

## **A. Georges Bank Atlantic Cod by L. O'Brien**

### **1.0 Background**

This stock was last assessed and peer reviewed in April 2000 (O'Brien 2000, Transboundary Resources Assessment Committee 2000) and is summarized in this report. Fully recruited F (ages 4-8, u) was estimated to be 0.22 in 1999, the lowest in the time series (1978-1999). Spawning stock biomass was 34,800 mt in 1999 and continued the increasing trend from the record low estimate of 20,000 mt in 1994. Mean biomass was 43,000 mt in 1999 and has followed trends similar to SSB. Since 1992, recruiting year classes have all been below the long term average and the 1997 year class which entered the 1999 fishery as 2 year olds, is the lowest on record. The NEFSC spring and autumn bottom trawl survey indices continue to remain near record low values. Recruitment indices for age 2 fish from the 1994, 1995, 1996, and 1997 year classes are below the time series (1963-1999) average. The most recent above average year class occurred in 1993.

### **2.0 2000 Assessment**

#### *The Fishery*

Total commercial landings of Georges Bank cod (Table A1, Figure A1) in 1999 (9,800 mt) increased 12% from 1998. USA landings increased 16% (8,100 mt) and Canadian landings declined 3% (1819 mt) in 1999 (Table A1). No discards estimates were derived for 1999. Recreational landings were estimated at 357 mt, a decline of about 31% from 1998.

The total number of commercial length samples in 1999 were less than in 1998. The number of quarterly samples were adequate for both scrod and market size categories, but poor for the large market category. The 'large' samples were pooled on a semi-annual basis. Spatial coverage was poor for eastern Georges Bank (SA 561, 562), as it has been for several years. As in the last assessment, length samples from western Georges Bank and combined US and Canadian age samples from eastern Georges Bank were applied to characterize the landings from eastern Georges Bank. Landings were dominated in numbers by age 3 fish in both the US and Canadian fisheries and in weight by age 3 fish in the USA fishery and age 4 fish in the Canadian fishery.

#### *Input data and Analyses*

The current assessment is an update of the 1999 assessment and employs the same VPA formulation (NDWG, NEFSC 2000). A slight variation from the previous assessment is that the number of surveys available as tuning indices in the terminal year decreases from three to two since the USA 2000 spring survey was not available when the assessment was conducted. Catch at age has been updated with total 1999 landings (USA and Canadian) and research survey indices have been estimated for the 1999 NEFSC spring and autumn bottom trawl surveys and the 2000 Canadian Department of Fisheries and Oceans (DFO) spring bottom trawl survey. A conditional non-parametric bootstrap procedure (Efron 1982) was used to evaluate the

precision of fishing mortality, spawning stock biomass, and mean biomass estimates. A retrospective analysis was performed for terminal year fishing mortality, spawning stock biomass, and age 1 recruitment.

### 3.0 Assessment Results

NEFSC spring and autumn survey abundance and biomass indices declined in 1999 to similar values observed in 1997, except for the autumn biomass index which has increased slightly since 1997. All indices, however, remain below the long term average (Table A2, Figure A2). The Canadian spring survey index of abundance increased in 1999 to similar values observed in 1996 (Figure A2). The recruitment indices for age 1 and 2 from the 1999 NEFSC autumn bottom trawl survey were well below average.

Fully recruited fishing mortality (age 4-8) was estimated at 0.22 in 1999 and the uncertainty of this estimate, as indicated by the retrospective analysis, is discussed below. The 1998 F estimate was 0.39, 39% higher than initially estimated in the 1999 assessment (NDWG, NEFSC 2000) (Figure A3). Biomass weighted fishing mortality declined from a time series high of 0.64 in 1993 to 0.23 in 1999 (Table A3, Figure A3). Spawning stock biomass in 1999 was estimated at 34,800 mt, a 10% increase from 1998 and a 74% increase from the record low in 1994 (Table A3, Figure A4). Mean biomass increased from a record low 31,000 mt in 1994 to 43,000 mt in 1999 (Table A3, Figure A4). Recruitment of the 1998 year class (5.3 million age 1 fish) is estimated to be similar to the 1994 year class (4.7 million age 1 fish) (Table A3, Figure A4). The survival ratio of recruit/SSB was above average for the 1995 and 1996 year classes and below average for the more recent year classes.

#### *VPA Diagnostics*

Stock size estimates for ages 1-8 were well estimated with CVs ranging from 0.21 to 0.47. The distribution of F estimates from the bootstrap analysis ranged from 0.16 to 0.40 with an 80% probability that F in 1999 was between 0.18 and 0.25. The distribution of SSB estimates from the bootstrap analysis ranged from 28,000 mt to 48,000 mt with an 80% probability that SSB in 1999 was between 31,000 mt and 39,000 mt. The distribution of the 1999 mean biomass estimates, derived from bootstrap analysis, ranged from 32,000 to 62,000 mt. There is a 80% probability that the mean biomass in 1999 was between 38,000 mt and 48,000 mt.

A retrospective pattern exists in this model formulation back to 1994 (Figure A5). The terminal year estimates of both recruits and fishing mortality are less than converged estimates since 1994 and 1995, respectively, and SSB estimates are greater than converged estimates since 1994. This may partially be due to the lack of Canadian indices in the calibration for 1993 and 1994. Other factors influencing the retrospective pattern may include mis-reporting of catch, immigration or emigration, an unrepresentative estimate of natural mortality, and mis-specification of the model.

The fishing mortality of 0.28 that was assumed for the projection analysis in 1999 (NDWG, 2000) was not within the 80% confidence interval (0.18 - 0.25) of the 1999 F derived from current VPA calibration.

#### 4.0 SFA control rule

The SFA control rule for Georges Bank cod is based on  $B_{MSY}$  (108,000 mt) and states that when the stock biomass is between  $1/4$  and  $1/2 B_{MSY}$  (27,000-54,000 mt), the threshold mortality rate is defined by a five year rebuilding time period, and if the stock is between  $1/2 B_{MSY}$  and  $B_{MSY}$  the rebuilding time period is 10 years (Figure A6). In 1999, mean biomass was estimated at 43,000 mt, about 40% of the target  $B_{MSY}$  and  $F$  weighted by biomass was estimated at 0.23.

#### 5.0 Sources of Uncertainty

- Landings data for 1994-1999 are derived by proration and are provisional.
- There was inadequate commercial sampling in 1999 both temporally and spatially. The large market category was not well sampled by quarter, and samples from eastern GB were minimal.
- The retrospective analysis indicates a pattern in the estimates of  $F$ , SSB, and recruits in the VPA. The terminal year estimates of both fishing mortality and recruits are less than the converged estimates and SSB estimates are greater than the converged estimates.
- There are inadequate data to characterize both the recreational and discarded catch, particularly if these components increase. The SARC previously rejected using poorly sampled recreational catch since a recreational catch at age with a similar age structure to the commercial catch at age would only be a scaling factor.

