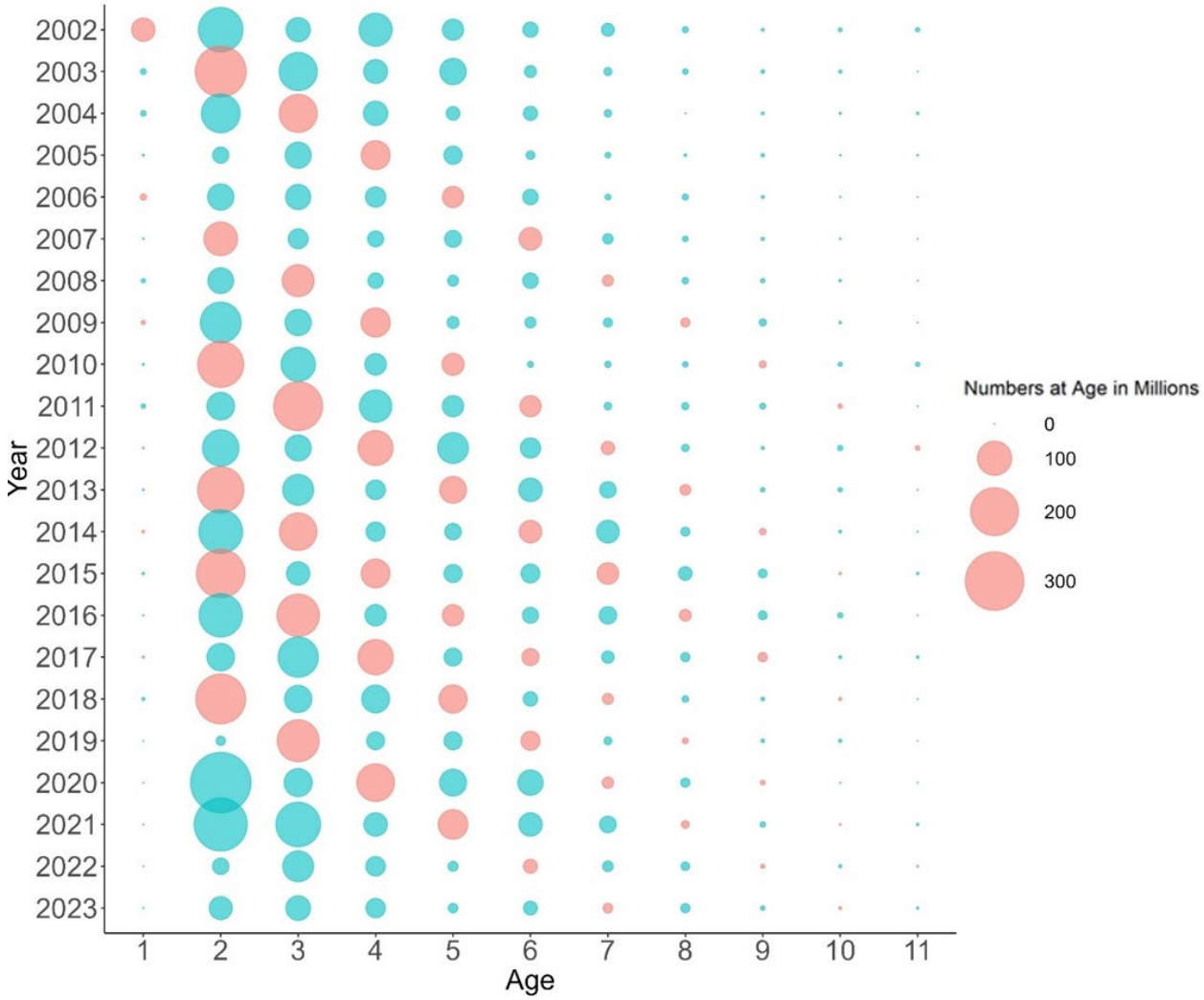

Figure 1. Numbers-at-age in the commercial landings for Southwest Nova Scotia/Bay of Fundy spawning component from 2002–2023 by quota year from purse seine and gillnet gear. The size of the bubble is proportional to the numbers by age. Selected cohort from 1998, 2005, 2007, 2011, 2013, and 2016 are shown in red.

Since the 1970s, trends in weight-at-age for Ages 4 to 11 decreased and mean weight-at-age for Age 2 and 3 has increased (Figure 2). Since about 2010–2015, the downward trend has been absent for Ages 4 to 11. Declining trends in the older age classes in the commercial mean weight-at-age since 1970s have reduced the productivity of the stock (Barrett 2022). The

mechanisms influencing changes in weight-at-age for SWNS/BoF component Herring are not well understood and require further study.

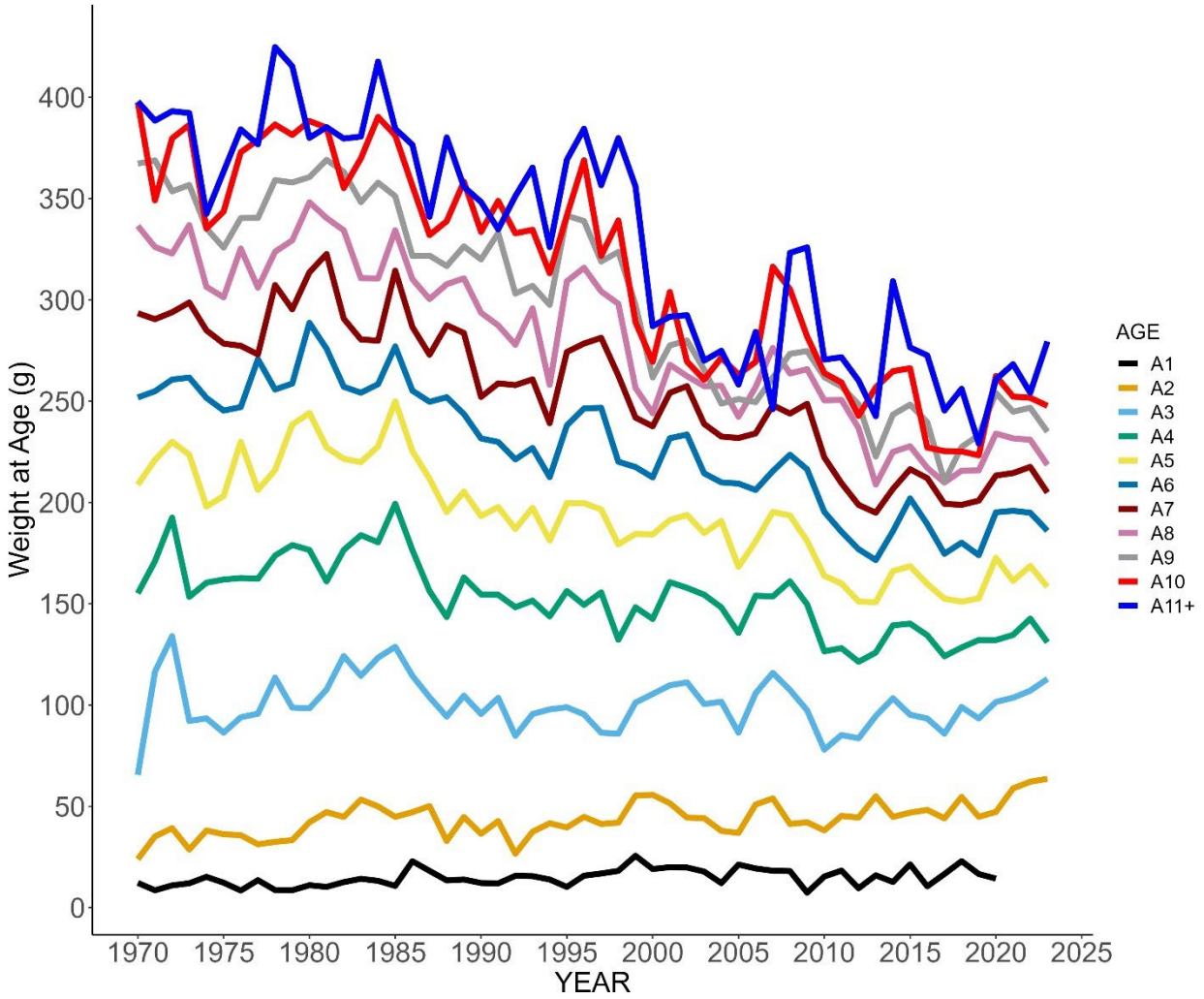

Figure 2. Fishery mean weight-at-age for the Southwest Nova Scotia/Bay of Fundy component from 1970 to 2023. Age 1 fish have not been sampled since 2020.

