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Maritimes Region

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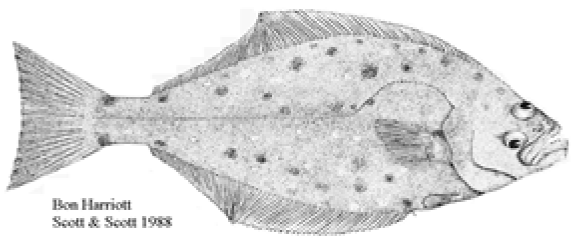
2022 ASSESSMENT OF ATLANTIC HALIBUT ON THE SCOTIAN SHELF AND SOUTHERN GRAND BANKS (NAFO DIVISIONS 3NOPS4VWX5ZC)



*Atlantic Halibut (*Hippoglossus hippoglossus*)*

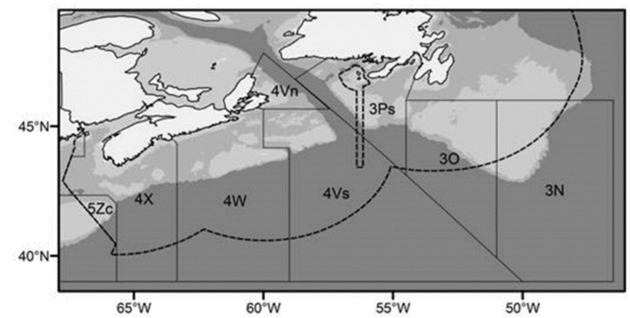


Figure 1. Atlantic Halibut management unit 3NOPs4VWX5Zc.

Context:

The Atlantic Halibut (Hippoglossus hippoglossus) is the largest of the flatfishes and ranges widely over Canada's East Coast. The management unit definition (3NOPs4VWX5Zc) is based largely on tagging results that indicate that Atlantic Halibut move extensively throughout the Canadian North Atlantic. The Atlantic Halibut fishery was unregulated until a total allowable catch (TAC) was implemented in 1988. An additional legal size limit (≥ 81 cm total length) was established in 1995. While the Fisheries and Oceans Canada (DFO) Maritimes Ecosystem Research Vessel (RV) survey provides a useful index of abundance for incoming recruitment, it does not provide an index of exploitable biomass (≥ 81 cm total length) since larger fish are captured infrequently. An industry-DFO longline Halibut Survey on the Scotian Shelf and southern Grand Banks (3NOPs4VWX5Zc) was initiated in 1998 to better estimate adult biomass. A commercial index is conducted in conjunction with the Industry-DFO Halibut Longline Survey. The Industry-DFO Halibut Longline Survey provides an index for exploitable biomass of Halibut from the Scotian Shelf and southern Grand Banks. The commercial index provides data on the population size structure. A tagging study was initiated in 2006, wherein, both recruits and commercial-sized fish were tagged and released. Recoveries are used to estimate natural mortality and exploitation rate.

A new assessment model and assessment procedures were peer-reviewed in November 2014, to inform Fisheries Management of the status of the Halibut resource and to provide harvest level advice based on standardized catch rates from the Industry-DFO Halibut Longline Survey and stratified mean numbers per tow from the RV survey. Science advice has since been provided through annual updates and evaluation of abundance indicators, landings, and estimates of fishing mortality from tagging data.

In November 2021, the first peer review meeting of a two-part assessment framework review took place and reviewed assessment data inputs. In March 2022, the second peer review meeting reviewed the assessment framework and used simulation modeling to assess performance of a suite of harvest control rules.

This Science Advisory Report is from the regional advisory meeting on the Framework Review for Atlantic Halibut on the Scotian Shelf and Southern Grand Banks in NAFO Divisions 3NOPs4VWX5Zc:

Part 2 - Review of Modelling Approaches held March 1 to 4, 2022. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- The new Spatially Integrated Statistical Catch-At-Length (SISCAL) age- and sex-structured model was used to assess the stock status. Closed-loop simulation was used to evaluate the impact of a suite of harvest strategies on the biomass/population trends and landings.
- A Richards-Schnute growth model, which accounts for gear size-selectivity and length-stratified sampling, was fit to all available age-length data and used to inform the length-based assessment model.
- The 2021 spawning stock biomass (SSB) estimate is at a time series high of 20.6 kt. Total and legal-sized biomass are near record levels at 54.1 kt and 46.5 kt, respectively.
- While the stock is in the healthy zone, it is likely to decline in the near term under either proposed harvest control rule (HCR). The model estimate of recruitment was higher from 2002–2013 leading to the stock increasing well above the biomass at maximum sustainable yield (B_{MSY}); however, since then, recruitment has been closer to the long-term mean.
- Recent exploitation rates have remained stable providing evidence of success of the constant fishing mortality (F) HCR adopted in 2015.
- Estimates of natural mortality (M) in the model were allowed to vary over the time series, with recent (2014–2021) estimates of M ranging from 0.128 to 0.143 for males and from 0.120 to 0.133 for females.
- Based on the new assessment model the limit reference point (LRP) was defined as 0.4 SSB_{MSY}=5.3 kt and a proposed upper stock reference (USR) was defined as 0.8 SSB_{MSY}=10.6 kt.
- Closed loop simulations were used to evaluate a range of candidate management procedures (MPs). Both tested HCRs met the conservation objectives for this stock. The increased precision of the random survey design allowed MPs to perform better than those based on the fixed survey portion of the Industry-DFO Halibut Longline Survey with respect to TAC stability and conservation measures.
- Simulations over two generations of the release of live Halibut >125 pounds (170 cm) did not improve stock performance, and in some cases led to increased probability of falling below the USR. There was also no indication that increasing the minimum legal size to 86 cm would impact stock performance as measured by the probability of falling below reference points or projected catch.
- Using the 3-year mean of the stratified random survey the TAC for the 2022 fishing season would be 4,040 t under the ramped HCR and 4,807 t under the articulated HCR.

INTRODUCTION

Biology

Atlantic Halibut are most abundant at depths of 200–500 m in the deep-water channels running between the banks and along the edge of the continental shelf, with larger individuals moving into deeper water in the winter. The geographic range of Atlantic Halibut in the Northwest Atlantic extends from the coast of Virginia in the south to the waters off northern Greenland.

Both sea surface temperature and bottom temperature have increased in most areas of Northwest Atlantic Fisheries Organization (NAFO) Divisions 3NOPs4VWX5Zc (Figure 1) since the late 1990s (DFO 2020). The consequent increase in both growing degree days (an index of growing potential; Shackell et al. 2019) and available thermal habitat (Czich et al. In press), in addition to the reduction in fishing mortality and other factors, may have contributed to recovery of this stock.

The diet of Atlantic Halibut changes with size, as well as with space and time. Halibut up to 30 cm eat invertebrates almost exclusively, with consumption of fish increasing as the size of Halibut increases. With the increasing temperature and other changes in oceanographic conditions, there have been shifts in zooplankton communities since 2010 (Casault et al. 2020, DFO 2020). The changes from the base of the marine food web may suggest a low productivity for the entire ecosystem. There have also been changes in the abundance of predators. Small Halibut are preyed on by Greenland Sharks (*Somniosus microcephalus*), seals, and Spiny Dogfish (*Squalus acanthus*). Predators are rare for large Halibut because of its size. Additionally, depredation by seals when fish are caught on fishing gear has been reported.

