STOCK STATUS UPDATE OF HADDOCK (*MELANOGRAMMUS AEGLEFINUS*) IN NAFO DIVISIONS 4X5Y

Context

Advice on the status of Haddock (*Melanogrammus aeglefinus*) in Northwest Atlantic Fisheries Organization (NAFO) Divisions 4X5Y (herein referred to as 4X5Y Haddock) is requested annually by Fisheries and Oceans Canada (DFO) Resource Management to help determine a Total Allowable Catch (TAC) that is consistent with the Integrated Fisheries Management Plan (IFMP). The most recent framework and assessment occurred in 2016 (Stone and Hansen 2015, Wang et al. 2017, DFO 2017). A Virtual Population Analysis (VPA) model with natural mortality (M) at ages 10 and older for three 5-year time blocks (2000–2004, 2005–2009, and 2010–2014) fixed at 0.3, 0.6, and 0.9, respectively, was recommended as the model for the 4X5Y Haddock stock assessment. Despite the uncertainties in estimating fishing morality at Maximum Sustainable Yield (F_{MSY}), it was agreed at this Framework meeting that a fishing mortality limit reference (F_{lim}) of 0.25 would be a removal fishing mortality reference when the stock is in the Healthy Zone, and a fishing mortality target reference (F_{ref}) of 0.15 would be an appropriate target when the stock is in the Cautious Zone. Given that the poor stock recruit relationship precludes the calculation of an appropriate biomass at Maximum Sustainable Yield (B_{MSY}), a more conservative biomass level from which the stock has been shown to recover ($B_{recover}$; Age 4+ biomass; 19,700 metric tonnes (t)) was recommended as the Limit Reference Point (LRP) for 4X5Y Haddock. In the spring of 2017, Resource Management agreed upon approximately twice the LRP, or 40,000 t, as the Upper Stock Reference (USR; Age 4+ biomass).

The 2018 update provided a two year projection of biomass and catch. The objectives of this interim update are to report new information from the DFO Summer Research Vessel (RV) Survey and commercial fishery landings data, provide the most recent data on the length of Haddock captured by the fleet, compare updated information to the 2018 results and projections, as well as provide indicators to maintain or reduce catch advice.

This Science Response Report results from the Science Response Process of December 4–5, 2019, on the Stock Status Updates of Groundfish Stocks in the Maritimes Region.

Background

Biology

Haddock are found on both sides of the North Atlantic and occur in the northwestern Atlantic from southwest Greenland to Cape Hatteras, USA. A major stock exists on the western Scotian Shelf and in the Bay of Fundy (NAFO Divisions 4X5Y; Figure 1). Growth rates of Haddock in the Bay of Fundy (Unit Areas 4Xqrs5Y) are higher than those of Haddock on the western Scotian Shelf (Unit Areas 4Xmnop; Hurley et al. 1998); therefore, separate age length keys are used for calculating the fishery Catch-At-Age (CAA) and survey indices of abundance. Major spawning grounds are found on Browns Bank, and peak spawning occurs from April to May, although it can occur as early as February if conditions are favourable (Head et al. 2005).

There was a declining trend in Weight-At-Age (WAA) and Length-At-Age (LAA) from the early 1990s, and the time series minimum for most ages occurred in the past five years. While it is not clear what caused the declining trend, the effect on stock productivity is significant and has been discussed in previous assessments (Hurley et al. 2009, Mohn et al. 2010).

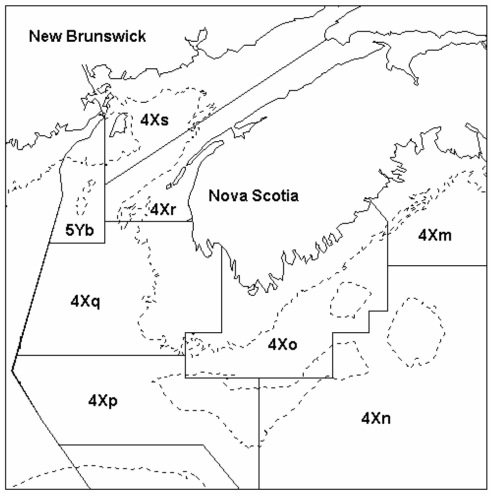

Figure 1. Northwest Atlantic Fisheries Organization Divisions, 4X5Y.

Analysis and Response

The Fishery

Haddock is harvested as part of a mixed groundfish fishery. The TAC for Haddock was 5,100 t for the 2012/13–2016/17 fishing years, and it increased to 7,650 t for 2017/18 and 2018/19, and then further increased to 9,000 t for 2019/20. However, catches have been lower than the TAC since 2002 (Figure 2). The fishing year landings for 2018/19 were 5,294 t (Table 1). The 2019/20 fishing season is still ongoing, and landing statistics are incomplete.

