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 objectives of this interim update are to report new information from the DFO Summer Research Vessel (RV) Survey and commercial fishery landings data, update the VPA model, evaluate the current stock status and provide catch advice.

This Science Response Report results from the Science Response Process of December 6, 2018, on the Stock Status Update of Haddock in NAFO division 4X5Y.

Background

Biology

Haddock are found on both sides of the North Atlantic and occur in the northwestern Atlantic from southwest Greenland to Cape Hatteras, US. 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 (NAFO Divisions 4Xqrs5Y) are higher than those of Haddock on the western Scotian Shelf (NAFO Division 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).

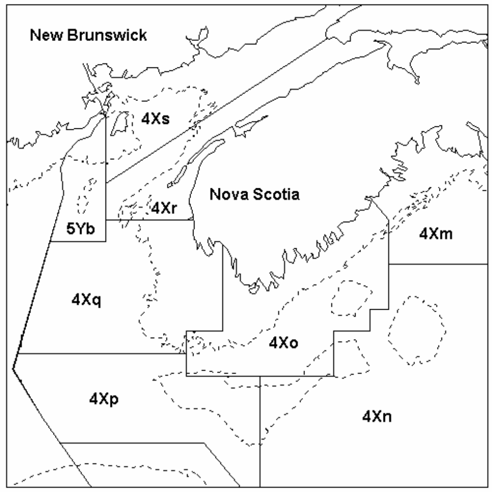

Figure 1. Northwest Atlantic Fisheries Organization Subdivisions, 4Xmnopqrs5Yb.

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. However, catches have been lower than the TAC since 2002 (Figure 2). The fishing year landings for 2017/18 were 5,087 t (Table 1). The 2018/19 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 1970-1999 (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*
TAC	14,650	21,385	5,050	8,030	5,400	5,100	7,650
Landings	18,522	19,851	7,219	6,579	3,719	3,567	5,087

*Extracted from MARFIS as October 2, 2018

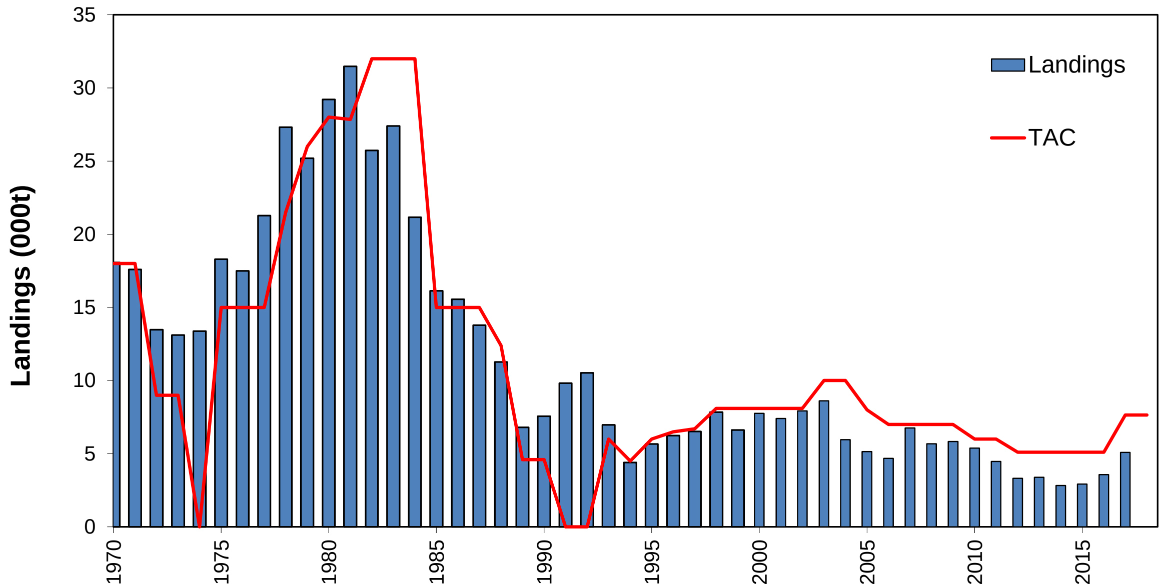

Figure 2. Reported fishing year landings and Total Allowable Catch (TAC) for the 4X5Y Haddock fishery, 1970-2018. The fishing year changed from Jan–Dec to April 1st-March 31st in 2000.