#### 6.0 References

- Efron, B. 1982. The jackknife, the bootstrap and other resampling plans. *Phila. Soc. Ind. and Appl. Math.* 34: 92 p.
- NDWG (Northern Demersal Working Group, Northeast Regional Stock Assessment Workshop). 2000.. Assessment of 11 Northeast groundfish stocks through 1999: a report to the New England Fishery Management Council's Multi-Species Monitoring Committee. *Northeast Fish. Sci. Cent. Ref. Doc* 00-05; 175 p.
- O'Brien, L. 2000. Assessment of the Georges Bank cod stock for 2000. *Northeast Fish. Sci. Cent. Ref. Doc* 00-17, 117 p.
- Transboundary Resources Assessment Committee. 2000. TRAC advisory report on stock status: a report of the third meeting of the Transboundary Resources Assessment Committee (TRAC), Woods Hole, Massachusetts, April 26-28, 2000. *Northeast Fish. Sci. Cent. Ref. Doc* 00-08, 20 p.

Table A1. Commercial landings (metric tons, live) of Atlantic cod from Georges Bank and South (Division 5Z and Subarea 6), 1960 - 1999.

| Year | Country |        |       |       |        |       | Total |
|------|---------|--------|-------|-------|--------|-------|-------|
|      | USA     | Canada | USSR  | Spain | Poland | Other |       |
| 1960 | 10834   | 19     | -     | -     | -      | -     | 10853 |
| 1961 | 14453   | 223    | 55    | -     | -      | -     | 14731 |
| 1962 | 15637   | 2404   | 5302  | -     | 143    | -     | 23486 |
| 1963 | 14139   | 7832   | 5217  | -     | -      | 1     | 27189 |
| 1964 | 12325   | 7108   | 5428  | 18    | 48     | 238   | 25165 |
| 1965 | 11410   | 10598  | 14415 | 59    | 1851   | -     | 38333 |
| 1966 | 11990   | 15601  | 16830 | 8375  | 269    | 69    | 53134 |
| 1967 | 13157   | 8232   | 511   | 14730 | -      | 122   | 36752 |
| 1968 | 15279   | 9127   | 1459  | 14622 | 2611   | 38    | 43136 |
| 1969 | 16782   | 5997   | 646   | 13597 | 798    | 119   | 37939 |
| 1970 | 14899   | 2583   | 364   | 6874  | 784    | 148   | 25652 |
| 1971 | 16178   | 2979   | 1270  | 7460  | 256    | 36    | 28179 |
| 1972 | 13406   | 2545   | 1878  | 6704  | 271    | 255   | 25059 |
| 1973 | 16202   | 3220   | 2977  | 5980  | 430    | 114   | 28923 |
| 1974 | 18377   | 1374   | 476   | 6370  | 566    | 168   | 27331 |
| 1975 | 16017   | 1847   | 2403  | 4044  | 481    | 216   | 25008 |
| 1976 | 14906   | 2328   | 933   | 1633  | 90     | 36    | 19926 |
| 1977 | 21138   | 6173   | 54    | 2     | -      | -     | 27367 |
| 1978 | 26579   | 8778   | -     | -     | -      | -     | 35357 |
| 1979 | 32645   | 5978   | -     | -     | -      | -     | 38623 |
| 1980 | 40053   | 8063   | -     | -     | -      | -     | 48116 |
| 1981 | 33849   | 8499   | -     | -     | -      | -     | 42348 |
| 1982 | 39333   | 17824  | -     | -     | -      | -     | 57157 |
| 1983 | 36756   | 12130  | -     | -     | -      | -     | 48886 |
| 1984 | 32915   | 5763   | -     | -     | -      | -     | 38678 |
| 1985 | 26828   | 10443  | -     | -     | -      | -     | 37271 |
| 1986 | 17490   | 8411   | -     | -     | -      | -     | 25901 |
| 1987 | 19035   | 11845  | -     | -     | -      | -     | 30880 |
| 1988 | 26310   | 12932  | -     | -     | -      | -     | 39242 |
| 1989 | 25097   | 8001   | -     | -     | -      | -     | 33098 |
| 1990 | 28193   | 14310  | -     | -     | -      | -     | 42503 |
| 1991 | 24175   | 13455  | -     | -     | -      | -     | 37630 |
| 1992 | 16855   | 11712  | -     | -     | -      | -     | 28567 |
| 1993 | 14594   | 8519   | -     | -     | -      | -     | 23113 |
| 1994 | 9893*   | 5276   | -     | -     | -      | -     | 15169 |
| 1995 | 6759*   | 1100   | -     | -     | -      | -     | 7859  |
| 1996 | 7020*   | 1885   | -     | -     | -      | -     | 8905  |
| 1997 | 7537*   | 2898   | -     | -     | -      | -     | 10435 |
| 1998 | 6959*   | 1873   | -     | -     | -      | -     | 8832  |
| 1999 | 8061*   | 1819   | -     | -     | -      | -     | 9880  |

\* Provisional data

Table A2. Standardized stratified mean catch per tow in numbers and weight (kg) for Atlantic cod in NEFSC offshore spring and autumn research vessel bottom trawl surveys on Georges Bank (Strata 13-25), 1963 - 2000. [a,b,c]

| Year    | Spring    |          | Autumn   |         |
|---------|-----------|----------|----------|---------|
|         | No/Tow    | Wt/Tow   | No/Tow   | Wt/Tow  |
| 1963    | -         | -        | 4.37     | 17.8    |
| 1964    | -         | -        | 2.98     | 11.6    |
| 1965    | -         | -        | 4.25     | 11.7    |
| 1966    | -         | -        | 4.81     | 8.1     |
| 1967    | -         | -        | 10.38    | 13.6    |
| 1968    | 4.72      | 12.6     | 3.30     | 8.6     |
| 1969    | 4.64      | 17.8     | 2.20     | 8.0     |
| 1970    | 4.34      | 15.6     | 5.07     | 12.5    |
| 1971    | 3.39      | 14.2     | 3.19     | 9.9     |
| 1972    | 8.97      | 19.0     | 13.09    | 23.0    |
| 1973    | 18.68 [d] | 39.7 [d] | 12.28    | 30.8    |
| 1974    | 14.75     | 36.4     | 3.49     | 8.2     |
| 1975    | 6.89      | 26.0     | 6.41     | 14.1    |
| 1976    | 7.06      | 18.6     | 10.44    | 17.7    |
| 1977    | 6.30      | 15.4     | 5.45     | 12.5    |
| 1978    | 12.31     | 31.2     | 8.59     | 23.3    |
| 1979    | 5.16      | 16.9     | 5.95     | 16.5    |
| 1980    | 6.12      | 16.7     | 2.91     | 6.7     |
| 1981    | 10.44     | 26.1     | 9.04     | 19.0    |
| 1982    | 8.20 [e]  | 15.4 [e] | 3.71     | 6.9     |
| 1983    | 7.70      | 24.0     | 3.64     | 6.5     |
| 1984    | 4.08      | 15.4     | 4.75     | 10.3    |
| 1985    | 6.94      | 21.5     | 2.43     | 3.5     |
| 1986    | 5.04      | 16.7     | 3.12     | 4.7     |
| 1987    | 3.26      | 10.3     | 2.33     | 4.4     |
| 1988    | 5.86      | 13.5     | 3.11     | 5.8     |
| 1989    | 4.80      | 10.8     | 4.78     | 4.6     |
| 1990    | 4.74      | 11.6     | 3.62 [f] | 7.1 [f] |
| 1991    | 4.39      | 9.0      | 0.96     | 1.4     |
| 1992    | 2.67      | 7.5      | 1.84     | 3.1     |
| 1993    | 2.48      | 7.3      | 2.15     | 2.2     |
| 1994    | 0.94      | 1.2      | 1.82     | 3.3     |
| 1995    | 3.29      | 8.4      | 3.62     | 5.6     |
| 1996    | 2.70      | 7.5      | 1.10     | 2.7     |
| 1997    | 2.32      | 5.2      | 0.87     | 1.9     |
| 1998    | 4.36      | 11.7     | 1.87     | 2.8     |
| 1999    | 2.15      | 4.7      | 1.02     | 3.0     |
| 2000    | 3.57      | 8.2      |          |         |
| Average | 5.86      | 16.64    | 4.46     | 9.55    |