Female Atlantic Halibut grow faster than the males and attain a much larger maximum size. Atlantic Halibut grow rapidly (approximately 10 cm per year) until the age at 50% maturity. There is evidence for spatial variation in growth and maturation length across the management unit, and there may be more variation in the age at first sexual maturity than length at maturity. Both the standard von Bertalanffy growth model and a Richards-Schnute growth model, which accounts for gear size-selectivity and length-stratified sampling, were fit, separately for males and females, to all available age-length data (Figure 2; Zheng et al. In prep.[1]). The Richards-Schnute model was used in the assessment model to estimate age from length and to estimate age of maturity. The age of 50% maturity for females was estimated to be 11.5 years and the age at 95% maturity was estimated at 14.5 years. With the approximate value of model-estimated natural mortality 0.13, the generation time is estimated as 19 years, although simulations were based on previous estimate of 14 years.

[1] Zheng, N., Perreault, A.M.J., Li, L., Hubley, B., den Heyer, C.E., and Cadigan, N.G. In preparation. A Spatiotemporal Richards-Schnute Growth Model for Atlantic Halibut (*Hippoglossus hippoglossus*) on the Scotian Shelf and Southern Grand Banks (fit to preliminary data). DFO Can. Sci. Advis. Sec. Res. Doc.

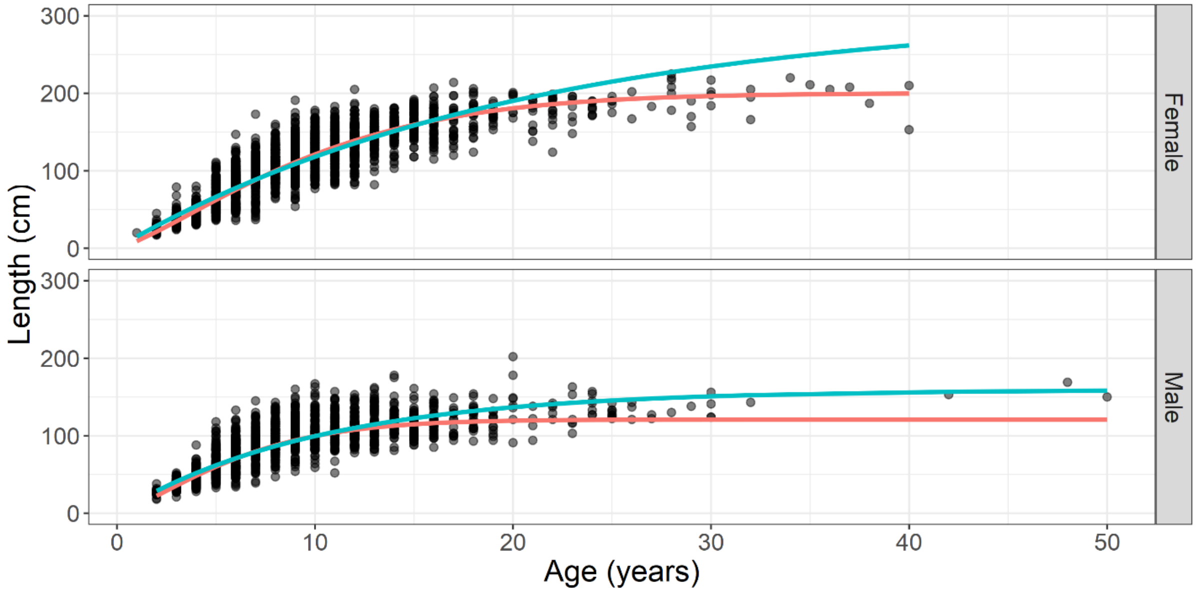


Figure 2. von Bertalanffy (blue) and Richards-Schnute (pink) growth models for female (top) and male (bottom) Atlantic Halibut (Zheng et al. In prep.[1]).

Description of the Fishery

The management unit definition (NAFO Divisions 3NOPs4VWX5Zc; Figure 1) was based largely on tagging results that indicated that Atlantic Halibut move extensively throughout the Canadian North Atlantic. Within the management unit, Atlantic Halibut were fished mostly along the edges of the continental shelf in early years. Longline and otter trawl are the predominant gears despite many gears having been used in the fishery (Li et al. In preparation). Until 1988, the fishery was unregulated. A Total Allowable Catch (TAC) of 3,200 tonnes (t) was first established in 1988 and, in response to an eight year decline in landings, was reduced to a low of 850 t in 1995. Management plans and licence conditions require the release of Atlantic Halibut < 81 cm. Beginning in 1999, the TAC has been increased several times and was last set at 5,445 t in 2021 (Table 1; Figure 3).

NAFO statistics are used to describe removals up to 2020 because landings occur in two Fisheries and Oceans Canada (DFO) regions (Maritimes Region and Newfoundland and Labrador Region [NL]). Other countries including Portugal, Spain, France, and the United States, also remove Halibut from within the stock area, but outside Canada's Exclusive Economic Zone (EEZ). Canadian landings reported for 2021 in Maritimes and NL regions are preliminary. Canadian landings in 3NOPs increased by 36% in 2020 compared to 2019, while Canadian landings in 4VWX5Zc and foreign landings had small changes. In some years, Canadian quota carry forward provisions and foreign catches result in total landings above the TAC.

Table 1. Total reported Canadian and foreign landings (tonnes) of Atlantic Halibut from Northwest Atlantic Fisheries Organization (NAFO) Divisions 3NOPs4VWX5Zc[1]. Ten-year annual average landings are presented for 1960 to 2009. The NAFO 21A table of landings by country are reported by calendar year; however, the total allowable catch (TAC) for the stock is set for the period of April-March. Data was extracted from the NAFO 21A database on January 18, 2022. Dash (-) indicates data not available.

	Canada			Foreign			3NOPs4VWX5Zc	
Year	**3NOPs**	**4VWX5Zc**	**Total**	**3NOPs**	**4VWX5Zc**	**Total**	**Total**	**TAC**
1960-1969	638.4	1,520.9	2,159.3	492.2	62	554.2	2,713.5	-
1970-1979	427.8	874	1,301.8	73.7	15.4	89.1	1,390.9	-
1980-1989*,**	738.2	1,624.6	2,362.8	217	13.8	230.8	2,593.6	-
1990-1999	323.2	815.4	1,138.6	179.6	4.3	183.9	1,322.5	1,855
2000-2009	460.9	878.1	1,339	147.8	0.1	147.9	1,486.9	1,340
2010	464	1,296	1,760	131	1	132	1,892	1,850
2011	373	1,346	1,719	218	1	219	1,938	1,850
2012	531	1,491	2,022	200	1	201	2,223	2,128
2013	562	1,836	2,398	205	1	206	2,604	2,447
2014	839	1,811	2,650	312	1	313	2,963	2,563
2015	693	2,174	2,867	395	1	396	3,263	2,738
2016	626	2,186	2,812	393	1	394	3,206	3,149
2017	759	2,353	3,112	403	1	404	3,516	3,621§
2018	699	3,171	3,870	343	0	343	4,213	4,164§
2019	841	3,414	4,255	480	0	480	4,735	4,789§
2020	1,142	3,692	4,834	465	0	465	5,299	5,507§
2021	1,472†	3,894†	5,366†	-	-			5,445§

[1] Canadian landings in 5Y are assumed to have been in the Canadian portion and are included in the 4VWX+5Zc value. Foreign/US landings in 5Y are not included.
*Landings were first listed in 5Zc in 1986; 5Zc and 5Ze are used to indicate same area.
**Prior to 1988 the Atlantic Halibut catch was unregulated.
§ Since 2017, 100 t of the Canadian TAC has been set aside annually to cover catches by US and France within the stock area.
† Landings from the Maritimes Fisheries Information System (MARFIS) and NL landing data for 2021 are preliminary as of January 18, 2022.

