A. GULF OF MAINE HADDOCK ASSESSMENT SUMMARY FOR 2014

State of Stock: The Gulf of Maine haddock (*Melanogrammus aeglefinus*) stock is not overfished and overfishing is not occurring in 2013 (Figure A1). Spawning stock biomass (SSB) in 2013 is estimated to be 4,153 mt which is 101% of the SSB_{MSY} proxy (4,108 mt) (Figure A2). The 2013 fully selected fishing mortality is estimated to be 0.39 which is below the F_{MSY} proxy (0.46) (Figure A3).

Projections: The short-term projection method samples future recruitment from a cumulative density function derived from ASAP estimated age-1 recruitment between 1977 and 2011. Age-1 recruitments in 2012 and 2013 were not included in the cumulative density function due to their greater variance. No retrospective adjustment needed to be applied in the projections. Due to the high uncertainty of the size of the 2012 year class, two projection models were developed. The first is based on the final population model and the second is based on a sensitivity model that constrained the size of the 2012 year class (Table A1). Both projection models were run under two different assumptions of calendar year 2014 catch – harvest at FMSY (0.46) and an assumed 2014 catch of 500 mt. The fishing year 2014 Gulf of Maine haddock Annual Catch Limit (ACL) is set at 323 mt, though the ACL does not account for recreational discards. The 500 mt estimate used in the projections was informed by the fishing year 2014 ACL and recent recreational discard amounts.

Catch and Status Table: Gulf of Maine Haddock
(weights in 000s mt, recruitment in millions, arithmetic means)

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Min[1]	Mean[1]	Max[1]
Commercial landings	0.95	0.98	0.62	0.68	0.54	0.50	0.62	0.50	0.42	0.21	0.12	1.54	6.32
Commercial discards	0.01	0.02	0.03	0.05	0.01	0.01	0.00	0.01	0.02	0.03	0.00	0.03	0.38
Recreational landings	0.31	0.54	0.45	0.57	0.54	0.41	0.31	0.23	0.25	0.24	0.00	0.15	0.57
Recreational discards[2]	0.04	0.04	0.07	0.05	0.07	0.02	0.02	0.01	0.05	0.21	0.00	0.03	0.21
Catch used in assessment	1.31	1.58	1.17	1.34	1.16	0.95	0.96	0.74	0.74	0.69	0.19	1.93	7.66
Spawning stock biomass	9.64	8.10	7.44	6.43	5.46	4.77	3.90	3.06	2.96	4.15	0.60	6.18	15.18
F_{full}[3]	0.19	0.29	0.24	0.37	0.34	0.29	0.36	0.34	0.49	0.39	0.19	0.59	1.54
Recruitment (age 1)	6.28	0.39	1.12	1.22	0.22	0.30	0.97	6.66	2.09	16.57	0.13	2.65	16.6

[1] Years 1977-2013
[2] Recreational discard amounts shown reflect assumption of 50% mortality
[3] F_{full} is the fishing mortality on fully selected ages

Stock Distribution and Identification: Haddock (*Melanogrammus aeglefinus*) is a demersal gadoid species whose range in United States (US) waters extends from the mid-Atlantic Bight north to the Canadian border. Within the United States Exclusive Economic Zone (EEZ) there are two recognized stocks of haddock: Gulf of Maine and Georges Bank. The current Gulf of Maine management unit extends from the northern tip of Cape Cod east to the US/Canadian border and north to the coast of Maine (Figure A4).

Recent reviews of historical and contemporary tagging studies suggest that there is movement of fish between the Gulf of Maine and Georges Bank stocks, though there is considerable uncertainty

regarding the degree of mixing. Several lines of evidence examined during the SAW/SARC59 assessment indicate that annual percent mixing from Georges Bank to the Gulf of Maine is low. While low mixing considered in the models amongst the stocks has limited impacts on current stock status, catch projections for Gulf of Maine haddock were found to be sensitive to the possibility of low movement both in terms of the amount of catch (Figure A5) and the risk to the stock if the wrong mixing rate is assumed.

Catches: Since 1977, fishery removals of Gulf of Maine haddock have ranged from 187 mt to 7,656 mt. Fishery removals over the past five years have ranged from 692 mt to 958 mt. Prior to 1989 there are no direct estimates of commercial discards but discards were hindcast back to 1982 by gear. Prior to 1981 there are no direct estimates of recreational removals and no attempt was made to hindcast recreational catch pre-1981. Over the assessment time series, commercial landings have been the dominant source of fishery removals, constituting 30-100% of the total catch. Commercial discards have been a small component of fishery removals with the exception of a period between 1993 and 1997 when trip limits were 1,000 lb or less. Recreational catch (landings plus discards) has varied annually from a low of 39 mt in 1981 to a high of 618 mt in 2007. Recreational catches have constituted between <1% and 65% of total annual removals, averaging 17% over the 1977-2013 period (Figure A6). The recreational proportion of the total catch has increased in recent years.

Data and assessment: The previous benchmark assessment (i.e., NEFSC 2008) of Gulf of Maine haddock was conducted using a virtual population analysis model (ADAPT-VPA) that incorporated commercial landings and discards as well as recreational landings but not recreational discards. For this assessment, catch-at-age was re-estimated owing to minor modifications to the commercial and recreational catch estimation methodologies. The updates had only minor impacts on the estimated catch-at-age.

