



# 4X5Y ATLANTIC COD (*GADUS MORHUA*) STOCK STATUS UPDATE TO 2023

## CONTEXT

The Fisheries Management Branch of Fisheries and Oceans Canada (DFO) has requested a review of resource status for 4X5Y Atlantic Cod in support of the decision-making process for the 2025 fishery.

This Science Response Report is from the regional peer review of December 11th, 2024, on the Stock Status Update of Atlantic Cod in NAFO Divisions 4X5Y.

## SCIENCE ADVICE

### Status

- The 2024 spawning stock biomass is at 22% of the limit reference point (LRP), indicating that the stock remains in the critical zone with a very high probability.

### Trends

- Landings in 2022–2023 and 2023–2024 were 599 mt and 533 mt, respectively, remaining below the bycatch total allowable catch (TAC).
- The commercial and survey catch-at-age continue to show the truncation in age structure that has occurred since the 1990s. Survey biomass and age-1 abundance indices have remained low in the past three years.
- Fishing mortality shows a decline for fully-recruited ages after 1994, which is consistent with management measures implemented over the past three decades. The 2023 estimate of fishing mortality on ages 4–7 is 0.10.
- Natural mortality has increased over time for older fish (ages 5+) and appears to have stabilized at high levels in the past five years, with the latest (2023) 5-year average of natural mortality for these ages estimated at 1.59.
- The 2024 estimate of SSB is 4,905 mt. SSB is estimated to decrease from 2024 to 2025, then remain stable or show slight increases under various fishery scenarios.

### Ecosystem and Climate Change Considerations

- Environmental and climate change considerations affecting the productivity of the stock are unknown. Many basic ecosystem indicators and the magnitude of their effect on the abundance and distribution of various life stages of Atlantic Cod are undetermined, hindering the quantitative incorporation of ecosystem considerations into the stock assessment.

## Stock Advice

- The 4X5Y Atlantic Cod stock has declined since the 1990s and remains in the critical zone. Despite decreases in fishing mortality, the productivity of the stock remains low. Few older fish have reappeared in the population and natural mortality for fish ages 5+ has stabilized at high levels. In the harvest scenarios evaluated, there is a moderately high to very high probability of biomass decreasing in each projected year compared to 2024, even in the absence of fishing.

## BASIS FOR ASSESSMENT

### Assessment Details

#### Year Assessment Approach was Approved

2018 (Wang and Irvine 2022).

#### Assessment Type

Interim-Year Update

#### Most Recent Assessment Date

1. Last Full Assessment: December 2022 (DFO 2023)
2. Last Interim Year Update: December 2020 (DFO 2019)

#### Assessment Approach

1. Broad category: single stock assessment model
2. Specific category: Virtual Population Analysis (VPA)

### Stock, Ecosystem and Fishery Overview Information

The following publications provide the relevant stock, ecosystem, and fishery overview information for 4X5Y Atlantic Cod: DFO 2023, Andrushchenko et al. 2022.

### Stock Structure Assumption

Although assessed together, Atlantic Cod in the Bay of Fundy (DFO statistical unit areas 4Xqrs5Yb) and Scotian Shelf (DFO statistical unit areas 4Xmno) components of the management unit exhibit distinctly different growth rates, with western fish (Bay of Fundy) growing faster than those from the east (Scotian Shelf). In general, a two-stock component structure within 4X5Y seems to persist, with a mixing area in 4Xp and some movement taking place between adjacent management areas.

### Reference Points

- Limit Reference Point (LRP): 22,193 mt ( $Sb_{50/90}$ ; Wang and Irvine 2022)
- Upper Stock Reference (USR): 48,000 mt (double the previous LRP; DFO 2012)
- Removal Reference (RR): NA

### Data

Inputs to the population model are:

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- Maritimes Summer Ecosystem Research Vessel Survey (1983–2023)
- Canadian fishery data (1978–2023)