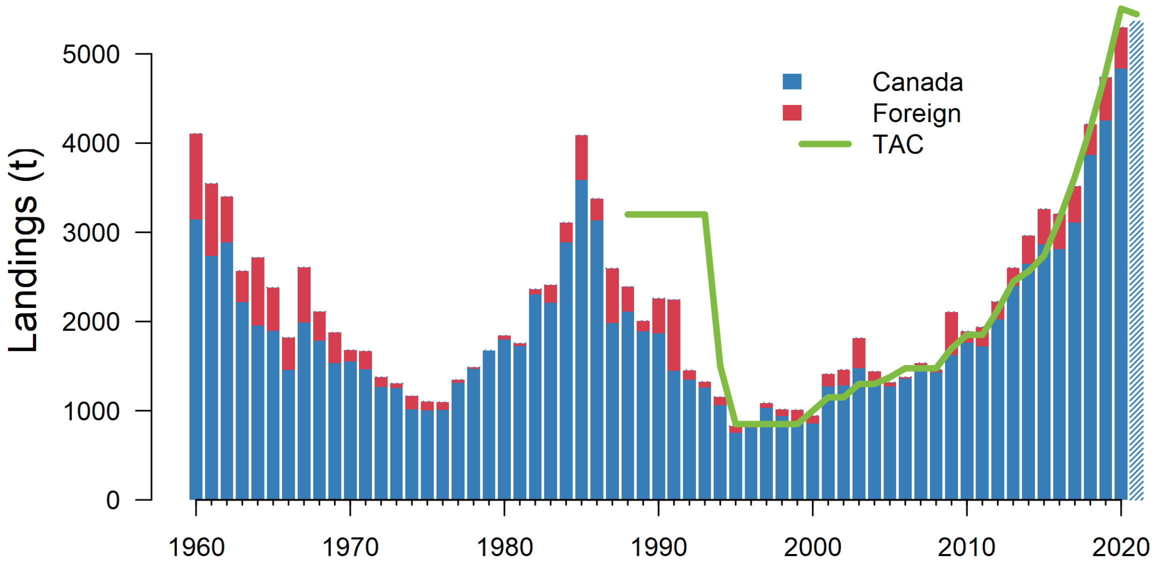


Figure 3. Northwest Atlantic Fisheries Organization (NAFO) reported Canadian (blue) and foreign (red) landings (tonnes) for 3NOPs4VWX5Zc Atlantic Halibut. Landings for 2021 (hashed bar) are preliminary, and taken from the Maritimes Fisheries Information System (MARFIS) and NL landing data as of January 18, 2022. The solid green line is the Canadian Total Allowable Catch (TAC). The NAFO 21A table of landings by country are reported by calendar year; however, the TAC for the stock is set for the period of April–March.

BYCATCH

Halibut is caught in a multi-species groundfish fishery. The bycatch associated with Halibut landings is composed of species caught and discarded at sea (including Halibut under 81 cm), kept for bait, or landed as part of the fishery. At-sea observer coverage provides data on the species caught and estimated weights of the portions kept and discarded. Observer coverage is variable across the management unit, but overall has declined. Across the entire fishery, the observation rate for Atlantic Halibut trips declined from a maximum of 5.1% in 2011 to 2.0% in 2019.

A new method was used to estimate the bycatch ratio of Halibut landed (Bowlby et al. 2024). The method extracts and links the at-sea observed trips and commercial landings data in Maritimes Region and uses a log-linear model. The proportion of total catches that were Atlantic Halibut increased for essentially all NAFO divisions and fishing quarters from the time period 2009–2013 to 2014-2020. The percentage of Atlantic Halibut catches that were below the legal limit and were discarded was twice as high in the 2009–2013 time period as compared to 2014–2020. From 2009 to 2020, there are relatively few instances where bycatch of a particular species or species group seems to be increasing, and nearly all examples come from 4X.

ASSESSMENT

The previous assessment model and assessment procedures were peer reviewed in 2014. The limit reference point (LRP, B_lim) was defined as the minimum spawning stock biomass (SSB) in the time series (1982–2013) that produced 50% of the maximum recruitment and the upper stock reference point (USR, B_upper) was defined as the highest SSB in the time series, which was in 2013. A fishing mortality (F) harvest strategy, F=0.14 with a cap on annual changes in TAC of 15%, has been used since 2015. Stock status and harvest advice in interim years was assessed based on the Halibut Survey index of exploitable biomass and the DFO Summer Research Vessel (RV) Survey (NAFO divisions 4VWX).

The new assessment framework uses a new sex- and age-structured model to assess stock status and provide maximum sustainable yield (MSY)-based reference points (Johnson et al. 2024). Additionally, closed-loop simulation was used to evaluate the impact of a suite of harvest strategies on the biomass/population trends and landings.

Spatially Integrated Statistical Catch-at-Length (SISCAL)

A new Spatially Integrated Statistical Catch-At-Length (SISCAL) age-structured model of population dynamics was developed (Johnson et al. 2024). It estimates biomass, fishing mortality, recruitment, and biological reference points fitted to:

- the Maritimes Ecosystem Research Vessel Surveyrelative abundance index from NAFO Divisions 4VWX (RV_4VWX; 1970–2020);
- the fixed station portion of the Industry-DFO Halibut Longline Survey biomass Catch Per Unit Effort (HSfix, 1998-2021);
- the stratified random portion of the Industry-DFO Halibut Longline Survey (HSrand, 2017–2021); and
- the male, female, and combined proportion-at-length data for longline commercial fisheries in 4VWX+5Zc and 3NOPs (1988–2021), RV_4VWX (1970–2020), HSfix (1998–2021), and HSrand (2017–2021).

The biggest changes from the 2014 assessment model (SCAL) to SISCAL are the inclusion of time-varying natural mortality (M), the updated abundance indices, and inclusion of the outputs from the updated growth model.

DFO RV Ecosystem Survey (RV_4VWX)

The Maritimes Ecosystem Research Vessel Survey (NAFO Divs. 4VWX) has been conducted every summer since 1970 and has been the main indicator of Halibut recruitment. The median size of Halibut caught in this trawl survey is between 40 and 50 cm. The catch per tow of Atlantic Halibut in this survey increased between 2000 and 2011 (Figure 4). It has declined since 2011, but has remained above the long-term mean. The 2018 DFO RV Ecosystem Survey was only conducted in 4X due to mechanical issues, so we cannot estimate the mean number of Halibut per tow in the entire area of 4VWX for 2018. Additionally, the 2021 DFO RV Ecosystem Survey was also incomplete and excluded (Figure 4).

Halibut Longline Survey

The Fixed Station portion of the Industry-DFO Halibut Longline Survey (HSfix) provides an index of abundance of Atlantic Halibut ranging in size between 31 and 220 cm since 1998. The survey, in collaboration between industry and DFO, is completed by commercial harvesters with onboard observers between May and August. In 2017, a Stratified Random portion of the survey (HSrand) was implemented to extend the longline survey coverage into areas and depths that were poorly sampled by the Fixed Station portion of the Survey and introduced standardized gear and more comprehensively defined fishing protocols. 100 of the most frequently fished fixed stations have continued to be fished alongside the new stratified random stations.