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 3).

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). A calculation error was identified, so the LRP has since been revised to 317,846 t. 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.

The results of the 2023 acoustic surveys for the SWNS/BoF component are summarized in Table 3. Inbox and outbox refer to survey tracks within and outside the designated survey boxes, respectively. There were 11 surveys in Scots Bay, 7 on German Bank, 7 on Seal Island, 5 on Trinity Ledge, and 6 in the Spectacle Buoy area. Tagging data to generate turnover estimates have not be considered for Trinity Ledge, Spectacle Buoy, and Seal Island. In these areas, if surveys do occur less than 10 days apart, they cannot be counted towards annual SSB estimates to avoid double-counting. Instead, annual SSB estimates are calculated by finding the maximum SSB estimates from surveys that occurred more than 10 days apart.

Table 3. Acoustic surveys spawning biomass index for Southwest Nova Scotia/Bay of Fundy spawning component average for 1999–2011 and biomass for 2012–2023 (rounded to thousands of tonnes).

Location	Avg. 1999–2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Avg. 2005–2010	Avg. 1999–2023
Scots Bay (inbox)	80	123	59	187	228	98	133	129	80	165	66	182	121	38	104
Scots Bay (outbox)	4	38	8	4	21	3	9	10	53	14	6	74	57	3	14
Scots Bay total	84	161	66	191	249	101	142	140	133	179	72	256	177	40	118
German Bank (inbox)	286	219	200	188	140	163	166	95	147	103	137	77	64	273	217
German Bank (outbox)	6	7	9	2	-	-	-	-	-	-	-	-	-	6	6
German Bank total	288	226	209	190	140	163	166	95	147	103	137	77	64	278	219
German + Scots	372	387	275	381	390	264	308	235	280	283	209	333	241	318	337
Trinity Ledge	7	3	1	5	1	1	14	7	20	14	4	17	7	6	7
Spec Buoy (spring)	1	-	-	-	-	-	-	-	-	-	-	-	-	1	1
Spec Buoy (fall)	44	-	-	-	-	-	9	10	23	13	23	16	3	-	21
Overall Stock Area	387	390	276	386	390	265	330	251	323	310	237	366	252	324	352
Seal Island	6	-	-	-	-	-	-	21	30	4	9	22	65	10	16
Browns Bank	26	-	-	-	-	-	-	-	-	-			-	8	26
Total All Areas	393	390	276	386	390	265	330	272	353	313	246	387	316	327	361

** 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.*
- = 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 observed acoustic SSB estimates are interpreted as a relative index of biomass and not as an absolute index (DFO 2007, Carruthers et al. 2023). The overall acoustic SSB estimate (Scots Bay, German Bank ,Trinity Ledge, Spectacle Buoy, and Seal Island) was 316,476 t (95% C.I.: +/- 116,359 t) in 2023, which is less than the 387,481 t estimated in 2022 (Table 3). The overall acoustic biomass estimate in 2023 was 12% below the long-term average (1999–2023) of 361,257 t. The combined annual acoustic SSB estimate for German Bank and Scots Bay decreased from 332,570 t in 2022, to 241,046 t in 2023 (Table 3). The 2023 Scots Bay acoustic SSB estimate was 50% above the long-term average (1999–2023) at 177,446 t (95% C.I.: +/- 92,974 t). The 2023 German Bank SSB estimate was 70% below the long-term average (1999–2023) at 63,600 t (95% C.I.: +/- 31,349 t). For a sixth year since 2018, surveys were completed on the Seal Island spawning area with an SSB estimate of 64,933 t (95% C.I.: +/- 61,769 t). The SSB estimate on Trinity Ledge decreased from 17,475 t in 2022 to 7,251 t (95% C.I.: +/- 9,433 t) in 2023. The SSB estimate on Spectacle Buoy decreased from 15,794 t in 2022 to 3,245 t (95% C.I.: +/- 2,846 t) in 2023.

The 2022 and 2023 acoustic catch-at-age shows more Age 4 Herring compared to 2021 which had very few Age 3 and 4s and ages 6 and 7 was a greater proportion (Table 4, Figure 3). For 2023, Age 7 had a the second highest proportion of age structure.

Table 4. Acoustic survey age composition (% by abundance) for Southwest Nova Scotia/Bay of Fundy spawning component for German Bank and Scots Bay for calendar years (2021, 2022, and 2023) from purse seine gear.

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11
2021	0%	0%	9%	7%	17%	25%	17%	8%	2%	11%	3%
2022	0%	0%	24%	32%	9%	8%	8%	13%	4%	1%	1%
2023	0%	1%	2%	34%	11%	6%	29%	8%	6%	3%	0%