The 4X5Y Haddock fishery CAA shows the presence of the strong 2013 year class (Figure 3). In the 2017 fishery, the 2013 year class at Age 4 was predominant and represented 68% of the CAA followed by the 2012 year class at 12% and the 2014 year class at 11%. The 2017 fishery CAA is similar to the projected CAA in the previous assessment (2016 assessment; DFO 2017); the 2013 year class at Age 4 was projected to represent 65% of the CAA followed by the 2014 year class at 12% and the 2012 year class at 10%.

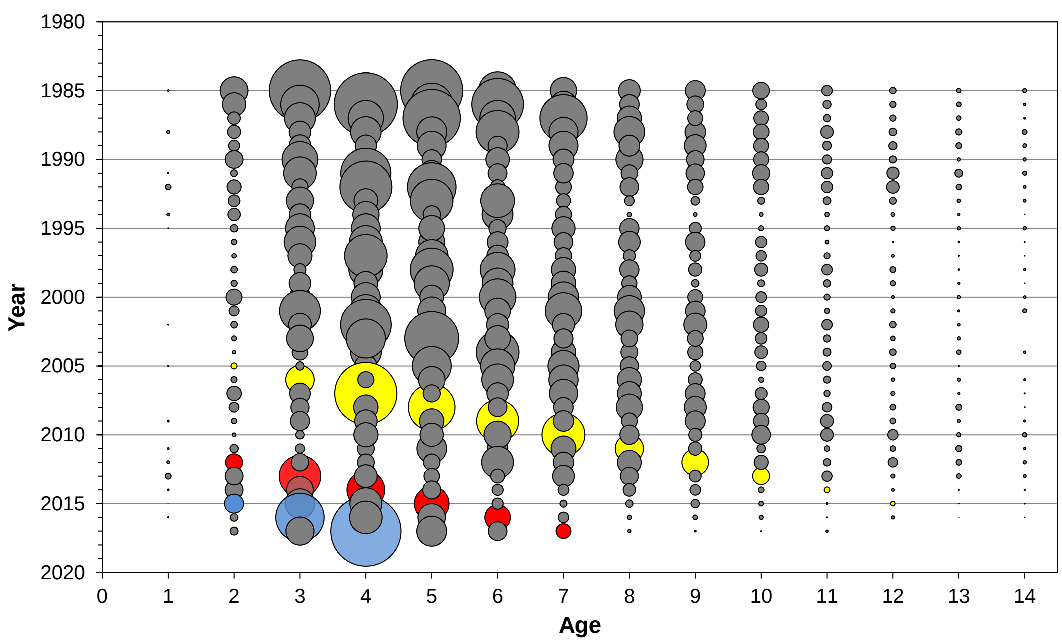

Figure 3. Fishery catch-at-age for 4X5Y Haddock for ages 1-14, 1985-2017. The area of the circle is proportional to the catch in numbers at that age and year. Three examples of recent strong cohorts are highlighted: 2003 (yellow), 2010 (red), and 2013 (blue).

Separate age length keys are used for Scotian Shelf and Bay of Fundy samples to generate numbers-at-age (NAA), which are then used for weighting the calculations of the overall fishery WAA. In 2017, the fishery weighted mean WAA for ages 2, 3, 4, and 11 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+**
2017	Fishery	-	0.35	0.52	0.65	0.85	1.03	1.16	1.47	1.73	2.11	1.10
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
2017	Survey	0.08	0.20	0.33	0.48	0.67	0.75	0.82	0.97	1.46	-	1.30
2018	Survey	0.08	0.21	0.35	0.51	0.61	0.69	0.83	0.96	1.07	-	-

Indicators of Stock Status

DFO Summer Research Vessel Survey

The DFO Summer RV Survey (NAFO Divs. 4VWX) biomass index in 2017 and 2018 were 37,850 t and 44,629 t, respectively (Figure 4). The 2017 and 2018 indices are below the short-term average (5 year: 51,589 t) and long-term (since 1970: 45,537 t) median. Haddock were caught in all of the 73 tows in 2018; including two large tows (>150 kg).

