3.2 Georges Bank cod

Catch and Survey Indices

Atlantic cod on Georges Bank have been exploited since 1758 (Serchuk and Wigley 1992) and landings data are available since the late 1800s (Fig. 3.2.1). Record high landings occurred in 1966 (53,100 mt) and 1982 (57,200) and then landings subsequently declined, except for a peak in 1990 (42,500 mt). In 1995, landings reached a record low (7,900 mt) and have remained relatively constant since that time. Both spring and autumn bottom trawl survey indices also indicate a declining trend in biomass starting in the early 1970s and the stock has remained at a relatively stable but low biomass during the 1990s. Although strict management regulations implemented in 1994 reduced the fishing mortality on Georges Bank cod for both the US and Canada, the stock does not appear to be responding positively.

Stock Assessment

The most current assessment of Georges Bank cod (O'Brien and Munroe 2001) was peer reviewed by the Transboundary Resources Assessment Committee (TRAC) in 2001 (NEFSC 2001d). The assessment included US and Canadian commercial landings catch at age (10+) data from 1978-2000. US recreational landings and discard estimates were reported but not included in the total catch at age. The NMFS and Department of Fisheries and Oceans (DFO) spring bottom trawl survey data for ages 1-8 and NMFS autumn bottom trawl survey data for ages 1-6 were used to calibrate the Virtual Population Analysis (VPA). Estimates of both spawning stock biomass and recruitment at age 1 indicate a declining trend over the time series (Fig. 3.2.2a, Fig. 3.3.2b). The most recent estimates of recruitment are subject to change in subsequent assessments as more catch is taken from each of the cohorts.

Yield and SSB per Recruit Analysis

A yield and spawning stock biomass (SSB) per recruit analyses conducted using recent assessment data (O'Brien and Munroe 2001) resulted in changes in the previously estimated biological reference points (Table 3.2.2). Input data for catch weights (ages 1-10+) and stock weights (ages 1-9) were derived from the long term average weight during 1978-2000 (O'Brien and Munroe 2001). Stock mean weights for ages 10+ were derived from an expanded age structure out to age 18 (oldest age observed in survey) at F = F 40% = 0.167 and M= 0.2. The mean weights for ages 10 to 18 were estimated from the length- weight equation (O'Brien and Munroe 2001) : ln Weight (kg, live) = -11.7231 + 3.0521 ln Length (cm). The mean length at ages 10-18 were derived from the linear regression of length vs ln(age) using the 1978-1997 commercial length sample data. The partial recruitment (PR) is based on a normalized geometric mean of 1996-1999 fishing mortality and the maturity ogive is from the most recent assessment.

The newly estimated YPR biological reference points for $F_{0.1}$=0.169 , F_{max} = 0.331 and $F_{40\%}$ = 0.167 are slightly lower than those reported in O'Brien and Munroe (2001).

MSY-based Reference Point Estimation

Empirical Nonparametric Approach

The stock-recruit relationship for Georges Bank cod indicates a general increasing trend of recruitment of age 1 fish with increased spawning stock biomass (Figure 3.2.2c). The recruitment expected at B_{msy} can be considered to be the mean or median recruitment associated with the upper quartile of SSB. Using $F_{40\%} = 0.167$ as a proxy for F_{MSY}, the SSB/R at $F_{40\%} =$ 10.769, and the mean recruitment of 23.25 million fish results in a SSB_{msy} of 250,000 mt. Similarly, multiplying the yield per recruit of 1.6714 by mean recruitment results in a MSY estimate of 38,900 mt.

The estimate of MSY is within the range of observed landings, although SSB is higher than the maximum (93,000 mt) observed in the VPA time series. Hindcasting of autumn research survey indices suggest that higher levels of SSB, ranging from 72,000 mt to 233,000 mt, occurred during the 1970s (Brodziak *et al.* 2001).

Parametric Model Approach

Maximum likelihood fits of the 10 parametric stock-recruitment models to the Georges Bank cod data from 1978-2000 are listed below (Table 3.2.1). The model acronyms (BH= Beverton-Holt, etc.) are described in Section 2.1.2 and Table 2.1.2. The six hierarchical criteria described in Section 2.1.2 are applied to each of the models to determine the set of candidate models.

The first criterion is not satisfied by the PRK and PARK models because the estimate of F_{MSY} lies on the boundary of its feasible range. The second criterion is satisfied by all remaining models except models BH and ABH, where the point estimate of MSY exceed 1000 kt. This eliminates the BH and ABH models from being candidates. The third criterion is not satisfied by the PBH and PABH models because the point estimate of S_{MSY} is substantially greater than the nonparametric proxy. The fourth criterion is not satisfied by the RK and ARK models, where the F_{MSY} estimates of 0.67 and 0.67 greatly exceed the value of F_{MAX} =0.33 for Georges Bank cod. The fifth criterion is satisfied by the remaining autoregressive model PRABH. Last, the sixth criterion is considered be satisfied by the remaining 2 models: PRBH and PRABH.

Given the two candidate models (PRBH and PRABH), the AIC criterion assigns the greatest probability to the PRBH model. The odds ratio of PRBH being true to PRABH being true is over 4:1. Thus, there is clear basis for choosing between these two parametric models, even though both give virtually identical point estimates of $S_{MSY,}$ F_{MSY}, and MSY.

The results of using the PRBH model as the best fit parametric model are shown below (Table 3.2.1 and Figures 3.2.3-3.2.6). 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 3.2.4), with the exception of the 1985 and 2000 data points.

In the equilibrium yield plot (Figure 3.2.5), the yield surface is relatively flat in the neighborhood of the point estimate of F_{MSY} = 0.175. The point estimates of S_{MSY} (217 kt) and MSY (35 kt) appear consistent with the nonparametric proxy estimate of S_{MSY} and previous estimates of MSY. The stock-recruitment plot (Figure 3.2.6) shows that recruitment values near S_{MSY} are roughly 23 million fish which is consistent with the long-term average of the observed recruitment series when spawning biomass was high, lying within its upper quartile of values.

