Draft Working Paper for Pre-Dissemination Peer Review Only

Working Paper 4.S
April 23, 2008

ATLANTIC HALIBUT

Laurel Col and Chris Legault
A Working Paper in support of
GARM Biological Reference Points Meeting Term of Reference 4

<u>Contents</u>

GARM Section 4
1. Background
2. The Fishery
    2.1 Landings
    2.2 Discards
3. Survey Indices
4. Index-Based Assessment
    4.1 Index-Based Results
    4.2 Previous Reference Points
    4.3 Updated Stock Status Based on Previous Reference Points
    4.4 Growth and Maturity at Age Estimation for Revised Reference Point Input
    4.5 YPR Analysis and Updated Status Based on Revised Reference Points
5. Replacement Yield Model
    5.1 Replacement Yield Model Input
    5.2 Replacement Yield Model Results
    5.2 Replacement Yield Model Reference Points and Status Determination
6. Summary Stock Status
    6.1 Index-Based Assessment Strengths and Weaknesses
    6.2 Replacement Yield Model Strengths and Weaknesses
    6.3 Reference Points and Stock Status Determination
    6.4 Comparison with Projected Amendment 13 Rebuilding Trajectory
7. Further Considerations
    7.1 US-Canada Transboundary Movement
    7.2 Minimum Size Regulations
8. References
Tables S1-S8
Figures S1-S13

Atlantic halibut

Laurel Col and Chris Legualt

1.0 Background

Atlantic halibut (*Hippoglossus hippoglossus*) is the largest species of flatfish in the northwest Atlantic Ocean. It is a long-lived, late-maturing species distributed from Labrador to southern New England (Bigelow and Schroeder 1953). The Atlantic halibut stock within the Gulf of Maine-Georges Bank region (NAFO Subareas 5Y and 5Z) has been exploited since the early 1800s (Figure S1). Based on the last assessment of Gulf of Maine-Georges Bank Atlantic halibut in 2005 (Brodziak and Col 2005), the stock was overfished (B_{2004} was 5% of B_{MSY}) and it was unknown whether overfishing was occurring.

The Atlantic halibut index-based assessment has been updated using available Northeast Fisheries Science Center (NEFSC) survey and commercial fishery data for 2005-2006. Additionally, estimates of discards from the United States (US) commercial fishery have been included in fishery removal estimates. Reference points were re-evaluated using recent estimates of growth and maturity parameters (Sigourney et al. 2006) and compared to survey swept-area biomass for status determination. Alternatively, a replacement yield model with corresponding reference points were presented, incorporating the entire time series of catch data and tuning to survey swept-area biomass indices.

2.0 The Fishery

2.1 Landings

Records of Atlantic halibut landings from the Gulf of Maine-Georges Bank region (Statistical Areas 511-515, 521-522, 525-526, 561-562) began in 1893 (ICNAF 1952, Table S1, Figure S1). However, substantial landings occurred prior to this, since the halibut fishery experienced sharp declines after the late 1870s (Hennemuth and Rockwell 1987, Goode 1887). Current US landings were extracted from the NEFSC commercial fisheries database (CFDBF) AA tables, and Canadian landings (Division 5Zc) were extracted from the NAFO 21A database[1].

Landings have continued to decrease since the 1890s as components of the resource have been sequentially depleted. Annual landings averaged 663 mt between1893 and1940, declined to an average of 144 mt during 1941-1976, and declined further to an average of 89 mt per year during 1977-2000 (Table S1, Figure S2). Total reported commercial landings of halibut increased slightly from record lows of 17-20 mt during 1998-2000 to 24 mt in 2006. Of the 2006 landings, 14 mt (58%) were landed by US fishermen and 10 mt were landed by Canadian fishermen.

---

[1] http://www.nafo.int/science/frames/research.html

2.2 Discards

Discards from the Northeast Fisheries Observer Program database were estimated for the period 1989 to 2006 based on the Standardized Bycatch Reporting Methodology combined ratio estimation (Wigley et al. 2007). The 1999 implementation of a one halibut per trip limit as well as a 91 cm minimum retention size increased the discard to kept ratio from 17% during 1989-1998 to 169% during 1999-2006 (Table S2, Figure S3). Due to the low occurrence of Atlantic halibut in the observer database, the 1989-1998 average was applied to 1893-1999 discards and the 1999-2006 average was used for those years (Table S2). Including US discards, total catches increased from 18 mt in 1998 to 60 mt in 2003, and have remained elevated at 48 mt in 2006 (Table S1, Figure S3).

3.0 Survey Indices

The NEFSC spring and autumn bottom trawl surveys provide measures of the relative abundance of Atlantic halibut within the Gulf of Maine-Georges Bank region (offshore survey strata 13-30 and 36-40, Table S3, Figure S4). Both indices have high interannual variability since the surveys capture low numbers of halibut, and in some years there are no halibut are caught (Figure S5), indicating that halibut are close to being below the detectability levels of the surveys. The autumn survey trend is relatively flat, whereas the spring survey index suggests that relative abundance increased during the 1970s to early 1980s, declined in the 1990s, and has increased since the late 1990s (Figure S6). However, it is unknown whether abundance trends in the Gulf of Maine-Georges Bank region have been influenced by changes in the seasonal distribution and availability of Atlantic halibut. Due to the lack of alternative population estimates, the autumn survey has been used in previous assessments to estimate biomass. The autumn survey was chosen over the spring survey because of the longer time series as well as possible environmental forcing in the spring survey indicated by a negative correlation with spring bottom water temperature anomalies. There are no conversion factors available for differences in Atlantic halibut catchability due to vessel, net or door changes that have occurred throughout the NEFSC survey time series.

4.0 Index-Based Assessment

4.1 Index-Based Results

An autumn survey index-based assessment was updated for Atlantic halibut. As in previous assessments, NEFSC autumn weight per tow survey indices were expanded to swept-area biomass estimates and the 5-year average served as the stock biomass index. For the years 1963-1967 a one- to four-year average was sequentially used for the swept-area biomass estimate (Table S3 and Figure S6). Overall, the autumn survey has little contrast in trend, but appears to be declining slightly in recent years (Figure S6). Total commercial fishery landings as well as US discards were used for the catch time series (Table S1, Figure S2). Although no estimates of fishing mortality are available, exploitation rate indices (annual landings/5-year moving average of survey index) suggest that exploitation rates have been relatively stable since the 1970s, declining slightly during the 1990s and increasing slightly since 1998 (Table S3, Figure S7). Thus, although the Atlantic halibut stock in the Gulf of Maine-Georges Bank region remains depleted, exploitation rates do not appear to have increased greatly since the 1970s. The autumn exploitation rate index was 0.23 in 2006, a three-fold increase from the 1995 low exploitation rate of 0.06, but still well below the rates observed during the late 1960s-1980s.

4.2 Previous Reference Points

Based on total landings, the MSY proxy of 300 mt was chosen for Atlantic halibut, since it was concluded that the 1893-1942 average landings (480 mt) did not appear sustainable (NEFMC 1998). Fishing mortality and stock biomass reference points were originally determined by the New England Fisheries Management Council in 1998 using length-weight equations from McCracken (1958) and Canadian Atlantic halibut Von Bertalanffy growth curves (Nielson and Bowering 1989) to perform yield-per-recruit and biomass-per-recruit analyses. Given the large size and late maturation of Atlantic halibut, the threshold F was set to $F_{0.1}$ (0.06) as a proxy for F_{MSY}. The F_{target} was chosen to be 0.04, 60% of the $F_{threshold}$. Based on the ratio of biomass-per-recruit to yield-per-recruit at $F_{0.1}$, and the MSY proxy of 300 mt, a biomass target of 5,400 mt was given as a proxy for B_{MSY}. The minimum biomass threshold was set as 2,700 mt (½ B_{MSY} proxy). During a re-evaluation of the reference points in 2002, updated yield and SSB per recruit analyses were presented with growth parameters from Sigourney (MS 2002). However the analysis was not accepted due to the need for further studies on partial recruitment and maturity at age (NEFSC 2002).

4.3 Updated Stock Status Based on Previous Reference Points

Based on the updated index-based assessment, the 5-year average stock biomass index was 252 mt in 2007 (9% of $B_{threshold}$ and 5% of B_{MSY}), indicating that the Gulf of Maine-Georges Bank Atlantic halibut stock was overfished in 2007 (Figure S8). Using this index-based assessment, no estimate of fishing mortality was available for 2007 and overfishing status was unknown.

4.4 Growth and Maturity at Age Estimation for Revised Reference Point Input

Bootstraping analyses were performed for combined years of NEFSC spring and autumn length and weight data, and results were used to estimate α and β length-weight parameters (0.0039 and 3.247 respectively):

$$W = \alpha L^{\beta}$$

Atlantic halibut from NEFSC spring and autumn surveys and the halibut experimental longline fishery were aged (Sigourney 2002) and growth parameters were used to calculate Von Bertalanffy age-length keys. The age-length key for female halibut was applied to the length-weight equation to get weight-at-age input for yield-per-recruit analysis (Table S5).

Ages at percent maturity from Sigourney et al. (2006) were used to calculate a maturity ogive for female halibut:

$S(a) = (1+e^{(-\alpha - \beta a)})^{\wedge -1}$

Where:
a is age,
β is a parameter assumed to be equal to $(2\ln 3)/(L_{75}-L_{25})$, estimated to be 0.518, and
α is a parameter assumed to be equal to $-\beta L_{50,}$ estimated to be -3.778.

The resulting weight at age and maturity at age were used along with a plus group at age 30 and a maximum age of 50 years (Table S5). Sigourney et al. (2006) recorded halibut from recent years up to age 40, and it is likely that larger halibut landed in the earlier part of the fishery time series were at least 50 years of age. Using –ln(0.05)/(max age) as a proxy for natural mortality, M was estimated as 0.06. As in the previous reference point determination (NEFMC 1998) a knife-edge selectivity at age 4 (~60cm and 2.38kg) was used for YPR analyses. Although current regulations prohibit landing halibut less than 91cm, there is evidence from observer data that smaller halibut are continuing to be landed (Table S4), and historically it is reasonable to assume that the fishery did not target halibut less than 60cm.

4.6 YPR Analysis and Updated Status Based on Revised Reference Points

NFT YPR version 2.7.2[2] was used to perform the YPR analysis, which resulted in an $F_{0.1}$ of 0.04 and an F_{target} (60% of $F_{0.1}$) of 0.024 (Table S6, Figure S9). This is slightly lower than the previous $F_{threshold}$ of 0.06, and F_{target} of 0.04. Again, using the index-based assessment, there is no reliable F estimate, so overfishing status is unknown. Given the previous MSY estimate of 300mt, B_{MSY} from the revised YPR was 6,400mt and ½ B_{MSY} was 3,200mt which is somewhat higher than the previous estimates of 5,400mt and 2,700mt (Figure S8). Using the revised reference points with the updated index-based method, the current autumn survey swept-area biomass of 252 mt is 7.9% of the threshold ½ B_{MSY} and 3.9% of the target B_{MSY}. Therefore the Gulf of Maine-Georges Bank component of the Atlantic halibut stock was overfished in 2007.

5.0 Replacement Yield Model

5.1 Replacement Yield Model Input

The 2008 GARM Models Meeting review panel (O'Boyle 2008) recommended that a simple depletion analysis be attempted for Atlantic halibut. Since halibut catch predate reliable landings statistics which began in 1893 (ICNAF 1953), it was recommended that a linear increase in landings be assumed from 1800-1893 (Table S7). Although this estimate is crude, it was concluded that this method would be better than assuming that 1893 biomass was representative of an unfished population.

