3.3 Georges Bank haddock

Catch and Survey Indices

The Georges Bank haddock (*Melanogrammus aeglefinus*) stock has been commercially exploited since the 19th century with reliable landings statistics available beginning in 1904 (Clark *et al.* 1982). The fishery for Georges Bank haddock can be separated into six periods (Figure 3.3.1): (1) the stable early period from 1904-1923 when annual landings averaged 17,400 mt; (2) the rapid fishery expansion during 1924-1930 when landings averaged 73,200 mt; (3) the thirty-year period of relative stability during 1931-1960 when landings averaged 46,300 mt; (4) the rapid fishery expansion by foreign distant water fleets during 1961-1968 when landings averaged 73,000 mt; (5) the fishery decline during 1969-1984 when landings averaged 13,400 mt; and (6) the recent period of fishery depletion from 1985-2000 when annual landings have averaged only 5,500 mt. Landings have increased moderately in recent years as stock biomass has begun to rebuild under restrictive management measures for the Georges Bank region. In 2000, the fishery yield (8,800 mt) was roughly four times larger than the lowest recorded landings observed in 1995.

Fishery-independent research survey data provide relative abundance indices for the Georges Bank haddock stock from the 1960s to the present (Figure 3.3.1). These indices show the long-term decline in stock biomass that has occurred since the 1960s. The NEFSC fall survey index series averaged 53.3 kg/tow during 1963-1968, declined to14.5 kg/tow during 1969-1984, and declined further to 6.3 kg/tow during 1985-2000. Similarly, the NEFSC spring survey index series averaged 19.3 kg/tow during 1968-1984 and then declined by more than ½ to an average of 8.2 kg/tow during 1985-2000. Survey indices have increased in recent years as stock biomass has begun to rebuild. In 2000, the fall survey index was 15.4 kg/tow while the spring index was 17.9 kg/tow.

Stock Assessment

The most recent assessment of the Georges Bank haddock stock was conducted in 2001, and the results were reviewed at the 4th meeting of the Transboundary Resource Assessment Committee in April 2001 (NEFSC 2001d). At that time, fully recruited fishing mortality in 2000 was estimated to be 0.19. Spawning stock biomass had continued to increase from the low (< 15,000 mt) of the early 1990s to 64,100 mt in 2000. Recruitment has improved in recent years, as the 1996 and 1998 year classes are among the strongest since the 1978 year class appeared.

The time series of spawning stock biomass (SSB) and recruitment for the Georges Bank haddock stock extends from the 1930s to present. Plots of the SSB and recruitment obtained from the most recent assessment are provided in Figure 3.3.2. There appears to be a significant positive relationship between SSB and the likelihood of obtaining good recruitment.

Yield and Spawning Biomass Per Recruit

A revised yield and spawning biomass analysis for Georges Bank haddock was conducted to ensure that the distribution of fish within the plus-group was consistent with what would be expected in a rebuilt stock. This was accomplished by recomputing the 9+ mean weight to match with the equilibrium survivorship under an F likely to rebuild spawning biomass ($F_{40\%}$=0.26). Fishery selectivity, growth, and fraction mature at age were the same as used in the most recent management projections and MSY-reference point calculations described below. The resulting estimates of $F_{40\%}$ and $F_{0.1}$ were equal to 0.26 (Table 3.3.2); these values are similar to the estimates in the most recent assessment.

A sensitivity analysis was conducted to evaluate whether the use of growth and maturity patterns from 1931 would have changed the calculated reference points based on historic data (Clark et al. 1982). The results of the sensitivity analysis (Table 3.3.3) indicated that spawning biomass per recruit values based on the historic data were very similar to those using the current data. Similarly, reference points were robust to the use of historic growth and maturity data with estimates of $F_{40\%}$ =0.28 and $F_{0.1}$=0.25. Yield per recruit values using the historic data were lower, however, primarily due to the lower weights at age observed in the 1930s.

MSY-Based Reference Point Estimation

Empirical Nonparametric Approach

The Georges Bank haddock stock has a much greater chance of producing high recruitment when spawning biomass is above its observed median value (Brodziak et al. 2001). Furthermore, average recruitment strength is roughly 5 times larger when spawning biomass is above its median than when it falls below its median. Based on these observations, average recruitment from the entire time series of stock-recruitment data is not representative of the expected recruitment at B_{MSY} because of the severe depletion of spawning biomass since the 1970s. Two cases for determining the expected recruitment at B_{MSY} are considered.

In the first case, mean recruitment from the distribution of spawning biomass values >/= 75,000 mt is used to represent the expected recruitment at B_{MSY}; this value is 68.87 million age-1 recruits (the 1963 year class is excluded from the mean because it is considered a significant outlier; Figure 3.3.2). The mean is considered the appropriate measure of central tendency of the recruitment distribution at the upper stanza of spawning biomass (> 75,000 mt). If the F_{MSY} proxy is $F_{40\%}$=0.263, then the expected spawning biomass per recruit is 3.6341 kg of spawning biomass per recruit and the expected yield per recruit is 0.7686 kg of yield per recruit (Table 3.3.2). Multiplying the expected spawning biomass per recruit times the expected recruitment at B_{MSY} produces an B_{MSY} proxy of 250,300 mt of spawning biomass. Multiplying the expected yield per recruit times the expected recruitment at B_{MSY} produces an MSY proxy of 52,900 mt of yield.

In the second case, average recruitment from the 1931-1960 time period is used to represent the expected recruitment at B_{MSY}; this value is 75.230 million age-1 recruits (Figure 3.3.2). The mean is considered to be the appropriate measure of central tendency of the recruitment distribution during 1931-1960 because of the relative stability of both the stock size and the fishery yield during this period. If the F_{MSY} proxy is $F_{40\%}$=0.277 using the 1931 growth and maturity patterns, then the expected spawning biomass per recruit is 3.0590 kg of spawning biomass per recruit and the expected yield per recruit is 0.5986 kg of yield per recruit (Table 3.3.3). Multiplying the expected spawning biomass per recruit times the expected recruitment at B_{MSY} produces an B_{MSY} proxy of 230,000 mt of spawning biomass. Multiplying the expected yield per recruit times the expected recruitment at B_{MSY} produces an MSY proxy of 45,000 mt of yield. Thus, the calculation of Bmsy in the 230-250,000 mt range is robust to the substantial variation in life history parameters that has occurred for this stock in the past 70 years.

Parametric Model Approach

Maximum likelihood fits of the 10 parametric stock-recruitment models to the Georges Bank haddock data from 1931-2000 are listed below (Table 3.3.1). The model acronyms are: BH = Beverton-Holt, ABH = Beverton-Holt with autoregressive errors, PBH = Beverton-Holt with steepness prior, PABH = Beverton-Holt with steepness prior and autoregressive errors, PRBH = Beverton-Holt with recruitment prior, PRABH = Beverton-Holt with recruitment prior and autoregressive errors, RK = Ricker, ARK = Ricker with autoregressive errors, PRK = Ricker with slope at the origin prior, PARK = Ricker with slope at the origin prior and autoregressive errors. The six hierarchical criteria are applied to each of the models to determine the set of candidate models.

The first criterion is satisfied by all models because none of the parameter estimates lie on the boundary of their feasible range. The second criterion is satisfied by all models except models BH and ABH, where the point estimate of MSY exceed 200 kt. This eliminates the BH and ABH models from being candidates. The third criterion is satisfied by all remaining models. The fourth criterion is satisfied for all remaining models because F_{MAX} exceeds 1.0 for Georges Bank haddock. The fifth criterion is not satisfied by the remaining autoregressive models, PABH, PRABH, ARK, and PARK, because the dominant period of environmental forcing is outside of the range of 1/2 of the length of the stock recruitment time series (Figure 3.3.4). The fact that the autoregressive parameters (ϕ) exceed ½ for the autoregressive models indicates that there must be a multidecadal environmental forcing term operating on the stock-recruitment process for Georges Bank haddock if these models represent the true state of nature. While the existence of multidecadal environmental forcing is not outside the realm of possibility, it is not a testable hypothesis within the available data. Furthermore, the detection of low-frequency oscillations is confounded by the appearance of two stock-recruitment stanzas for the stock: 1931-1960 and 1961-2000. Early in the second stanza, the stock virtually collapsed after intensive harvest by distant water fleets in the 1960s. Thus, the serial correlation in the stock-recruitment time series is coincident and confounded with the significant decreasing trends in both recruitment and spawning biomass data. As a result, the possible effects of strong serial correlation and density-dependence are not separable without a longer (100+ year) time series (see, for example, Manly 1997). Last, the sixth criterion is considered be satisfied by the remaining 4 models: PBH, PRBH, RK, and PRK. In this case, the R_{MAX} values may be lower than expected under the RK and PRK models but they do not appear to be anomalously low.