**ASSESSMENT**

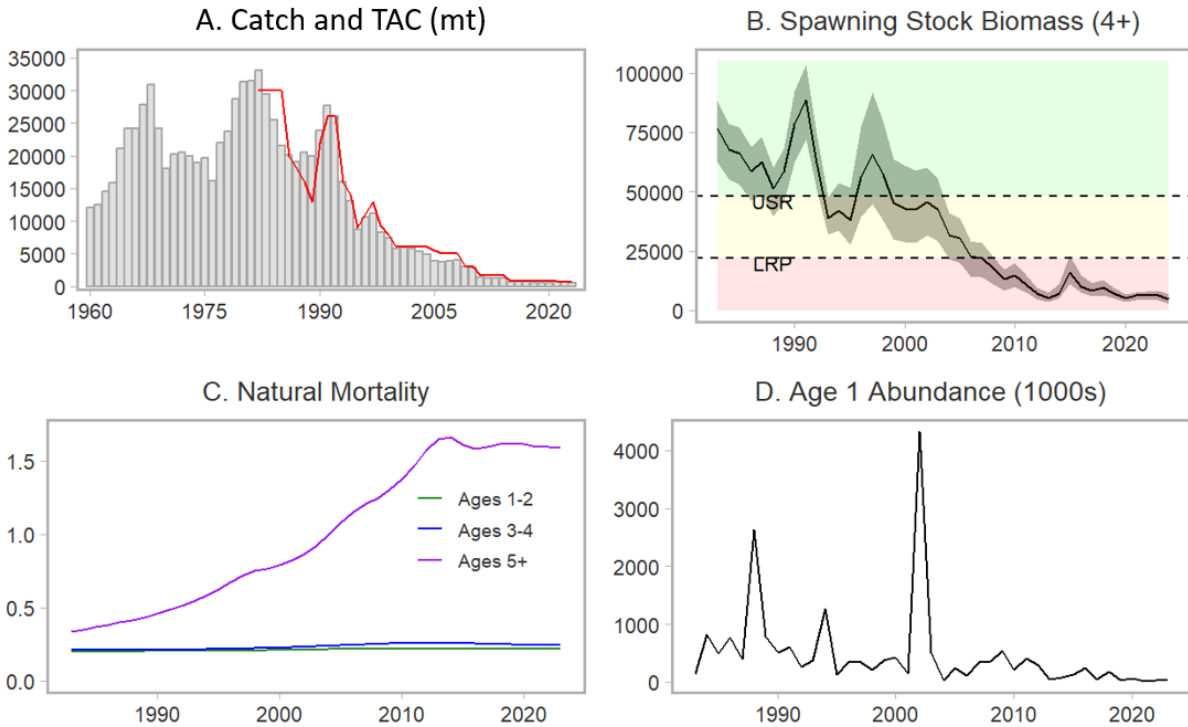


Figure 1. (A) Catch as indicated by grey bars (2023=533 mt) and total allowable catch (TAC) as indicated by the red line (2023=660 mt), (B) spawning stock biomass (SSB; 2024=4,905 mt; with 2.5 and 97.5 confidence intervals) in relation to the limit reference point (LRP; 22,193 mt) and upper stock reference (USR; 48,000 mt), (C) Natural mortality (2023; 0.218 on ages 1–2, 0.246 on ages 3–4, and 1.59 on ages 5+), (D) survey age 1 abundance (14,200 in 2023).