For SAW/SARC59, the assessment was conducted using the statistical catch-at-age model, ASAP. The catch inputs included landings and discards from both the commercial and recreational fleets. Trawl gear is the primary mode of capture in the commercial fishery, and as such, commercial discards were assumed to suffer 100% mortality. The recreational discard mortality was assumed to be 50%, though model results were relatively insensitive to alternate assumptions. Fishery removals were modeled as a single fleet, though model sensitivities which explored separate commercial and recreational fleets indicated that the model results were robust to this configuration.

Swept-area estimates of abundance from the NEFSC spring and autumn surveys (1977-2013) were used in the ASAP model along with associated estimates of uncertainty and annual age composition. Current survey indices are at, or near, time series highs (Figure A7) owing to the presence of several strong year classes.

The updated model used three fishery selectivity time blocks and allowed fishery selectivity to be freely estimated at age. Estimated selectivities were similar across time blocks, with the age 5 fish being 50% selected. Selectivity was estimated to be flat-topped in the two earlier time blocks, though there was slight doming in the final block. The model assumed flat-topped selectivity for the

NEFSC survey indices; model results were robust to this assumption.

The size of the potentially large 2012 year class is the largest source of uncertainty in this stock assessment, owing to the fact that the estimate is based on only two surveys. Model sensitivities were explored to evaluate the effects of constraining the size of the 2012 year class. The final base model (ASAP_final_temp10) applies equal constraint to all recruitment estimates. In addition, a sensitivity run placed additional constraint on the estimation of the 2012 year class to illustrate the impacts of this uncertainty on catch projections (Table A1).

Biological Reference Points: Like many haddock stocks, recruitment of Gulf of Maine haddock is highly episodic and not well described by traditional stock recruitment relationships. Given this, an MSY proxy was used for reference points. $F_{40\%}$ is the proxy used for the overfishing threshold (F_{MSY}). This is consistent with the choice of proxy in the previous assessment. A deterministic value of $F_{40\%}$ was calculated from a spawner-per-recruit analysis using 2009-2013 average SSB weights, catch weights, selectivity and maturity. Expressed as a fully selected fishing mortality, $F_{40\%}$ is 0.46.

Stochastic projections at $F_{40\%}$ were used to determine new recommended biomass-related reference points (proxies for both SSB_{MSY} and MSY). The projection methodology used to determine SSB_{MSY} and MSY proxies was identical to those used for short-term projections.

Recruitment series	F_{MSY} (proxy)	Fmsy	SSB_{MSY} (mt)	MSY (mt)	Median age1 recruitment (000s)
1977-2011	$F_{40\%}$	0.46 (0.36 - 0.54)	4,108 (1,774 - 7,861)	955 (421 - 1,807)	1,121

Intervals shown are the 5th and 95th percentiles.

The overfished biomass threshold is ½ SSB_{MSY}.

The biological reference points estimated in the previous assessment which used a VPA model (NEFSC 2012) were $F_{MSY}=F_{40\%}=0.46$, $SSB_{MSY}=4{,}904$ mt, and MSY=1,177 mt.

Fishing Mortality: The lowest estimate of fully selected fishing mortality (F_{full}) over the assessment time series is 0.19 (2004). The 2013 F_{full} is 0.39 (90% posterior probability interval 0.24 – 0.60) which is lower than the time series average of 0.59 and the current F_{MSY} proxy of 0.46 (Figure A3).

Biomass: The estimate of 2013 spawning stock biomass (SSB) is 4,153 mt (90% posterior probability interval 2,960 – 6,043 mt). The estimate of 2013 spawning stock biomass is below the time series mean of 6,180 mt, but above the SSB_{MSY} proxy of 4,108 mt (Figure A2).

Recruitment: Recruitment patterns of Gulf of Maine haddock are highly episodic, a feature common among many haddock stocks. Several moderate to strong year classes have been spawned

in the last fifteen years, including the 1998, 2003, 2010 and most recently, the 2012 year class (Figure A8). The absolute size of the 2012 year class is highly uncertain as the estimate is based on only two surveys.

Special Comments:

- The change in stock status from the 2012 update (i.e., not overfished but approaching an overfished condition and overfishing occurring) to the current evaluation of not overfished and no overfishing is due primarily to the addition of three more years of fishery and survey data. The final assessment model updated with this new information indicates that the change in status is driven by the estimate of the very strong 2010 year class, which is estimated to be 6.7 million age-1 fish.

- The absolute size of the potentially strong 2012 year class is the largest source of uncertainty in this assessment. Based on the estimated selectivity patterns, this year class is predicted to be 50% selected by the fishery in 2017 at age 5. Recent changes to the commercial minimum retention size may result in this year class recruiting to the fishery sooner. Catch projections for 2015 reflecting a likely range of the 2012 year class size indicate that the catches vary from 1,271 to 1,871 mt (Table A1) dependent on the assumed strength of this year class and the magnitude of the 2014 catch. Given the high uncertainty with respect to this year class size, the assessment should be updated if future estimates of its size differ significantly from those used in this assessment.

- Stock structure cannot be specified conclusively with available information. If concerns remain, biological analyses such as directed tagging studies, egg dispersal modeling, genetic differentiation, or otolith microchemistry analysis would be needed to estimate the degree of mixing.