[a] During 1963-1984, BMV oval doors were used in spring and autumn surveys; since 1985, Portuguese polyvalent doors have been used in both surveys. Adjustments have been made to the 1963-1984 catch per tow data to standardize these data to polyvalent door equivalents. Conversion coefficients of 1.56 (numbers) and 1.62 (weight) were used in this standardization (NEFC 1991).

[b] Spring surveys during 1980-1982, 1989-1991 and 1994 and autumn surveys during 1977-1981, 1989-1991, and 1993 were accomplished with the *R/V Delaware II*; in all other years, the surveys were accomplished using the *R/V Albatross IV*. Adjustments have been made to the *R/V Delaware II* catch per tow data to standardize these to *R/V Albatross IV* equivalents. Conversion coefficients of 0.79 (numbers) and 0.67 (weight) were used in this standardization (NEFC 1991).

[c] Spring surveys during 1973-1981 were accomplished with a '41 Yankee' trawl; in all other years, spring surveys were accomplished with a '36 Yankee' trawl. No adjustments have been made to the catch per tow data for these gear differences.

[d] Excludes unusually high catch of 1894 cod (2558 kg) at Station 230 (Strata tow 20-4).

[e] Excludes unusually high catch of 1032 cod (4096 kg) at Station 323 (Strata tow 16-7).

[f] Excludes unusually high catch of 111 cod (504 kg) at Station 205 (Strata tow 23-4).

Table A3. Estimates of beginning year stock size (thousands of fish), instantaneous fishing mortality (F), mean biomass (mt), spawning stock biomass (mt), and percent mature of Georges Bank cod, estimated from virtual population analysis (VPA), calibrated using the commercial catch at age ADAPT formulation, 1978-1999.