Table 1. Reported annual and fishing year catch (t) of 4X5Y Haddock. Annual catch is used for 1970 to 1999 (January 1st–December 31st); subsequent years use fishing year catch (April 1st–March 31st).

Year	1970–79 Average	1980–89 Average	1990–99 Average	2000/01–2009/10 Average	2010/11–2015/16 Average	2016/17	2017/18	2018/19*
TAC	14,650	21,385	5,050	8,030	5,400	5,100	7,650	7,650
Landings	18,522	19,851	7,219	6,579	3,719	3,567	5,087	5,294

*Extracted from MARFIS as of October 11, 2019.

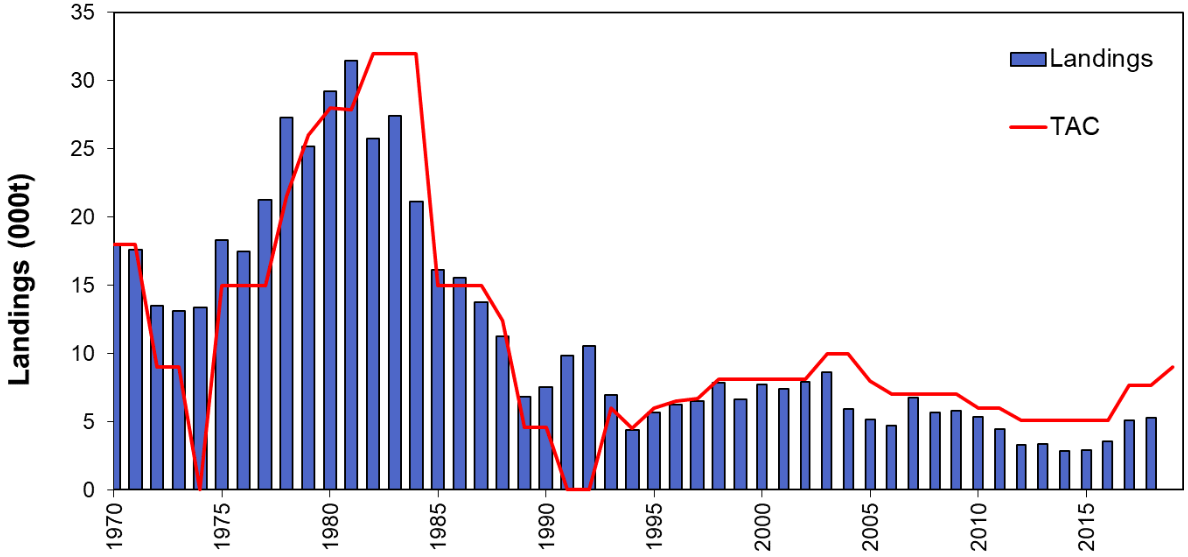

Figure 2. Reported fishing year landings and Total Allowable Catch (TAC) for the 4X5Y Haddock fishery, 1970–2019. The fishing year changed from Jan–Dec to April 1st–March 31st in 2000.

The 4X5Y Haddock fishery CAA shows the presence of the strong 2013 year class (yc) (Figure 3). In the 2018 fishery, the 2013 yc at Age 5 was predominant and represented 66% of numbers at age (NAA) in the catch, followed by the 2014 yc at 22% and the 2012 yc at 4%. The 2018 fishery CAA is similar to the projected CAA in the previous model run (DFO 2019a); the 2013 yc at Age 5 was projected to represent 64% of the NAA followed by the 2014 yc at 15% and the 2012 yc at 8%.