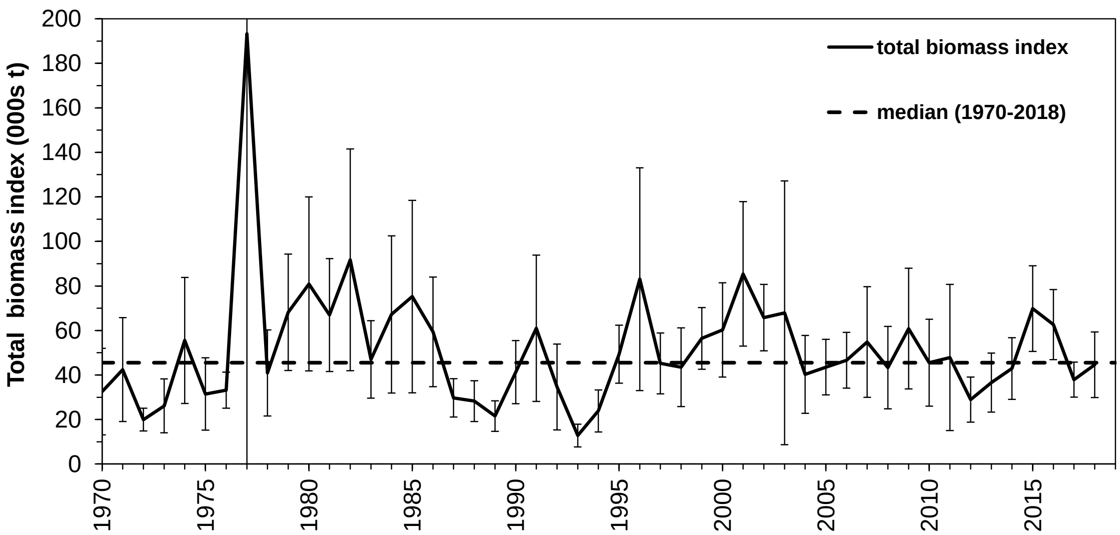

Figure 4. The total biomass index (all ages) ± 2 standard error (000s t) from the DFO Summer RV Survey for 4X5Y Haddock, 1985-2018. The black dashed line represents the long-term median from 1970-2018.

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; however, no fish greater than Age 9 were collected during the survey in 2018 for either area.

Recruitment is variable throughout the survey time series, with the 2013 year class index at Age 1 being the highest on record with an estimate of 168 million fish (Figure 5). The young of the year index for the 2018 year class was estimated to be the largest in the time series at 137 million (DFO 2019). In 2018, the 2013 year class (Age 5) made up 49% of the survey CAA followed by the 2014 year class (Age 4), which made up 24%.