- This assessment has assumed a 50% mortality rate of recreational discards. While the assessment results were shown to be relatively insensitive to this assumption, it does have implications for management and catch allocation between the commercial and recreational fleets. Experimental work is needed to reduce the uncertainty of this 50% mortality assumption. The 2012 year class is expected to become available to the recreational fishery in 2015. Given the minimum landing size, those fish would be expected to be discarded.

- Weights at age of older fish declined between the early 1990s and the mid-2000s, but have since stabilized. The SARC 59 was unable to predict whether weights at age would change in the future, and recommends that this be monitored.

References:

Northeast Fisheries Science Center (NEFSC). 2008. Assessment of 19 Northeast Groundfish Stocks through 2007: Report of the 3rd Groundfish Assessment Review Meeting (GARM III), Northeast Fisheries Science Center, Woods Hole, Massachusetts, August 4-8, 2008. US Dep Commer, NOAA Fisheries, Northeast Fish Sci Cent Ref Doc. 08-15; 884 p + xvii.

Northeast Fisheries Science Center (NEFSC). 2012. Assessment or Data Updates of 13 Northeast Groundfish Stocks through 2010. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 12-06; 789 p.

Northeast Fisheries Science Center (NEFSC). In prep. Stock Assessment of Gulf of Maine Haddock. 59th Northeast Stock Assessment Workshop.

Table A1. Short-term projections of total fishery yield and spawning stock biomass for Gulf of Maine haddock based on a harvest scenario of a) fishing at $F_{40\%}$ between 2014 and 2017 and b) an assumed catch of 500 mt in 2014 and fishing at $F_{40\%}$ between 2015 and 2017. Projections are shown based on two different population models to highlight the sensitivity of catch projections to the size of the 2012 year class. Projection results are shown for the base ASAP model (upper table: ASAP_final_temp10) and a sensitivity model that constrains the size of the terminal year class (lower table: ASAP_final_temp11). Confidence intervals in parentheses are 90% intervals.

		ASAP_final_temp10 (1977-2011 recruitment)						
Year	**Input**	**Catch (mt)**		**Spawning stock biomass (mt)**		**Harvest strategy**	**F_{full}**	
2013	Catch input/model result	692		4,153	(2,690 - 6,043)		0.39	(0.24 - 0.60)
2014	Projection	1,085	(713 - 1,605)	6,341	(4,272 - 9,237)	$F_{40\%}$	0.46	
2015	Projection	1,752	(1,140 - 2,633)	10,014	(6,556 - 15,250)	$F_{40\%}$	0.46	
2016	Projection	2,085	(1,367 - 3,181)	10,844	(7,036 - 16,645)	$F_{40\%}$	0.46	
2017	Projection	2,424	(1,567 - 3,755)	9,808	(6,355 - 14,914)	$F_{40\%}$	0.46	
2013	Catch input/model result	692		4,153	(2,690 - 6,043)		0.39	(0.24 - 0.60)
2014	Imputed catch	500		6,472	(4,328 - 9,473)		0.20	(0.13 - 0.31)
2015	Projection	1,871	(1,189 - 2,848)	10,507	(6,788 - 16,090)	$F_{40\%}$	0.46	
2016	Projection	2,189	(1,409 - 3,369)	11,223	(7,223 - 17,291)	$F_{40\%}$	0.46	
2017	Projection	2,512	(1,607 - 3,896)	10,078	(6,487 - 15,332)	$F_{40\%}$	0.46	

		ASAP_final_temp11 (1977-2011 recruitment)						
Year	**Input**	**Catch (mt)**		**Spawning stock biomass (mt)**		**Harvest strategy**	**F_{full}**	
2013	Catch input/model result	692		3,643	(2,500 - 5,089)		0.43	(0.28 - 0.67)
2014	Projection	870	(563 - 1,276)	4,961	(3,323 - 7,036)	$F_{40\%}$	0.46	
2015	Projection	1,271	(843 - 1,850)	6,833	(4,620 - 9,805)	$F_{40\%}$	0.46	
2016	Projection	1,456	(989 - 2,104)	7,148	(4,869 - 10,253)	$F_{40\%}$	0.46	
2017	Projection	1,620	(1,099 - 2,376)	6,568	(4,459 - 9,719)	$F_{40\%}$	0.46	
2013	Catch input/model result	692		3,643	(2,500 - 5,089)		0.43	(0.28 - 0.67)
2014	Imputed catch	500		5,050	(3,345 - 7,213)		0.25	(0.17 - 0.40)
2015	Projection	1,350	(863 - 2,011)	7,154	(4,698 - 10,401)	$F_{40\%}$	0.46	
2016	Projection	1,524	(1,004 - 2,239)	7,388	(4,947 - 10,679)	$F_{40\%}$	0.46	
2017	Projection	1,674	(1,113 - 2,473)	6,739	(4,525 - 9,986)	$F_{40\%}$	0.46	