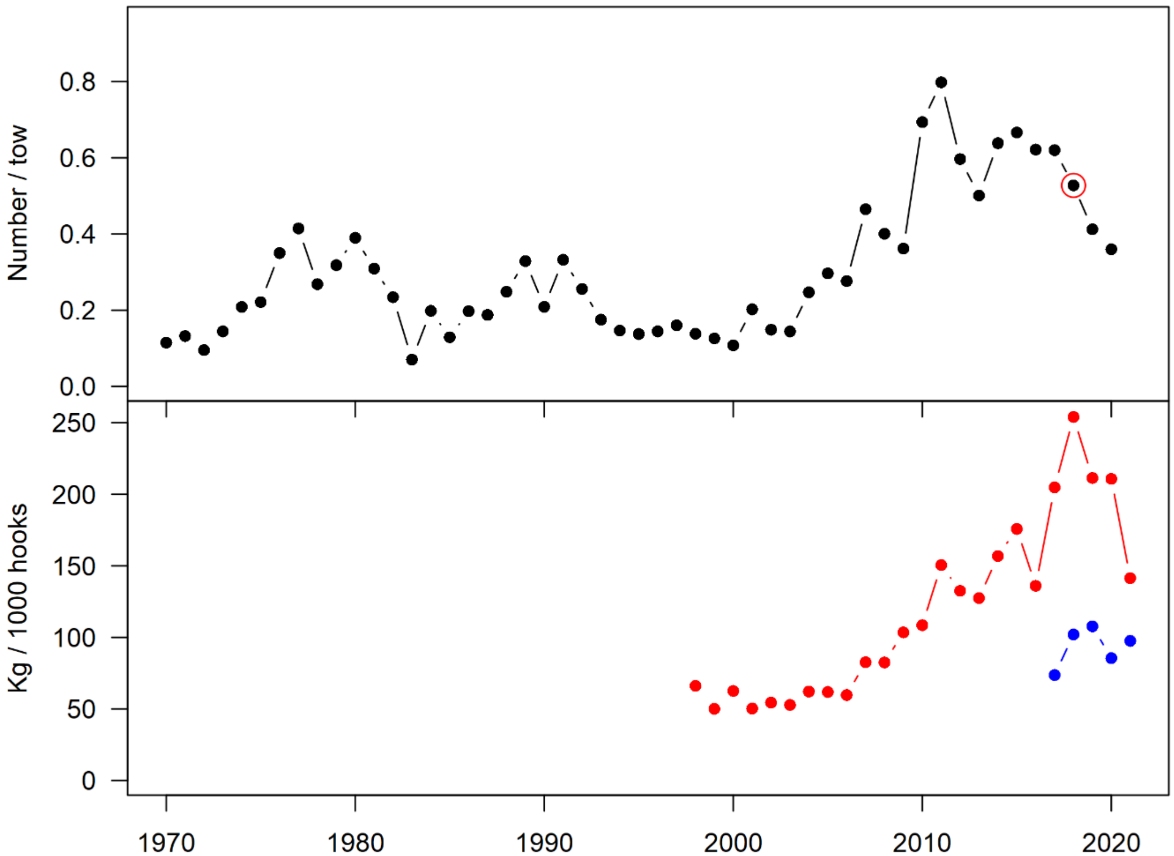


Figure 4. Indices of abundance used to fit the SISCAL model. Top panel is number per tow from 4VWX DFO Maritimes Ecosystem Research Vessel Survey. The red circle highlights 2018 when the survey coverage was only in 4X. Data for 2021 was not included as a conversion factor for the survey vessel has not yet been estimated. *Bottom panel shows the biomass indices in kg/1000 hooks from the fixed station (red) and stratified random (blue) Halibut longline surveys.*

Multi-year Mark-Recapture Tagging Model

In 2006, DFO and the Atlantic Halibut Council (AHC) began the Halibut All Sizes Tagging (HAST) program to estimate population size, exploitation rate, and to evaluate the distribution of Halibut within the Scotian Shelf and southern Grand Banks management unit. More than 6,000 Halibut have been double tagged with t-bar anchor tags since 2006. As of October 21, 2021, 993 Halibut were recaptured with sufficient information to be used in the multi-year mark-recapture model. The model estimates annual F, constant M, and tag loss. Assuming 70% tag reporting and 100% survival from tagging, M is estimated to be 0.10 and F has declined from 0.20 in 2008 to 0.03–0.04 between 2017 and 2020.

Stock Status

The SISCAL model estimates of SSB for 1970–2021 show that the Halibut stock is growing from a depleted state in the early 1990s (Figure 5). The 2021 SSB estimate is at a time series high of 20.6 kt, with 95% credible interval (17.0, 24.9). Estimates of total and legal-sized (greater than 81 cm) biomass are near record levels at 54.1 kt (45.4, 64.7) and 46.5 kt (38.7, 55.7) respectively. Based on an equilibrium analysis of MSY from the model, the LRP was defined as 0.4 SSB_{MSY}=5.3 kt and a proposed USR was defined as 0.8 SSB_{MSY}=10.6 kt (conversion to survey biomass is shown in Table 2).

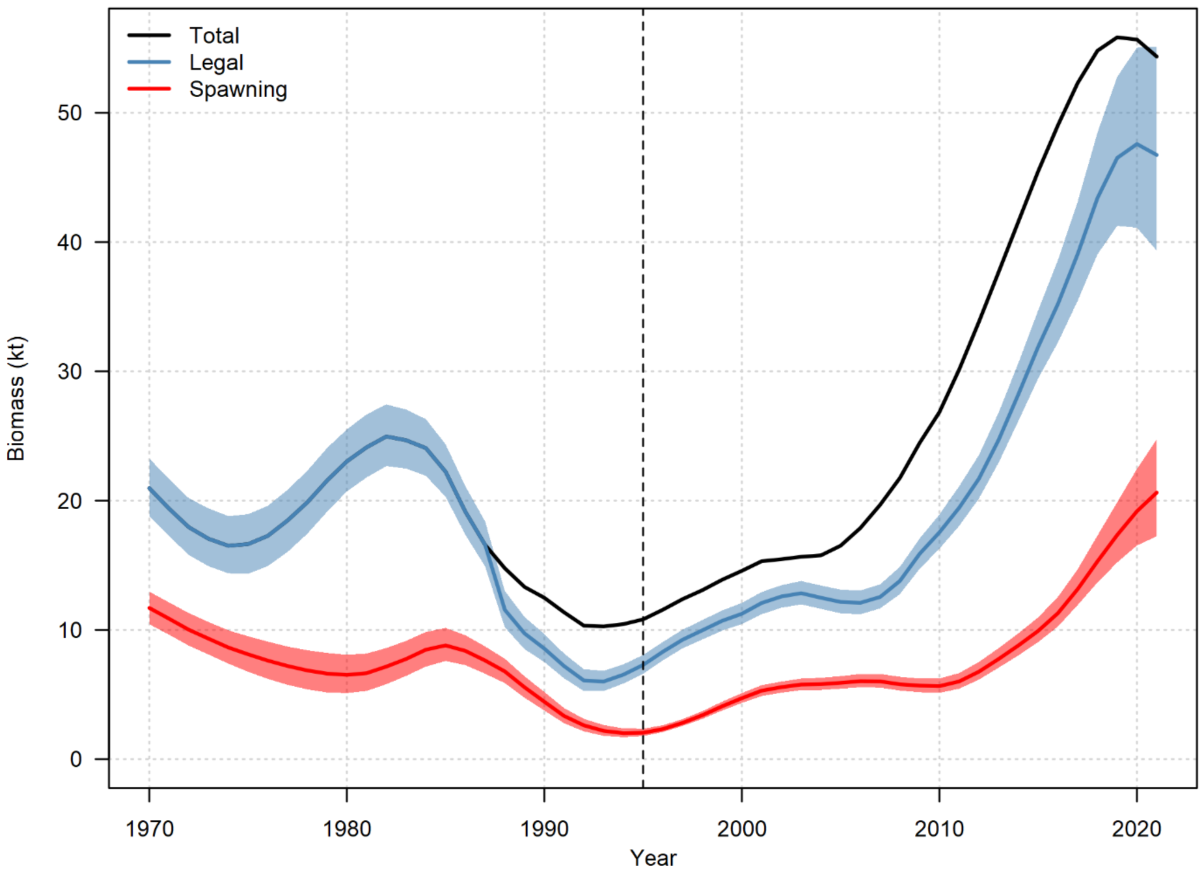


Figure 5. Posterior mean and 95% credibility intervals of legal-sized (< 81 cm) and spawning biomass, and posterior mean total Atlantic Halibut biomass. The vertical dashed line shows 1995, when the minimum size was fully implemented.