Given the four candidate models (PBH, PRBH, RK, and PRK), the AIC criterion assigns the greatest likelihood to the PRBH model, followed closely by the PBH model. In particular, the odds ratio of PRBH being true to PBH being true is 1.3:1 (Table 3.3.1). Thus, there is limited basis for choosing between these two parametric models, although both models give very similar point estimates of B_{MSY}, F_{MSY}, and MSY. The other two models, RK and PRK, are much less likely than the PRBH model. In particular, the odds ratio of PRBH being true to RK being true is over 50:1 while the odds ratio of PRBH being true to PRK being true is over 500:1. This indicates that overcompensatory stock-recruitment dynamics are very unlikely in this stock given the available data.

The results of using the PRBH model as the best fit parametric model are shown below (Table 3.3.1 and Figures 3.3.5, 3.3.6, and 3.3.7). The standardized residual plot of the fit of the PRBH model to the stock-recruitment data shows that the standardized residuals generally lie within ± two standard deviations of zero (Figure 3.3.5), with the exception of the time period immediately following the exceptional 1962-63 year classes and coincident with the highest catches by distant water fleets in the 1960s. The early part of the residual plot shows that residuals were consistently positive. This feature may represent the fact that the stock-recruitment time series likely underestimates the actual recruitment values during the 1931-early 1950s period when there was no mesh size regulation and discarding of undersized haddock was commonplace (Herrington 1932; Herrington 1935; Premetz et al. 1954). If recruitment estimates during the 1931-early 1950s period were increased upwards to account for discards, the model fit would change and likely produce a higher steepness. The latter part of the residual plot shows that residuals were generally negative during the 1980s. This feature may represent the fact that the magnitude and seasonal extent of spawning output was severely reduced after the spawning stock was depleted in the 1970s. In this context, accurately modeling the stock-recruitment dynamics during this time period may require a non-stationary model.

The equilibrium yield plot (Figure 3.3.6) shows that the yield surface is relatively flat from F=0.16 to F=0.22 in the neighborhood of the point estimate of F_{MSY} = 0.18. The point estimates of B_{MSY} =243,000 mt and MSY =36,700 mt are consistent with the observed values of maximum observed spawning stock size (200,000 mt) and long-term average yield (32,300 mt during 1904-2000), although the MSY value may seem low relative to the observed yields during 1931-1960. Again, the effect of not including discards of undersized haddock during the time period of unregulated mesh size, 1931 to the early-1950s, likely leads to a downward bias in the estimates of recruitment from this period and this reduces the apparent stock productivity. Regardless, the stock-recruitment plot (Figure 3.3.7) shows that recruitment values near B_{MSY} are roughly 54 million fish which is consistent with the long-term average (56 million) of the observed recruitment series during 1931-2000 excluding the exceptional 1962 and 1963 year classes.

Parameter uncertainty plots show histograms of 5000 MCMC sample estimates of MSY, B_{MSY}, and F_{MSY} drawn from the posterior distribution of the MLE based on an uninformative prior (Figure 3.3.8). For MSY, the 80 percent credibility interval was (33,100 mt, 41,500 mt) with a median of 37,300 mt. For B_{MSY}, the 80 percent credibility interval was (213,700 mt, 253,000 mt) with a median of 233,500 mt. For F_{MSY}, the 80 percent credibility interval was (0.165, 0.225) with a median of 0.19. Overall, the point estimates of MSY, B_{MSY}, and F_{MSY} were similar to the medians of the MCMC samples.

Reference Point Advice

Based on the conformance of the nonparametric proxy and parametric analyses, the following management parameters (based on the non-parametric approach) were selected by the Working Group as being most appropriate: Bmsy = 250,300 mt, Fmsy = 0.263, MSY=52,900 mt. The median recruitment, stock-recruitment scatterplot, and replacement lines under F=0 and F=0.263 are given in Figure 3.5.9. The non-parametric approach was selected because the best fit parametric model had a nonstationary residual pattern (Figure 3.3.5) which suggested that further research w needed to apply this approach.

Projections

Stochastic age-based projections were performed over a 10-year time horizon for 2001-2010 to compute likely trajectories of spawning biomass and catch under two fishing mortality scenarios: (i) $F = F_{MSY}$ and (ii) F calculated to rebuild the stock to B_{MSY}=250,300 mt in 2009. Recruitment was modeled by resampling from the CDF of the recruitments from SSBs > 75,000 mt, excepting the 1963 year class.

Projections used values of spawning stock weights at age, catch weights at age, maturity fraction at age, fishery selectivity at age, and natural mortality that were equal to those used in the spawning biomass and yield per recruit analyses of the current fishery (Table 3.3.2). A total of 1,000 bootstrap realizations of the initial population size at age vector at the beginning of 2001 were used for the projections. A total of 50 simulations were conducted for each initial population vector giving a total of 50,000 simulated population trajectories. Fully-recruited fishing mortality in 2001 was based on preliminary estimates of total catch in 2001 (11,553.6 mt with USA catch=4841.6 mt and Canadian catch=6712.0 mt); this gave a median F_{2001}=0.19. The fully-recruited fishing mortality in 2002 was taken to be the Amendment 7 fishing mortality target for Georges Bank haddock of $F_{0.1}$=0.26. Fishing mortality rates in 2003-2009 were set according to the two scenarios: (i) $F = F_{MSY}$ and (ii) F calculated to rebuild the stock to B_{MSY}=250,300 mt in 2009.

The medium term projections under fishing mortality scenario (i) (Figure 3.3.10) show that fishing at F_{MSY} during 2003-2009 would give a 35% probability of achieving B_{MSY} in 2009.

The medium term projections under fishing mortality scenario (ii) (Figure 3.3.10) show that the F calculated to rebuild the stock to B_{MSY} in 2009 with at least a 50% probability would be $F_{REBUILD}$=0.21. Projections results show that fishing at $F_{REBUILD}$ during 2003-2009 would give a 53% probability of achieving B_{MSY} in 2009. Projected median spawning biomass would increase from 80,500 mt in 2001 to 254,000 mt in 2009 (Figure 3.3.11). Projected median catches would increase from 11,500 mt in 2001 to roughly 43,600 mt in 2009 (Figure 3.3.12).

Table 3.3.1. Stock-recruitment model comparisons for Georges Bank haddock

Georges Bank Haddock Model Comparison										
SMAX =	199.5									
	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior
	0	0	0.25	0	0.25	0	0.25	0	0.25	0
	BH	ABH	**PBH**	PABH	**PRBH**	PRABH	**RK**	ARK	**PRK**	PARK
Posterior Probability	0.00	0.00	**0.43**	0.00	**0.56**	0.00	**0.01**	0.00	**0.00**	0.00
Odds Ratio for Most Likely Model			1.31		**1.00**		50.70		588.75	
Normalized Likelihood	0.00	0.00	0.43	0.00	0.56	0.00	0.01	0.00	0.00	0.00
Model AIC Ratio			450.1136		588.74903		11.6115466		1	
	BH	**ABH**	**PBH**	**PABH**	**PRBH**	**PRABH**	**RK**	**ARK**	**PRK**	**PARK**
Number_of_data_points	70	70	70	70	70	70	70	70	70	70
Number_of_parameters	3	4	3	4	3	4	3	4	3	4
Negative_loglikelihood	337.963	328.003	338.497	327.477	341.129	330.825	342.401	329.758	346.749	331.503
Bias-corrected_AIC	682.29	664.622	683.851	665.937	683.314	664.965	691.166	668.131	696.07	672.205
Diagnostic Comments	MSY and SMSY are outside credible range	Power spectrum dominant frequency exceeds 1/2 time series length		Power spectrum dominant frequency exceeds 1/2 time series length	**Most Likely Model**	Power spectrum dominant frequency exceeds 1/2 time series length		Power spectrum dominant frequency exceeds 1/2 time series length		Power spectrum dominant frequency exceeds 1/2 time series length
Parameter Point Estimates										
***********************										
MSY	250.308	1990.13	40.8311	28.0879	36.7247	37.1899	35.0312	39.1603	36.9555	47.2048
FMSY	0.145	0.145	0.21	0.29	0.18	0.19	0.53	0.53	0.71	1.04
SMSY	2020.56	16065	235.313	122.094	243.145	234.469	93.4673	104.484	79.4513	78.0314
alpha	824.447	6676.98	94.6193	50.7077	96.3656	95.0454	4.54054E-05	4.54149E-05	0.246943	0.54437
expected_alpha	1961.96	15797.2	229.613	127.855	232.272	227.714	0.000121489	0.00012059	0.709649	1.73527
beta	2068.06	17047.7	154.847	51.8471	187.557	178.74	-9.12E-03	-8.16E-03	-0.011437	-0.012309
RMAX	72.5348	77.2331	53.2713	40.2478	49.6695	50.131	32.3677	39.2096	26.08	29.5075
expected_RMAX	172.613	182.728	129.274	101.481	119.719	120.106	86.6045	104.113	74.947	94.0604
Prior_mean			0.74	0.74	75.229	75.229			0.72	0.72
Prior_se			0.11	0.11	5.646	5.646			0.21	0.21
Z_Myers	0.48	0.47	0.58	0.69	0.54	0.55				
sigma	1.317	1.312	1.332	1.360	1.326	1.322	1.403	1.398	1.453	1.523
phi		0.50		0.53		0.50		0.55		0.61
sigmaw		1.14		1.15		1.14		1.17		1.20
last log-residual R		0.899		0.747		0.878		0.445		0.149
expected lognormal error term	2.38	2.37	2.43	2.52	2.41	2.40	2.68	2.66	2.87	3.19