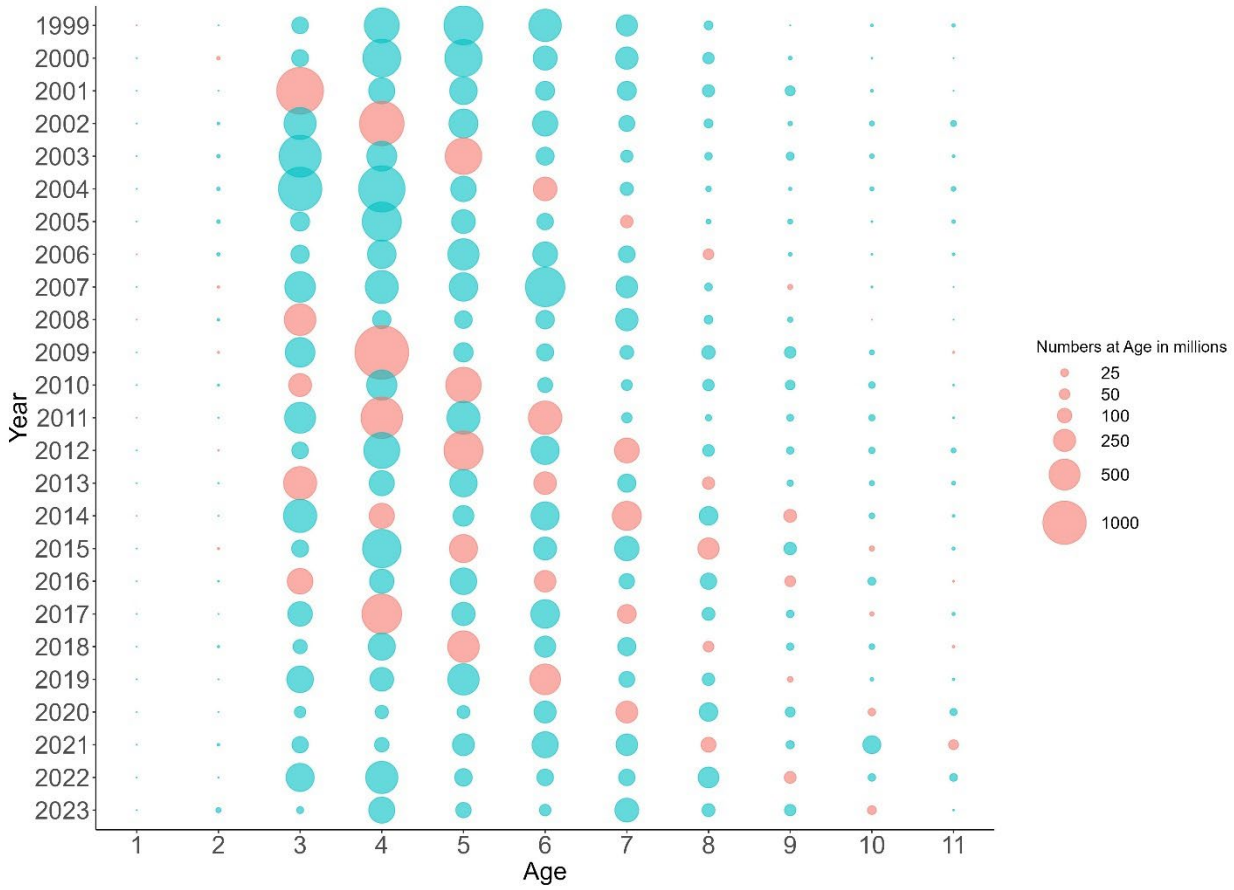

Figure 3. Acoustic survey relative numbers at age (denoted by circle size) for the German Bank and Scots Bay (main spawning areas in the Southwest Nova Scotia/Bay of Fundy spawning component from purse seine gear from 1999 to 2023. The size of the bubble is proportional to the numbers by age. Selected year-classes 1998, 2005, 2007, 2011, and 2013 are shown in red.

Stock Status

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). The 3-year moving average of German Bank and Scots Bay was 261,092 t in 2023 and still remains below the LRP, placing the SWNS/BOF stock component in the Critical zone (Figure 4). The 3-year moving average of the observed acoustic SSB index has been at or below the LRP for the past

six years (Figure 4), this suggests the subcomponent is not rebuilding despite reductions in TAC. The German Bank SSB has been in decline and is at the lowest it has been since 1999, whereas Scots Bay has trended upward since 2005–2010 (Figure 5).

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. In 2023, the index of relative exploitation rate for the SWNS/BoF component was 9% (7% in 2022), compared to a long-term (1999–2023) average of 15.3%.

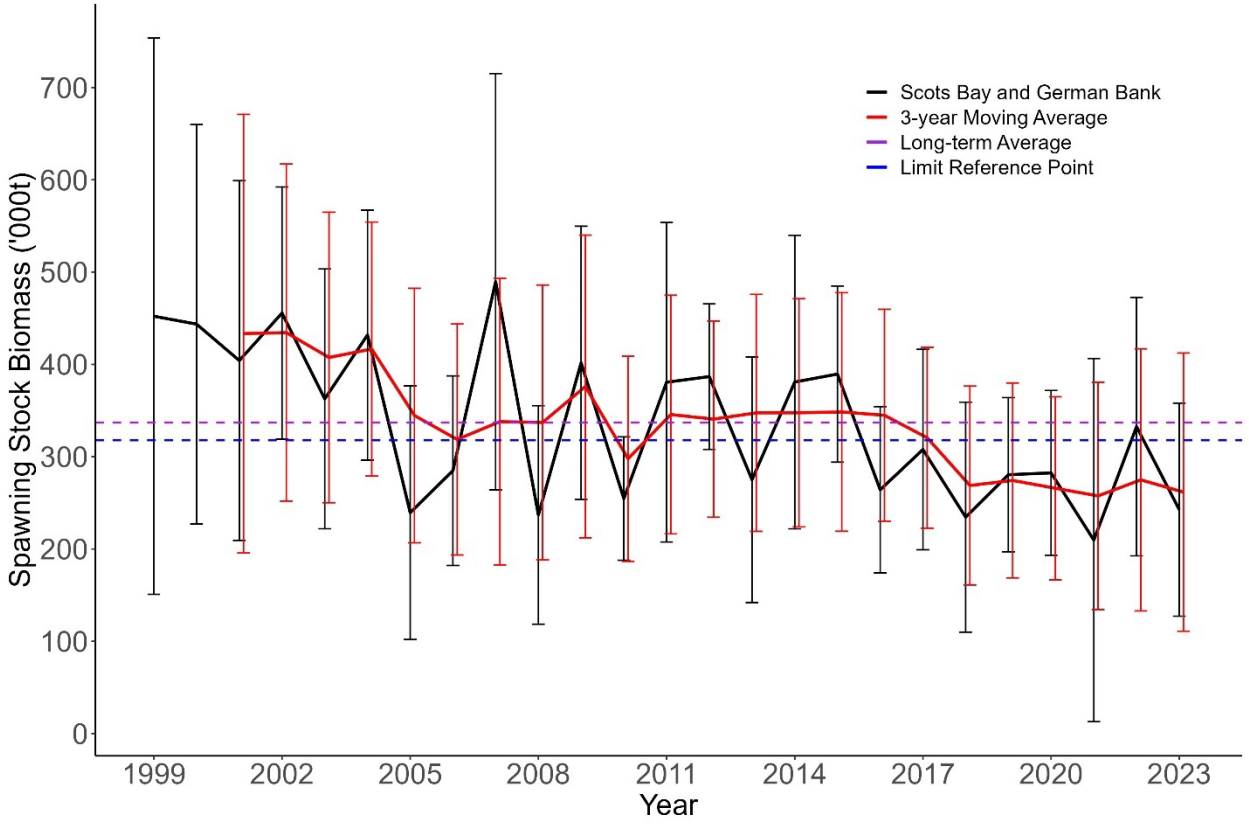

Figure 4. Annual acoustic index of Spawning Stock Biomass (in thousands of metric tons) (black line with 95% confidence intervals), the 3-year moving average (red line with 95% confidence interval), the long-term average since 1999 (dashed purple line), and the Limit Reference Point (dashed blue line) for the Southwest Nova Scotia/Bay of Fundy spawning component.

