A. ATLANTIC HERRING ASSESSMENT SUMMARY FOR 2012

State of Stock: A statistical catch-at-age model, ASAP (Legault and Restrepo 1999), is proposed as the best scientific information available for determining the stock status for Atlantic herring. Spawning stock biomass (SSB) was estimated to be 517,930 mt in 2011 and fishing mortality rate at age 5 (F) was estimated to be 0.14 (Figure A1). Age 5 was used as the reference age for reporting fishing mortality rates because that age is fully selected in the mobile gear fleet, which accounted for most of the catches in recent years (see Catch and Status Table).

Maximum sustainable yield (MSY) reference points were estimated based on the fit of a Beverton-Holt stock-recruitment curve, which was estimated internally to ASAP. Steepness of the Beverton-Holt curve = 0.53, F_{MSY} = 0.27, SSB_{MSY} = 157,000 mt (½ SSB_{MSY} = 78,500), and MSY = 53,000 mt. Based on a comparison of the MSY reference points with the estimates of F and SSB for 2011, overfishing is not occurring and the stock is not overfished.

Projections: Short-term projections of future stock status were conducted based on the results of the ASAP model. The degree of retrospective error was sufficiently small, and did not warrant adjustment in the projections. Numbers-at-age in 2012 were drawn from 1000 vectors of numbers-at-age produced from MCMC simulations of the ASAP model. The projections assumed that catch in 2012 equaled the annual catch limit. Age-1 recruitment was based on the Beverton-Holt relationship estimated within ASAP. In general, results from several harvest scenarios suggested that overfishing will not occur and the stock will not become overfished through 2015. Results from the status quo catch projection were a notable exception because they resulted in small probabilities that overfishing could occur (Table A1).

Catch and Status Table: Atlantic herring

Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Min[1]	Max[1]	Mean[1]
US Mobile Landings (000s mt)	93	102	94	93	103	81	84	103	67	81	67	124	99
US Fixed Landings (000s mt)	0.05	0.15	0.09	0.07	1.01	0.40	0.03	0.10	1.23	0.42	0.02	4.89	0.63
New Brunswick Weir Landings (000s mt)	12	9	21	13	13	31	6	4	11	4	4	31	15
Discards (000s mt)	0.04	0.03	0.49	0.30	0.20	0.06	0.53	0.46	0.26	0.17	0.03	0.55	0.25
Total Catch (000s mt)	105	111	115	107	117	112	91	108	79	85	79	145	115
Spawning Stock Biomass (000s mt)	433	371	371	410	376	367	385	301	313	518	301	840	468
Recruitment (millions age 1)	17,356	21,101	10,011	7,331	17,023	5,273	13,839	59,412	7,314	5,919	5,273	59,412	15,782
F	0.21	0.24	0.23	0.22	0.25	0.23	0.23	0.32	0.18	0.14	0.14	0.32	0.21

[1]Over the period 1996-2011, which is when natural mortality was increased.

Stock Distribution and Identification: The Gulf of Maine/Georges Bank Atlantic herring complex is composed of several spawning aggregations. Fisheries and research surveys, however, catch fish from a mix of the spawning aggregations and methods to distinguish fish from each aggregation are not yet well established. Consequently, recent assessments have combined data from all areas and conducted a single assessment of the entire complex. Although this approach poses a challenge to optimally managing each stock component and can create retrospective patterns within an assessment, the mixing of the spawning components in the fishery and surveys precludes separate assessments. Atlantic herring caught in the New Brunswick, Canada, weir fishery were considered part of the Gulf of Maine/Georges Bank complex because tagging studies suggested mixing. Herring from the Canadian Scotian Shelf stock also likely mix with the Gulf of Maine/Georges Bank complex, but the degree of mixing is unknown and methods to distinguish fish from each stock are not yet developed. Catches from the Scotian shelf were not considered part of the Gulf of Maine/Georges Bank complex. Despite a single assessment for the entire complex, catch limits are allocated to spatial management areas and catch allocations are based on estimates of stock composition and relative biomass among areas (Correia 2012).

Catches: US catch data were separated into two aggregate gear types, fixed and mobile gears, during 1964-2011. The reported catch is a sum of landings and self-reported discards, but discard estimates have only been available since 1996. Discards, however, were generally less than 1% of landings and do not represent a significant source of mortality (Wigley et al. 2011). Consequently, a lack of historical estimates of discards is not considered problematic to the assessment.

New Brunswick, Canada weir catches were provided for the years 1965-2011. Catches from this fishery were combined with US fixed gear catches for this assessment.

Catch in the US mobile gear fishery peaked in the late 1960s and early 70s, largely due to efforts from foreign fleets (Figure A2). Catch in this fishery has been relatively stable since about 2000 and has accounted for most of the Atlantic herring catches in recent years. Catch in the US fixed gear fishery has been variable, but has been relatively low since the mid-1980s (Figure A2). Catch in the NB weir fishery has also declined since the 1980s (Figure A2).