Table 3.3.2. Yield and biomass per recruit for Georges Bank haddock, using current growth and maturity.

The NEFC Yield and Stock Size per Recruit Program - PDBYPRC
PC Ver.2.0 [Method of Thompson and Bell (1934)] 1-Jan-1999

Run Date: 21- 2-2002; Time: 09:17:28.80
Gb Haddock using recent weight at age and maturity

Proportion of F before spawning: 0.2500
Proportion of M before spawning: 0.2500
Natural Mortality is Constant at: 0.200
Initial age is: 1; Last age is: 9
Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file:
==> C:\groundfish\ypr\gbhad_new_ypr.dat

Age-specific Input data for Yield per Recruit Analysis

Age	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights Catch	Average Weights Stock
1	0.0030	1.0000	0.0400	0.545	0.388
2	0.0880	1.0000	0.4900	1.060	0.732
3	0.4710	1.0000	0.9500	1.533	1.277
4	0.9200	1.0000	1.0000	1.874	1.704
5	1.0000	1.0000	1.0000	2.247	2.039
6	1.0000	1.0000	1.0000	2.498	2.350
7	1.0000	1.0000	1.0000	2.970	2.749
8	1.0000	1.0000	1.0000	3.180	3.204
9	1.0000	1.0000	1.0000	3.678	3.678

Summary of Yield per Recruit Analysis:

Slope of the Yield/Recruit Curve at F=0.00: --> 8.3488
F level at slope=1/10 of the above slope (F0.1): -----> 0.263
Yield/Recruit corresponding to F0.1: -----> 0.7683
F level to produce Maximum Yield/Recruit (Fmax): -----> 1.312
Yield/Recruit corresponding to Fmax: -----> 0.9211
F level at 40 % of Max Spawning Potential (F40): -----> 0.263
SSB/Recruit corresponding to F40: --------> 3.6341

1
Listing of Yield per Recruit Results for:

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	0.00	0.00000	0.00000	5.5167	10.2738	3.9054	9.0870	100.00
	0.10	0.20503	0.50516	4.4964	6.9291	2.8811	5.7783	63.59
	0.20	0.30918	0.70302	3.9803	5.3582	2.3612	4.2323	46.58
F0.1	0.26	0.35212	0.76827	3.7682	4.7516	2.1470	3.6374	40.03
F40%	0.26	0.35237	0.76861	3.7670	4.7481	2.1457	3.6341	39.99
	0.30	0.37288	0.79587	3.6660	4.4694	2.0435	3.3611	36.99
	0.40	0.41630	0.84475	3.4529	3.9066	1.8272	2.8109	30.93
	0.50	0.44807	0.87270	3.2978	3.5214	1.6691	2.4349	26.80
	0.60	0.47253	0.88973	3.1790	3.2422	1.5475	2.1625	23.80
	0.70	0.49208	0.90061	3.0846	3.0307	1.4505	1.9560	21.53
	0.80	0.50816	0.90782	3.0073	2.8646	1.3709	1.7939	19.74
	0.90	0.52171	0.91271	2.9425	2.7304	1.3039	1.6628	18.30
	1.00	0.53332	0.91607	2.8872	2.6194	1.2465	1.5544	17.11
	1.10	0.54345	0.91838	2.8393	2.5258	1.1966	1.4629	16.10
	1.20	0.55238	0.91994	2.7971	2.4455	1.1527	1.3844	15.23
	1.30	0.56035	0.92097	2.7596	2.3757	1.1135	1.3161	14.48
Fmax	1.31	0.56126	0.92106	2.7554	2.3678	1.1091	1.3084	14.40
	1.40	0.56752	0.92160	2.7260	2.3143	1.0784	1.2561	13.82
	1.50	0.57404	0.92192	2.6956	2.2597	1.0465	1.2028	13.24
	1.60	0.58000	0.92201	2.6679	2.2107	1.0175	1.1550	12.71
	1.70	0.58547	0.92192	2.6425	2.1665	0.9908	1.1118	12.24
	1.80	0.59054	0.92169	2.6190	2.1262	0.9662	1.0726	11.80
	1.90	0.59525	0.92135	2.5973	2.0893	0.9434	1.0367	11.41
	2.00	0.59964	0.92092	2.5770	2.0554	0.9221	1.0038	11.05

Table 3.3.3. Yield and biomass per recruit of Georges Bank haddock using 1931 growth and maturity patterns.

The NEFC Yield and Stock Size per Recruit Program - PDBYPRC
PC Ver.2.0 [Method of Thompson and Bell (1934)] 1-Jan-1999

Run Date: 19- 2-2002; Time: 14:33:20.07
Gb Haddock using 1931 weight at age and maturity

Proportion of F before spawning: 0.2500
Proportion of M before spawning: 0.2500
Natural Mortality is Constant at: 0.200
Initial age is: 1; Last age is: 9
Last age is a PLUS group;
Original age-specific PRs, Mats, and Mean Wts from file:
==> C:\groundfish\ypr\gbhad_old_ypr.dat

Age-specific Input data for Yield per Recruit Analysis

Age	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights Catch	Average Weights Stock
1	0.0030	1.0000	0.0000	0.750	0.750
2	0.0880	1.0000	0.5000	0.780	0.780
3	0.4710	1.0000	1.0000	1.180	1.180
4	0.9200	1.0000	1.0000	1.370	1.370
5	1.0000	1.0000	1.0000	1.650	1.650
6	1.0000	1.0000	1.0000	2.010	2.010
7	1.0000	1.0000	1.0000	2.310	2.310
8	1.0000	1.0000	1.0000	2.540	2.540
9	1.0000	1.0000	1.0000	3.030	3.030

Summary of Yield per Recruit Analysis:

Slope of the Yield/Recruit Curve at F=0.00: --> 6.6163
F level at slope=1/10 of the above slope (F0.1): -----> 0.246
Yield/Recruit corresponding to F0.1: -----> 0.5795
F level to produce Maximum Yield/Recruit (Fmax): -----> 2.313
Yield/Recruit corresponding to Fmax: -----> 0.6949
F level at 40 % of Max Spawning Potential (F40): -----> 0.277
SSB/Recruit corresponding to F40: --------> 3.0590