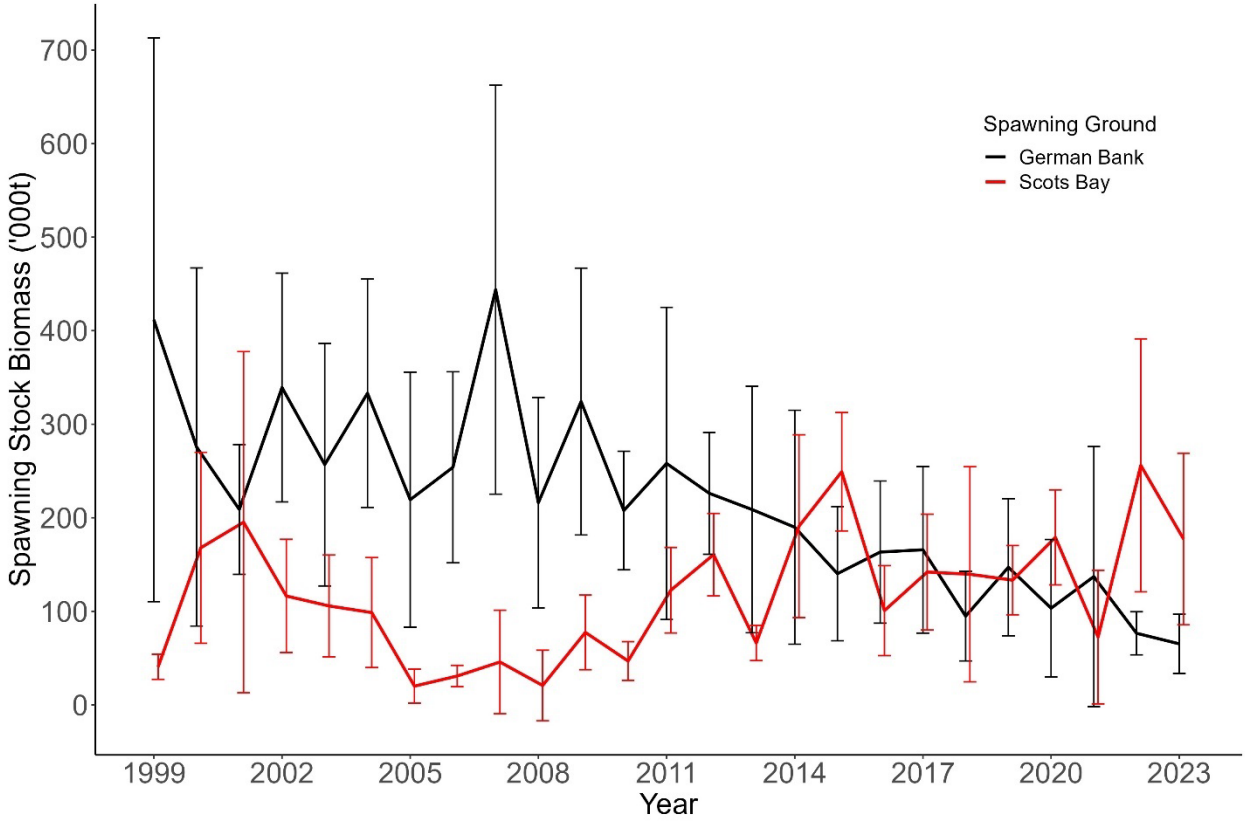

Figure 5. Acoustic index of Spawning Stock Biomass from 1999 to 2023 (in thousands of metric tonnes) for German Bank (black) and Scots Bay (red) (Error bars are 95% confidence intervals).

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 component (Singh et al. 2020, Carruthers et al. 2023, Barrett 2023). The Operating Models (OMs) were conditioned using data up to 2020 and there have been no changes to the reference set OMs since the analytical framework. A simulation loop was repeated for 25 years, where year one of the projection is 2021. Candidate MPs that enabled the rebuilding of the SWNS/BoF component above the LRP with a high probability in years 10–15 of the projection period were evaluated across OMs The following conservation objective was defined by DFO to be consistent with DFO's PA policy (DFO 2009) and serves as a minimum performance metric 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 OM in the reference set.

Additional MSE objectives were defined by stakeholders and performance metrics are used to rank the relative performance of MPs and evaluate trade-offs among MPs. A minimum performance value is not defined for the additional MSE objectives and they are not used to eliminate MPs from consideration.

The MSE objectives 2 to 6 and performance metrics (in brackets) are as follows:

2. Maintain SSB above a target biomass in the long-term [P(3-yr moving average of acoustic index of SSB > 425 kt in years 16–25)].

3. Maximize short-term yield (Catch in years 4–8).
4. Maximize long-term yield (Catch in years 9–25).
5. Minimize variability in catch (Percent variance of Catch in years 4–25).
6. Limit the removal of small fish (Percent of fish < 23 cm by number in catch in years 4–15).

It should be noted for objective 2, an upper stock reference point has not been formally defined for the stock (Barret 2023). Therefore, target biomass value of the acoustic index of SSB years 10–15 reported herein should be considered only as means to evaluate tradeoffs.

Candidate MPs were evaluated in 2022 and 2023 (DFO 2022, DFO 2023), but an MP was not implemented for TAC decisions. Instead, in 2022 and in 2023, one-year TACs were set.

For this update, the suite of candidate MPs are presented that meet Objective 1 and used catch data from 2021, 2022, and 2023 to inform the projected SSB within each simulation. Additionally, trade-offs among other management objectives were evaluated. MPs that were evaluated and passed Objective 1 are described in Table 5 and Figure 6. Fisheries removals (i.e., catch) and the estimated acoustic index in 2021, 2022, and 2023 (i.e., projection year 1, 2, and 3, in the closed-loop simulation framework) were accounted for in the projections. NFRef_FY23 was included in this update to determine, with a 75% probability, the minimum number of years required to rebuild the SSB above the LRP across the OMs.

Table 5. Candidate Management Procedures (MPs).

MP	Category	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_FY23	No Fishing	No fishing reference (u = 0), with catch in 2021, 2022, and 2023
Fix13.2	Fixed	Fixed TAC of 13.2 kt
P3.4a	Harvest Rate	Fixed relative u of 3.4% of I
P4.4a	Harvest Rate	Fixed relative u of 4.4% of I
P4.5s	Harvest Rate	Fixed relative u of 4.5% of I_3
P4.8a_20_80	Harvest Rate	Fixed relative u of 4.8% of I, 20% of purse seine TAC for juvenile fish; 80% for adult fish as described in (Barrett 2023)
HS_PA_8.1a	Hockey Stick	Hockey stick with (I, u) control points at (0, 0%), (318, 0%), (425, 8.1%), and (∞, 8.1%)
HS_1.8_5.8_200_425a	Hockey Stick	Hockey stick with (I, u) control points at (0, 1.8%), (200, 1.8%), (425, 5.8%), and (∞, 5.8%)
nALT_f11_d7_35_7u20	Smoothed Hockey Stick with limit of variability of TAC changes	$u = 0$ when $I_3 < 200$ kt $u = [1-\exp(-0.11)]/2 * [(I_3-200)/(425-200)]^{0.5}$ when 200 kt ≤ I_3 ≤ 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%

MP	Category	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).
nALT_f11_d100_ u20_3sq_mod10	Smoothed Hockey Stick with limit of variability of TAC changes	TAC of 21 kt in years 2024, 2025 & 2026; 10 kt in years 2027. *After 2028:* • $u = 0$ when $I_3 < 200$ kt • $u = [1-\exp(-0.11)]/2 * [(I_3-200)/(425-200)]^{0.5}$ when 200 kt ≤ I_3 ≤ 425 kt • $u = [1-\exp(-0.11)]/2$ when $I_3 > 425$ kt with restriction on TAC adjustments as: maximum increase or decrease of 20%.

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. P3.4a was also tuned to meet a probability of SSB > $SSB_{2005–2010}$ above 0.75 in each year for years 8–15 of the projections to determine whether a lower rate of exploitation would allow rebuilding above model $SSB_{2005–2010}$ by 2028.