Total catches during 1964-2011 ranged from 44,613 mt in 1983 to 477,767 mt in 1968. Total catches during the past five years ranged from 79,413 mt in 2010 to 112,462 mt in 2007 and averaged 95,081 mt.

The US mobile gear fishery catches a relatively broad range of ages and some strong cohorts can be seen for several years. In contrast, the US fixed gear fishery and the NB weir fishery harvest almost exclusively age 2 herring.

Data and Assessment: The previous assessment of Atlantic herring used the statistical catch-at-age model ASAP and had a severe retrospective pattern (TRAC 2009). The new 2012 assessment also uses ASAP, but nearly all data inputs and model settings were reconsidered during development. Major changes to the input data are summarized here. Natural mortality during the 2009 TRAC was assumed to equal 0.2 for all ages and years. For this assessment, natural mortality was based on a combination of the Hoenig and Lorenzen methods, with the Hoenig method providing the scale of natural mortality and the Lorenzen method defining how natural mortality declined with age (Hoenig 1983; Lorenzen 1996). The natural mortality rates during 1996-2011 were increased by 50% to resolve a retrospective pattern and to ensure that the implied levels of consumption were consistent with observed increases in estimated consumption of herring. Consumption estimates were based on food habits data primarily for groundfish, but also informed by consumption estimates from marine mammals, highly migratory species, and seabirds. The 2009 TRAC also used catch data combined among all fishing gears and assumed selectivity equaled 1.0 for all ages. This assessment included separate catches and estimated selectivity separately for two aggregate gear types: fixed and mobile gears. This assessment also estimated selectivity for any survey with age composition data, which is in contrast to the 2009 TRAC which used age-specific indices. Finally, maturity at age varied through time in this assessment, but was constant among years in the 2009 TRAC. The time variation in maturity in this assessment was based on annual fits of general additive models to maturity data from males and females collected from commercial catches during July to September.

Abundances (i.e., arithmetic mean numbers per tow) from the NMFS spring, fall, and summer shrimp bottom trawl surveys were used in the assessment model along with annual coefficients of variation and age composition when they were available. The trawl door used on the spring and fall surveys changed in 1985 and likely altered the catchability of the survey gear. Consequently, the spring and fall surveys were split into two time series between 1984 and 1985, and these were treated as separate indices in assessment models. Calibrations were applied to the spring and fall surveys to account for changes in survey methods, including changes in research vessels.

Five other indices of abundance were considered, but not used in the final assessment model. These indices included: NMFS winter survey, NMFS herring acoustic survey, Massachusetts state surveys (spring and fall), joint Maine/New Hampshire state surveys (spring and fall), and a larval index of abundance.

Biological Reference Points (BRPs): Updated MSY reference points were estimated based on the fit to a Beverton-Holt stock-recruitment curve, which was estimated internally to the ASAP model. Steepness of the Beverton-Holt curve = 0.53. For calculating MSY reference points, ASAP used the inputs (e.g., weights at age, M) from the terminal year of the assessment (i.e., 2011). Using inputs from the terminal year of the assessment had the consequence of using natural mortality rates from the period when these rates were increased by 50% (see Data and Assessment). Estimates of MSY BRPs were: F_{MSY} = 0.27, SSB_{MSY} = 157,000 mt (½ SSB_{MSY} = 78,500), and MSY = 53,000 mt.

MSY reference points from the previous assessment (TRAC 2009) were based on the fit of a Fox surplus production model (TRAC 2009), and F_{MSY} = 0.27, SSB_{MSY} = 670,600 mt (½ SSB_{MSY} = 335,300 mt) and MSY = 178,000 mt.

BRPs changed since the previous assessment primarily because the Fox model had been used during the 2009 TRAC and assumed natural mortality rates were revised.

Fishing Mortality: F at age-5 equaled 0.14 in 2011, and was near the all-time low of 0.13 (1994) (Figure A3). F in 2011, however, was not representative of fishing mortality rates in recent years, which averaged 0.23 during 2000-2009 and also showed an increasing trend during those years (Figure A3). Fishing mortality rates in 2010 and 2011 were relatively low due to the presence of a strong cohort which increased the stock biomass (see below). The maximum F over the time series was 0.80 in 1980 (Figure A3).

Biomass: Based on the ASAP model, SSB = 517,930 mt in 2011. Over the entire time series, SSB ranged 53,349 mt in 1978 to 839,710 mt in 1997 (Figure A4). SSB declined during 1997-

2010, but increased in 2011 (Figure A4). Estimated total January 1 biomass was 1,322,446 mt in 2011, and ranged from a minimum of 180,527 mt in 1982 to a maximum of 1,936,769 mt in 2009 (Figure A4). Total biomass and SSB showed similar trends over time, but with 1-2 year lags caused by total biomass being more reflective of immature recruits than SSB. Spawning stock and total biomass increased after 2009, mostly due to the presence of a strong cohort (see below).