1
Listing of Yield per Recruit Results for:

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	0.00	0.00000	0.00000	5.5167	9.1092	3.9070	7.6478	100.00
	0.10	0.20503	0.39463	4.4964	6.3547	2.8820	4.9214	64.35
	0.20	0.30918	0.54308	3.9803	5.0604	2.3615	3.6462	47.68
F0.1	0.25	0.34162	0.57951	3.8200	4.6804	2.1993	3.2728	42.79
F40%	0.28	0.36076	0.59856	3.7257	4.4627	2.1037	3.0590	40.00
	0.30	0.37288	0.60964	3.6660	4.3277	2.0431	2.9265	38.27
	0.40	0.41630	0.64304	3.4529	3.8633	1.8262	2.4712	32.31
	0.50	0.44807	0.66132	3.2978	3.5453	1.6675	2.1594	28.23
	0.60	0.47253	0.67205	3.1790	3.3146	1.5453	1.9330	25.28
	0.70	0.49208	0.67877	3.0846	3.1398	1.4477	1.7611	23.03
	0.80	0.50816	0.68321	3.0073	3.0025	1.3674	1.6258	21.26
	0.90	0.52171	0.68628	2.9425	2.8916	1.2999	1.5161	19.82
	1.00	0.53332	0.68848	2.8872	2.7998	1.2420	1.4252	18.64
	1.10	0.54345	0.69012	2.8393	2.7224	1.1915	1.3482	17.63
	1.20	0.55238	0.69136	2.7971	2.6560	1.1470	1.2820	16.76
	1.30	0.56035	0.69232	2.7596	2.5983	1.1074	1.2243	16.01
	1.40	0.56752	0.69306	2.7260	2.5475	1.0717	1.1733	15.34
	1.50	0.57404	0.69364	2.6956	2.5023	1.0393	1.1279	14.75
	1.60	0.58000	0.69408	2.6679	2.4617	1.0098	1.0871	14.21
	1.70	0.58547	0.69442	2.6425	2.4250	0.9826	1.0501	13.73
	1.80	0.59054	0.69466	2.6190	2.3916	0.9575	1.0163	13.29
	1.90	0.59525	0.69482	2.5973	2.3609	0.9343	0.9853	12.88
	2.00	0.59964	0.69492	2.5770	2.3327	0.9126	0.9567	12.51

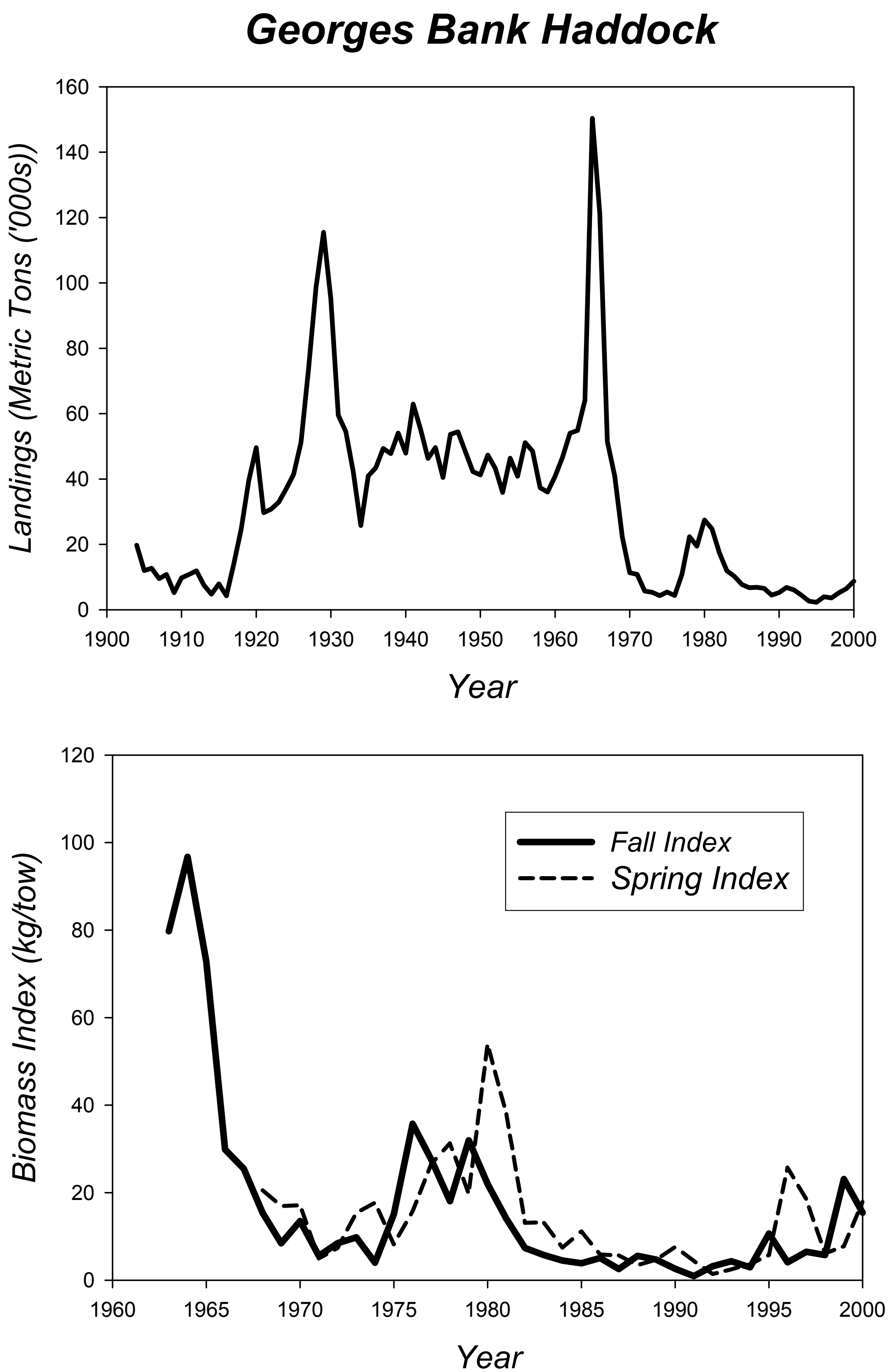
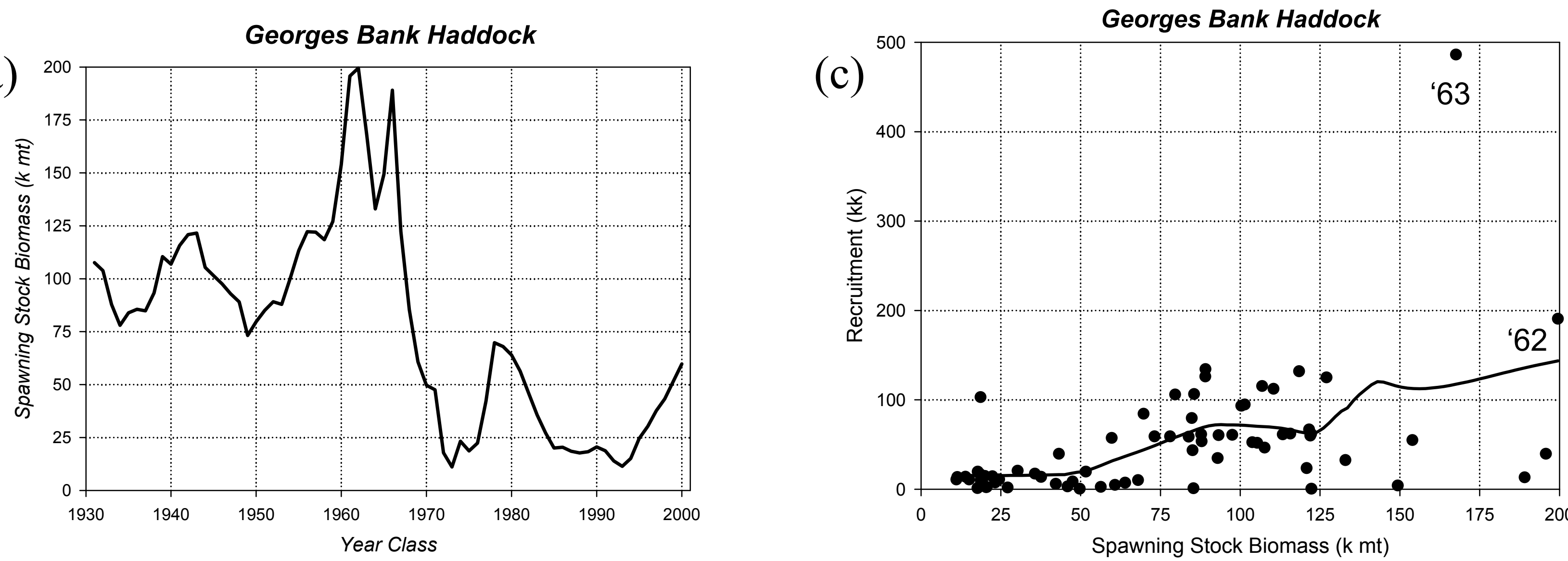


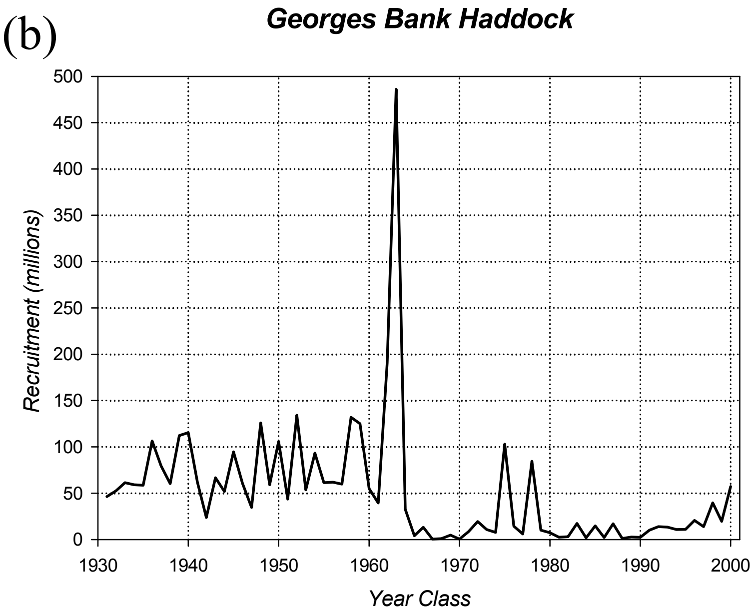
Figure 3.3.1. Landings and research vessel survey abundance indices for Georges Bank haddock.