Parameter uncertainty plots show histograms of 5000 MCMC sample estimates of MSY, S_{MSY}, and F_{MSY} drawn from the posterior distribution of the MLE based on an uninformative prior. For MSY, the 80 percent credibility interval was (29.4, 38.0) with a median of 33.6 kt (Figure 3.2.7, upper panel). For S_{MSY}, the 80 percent credibility interval was (169.6, 234.1) with a median of 201.7 kt (Figure 3.2.7, middle panel). For F_{MSY}, the 80 percent credibility interval was (0.165, 0.200) with a median of 0.18 (Figure 3.2.7, lower panel). Overall, the point estimates of MSY and S_{MSY} were slightly larger than the medians of the MCMC samples.

Reference Points

Reference points derived from the Beverton-Holt stock recruit relationship with an assumed prior for the unfished recruitment from the VPA data are : F_{MSY} = 0.175, MSY = 35,200 mt and SSB_{MSY} = 217,000 mt. The MSY includes commercial landings only and does not include recreational landings or discards.

Projections

Stochastic age-based projections (Brodziak and Rago 2002) were performed to forecast the probability of attaining SSB_{MSY} within 10 years under an F_{MSY} (0.175) and an $F_{rebuilding}$ (0.0) strategy. Recruitment was derived from the Beverton-Holt stock recruit relationship using parameter values from the PRBH model (Table 3.2.1). Stock and catch mean weight, maturity at age, and partial recruitment input data are the same as described above for the yield and SSB per recruit analysis. The 2001 starting year population vector was derived from 1000 bootstrap iterations of the final VPA formulation (O'Brien and Munroe 2001). Fishing mortality in 2001 was derived based on estimated landings of 12,765 mt (US:10,631 mt + CAN:2,134 mt) and F in 2002 was set equivalent to the Amendment 7 target ($F_{0.1}$=0.169), the current management target.

The projections (Figures 3.2.8-3.2.10) indicate that there is only a 0.2% probability of reaching SSB_{MSY} (217,000 mt) by 2009 under an F_{MSY} strategy. A 50% probability of achieving SSB_{MSY} by 2009 is not possible under any F strategy (Figure 3.2.8). Under a rebuilding F=0.0, there is only a 34% probability of achieving SSB_{MSY} by 2009 (Figure 3.2.8-3.2.9). The landings would decline to zero in 2003 under F rebuilding (Figure 3.2.10).

Table 3.2.1. Stock-recruitment model comparisons for Georges Bank cod.

Georges Bank Cod Model Comparison										
SMAX =	104.2									
	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior	Prior
	0	0	0	0	0.5000	0.5000	0	0	0	0
	BH	ABH	PBH	PABH	**PRBH**	**PRABH**	RK	ARK	PRK	PARK
Posterior Probability	0.00	0.00	0.00	0.00	**0.82**	**0.18**	0.00	0.00	0.00	0.00
Odds Ratio for Most Likely Model					1.00	4.41				
Normalized Likelihood	0.00	0.00	0.00	0.00	0.82	0.18	0.00	0.00	0.00	0.00
Model AIC Ratio					4.40835	1				
	BH	**ABH**	**PBH**	**PABH**	**PRBH**	**PRABH**	**RK**	**ARK**	**PRK**	**PARK**
Number_of_data_points	23	23	23	23	23	23	23	23	23	23
Number_of_parameters	3	4	3	4	3	4	3	4	3	4
Negative_loglikelihood	74.3004	74.1295	75.1716	75.163	78.3868	78.382	83.8389	80.4065	92.8811	81.6877
Bias-corrected_AIC	155.864	158.481	158.403	161.161	159.003	161.97	174.941	171.035	193.927	175.53
Diagnostic Comments										
Parameter Point Estimates	MSY and SMSY are outside credible range	MSY and SMSY are outside credible range	SMSY is substantially greater than nonparametric proxy	SMSY is substantially greater than nonparametric proxy	**Most Likely Model**		Estimate of FMSY is substantially greater than FMAX	Estimate of FMSY is substantially greater than FMAX	FMSY at boundary of feasible range	FMSY at boundary of feasible range
**********										
MSY	20436.3	38550.8	45.8844	47.614	35.236	35.1229	28.1625	27.9784	39.4505	50.5792
FMSY	0.135	0.14	0.175	0.175	0.175	0.175	0.67	0.67	2	2
SMSY	161234	293660	282.291	292.932	216.78	216.083	54.8568	54.4983	39.1762	50.2274
alpha	20193.6	37973.7	36.4922	38.1719	28.2855	28.2016	0.000046	4.54183E-05	1.37	1.34697
expected_alpha	23621.4	44444.3	43.475	45.4171	33.8542	33.7593	0.0000659	0.000067713	0.15	5.30705
beta	88263.2	165045	97.6222	104.468	77.6945	77.5179	-2.20E-02	-2.21E-02	1.21594	-0.033924
RMAX	23.8117	23.9592	18.8408	19.0615	16.2036	16.1713	10.5563	10.3985	2.7619	11.6858
expected_RMAX	27.8536	28.0418	22.446	22.6794	19.3937	19.3581	15.121	15.5029	-0.04015	46.0419
Prior_mean			0.84	0.84	23.248	23.248			5.35846	1.37
Prior_se			0.08	0.08	4.38	4.38			12.1712	0.15
Z_Myers	0.61	0.61	0.72	0.71	0.71	0.71				
sigma	0.560	0.561	0.592	0.590	0.600	0.600	0.848	0.894	1.281	1.656
phi		-0.14		-0.04		0.02		0.59		0.88
sigmaw		0.56		0.59		0.60		0.72		0.78
last log-residual R		-1.361		-1.579		-1.502		-2.189		-3.194
expected lognormal error term	1.170	1.17	1.19	1.19	1.20	1.20	1.43	1.49	2.27	3.94

Table 3.2.2. Yield and biomass per recruit of Georges Bank cod.

```
   The NEFC Yield and Stock Size per Recruit Program - PDBYPRC
    PC Ver.1.2 [Method of Thompson and Bell (1934)] 1-Jan-1992
              ---------------------------------------
              Run Date: 21- 2-2002;  Time: 14:26:43.51
 Cod Georges Bank 2002 -10+ from 18+ mean wt, 78-2000 weights,96-99 P
```

```
 Proportion of F before spawning:  .1667
 Proportion of M before spawning:  .1667
 Natural Mortality is Constant at:  .200
 Initial age is:  1; Last age is: 10
 Last age is a PLUS group;
 Original age-specific PRs, Mats, and Mean Wts from file: ==> GBYPR102.DAT
```