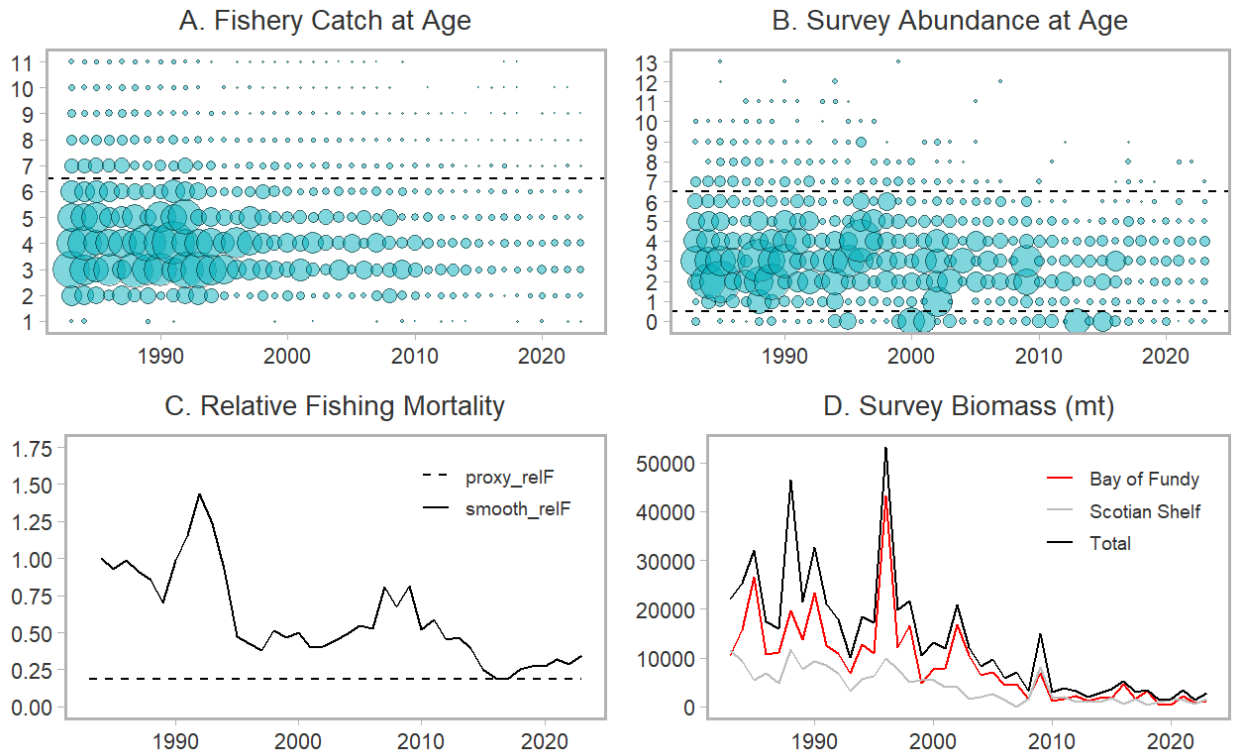


Figure 2. (A) fishery catch at age; (B) survey abundance at age (combined Bay of Fundy and Scotian Shelf); (C) fishing mortality-relative  $F$  (2023=0.35) and proxy  $F$  (0.19); (D) survey biomass (547 mt in the Bay of Fundy and 636 mt on the Scotian Shelf in 2023).

## Stock Status and Trends

### Abundance

Both the commercial and survey catches at age have shown a truncation in age structure since the 1990s. From then on, older fish (ages 6+) have become rare. The decline reached its lowest point in 2013–2014, when there were no fish older than age 5 in the survey and age 7 in the fishery. In 2023, the fishery included ages 1 to 9, with ages 3 and 4 being the dominant cohorts. The survey included ages 0 to 7, with the same dominant cohorts.

### Biomass

The spawning stock biomass (SSB) first dropped below the LRP in 2008, and has remained below the LRP since that time. In 2023 and 2024, SSB is below the LRP with a high probability, and was estimated to be at 29% and 22% of the LRP, respectively.

### Fishing Mortality

In the absence of an RR, relative fishing mortality (relF), calculated as annual catch over the 3-year mean survey biomass, is compared to the relF of 0.19 determined by DFO Resource Management in 2019 (SFGAC 2019). RelF declined around 1994, corresponding to a large decrease in total allowable catch (TAC), which is consistent with model-dependent estimates of  $F$ . It remained at low levels until the early 2010s and decreased again in 2014 when the TAC was reduced by 50%. After 2015, relF remained around 0.19, increasing since 2019.

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Fishing mortality from the model showed a reduction in all fully recruited ages from 1994 until the late 2010s, consistent with management measures implemented. Fishing mortality (F) on ages 3–6 was higher than on older fish (ages 7+) until the early 2000s, with F on ages 7+ increasing substantially in the early 2000s and fluctuating at a high level since then. The most recent F estimate for 2023 is 0.10 for ages 4–7.

A model-independent estimate of total mortality for fish aged 4–7 increased in the early 2000s. It remains high, consistent with low survivorship for older fish and the truncated age structure in the survey and fishery.

**Recruitment**

The most recent estimate of recruitment by the model for the 2023 year-class is 1.3 million fish, which is the third lowest in the series. Overall, recruitment levels remain low which is consistent with fewer spawning fish observed in the population. The age 1 recruitment index from the survey also remains low.