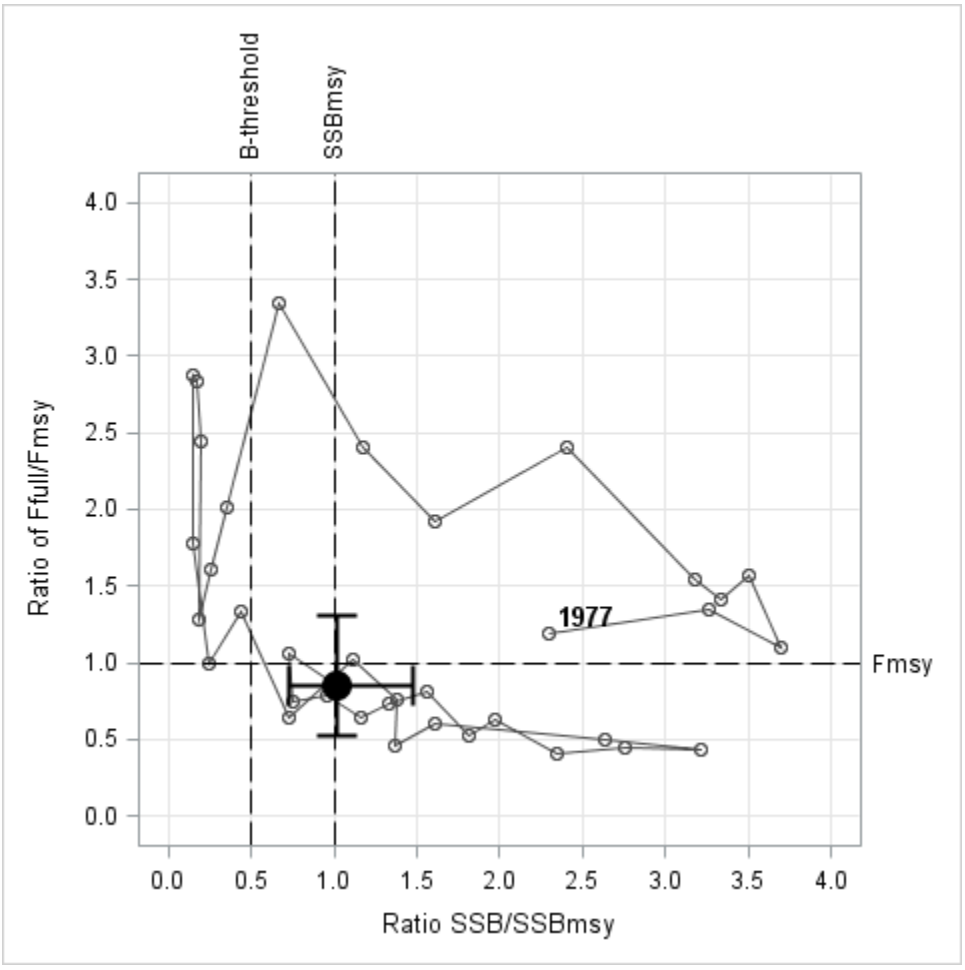

Figure A1. Time series plot of the Gulf of Maine haddock fully selected fishing mortality/F_{MSY} ratio relative to the spawning stock biomass/ SSB_{MSY} ratio from 1977 to 2013. The current stock status is indicated with a solid black circle along with the corresponding 90% confidence intervals.