Age-specific Input data for Yield per Recruit Analysis

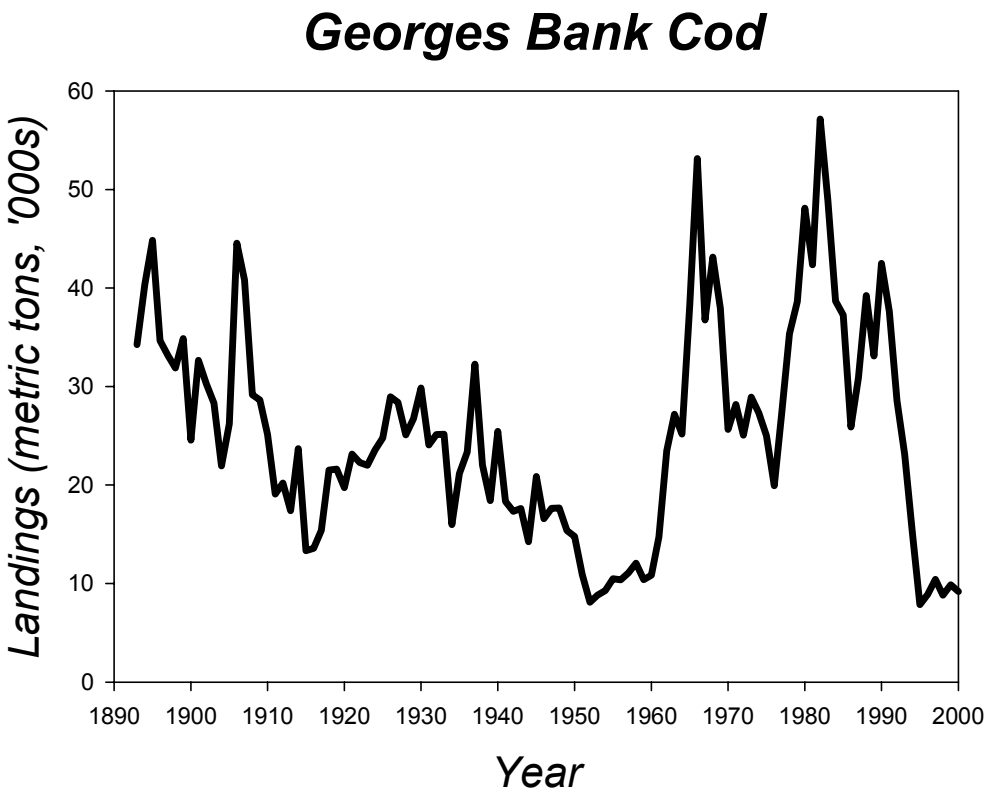
Age	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Weights Catch	Stock
1	.0001	1.0000	.1300	.888	.682
2	.1900	1.0000	.5700	1.514	1.146
3	.6600	1.0000	.9200	2.361	1.882
4	1.0000	1.0000	1.0000	3.634	2.926
5	1.0000	1.0000	1.0000	5.024	4.245
6	1.0000	1.0000	1.0000	6.588	5.716
7	1.0000	1.0000	1.0000	8.334	7.387
8	1.0000	1.0000	1.0000	9.742	8.963
9	1.0000	1.0000	1.0000	11.366	10.489
10+	1.0000	1.0000	1.0000	14.736	15.231

```
 Summary of Yield per Recruit Analysis for:
 Cod Georges Bank 2002 -10+ from 18+ mean wt, 78-2000 weights,96-99 PR
```

```
  Slope of the Yield/Recruit Curve at F=0.00: -->   25.9200
    F level at slope=1/10 of the above slope (F0.1): ----->    .169
      Yield/Recruit corresponding to F0.1: ----->    1.6768
    F level to produce Maximum Yield/Recruit (Fmax): ----->    .331
      Yield/Recruit corresponding to Fmax: ----->    1.8234
    F level at 40 % of Max Spawning Potential (F40): ----->    .167
      SSB/Recruit corresponding to F40: -------->   10.7691
```

```
 Listing of Yield per Recruit Results for:
 Cod Georges Bank 2002 -10+ from 18+ mean wt, 78-2000 weights,96-99 PR
```

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	.000	.00000	.00000	5.5167	28.9398	4.1019	26.9291	100.00
	.050	.13176	.92201	4.8605	21.2025	3.4448	19.2924	71.64
	.100	.22012	1.38404	4.4213	16.4507	3.0046	14.6204	54.29
	.150	.28367	1.62149	4.1061	13.3248	2.6884	11.5583	42.92
F0.1	.169	.30318	1.67679	4.0095	12.4235	2.5914	10.6776	39.65
F40%	.167	.30112	1.67136	4.0197	12.5172	2.6016	10.7691	39.99
	.200	.33169	1.74194	3.8684	11.1619	2.4498	9.4469	35.08
	.250	.36936	1.79889	3.6825	9.6051	2.2629	7.9321	29.46
	.300	.39976	1.82056	3.5327	8.4480	2.1123	6.8094	25.29
Fmax	.331	.41593	1.82339	3.4532	7.8716	2.0324	6.2514	23.21
	.350	.42489	1.82243	3.4093	7.5643	1.9881	5.9543	22.11
	.400	.44604	1.81326	3.3057	6.8737	1.8837	5.2876	19.64
	.450	.46412	1.79810	3.2173	6.3229	1.7946	4.7570	17.66
	.500	.47980	1.77992	3.1409	5.8757	1.7175	4.3270	16.07
	.550	.49355	1.76043	3.0741	5.5069	1.6501	3.9729	14.75
	.600	.50572	1.74066	3.0152	5.1984	1.5905	3.6773	13.66
	.650	.51659	1.72119	2.9627	4.9371	1.5374	3.4272	12.73
	.700	.52637	1.70234	2.9155	4.7133	1.4896	3.2132	11.93
	.750	.53524	1.68430	2.8729	4.5197	1.4465	3.0283	11.25
	.800	.54332	1.66712	2.8342	4.3506	1.4072	2.8670	10.65
	.850	.55073	1.65084	2.7988	4.2017	1.3713	2.7251	10.12
	.900	.55755	1.63544	2.7663	4.0696	1.3383	2.5993	9.65
	.950	.56386	1.62088	2.7363	3.9517	1.3078	2.4871	9.24
	1.000	.56972	1.60712	2.7086	3.8457	1.2796	2.3863	8.86



