Supplementary materials for Swain and Mohn, CJFAS

Contents

Supplementary Appendix S1: Assessment model for Atlantic cod on the eastern Scotian Shelf

The population model used to assess the status of eastern Scotian Shelf (ESS) cod is a sequential population analysis (SPA; Hilborn and Walters 1992) calibrated using abundance indices from a stratified-random bottom-trawl survey conducted each July since 1970. Model inputs are annual fishery catches at ages 1 to 15 years and survey catch rates at ages 1 to 10 years (Tables S1.1 and S1.2). In order to include the recent cod "recovery", the model used in the most recent assessment (DFO 2011a) was updated with survey data for 2010 and 2011. Because age data were not available for the 2011 survey, the age-length relationship in the 2010 survey was applied to the catch-at-length in the 2011 survey to estimate the survey catch rate at age in 2011. Fishery catch at age in 2009 was used as a proxy for the 2010 and 2011 values, which are not yet available. Because fishing mortality is currently negligible for this stock (DFO 2011a), the use of this proxy will introduce little bias.

In addition to estimating abundance at age in the terminal year and catchabilities at age to the survey, the model used in the most recent assessment estimates time trends in the instantaneous rate of natural mortality (*M*) for two age groups, cod aged 1-4 years and those five years and older (5+). These time trends in *M* were modelled as random walks as follows:

$$M_{j,y} = M\text{init}_j \text{ if } y\text{=1970}$$

$$M_{j,y} = M_{j,y\text{-}1} * \exp(M\text{dev}_{j,y}) \text{ if } y\text{>1970}$$

where *y* indexes year and *j* indexes age class (1-4 or 5+ years), the $M\text{dev}_{j,y}$ are parameters assumed to be normally distributed with mean 0 and standard deviation *s*dev, and $M\text{init}_j$ is a parameter for *M* of age-class *j* in 1970. The value of *s*dev affects the degree to which the random walk is constrained. If it is too large, estimated *M* will tend to fluctuate erratically in response to year-effects. In the assessment model, *s*dev is set at 0.1 for both age classes. Simulation studies indicate that time trends in M are well estimated by this model (Swain 2011), given the characteristics of the ESS cod data (i.e., a sharp drop in fishing effort and substantial variation in yearclass strength).

The ESS cod model is implemented in AD Model Builder (Fournier et al. 2011). Parameters were estimated by minimizing an objective function with the following components:

1. residuals between observed and predicted abundance indices:

$$\mathrm{f}_1 = 0.5 \cdot \sum_{a,y} (\log(I_{a,y} / (q_a N_{a,y})) / s_{a,y})^2 + \sum_{a,y} \log(s_{a,y})$$

where

$$s_{a,y} = (\log(1 + cv_{a,y}^2))^{0.5}$$

and I is the survey abundance index, N is estimated population abundance, q is catchability to the survey, cv is the coefficient of variation for the survey index, a indexes age and y indexes year. The cv of the index was set to a constant value of 0.3 for all ages and years, and thus had no effect on the minimization (except for its effect on the weight attributed to this component of the objective function).

2. random-walk deviates

$$\mathrm{f}_2 = 0.5 \cdot (\sum_{j,y} M\mathrm{dev}_{j,y}^2) / s\mathrm{dev}^2$$

3. prior value for initial M

$$\mathrm{f}_3 = 0.5 \cdot (\sum_j (M\mathrm{init}_j - M\mathrm{prior}_j)^2) / 0.1^2$$

where the prior for M in 1970 was set at 0.4 for ages 1-4 and 0.21 for ages 5+ years.

4. penalty on divergent M trends between age groups 1 (1-4) and 2 (5+).

$$\mathrm{f}_4 = 0.5 \cdot (\sum_y (M\mathrm{dev}_{1,y} - M\mathrm{dev}_{2,y})^2) / 0.15^2$$

Estimates of abundance, mortality and spawning stock biomass (SSB) from the model are given in Tables S1.3 to S1.5. SSB was calculated from the estimates of abundance at age in Table S1.3 and the weights at age in Table S1.6, assuming that all fish aged 5 years and older were mature. Further details on the assessment model and diagnostics of its fit are given in DFO (2011b).

References

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Table S1.1. Catch at age (thousands) of Atlantic cod on the eastern Scotian Shelf. Zeros replaced by a catch of 10 fish (0.01).