(a)

(c)



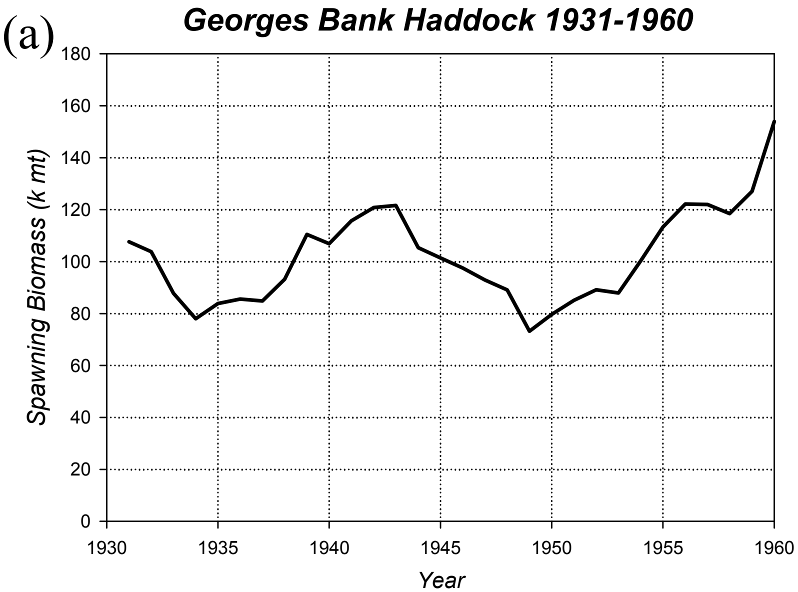
(b)



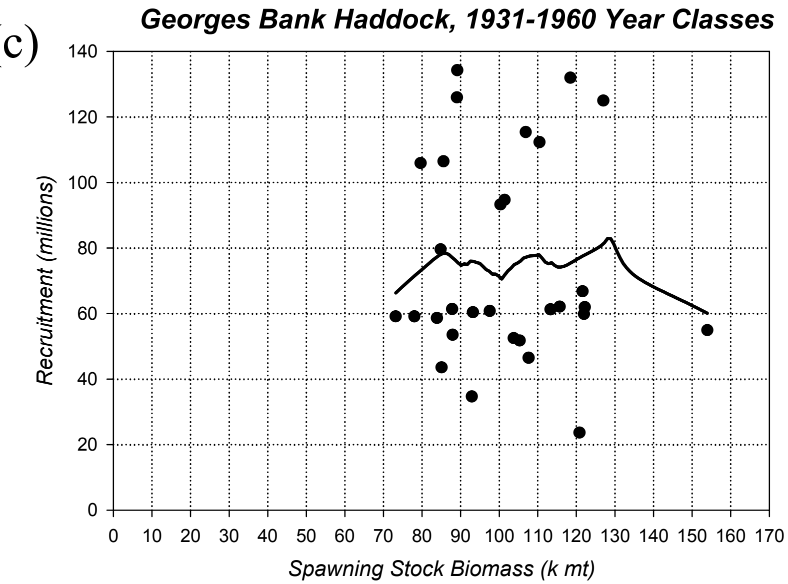
		F0.1	F40% MSP
F reference point		0.263	0.263
ssb per recruit at F		3.6374	3.6341
	Recruitment (millions)	SS Biomass at F0.1	SS Biomass at F40%
n	70	70	70
mean	51.09	185.83	185.66
min	0.42	1.53	1.53
max	486.22	1768.56	1766.95
10th %'tile	2.49	9.07	9.06
25th %'tile	10.30	37.47	37.43
50th %'tile	37.08	134.86	134.74
75th %'tile	61.80	224.78	224.58
90th %'tile	112.58	409.51	409.14
Std Dev	67.73	246.38	246.15
CV	1.33	1.33	1.33
For SSB >/= 75 kmt - w/o '63 YC			
Mean	68.87	250.49	250.27
Median	60.57	220.30	220.10
Mean w/'63 YC	80.15	291.52	291.26

Figure 3.3.2. Spawning stock (a), recruitment (age 1 millions, b), and scatterplot (c) for Georges Bank haddock. Data are the calculated spawning stock biomasses for various recruitment scenarios multiplied by the expected SSB per recruit for F0.1 and F40% MSP, assuming recent patterns of growth, maturity and partial recruitment at age (Table 3.3.2). Smoother in the stock-recruitment plot is lowess with tension = 0.5.

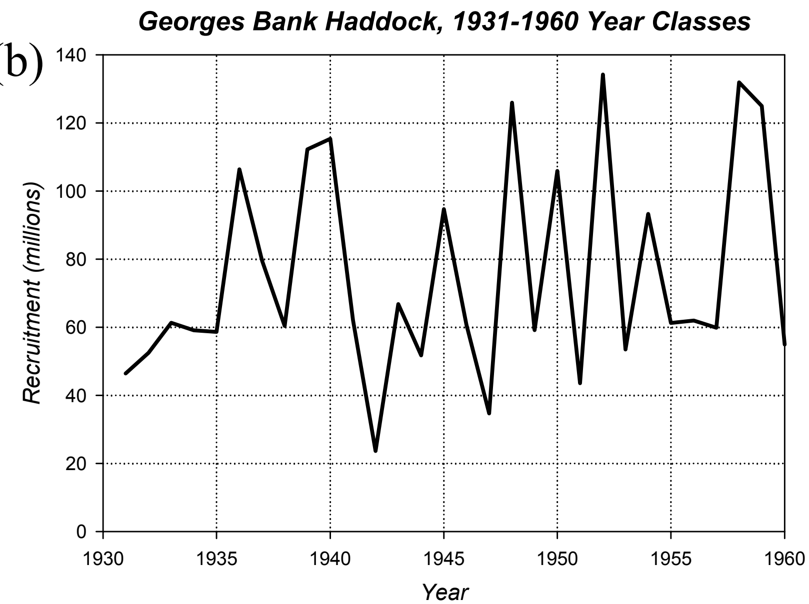
(a)



(c)



(b)



		F0.1	F40% MSP
F reference point		0.246	0.277
ssb per recruit at F		3.27	3.06
1931-1960 Year Classes	Recruitment (millions)	SS Biomass at F0.1	SS Biomass at F40%
n	30	30	30
mean	75.23	246.00	230.20
min	23.64	77.29	72.33
max	134.23	438.93	410.74
10th %'tile	46.16	150.93	141.24
25th %'tile	55.85	182.64	170.91
50th %'tile	61.30	200.43	187.56
75th %'tile	103.12	337.20	315.54
90th %'tile	125.09	409.03	382.76
Std Dev	30.92	101.12	94.62
CV	0.41	0.41	0.41
For Top Quartile of SSB			
Mean	73.27	239.61	224.22
Median	62.02	202.81	189.79

Figure 3.3.3. Spawning stock (a), recruitment (age 1 millions, b), and scatterplot (c) for Georges Bank haddock, 1931-1960. Data are the calculated spawning stock biomasses for various recruitment scenarios multiplied by the expected SSB per recruit for F0.1 and F40% MSP, assuming early patterns of growth and maturity at age (Table 3.3.3). Smoother in the stock-recruitment plot is lowess with tension = 0.5.