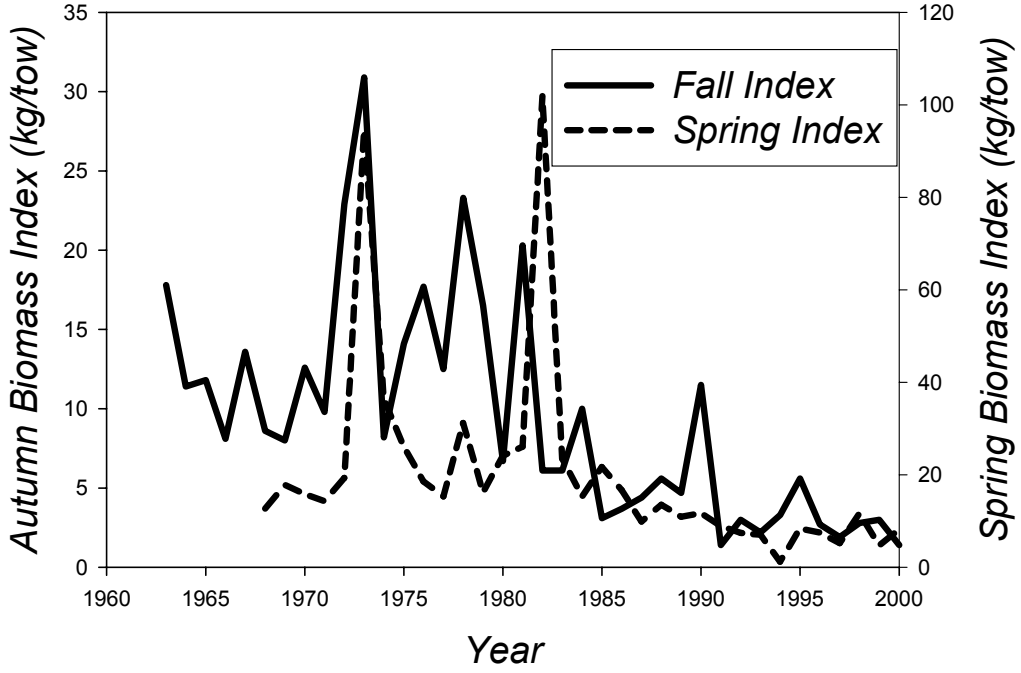
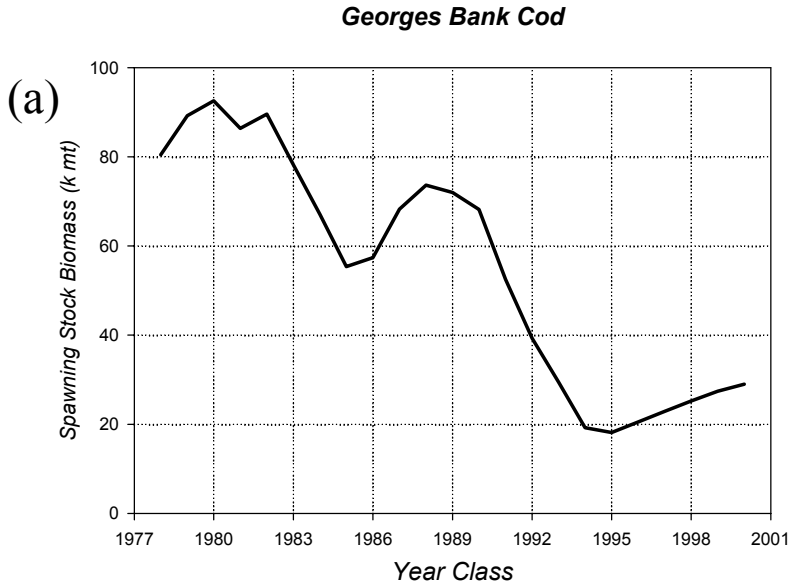
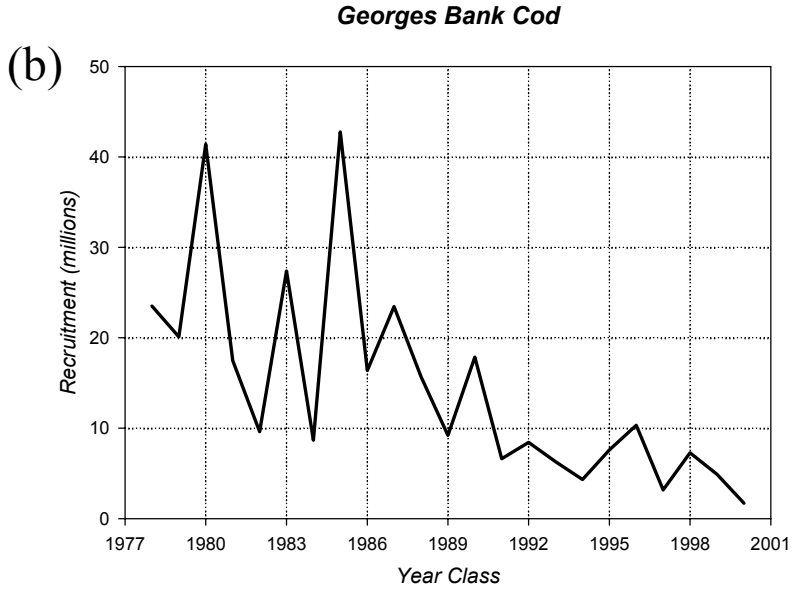
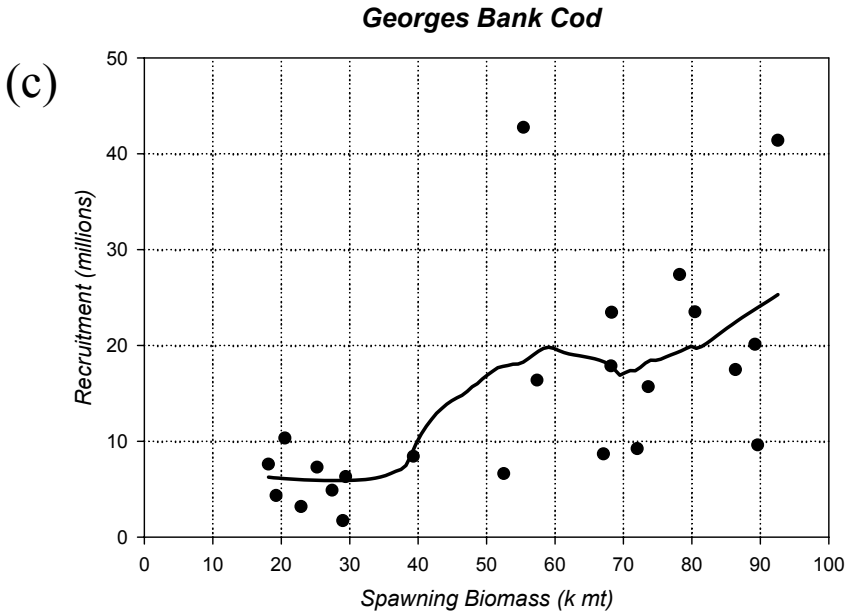