Recruitment: With the exception of 2009, age-1 recruitment since 2006 has been below the 1996-2011 average of 15.8 billion fish (Figure A5). The 2009 age-1 recruitment, however, was the largest in the time series at 59.4 billion fish. This large 2009 age-1 cohort consistently appeared in all sources of data that contain age composition.

Special Comments:

- This assessment represents a significant change from previous assessments. Unlike previous assessments, the catch at age was partitioned into mobile and fixed gear fleets and treated separately in a new formulation of the ASAP model. Age-specific and time-varying natural mortality rates were developed. Estimates of herring consumption by a representative suite of predators justified a 50% increase in natural mortality beginning in 1996, which implies a decrease in sustainable yield.
- The assessment was evaluated for uncertainty and robustness to various parameters. The justification for the 50% increase in natural mortality (M) beginning in 1996 was further evaluated using alternative increases of 0%, 30%, 40%, 60%, 70%, and a reduction in the average M among ages in each year from 0.3 (as in the base model) to 0.2. Based on fits to data, degree of retrospective pattern, and general similarity between levels of implied consumption to estimates of consumption, the 50% increase used in the base model was considered appropriate.
- The steepness parameter of the stock-recruitment model was also profiled across a range of values. This profile suggested that the data did not contain much information about the appropriate value for steepness and that subsequent biological reference points were also highly uncertain. For example, over approximate 95% confidence intervals for steepness (0.35-0.85), MSY ranged from 40,000 to 78,000 mt, SSB_{msy} ranged from 73,000 to 277,000 mt, and F_{msy} ranged from 0.12 to 0.7. Stock status in 2011, however, was robust to this uncertainty, with a broad range of comparisons resulting in the conclusion of not overfished and no overfishing ($SSB > ½ SSB_{MSY}$ and $F < F_{msy}$). Only in the extreme case of steepness equal to 0.35, which was considered implausible, would overfishing be occurring. Similarly, sensitivity runs of projections through 2015 based inputs and results of the current assessment, mostly over a range of assumptions about natural mortality, suggested that the probability of the stock being overfished or for overfishing to occur using commonly applied harvest scenarios (e.g., F_{MSY}, MSY) was generally zero.
- The robust nature of stock status was likely driven by the age-1 cohort in 2009, which was estimated to be the largest on record. To test the sensitivity of stock status to the presence of this cohort, projections through 2015 at F_{MSY} were conducted with the size of that cohort cut in half, which made the age-1 2009 cohort approximately equal to previous high recruitments. The probability of the stock being overfished or for overfishing to occur remained at zero. Furthermore, a sensitivity run was conducted with

the variation of the annual recruitments from the underlying Beverton-Holt relationship being more restricted than in the base model (CV in base =1, CV in sensitivity = 0.67). This sensitivity suggested that even with these additional restrictions on recruitment variation, the age-1 2009 cohort would still be the largest on record.

- Natural mortality is an uncertainty in this assessment. Of particular importance is acceptance of the scale of the herring consumption estimates (Figure A6). The 50% increase in natural mortality from the original natural mortality values during 1996-2011 used in the ASAP model was employed to reduce retrospective patterns in SSB and to make implied biomass removals from input natural mortality rates and the consumption data more consistent.
- The reference points and projections were based on the assumption that prevailing conditions would persist, including the relatively high natural mortality rates of 1996-2011. If life history traits such as natural mortality change rapidly, and prevailing conditions become altered, the associated biological reference points and projections would likewise need to be reexamined.
- In the short-term, the 2009 age-1 cohort (2008 year class) may reduce the vulnerability of this stock to overfishing. The strength of large cohorts, however, is often overestimated in the short-term. Consequently, the strength of this cohort should be interpreted cautiously and decisions based on this assessment should consider this uncertainty.
- Recent annual catches have been well above MSY. Consistent with this observation, SSB has declined since 1996 with the exception of recent increases driven by the 2009 age-1 cohort. The reference points (e.g., MSY), however, are uncertain.

References:

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Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin 82(1): 898-903.

Legault, C. M., and V. R. Restrepo. 1999. A flexible forward age-structured assessment program. ICCAT Coll. Vol. Sci. Pap. 49(2): 246-253.

Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. Journal of Fish Biology 49: 627-647.