Table 2. Maximum sustainable yield based reference points for Atlantic Halibut spawning biomass, and fixed station and stratified random Industry-DFO Halibut Longline Survey biomass. Survey biomass reference points are derived from model equilibrium survey biomass at long term fishing mortality rates that produce the female spawning biomass levels shown. Biomass reported in kilotons (kt).

Biomass	LRP	USR	B_{MSY}	Catchability (*q*)
Female Spawning Biomass	5.3 kt	10.6 kt	13.3 kt	-
Fixed station survey biomass	11.8 kt	23.52 kt	29.4 kt	0.0046
Stratified random survey biomass	10.9 kt	21.84 kt	27.3 kt	0.0020

Estimates of age-1 Halibut abundance indicate three periods of high recruitment, one in the mid–1970s, another in 1987–1988, and the most recent from 2002–2013 (Figure 6). Recruitment was below the long-term average throughout the 1990s and recent levels of recruitment are near the long-term average. SISCAL model estimates of the legal-sized (greater than 81 cm since 1995) exploitation rate (Figure 7) suggest recent levels are similar to those estimated for the late-1970s and early-1980s. There was a short period of very intense exploitation from the mid-1980s up to the mid-1990s following a period of peak catches and stock decline. Recent exploitation rates have remained stable providing evidence of success of the constant F harvest rule adopted in 2015. Estimates of M were allowed to vary over the time series, with recent (2014–2021) estimates of M ranging from 0.128 to 0.143 for males, and from 0.120 to 0.133 for females. SISCAL estimates higher M during the early 1990s when high RV survey catches indicated a recruitment pulse that did not result in an increase in legal biomass.

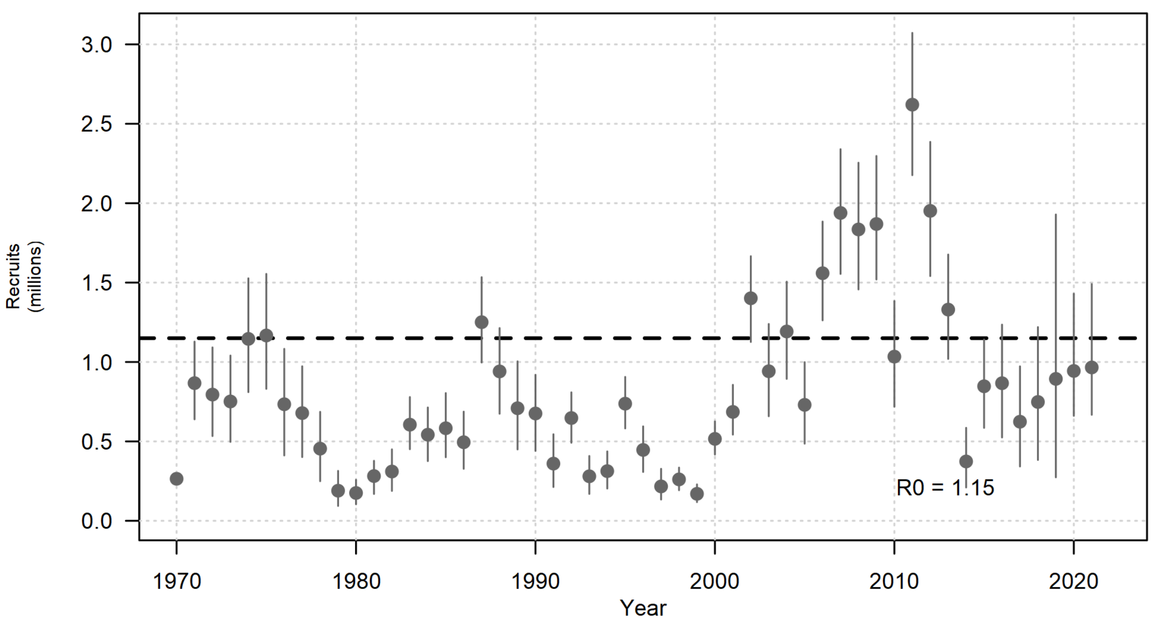


Figure 6. Age-1 recruitments for all stocks. Equilibrium unfished recruitment (R0=1.15) is indicated by the horizontal dashed line. Vertical lines represent 95% credible intervals.

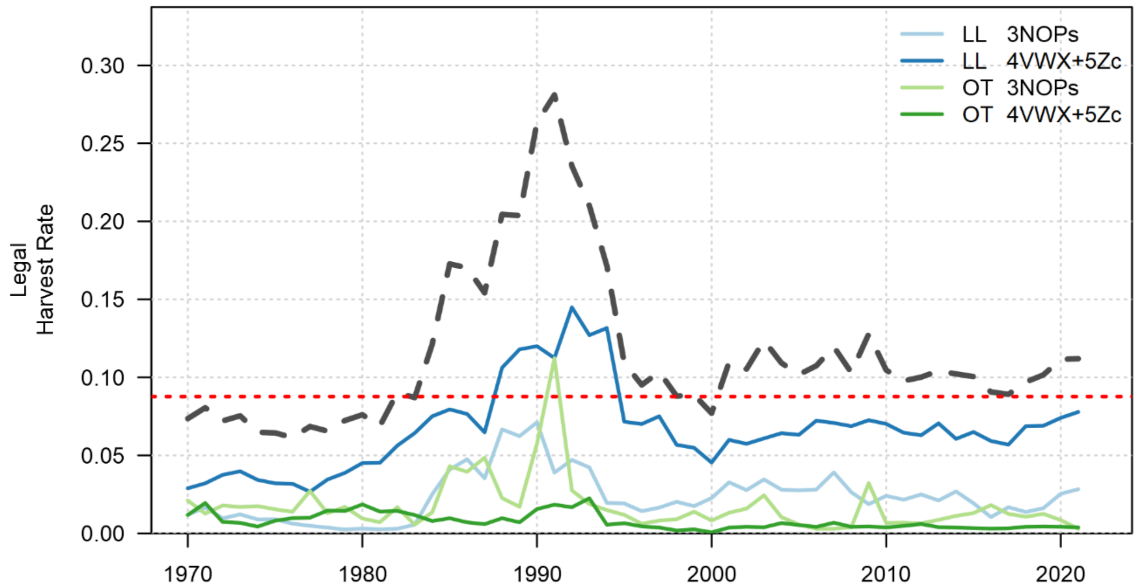


Figure 7. Time series of harvest rate for each gear type, longline (LL) or otter trawl (OT), and Northwest Atlantic Fisheries Organization (NAFO) Divisions, 3NOPs and 4VWX5Zc. Dashed black line is overall harvest rate and the dotted red line is the harvest rate at maximum sustainable yield (U_{MSY}).

Closed Loop Simulations

SISCAL was used to condition an updated operating model and test candidate management procedures (MP) for Atlantic Halibut using closed loop simulations against Atlantic Halibut fishery management objectives. The previous interim MP with a constant F rule (F=0.14) and a no fishing MP were tested alongside 16 MPs based on either the HSfix and HSrand survey data used to estimate stock status, four combinations of size-based discarding options, and two DFO precautionary approach compliant harvest control rules (HCRs) (Table 4, Figure 8). The HCRs included:

- rampedFmsy: a standard precautionary ramped HCR, with 2 control points at survey biomass LRP and the upper stock reference (0.8 Bmsy) and a 100% TAC change limit at all biomass levels; and
- artic1.2Fmsy: an articulated HCR, with three control points at the LRP, the USR, and at 1.2 Bmsy, with a sliding inter-annual TAC change limit going from 15% at the USR to 100% at the LRP

TACs are generated by applying the F from the HCR to the survey biomass, which is calculated by dividing the 3-year mean of the index by the catchability (q) estimate from SISCAL.