Figure 3.2.1. Landings and research vessel survey abundance indices for Georges Bank cod.







		F0.1	F40% MSP
F reference point		0.169	0.167
ssb per recruit at F		10.6776	10.7691
	Recruitment (millions)	SS Biomass at F0.1	SS Biomass at F40%
n	23	23	23
mean	14.53	155.16	156.49
min	1.71	18.26	18.42
max	42.75	456.48	460.39
10th %'tile	4.44	47.45	47.86
25th %'tile	6.96	74.33	74.97
50th %'tile	9.62	102.67	103.54
75th %'tile	18.99	202.74	204.48
90th %'tile	26.61	284.18	286.61
Std Dev	11.20	119.62	120.65
CV	0.77	0.77	0.77
For Top Quartile of SSB			
Mean	23.25	248.23	250.36
Median	21.81	232.88	234.88

Figure 3.2.2. Spawning stock (a), recruitment (age 1 millions, b), and scatterplot (c) for Georges Bank cod. 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 3.2.2). Smoother in the stock-recruitment plot is lowess with tension = 0.5.

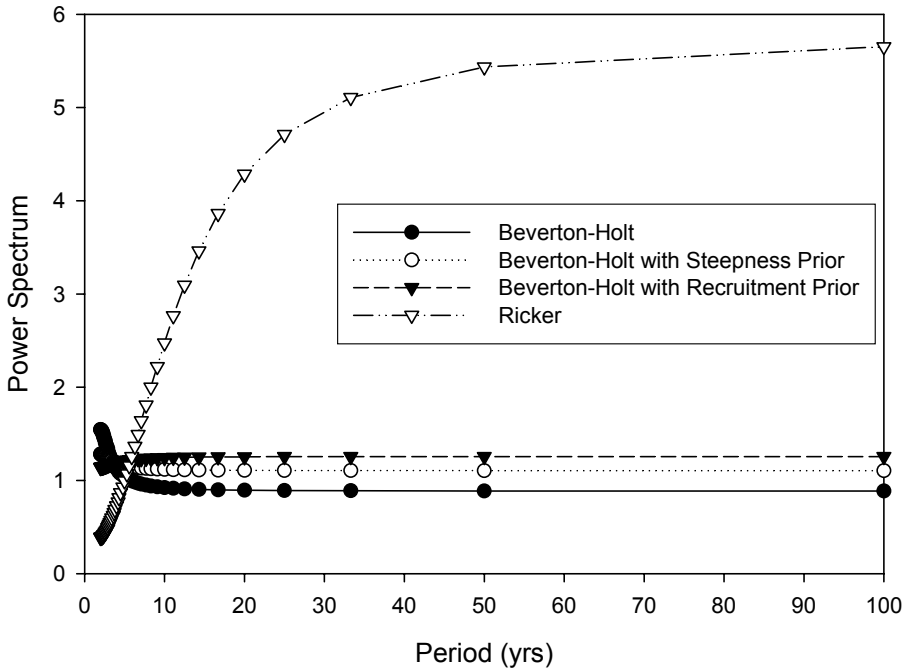


Figure 3.2.3. Georges Bank cod periodicity of environmental forcing for autoregressive stock-recruitment models

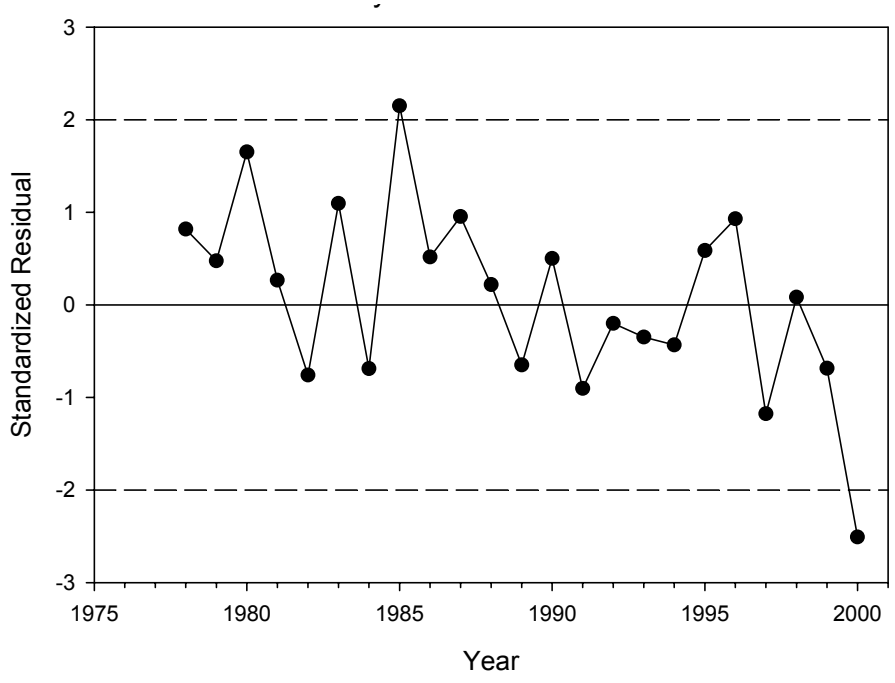


Figure 3.2.4. Georges Bank cod standardized residuals for the most likely stock-recruitment model