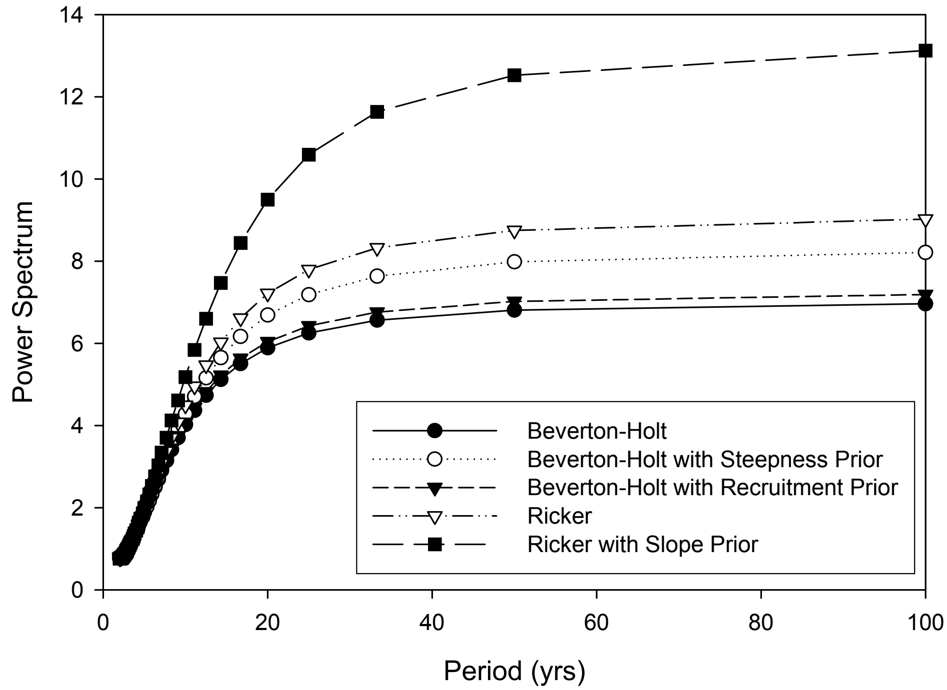


Figure 3.3.4. Georges Bank haddock periodicity of environmental forcing for autoregressive stock-recruitment models

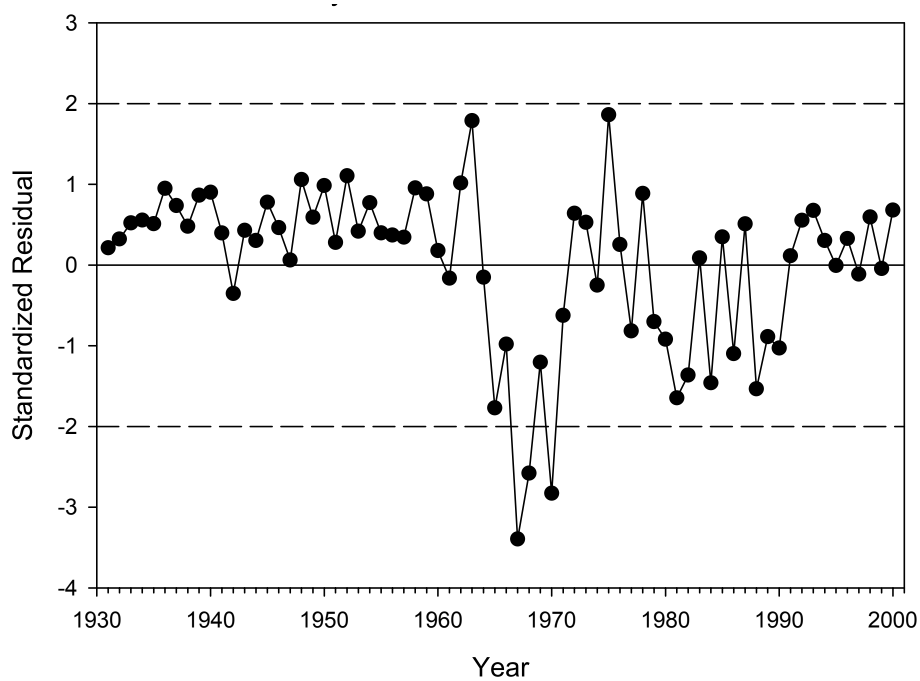


Figure 3.3.5. Georges Bank haddock standardized residuals for the most likely stock-recruitment model

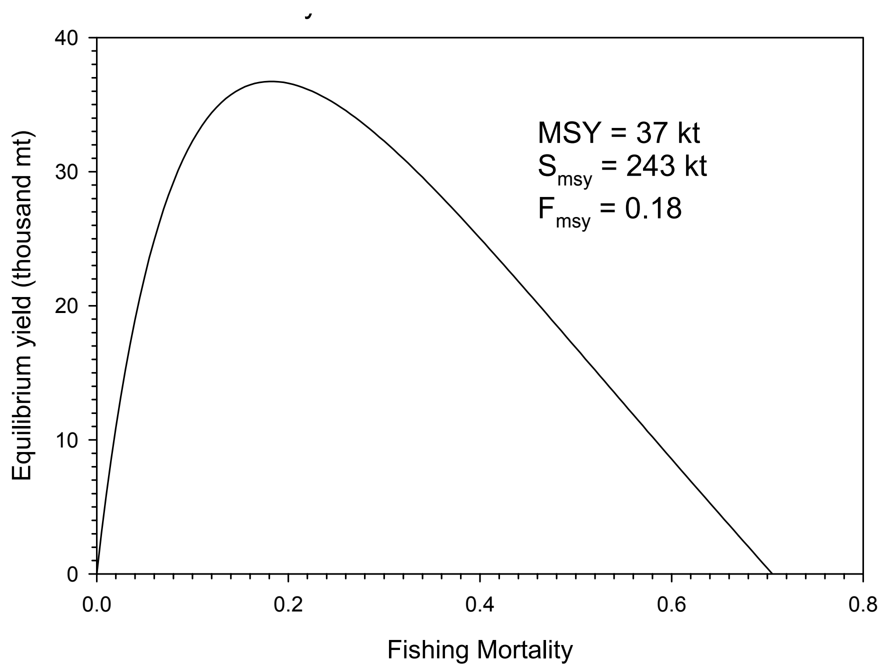


Figure 3.3.6. Georges Bank haddock equilibrium yield vs. F for the most likely stock-recruitment model

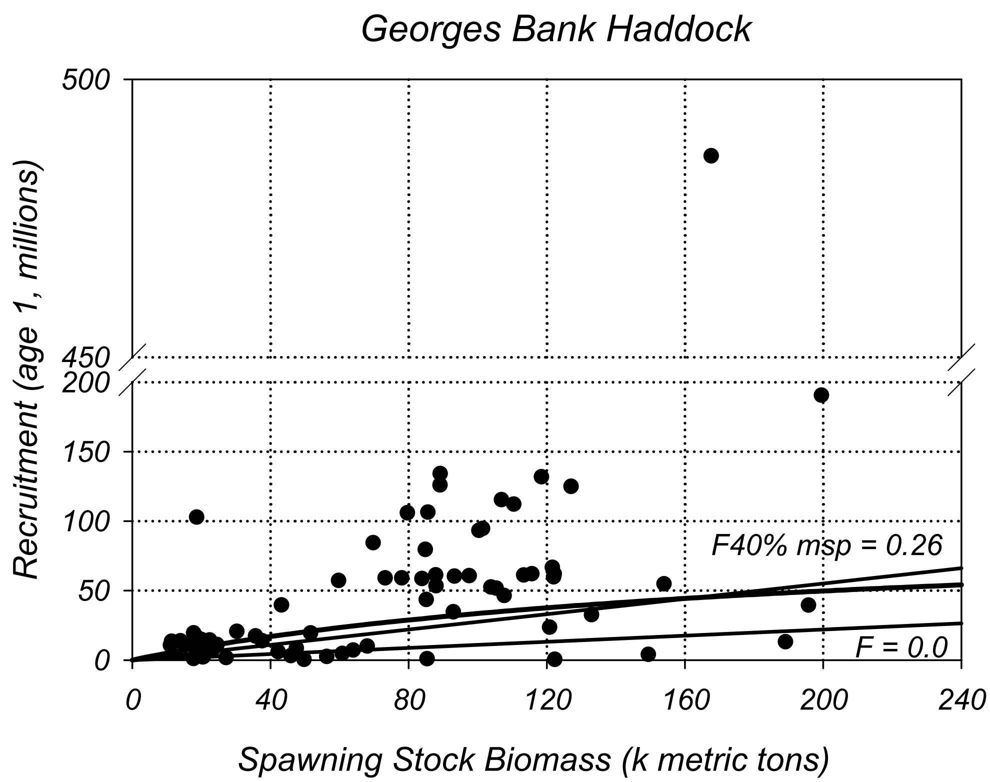


Figure 3.3.7. Stock recruitment relationship for best fit parametric model Georges Bank haddock. Stock-recruitment data points are overplotted, along with the predicted S-R line and replacement lines for F=100% msp=0.00 and F40%msp = 0.26.