| Stock Numbers (Jan 1) in thousands |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|                                    | 1978  | 1979  | 1980  | 1981  | 1982  | 1983  | 1984  | 1985  | 1986  | 1987  | 1988  | 1989  | 1990  | 1991  | 1992  | 1993  | 1994  | 1995  | 1996  | 1997  | 1998  | 1999  | 2000  |
| 1                                  | 27711 | 23512 | 20109 | 41393 | 17471 | 9615  | 27391 | 8675  | 42754 | 16377 | 23456 | 15718 | 9252  | 17881 | 6880  | 9225  | 7706  | 4656  | 8803  | 10420 | 2842  | 6830  | 5329  |
| 2                                  | 4270  | 22686 | 19220 | 16383 | 33865 | 14004 | 7774  | 22352 | 6981  | 34863 | 13385 | 19195 | 12869 | 7568  | 14593 | 5569  | 7549  | 6308  | 3812  | 7206  | 8528  | 2327  | 5590  |
| 3                                  | 25527 | 3140  | 16774 | 12318 | 10514 | 19458 | 7588  | 5182  | 12486 | 4516  | 21781 | 9532  | 13827 | 6064  | 4817  | 8168  | 3625  | 5820  | 4810  | 2933  | 5432  | 6314  | 1647  |
| 4                                  | 7933  | 13889 | 1756  | 8460  | 6266  | 5148  | 8635  | 3115  | 2032  | 6085  | 2425  | 10574 | 5160  | 6758  | 2031  | 1980  | 2846  | 1587  | 3808  | 3121  | 1823  | 3373  | 3426  |
| 5                                  | 2877  | 4411  | 6965  | 986   | 4697  | 2608  | 1992  | 4052  | 1312  | 943   | 3063  | 1070  | 4898  | 2522  | 2564  | 723   | 612   | 679   | 673   | 2001  | 1758  | 1110  | 2122  |
| 6                                  | 1127  | 1604  | 2515  | 3614  | 594   | 2036  | 1181  | 871   | 1611  | 640   | 519   | 1153  | 576   | 1962  | 745   | 758   | 194   | 145   | 293   | 333   | 920   | 1146  | 727   |
| 7                                  | 1414  | 804   | 899   | 1085  | 1687  | 232   | 965   | 500   | 340   | 752   | 296   | 205   | 455   | 265   | 622   | 245   | 194   | 72    | 79    | 129   | 154   | 539   | 850   |
| 8                                  | 67    | 846   | 588   | 334   | 511   | 772   | 104   | 375   | 212   | 200   | 371   | 97    | 93    | 150   | 103   | 229   | 57    | 35    | 35    | 51    | 29    | 91    | 333   |
| 9                                  | 147   | 12    | 463   | 403   | 162   | 226   | 419   | 46    | 124   | 108   | 107   | 126   | 40    | 44    | 60    | 53    | 58    | 5     | 15    | 26    | 27    | 11    | 60    |
| 10+                                | 55    | 148   | 27    | 191   | 187   | 145   | 293   | 208   | 76    | 68    | 99    | 45    | 89    | 43    | 18    | 28    | 9     | 2     | 1     | 2     | 18    | 17    | 19    |
| 1 +                                | 71127 | 71053 | 69317 | 85167 | 75953 | 54244 | 56343 | 45375 | 67929 | 64552 | 65503 | 57714 | 47259 | 43258 | 32432 | 26979 | 22850 | 19308 | 22328 | 26222 | 21533 | 21757 | 20104 |
| Fishing Mortality                  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|                                    | 1978  | 1979  | 1980  | 1981  | 1982  | 1983  | 1984  | 1985  | 1986  | 1987  | 1988  | 1989  | 1990  | 1991  | 1992  | 1993  | 1994  | 1995  | 1996  | 1997  | 1998  | 1999  |       |
| 1                                  | 0     | 0     | 0     | 0     | 0.02  | 0.01  | 0     | 0.02  | 0     | 0     | 0     | 0     | 0     | 0     | 0.01  | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| 2                                  | 0.11  | 0.1   | 0.24  | 0.24  | 0.35  | 0.41  | 0.21  | 0.38  | 0.24  | 0.27  | 0.14  | 0.13  | 0.55  | 0.25  | 0.38  | 0.23  | 0.06  | 0.07  | 0.06  | 0.08  | 0.1   | 0.15  |       |
| 3                                  | 0.41  | 0.38  | 0.48  | 0.48  | 0.51  | 0.61  | 0.69  | 0.74  | 0.52  | 0.42  | 0.52  | 0.41  | 0.52  | 0.89  | 0.69  | 0.85  | 0.63  | 0.22  | 0.23  | 0.28  | 0.28  | 0.41  |       |
| 4                                  | 0.39  | 0.49  | 0.38  | 0.39  | 0.68  | 0.75  | 0.56  | 0.66  | 0.57  | 0.49  | 0.62  | 0.57  | 0.52  | 0.77  | 0.83  | 0.97  | 1.23  | 0.66  | 0.44  | 0.37  | 0.3   | 0.26  |       |
| 5                                  | 0.38  | 0.36  | 0.46  | 0.31  | 0.64  | 0.59  | 0.63  | 0.72  | 0.52  | 0.4   | 0.78  | 0.42  | 0.72  | 1.02  | 1.02  | 1.12  | 1.24  | 0.64  | 0.5   | 0.58  | 0.23  | 0.22  |       |
| 6                                  | 0.14  | 0.38  | 0.64  | 0.56  | 0.74  | 0.55  | 0.66  | 0.74  | 0.56  | 0.57  | 0.73  | 0.73  | 0.58  | 0.95  | 0.91  | 1.16  | 0.79  | 0.41  | 0.62  | 0.57  | 0.34  | 0.1   |       |
| 7                                  | 0.31  | 0.11  | 0.79  | 0.55  | 0.58  | 0.6   | 0.74  | 0.66  | 0.33  | 0.51  | 0.92  | 0.59  | 0.91  | 0.75  | 0.8   | 1.27  | 1.52  | 0.51  | 0.24  | 1.28  | 0.33  | 0.28  |       |
| 8                                  | 1.49  | 0.4   | 0.18  | 0.52  | 0.62  | 0.41  | 0.63  | 0.91  | 0.47  | 0.43  | 0.88  | 0.68  | 0.56  | 0.72  | 0.46  | 1.17  | 2.3   | 0.65  | 0.1   | 0.43  | 0.75  | 0.22  |       |
| 9                                  | 0.36  | 0.44  | 0.51  | 0.44  | 0.66  | 0.67  | 0.6   | 0.71  | 0.54  | 0.49  | 0.73  | 0.58  | 0.63  | 0.87  | 0.94  | 1.09  | 1.27  | 0.64  | 0.46  | 0.47  | 0.28  | 0.22  |       |
| 10+                                | 0.36  | 0.44  | 0.51  | 0.44  | 0.66  | 0.67  | 0.6   | 0.71  | 0.54  | 0.49  | 0.73  | 0.58  | 0.63  | 0.87  | 0.94  | 1.09  | 1.27  | 0.64  | 0.46  | 0.47  | 0.28  | 0.22  |       |
| mn4-8,u                            | 0.54  | 0.35  | 0.49  | 0.47  | 0.65  | 0.58  | 0.64  | 0.74  | 0.49  | 0.48  | 0.79  | 0.60  | 0.65  | 0.84  | 0.80  | 1.14  | 1.42  | 0.57  | 0.38  | 0.65  | 0.39  | 0.22  |       |
| Fwb                                | 0.31  | 0.29  | 0.39  | 0.32  | 0.47  | 0.52  | 0.41  | 0.53  | 0.29  | 0.33  | 0.42  | 0.35  | 0.53  | 0.55  | 0.57  | 0.64  | 0.5   | 0.26  | 0.25  | 0.26  | 0.22  | 0.22  |       |

Table A3 continued. Estimates of beginning year stock size (thousands of fish), instantaneous fishing mortality (F), mean biomass (mt), spawning stock biomass (mt), and percent mature of Georges Bank cod, estimated from virtual population analysis (VPA), calibrated using the commercial catch at age ADAPT formulation, 1978-1999.