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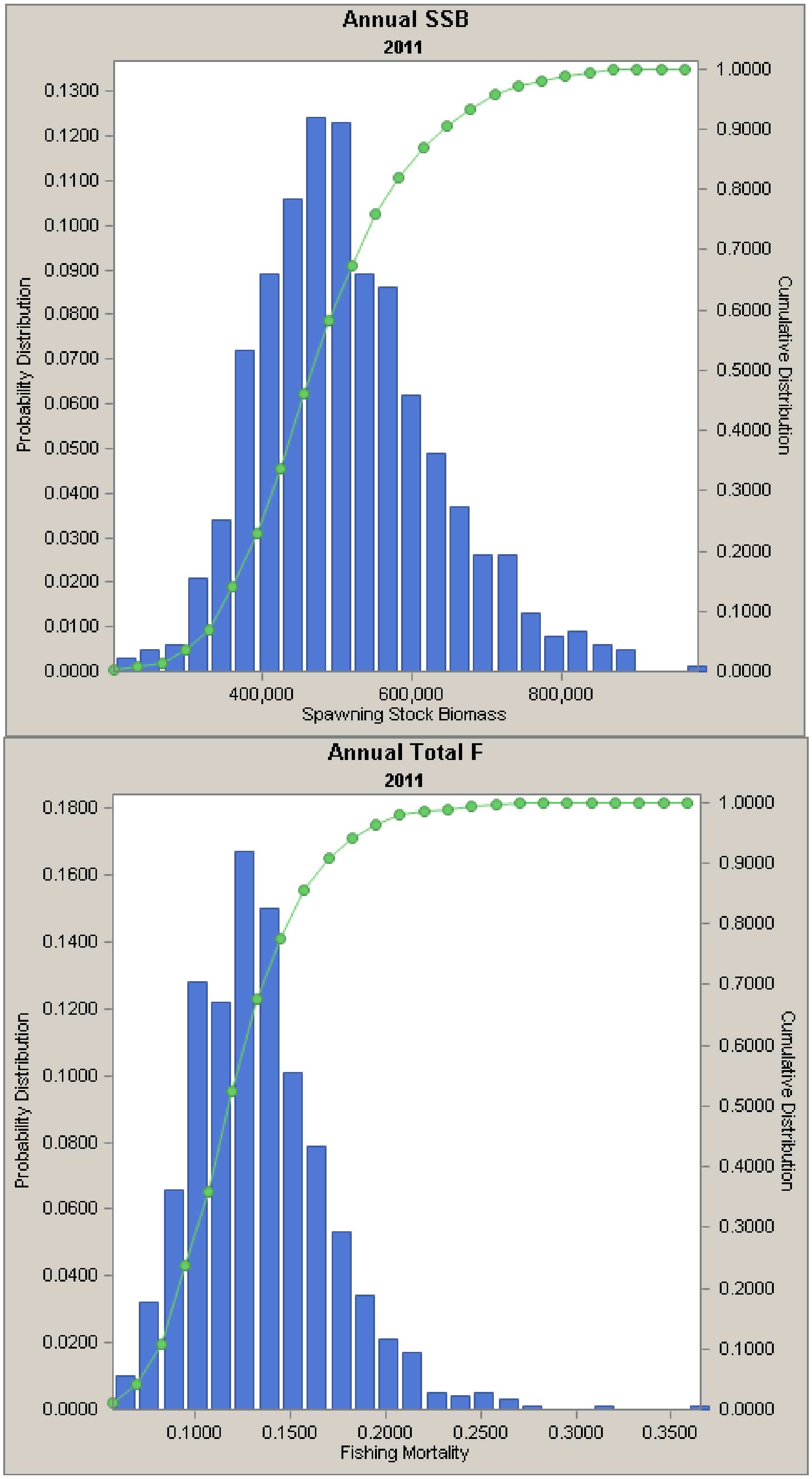
Wigley, S.E., J. Blaylock, P.J. Rago, J. Tang, H.L. Haas, and G. Shield. 2011. Standardized bycatch reporting methodology 3-year review report – 2011 Part 1. Northeast Fisheries Science Center Reference Document 11-09.