A replacement yield model similar to that described in Brandao and Butterworth (2008) was used to provide annual biomass, recruitment and fishing mortality estimates. In this model, estimated biomass is defined as:

[2] http://nft.nefsc.noaa.gov/YPR.html NOAA Fisheries Toolbox Version 3.0, 2008. Age Based Yield per Recruit Version 2.7.2

$B_y = B_{y-1} + R_{y-1} – C_{y-1}$

Where:
B_y is the biomass at the start of year y,
B_{y-1} is the biomass at the start of the previous year,
C_{y-1} is the total catch in the previous year, and
R_{y-1} is the variable recruitment in the previous year.

Recruitment was assumed to be variable annually, and is defined as:

$R_y = rB_y (1- B_y /K)$

Where:
r is a constant recruitment parameter, and
K is the carrying capacity. Biomass in the first year was set to K.

The model is fitted to the 5-year moving average of the NEFSC autumn survey swept-area biomass index, and the following negative log-likelihood (-ln*L*) was used to determine the model with the best estimates of carrying capacity and recruitment parameters:

$-\ln L = \log (\delta) + 0.5\sum(\ln(I_y)-\ln(B_y q^2))^2/\delta^2 + p_1 + p_2$

Where:
δ is a constant,
I_y is the swept-area biomass index in year y,
q is the catchability of the NEFSC fall survey defined as the exponent of the average of $\ln(I_y)-\ln(B_y)$,
p_1 is the sum of the penalties for biomass going to the defined minimum boundary in a given year, and
p_2 is a penalty for the difference between the model-estimated q and the assumption that the NEFSC autumn survey q is roughly 0.5

5.2 Replacement Yield Model Results
As expected, certain initial biomass and recruitment parameter inputs resulted in models that either led to population explosions or extinctions (Table S8, Figure S10). However, the cases with the lowest negative log likelihood estimates for each K led to reasonable trends in biomass during the time period that catch was recorded (Figure S11). Simulations were run with varying carrying capacity and recruitment parameters (Table S8), and case 32 was chosen as the best model since it had the lowest negative log likelihood. This model indicated that biomass levels declined from around 40,000 mt to 30,000 mt during the early 1900s, declined further during 1920 to1935 to around 20,000 mt, and have remained fairly stable since (Figure S11). Recruitment has decreased sharply since the 1870s, but has remained at a fairly constant, low level since the 1940s

(Figure S12). Relative F has been highly variable with spikes of fishing mortality early in the time series, but has remained relatively low since the mid-1990s (Figure S13).

5.3 Replacement Yield Model Reference Points and Status Determination

Carrying capacity for the replacement yield model was 300,000 mt, indicating a B_{MSY} (B_{target}) of approximately 150,000 mt and a ½ B_{MSY} ($B_{threshold}$) of 75,000 mt. Biomass in 2006 was estimated to be 21,000 mt, or 28% of the $B_{threshold}$, indicating that Atlantic halibut is currently in an overfished condition. F_{MSY} was assumed to be half of the recruitment parameter (0.003), and relative F in 2006 was estimated to be 0.0022 (75% F_{MSY}). Therefore, overfishing is not currently occurring for Atlantic halibut.

6.0 Comparison of Models and Reference Points

6.1 Index-Based Assessment Strengths and Weaknesses

The index-based assessment is the method that has been previously accepted in Stock Assessment Workshops and Groundfish Assessment Review Meetings (Brodziak 2002, Broziak and Col 2005). The Gulf of Maine-Georges Bank component of the Atlantic halibut stock is extremely data limited, and the index method is often used as a default in this situation. However, it should be noted that the NEFSC autumn survey began more than 100 years after a major collapse of the fishery, and that the lack of contrast as well as the extremely low encounter rate of Atlantic halibut in the autumn survey suggest that the index is a poor indicator of biomass. Additionally, there have been changes in doors, nets and vessels throughout the time series which may affect catchability of Atlantic halibut over the time series. Since the surveys encounter so few halibut, conversion factors have not been estimable. Calibration of catchability will become a much larger issue in 2009 when the survey will change to the RV Henry Bigelow, which is likely to have vastly different catchability for most species. Therefore, relying entirely on the autumn survey index for the Atlantic halibut assessment is not recommended.

The lack of contrast and trend in the autumn survey also causes the exploitation index to largely follow the catch, which is uninformative as a relative F. This in combination with the strong catch limits and large minimum size implemented in 1999 has prohibited the estimation of current F using the index-based method.

6.2 Replacement Yield Model Strengths and Weaknesses

The replacement yield model is another simplistic approach used for data-poor stocks (Brandao and Butterworth 2008), which incorporates the entire time series of Atlantic halibut commercial catch. Although using fishery-dependent catch data as an indicator of biomass is not ideal, it is likely a reliable indication of the direction and relative magnitude of the changes that the stock component has experienced. The inclusion of the NEFSC autumn survey swept-area biomass and the NEFSC catchability coefficient for tuning are an attempt to ground truth the model with fishery-independent information.

The main strengths with the replacement yield model are that annual estimates of relative F and recruitment are given. Providing overfishing status determination is an improvement over the previous index-based method.

6.3 Reference Points and Stock Status Determination

For either the index-based method or the replacement yield model, Atlantic halibut is in an overfished status. Whereas the index-based method is not able to determine current overfishing status, the replacement yield model indicates that overfishing is not currently occurring for Atlantic halibut. Reference points for the methods above are listed for comparison.

Previous Index-Based Reference Points:

	Threshold	Target	Current Estimate	% Threshold
Fishing mortality	0.06	0.04	none	n/a
Stock biomass	2,700 mt	5,400 mt	252 mt	9%

Revised Index-Based Reference Points:

	Threshold	Target	Current Estimate	% Threshold
Fishing mortality	0.04	0.02	none	n/a
Stock biomass	3,200 mt	6,400 mt	252 mt	8%

Replacement Yield Model Reference Points:

	Threshold	Target	Current Estimate	% Threshold
Fishing mortality	0.003	n/a	0.0022	75%
Stock biomass	75,000 mt	150,000 mt	21,200 mt	28%

6.4 Projected Amendment 13 Rebuilding Trajectory

There is no Amendment 13 rebuilding trajectory for Gulf of Maine-Georges Bank Atlantic halibut.

7.0 Further Considerations

7.1 US-Canada Transboundary Movement

There is increasing evidence of transboundary movement for Atlantic halibut, with recent longline tagging estimates from a Federal Experimental Fishery on the order of 28% movement from coastal Maine waters into Canadian waters (Kanwit 2007). A few individual halibut in this study traveled as far north as Newfoundland and the Grand Banks, up to 1,758 km. More work should be conducted in order to clarify stock boundaries, since the current information indicates that Atlantic halibut should be included as a transboundary stock.

7.2 Minimum Size Regulations

Atlantic halibut maturity at length estimations from Sigourney et al. (2006) indicate that the female L_{50} (103 cm) is above the current minimum size limit (91 cm), and that recruitment overfishing could be occurring. Increasing the minimum size limit may increase survival of halibut to spawning size, especially in the longline fishery where survival rates are higher than otter trawl catches (77% and 35% respectively, Neilson et al. 1989). However, regulation of the minimum size is a concern since it appears that even with the current regulations, there are undersized halibut being landed (Table S4).

8.0 References

Bigelow, H.B, and Schroeder, W.C. 1953. Fishes of the Gulf of Maine. Fishery Bulletin of the Fish and Wildlife Service, No. 74, 577 p.

Brandao, A., and Butterworth, D.S. 2008. A "replacement yield" model fit to catch and survey data for the south coast kingklip resource of South Africa. WG-Dem:K:05.

Brodziak, J. 2002. Atlantic halibut. In NEFSC, *Assessment of 20 Northeast groundfish stocks through 2001*, pp.306-313. *NEFSC Ref. Doc.* 02-16, 509 p.
Available at: http://www.nefsc.noaa.gov/nefsc/publications/crd/crd0216/

Brodziak, J., and Col, L. 2005. Atlantic halibut. In NEFSC, *Assessment of 19 Northeast groundfish stocks through 2004*. 2005 Groundfish Assessment Review Meeting (2005 GARM), Northeast Fisheries Science Center, Woods Hole, MA, 15-19 Aug. 2005. pp.424-431. *NEFSC Ref. Doc.* 05-14, 499 p.
Available at: http://www.nefsc.noaa.gov/nefsc/publications/crd/crd0513/

Goode, G.B.1887. The fisheries and fishing industries of the United States. U.S. Commission of Fish and Fisheries. Vol. 1, Part 1: 1-119.

Hennemeth, R.C., and Rockwell, S. 1987. History of fisheries conservation and management. *In* Georges Bank. *Edited by* R. Backus, R. Price, and D. Bourne. MIT Press, Cambridge, MA. pp. 431-446.

Kanwit, J.K. 2007. Tagging results from the 2000-2004 Federal Experimental Fishery for Atlantic halibut (*Hippoglossus hippoglossus*) in the Eastern Gulf of Maine. J. Northw. Atl. Fish. Sci. 38:37-42.

Neilson, J.D., Waiwood, K.G., and Smith, S.J. 1989. Survival of Atlantic halibut (*Hippoglossus hippoglossus*) caught by longline and otter trawl gear. Can. J. Fish. Aquat. Sci. 46: 887-897.

New England Fishery Management Council. 1998. Evaluation of existing overfishing definitions and recommendations for new overfishing definitions to comply with the Sustainable Fisheries Act. NEFMC, 50 Water Street, Mill 2 Newburyport, MA 01950.

North Atlantic Fishery Investigations, Fish and Wildlife Service. 1952. United States Landings of Groundfish from the Convention Area, 1893-1950. ICNAF Annual Meeting. Vol. 4, Index Doc. 7.

Northeast Fisheries Science Center [NEFSC]. 2001. Assessment of 19 Northeast groundfish stocks through 2000. NEFSC Reference Document 01-20, Woods Hole, MA, 02543.

Northeast Fisheries Science Center [NEFSC]. 2002. Final Report of the Working Group on Re-Evaluation of Biological Reference Points for New England Groundfish. NEFSC Reference Document 02-04, Woods Hole, MA, 02543.

Sigourney, D.B. 2002. Biology of the Atlantic halibut (*Hippoglossus hippoglossus*) in the Gulf of Maine-Georges Bank region. M.Sc. Thesis, Univ. Mass. Amherst, Amherst, MA 01003.

Sigourney, D.B., Ross, M.R., Brodziak, J., and Burnett, J. 2006. Length at Age, Sexual Maturity and Distribution of Atlantic Halibut, *Hippoglossus hippoglossus* L., off the Northeast USA. *Northw. Atl. Fish. Sci*., 36:81-90.

Wigley, S.E., Rago, P.J., Sosebee, K.A., and Palka, D.L. 2007. The analytic component to the Standardized Bycatch Reporting Methodology omnibus amendment: sampling design and estimation of precision and accuracy. NEFSC Reference Document 07-09, p.156.

Wise, J.P., and Jensen, A.C. 1959. Movement of tagged halibut off New England. Trans. Amer. Fish. Soc. 88:357-358.

Table S1. Reported catch (mt) of Atlantic halibut from the Gulf of Maine and Georges Bank (Statistical Subareas 5Y and 5Z), 1893-2006.