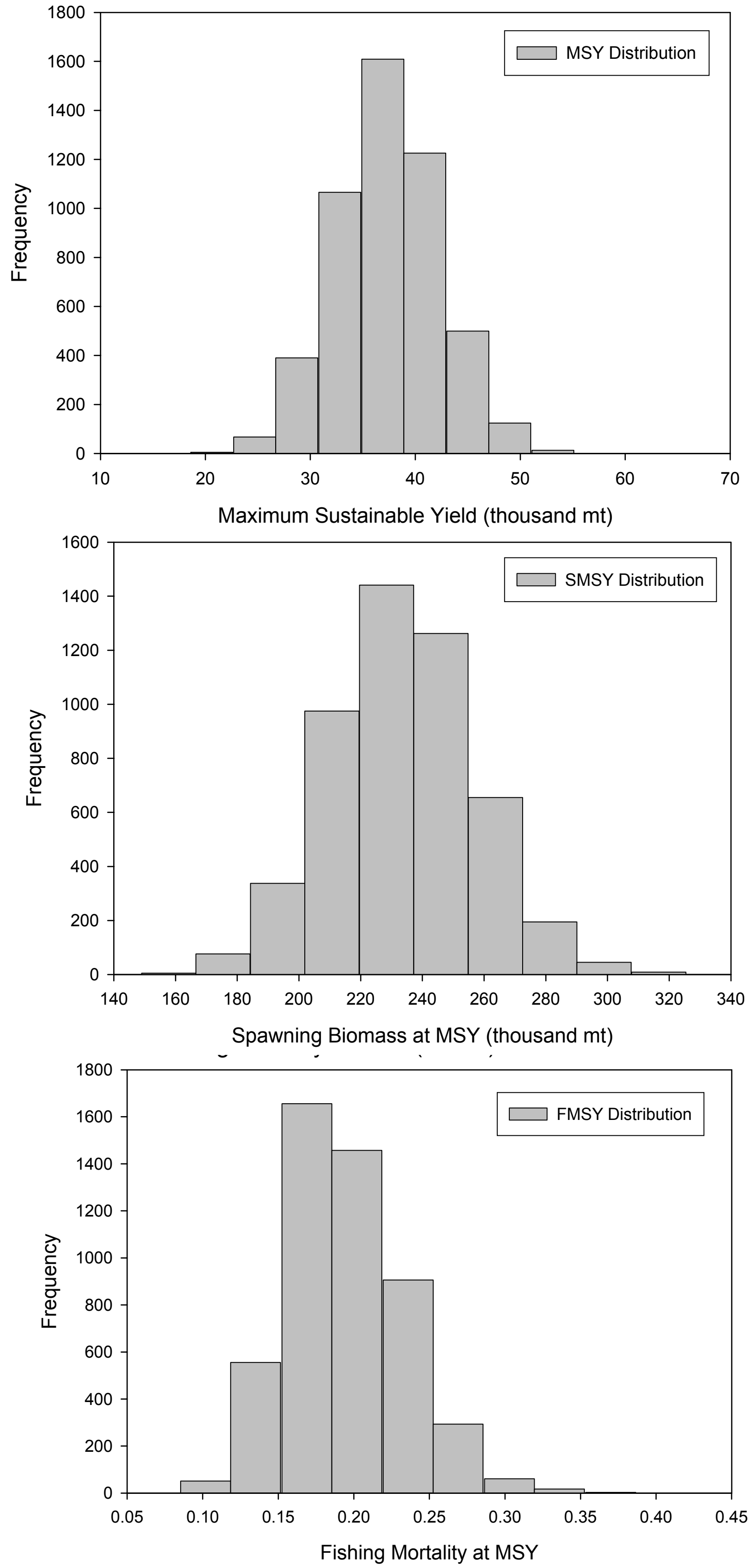


Figure 3.3.8. Georges Bank haddock posterior distribution of MSY, BMSY and FMSY for most likely model fit.

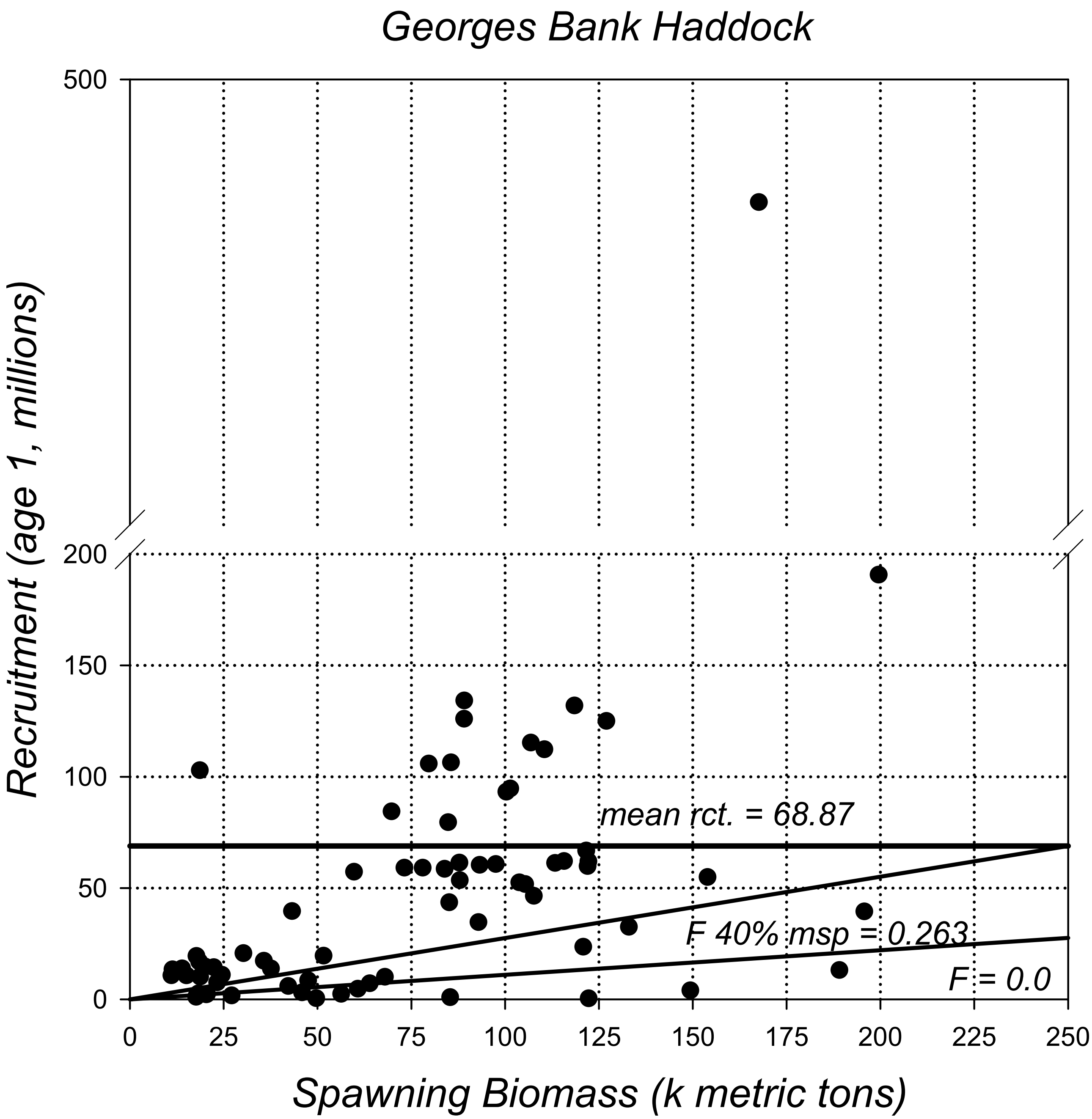


Figure 3.3.9. Stock and recruitment data for Georges Bank haddock. For the empirical non-parametric approach the mean recruitment above 75,000 mt of spawning stock biomass is plotted (excluding the 1963 year class), along with replacement lines for F=0.0 and F 40% msp = 0.263.