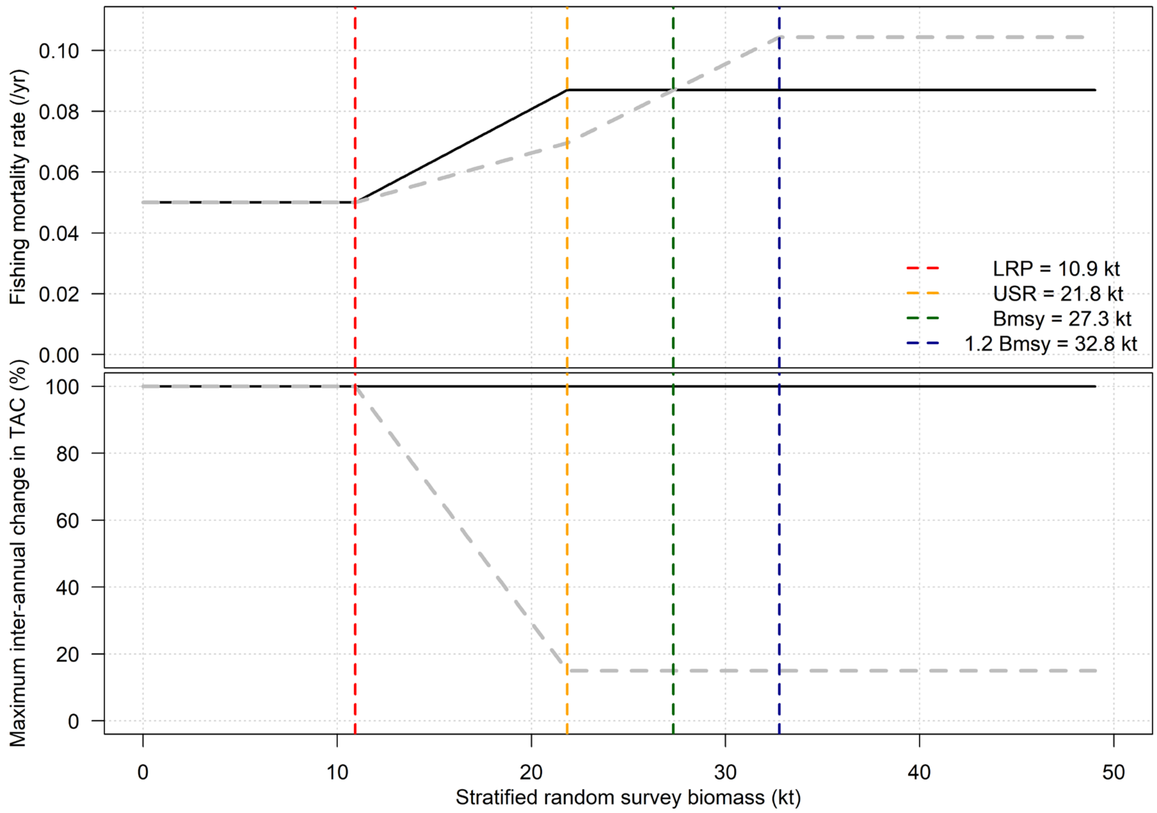


Figure 8. The artic1.2Fmsy (dashed grey line) and rampedFmsy (solid black line) harvest control rules used for determining target harvest rates for Atlantic Halibut based on estimates of survey biomass. This example is for management procedures using stratified random halibut survey biomass for estimating stock status.

Performance Metrics

Candidate MPs are quantitatively evaluated based on a suite of conservation and catch performance metrics. Performance metrics are defined based on Atlantic Halibut fishery management objectives (Table 3).

Table 3. Performance metrics (and their associated objectives) are:

Objective 1-Probability that Biomass is below the LRP (pLRP): The mean proportion of simulation replicates and years that spawning biomass is below the LRP of 5,300 t over two generations (28 years);
Objective 2-Probability of decline (pDecline): The proportion of simulation replicates that decline (on average) over one generation (14 projection years);
Objectives 3 and 4-Mean Absolute Annual Change in catch over 10 years (mAAC10): Mean interannual absolute change in TACs for 2022–2031.
Objective 5 a)-Average Catch over 10 years (avgC): Median average catch for 2022–2031;

Objective 5 b)-Duration of peak resource utilization (nPeak): Median number of projection years before TACs drop below 120% of MSY.
Objective 5 c)-Average Annual Variation in catch over 28 years (mAAC2gen): Mean interannual absolute change in TACs for 2022–2049.

Additional performance metrics not based on the objectives above are also included:

- **Probability that biomass is in the healthy zone at end of simulation (pHealthy):** Mean proportion of simulation replicates and years (after 2040) where biomass is above the healthy zone boundary of $0.8\ B_{MSY}$
- **Probability that biomass is above a target reference point (pTarget):** Mean proportion of simulation replicates and years (after 2040) where biomass is above a proposed target reference point of B_{MSY}
- **Probability of exceeding the harvest rate at maximum sustainable yield, U_{MSY} (p >U_{MSY})** :Mean proportion of simulation replicates and years where legal harvest rate is above U_{MSY}
- **Mean legal harvest rate above U_{MSY} (mU >U_{MSY}):** Mean harvest rate in years/replicates where $U>U_{MSY}$

While the stock is in the healthy zone, previously high recruitment levels (2002–2013) have returned to average levels. Over the long term, current harvest levels would lead to a decline in the stock. Closed loop simulation results showed two main outcomes (Figure 9, Table 4). First, the current catch levels are above MSY because of the currently high stock status. Simulations show that catches will likely be reduced in the upcoming years, but will remain above 120% MSY for 10–12 years. Second, the MPs that are based on the stratified random survey perform better than those based on the fixed survey with respect to TAC stability (mAAC10, mAAC2gen) and conservation measures (pHealthy, pTarget, p>U_{MSY}, mU>U_{MSY}).

Relative to the ramped HCR, the articulated HCR allows for higher fishing mortality while the stock was in the healthy zone. While articulated HCRs did not violate either of the Atlantic Halibut conservation objectives, the higher short-term yields do increase the average annual variation in catch, illustrating a tradeoff between TAC stability and maximizing catch. Furthermore, the articulated HCR has a higher probability that the biomass is below B_{MSY} due to a higher fishing pressure (Table 4b) compared to the ramped HCR. Sometimes the articulated HCR overshoots the target when using the less precise fixed station survey, due to a wider range of effective harvest rates and TAC advice (Figure 9).

The main differences between the release factors (higher minimum size limit and release of 170+ cm fish) were in the fishing pressure exerted on the stock. Since the TACs were all taken in full, and the “exploitable” portion of the biomass is reduced by shifting the minimum length higher and releasing large fish, harvest rates on the legal-sized biomass increase. As a result, under the base fecundity assumption, there are no conservation benefits to offset the changes in fishing pressure (Table 4).

The calculation of potential TACs for the 2022 fishing season using the four MPs that include both surveys and HCRs and current rules for size limits are presented in Table 5.