Year	USA	US Discards	Canada	Other	Total Landings	Total Catch	Year	USA	US Discards	Canada	Other	Total Landings	Total Catch
1893	684	114	0	0	684	798	1950	116	19	0	0	116	135
1894	843	140	0	0	843	983	1951	154	26	0	0	154	180
1895	4200	699	0	0	4200	4899	1952	123	20	0	0	123	143
1896	4908	817	0	0	4908	5725	1953	104	17	0	0	104	121
1897	733	122	0	0	733	855	1954	125	21	0	0	125	146
1898	564	94	0	0	564	658	1955	74	12	0	0	74	86
1899	407	68	0	0	407	475	1956	62	10	0	0	62	72
1900	331	55	0	0	331	386	1957	80	13	0	0	80	93
1901	287	48	0	0	287	335	1958	73	12	0	0	73	85
1902	367	61	0	0	367	428	1959	59	10	0	0	59	69
1903	502	84	0	0	502	586	1960	63	10	0	0	63	73
1904	332	55	0	0	332	387	1961	79	13	5	0	84	97
1905	580	97	0	0	580	677	1962	86	14	35	25	146	160
1906	542	90	0	0	542	632	1963	94	16	88	1	183	199
1907	447	74	0	0	447	521	1964	115	19	120	1	236	255
1908	891	148	0	0	891	1039	1965	128	21	153	18	299	320
1909	193	32	0	0	193	225	1966	110	18	110	62	282	300
1910	329	55	0	0	329	384	1967	102	17	386	26	514	531
1911	389	65	0	0	389	454	1968	74	12	193	3	270	282
1912	460	77	0	0	460	537	1969	63	10	96	9	168	178
1913	402	67	0	0	402	469	1970	52	9	67	19	138	147
1914	329	55	0	0	329	384	1971	81	13	38	0	119	132
1915	336	56	0	0	336	392	1972	63	10	37	8	108	118
1916	478	80	0	0	478	558	1973	51	8	38	0	89	97
1917	293	49	0	0	293	342	1974	46	8	29	1	76	84
1918	375	62	0	0	375	437	1975	70	12	36	0	106	118
1919	498	83	0	0	498	581	1976	58	10	33	0	91	101
1920	896	149	0	0	896	1045	1977	50	8	31	0	81	89
1921	689	115	0	0	689	804	1978	84	14	50	0	134	148
1922	694	115	0	0	694	809	1979	125	21	29	0	154	175
1923	508	85	0	0	508	593	1980	80	13	88	0	168	181
1924	616	103	0	0	616	719	1981	80	13	118	0	198	211
1925	843	140	0	0	843	983	1982	85	14	116	0	201	215
1926	944	157	0	0	944	1101	1983	72	12	131	0	203	215
1927	831	138	0	0	831	969	1984	75	12	62	0	137	149
1928	781	130	0	0	781	911	1985	61	10	57	0	118	128
1929	570	95	0	0	570	665	1986	44	7	32	0	76	83
1930	716	119	0	0	716	835	1987	27	4	23	0	50	54
1931	511	85	0	0	511	596	1988	47	8	81	0	128	136
1932	443	74	0	0	443	517	1989	13	2	65	0	78	80
1933	279	46	0	0	279	325	1990	16	3	58	0	74	77
1934	192	32	0	0	192	224	1991	30	5	58	0	88	93
1935	292	49	0	0	292	341	1992	22	4	47	0	69	73
1936	374	62	0	0	374	436	1993	15	2	50	0	65	67
1937	187	31	0	0	187	218	1994	22	4	24	0	46	50
1938	146	24	0	0	146	170	1995	11	2	8	0	19	21
1939	124	21	0	0	124	145	1996	13	2	12	0	25	27
1940	499	83	0	0	499	582	1997	14	2	14	0	28	30
1941	145	24	0	0	145	169	1998	8	1	9	0	17	18
1942	250	42	0	0	250	292	1999	12	20	8	0	20	40
1943	76	13	0	0	76	89	2000	11	19	6	0	17	36
1944	77	13	0	0	77	90	2001	11	19	11	0	22	41
1945	55	9	0	0	55	64	2002	10	17	10	0	20	37
1946	124	21	0	0	124	145	2003	17	29	14	0	31	60
1947	198	33	0	0	198	231	2004	11	19	12	0	23	42
1948	156	26	0	0	156	182	2005	17	29	9	0	26	55
1949	157	26	0	0	157	183	2006	14	24	10	0	24	48

Table S2. Atlantic halibut United States discards (mt) based on Standardized Bycatch Reduction Methodology combined ratio estimation (1989-2006).

Year	US Discards	cv	US Landings		Average Discards	Total US Catch
1989	3.36	0.5248	13		2	15
1990	10.17	0.5784	16		3	19
1991	5.22	0.3480	30		5	35
1992	1.62	0.3936	22		4	26
1993	1.26	0.4445	15		2	17
1994	1.40	0.4744	22		4	26
1995	2.85	1.3187	11		2	13
1996	0.63	0.4915	13	1989-1998 Average	2	15
1997	0.62	0.7884	14	Discards/Landings=	2	16
1998	0.16	1.0139	8	0.166	1	9
1999	76.06	0.7018	12		20	32
2000	9.31	0.3525	11		19	30
2001	9.38	0.2713	11		19	30
2002	16.76	0.4105	10		17	27
2003	15.72	0.2120	17		29	46
2004	18.15	0.2071	11	1999-2006 Average	19	30
2005	13.95	0.1144	17	Discards/Landings=	29	46
2006	14.29	0.1708	14	1.686	24	38

Table S3. Atlantic halibut stratified mean weight (kg) per tow from NEFSC spring and autumn surveys (offshore strata 13-30, 36-40) and exploitation rate indices calculated as annual catch divided by the 5-year moving average of swept-area biomass indices.

Year	Total Catch (mt)	Spring Survey Index (wt/tow)	5-Year Average Spring Swept-Area Biomass (mt)	Spring Explotiation Rate Index	Autumn Survey Index (wt/tow)	5-Year Average Autumn Swept-Area Biomass (mt)	Autumn Explotiation Rate Index
1963	199				0.085	282	0.70
1964	255				0.067	252	1.01
1965	320				0.032	204	1.57
1966	300				0.004	156	1.93
1967	531				0.009	131	4.06
1968	282	0.129	428	0.66	0.233	229	1.23
1969	178	0.236	606	0.29	0.494	512	0.35
1970	147	0.105	520	0.28	0.000	491	0.30
1971	132	0.033	417	0.32	0.091	549	0.24
1972	118	0.005	337	0.35	0.018	555	0.21
1973	97	0.113	327	0.30	0.131	487	0.20
1974	84	0.112	244	0.34	0.014	169	0.50
1975	118	0.000	175	0.67	0.095	232	0.51
1976	101	0.644	580	0.17	0.378	422	0.24
1977	89	0.142	671	0.13	0.059	449	0.20
1978	148	0.163	704	0.21	0.294	558	0.27
1979	175	0.357	867	0.20	0.040	575	0.30
1980	181	0.563	1241	0.15	0.010	518	0.35
1981	211	0.066	857	0.25	0.321	481	0.44
1982	215	0.082	817	0.26	0.115	518	0.42
1983	215	0.611	1115	0.19	0.000	323	0.67
1984	149	0.022	892	0.17	0.124	378	0.40
1985	128	0.063	560	0.23	0.106	442	0.29
1986	83	0.000	516	0.16	0.313	437	0.19
1987	54	0.287	653	0.08	0.033	382	0.14
1988	136	0.023	262	0.52	0.004	385	0.35
1989	80	0.000	248	0.32	0.066	347	0.23
1990	77	0.064	248	0.31	0.060	316	0.24
1991	93	0.062	289	0.32	0.243	270	0.35
1992	73	0.037	123	0.59	0.201	381	0.19
1993	67	0.006	112	0.60	0.046	409	0.17
1994	50	0.017	123	0.40	0.000	365	0.14
1995	21	0.005	84	0.25	0.066	369	0.06
1996	27	0.013	52	0.52	0.053	243	0.11
1997	30	0.063	69	0.44	0.174	225	0.13
1998	18	0.017	76	0.24	0.103	263	0.07
1999	40	0.239	224	0.18	0.015	273	0.15
2000	36	0.000	220	0.16	0.021	243	0.15
2001	41	0.163	320	0.13	0.247	372	0.11
2002	37	0.128	363	0.10	0.004	259	0.14
2003	60	0.052	386	0.15	0.049	223	0.27
2004	42	0.168	339	0.12	0.112	287	0.14
2005	55	0.025	356	0.15	0.111	347	0.16
2006	48	0.383	502	0.09	0.031	204	0.23
2007		0.195	546		0.077	252	

Table S4. Mean and minimum sizes of Atlantic halibut discarded and landed from Northeast Fisheries Observer Program data. Red numbers indicate years of potential enforcement problems with minimum size regulation.

Discarded Atlantic Halibut

Year	Mean Length (cm)	Std Err	N	Minimum Length (cm)
1992	33.0	.	1	33
1993	31.3	13.3458	3	17
1994	42.4	5.1049	5	24
1995	27.2	5.4858	6	18
1997	36.3	2.1858	3	32
1999	62.0	.	1	62
2000	57.0	4.0778	13	18
2001	67.5	2.9518	13	48
2002	70.2	4.7648	13	38
2003	64.0	1.6363	91	31
2004	57.1	1.3502	87	26
2005	60.4	1.3042	160	33
2006	63.0	1.495	107	38
2007	64.3	1.9969	75	24

Landed Atlantic Halibut

Year	Mean Length (cm)	Std Err	N	Minimum Length (cm)
1990	46.6	2.0012	6	42
1991	92.0	.	1	92
1992	67.1	5.2457	11	29
1993	62.8	5.5333	10	42
1994	73.3	5.0781	16	46
1995	79.6	4.6356	29	42
1996	69.2	10.027	5	50
1997	67.5	11.3893	6	44
2001	118.0	6	2	112
2002	88.0	9.0738	6	52
2003	81.0	5.349	29	41
2004	83.9	3.9709	33	43
2005	76.4	2.5691	80	40
2006	84.9	3.5611	37	50
2007	90.5	4.225	33	49

Note: 1999-2007 avgerage observed minimum size = 55cm
Minimum size regulation for 1999-present = 91cm

Table S5. Input parameters for Atlantic halibut YPR analysis.

Age	Selectivity on Fishing Mortality	Natural Mortality Rate	Fraction Mature	Mean Weight (kg)
0	0	0.06	0.012889	0.00
1	0	0.06	0.0370	0.02
2	0	0.06	0.0606	0.25
3	0	0.06	0.0977	0.96
4	1	0.06	0.1538	2.38
5	1	0.06	0.2338	4.62
6	1	0.06	0.3388	7.75
7	1	0.06	0.4625	11.75
8	1	0.06	0.5910	16.60
9	1	0.06	0.7081	22.24
10	1	0.06	0.8029	28.57
11	1	0.06	0.8724	35.51
12	1	0.06	0.9199	42.96
13	1	0.06	0.9507	50.82
14	1	0.06	0.9700	58.99
15	1	0.06	0.9819	67.40
16	1	0.06	0.9892	75.95
17	1	0.06	0.9935	84.57
18	1	0.06	0.9961	93.20
19	1	0.06	0.9977	101.77
20	1	0.06	0.9986	110.25
21	1	0.06	0.9992	118.58
22	1	0.06	0.9995	126.73
23	1	0.06	0.9997	134.67
24	1	0.06	0.9998	142.38
25	1	0.06	0.9999	149.84
26	1	0.06	0.9999	157.04
27	1	0.06	1.0000	163.95
28	1	0.06	1.0000	170.59
29	1	0.06	1.0000	176.95
30-50	1	0.06	1.0000	183.02

Table S6. Atlantic halibut yield and biomass per recruit analysis from NFT YPR v.2.7.