A. Atlantic Herring – Tables

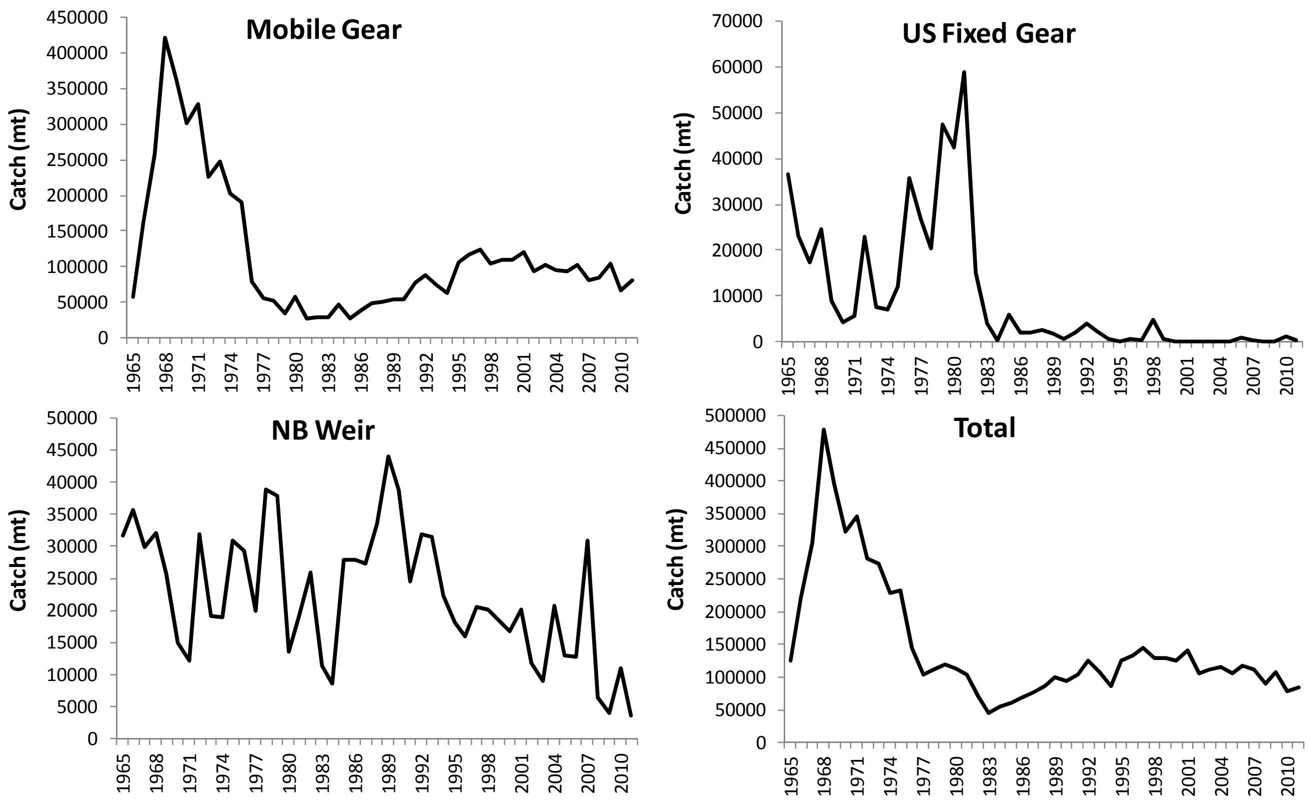
Table A1. Results of three-year Atlantic herring projections for the base ASAP model.

Fmsy = 0.267	SSBmsy = 157,000 mt	steepness = 0.53	MSY = 53,000 mt
2011 F (age 5)	SSB 2011		2011 catch
0.14	518,000 mt		85,000 mt
2012 catch = 87,683 mt (quota)			
	2013	**2014**	**2015**
	F_{msy}		
F	0.267	0.267	0.267
SSB	496,064 mt	368,501 mt	308,949 mt
80% CI	362,965 - 688,585 mt	275,695 - 517-815 mt	237,755 - 411,808 mt
Prob < SSBmsy/2	0	0	0
catch	168,775 mt	126,589 mt	104,430 mt
80% CI	124,868 - 230,764 mt	95,835 - 171,145 mt	79,505 - 139,925 mt
	$F_{75\%\ msy}$		
F	0.2	0.2	0.2
SSB	523,243 mt	409,309 mt	354,559 mt
80% CI	382,573 - 723,975 mt	306,011 - 574,128 mt	272,751 - 473,021 mt
Prob < SSBmsy/2	0	0	0
catch	130,025 mt	102,470 mt	87,574 mt
80% CI	96,216 - 177,894 mt	77,476 - 138,665 mt	66,739 - 117,318 mt
	$F_{status\ quo}$		
F	0.14	0.14	0.14
SSB	548,788 mt	450,496 mt	402,551 mt
80% CI	401,571 - 760,028 mt	336,594 - 631,502 mt	309,334 - 537,414 mt
Prob < SSBmsy/2	0	0	0
catch	93,159 mt	76,823 mt	67,912 mt
80% CI	68,954 - 127,518 mt	58,022 - 104,055 mt	51,752 - 91,001 mt
	MSY		
F	0.08	0.09	0.1
80% CI	0.06 - 0.11	0.07 - 0.12	0.07 - 0.14
Prob > Fmsy	0	0	0
SSB	576,092 mt	492,162 mt	448,725 mt
80% CI	413,046 - 813,298 mt	351,530 - 716,931 mt	321,209 - 633,132 mt
Prob < SSBmsy/2	0	0	0
catch	53,000 mt	53,000 mt	53,000 mt
	Status quo catch		
F	0.13	0.16	0.19
80% CI	0.1 - 0.18	0.11 - 0.23	0.13 - 0.27
Prob > Fmsy	1%	4%	10%
SSB	551,686 mt	446,496 mt	385,995 mt
80% CI	388,989 - 789,568 mt	306,349 - 669,721 mt	259,178 - 569,560 mt
Prob < SSBmsy/2	0	0	0
2012 quota	87,683 mt	87,683 mt	87,683 mt