Table 4a. Management performance (MP) metrics for the 18 tested Atlantic Halibut management procedures. Conservation metrics (probability that biomass is below the LRP (pLRP), probability of decline (pDecline)) are measured in probability (proportion of simulations and time steps), and a dash (−) indicates that the performance threshold for decline probability, based on the stock status in 2021, has been met. The catch metrics mean absolute annual change in catch over 10 years (mAAC10), average catch over 10 years (avgC), and average annual variation in catch over 28 years (mAAC_2gen) are in kt units, and duration of peak resource utilization in years (nPeak). Highlighted MPs had no changes in size discarding and were presented in Figure 9.

Management Procedures	Max F	Min Size Limit	pLRP	pDecline	mAAC10	avgC	nPeak	mAAC2gen
NoFish	0	81	0.00	0	0.00	0.00	0	0.00
conF.14_15%	0.14	81	0.44	-	0.47	5.50	13	0.33
HSfix_rampedFmsy_sl81_rel170	0.087	81	0.00	-	0.25	3.50	10	0.24
HSfix_artic1.2Fmsy_sl81_rel170	0.103	81	0.00	-	0.33	3.90	10	0.30
HSfix_rampedFmsy_sl86_rel170	0.087	86	0.00	-	0.25	3.40	10	0.24
HSfix_artic1.2Fmsy_sl86_rel170	0.103	86	0.00	-	0.33	3.90	10	0.30
HSfix_rampedFmsy_sl81_keep170	0.087	81	0.00	-	0.25	3.50	11	0.24
HSfix_artic1.2Fmsy_sl81_keep170	0.103	81	0.00	-	0.33	4.00	11	0.31
HSfix_rampedFmsy_sl86_keep170	0.087	86	0.00	-	0.25	3.50	12	0.24
HSfix_artic1.2Fmsy_sl86_keep170	0.103	86	0.00	-	0.33	4.00	11	0.31
HSrand_rampedFmsy_sl81_rel170	0.087	81	0.00	-	0.16	3.50	10	0.16
HSrand_artic1.2Fmsy_sl81_rel170	0.103	81	0.00	-	0.23	3.90	10	0.22
HSrand_rampedFmsy_sl86_rel170	0.087	86	0.00	-	0.16	3.50	10	0.16
HSrand_artic1.2Fmsy_sl86_rel170	0.103	86	0.00	-	0.23	3.90	10	0.22
HSrand_rampedFmsy_sl81_keep170	0.087	81	0.00	-	0.16	3.50	11	0.16
HSrand_artic1.2Fmsy_sl81_keep170	0.103	81	0.00	-	0.22	4.00	11	0.22
HSrand_rampedFmsy_sl86_keep170	0.087	86	0.00	-	0.16	3.50	12	0.16
HSrand_artic1.2Fmsy_sl86_keep170	0.103	86	0.00	-	0.22	4.00	11	0.22

Table 4b. Additional performance metrics for the 18 tested Atlantic Halibut management procedures. pHealthy, pTarget and p > U_{MSY} metrics are measured in probability (proportion of simulations and time steps), and mU > U_{MSY} is in yr^{-1}. Highlighted MPs had no changes in size discarding and were presented in Figure 9.

Management Procedures	Max F	Min Size Limit	pHealthy	pTarget	p > U_{MSY}	mU > U_{MSY}
NoFish	0	81	1.00	1.00	0.00	0.00
conF.14_15%	0.14	81	0.00	0.00	1.00	0.20
HSfix_rampedFmsy_sl81_rel170	0.087	81	0.84	0.50	0.54	0.10
HSfix_artic1.2Fmsy_sl81_rel170	0.103	81	0.80	0.44	0.63	0.11
HSfix_rampedFmsy_sl86_rel170	0.087	86	0.81	0.44	0.66	0.10
HSfix_artic1.2Fmsy_sl86_rel170	0.103	86	0.75	0.40	0.68	0.12
HSfix_rampedFmsy_sl81_keep170	0.087	81	0.90	0.61	0.53	0.10
HSfix_artic1.2Fmsy_sl81_keep170	0.103	81	0.85	0.49	0.66	0.11
HSfix_rampedFmsy_sl86_keep170	0.087	86	0.87	0.56	0.65	0.10
HSfix_artic1.2Fmsy_sl86_keep170	0.103	86	0.81	0.45	0.71	0.12
HSrand_rampedFmsy_sl81_rel170	0.087	81	0.88	0.60	0.49	0.10
HSrand_artic1.2Fmsy_sl81_rel170	0.103	81	0.88	0.50	0.63	0.11
HSrand_rampedFmsy_sl86_rel170	0.087	86	0.86	0.56	0.65	0.10
HSrand_artic1.2Fmsy_sl86_rel170	0.103	86	0.84	0.45	0.68	0.11
HSrand_rampedFmsy_sl81_keep170	0.087	81	0.93	0.68	0.49	0.10
HSrand_artic1.2Fmsy_sl81_keep170	0.103	81	0.90	0.55	0.66	0.11
HSrand_rampedFmsy_sl86_keep170	0.087	86	0.90	0.64	0.64	0.10
HSrand_artic1.2Fmsy_sl86_keep170	0.103	86	0.87	0.49	0.72	0.11