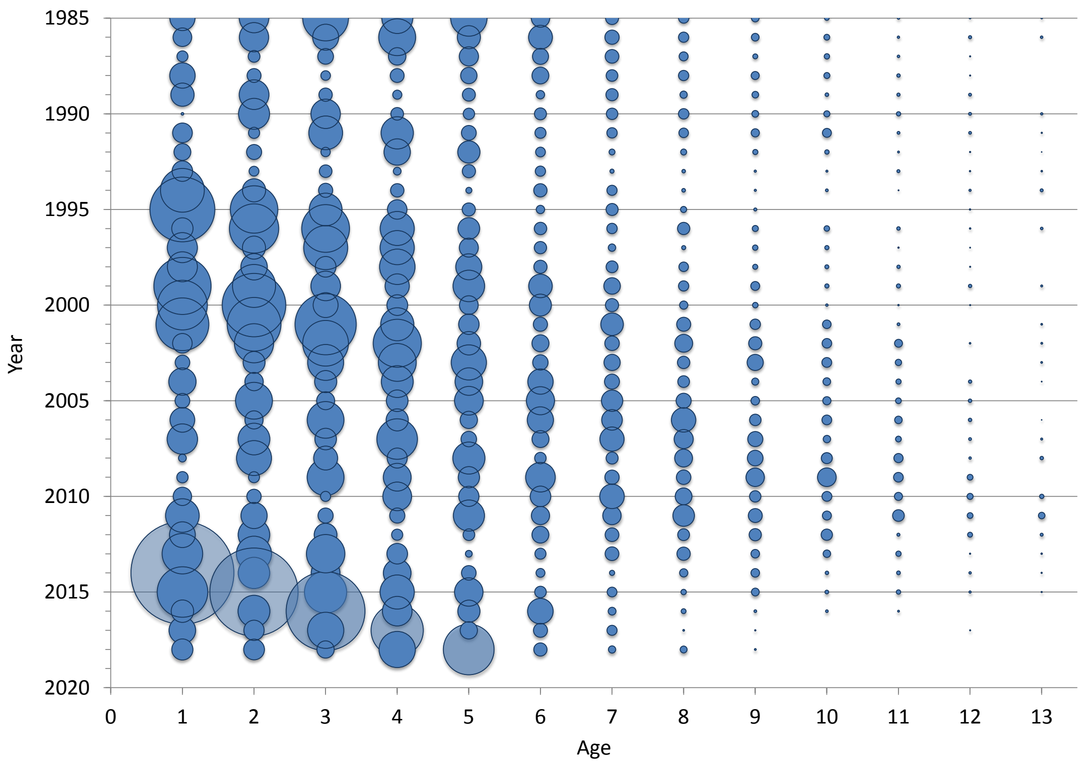

Figure 5. Stratified total number per tow at age (1-13) for 4X5Y Haddock from the DFO Summer RV Survey, 1985-2018. The semi-transparent circles represents the 2013 year class at Age 1 in 2014 to Age 5 in 2018. The area of the circle is proportional to the number at age for each age and year.

Estimate of Stock Parameters and Comparison to Reference Points

The VPA model output shows a retrospective pattern, overestimating the biomass and underestimating Fishing Mortality (F) in the most recent years when compared to the terminal year (Figure 6).

Estimates for the 2013 year class at Age 1 remain extraordinarily high for this stock at 164 million recruits. The estimate for the 2014 year class (Age 1 in 2015) is 40 million, above the long-term geometric mean for Age 1 of 20 million recruits (Figure 6).

The estimated F for ages 6 to 10 in 2017 was 0.05 for 4X5Y Haddock, therefore below the F_{ref} and F_{lim} (Figure 6).