Yield per Recruit and Spawning Stock Biomass per Recruit
YPR Version 2.7
Date of Run: 10 Apr 2008 12:47
Input Data File: L:\HALIBUT\NFTYPR\BRP2008\HALIBUT_YPR_ORIG.DAT

Model Title: HalibutYPR6307

Start Age = 0
End Age = 30 - Includes Plus Group with Maximum Age = 50

Fishing Mortality Upper Bound = 1.0000
Fishing Mortality Calculation Increment = 0.0001
Fishing Mortality Printing Increment = 0.001

Natural Mortality = 0.0600

Proportion Fishing Mortality Before Spawning = 0.9200
Proportion Natural Mortality Before Spawning = 0.9200

Age	Selectivity F	Selectivity M	Stock Weight	Catch Weight	SSB Weight	Maturity
0	0.0000	1.0000	0.0000	0.0000	0.0000	0.0200
1	0.0000	1.0000	0.0200	0.0200	0.0200	0.0400
2	0.0000	1.0000	0.2500	0.2500	0.2500	0.0600
3	0.0000	1.0000	0.9600	0.9600	0.9600	0.1000
4	1.0000	1.0000	2.3800	2.3800	2.3800	0.1500
5	1.0000	1.0000	4.6200	4.6200	4.6200	0.2300
6	1.0000	1.0000	7.7500	7.7500	7.7500	0.3400
7	1.0000	1.0000	11.7500	11.7500	11.7500	0.4600
8	1.0000	1.0000	16.6000	16.6000	16.6000	0.5900
9	1.0000	1.0000	22.2400	22.2400	22.2400	0.7100
10	1.0000	1.0000	28.5700	28.5700	28.5700	0.8000
11	1.0000	1.0000	35.5100	35.5100	35.5100	0.8700
12	1.0000	1.0000	42.9600	42.9600	42.9600	0.9200
13	1.0000	1.0000	50.8200	50.8200	50.8200	0.9500
14	1.0000	1.0000	58.9900	58.9900	58.9900	0.9700
15	1.0000	1.0000	67.4000	67.4000	67.4000	0.9800
16	1.0000	1.0000	75.9500	75.9500	75.9500	0.9900
17	1.0000	1.0000	84.5700	84.5700	84.5700	0.9900
18	1.0000	1.0000	93.2000	93.2000	93.2000	1.0000
19	1.0000	1.0000	101.7700	101.7700	101.7700	1.0000
20	1.0000	1.0000	110.2500	110.2500	110.2500	1.0000
21	1.0000	1.0000	118.5800	118.5800	118.5800	1.0000
22	1.0000	1.0000	126.7300	126.7300	126.7300	1.0000
23	1.0000	1.0000	134.6700	134.6700	134.6700	1.0000
24	1.0000	1.0000	142.3800	142.3800	142.3800	1.0000
25	1.0000	1.0000	149.8400	149.8400	149.8400	1.0000
26	1.0000	1.0000	157.0400	157.0400	157.0400	1.0000
27	1.0000	1.0000	163.9500	163.9500	163.9500	1.0000
28	1.0000	1.0000	170.5900	170.5900	170.5900	1.0000
29	1.0000	1.0000	176.9500	176.9500	176.9500	1.0000
30	1.0000	1.0000	183.0200	183.0200	183.0200	1.0000

Reference Point	F	YPR	SSBR	TSBR	Mean Age	Mean GT	Exp Spawn
F Zero	0.00000	0.00000	916.59140	999.75951	13.66276	26.89984	7.80214
F-01	0.04160	17.14462	371.94281	434.46329	9.35320	22.75157	4.80484
F-Max	0.05970	17.90411	264.24565	319.25092	8.14853	21.21204	3.98706
F at 40 %MSP	0.04230	17.21033	366.86431	429.07197	9.30049	22.68885	4.76904

FMORT	CTHN	CTHW	STKN	STKW	SPNSTKN	SPNSTKW	MSP	MNAGE	MNGT	EXSP
0.04000	0.31179	16.98003	11.85492	447.12198	5.36486	383.87988	41.88124	9.47574	22.89589	4.88806

Table S7. Atlantic halibut catch and biomass index input and resulting biomass, recruitment and relative F from Case 32 of Replacement Yield model.

Year	Total Catch (mt)	Swept-Area Biomass (mt)	Biomass (mt)	Recruitment (mt)	Relative F
1800	10		300000	0	0.0000
1801	20		299990	0	0.0001
1802	30		299970	0	0.0001
1803	37		299940	0	0.0001
1804	104		299903	1	0.0003
1805	171		299800	1	0.0006
1806	238		299630	2	0.0008
1807	305		299394	4	0.0010
1808	372		299093	5	0.0012
1809	439		298726	8	0.0015
1810	506		298295	10	0.0017
1811	573		297799	13	0.0019
1812	640		297239	16	0.0022
1813	707		296616	20	0.0024
1814	774		295929	24	0.0026
1815	841		295179	28	0.0028
1816	908		294366	33	0.0031
1817	975		293491	38	0.0033
1818	1042		292555	44	0.0036
1819	1109		291556	49	0.0038
1820	1176		290496	55	0.0040
1821	1243		289376	61	0.0043
1822	1310		288194	68	0.0045
1823	1377		286952	75	0.0048
1824	1444		285650	82	0.0051
1825	1511		284288	89	0.0053
1826	1578		282866	97	0.0056
1827	1645		281385	105	0.0058
1828	1712		279845	113	0.0061
1829	1779		278246	121	0.0064
1830	1846		276588	130	0.0067
1831	1913		274871	138	0.0070
1832	1980		273096	147	0.0073
1833	2047		271263	156	0.0075
1834	2114		269372	165	0.0078
1835	2181		267423	174	0.0082
1836	2248		265417	184	0.0085
1837	2315		263352	193	0.0088
1838	2382		261230	203	0.0091
1839	2449		259051	212	0.0095
1840	2516		256814	222	0.0098
1841	2583		254520	232	0.0101
1842	2650		252168	241	0.0105
1843	2717		249759	251	0.0109
1844	2784		247293	261	0.0113
1845	2851		244770	270	0.0116
1846	2918		242189	280	0.0120
1847	2985		239551	290	0.0125
1848	3052		236856	299	0.0129
1849	3119		234103	309	0.0133
1850	3186		231293	318	0.0138
1851	3253		228425	327	0.0142
1852	3320		225499	336	0.0147
1853	3387		222515	345	0.0152
1854	3454		219472	353	0.0157
1855	3521		216372	362	0.0163
1856	3588		213213	370	0.0168
1857	3655		209995	378	0.0174
1858	3722		206718	386	0.0180
1859	3789		203381	393	0.0186
1860	3856		199985	400	0.0193
1861	3923		196530	407	0.0200
1862	3990		193013	413	0.0207
1863	4057		189436	419	0.0214
1864	4124		185798	424	0.0222
1865	4191		182098	429	0.0230
1866	4258		178337	434	0.0239
1867	4325		174513	438	0.0248
1868	4392		170626	441	0.0257
1869	4459		166675	444	0.0268
1870	4526		162661	447	0.0278
1871	4593		158582	449	0.0290
1872	4660		154437	450	0.0302
1873	4727		150227	450	0.0315
1874	4794		145950	450	0.0328
1875	4861		141605	449	0.0343
1876	4928		137193	447	0.0359
1877	4995		132712	444	0.0376
1878	5062		128161	440	0.0395
1879	5129		123539	436	0.0415
1880	5196		118846	431	0.0437
1881	5263		114081	424	0.0461
1882	5330		109242	417	0.0488
1883	5397		104329	408	0.0517
1884	5464		99340	399	0.0550
1885	5531		94275	388	0.0587
1886	5598		89131	376	0.0628
1887	5665		83909	363	0.0675
1888	5732		78607	348	0.0729
1889	5799		73223	332	0.0792
1890	5866		67756	315	0.0866
1891	5933		62205	296	0.0954
1892	6000		56568	275	0.1061
1893	798		50843	253	0.0157
1894	983		50299	251	0.0195
1895	4899		49567	248	0.0988
1896	5725		44916	229	0.1275
1897	855		39421	205	0.0217
1898	658		38771	203	0.0170
1899	475		38316	201	0.0124
1900	386		38042	199	0.0101
1901	335		37855	198	0.0088
1902	428		37719	198	0.0113
1903	586		37489	197	0.0156
1904	387		37100	195	0.0104
1905	677		36908	194	0.0183
1906	632		36425	192	0.0174
1907	521		35985	190	0.0145
1908	1039		35654	188	0.0291
1909	225		34803	185	0.0065
1910	384		34763	184	0.0110
1911	454		34563	183	0.0131
1912	537		34293	182	0.0156
1913	469		33939	181	0.0138
1914	384		33650	179	0.0114
1915	392		33446	178	0.0117
1916	558		33232	177	0.0168
1917	342		32852	176	0.0104
1918	437		32686	175	0.0134
1919	581		32423	174	0.0179
1920	1045		32016	172	0.0326
1921	804		31142	167	0.0258
1922	809		30506	164	0.0265
1923	593		29861	161	0.0198
1924	719		29430	159	0.0244
1925	983		28871	157	0.0341
1926	1101		28044	153	0.0393
1927	969		27095	148	0.0358
1928	911		26274	144	0.0347
1929	665		25507	140	0.0261
1930	835		24982	137	0.0334
1931	596		24284	134	0.0245
1932	517		23822	132	0.0217
1933	325		23437	130	0.0139
1934	224		23241	129	0.0096
1935	341		23146	128	0.0147
1936	436		22933	127	0.0190
1937	218		22624	126	0.0096

Table S7 (cont.). Atlantic halibut catch and biomass index input and resulting biomass, recruitment and relative F from Case 32 of Replacement Yield model.

Year	Total Catch (mt)	Swept-Area Biomass (mt)	Biomass (mt)	Recruitment (mt)	Relative F
1938	170		22532	125	0.0076
1939	145		22486	125	0.0064
1940	582		22467	125	0.0259
1941	169		22009	122	0.0077
1942	292		21962	122	0.0133
1943	89		21793	121	0.0041
1944	90		21826	121	0.0041
1945	64		21857	122	0.0029
1946	145		21915	122	0.0066
1947	231		21892	122	0.0105
1948	182		21783	121	0.0084
1949	183		21722	121	0.0084
1950	135		21660	121	0.0062
1951	180		21645	121	0.0083
1952	143		21586	120	0.0066
1953	121		21563	120	0.0056
1954	146		21561	120	0.0068
1955	86		21536	120	0.0040
1956	72		21569	120	0.0034
1957	93		21617	120	0.0043
1958	85		21644	120	0.0039
1959	69		21679	121	0.0032
1960	73		21731	121	0.0034
1961	97		21779	121	0.0045
1962	160		21803	121	0.0074
1963	199	282	21764	121	0.0091
1964	255	252	21686	121	0.0118
1965	320	204	21552	120	0.0149
1966	300	156	21352	119	0.0141
1967	531	131	21170	118	0.0251
1968	282	229	20757	116	0.0136
1969	178	512	20591	115	0.0087
1970	147	491	20528	115	0.0071
1971	132	549	20496	115	0.0065
1972	118	555	20478	114	0.0058
1973	97	487	20474	114	0.0048
1974	84	169	20491	115	0.0041
1975	118	232	20522	115	0.0057
1976	101	422	20519	115	0.0049
1977	89	449	20533	115	0.0044
1978	148	558	20558	115	0.0072
1979	175	575	20525	115	0.0085
1980	181	518	20465	114	0.0089
1981	211	481	20398	114	0.0104
1982	215	518	20301	114	0.0106
1983	215	323	20199	113	0.0106
1984	149	378	20097	113	0.0074
1985	128	442	20060	112	0.0064
1986	83	437	20045	112	0.0042
1987	54	382	20073	112	0.0027
1988	136	385	20131	113	0.0067
1989	80	347	20108	113	0.0040
1990	77	316	20141	113	0.0038
1991	93	270	20177	113	0.0046
1992	73	381	20197	113	0.0036
1993	67	409	20237	113	0.0033
1994	50	365	20283	113	0.0024
1995	21	369	20346	114	0.0010
1996	27	243	20439	114	0.0013
1997	30	225	20527	115	0.0015
1998	18	263	20611	115	0.0009
1999	40	273	20708	116	0.0019
2000	36	243	20783	116	0.0017
2001	41	372	20864	116	0.0019
2002	37	259	20940	117	0.0018
2003	60	223	21020	117	0.0028
2004	42	287	21077	118	0.0020
2005	55	347	21153	118	0.0026
2006	48	204	21217	118	0.0022

Table S8. Summary of Atlantic halibut replacement yield model runs with varying carrying capacity (K) and recruitment (r) parameters.