| Mean biomass (mt)  |        |        |        |        |        |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|--|--------|--------|--------|--------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Age  | 1978   | 1979   | 1980   | 1981   | 1982   | 1983  | 1984  | 1985  | 1986  | 1987  | 1988  | 1989  | 1990  | 1991  | 1992  | 1993  | 1994  | 1995  | 1996  | 1997  | 1998  | 1999  |
| 1  | 17756  | 18930  | 15201  | 33078  | 11990  | 8411  | 26100 | 7072  | 35928 | 10767 | 16706 | 11525 | 6965  | 18026 | 7119  | 7289  | 6327  | 3823  | 7037  | 9008  | 1492  | 5137  |
| 2  | 4816   | 29255  | 22650  | 19782  | 36452  | 15601 | 10449 | 24026 | 8347  | 41188 | 17252 | 26461 | 14109 | 9907  | 17073 | 6946  | 9698  | 8127  | 5054  | 9900  | 10923 | 3079  |
| 3  | 47057  | 5118   | 29978  | 21113  | 20017  | 31667 | 12313 | 7020  | 21792 | 8390  | 36585 | 16164 | 24310 | 9394  | 7862  | 11373 | 5349  | 9937  | 9507  | 5419  | 9947  | 10500 |
| 4  | 20817  | 42243  | 4894   | 21840  | 16000  | 10999 | 21921 | 8106  | 5192  | 18433 | 5814  | 27821 | 12978 | 14801 | 4867  | 3884  | 5528  | 4082  | 9512  | 8386  | 5027  | 9319  |
| 5  | 9449   | 16495  | 28841  | 4033   | 17037  | 8352  | 6889  | 13464 | 5247  | 4126  | 10558 | 4304  | 15698 | 6951  | 6973  | 1999  | 1557  | 2522  | 2375  | 5708  | 6772  | 4427  |
| 6  | 5533   | 8742   | 11357  | 18264  | 2510   | 9170  | 5214  | 3621  | 8109  | 3448  | 2246  | 5023  | 2536  | 6869  | 2768  | 2640  | 916   | 800   | 1323  | 1398  | 4228  | 6364  |
| 7  | 8154   | 6341   | 4785   | 6532   | 10957  | 1273  | 5563  | 2718  | 2353  | 4828  | 1564  | 1165  | 2326  | 1267  | 2954  | 965   | 742   | 553   | 533   | 541   | 981   | 3141  |
| 8  | 275    | 6555   | 4453   | 2347   | 3458   | 5943  | 717   | 2321  | 1538  | 1487  | 2266  | 691   | 697   | 1034  | 741   | 1151  | 195   | 273   | 259   | 326   | 163   | 721   |
| 9  | 1326   | 107    | 2801   | 4217   | 1355   | 1693  | 3264  | 341   | 1107  | 894   | 774   | 1020  | 345   | 260   | 431   | 290   | 296   | 33    | 140   | 227   | 273   | 113   |
| 10+  | 553    | 1376   | 303    | 2611   | 2091   | 1408  | 3101  | 1839  | 751   | 735   | 986   | 533   | 880   | 407   | 202   | 206   | 79    | 23    | 5     | 19    | 209   | 191   |
| Total  | 115735 | 135163 | 125263 | 133817 | 121867 | 94516 | 95531 | 70527 | 90365 | 94297 | 94751 | 94707 | 80844 | 68916 | 50990 | 36742 | 30687 | 30172 | 35744 | 40933 | 40013 | 42991 |
| SSB at the start of the spawning season - males and females (mt) |        |        |        |        |        |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Age  | 1978   | 1979   | 1980   | 1981   | 1982   | 1983  | 1984  | 1985  | 1986  | 1987  | 1988  | 1989  | 1990  | 1991  | 1992  | 1993  | 1994  | 1995  | 1996  | 1997  | 1998  | 1999  |
| 1  | 912    | 1104   | 850    | 1962   | 1200   | 902   | 3122  | 773   | 8516  | 2226  | 3481  | 2482  | 638   | 1964  | 791   | 722   | 106   | 63    | 112   | 1002  | 126   | 622   |
| 2  | 1411   | 7540   | 6911   | 5784   | 16138  | 6347  | 4303  | 11650 | 5032  | 25333 | 8898  | 13723 | 6629  | 4245  | 9031  | 3577  | 3180  | 2713  | 1662  | 4620  | 5497  | 1192  |
| 3  | 33839  | 3730   | 22412  | 15924  | 15649  | 26066 | 10500 | 6879  | 18778 | 7106  | 32841 | 14541 | 22033 | 9069  | 7483  | 11494 | 5473  | 9005  | 8047  | 4662  | 8793  | 9526  |
| 4  | 20179  | 38255  | 4300   | 21375  | 15792  | 12655 | 21656 | 8076  | 4842  | 17024 | 6137  | 27191 | 12817 | 16519 | 5296  | 4619  | 6431  | 3965  | 9113  | 8318  | 4783  | 8801  |
| 5  | 8796   | 16541  | 30441  | 3962   | 17468  | 9636  | 7118  | 14908 | 5434  | 3936  | 12375 | 4200  | 18065 | 8434  | 8395  | 2538  | 1926  | 2644  | 2597  | 6554  | 6695  | 4279  |
| 6  | 4892   | 8127   | 12487  | 20325  | 2961   | 10514 | 5653  | 4252  | 8584  | 3704  | 2763  | 5937  | 2959  | 8694  | 3355  | 3310  | 1000  | 779   | 1541  | 1593  | 4152  | 6013  |
| 7  | 8094   | 5563   | 5914   | 7240   | 12174  | 1464  | 6221  | 3163  | 2355  | 5364  | 2024  | 1326  | 2844  | 1548  | 3501  | 1303  | 1041  | 572   | 575   | 734   | 991   | 3282  |
| 8  | 366    | 6672   | 5047   | 2693   | 4108   | 6842  | 815   | 2980  | 1702  | 1701  | 2932  | 811   | 769   | 1217  | 786   | 1518  | 313   | 291   | 321   | 389   | 209   | 756   |
| 9  | 1339   | 111    | 3841   | 4111   | 1557   | 2059  | 3958  | 420   | 1245  | 1030  | 965   | 1193  | 408   | 372   | 557   | 420   | 432   | 40    | 163   | 236   | 262   | 109   |
| 10+  | 657    | 1674   | 376    | 3178   | 2704   | 1825  | 3942  | 2407  | 941   | 907   | 1296  | 673   | 1127  | 554   | 281   | 296   | 117   | 30    | 6     | 24    | 242   | 217   |
| Total  | 80485  | 89318  | 92581  | 86552  | 89751  | 78311 | 67288 | 55509 | 57430 | 68331 | 73713 | 72077 | 68289 | 52617 | 39476 | 29798 | 20019 | 20102 | 24138 | 28131 | 31750 | 34796 |
| Percent Mature (females)   |        |        |        |        |        |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Age  | 1978   | 1979   | 1980   | 1981   | 1982   | 1983  | 1984  | 1985  | 1986  | 1987  | 1988  | 1989  | 1990  | 1991  | 1992  | 1993  | 1994  | 1995  | 1996  | 1997  | 1998  | 1999  |
| 1  | 7      | 7      | 7      | 7      | 13     | 13    | 13    | 13    | 28    | 28    | 28    | 28    | 12    | 12    | 12    | 12    | 2     | 2     | 2     | 13    | 13    | 13    |
| 2  | 34     | 34     | 34     | 34     | 47     | 47    | 47    | 47    | 67    | 67    | 67    | 67    | 52    | 52    | 52    | 52    | 39    | 39    | 39    | 57    | 57    | 57    |
| 3  | 78     | 78     | 78     | 78     | 84     | 84    | 84    | 84    | 91    | 91    | 91    | 91    | 90    | 90    | 90    | 90    | 95    | 95    | 95    | 92    | 92    | 92    |
| 4  | 96     | 96     | 96     | 96     | 97     | 97    | 97    | 97    | 98    | 98    | 98    | 98    | 99    | 99    | 99    | 99    | 100   | 100   | 100   | 100   | 100   | 100   |
| 5-10+  | 100    | 100    | 100    | 100    | 100    | 100   | 100   | 100   | 100   | 100   | 100   | 100   | 100   | 100   | 100   | 100   | 100   | 100   | 100   | 100   | 100   | 100   |