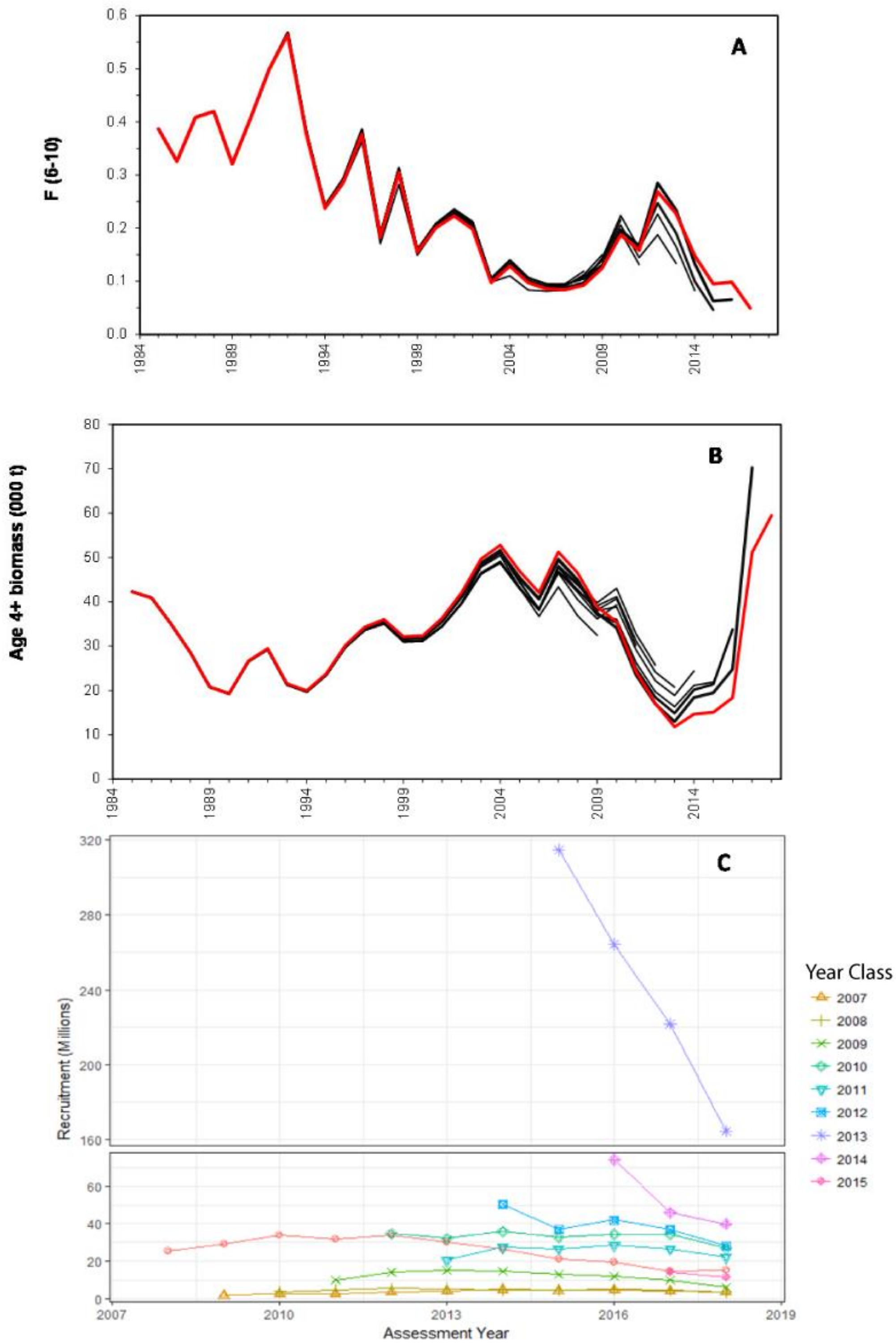

Figure 6. The retrospective analysis for (A) fishing mortality 2009-2018, (B) biomass 2009-2018, and (C) the Age 1 recruitment 2008-2018 from the ADAPT VPA model. See DFO 2017 for analysis details. The full assessment time series is compared with model runs of identical structure but with one to seven of the most recent years of data removed to illustrate uncertainty and consistent directional bias in terminal years estimates.

Spawning Stock Biomass (SSB, Age 4+) decreased from 42,000 t in 1985 to 20,000 t in 1990 and started to increase in 1996 due to the contribution of the stronger year classes. A period of lower recruitment followed, resulting in a low SSB in 2013, but the SSB started to increase due to the strong incoming year classes (moderate 2010-2012 year classes and strong 2013 year class). The estimated SSB at the beginning of 2018 was 59,479 t (36,929 – 92,826 95% Confidence Interval [CI]), above the established biomass limit reference point (B_{lim}) of 19,700 t and the long-term average of 32,351 t (Figure 7).

Indicators that would trigger an earlier than scheduled assessment based on the established recommendations in DFO 2017 include:

1. A difference in strong year class projected versus realized. In this case, if the perception of 2013 year class strength goes below the second highest observed year class, (i.e. below the value used for sensitivity analysis (1999 year class) and outside the range of sensitivity projections), then a more complete review will be conducted.
2. Low survey biomass trigger (suggested a 3-year running q (catchability) average below B_{lim}) using the previous year's q values.

The 2013 year class continues to be the highest in the data series, and it is within the range of the sensitivity projections. The 3-year running q adjusted Age 4+ survey biomass is 26,082 t, therefore above B_{lim}, and the VPA SSB estimate is also above B_{lim}. No triggers for an earlier than scheduled assessment occurred, therefore an update will be provided as scheduled in 2019.