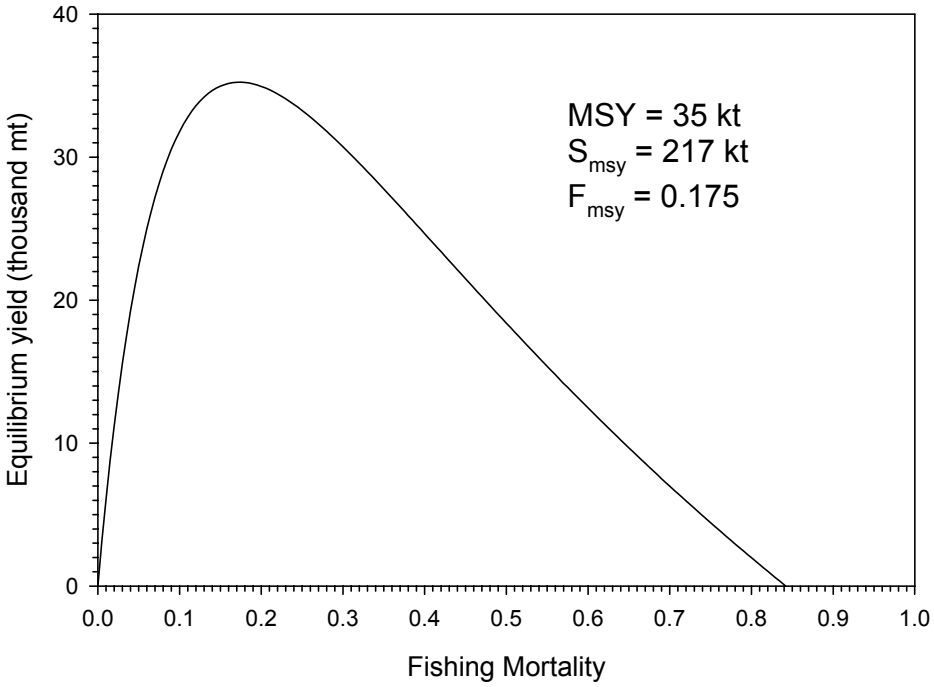


Figure 3.2.5. Georges Bank cod equilibrium yield vs. F for the most likely stock-recruitment model.

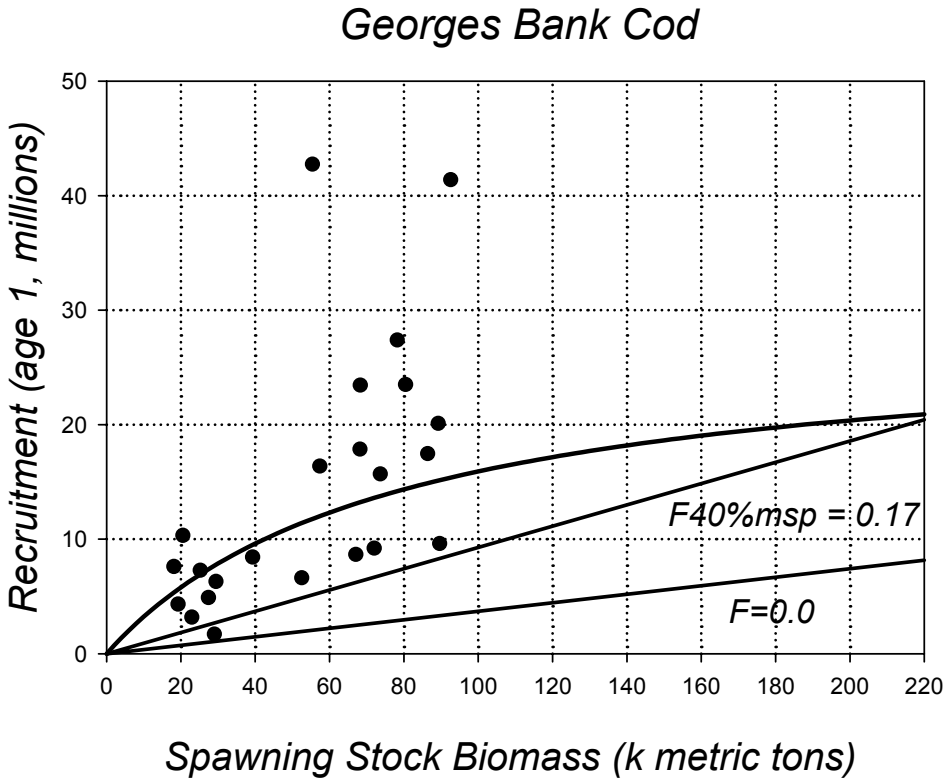


Figure 3.2.6. Stock recruitment relationship for best fit parametric model Georges Bank cod. Stock-recruitment data points are overplotted, along with the predicted S-R line and replacement lines for F=100% msp=0.00 and F40%msp = 0.17.