	Case 1	Case 2	Case 3
K	50000	50000	50000
r	**0.353807079975544**	**0.353807079975545**	**0.353807079975546**
B2006 as % of K	0.0%	55.4%	87.5%
-ln L	19201.398	141.895	198.056
q	128.790	0.306	0.182
sigma	0.6	0.6	0.6
penalty	17508.2800	0.0376	0.1010
Fmsy	0.1769	0.1769	0.1769
1/2 Bmsy	12500	12500	12500
F2006/Fmsy	26907.4651	0.0097	0.0062
B2006/(1/2 Bmsy)	8.0000E-07	2.2177	3.4983

	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
K	90000	90000	90000	90000	90000	90000
r	**0.16307849140**	**0.16307849145**	**0.16307849150**	**0.16307849155**	**0.16307849160**	**0.16307860000**
B2006 as % of K	0.0%	0.7%	1.6%	2.5%	3.4%	96.8%
-ln L	805.999	23.482	22.557	25.079	28.249	65.574
q	2.089	0.547	0.439	0.380	0.341	0.011
sigma	0.6	0.6	0.6	0.6	0.6	0.6
penalty	202.5252	0.0022	0.0037	0.0143	0.0252	0.2392
Fmsy	0.0815	0.0815	0.0815	0.0815	0.0815	0.0815
1/2 Bmsy	22500	22500	22500	22500	22500	22500
F2006/Fmsy	58377.1139	0.9201	0.4010	0.2579	0.1908	0.0067
B2006/(1/2 Bmsy)	4.4444E-07	0.0282	0.0647	0.1006	0.1360	3.8731

	Case 10	Case 11	Case 12	Case 13	Case 14	Case 15	Case 16
K	100000	100000	100000	100000	100000	100000	100000
r	**0.139766823**	**0.139766824**	**0.139766825**	**0.139766826**	**0.139766827**	**0.139766828**	**0.13977**
B2006 as % of K	0.0%	0.2%	2.2%	4.2%	6.1%	7.9%	98.8%
-ln L	2888.269	34.087	22.373	29.172	35.703	41.399	16.912
q	22.308	0.615	0.335	0.260	0.219	0.191	0.005
sigma	0.6	0.6	0.6	0.6	0.6	0.6	0.6
penalty	1225.5960	0.0132	0.0272	0.0577	0.0792	0.0953	0.2451
Fmsy	0.0699	0.0699	0.0699	0.0699	0.0699	0.0699	0.0699
1/2 Bmsy	25000	25000	25000	25000	25000	25000	25000
F2006/Fmsy	68113.8160	3.7613	0.3085	0.1636	0.1126	0.0865	0.0069
B2006/(1/2 Bmsy)	4.0000E-07	0.0072	0.0883	0.1665	0.2420	0.3149	3.9524

	Case 17	Case 18	Case 19	Case 20	Case 21	Case 22
K	150000	150000	150000	150000	150000	150000
r	**0.0708170**	**0.0708175**	**0.0708180**	**0.0708185**	**0.0708190**	**0.0720000**
B2006 as % of K	0.0%	1.1%	2.2%	3.3%	4.4%	96.9%
-ln L	862.258	15.744	15.858	18.157	20.515	8.797
q	1.389	0.231	0.164	0.130	0.110	0.003
sigma	0.6	0.6	0.6	0.6	0.6	0.6
penalty	200.7897	0.0726	0.1130	0.1365	0.1524	0.2474
Fmsy	0.0354	0.0354	0.0354	0.0354	0.0354	0.0360
1/2 Bmsy	37500	37500	37500	37500	37500	37500
F2006/Fmsy	134431.7278	0.8406	0.4040	0.2679	0.2015	0.0091
B2006/(1/2 Bmsy)	2.6667E-07	0.0426	0.0887	0.1338	0.1779	3.8764

	Case 23	Case 24	Case 25	Case 26	Case 27	Case 28
K	200000	200000	200000	200000	200000	200000
r	**0.0368**	**0.0369**	**0.037**	**0.0371**	**0.0372**	**0.045**
B2006 as % of K	0.0%	1.0%	7.8%	13.8%	19.0%	93.2%
-ln L	168917325.973	13.800	15.152	16.674	17.078	8.782
q	12997.220	0.149	0.036	0.022	0.016	0.002
sigma	0.60	0.60	0.60	0.60	0.60	0.60
penalty	168916733.9256	0.1234	0.2150	0.2288	0.2346	0.2480
Fmsy	0.0184	0.0185	0.0185	0.0186	0.0186	0.0225
1/2 Bmsy	50000	50000	50000	50000	50000	50000
F2006/Fmsy	258697.0562	1.2845	0.1659	0.0931	0.0667	0.0113
B2006/(1/2 Bmsy)	2.0000E-07	2.0000E-07	0.3101	0.5511	0.7675	3.7295

	Case 29	Case 30	Case 31	Case 32	Case 33	Case 34	Case 35
K	300000	300000	300000	300000	300000	300000	300000
r	**0.003**	**0.004**	**0.005**	**0.006**	**0.007**	**0.008**	**0.030**
B2006 as % of K	0.0%	1.1%	3.9%	7.1%	10.7%	14.8%	92.3%
-ln L	18555487.020	12.982	9.242	8.935	8.948	9.029	8.593
q	4307.755	0.071	0.027	0.016	0.011	0.008	0.001
sigma	0.6	0.6	0.6	0.6	0.6	0.6	0.6
penalty	18554249.0505	0.1841	0.2236	0.2342	0.2391	0.2418	0.2487
Fmsy	0.0015	0.0020	0.0025	0.0030	0.0035	0.0040	0.0150
1/2 Bmsy	75000	75000	75000	75000	75000	75000	75000
F2006/Fmsy	3173350.5555	7.1393	1.6432	0.7478	0.4222	0.2673	0.0115
B2006/(1/2 Bmsy)	1.3333E-07	0.0444	0.1545	0.2829	0.4295	0.5936	3.6913

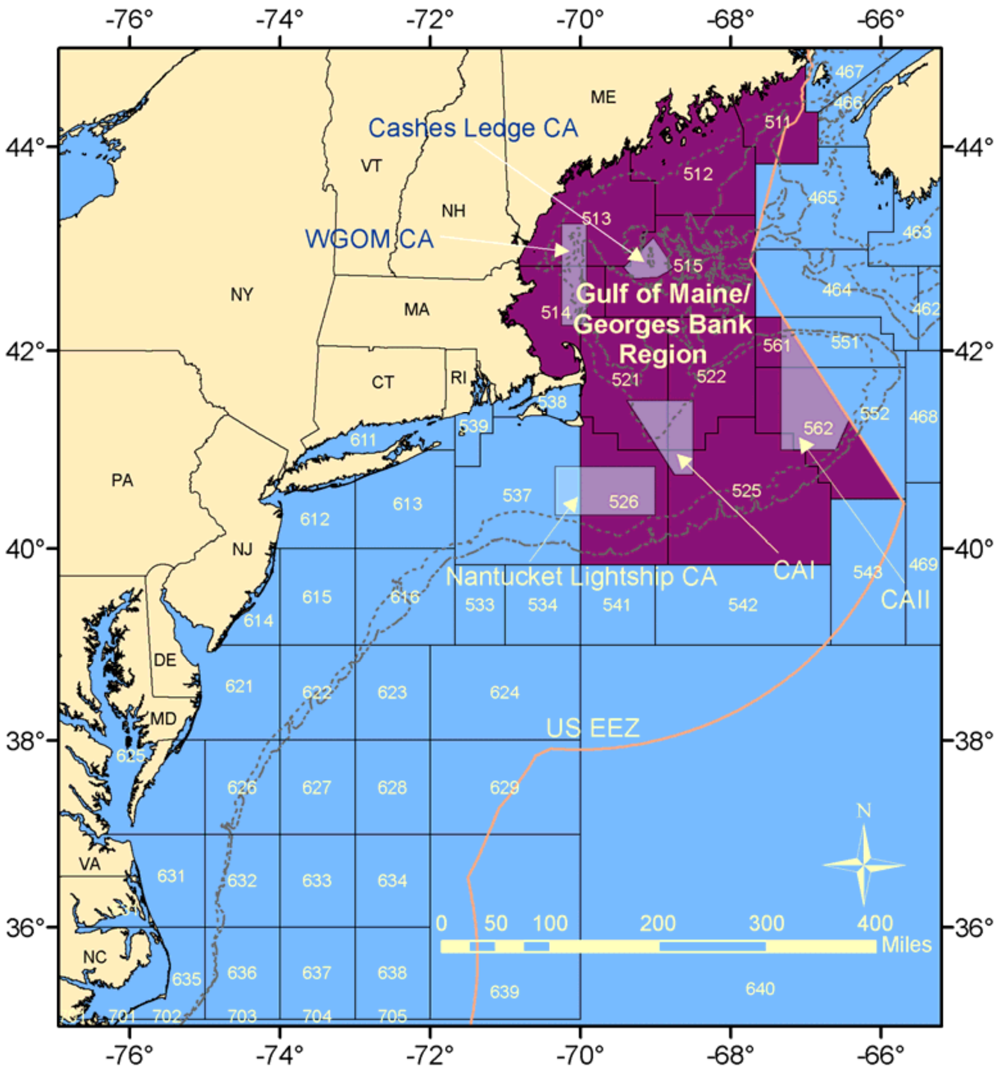

Figure S1. Statistical areas used to determine United States commercial fishing catch for the Gulf of Maine-Georges Bank region of the Atlantic halibut stock.

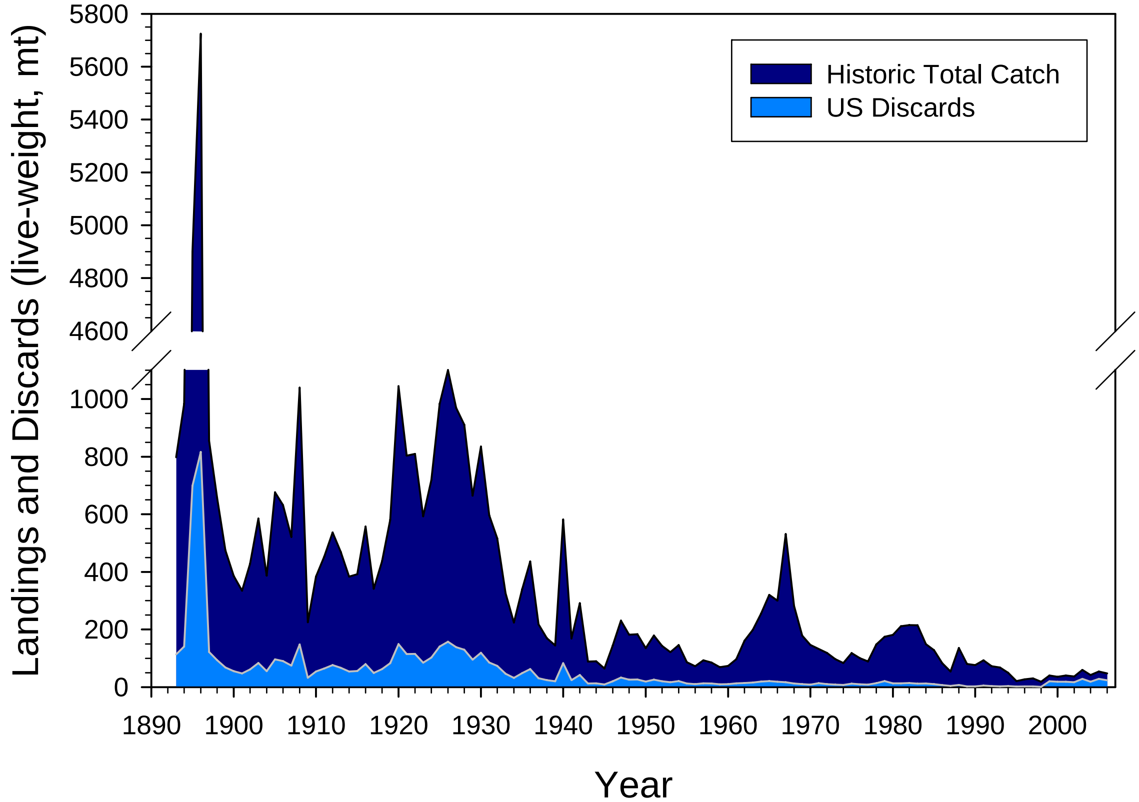

Figure S2. Atlantic halibut total catch (mt) from the Gulf of Maine-Georges Bank region (NAFO Subareas 5Y and 5Z), 1892-2006.