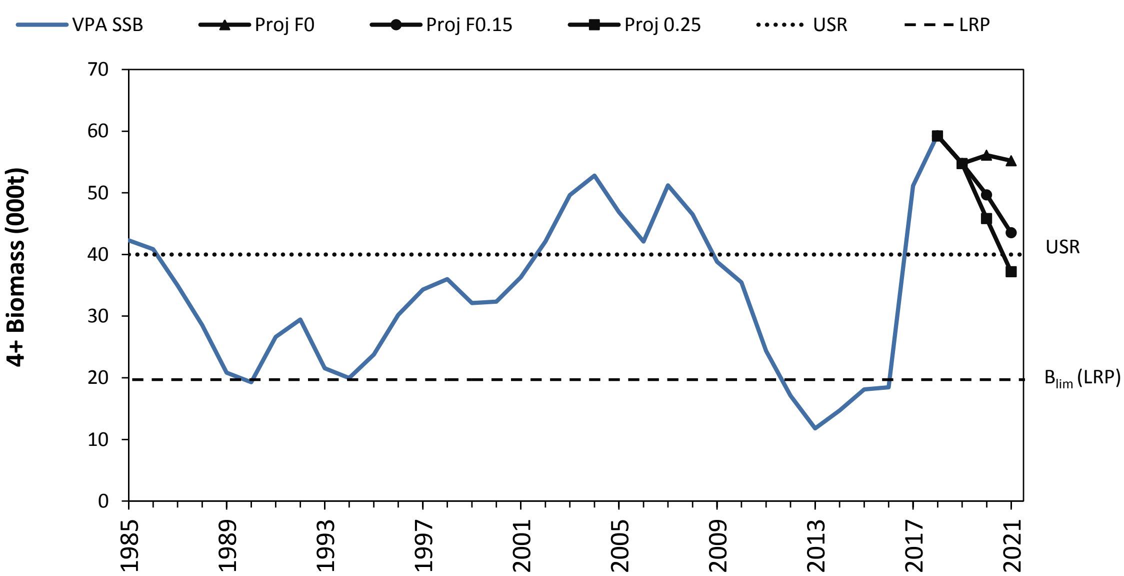

Figure 7. The model estimated spawning stock biomass 1985-2018 (SSB; solid blue line) projections under F_{ref} (F=0.15; black circle markers), F_{lim} (F=0.25; black square markers), and no fishing (F=0, black triangle markers) scenarios for start of year 2019-2021. The established B_{lim} (black dashed reference line) is 19,700 t, and the Upper Stock Reference (USR) point (black dotted reference line) is 40,000 t.

Projection and Probability Analysis

Projections were conducted using the 2018 survey WAA (back-calculated) and the time series minimum fishery WAA; all fisheries minimum WAA occurred in the last five years (Table 2). Given the decreasing trend in WAA, this was believed to be a more precautionary approach than an average. Deterministic projections were conducted with a catch of 7,650 t in 2018 and fishing at F_{lim}=0.25 for 2019 and 2020, and a second deterministic projection was conducted under fishing at F_{ref}=0.15 for 2019 and 2020 (Figure7). The probability of the Age 4+ biomass in 2020 and 2021 decreasing into the Critical Zone (less than B_{lim}) is <1% in all the provided catch scenarios. There is a 59% probability that fishing at the F_{lim} in 2020 would reduce the SSB to the Cautious Zone at the start of the year 2021 (Table 3). This analyses assumes the 2017 year class (Age 4 in 2021) is the 10 year geometric mean of Age 1 recuits, 17,514.

Table 3. The probability of Spawning Stock Biomass (SSB) being in the Critical Zone (below B_{lim}) or Cautious Zone (below the Upper Stock Reference; USR) beginning of year 2020 and 2021 given a range of catch scenarios in 2019 and 2020.

	Yield ('000 t)		P (SSB<LRP=19,700 t)		P (SSB<USR = 40,000 t)	
	2019	2020	2020	2021	2020	2021
Constant TAC	7,650	7,650	<1%	<1%	16%	47%
F_{ref} = 0.15	8,143	7,294	<1%	<1%	17%	45%
F_{lim} = 0.25	13,025	10,755	<1%	<1%	28%	59%

A stochastic projection was conducted with a catch of 7,650 t in 2018 and fishing at F_{lim}=0.25 in 2019 and 2020, and a second stochastic projection with F=0.15 in 2019 and 2020. Catch estimates (50%) for 2019 and 2020 ranged from 7,294 t to 13,025 t (Table 4). Probability calculations assist in evaluating the consequences of alternative catch quotas by providing a general measure of the uncertainties. Table 4 provides the probability of F in 2019 and 2020 exceeding F_{lim}=0.25 and F_{ref}=0.15 under a range of catch values.