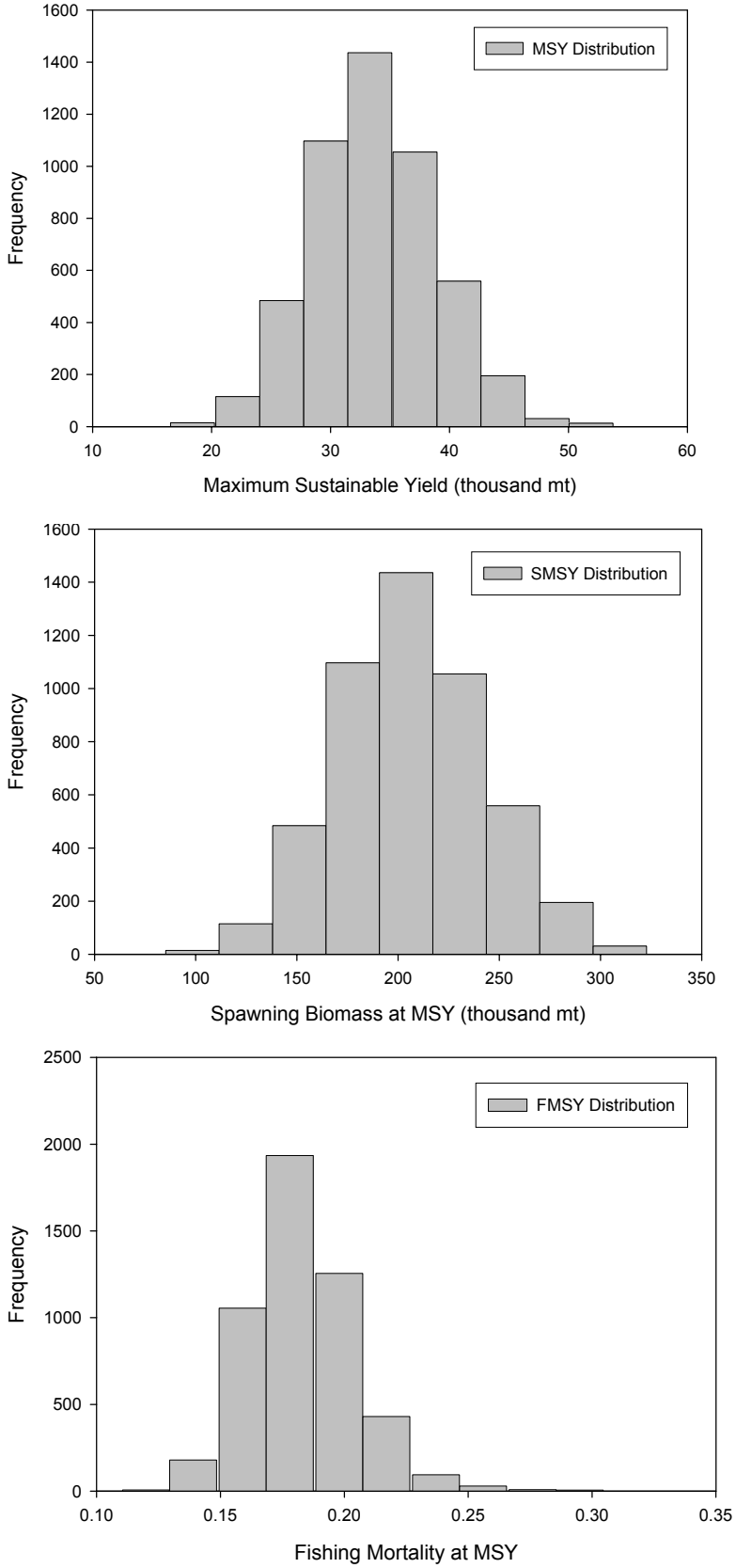


Figure 3.2.7. Georges Bank cod posterior distribution of MSY, BMSY and FMSY for most likely model fit.