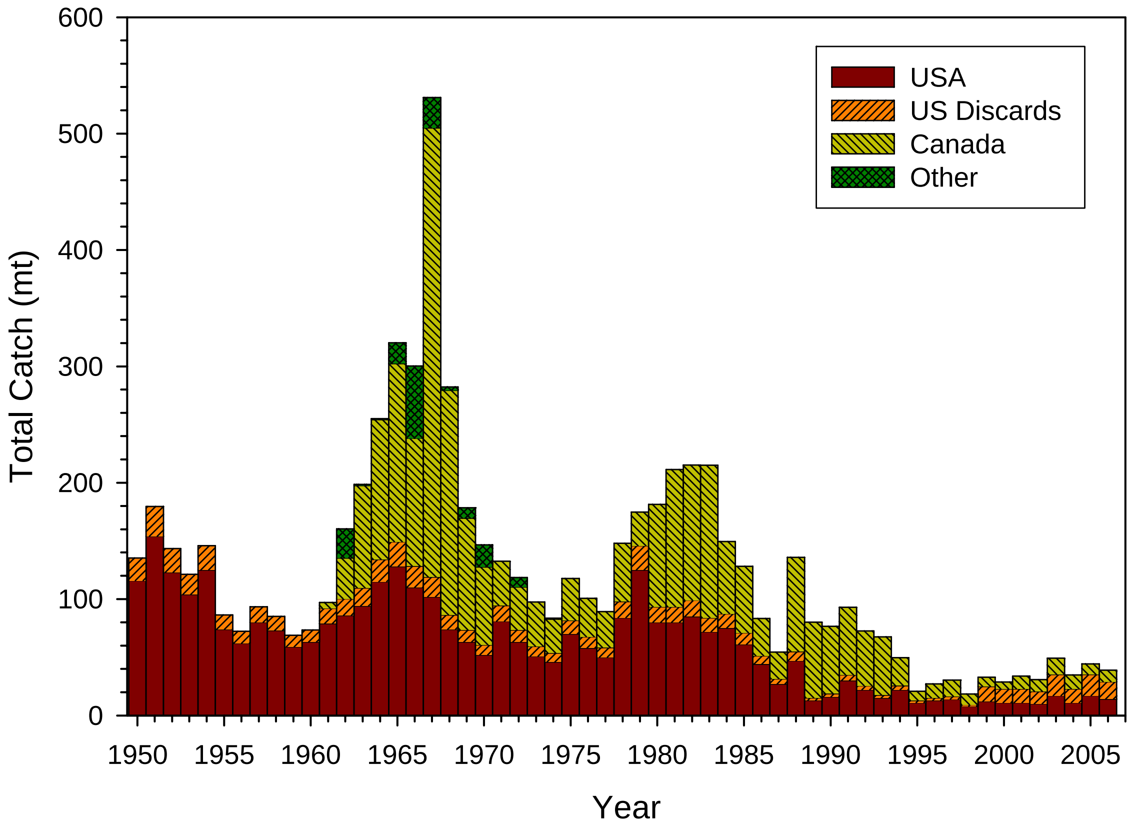

Figure S3. Atlantic halibut catch (mt) by country, 1950-2006.

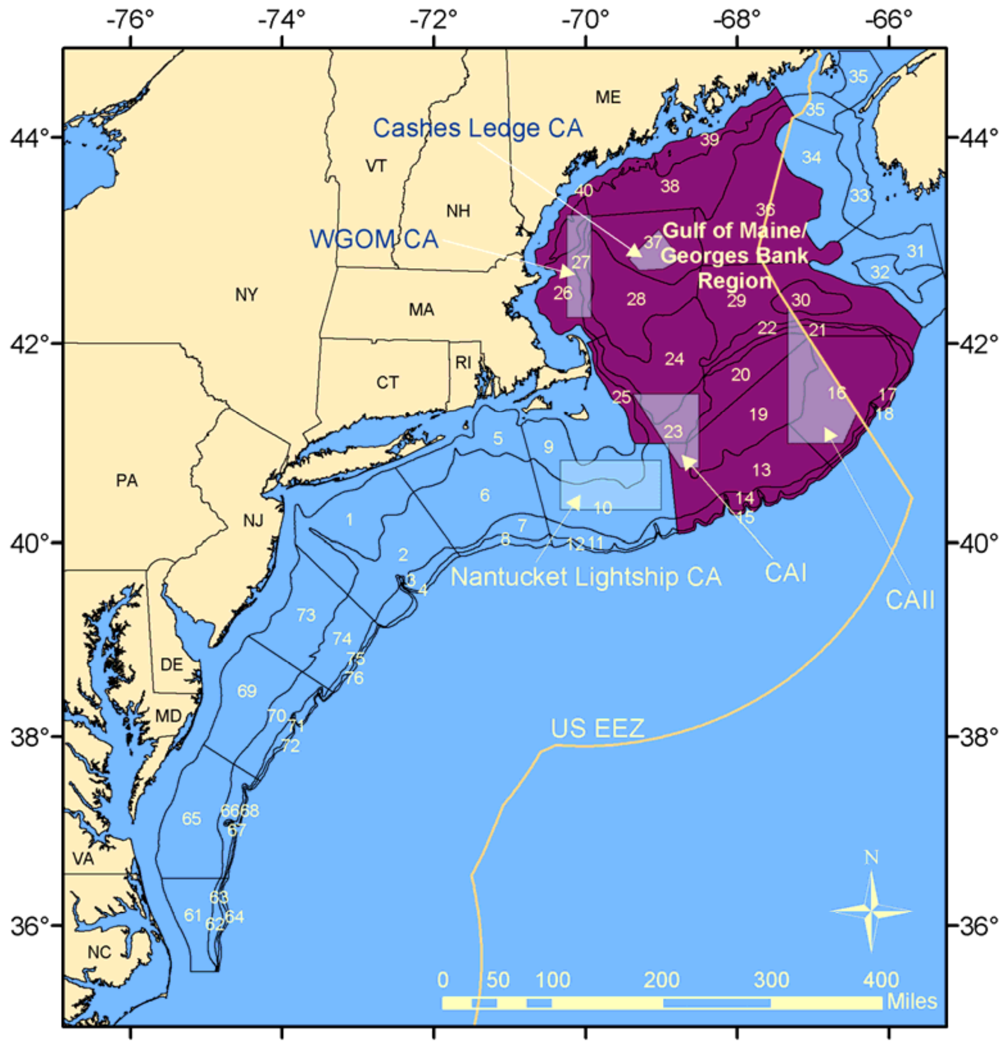

Figure S4. Northeast Fisheries Science Center offshore bottom trawl survey strata used for calculating Gulf of Maine-Georges Bank Atlantic halibut biomass indices.

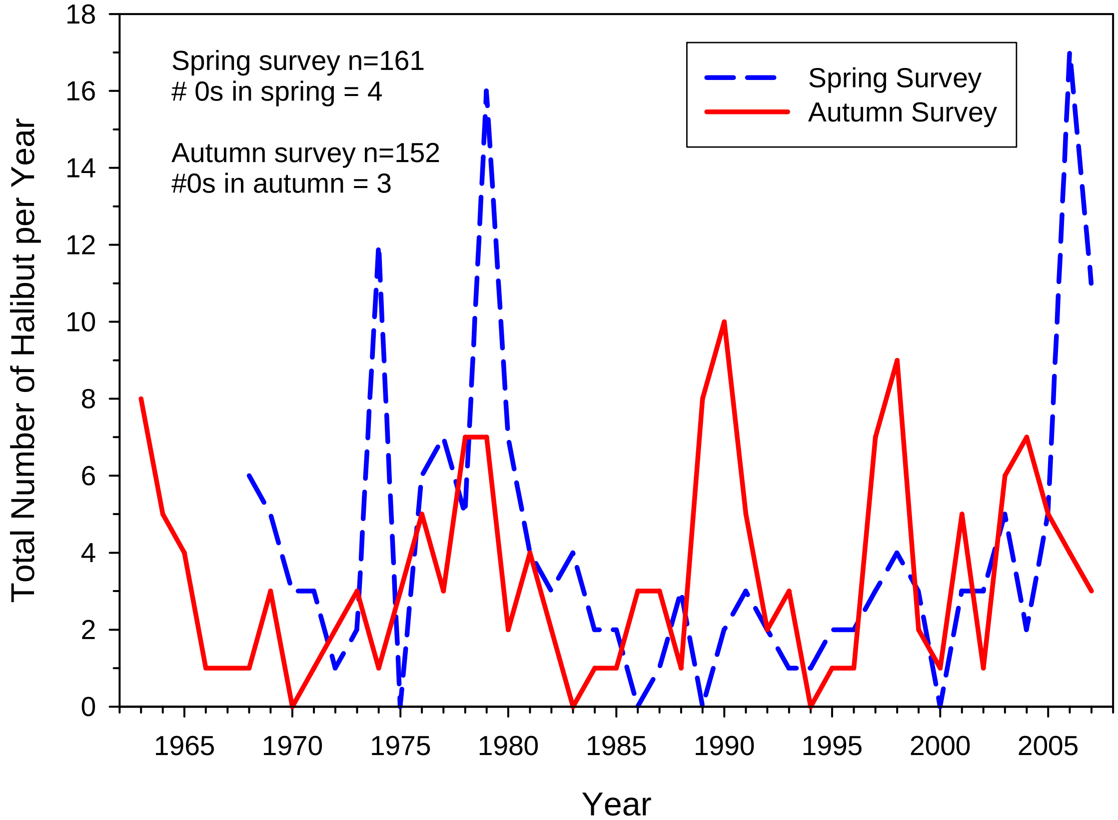

Figure S5. Total numbers of Atlantic halibut caught annually in Northeast Fisheries Science Center spring and autumn surveys.