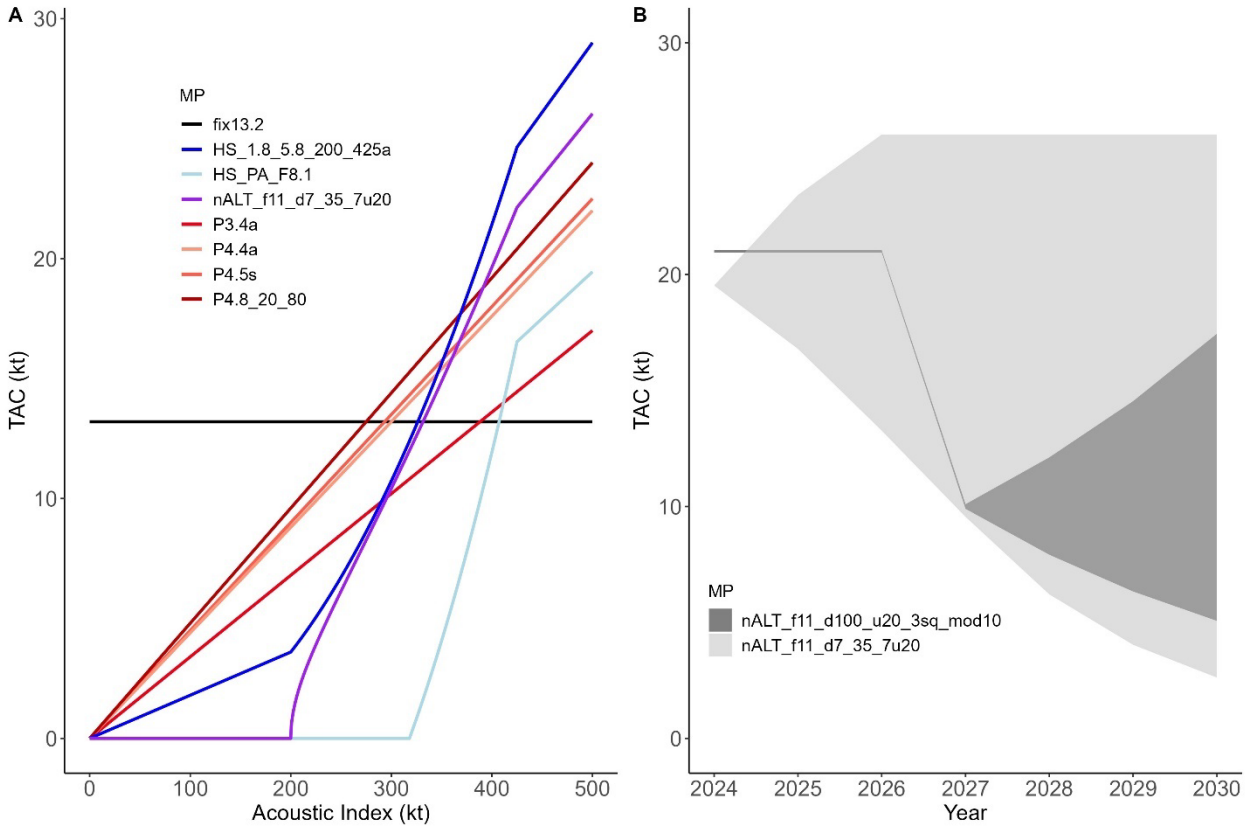

Figure 6. (A) TAC outcomes from Candidate management procedures (MPs; coloured lines) plotted against the acoustic index (annual or 3-year average, depending on the MP). (B) Range of potential TAC (kt) based on the variability limits rules for nALT_f11_d7_35_7u20 (light gray) and nALT_f11_d100_ u20_3sq_mod10 (dark gray) MPs. For full description of MPs see Table 5.

Performance metrics are used to quantitatively asses the ability of MPS to meet the MSE objectives (Barrett 2023). Performance metrics were measured from 1,000 simulations loops of each candidate MPs under OMs (1,4,7,10,13,16,19,22,25,28,31,34) to determine relative performance. In many cases, there was little difference in trade-offs among candidate MPs. HS_PA_8.1a, HS_1.8_5.8_ 200_425a candidate MPs had the greatest short-term (objective 3) and long-term yield (objective 4) (Figure 7), but did not perform as well as other MPs for minimizing variability (objective 5) (Figure 10). Fix13.2 had the least variability in catch (objective 5) (Figure 10), but had lower short-term (objective 3) and long-term yield (objective 4) (Figure 7). P4.8a_ 20_80 had the lowest percentage of small fish in the catch (Objective 6) (Figure 9), and aside from HS_PA_8.1a and HS_1.8_5.8_ 200_425a, had greater performance of short-term and long-term yield among the other MPs (Figure 7). P4.8a_ 20_80 had optimal trade-off between reaching a target-biomass in years 16-25 of the projection and long-term yield (Figure 8). P4.8a_ 20_80 also had less variability in catch compared to HS_PA_8.1a and HS_1.8_5.8_ 200_425a (Figure 10). To pass objective 1, MPs could either allow for higher catch in the short-term (i.e. next 3 years), and reduce catch or vice-versa (Figure 11).

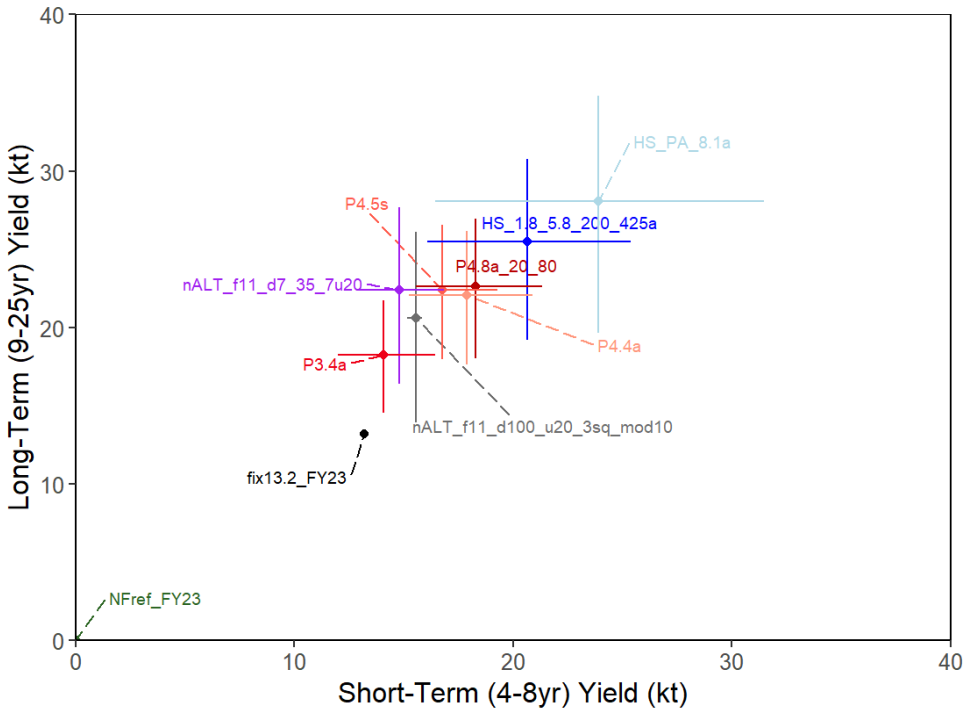

Figure 7. Trade-offs among candidate management procedures (MPs) in short-term (4–8 years) yield (kt; Objective 3) and long-term (8–25 years) yield (kt ; Objective 4). The median value among Operating Models (OMs) is represented as a point and the lines represent the minimum or maximum measured value among the OMs.

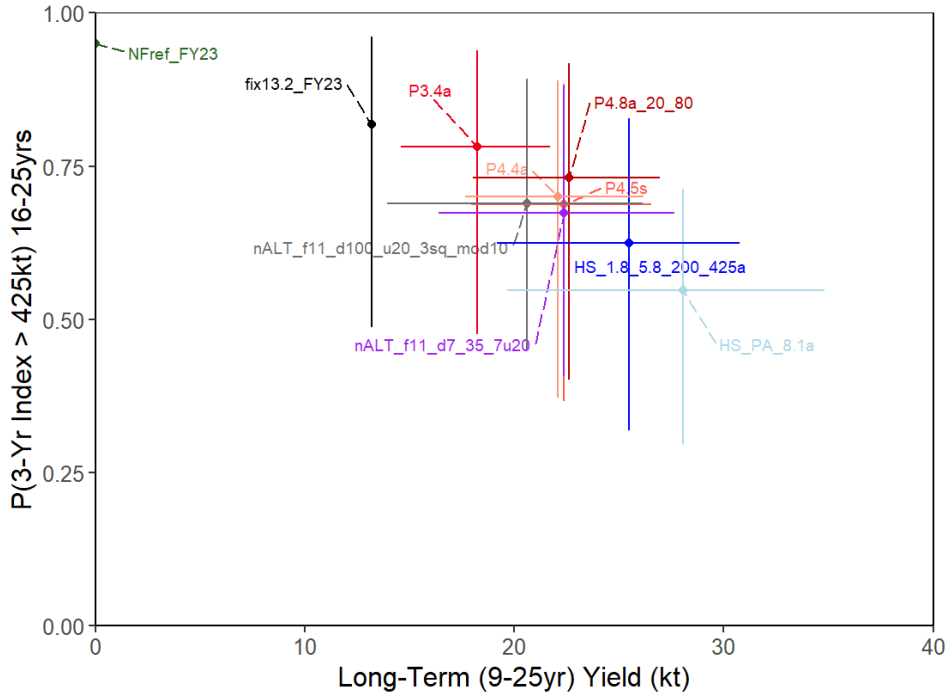

Figure 8.Trade-offs among candidate management procedures (MPs) in long-term yield in years 8 to 25 (Objective 4) and estimated index biomass > 425 kt (Objective 2) for the reference set of 12 Operating Models (OMs). The median value among Operating Models (OMs) is represented as a point and the lines represent the minimum or maximum measured value among the OMs.