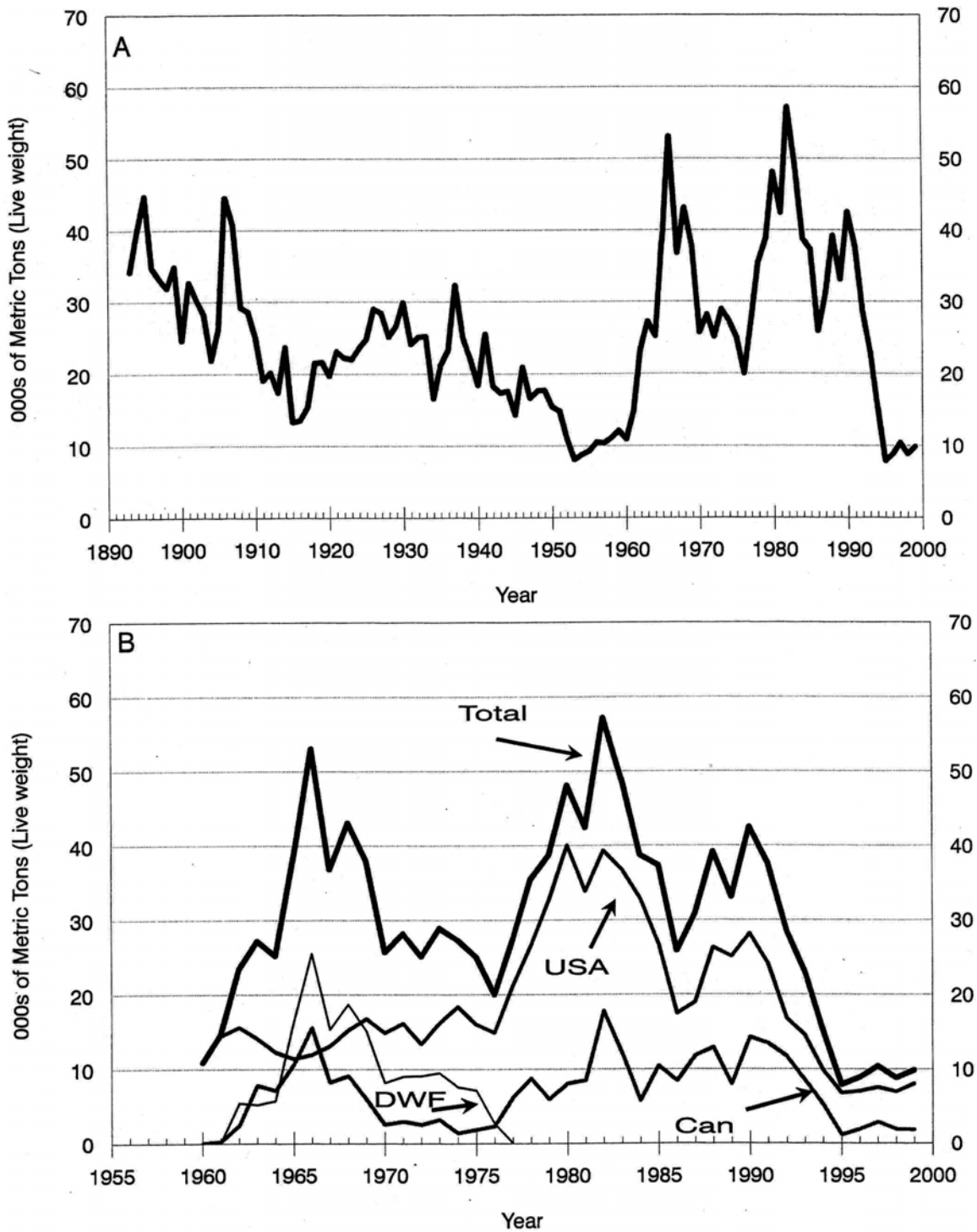


Figure A1. Total commercial landings of Georges Bank cod (Division 5Z and Subarea 6), 1893-1999 (Panel A) and total commercial landings of Georges Bank cod by country, 1960-1999 (Panel B).



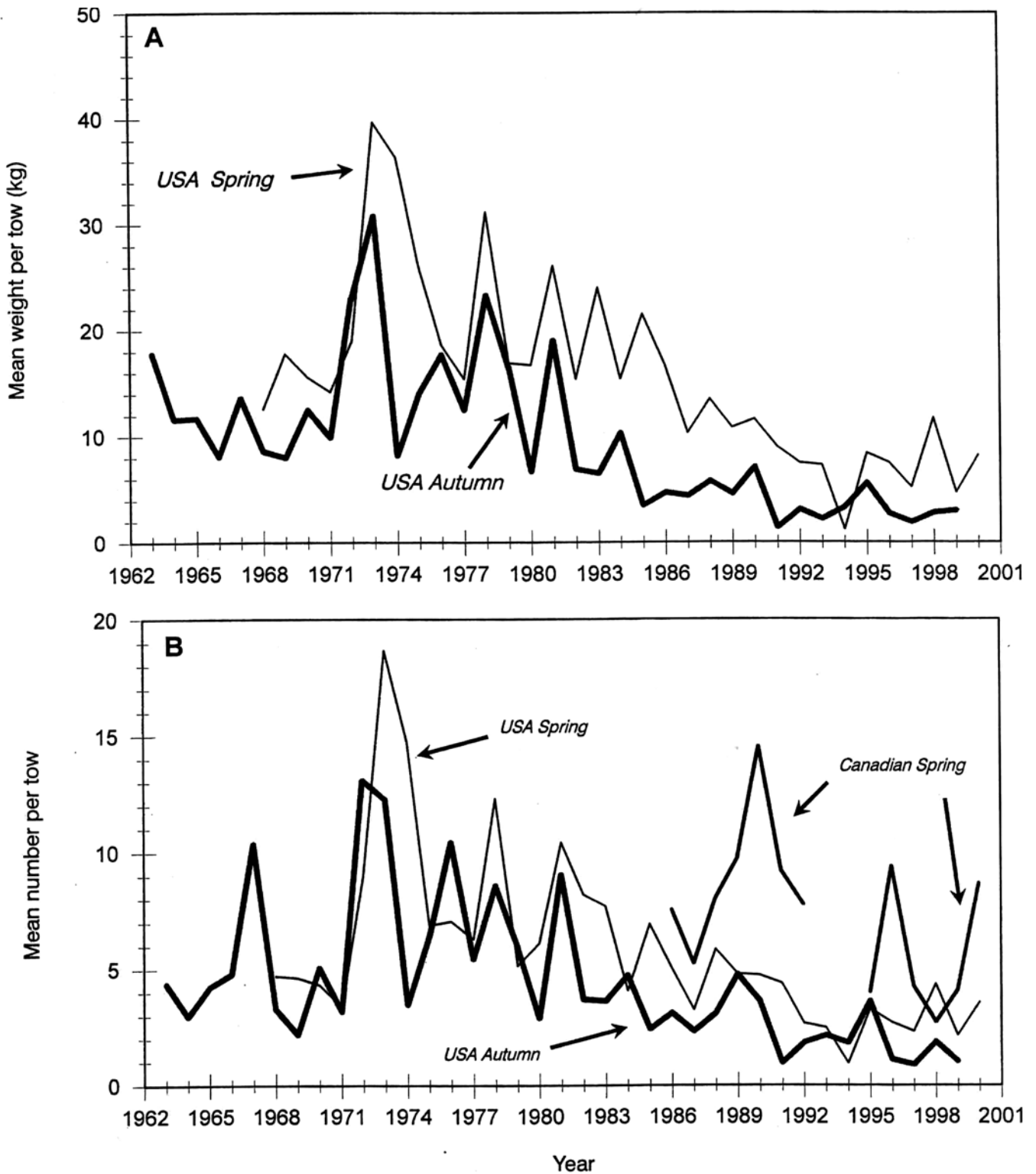


Figure A2. Standardized stratified mean weight (Panel A) and number (Panel B) per tow of Atlantic cod in NEFSC spring and autumn research vessel bottom trawl surveys, 1963 -1999, and Canadian spring research vessel bottom trawl surveys, 1986-1992 and 1994-2000, on Georges Bank.