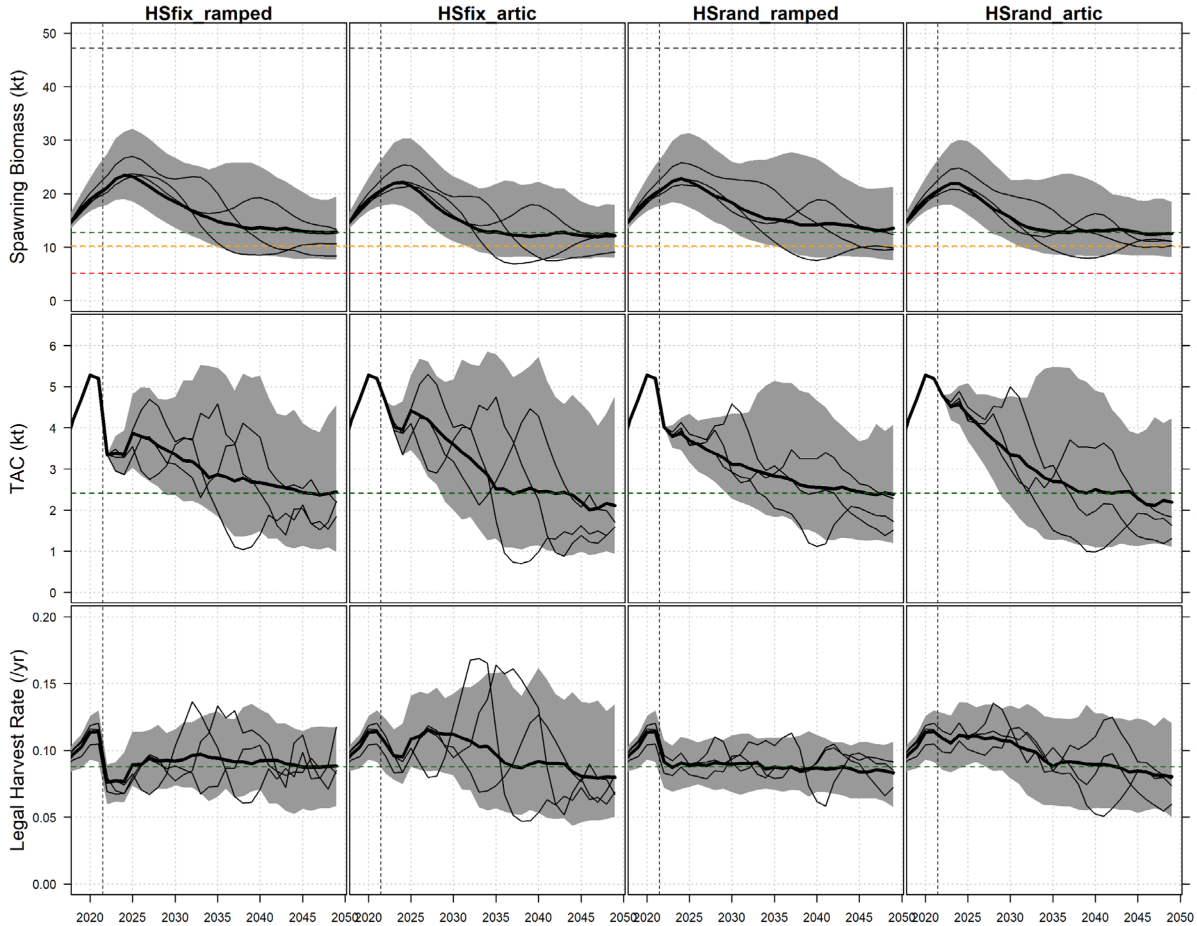


Figure 9. Simulation envelopes for spawning biomass (top row), total allowable catch (TAC, middle row), and realized fishing mortality rate (bottom row) for 2022–2050 for each survey and harvest control rule. Envelopes represent the central 95% (grey) of outcomes, median (50% above/below; thick black line), and spaghetti traces (thin lines) showing three randomly chosen example outcomes. Horizontal dashed reference lines in top row show B_{MSY} (green), 0.8 B_{MSY} (yellow), and the limit reference point of 0.4 B_{MSY} (red). Horizontal green dashed line in middle row represents MSY. Horizontal green dashed line in bottom row represents legal U_{MSY}.

Table 5. Resulting total allowable catch (TAC) for 2022 from four management procedures that include both Halibut surveys (HSfix, HSrand) and harvest control rules (ramped, artic). The TAC results from the fishing mortality (F) applied to the survey biomass that is estimated by dividing the 3-year mean survey index by the catchability.

Management Procedure	3-year mean survey index	Catchability *q*	Survey biomass	Fishing mortality *F*	TAC
HSfix_ramped	187.89 KgPKH	0.0046	40.85 kt	0.087	3,403 t
HSfix_artic	187.89 KgPKH	0.0046	40.85 kt	0.104	4,050 t
HSrand_ramped	96.98 KgPKH	0.0020	48.49 kt	0.087	4,040 t
HSrand_artic	96.98 KgPKH	0.0020	48.49 kt	0.104	4,807 t

Sources of Uncertainty

The Industry-DFO Halibut Longline Survey indices are the mean catch per tow and do not account for variation associated with hook competition, vessels, and temperature effects. In the case of the fixed station survey there may be additional uncertainty associated with survey design, as well as, hook size and bait used. Further, the impact of delays in the start time for the survey have not been assessed.

The mark-recapture model assumes that M, tag reporting rate, and initial tag survival are constant over time. There is also limited information to estimate the reporting rate.

There is potential for considerable variability in biology of this stock across the large management unit and in response to changes in environment. The current model SISCAL, like SCAL, uses the area-as-fleet approach to better describe the removals, for which we have evidence of spatial variation in the length composition; however, a more spatially explicit implementation of SISCAL should be evaluated.

Size-selectivity of the longline fishery may not be well estimated with a flat top selectivity curve. If there are modifications in fishing practices that reduce the catch of large, less valuable Halibut, then population size may be underestimated in some or all years.

The interpretation of trends assumes no changes in vital rates, such as, growth or fecundity, that impact the dynamics of the population. Therefore, it is not known if, or how, vital rates and population growth rate will change with changes in stock size and/or variable environmental conditions. Further, there is uncertainty in the stock recruitment relationship and natural mortality in Halibut which can affect outcomes, especially reference points.

Observer coverage is variable geographically and seasonally and is not well matched to the spatial and temporal distribution of the fishery. This contributes to uncertainty in the length composition of the fishery (a major input to the assessment model) and extrapolation of bycatch from the observed sets.

CONCLUSIONS AND ADVICE

The Atlantic Halibut stock has a history of overfishing that predates the time series used in the stock assessment model (i.e., prior to 1970). SISCAL model estimates of SSB levels between 1970 and 2021 indicate that the Halibut stock has increased from a depleted state observed in the early 1990s, to the highest estimated SSB in the time series in 2021. The 2021 SSB estimate was 20.6 kt, with 95% credible interval (17.0, 24.9). Estimates of M were allowed to vary over the time series, with recent (2014–2021) estimates of M ranging from 0.128 to 0.143, for males and from 0.120 to 0.133 for females. Estimates of total and legal-sized biomasses are also at record levels. Recent exploitation rates have remained stable providing evidence of success of the constant F harvest rule adopted in 2015.

SISCAL allows for definition of MSY reference points. The LRP was defined as 0.4 SSB_{MSY}=5.3 kt and a proposed USR was defined as 0.8 SSB_{MSY}=10.6 kt.

Closed loop simulations were used to evaluate a range of candidate MPs. These included procedures based on the 3-year mean of either the stratified random (HSrand) or fixed station (HSfix) longline survey biomass indices. Two HCRs were tested; one without a cap in the change in TAC between years, and one with a cap on the change in TAC (15% cap when the stock is in the healthy zone; 100% cap when the stock is in the critical zone; Figure 7). MPs that included changes in minimum legal size and voluntary release of large Halibut were also tested.

Both tested HCRs met conservation objectives for this stock. The increased precision of the random survey design allowed MPs to perform better than those based on the fixed survey portion of the Industry-DFO Halibut Longline Survey with respect to TAC stability and conservation measures. The articulated HCR that allows for higher harvest rates when biomass is above B_{MSY} results in higher short term yields, larger annual absolute changes in TAC, and lower probability that biomass will be above B_{MSY} in the long term. While the stock is in the healthy zone, it is likely to decline in the near term under either proposed HCR. Higher model-estimated recruitment from 2002–2013 led to the stock increasing well above B_{MSY}, but recruitment has since been closer to the long term mean (Figure 6). Using the 3-year mean of the stratified random survey, the TAC for the 2022 fishing season would be 4,040 t under the ramped HCR and 4,807 t under the articulated HCR (Table 5).

Simulations over two generations of the release of live Halibut greater than 170 cm, assuming fecundity is proportional to biomass, did not improve stock performance, and in some cases lead to increased probability of falling below the USR. There was also no indication that increasing the minimum legal size to 86 cm would impact stock performance as measured by the probability of falling below reference points or projected catch.

The Scotian Shelf and southern Grand Banks Halibut stock has benefited from high recruitment between 2002–2013, and has continued to increase from a depleted state observed in the 1990s. Both sea surface temperature and bottom temperature have increased across the management unit. The consequent increase in both growing degree days and available thermal habitat, may have also contributed to recovery of this stock.

OTHER CONSIDERATIONS

The Halibut framework assessment has assessed the risk of numerous management procedures over the long term. This is a long-lived species, assessed to have healthy stock status, but with recent changes in the trajectory of the abundance indices. Stock status and science advice will be assessed annually based on the most recent 3-year mean Halibut Survey index of exploitable biomass. After five years, the modelling framework will be reviewed and updated with more recent data. An earlier review could be triggered due to significant changes in data sources, such as, missing indices, new data (e.g., age data), or changes in growth, maturation and fecundity, or natural mortality. An earlier review could also be triggered if stock status deviates significantly from expectations, e.g., the 3-year mean index from the survey falls above or below the 90% probability envelope for that index from the closed-loop simulation.

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SOURCES OF INFORMATION

This Science Advisory Report is from the March 1 to 4, 2022, regional advisory meeting on the Framework Review for Atlantic Halibut on the Scotian Shelf and Southern Grand Banks in NAFO Divisions 3NOPs4VWX5Zc: Part 2 - Review of Modelling Approaches. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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