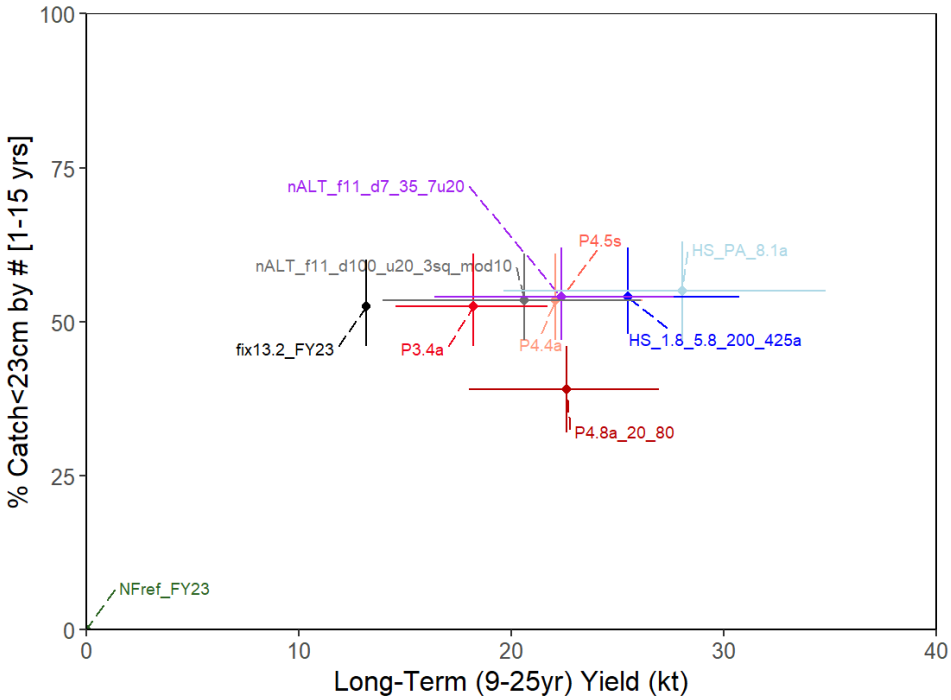

Figure 9. Trade-offs among candidate management procedures (MPs) in long-term yield in years 8 to 25 (Objective 4) and % of herring less than 23 cm in catch (years 1 to 15) across candidate MPs for the reference set of 12 Operating Models (OMs). The median value among OMs is represented as a point and the lines represent the minimum or maximum measured value among the OMs.

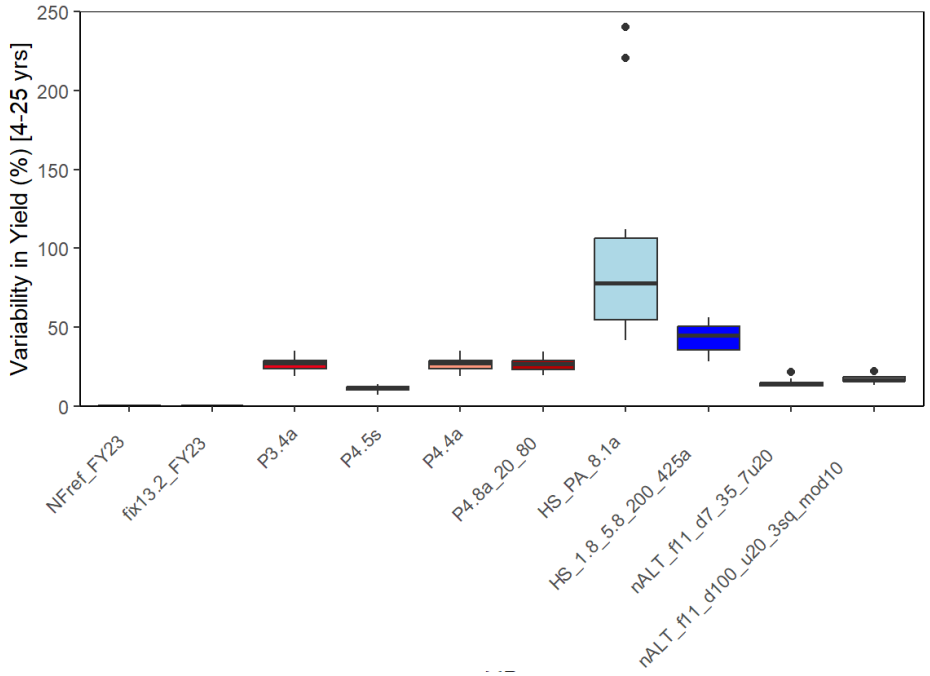

Figure 10. Trade-offs among candidate management procedures (MPs) for the reference set of 12 Operating Models (OMs) for percent variability in yield (years 4 to 25) (Objective 5). The boxplots display the minimum, 25th, 50th, and 75th percentiles, and maximum values the 12 OMs. Values more than 1.5 times the interquartile range beyond 25th and 75th percentiles are plotted as individual values.

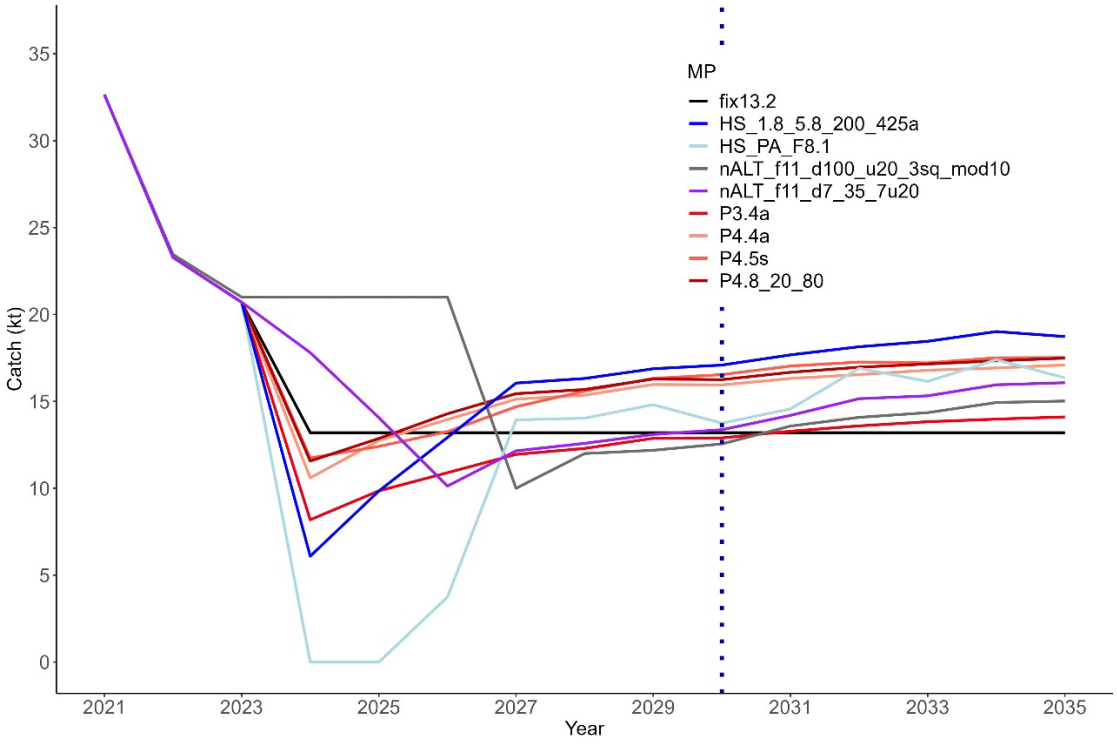

Figure 11. Median catch (kt) across 1,000 closed-loop simulations for candidate management procedures (MP; coloured lines) for OM10. Dotted vertical line is year 10 of the projection when passing MPs must be above LRP for OM10.