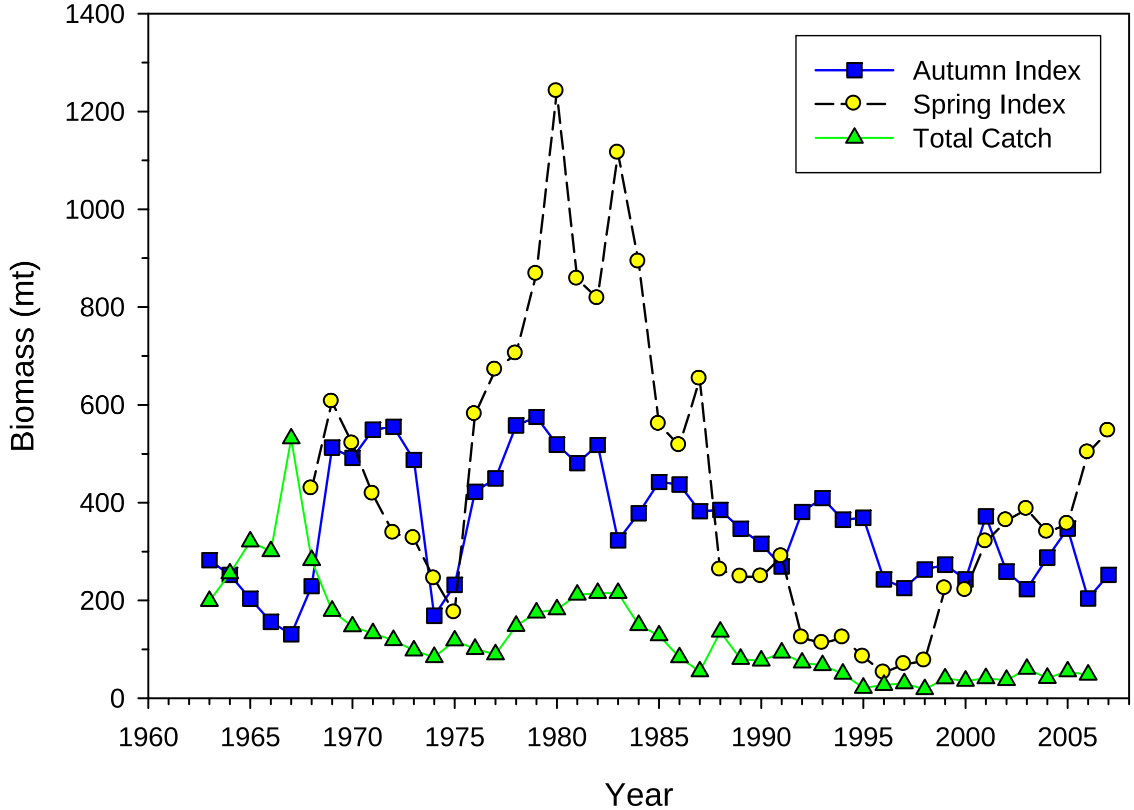

Figure S6. Trends in Atlantic halibut catch from the Gulf of Maine-Georges Bank region and 5-year moving averages of Northeast Fisheries Science Center spring and autumn survey swept-area biomass indices, 1963-2007.

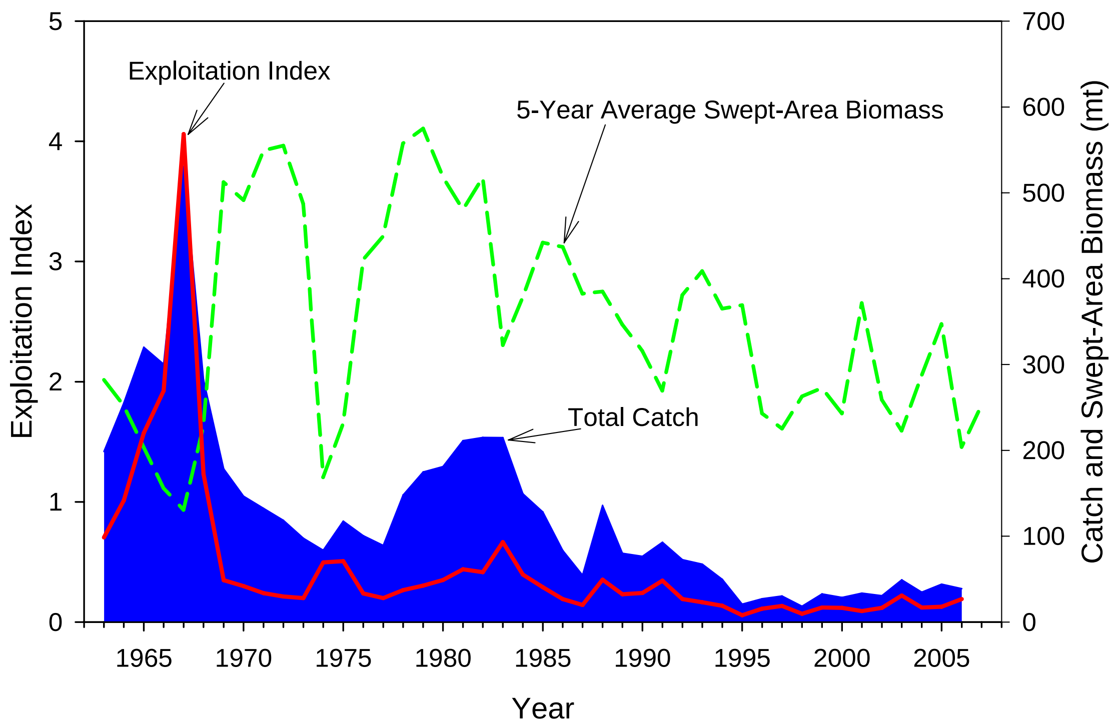

Figure S7. Trends in Atlantic halibut commercial catch, fall stratified swept-area biomass, and exploitation index calculated as annual catch divided by the 5-year moving average of the swept-area biomass index.

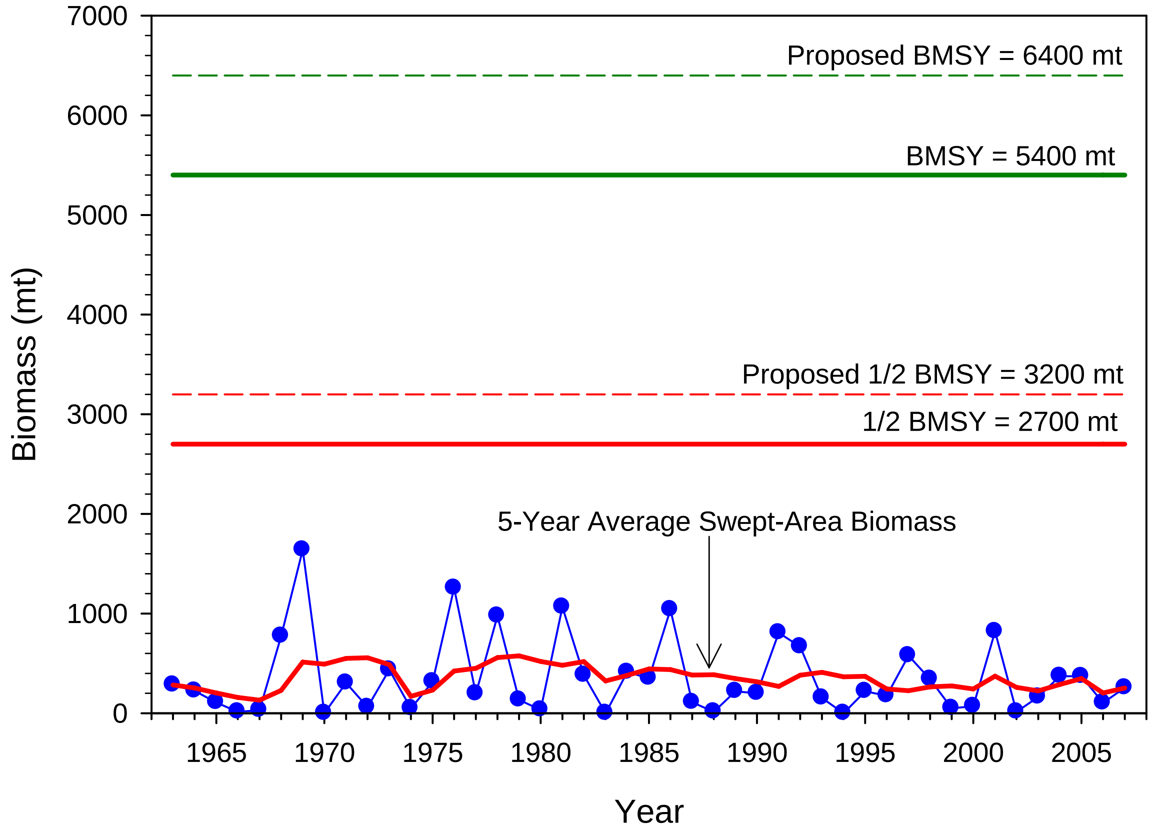

Figure S8. Trends in swept-area biomass indices of Atlantic halibut from Northeast Fisheries Science Center autumn bottom trawl surveys. Proposed reference points based on recent YPR analysis.