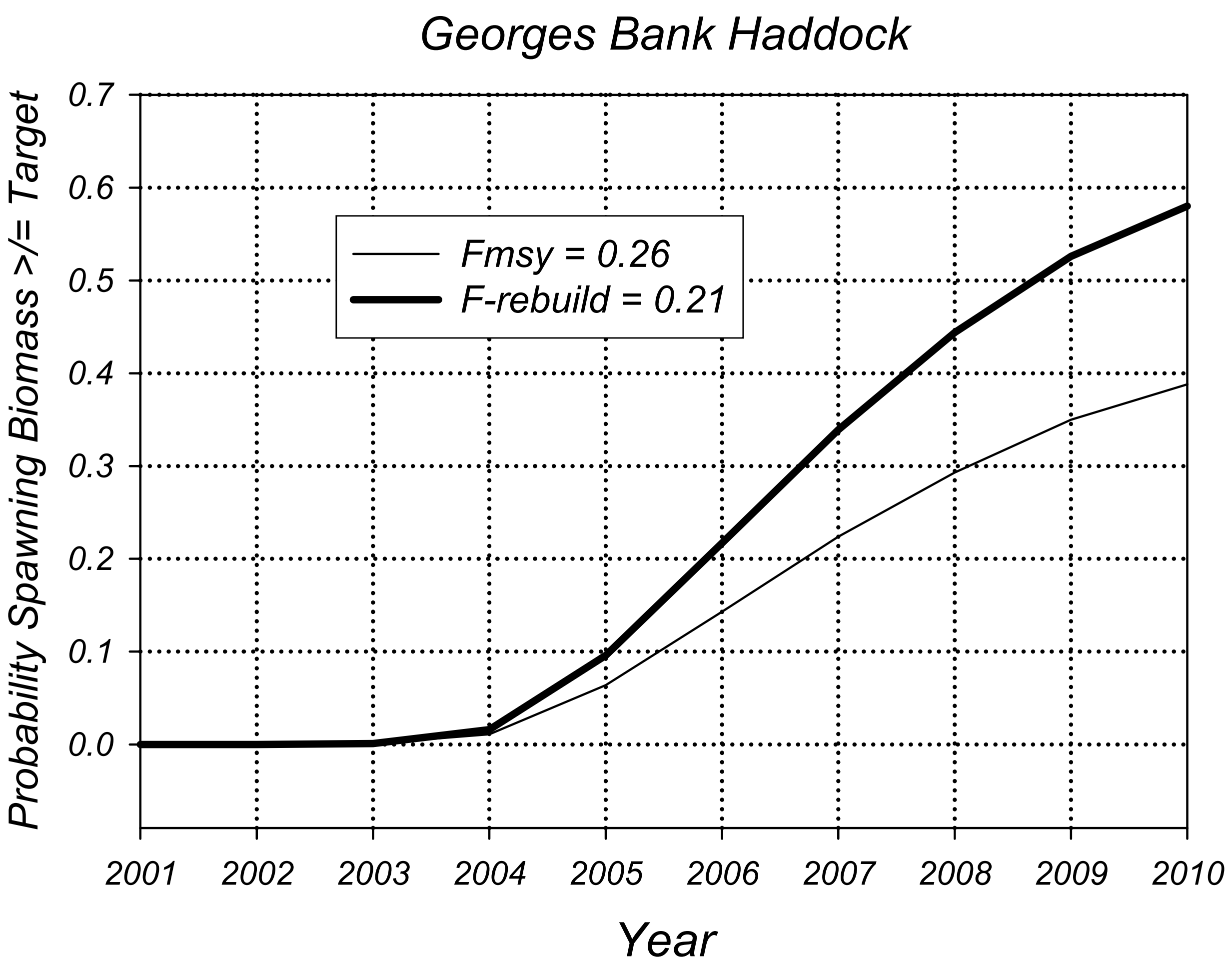


Figure 3.3.10. Probability that Georges Bank haddock spawning biomass will exceed Bmsy (250,300 mt) annually under two fishing mortality scenarios: Fmsy and F required to rebuild the stock to Bmsy by 2009.

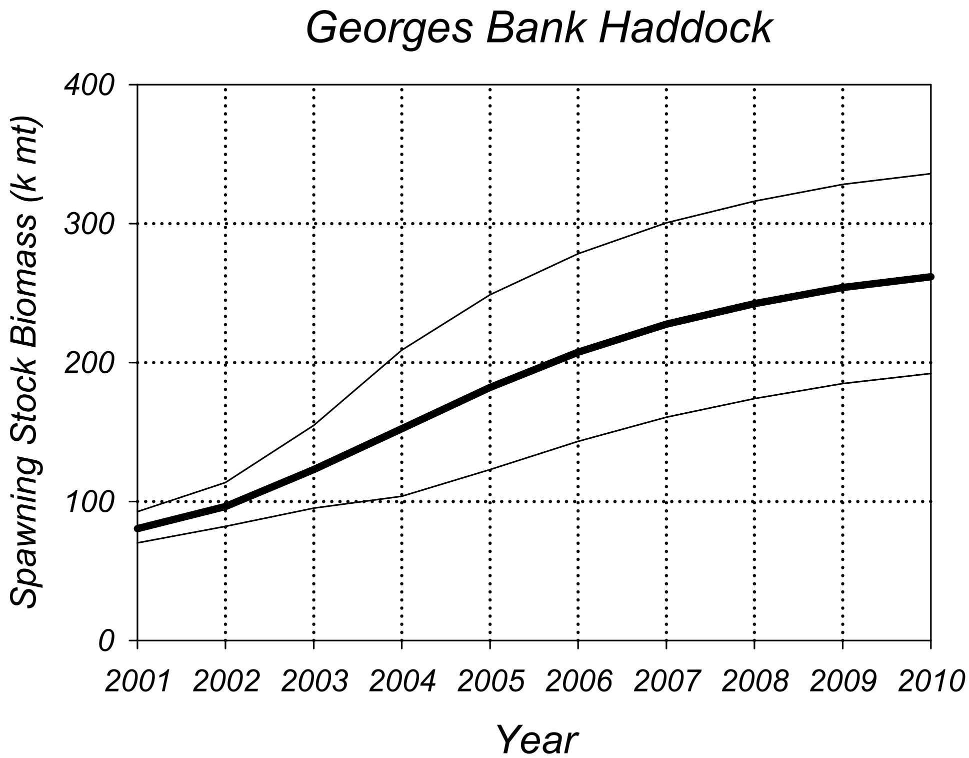


Figure 3.3.11. Median and 80% confidence interval of predicted spawning biomass for Georges Bank haddock under F-rebuild fishing mortality rates.

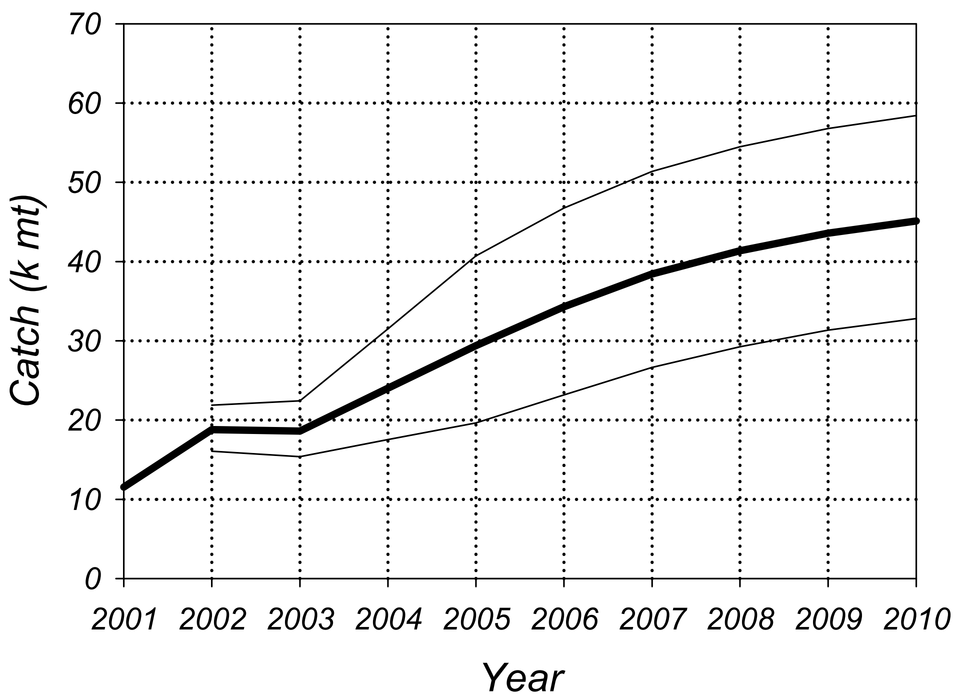


Figure 3.3.12. Median and 80% confidence interval of predicted catch for Georges Bank haddock under F-rebuild fishing mortality rates.