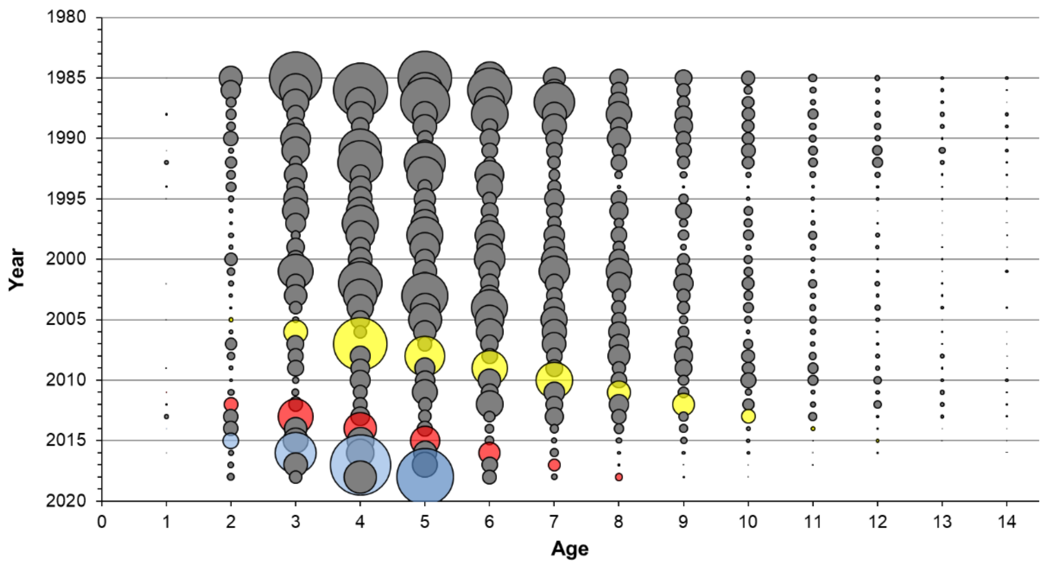

Figure 3. Fishery catch-at-age for 4X5Y Haddock for ages 1–14, 1985–2018. The area of the circle is proportional to the catch in numbers at that age and year. Three examples of recent strong cohorts are highlighted: 2003 (yellow), 2010 (red), and 2013 (blue).

Separate age length keys are used for Scotian Shelf and Bay of Fundy samples to generate NAA, which are then used for weighting the calculations of the overall fishery WAA. In 2018, the fishery weighted mean WAA for ages 3 and 5 are the lowest in the time series (Table 2).

Table 2. Fishery and DFO Summer RV Survey weighted mean weight-at-age (kg) of 4X5Y Haddock for ages 1–11+ calculated separately for Scotian Shelf strata (470–481) and Bay of Fundy strata (482–495) then combined after weighting. Cells with dashes have no data available.

		Age Group										
Year	**Source**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11+**
2018	Fishery	-	0.42	0.44	0.66	0.74	0.97	1.20	1.04	1.12	2.04	-
1985–2017 Minimum	Fishery	0.11	0.35	0.52	0.65	0.80	0.86	0.96	0.86	1.02	1.12	1.10
2018	Survey	0.08	0.21	0.35	0.51	0.61	0.69	0.83	0.96	1.07	-	-
2019	Survey	0.07	0.21	0.35	0.39	0.58	0.66	0.96	1.03	0.96	1.4	1.68

Catch size composition is characterized using biological measurements collected from observer and port sampling programs. The realized observer coverage for the 4X5Y Haddock mobile fishery was 4% of trips (19 observer trips) and a total of 59 port samples were completed in 2018 (Table 3). The preliminary 2019 data consist of 21 observer trips and 52 port samples (Table 3). There have been significant changes in the catch at size by gear type (mobile versus. fixed) and area (Bay of Fundy versus. Scotian Shelf; Wang et al. 2017). The peak length of fish in the catch has decreased from 46.5 cm in 2008 (Wang et al. 2017) to 40.5 cm in 2018 (Figure 4). In 2018, 10% of observer samples and 6% of port samples had greater than 30% of small fish in the catch. Of the available data for 2019, 14% of observer and 12% of port samples had greater than 30% small fish (<38 cm) in the catch. Of the trips that exceeded 30% small fish in 2019, most occurred on the Scotian Shelf during the first quarter.

Table 3. The number of samples and lengths from the 4X5Y observer and port sampling program for 2018 and 2019. Small fish as identified in the Conservation Harvesting Plan are Haddock <38 cm. No data or data not available is indicated by a '-'.

			Observer			Port		
Year	Quarter	Landings (t)	Sample (N)	N Trips >30% small fish	Lengths (N)	Samples (N)	N Trips >30% small fish	Lengths (N)
2018	1	1739	10	-	9714	16	-	3549
2018	2	1107	3	-	3518	11	-	2544
2018	3	974	5	-	3221	10	-	2387
2018	4	959	3	-	2894	22	-	5440
Total 2018		4780	21	2	19347	59	3	13920
2019*	1	2253	11	-	11642	15	-	3603
2019*	2	1109	4	-	4834	19	-	4628
2019*	3	891	4	-	2450	7	-	1636
2019*	4	507	-	-	-	11	-	2489
Total 2019*		4759	21	3	18926	52	6	12356

*Sample collection and data entry are not complete for 2019; therefore, results are considered preliminary.