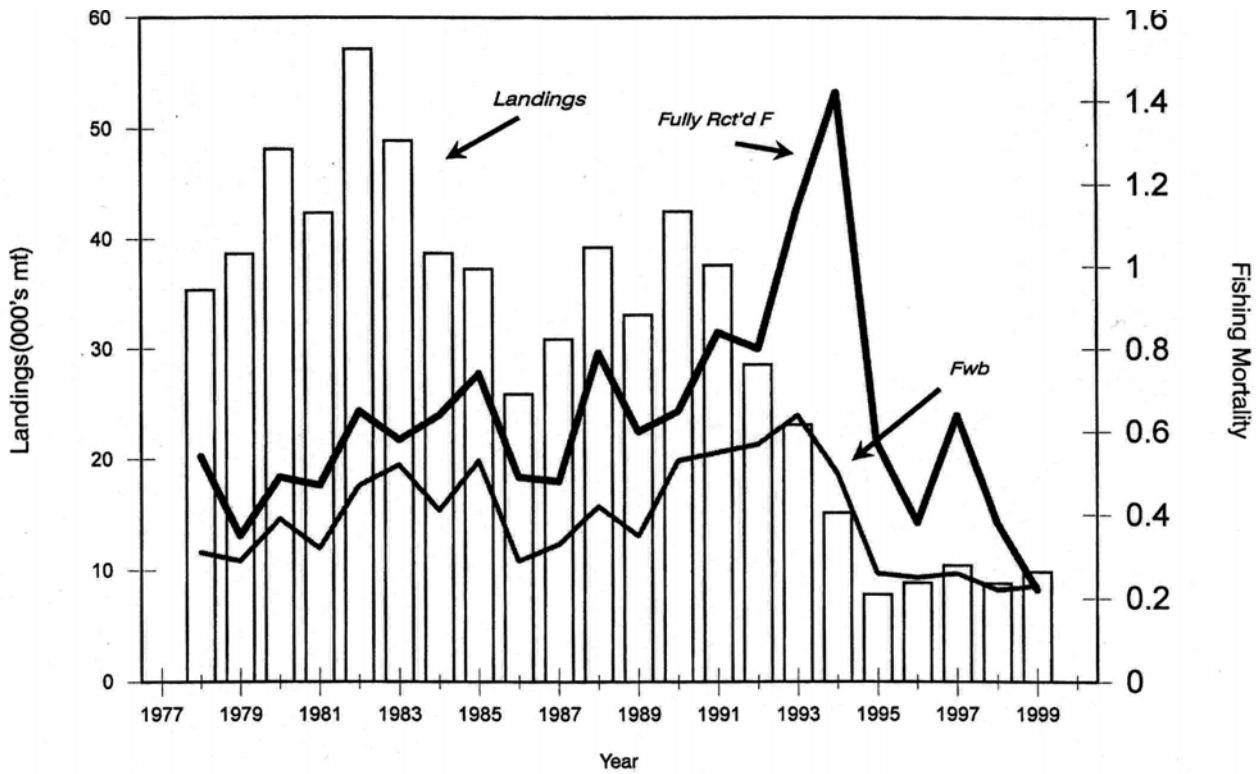


Figure A3. Trends in total commercial landings and fishing mortality for Georges Bank cod, 1978-1999.

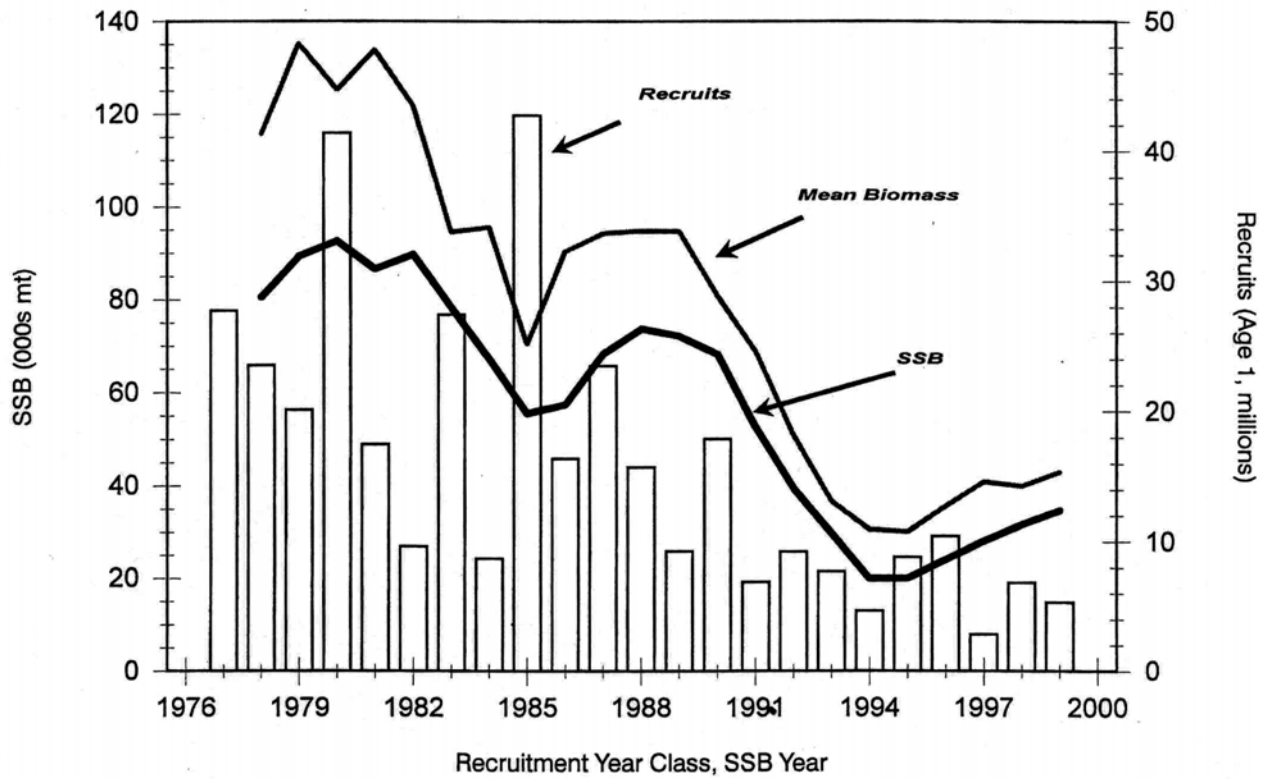


Figure A4. Trends in spawning stock biomass and recruitment for Georges Bank cod, 1978-1999.