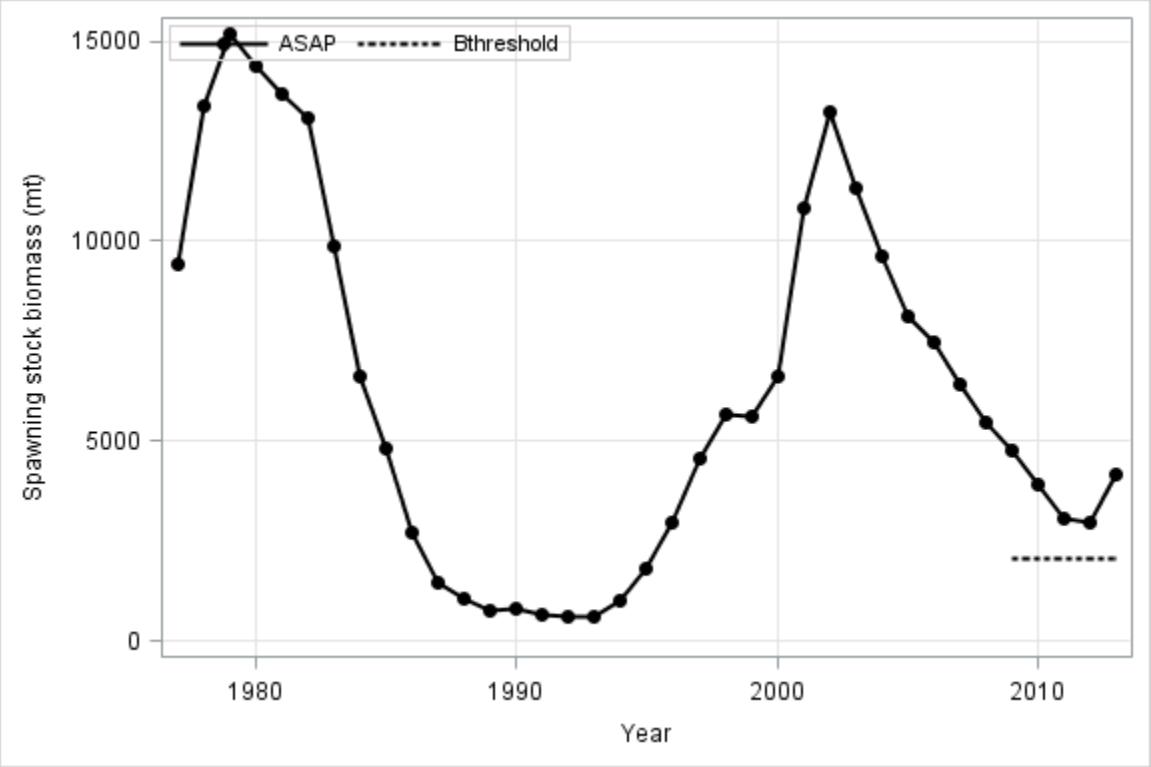

Figure A2. Estimated trends in the spawning stock biomass of Gulf of Maine haddock between 1977 and 2013 and the corresponding $B_{threshold}$ (1/2 SSB_{MSY}) based on the 2014 assessment.

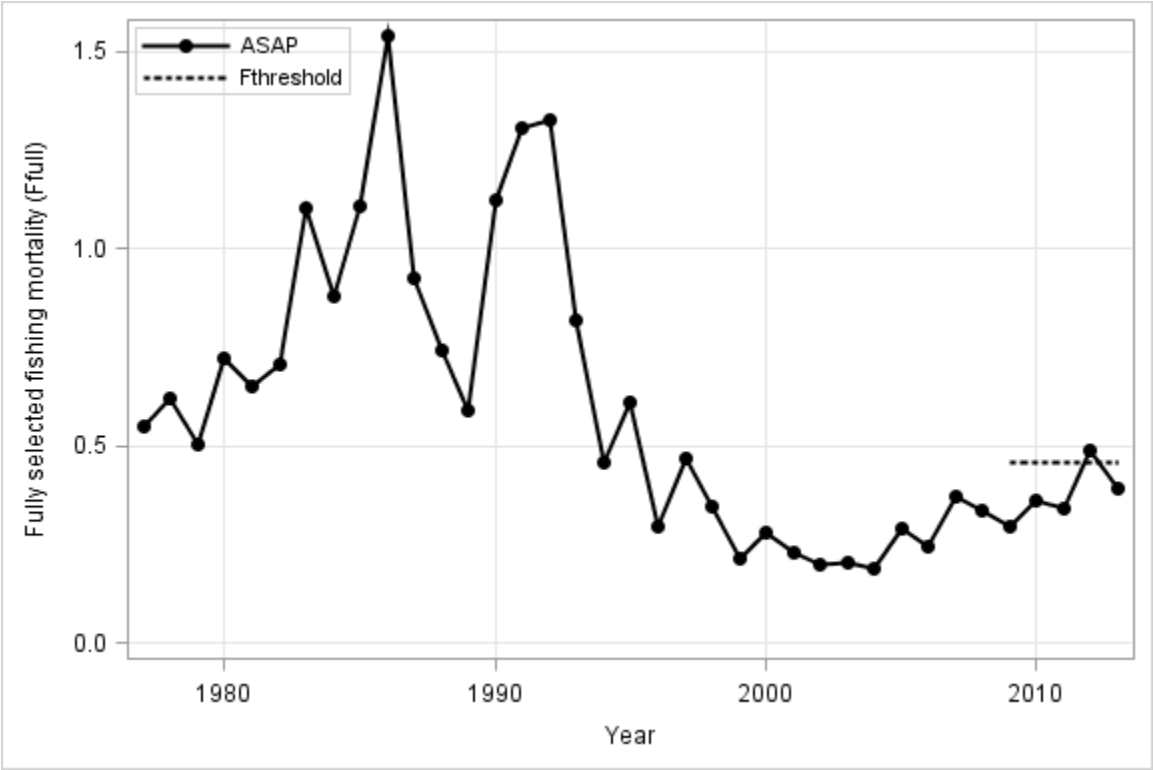

Figure A3. Estimated trends in the fully selected fishing mortality (F_{full}) of Gulf of Maine haddock between 1977 and 2013, and the corresponding F_{MSY} based on the 2014 assessment.