**Natural Mortality**

Estimates of natural mortality (M; random walk for age groups 1–2, 3–4, and 5+) from the model show that it has increased over time for older fish (ages 5+), though it appears to have stabilized at high levels (1.59 average in the past 5 years).

**Current Outlook**

The 2024 spawning stock biomass is at 22% of the LRP, indicating that the stock remains in the critical zone with a very high probability.

**History of Landings and Total Allowable Catch**

Before the late 1990s, the proportion of Atlantic Cod landings from the Scotian Shelf was greater than that from the Bay of Fundy. In the late 1990s, this proportion switched with the redistribution of fishery efforts, followed by a shift to similar proportions of the two components in the 2010s.

In the past three years, removals of Atlantic Cod from the Bay of Fundy have decreased substantially, resulting in Scotian Shelf landings accounting for 70% of the total fishery removals in 4X5Y. Landings in the 4Xp mixing area increased starting in the 1980s and have remained at, or below, 30% of landings since the early 2010s (Table 1).

Atlantic Cod quotas and catches have declined throughout the time series with quota year catches remaining below the TAC in all years. Landings for the 2022–2023 and 2023–2024 management years were 599 mt and 533 mt, respectively, up from the series low in 2020–2021 (507 mt).

*Table 1. Historical landings and total allowable catch (TAC; mt=metric tonnes) for 4X5Y Cod. Values are presented as ten-year averages for time period from 1982 to 1991. Landings for 2001 and prior are based on the calendar year. Landings post-2001 are based on the management year (April–March). Landings are not complete for 2024/2025 as noted by “-”.*

	1982-1991	1992-2001	2002-2011	2012-2021	2020-2021	2021/2022	2022/2023	2023/2024	2024/2025
TAC (mt)	23,500	11,821	4,615	1,072	825	825	660	594	660
Landings (mt)	24,075	11,178	3,887	801	507	630	599	533	-

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**Projections**

Updated projections assumed the 2024 TAC of 660 mt was taken in full and were run under three harvest scenarios for 2025 and 2026: current TAC (660 mt annually), half of current TAC (330 mt annually), and no catch (0 mt). The projected SSB at the beginning of the calendar year for each harvest scenario is provided in Table 2, along with probability of SSB in each projected year being lower than the SSB in 2024. In addition, the probability of SSB in each projected year being below SSB in 2024 is presented for incremental decreases in TAC between 660 mt and 0 mt (Table 3).

The projections indicate there is a high probability that SSB will decrease from 2024 to 2025, due to a number of weaker year classes observed in the survey (2020–2022). In subsequent projected years, the SSB is expected to remain stable or show a modest increase under various fishing scenarios, noting the large credible intervals for each projected value (Table 2).

*Table 2. Short-term projection outputs of median spawning stock biomass (SSB), median fishing mortality (F) and probability (P) of SSB change under 3 harvest scenarios. Numbers in parentheses indicate the 95% credible interval. mt=metric tonnes*

Harvest scenario (mt)	2025 SSB (mt)	2026 SSB (mt)	2027 SSB (mt)	2025 F	2026 F	P(SSB2025 < SSB2024)	P(SSB2026 < SSB2024)	P(SSB2027 < SSB2024)
660	2,627 (1,464–5,185)	2,633 (921–11,922)	2,890 (1,126–13,230)	0.49 (0.14–1.06)	0.46 (0.13–0.97)	96.5%	78%	72%
330	2,627 (1,464–5,185)	2,942 (1,179–12,299)	3,493 (1,629–14,037)	0.234 (0.067–0.481)	0.206 (0.061–0.389)	96.5%	75%	65%
0	2,627 (1,464–5,185)	3,266 (1,454–12,678)	4,094 (2,124–14,848)	0	0	96.5%	71%	56%

*Table 3. Probability of change in projected spawning stock biomass (SSB) compared to 2024 SSB under various levels of total allowable catch (TAC; mt=metric tonnes).*

TAC (mt)	P(SSB2025 < SSB2024)	P(SSB2026 < SSB2024)	P(SSB2027 < SSB2024)
660	96.5%	77.9%	71.8%
594	96.5%	77.1%	70.8%
528	96.5%	76.6%	69.7%
462	96.5%	76.3%	68.3%
396	96.5%	75.8%	66.9%
330	96.5%	74.8%	64.9%
264	96.5%	73.8%	62.8%
198	96.5%	72.7%	61.3%
132	96.5%	72.2%	59.9%
66	96.5%	71.5%	57.6%
0	96.5%	70.8%	55.5%

**Ecosystem and Climate Change Considerations**

Environmental and climate change considerations affecting the productivity of the stock are unknown. Many basic ecosystem indicators and the magnitude of their effect on the abundance

and distribution of various life stages of Atlantic Cod are undetermined, hindering the incorporation of ecosystem considerations into the stock assessment.