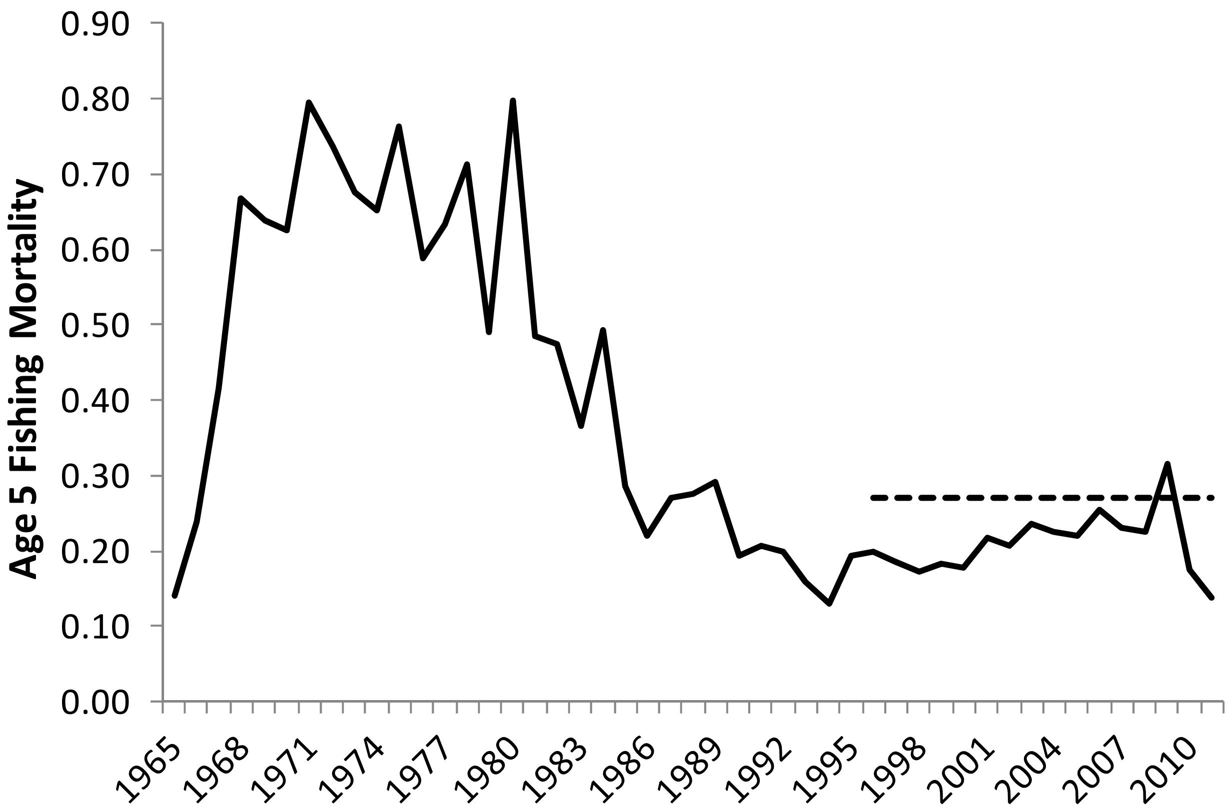
A. Atlantic Herring – Figures



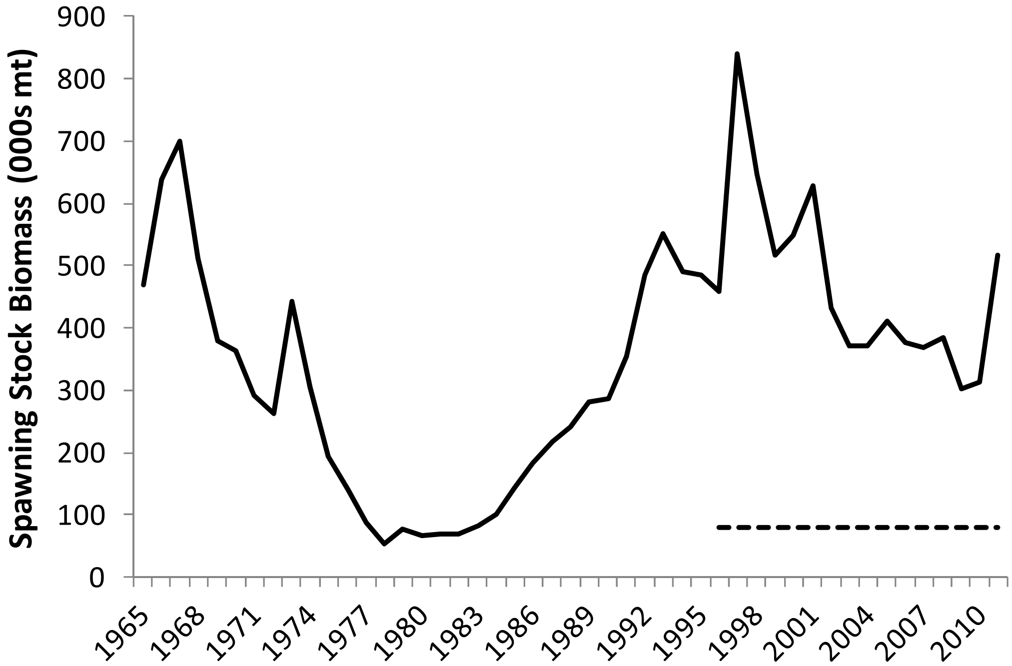
A1. Posterior densities of Atlantic herring SSB and F in 2011 from the ASAP base run.