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 stock assessment framework (Barrett 2023) set measurements for each exceptional circumstance. Exceptional circumstances are evaluated annually or when new data become available.

Within this update, the exceptional circumstances were evaluated and include fishery catch data for 2021, 2022, and 2023, and the acoustic index of SSB for SWNS/BoF for 2021, 2022, and 2023. No exceptional circumstances were triggered from the 2023 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 (5th and 95th percentiles) for all operating models (OMs) in the reference set in a single year.

   The observed index in 2023 (242.57 kt) is within the 90% prediction interval for the projected index in 2023 for all OMs. The 90% prediction interval for the projected index in 2023 is (58 kt–914 kt) for OM10 (most pessimistic OM) and (97 kt–1387 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 2023 for Age 3 to 7 fish were within the lower/upper 98% (2-tailed) prediction interval for the growth scenario B/Binv (Table 6). The mean weights-at-age were 113 g, 131 g, 158 g, 186 g, 205 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 6. Upper and Lower 98% prediction intervals for mean weight-at-age (g) for 2023 (projection Year 1) compared to observed mean weight-at-age taken from commercial catch samples in 2023.

Age	Predicted Lower	Predicted Upper	Observed mean 2023
3	76	115	113
4	113	149	131
5	139	172	158
6	159	204	186
7	183	225	205

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

   In 2023, New Brunswick southwest weir/shutoff landings were 4.3% 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 2023.

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

   The MSE framework was peer-reviewed in 2022 and there is no evidence to suggest that that model assumptions are no longer valid. The MP evaluations were updated and included observed catch and estimated acoustic index of SSB for 2021, 2022, and 2023 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 2023 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 90th 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 75,203 t in 2023. The acoustic index in 2023 was 242,566 t giving a trigger for this exceptional circumstance of 74,952 t. This exceptional circumstance could be triggered next year, if spawning stock biomass outside of German Bank and Scots Bay exceeds 30.9% of the index in the following year.

Offshore Scotian Shelf Component

In 2023, offshore landings were 781 t (Table 1). Since 1996, during May and June, catches ranged from 20,261 t in 1997 to 37 t in 2020. Acoustic surveys were conducted in 1996 (estimated value not given, documented as moderate amount of Herring) and in 1998 (estimated 17,445 t) (Harris and Stephenson 1999). Systematic acoustic surveys have not been conducted since 1998; there is little basis for evaluating this component.

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 8,631 t against the 2023 allocation of 8,392 t (Table 7). In the Eastern Shore area, landings were 3,487 t in 2023 against the allocation of 4,969 t. In Glace Bay, landings of 0 t were reported in 2023, and have been between 0 t to 9 t since 2018, annually. The Bras d'Or Lakes area remained closed to Herring fishing.

Tagging data to generate turnover estimates have not be considered for Little Hope/Port Mouton and Eastern Shore. In these areas, if surveys do occur less than 10 days apart, they cannot be counted towards annual SSB estimates to avoid double-counting. Instead, annual SSB estimates are calculated by finding the maximum SSB estimates from surveys that occurred more than 10 days apart.

The acoustic index of the SSB for the Little Hope/Port Mouton area increased to 68,573 t in 2023 from to 41,383 t in 2022 and is above the 5-year average of 64,002 t (Table 8).

The acoustic index of the SSB for the Halifax/Eastern Shore area increased to 28,057 t in 2023 from 20,313 t in 2022 and is below the 5-year average of 46,823 t (Table 8). 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 7. Recorded landings and allocations (tonnes) of Herring from major gillnet fisheries on the Coastal Nova Scotia spawning component average for 1998 to 2013 and biomass for 2014–2023. Landings reported are from the Maritime Fishery Information System (MARFIS) database and include Herring landed outside of the allocation season.

Landings and Allocations (t)		Avg. 98–13	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Little Hope/Port Mouton	Catch	2,627	3,596	4,160	5,943	5,557	7,353	8,707	10,747	6,355	6,900	8,631
	Allocation	2,479	3,577	3,772	6,151	6,803	7,884	9,757	10,676	8,622	8,595	8,392
Halifax/Eastern Shore	Catch	2,521	1,163	1,001	1,837	2,259	2,553	4,544	6,871	5,635	5,495	3,487
	Allocation	3,292	1,959	1,066	1,884	2,856	3,960	4,671	7,303	6,649	5,699	4,969
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 8. Estimated acoustic index of the Herring spawning stock biomass (tonnes) average for 1998–2013, biomass for 2014 to 2023 and recent 5-year average for the Coastal Nova Scotia spawning component areas.

Acoustic index of SSB (t)	Avg. 98–13	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Avg. last 5 years
Little Hope (SSB)	28,325	46,077	145,395	61,408	66,815	168,164	92,019	35,739	82,297	41,383	68,573	64,002
Allocation	2,479	3,577	3,772	6,151	6,803	7,884	9,757	10,676	8,622	8,595	8,392	
Halifax (SSB)	28,549	9,586	68,562	54,312	58,681	42,416	141,198	26,205	18,341	20,313	28,057	46,823
Allocation	3,292	2,240	1,066	1,884	2,856	3,960	4,671	7,303	6649	5,699	4,969	
Glace Bay	7380	-	50	-	-	-	-	-	-	-	-	-
Bras d'Or Lakes	300	-	-	-	-	-	-	-	-	-	-	-

"-" = no survey

* A*djustments in estimated biomass were made in survey area in this report compared to DFO 2022 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 907 t in 2023, which is lower than the 3,286 t in 2022 (Figure 12). In 2021, 2022, and 2023, Age 2 were primarily caught (> 95% composition) in the fishery.

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.

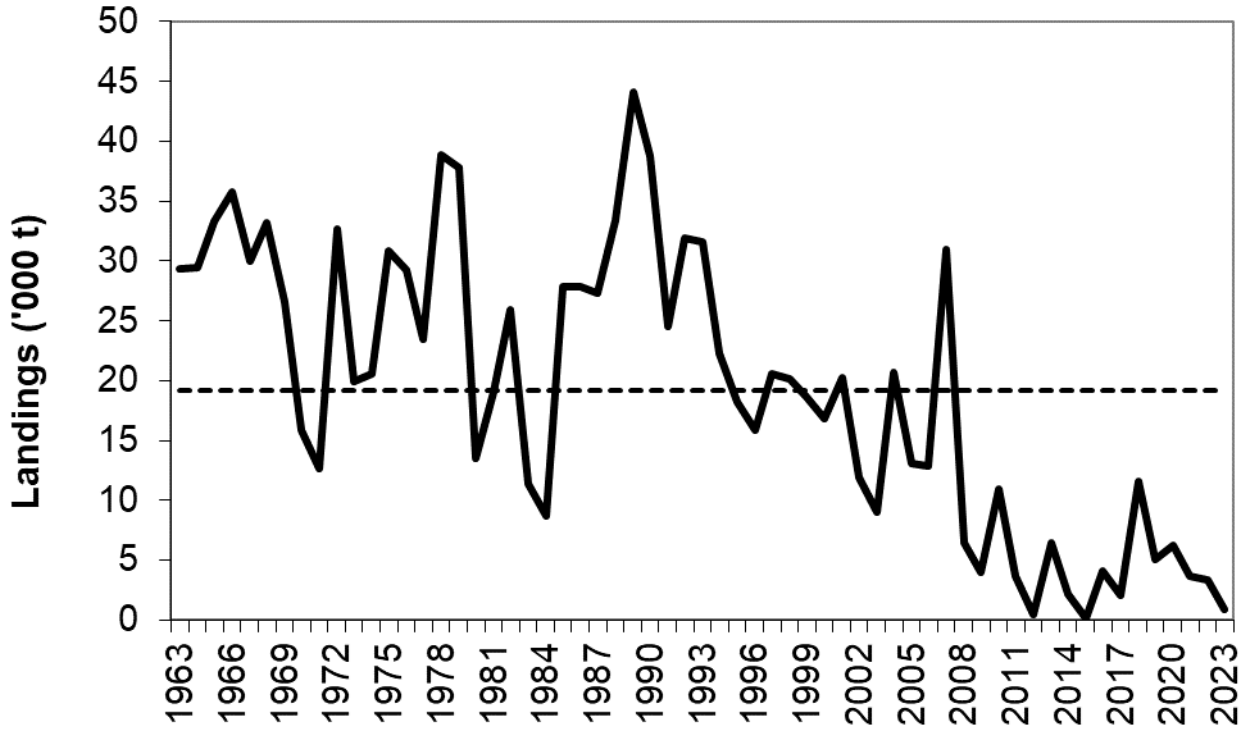

Figure 12. Herring landings (in thousands of metric tonnes) from the New Brunswick weir and shutoff fishery for 1963–2023 (solid Line). The dashed horizontal line indicates the overall long-term mean of the landings.