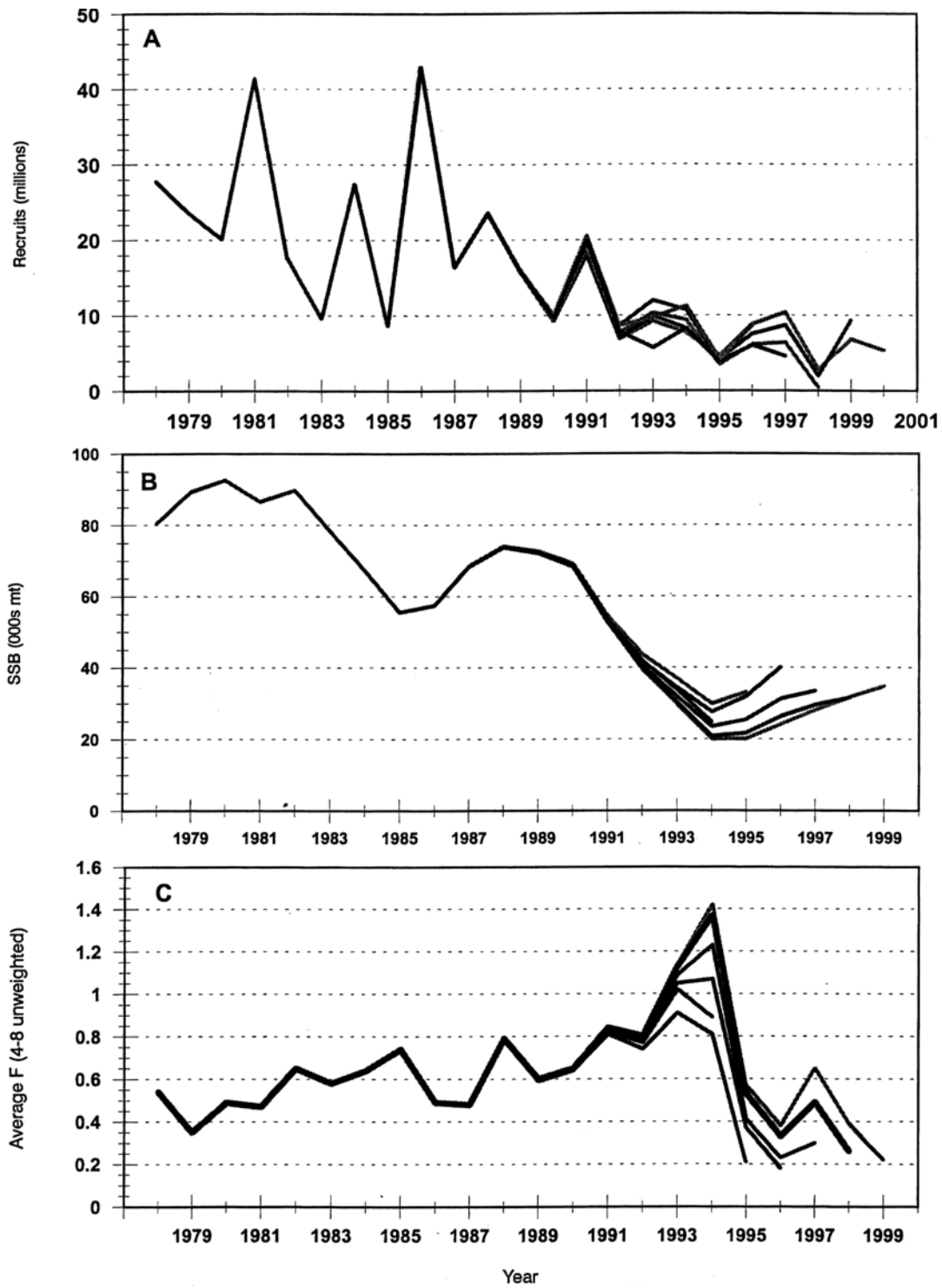


Figure A5 Retrospective analysis of Georges Bank cod recruits at age 1 (A), spawning stock biomass (B) and fishing mortality (C, average F, ages 4-8, unweighted) based on the final ADAPT VPA formulation, 1999-1994.

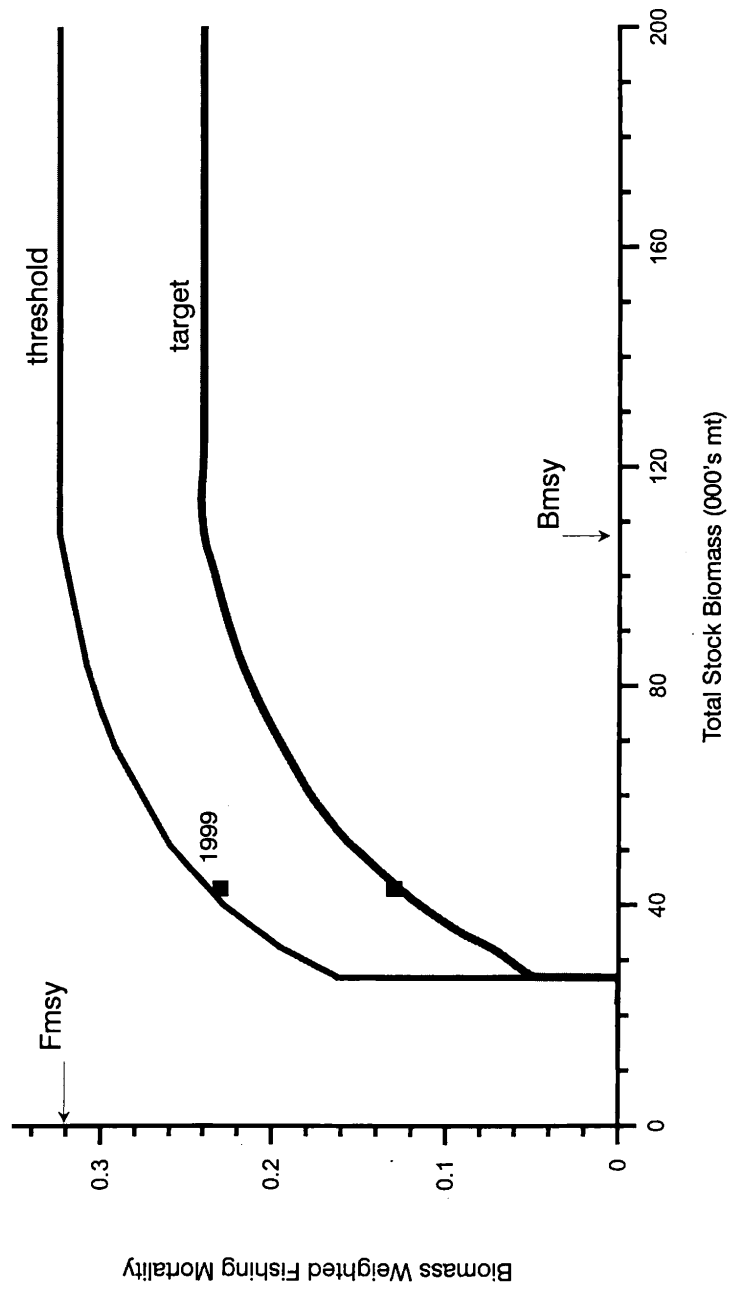


Figure A6. SFA control rule and recent stock status for Georges Bank Atlantic cod.