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

Probability of Exceeding	Catch Year	25%	50%	75%
F=0.15	2019	7,000	8,143	9,550
F=0.25	2019	11,200	13,025	15,300
F=0.15 if F=0.15 in 2019	2020	6,350	7,294	8,700
F=0.25 if F=0.25 in 2019	2020	9,400	10,755	12,800

Sources of Uncertainty

The model retrospective analysis indicates a pattern of overestimating biomass and recruitment (numbers at Age 1), and underestimating F (Figure 6). This pattern has occurred in the past for this stock, particularly when strong year classes occur (Hurley et al. 2002). The 1998 year class 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 year class at Age 1 was first estimated at 314 million in 2016; the most recent model estimate is 164 million. However, at Age 5 the 2013 year class is the largest in the time series for both the survey and the model estimate.

Conclusions

At the 2016 framework and assessment, it was concluded that 2016 4X5Y Haddock biomass, 33,770 t, was above the established B_{lim} reference point (19,700 t) and marginally below the

USR (40,000 t). The framework also found that the estimated fishing mortality (F) of 0.05 for ages 6 to 10 4X5Y Haddock was below both the Healthy Zone (F_{lim}=0.25) and Cautious Zone (F_{ref}=0.15) fishing mortality references. Since that assessment of the resource, new information is available from two sources: commercial landings data (2016 and 2017) and the DFO Summer RV Survey (2017 and 2018).

The model estimate of the 4X5Y Haddock Age 4+ biomass in 2018 is 59,479 t. The estimated fishing mortality (F) for ages 6 to 10 in 2017 was 0.05 for 4X5Y Haddock, well below target F (Figure 6). Biomass is expected to decline after 2018 at F_{lim} or F_{ref} as the very strong 2013 year class ages (Figure 7). The model estimates for Age 4+ biomass in 2018 and projections with F=0.15 for 2019 -2021 remain above the USR of 40,000 t (Figure 7). The probability of the Age 4+ biomass dropping into the Critical Zone (< B_{lim}) by 2021 is <1% in all the provided catch scenarios. There is a 59% probability that fishing at the F_{lim} in 2019 and 2020 would reduce the SSB to the Cautious Zone by 2021 (Table 3). However, the retrospective analysis shows an increased pattern and, historically, when strong year classes are present, the past models tended to overestimate biomass for this stock.

Catch estimates for 2019 and 2020 (50% risk of the fishing mortality exceeding F=0.25 and F=0.15) ranged from 7,294 t to 13,025 t (Table 4). Due to the increased retrospective pattern overestimating biomass and underestimating fishing mortality, a lower probability of exceeding F would be in line with the precautionary approach.

Moving forward, a priority should be made for future model runs to include survey data from the most recent year as well as the first half of the fishing year.

Contributors

Name	Affiliation
Monica Finley (Lead)	DFO Science, Maritimes Region
Ryan Martin	DFO Science, Maritimes Region
Brendan Wringe	DFO Science, Maritimes Region
Irene Andrushchenko	DFO Science, Maritimes Region
Quinn McCurdy	DFO Science, Maritimes Region
Don Clark	DFO Science, Maritimes Region
Kirsten Clark	DFO Science, Maritimes Region
Jamie Emberley	DFO Science, Maritimes Region
Cornelia den Heyer	DFO Science, Maritimes Region
Daphne Themelis	DFO Science, Maritimes Region
Caira Clark	DFO Science, Maritimes Region
Heath Stone	DFO Science, Maritimes Region
Lottie Bennett	DFO Science, Maritimes Region
Alida Bundy	DFO Science, Maritimes Region
Melanie Barrett	DFO Science, Maritimes Region
Alan Debertin	DFO Science, Maritimes Region
Virginia Noble Dalton	DFO Science, Maritimes Region
Yanjun Wang	DFO Science, Maritimes Region
Catriona Régnier-McKellar	DFO Science, Maritimes Region
Fonya Irvine	DFO Science, Maritimes Region
Jennifer Ford	DFO Science, Maritimes Region
Penny Doherty	DFO Resource Management, Maritimes Region

Approved by

Alain Vézina
Regional Director of Science, DFO Maritimes Region
Dartmouth, Nova Scotia
Ph. 902-426-3490

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Sources of Information

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Center for Science Advice (CSA)
Maritimes Region
Fisheries and Oceans Canada
1 Challenger Drive, PO Box 1006
Dartmouth, Nova Scotia B2Y 4A2
Canada

Telephone: 902-426-7070
E-Mail: MaritimesRAP.XMAR@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

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