Conclusions

The uncertainties for each of the following spawning components have not changed since the last assessment (DFO 2022).

Southwest Nova Scotia/Bay of Fundy Spawning 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 decreased from 2022 (274,882 t) to 2023 (261,091 t) and remains below the LRP, and the SWNS/BoF component is considered to be in the Critical zone (Figure 4).

However, there appears to be contrasting trends in the SSB on the two remaining major spawning grounds; declining on German Bank and increasing in Scots Bay. The annual acoustic index for 2023 on German Bank SSB was 71% below the long-term average (1999–2023) making it the lowest this area has been since 1999 (Figure 5). The annual 2023 Scots Bay acoustic SSB was 50% above the long-term average (1999–2023).

The acoustic index of biomass for Trinity Ledge decreased from 17,475 t in 2022 to 7,251 t in 2023. The acoustic index of biomass for Seal Island was 64,707 t in 2023, which is the highest estimate observed since consecutive surveys began in 2018.

Offshore Scotian Shelf Component

There was a decrease in the landings from the offshore banks from 2,548 t in 2022 to 781 t in 2023, below the annual allocation limit of 4,000 t. In the absence of recent information about stock status, there is no basis for evaluating the current catch allocation.

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

From 2019 to 2023, landings in the Little Hope/Port Mouton area have ranged from 6,355 t to 10,747 t, and were near or above the allocation in some years (from −2,267 t to +71 t).

From 2019 to 2023, landings in the Eastern Shore area have ranged from 3,487 t to 6,871 t, and were below 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 to 2023.

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 basis to recommend a change to the management approach for the Bras d'Or Lakes.

Southwest New Brunswick Migrant Juveniles Component

Landings in the New Brunswick weir and shut-off fishery decreased to a historic low of 146 t in 2015, increased to 4,060 t in 2016, and decreased to 2,102 t in 2017. From 2018 to 2023, weir landings decreased from 11,574 t to 907 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 were the greatest in the catch of the fishery in 2021, 2022, and 2023.

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Date: 28 March 2024

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Appendix

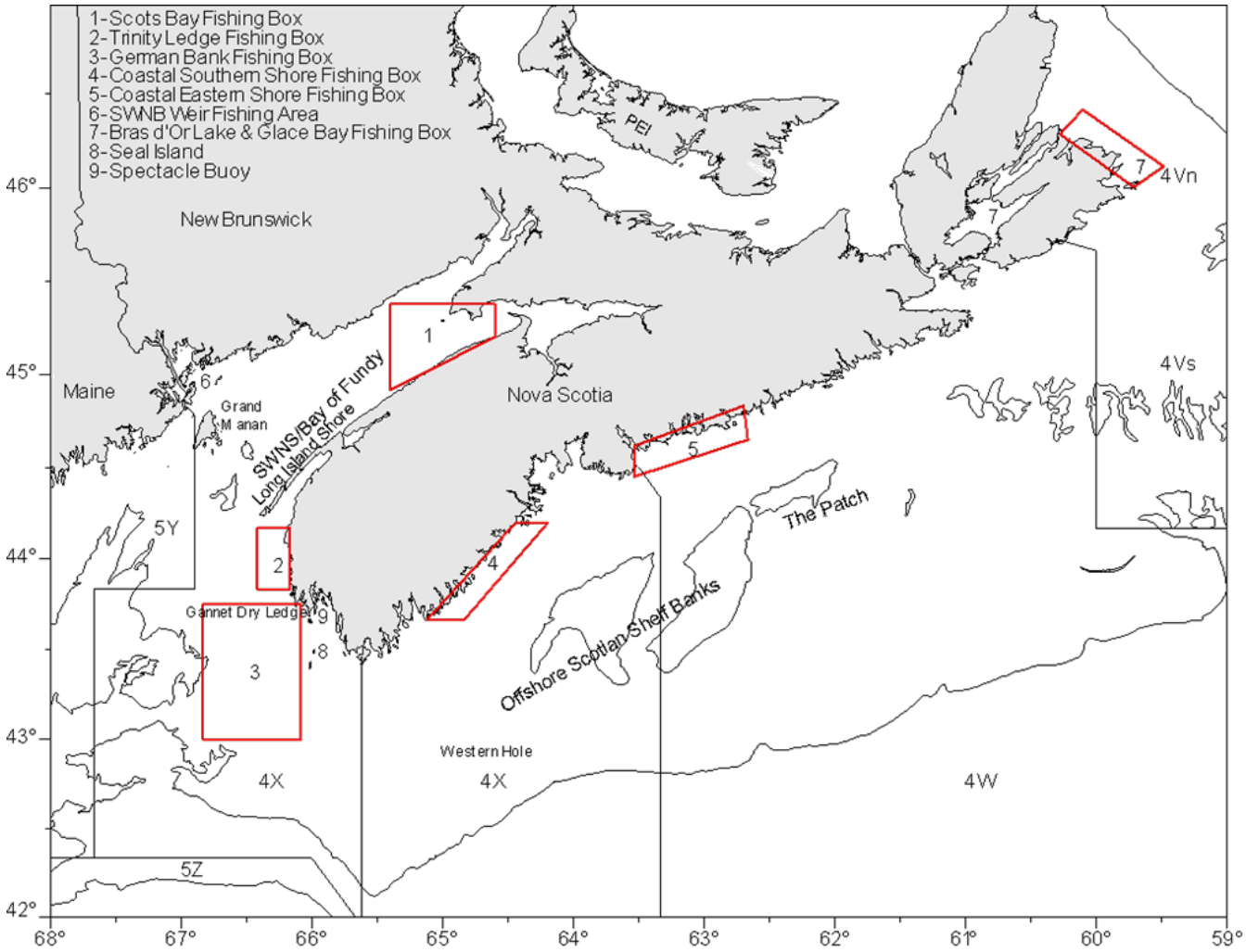

Figure A1. Place names and fishing locations for Southwest Nova Scotia/Bay of Fundy, Coastal NS (South Shore, Eastern Shore, Cape Breton), Offshore Scotian Shelf, and SWNB weirs. The vertical line between the two 4X labels indicates the outer boundary of the Southwest Nova Scotia/Bay of Fundy (SWNS/BoF)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

This Report is Available from the:

Center for Science Advice (CSA)
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ISSN 1919-3769
ISBN 978-0-660-72432-4 Cat. No. Fs70-7/2024-030E-PDF

Correct Citation for this Publication:

DFO. 2024. Stock Status Update of 4VWX Herring for the 2024 Fishing Season. DFO Can. Sci. Advis. Sec. Sci. Resp. 2024/030.

Aussi disponible en français :

MPO. 2024. Mise à jour de l'état du stock de hareng des divisions 4VWX pour la saison de pêche 2024. Secr. can. des avis sci. du MPO. Rép. des Sci. 2024/030.