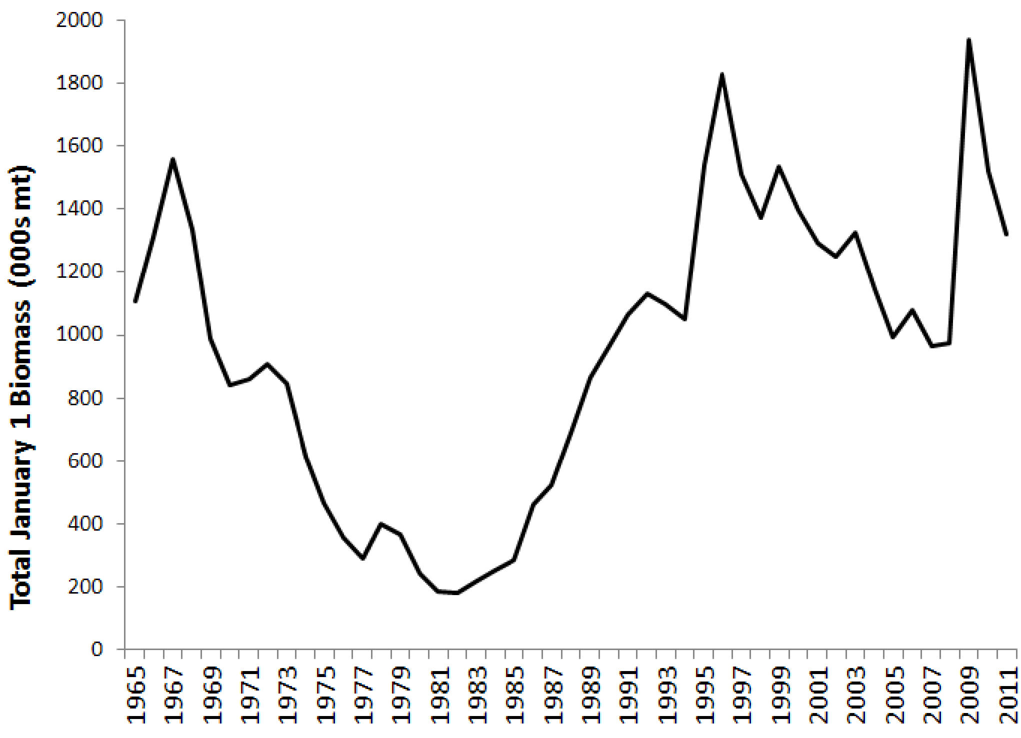


A2. Atlantic herring catch (mt) during 1965-2011 for US mobile gears, US fixed gears, NB weir fishery, and total catch. Discards estimates were only available since 1996.