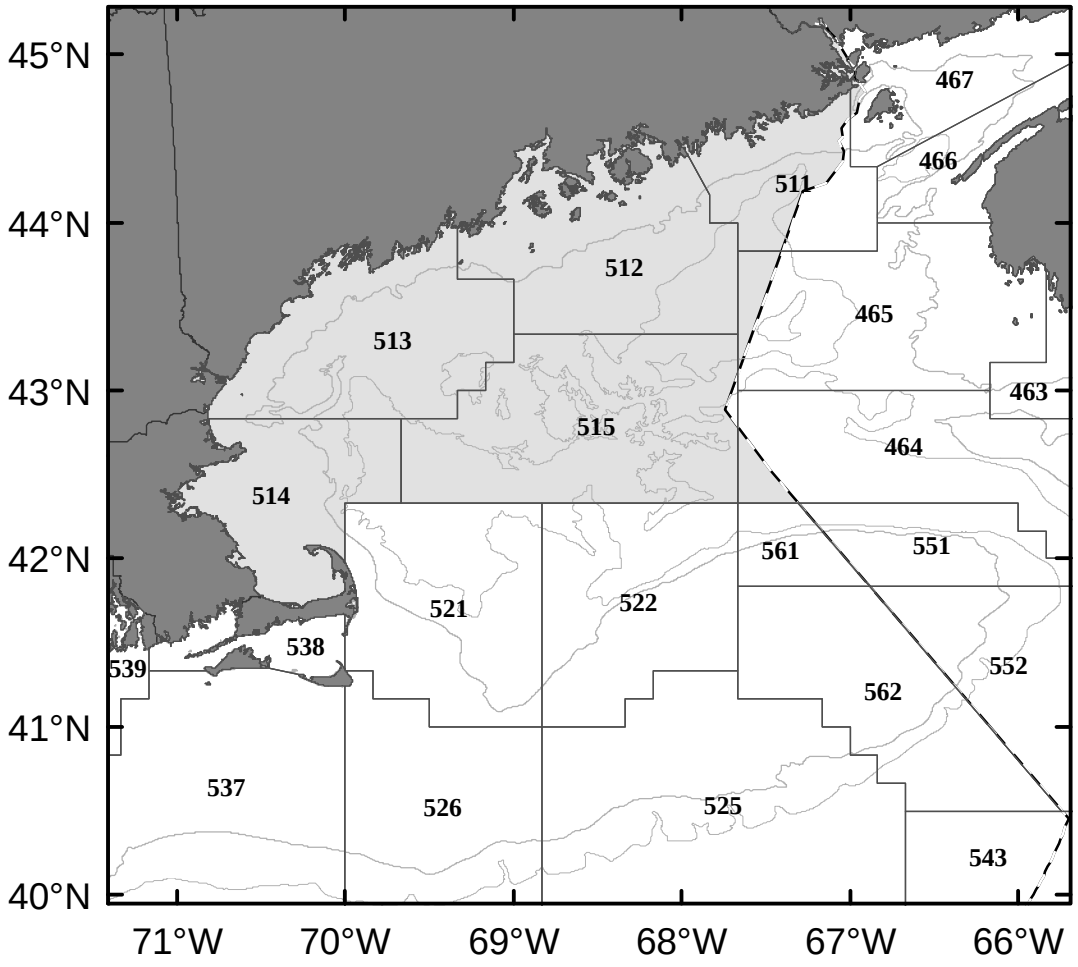

Figure A4. Map of the Gulf of Maine haddock (*Melanogrammus aeglefinus*) management and assessment area (shaded grey). The United States exclusive economic zone (EEZ) is defined by the dashed line.

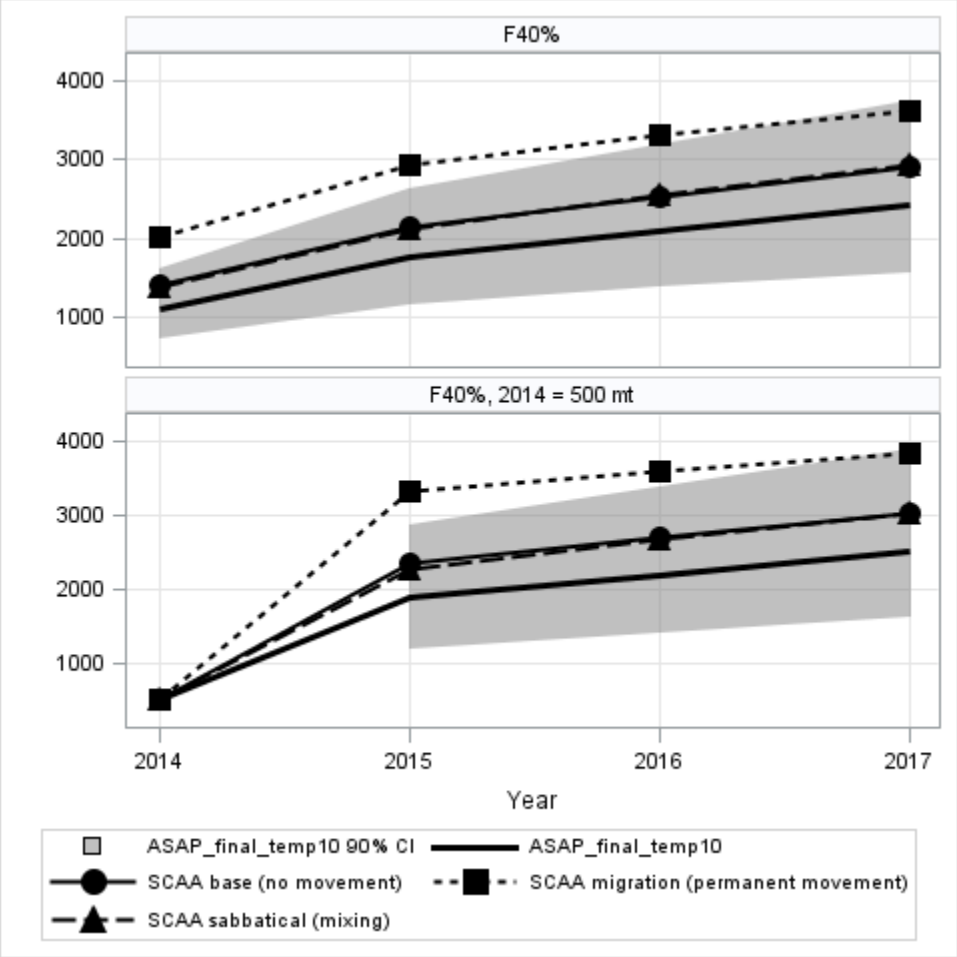

Figure A5. Short-term projections of total fishery yield and spawning stock biomass for Gulf of Maine haddock based on a harvest scenario of a) fishing at $F_{40\%}$ between 2014 and 2017 [upper panel] and b) an assumed catch of 500 mt in 2014 and fishing at $F_{40\%}$ between 2015 and 2017 [lower panel]. Projections from the base ASAP model (ASAP_final_temp10) are compared to three alternate runs from the SCAA model, two of which incorporate mixing between the Gulf of Maine and Georges Bank stocks.