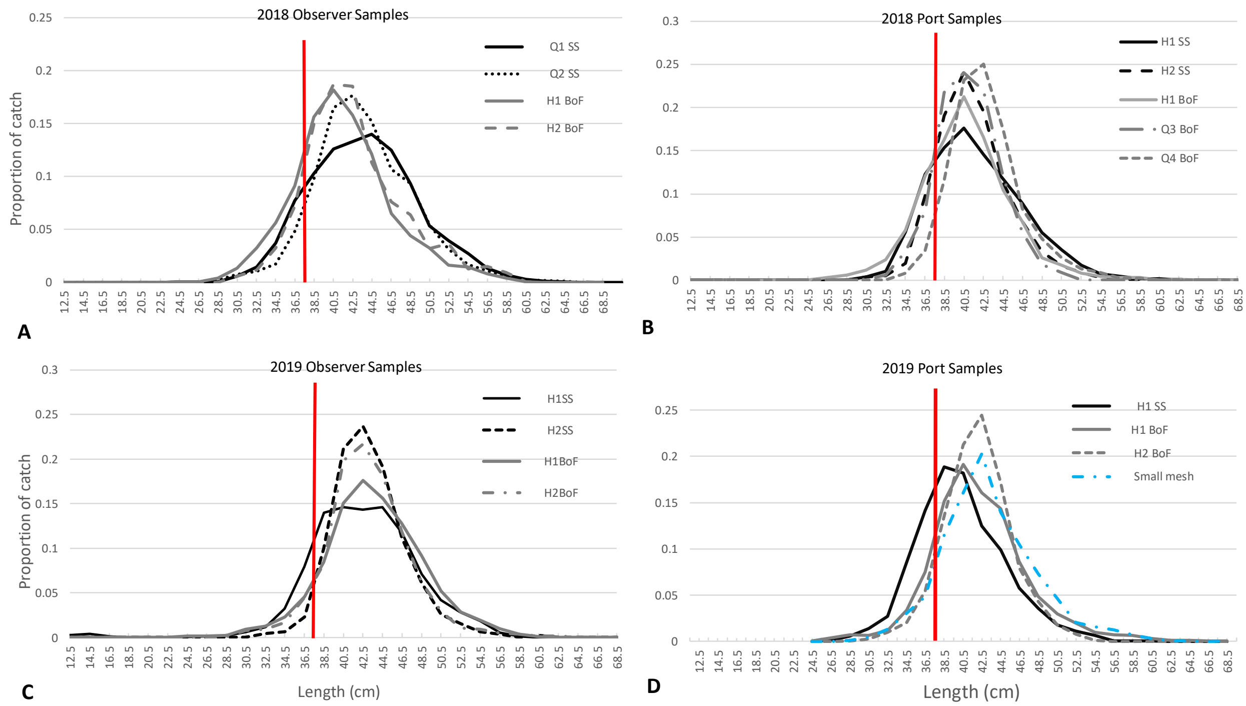

Figure 4. The proportion of catch at length from the 4X5Y Haddock observer (A & C) and port samples (B & D) from mobile gear trips by quarter (Q) or half (H) year from the Scotian Shelf (SS) or Bay of Fundy (BoF) in 2018 and 2019. Haddock are caught as bycatch in the redfish fishery, the small mesh length frequency data (blue line) are port samples from redfish trips. The red reference line indicates small fish as identified in the Conservation Harvesting plan, which are Haddock <38 cm.

Indicators of Stock Status

DFO Summer Research Vessel Survey

The DFO Summer RV Survey (NAFO Divs. 4VWX) biomass indices in 2018 and 2019 were 44,629 t and 28,082 t, respectively (Figure 5). The 2018 and 2019 indices are below the short-term average (5 year: 48,622 t) and long-term median (since 1970: 45,374 t). Haddock were caught in 85 of the 89 tows in 2019; including one large tow (>150 kg).

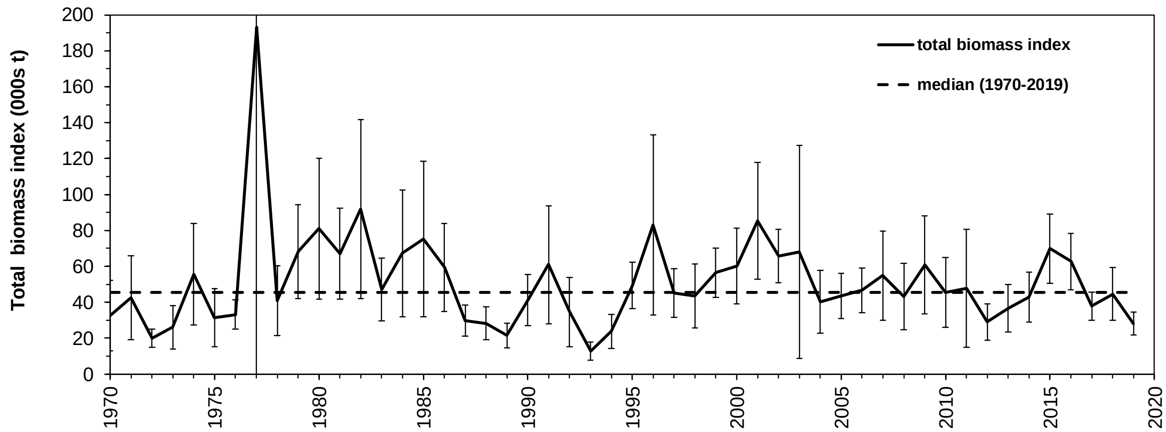

Figure 5. The total biomass index (all ages) ± 2 standard error (000s t) from the DFO Summer RV Survey for 4X5Y Haddock, 1970–2019. The black dashed line represents the long-term median from 1970–2019.