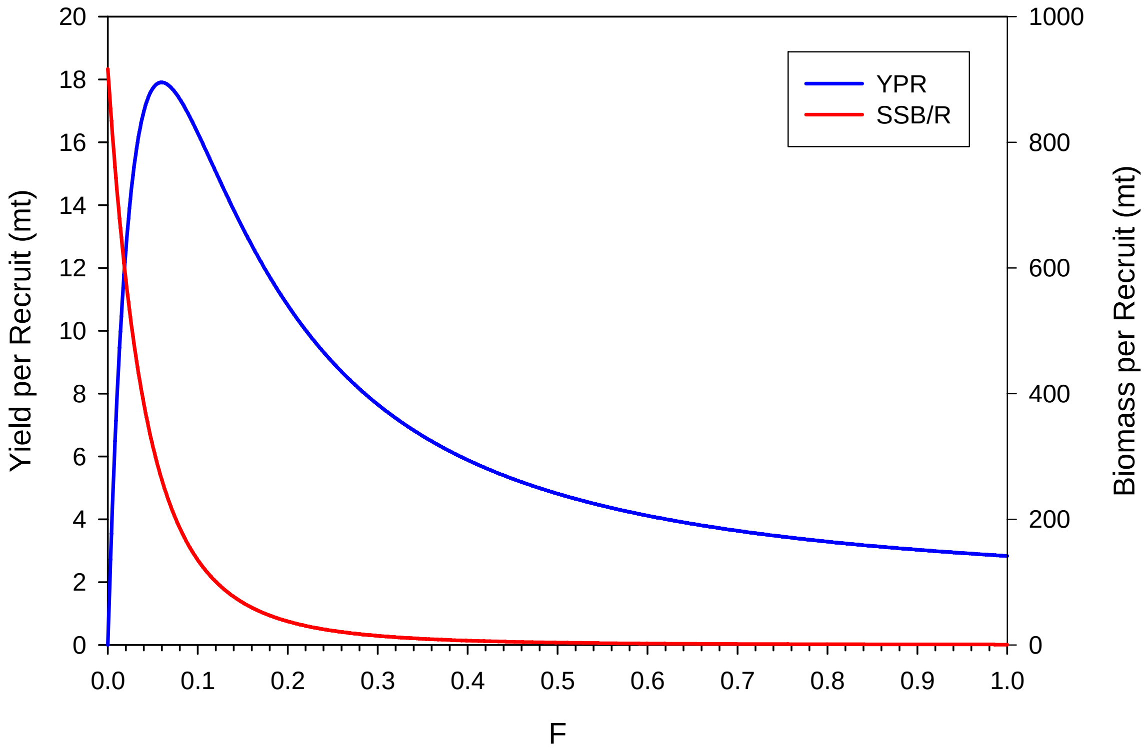

Figure S9. Atlantic halibut Yield per Recruit and Biomass per Recruit

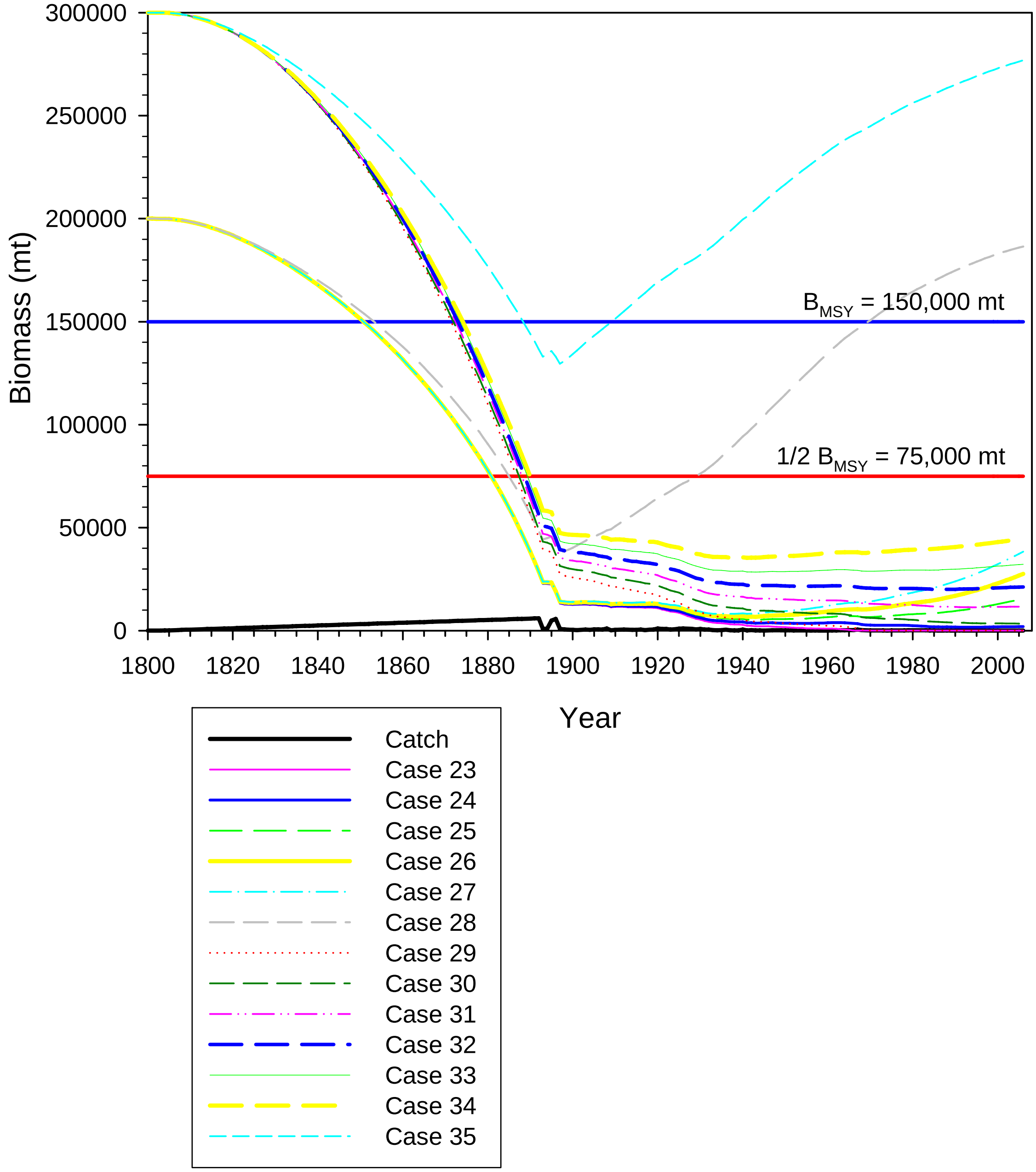

Figure S10. Atlantic halibut biomass from replacement yield model runs with K=300,000 mt and K=200,000 mt. Reference points from case 32.

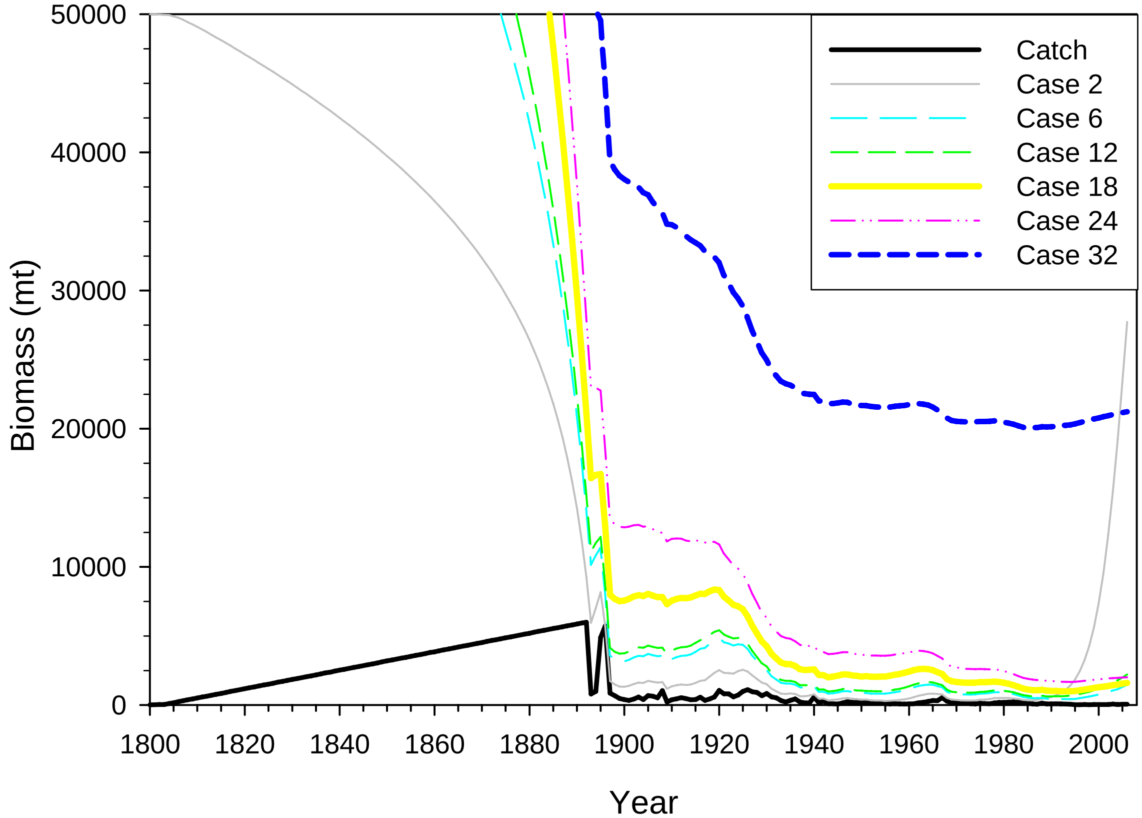

Figure S11. Atlantic halibut biomass output from replacement yield models with the lowest negative log likelihood for each level of carrying capacity.

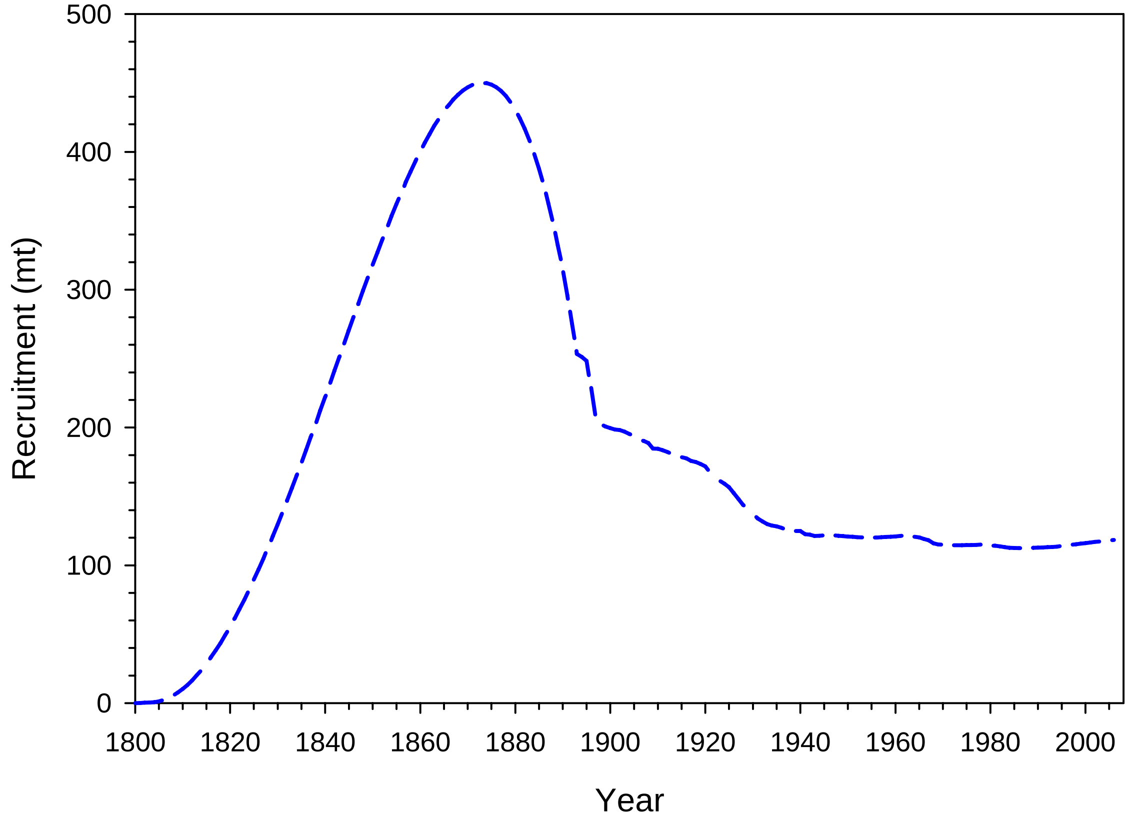

Figure S12. Atlantic halibut recruitment from case 32 of the replacement yield model.

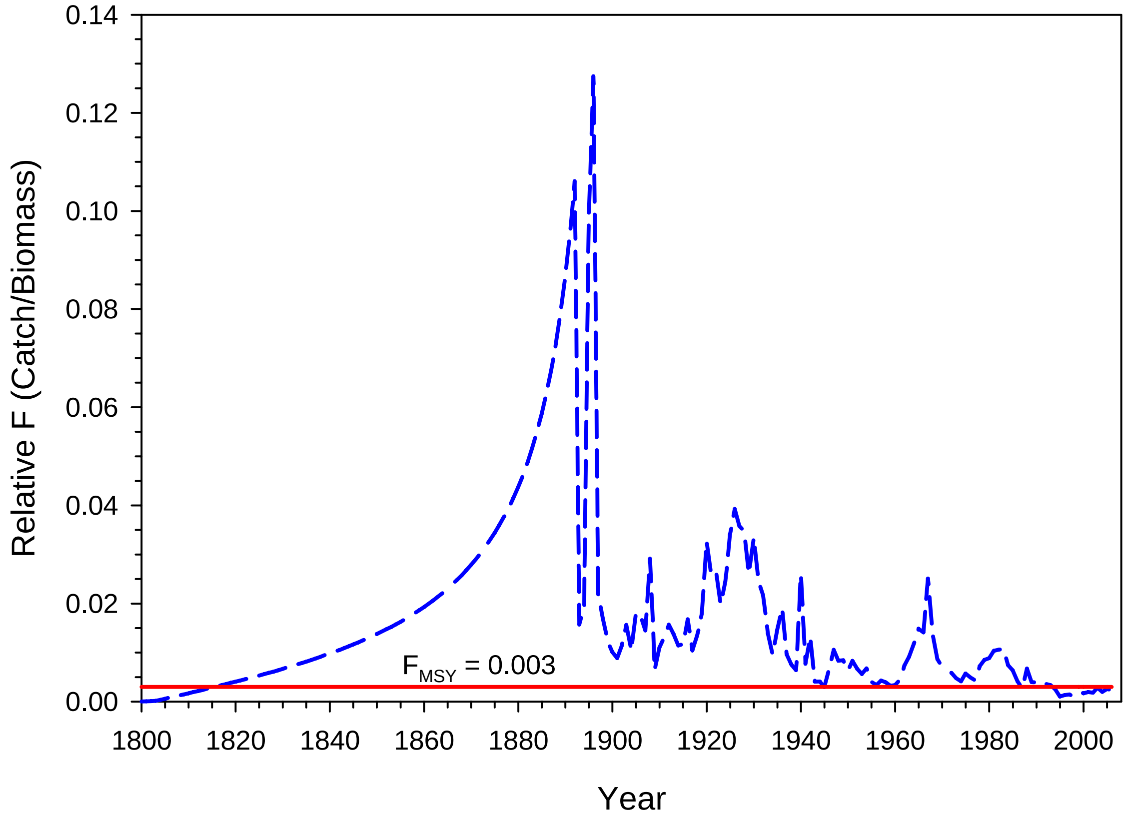

Figure S13. Atlantic halibut relative fishing mortality from case 32 of replacement yield model.