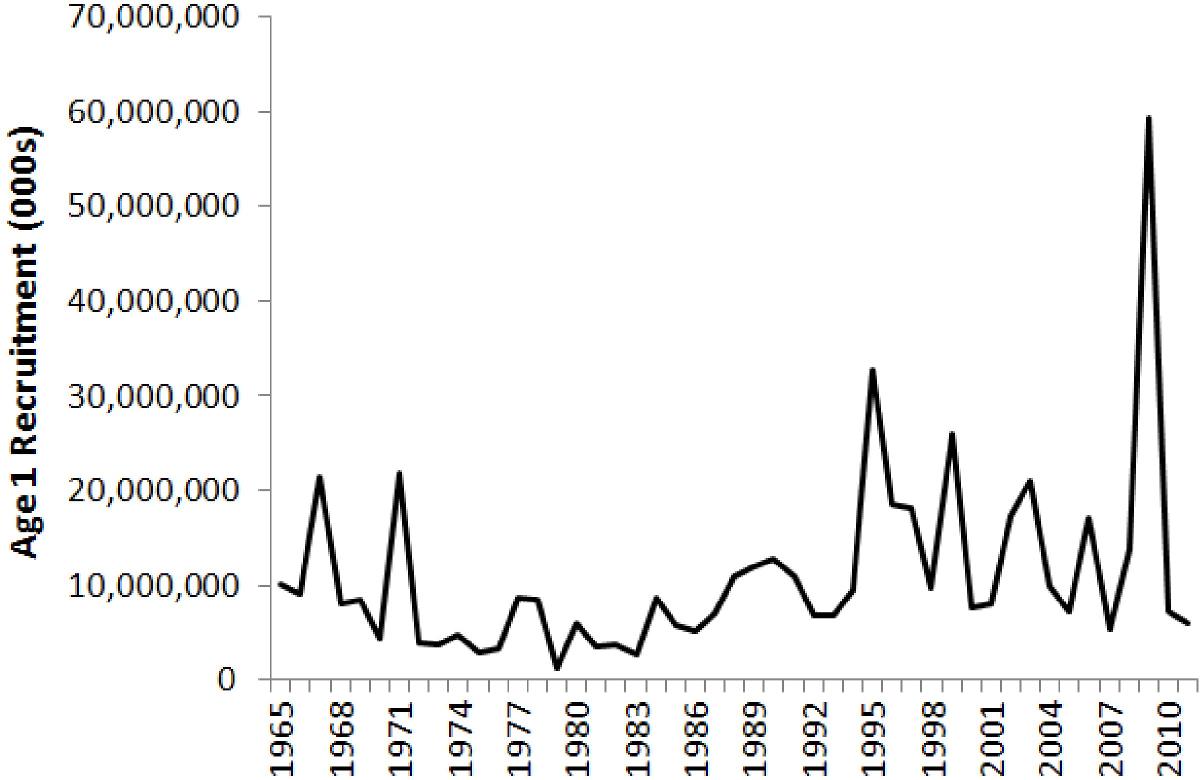


A3. Atlantic herring age-5 fishing mortality (solid line) and F_{MSY} (dashed line) estimated from the ASAP model base run. The F_{MSY} reference line is only provided during 1996-2011 because the reference point from this assessment is only for this time period.

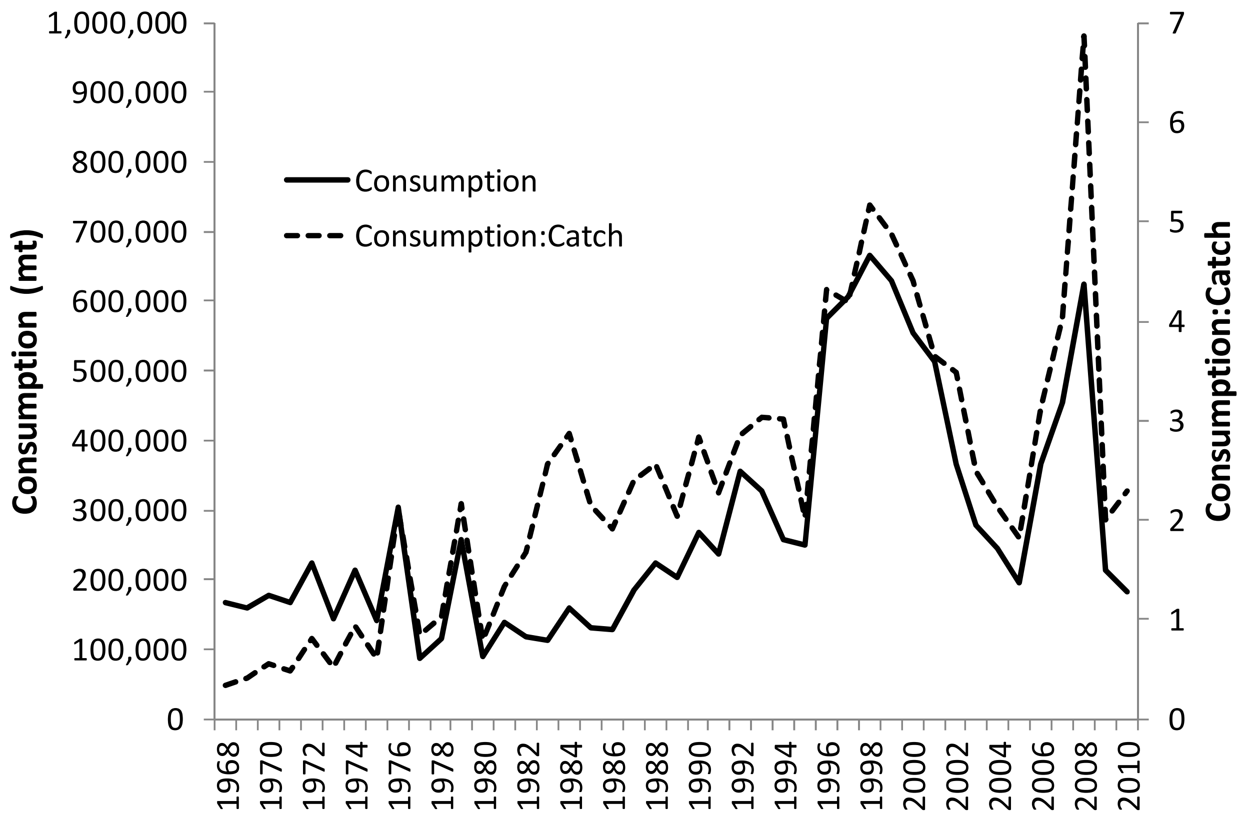




A4. Atlantic herring spawning stock biomass (000s MT; solid line; top panel), ½ SSB_{MSY} (dashed line; top panel), and total biomass (000s MT; bottom panel) time series estimated from the ASAP base run. The ½ SSB_{MSY} reference line is shown for 1996-2011 because the reference point from this assessment is only for this time period.



A5. Atlantic herring age-1 recruitment (000s) over time, estimated from the ASAP model base run.



A6. Consumption of Atlantic herring by groundfish species, marine mammals, highly migratory species and seabirds (solid line). Also shown, the ratio of consumption to fishery catch (dashed line), 1968-2010.