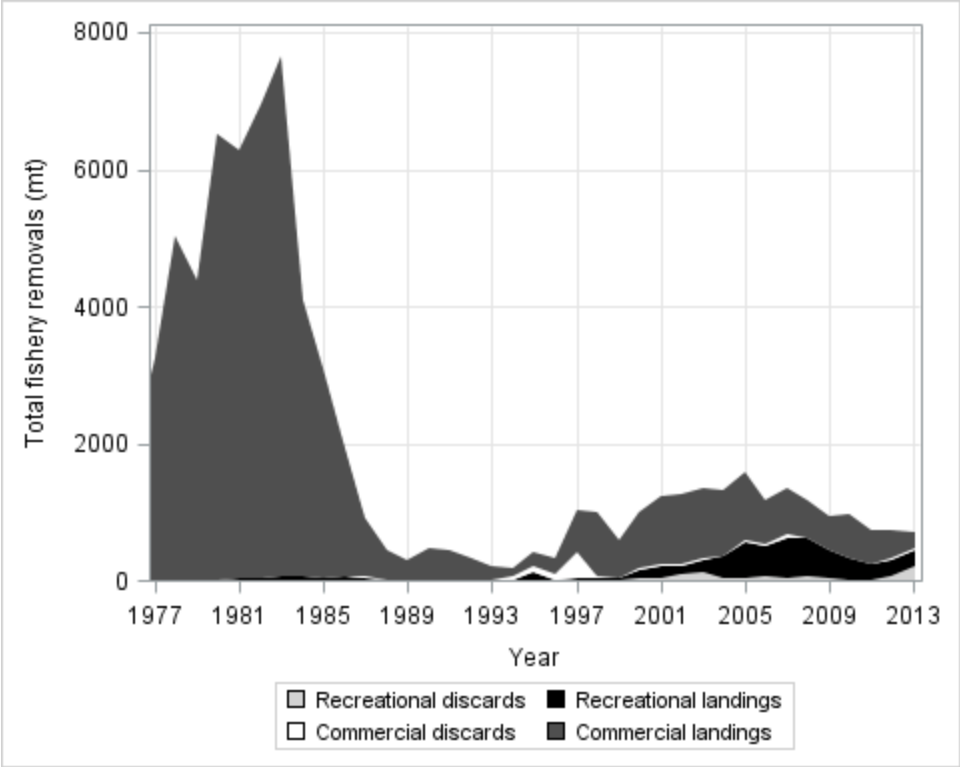

Figure A6. Total catch of Gulf of Maine haddock from 1977 to 2013 by fleet (commercial and recreational) and disposition (landed, discarded).