Similar to the trends observed for the commercial fishery, the DFO Summer RV Survey values for the mean WAA and LAA show a decline from the early 1990s to the mid-2000s and then a levelling off or a modest increase, then further decline, with the lowest WAA for most ages occurring in the past five years. The age composition between the Bay of Fundy and the Scotian Shelf has differed in recent years. The lack of older fish (Age 7+) in the Bay of Fundy means that the WAA calculations for older fish are derived primarily from those caught on the Scotian Shelf.

Recruitment is variable throughout the survey time series, with the 2013 yc index at Age 1 being the highest on record with an estimate of 168 million fish (Figure 6). The young of the year index for the 2018 yc was estimated to be the largest in the time series at 137 million (DFO 2019a; DFO 2019b); however, the most recent estimate suggests that the 2018 yc is only moderately strong. In 2019, the 2013 yc (Age 6) made up 33% of the survey CAA followed by the 2018 yc (Age 1), which made up 20%.

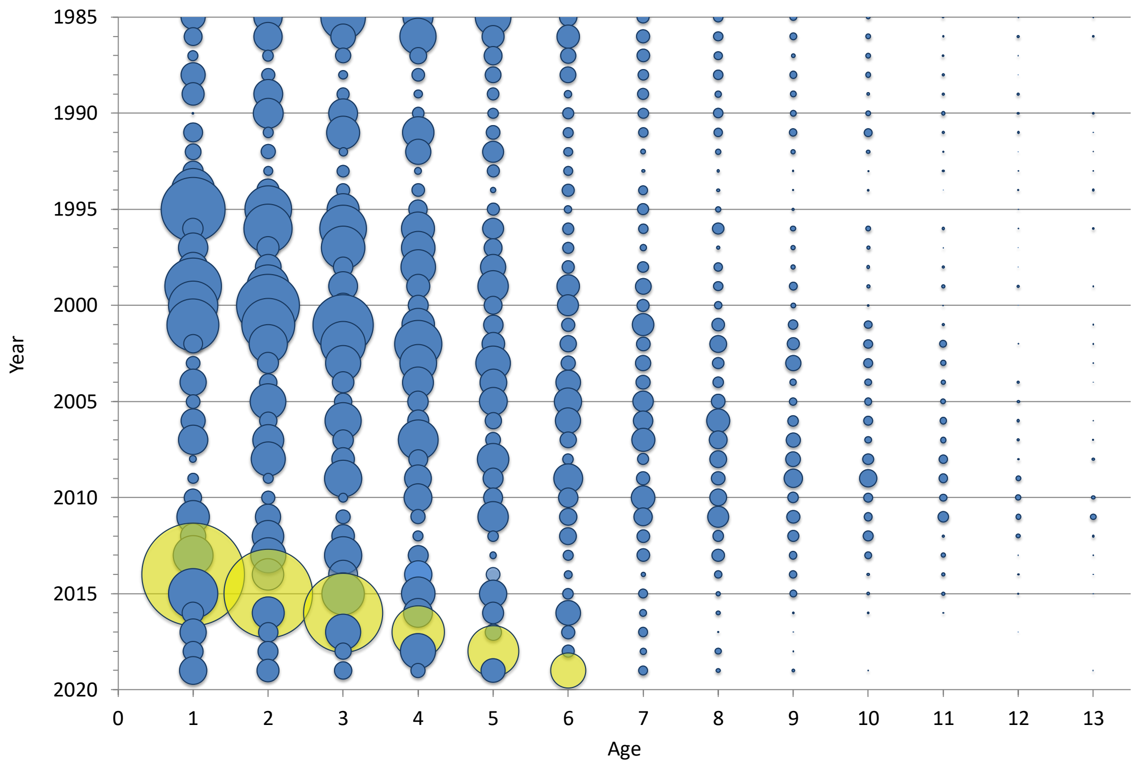

Figure 6. Stratified total number per tow at age (1–13) for 4X5Y Haddock from the DFO Summer RV Survey, 1985–2019. The yellow circles represent the 2013 year class at Age 1 in 2014 to Age 6 in 2019. The area of the circle is proportional to the number at age for each age and year.

Sources of Uncertainty

The model retrospective analysis indicates a pattern of overestimating biomass and recruitment (numbers at Age 1), and underestimating F. This pattern has occurred in the past for this stock, particularly when strong year classes occur (Hurley et al. 2002). The 1998 yc was the largest in the time series during the 2002 assessment of 4X5Y Haddock. The model retrospective analysis indicated that the early estimates of large year classes may be over estimated by a factor of at least 2 and that the pattern can persist at older ages. It is likely that M is higher due to density dependent effects on large year classes than assumed in the model. The 2013 yc at Age 1 was first estimated at 314 million in 2016; the 2018 model estimate was 164 million. However, at Age 6 the 2013 yc is the largest in the time series for both the survey and the model estimate.