Overall, the productivity, trophic interactions, and structure of the Scotian Shelf ecosystem have undergone significant changes in the past four decades. Increases in bottom water temperature are accompanied by increases in invertebrate landings, while demersal fish biomass from the RV survey has decreased in 4V and 4W (DFO 2024). Biomass of demersal fish in 4X has not shown a directional change, as decreases in the biomass of species like Atlantic Cod have been counteracted by increases in the biomass of species like redfish (*Sebastes sp.*; DFO 2024). A shift towards smaller zooplankton from larger, energy-rich copepods has been observed since 2010 and may indicate less productive conditions for planktivorous fish (Casault et al. 2023).

Additionally, the abundance of Grey Seals (*Halichoerus grypus*) has increased substantially on the Scotian Shelf beginning in the 1960s, and breeding colonies were re-established in southwest Nova Scotia in the early 1990s (den Heyer et al. 2021). While the rate of increase for the total population growth has slowed down more recently (1.5% per year between 2016 and 2021; DFO 2022), there has been a more rapid increase in the pup production at the breeding colonies in southwest Nova Scotia (den Heyer et al. 2021). The increase in Grey Seals likely results in increased predation pressure on Atlantic Cod, contributing to higher natural mortality. Finally, condition of cod has increased for the Bay of Fundy area in recent years, but remains below average for the Scotian Shelf.

### Evaluation of Assessment Triggers

According to the assessment schedule established during the development of the assessment framework, the next stock status review for 4X5Y Cod is an interim-year update. As with previous updates, it is expected to include a review of exceptional circumstances to determine if a new run of the assessment model, using updated survey information and projections, is triggered for the following year. It was an evaluation of triggers in 2023 that triggered the assessment model run in 2024. The trigger mechanisms defined in the 2018 framework review (DFO 2019) are as follows:

1. The 3-year median abundance for ages 7 through 9 is above 0 for all three ages
2. The q-adjusted, 3-year median survey SSB falls outside of the 95% confidence interval of the projection
3. The 3-year median of the age 7+ group abundance index falls outside of the 95% confidence interval of the projection.
4. The q-adjusted 3-year median survey biomass index exceeds Blim.

In addition, a framework review would be triggered if the perception of stock structure changes or a framework is developed for incorporating ecosystem information into the stock assessment.

Triggers 1 and 4 were evaluated for this update and were not triggered.

### SOURCES OF UNCERTAINTY

Several data gaps and uncertainties were identified during the last modelling assessment framework (Wang and Irvine 2022) and assessment (DFO 2019), which continue to persist for 4X5Y Atlantic Cod.

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Although 4X5Y Atlantic Cod is regarded as a data-rich stock with age-structured fishery and survey information dating back to 1983, periods of bias in the historical catch, time-varying natural mortality, and stock mixing are problematic for modelling this stock.

High natural mortality rates persist in the stock from the latest model, which could be aliasing other factors contributing to the decline of Atlantic Cod. These include the emigration of fish to deeper, colder waters, predation, and/or unreported/discarded catch of Atlantic Cod from all 4X5Y fisheries.

Any unaccounted-for fishing mortality is included in the population modelling as natural mortality. This would include recreational fishing and catch from non-groundfish fisheries within the management area.

While these uncertainties and data gaps have been identified and continue to persist, it is unlikely that they impact the relative stock trajectory and status.

**Research Recommendations**

Unaccounted-for fishing mortality from the Lobster fishery is currently being estimated. This source of mortality should be incorporated into the population modelling.

Additional research should be conducted to assess drivers of Atlantic Cod productivity in 4X5Y and determine other sources of natural mortality.

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