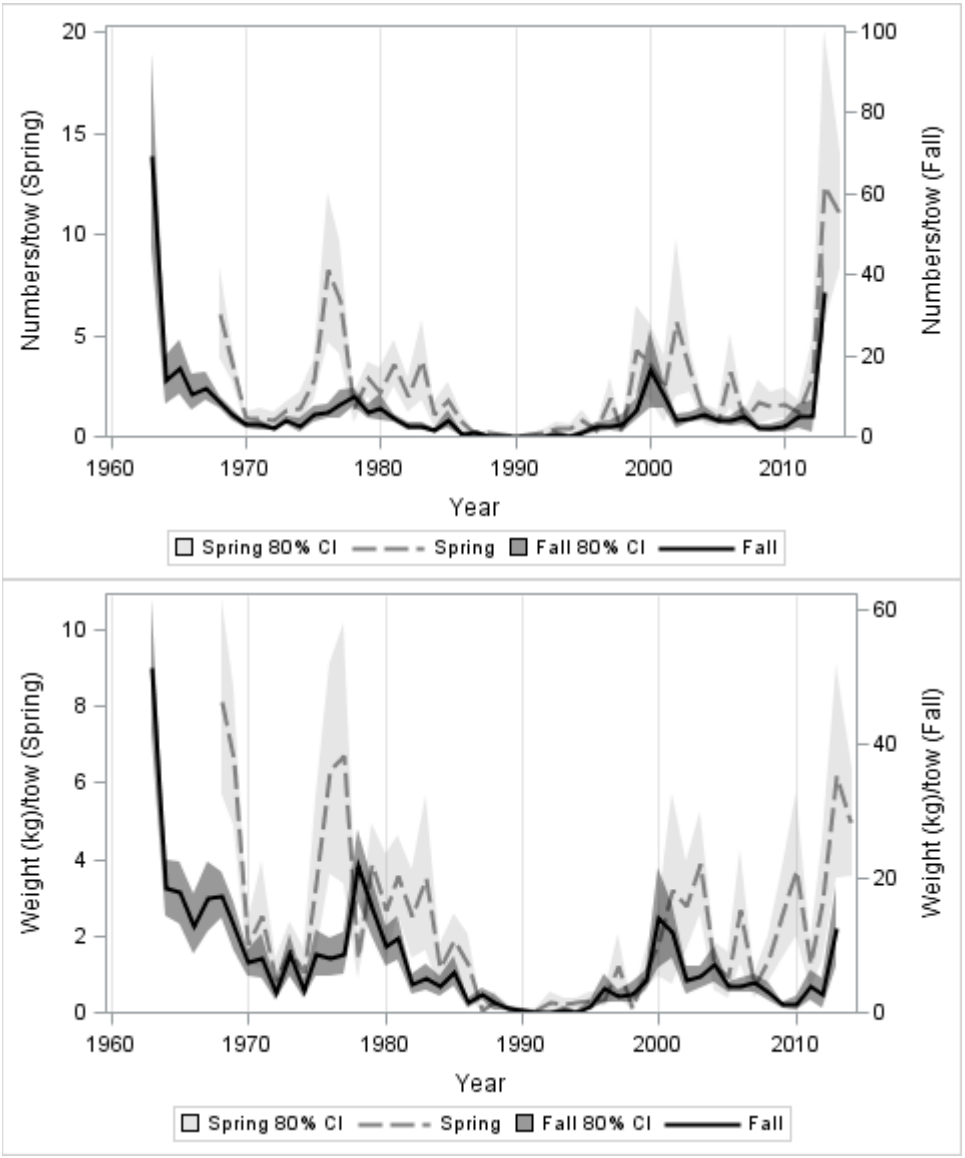

Figure A7. Indices of abundance (numbers/tow; top) and biomass (weight/tow; bottom) for the Gulf of Maine haddock between 1963 and 2014 (spring only) for the Northeast Fisheries Science Center (NEFSC) spring and fall bottom trawl surveys. *Note that the 2014 spring value was not used in the assessment model.*

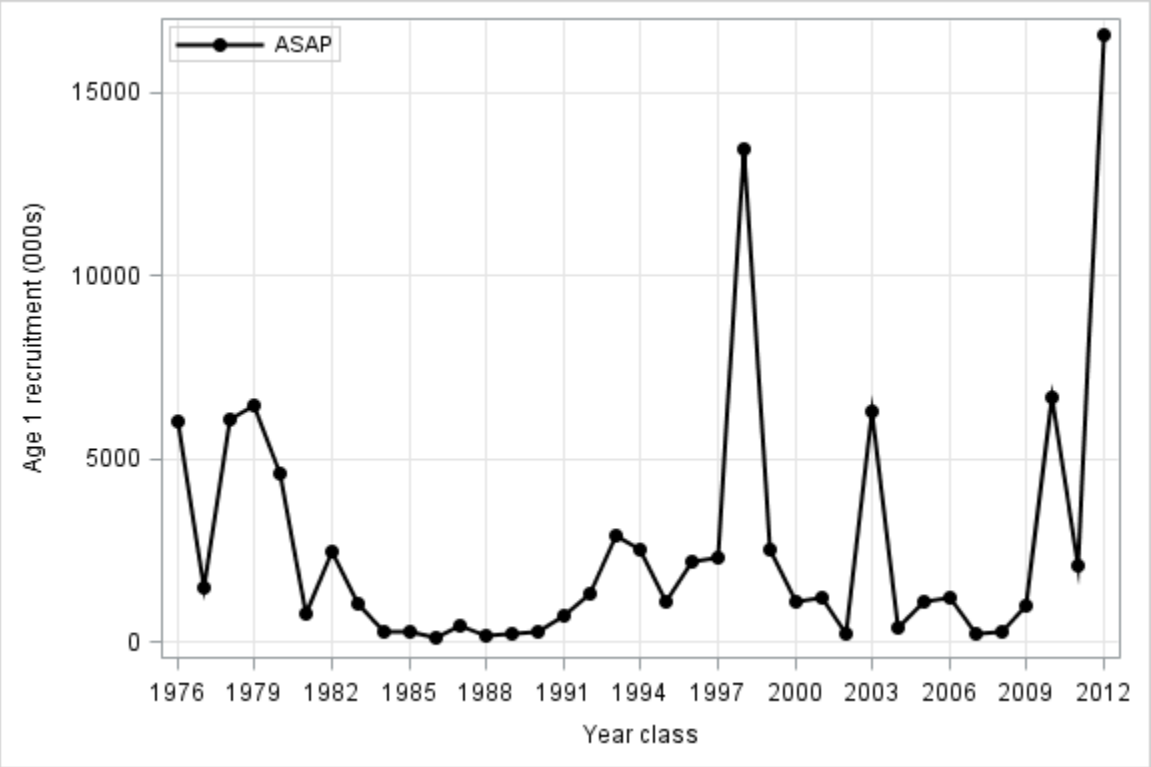

Figure A8. Estimated annual age-1 recruitment (000s fish) of Gulf of Maine haddock between 1977 and 2013 (1976 to 2012 year classes) based on the 2014 assessment.