The model and projection performance are impacted by the substantial fluctuations in the survey biomass index and the decreasing WAA (survey and fishery). The time series minimum fisheries weight at age was used in the 2018 projection, the minimum weight was an overestimate for ages 3 and 5 (Table 2). Two years of survey data were collected since the 2018 model run, and a mismatch in the magnitude of decline between survey biomass index and the VPA are apparent for 2018 and 2019 (Figure 7). Assuming average recruitment, the biomass was predicted to decline each year from 2018 to 2021. The overall predicted biomass decline was 25% from 2018 to 2021 as the 2013 yc aged; however, the survey biomass decreased 37% from 2018 to 2019, suggesting that model predictions do not fit the latest observations.

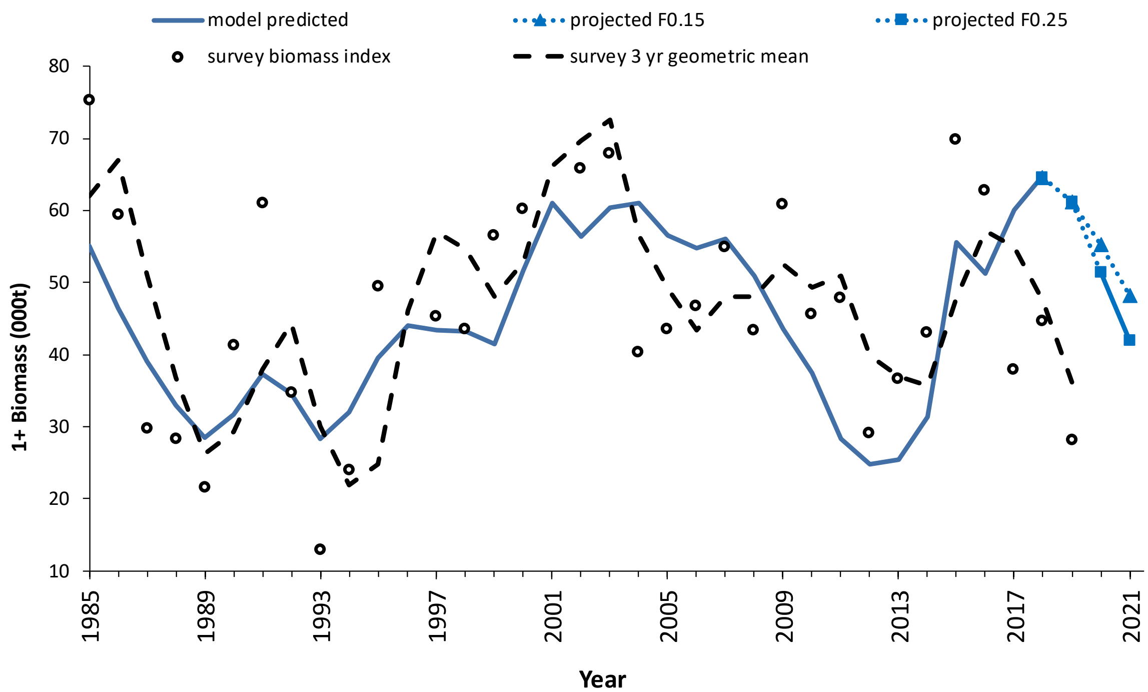

Figure 7. The VPA model estimated 1985–2018 (solid blue line), projected 2019–2021 (F=0.15, blue triangles and F=0.25, blue squares), survey biomass index (circle markers) and 3-year geometric mean survey biomass index (dashed black line; t) for Age 1+ biomass of 4X5Y Haddock.

State of the Resource Relative to Adopted Reference Points

The VPA modeled Age 4+ SSB (spawning stock biomass) is an overestimate as shown by the recent survey trends. The model estimated an increase in biomass from 2016–2018, which was not apparent in the survey biomass indices. The estimate of the 4X5Y Haddock Age 4+ biomass in 2018 was 59,479 t. Biomass was expected to decline after 2018 at F_{lim} or F_{ref} as the very strong 2013 yc aged. The projected Age 4+ biomass of 4X5Y Haddock in 2019 and 2020 was 54,740 t and 49,658 t, respectively (fishing at F_{ref} in 2019). The survey biomass indices (3-yr geometric mean) have declined since 2016 to a level consistent with those seen in 2012–2014. The 3-year geometric mean of the survey biomass index is currently below the 80% of the long-term (1970–2018) geometric mean (Figure 9).