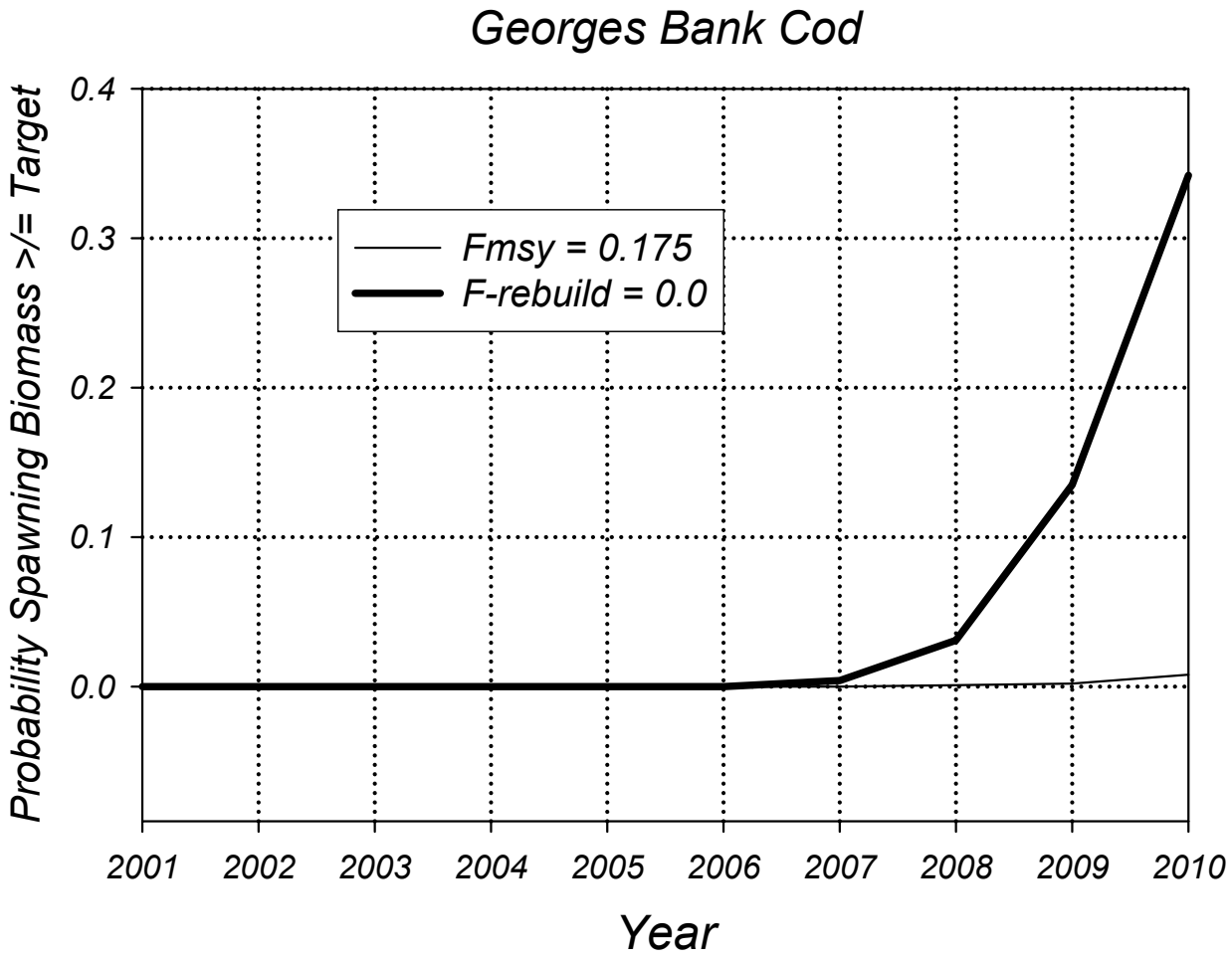


Figure 3.2.8. Probability that Georges Bank cod spawning biomass will exceed Bmsy (216,800 mt) annually under two fishing mortality scenarios: Fmsy and F required to rebuild the stock to Bmsy by 2009.

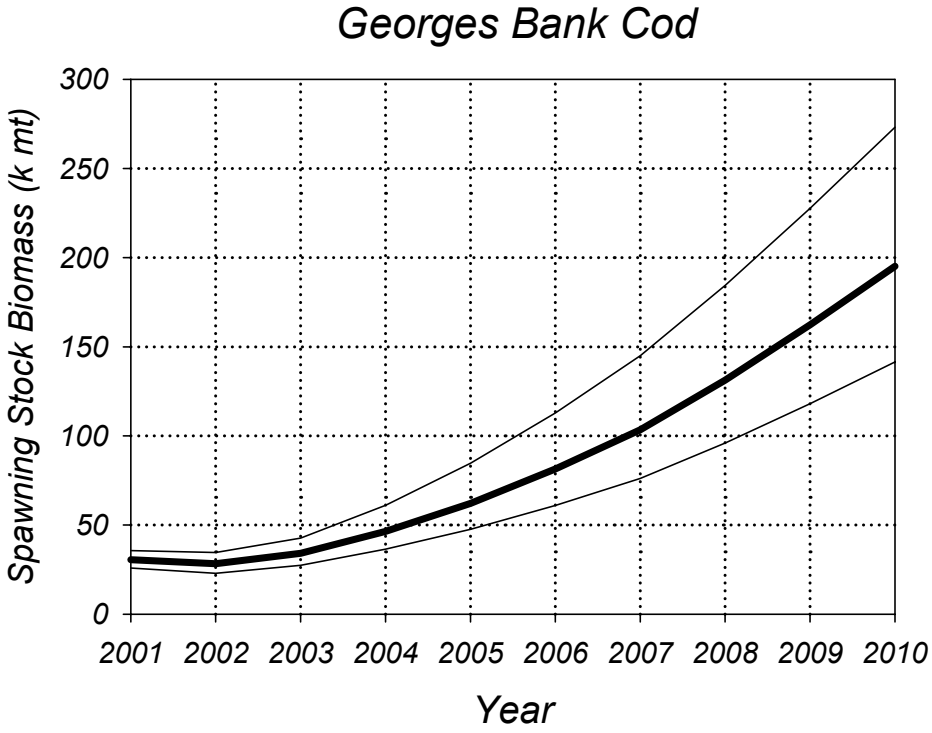


Figure 3.2.9. Median and 80% confidence interval of predicted spawning biomass for Georges Bank cod under F-rebuild fishing mortality rates.

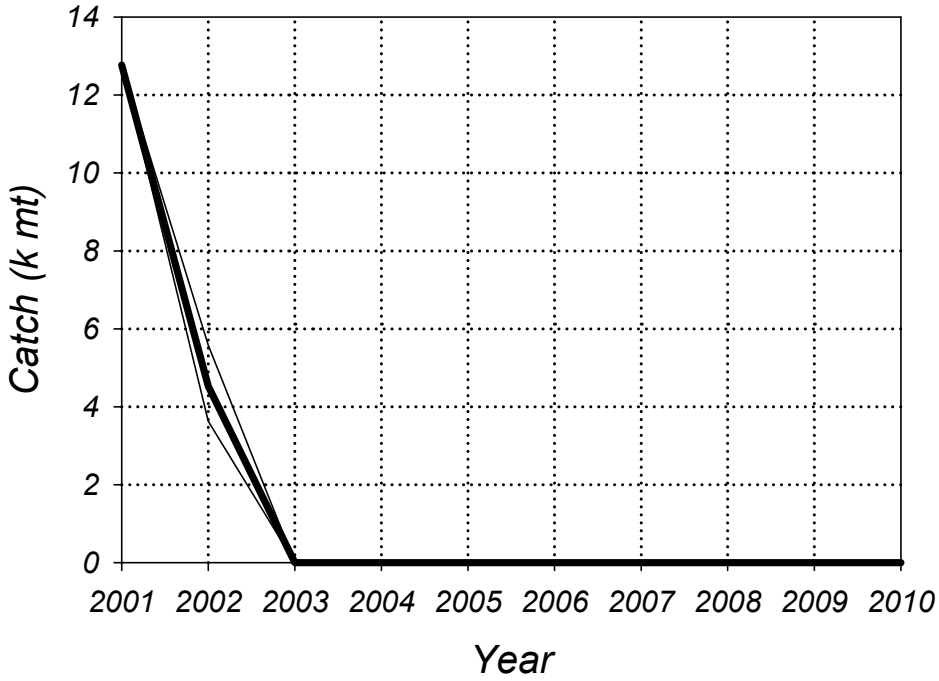


Figure 3.2.10. Median and 80% confidence interval of predicted catch for Georges Bank cod under F-rebuild fishing mortality rates.