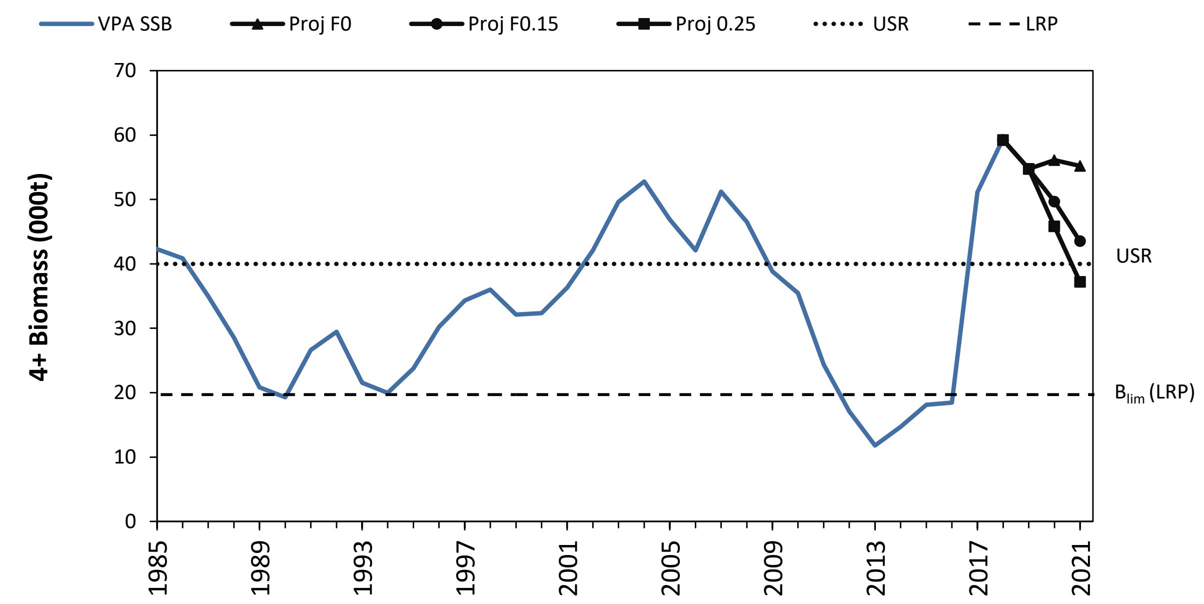

Figure 8. The model estimated spawning stock biomass 1985–2018 (SSB; solid blue line) projections under F_{ref} (F=0.15; black circle markers), F_{lim} (F=0.25; black square markers), and no fishing (F=0, black triangle markers) scenarios for start of year 2019–2021. The established B_{lim} (black dashed reference line) is 19,700 t, and the Upper Stock Reference (USR) point (black dotted reference line) is 40,000 t.

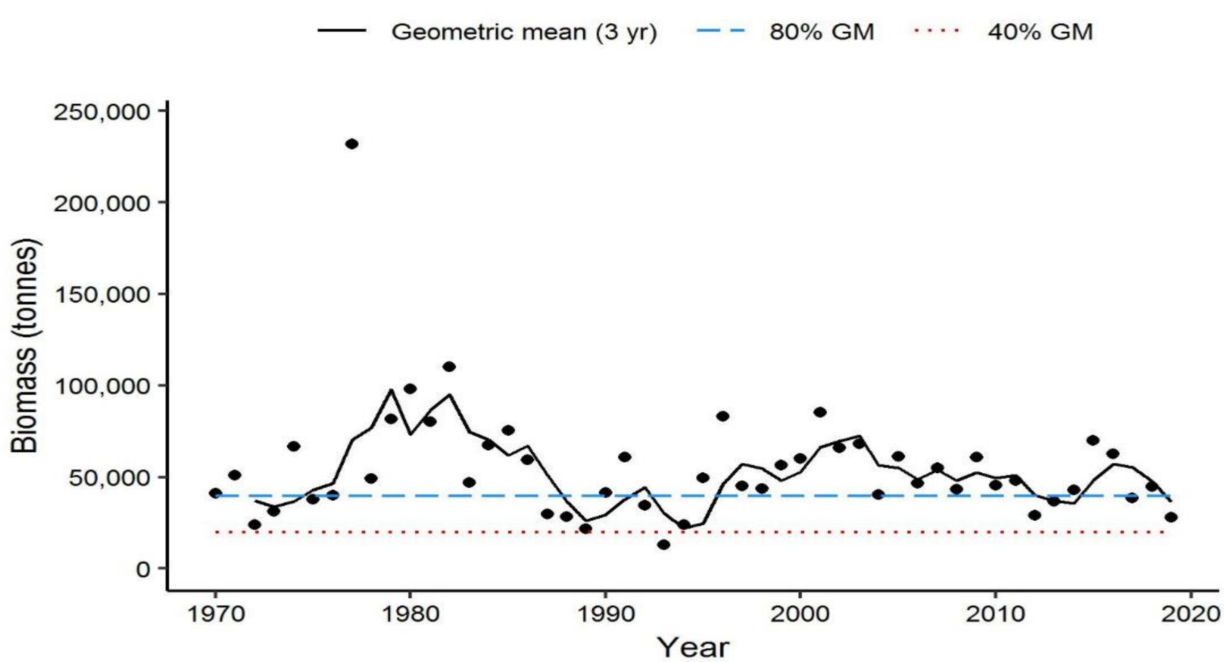

Figure 9. Biomass index for Haddock in 4X from the DFO Summer RV Survey. The 3-year geometric *mean biomass index is represented by the solid black line. The dashed blue and red lines represent 80% and 40% of the long-term geometric mean (1970–2018), respectively. The black dots represent the biomass index for that year.*

Conclusions

Catch estimates provided in 2018 for 2020 (25%, 50%, and 75% risk of fishing mortality exceeding F=0.25 and F=0.15) ranged from 6,350 t to 12,800 t (Table 4). Considering the retrospective pattern that was observed in 2018, the mismatch between the model results, and the survey biomass indices, as well as the other information provided to inform catch advice (Table 5), the standard projection from the 2018 model run is not supported for providing catch advice. A lower probability of exceeding F for 2020/21 would be in line with the precautionary approach. Two methods are provided for lowering the probability of exceeding F; 1) apply the rho adjustment, and 2) a projected biomass to survey index ratio method. During the 2018 VPA model run, the rho adjustment was estimated to be 66% after 7 peels. The resulting catch estimates for 2020 range from 4,814 to 7,098 t, reducing the catch by 34% (Table 4). The second method used the difference between the Age 1+ projected biomass in 2019 and the 3-year geometric mean of the Age 1+ survey biomass index as a multiplier for the catch estimates. For 2018, the 3-year geometric mean Age 1+ survey biomass index (47,331 t) was 73% of the Age 1+ projected biomass (64,545 t). The resulting estimates for 2020 range from 5,325 to 7,851 t, a reduction of 27% (Table 4). For 2019, the 3-year geometric mean Age 1+ survey biomass index (36,218 t) was 59% of the Age 1+ projected biomass (61,118 t). The resulting catch estimates for 2020 range from 4,303 to 6,345 t, reducing the catch by 41% (Table 4). Considering the proposed methods, a reduction of 27%–41% of the projected catch may be appropriate to lower the probability of exceeding F.

Table 4. The levels of catch (t) that were projected in 2018 for 2019 and 2020, for which there was a 25%, 50%, and 75% probability exceeding F=0.25 and F=0.15.

Method	Probability of Exceeding	Catch Year	25%	50%	75%
Model Projection	F=0.15	2019	7,000	8,143	9,550
Model Projection	F=0.25	2019	11,200	13,025	15,300
Model Projection	F=0.15 if F=0.15 in 2019	2020	6,350	7,294	8,700
Model Projection	F=0.25 if F=0.25 in 2019	2020	9,400	10,755	12,800
Rho adjustment	F=0.15 if F=0.15 in 2019	2020	-	4,814	-
Rho adjustment	F=0.25 if F=0.25 in 2019	2020	-	7,098	-
73% Projection vs Survey Index	F=0.15 if F=0.15 in 2019	2020	-	5,325	-
73% Projection vs Survey Index	F=0.25 if F=0.25 in 2019	2020	-	7,851	-
59% Projection vs Survey Index	F=0.15 if F=0.15 in 2019	2020	-	4,303	-
59% Projection vs Survey Index	F=0.25 if F=0.25 in 2019	2020	-	6,345	-

Table 5. Information either supporting the catch advice from the 2018 update or supporting a reduction in the advice.

Maintain Existing Catch Advice	Reduce Catch Advice
The projected adult biomass in 2019 is above the upper stock reference.	A retrospective pattern was observed in the 2018 model run. The pattern leads to overestimated biomass and underestimated F.
Only 70% of the 2018/19 TAC was caught.	A difference in magnitude of decline between survey biomass index and the VPA is apparent for 2018 and 2019.
In 2019, DFO summer survey indices of abundance for 2013 yc at Age 6 are at the highest levels observed for the time series.	The lowest survey and fishery weight-at-age for most ages occurred in the past 5 years.
The 2019 DFO Summer RV survey caught Haddock in >95% of the tows, including one large tow (>150 kg).	The 2018 and 2019 survey biomass index is below the time series average.
The number at Age 1 (2018 yc) is above the time series median.	There are no indications of exceptional year classes coming into the population.
	Availability to the fishery is less certain for the 2013 yc at Age 7 in 2020; reduced availability at older ages has been indicated in the recent VPA.

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Sources of Information

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