	Age														
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1970	1293	8631	8886	14802	13673	4539	1942	759	236	72	137	56	9	12	4
1971	1984	12824	9643	5125	6612	5128	3419	1963	704	367	159	173	156	80	40
1972	2046	15865	11801	11989	7384	6527	3308	1880	347	466	68	8	36	0.01	3
1973	1218	10221	8001	5803	9634	3324	3370	4732	1684	389	551	8	21	21	18
1974	1273	7321	13324	11695	6854	2247	669	1008	196	153	13	2	0.01	0.01	0.01
1975	1538	8571	7402	3163	4788	3297	2943	623	497	686	172	123	41	6	6
1976	513	2866	2860	4707	3900	2085	1287	447	136	53	12	47	0.01	4	0.01
1977	1	23	532	1229	1591	845	490	199	118	33	42	44	11	3	2
1978	34	94	1168	4078	4817	2582	767	247	107	75	31	27	28	10	1
1979	12	93	1762	6559	9525	5056	1210	377	76	23	10	4	3	0.01	0.01
1980	31	92	1765	4873	6937	6177	3050	1121	313	92	50	26	4	0.01	1
1981	3	258	3200	9136	7281	4651	2957	1421	397	135	69	32	22	2	5
1982	3	138	2473	7667	10123	3681	2568	1315	679	318	153	65	54	55	19
1983	0.01	6	3507	8679	7484	6278	1905	1012	625	224	149	52	24	15	6
1984	0.01	1	430	5778	9101	5678	3829	1250	544	290	153	63	34	17	8
1985	0.01	4	156	2253	8151	7523	4284	2430	1063	452	284	173	68	20	17
1986	0.01	3	124	4089	7098	7584	3368	1358	922	339	189	81	66	11	19
1987	0.01	0.01	30	815	5400	5367	5465	2636	928	492	220	122	61	11	14
1988	0.01	8	185	1507	2008	3920	3496	2782	1454	471	260	152	64	9	10
1989	0.01	7	671	2544	4066	3133	3316	1244	1354	484	202	38	29	15	58
1990	0.01	0.01	291	2264	3889	2577	1606	2936	891	1051	323	135	55	15	14
1991	0.01	1	274	3237	6295	3589	608	629	327	61	432	69	65	10	6
1992	0.01	2	568	2404	8232	5897	1690	652	185	285	84	108	33	7	6
1993	0.01	0.01	32	427	605	758	513	129	44	8	7	4	2	1	0.01
1994	0.01	0.01	0.01	4	68	29	72	15	5	1	0.01	0.01	0.01	0.01	0.01
1995	0.01	0.01	6	14	45	51	21	18	8	2	0.01	0.01	0.01	0.01	0.01
1996	0.01	0.01	36	87	53	31	17	5	1.3	1.2	0.1	0.01	0.01	0.01	0.01
1997	0.01	1	4	18	44	20	22	23	11	5	3	2	0.01	1	0.01
1998	0.01	0.01	2	20	44	40	19	15	9	2	3	2	0.01	0.01	0.01
1999	0.01	0.01	1.32	20.12	54.08	46.47	41.11	14.34	4.97	3.73	2.71	1.46	0.19	0.02	0.01
2000	0.01	0.01	5.03	7.3	26.5	46.11	20.21	6.3	0.35	2.01	0.01	0.01	0.01	0.01	0.01
2001	0.01	0.2	5.4	26.6	22.9	30.2	15.1	5.2	1.6	0.3	0.01	0.01	0.01	0.01	0.01
2002	0.01	0.01	0.8	9.6	21.9	5.4	9.1	6.3	1.9	1.9	0.5	0.4	0.01	0.01	0.1
2003	0.01	0.01	0.01	3.1	5.5	4.8	4.3	2.8	1.5	0.4	0.2	0.2	0.01	0.01	0.01
2004	0.01	0.01	0.01	0.1	1.4	6.6	6.2	1.9	2.3	0.9	0.4	0.5	0.01	0.01	0.01
2005	0.01	0.01	0.01	0.7	2.2	7.6	6.1	2.4	1.4	0.5	0.3	0.2	0.01	0.01	0.01
2006	0.01	0.1	6.2	11.6	11.3	4.8	4.2	1.9	1.4	0.4	0.4	0.1	0.1	0.01	0.01
2007	0.01	0.01	0.01	4.3	7.3	14.9	5.4	2.1	0.3	0.6	0.01	0.01	0.01	0.01	0.01
2008	0.01	0.01	0.01	1.23	2.26	6.14	7.79	3.46	2.51	0.83	0.46	0.01	0.01	0.08	0.01
2009	0.01	0.01	0.01	0.16	1.86	4.99	9.22	5.69	2.11	1.51	1.46	0.11	0.02	0.01	0.01
2010	0.01	0.01	0.01	0.16	1.86	4.99	9.22	5.69	2.11	1.51	1.46	0.11	0.02	0.01	0.01
2011	0.01	0.01	0.01	0.16	1.86	4.99	9.22	5.69	2.11	1.51	1.46	0.11	0.02	0.01	0.01

Table S1.2. Survey abundance indices (trawlable abundance in thousands) for Atlantic cod on the eastern Scotian Shelf. Zero catches replaced by a value of 10.0.

	Age									
Year	1	2	3	4	5	6	7	8	9	10
1970	1791.0	14278.8	6433.3	6934.4	2905.8	1055.9	1461.0	448.6	112.2	285.9
1971	1288.4	8782.2	28984.3	9136.5	11852.1	4518.6	2214.7	1071.4	584.9	92.9
1972	5049.6	10007.7	15434.8	21843.0	5318.2	3426.0	894.7	334.5	417.3	102.1
1973	5307.4	38395.1	58197.3	40828.5	26074.1	1284.0	2517.2	1004.2	182.4	363.1
1974	3976.7	27282.1	17727.6	5045.7	1641.8	1706.8	283.9	427.3	180.5	146.3
1975	2694.3	6776.3	10296.5	5575.8	2247.7	405.0	368.8	180.1	267.8	16.0
1976	1889.2	11185.0	12498.2	7869.8	4772.6	1163.8	591.4	484.4	10.0	476.8
1977	680.4	8171.6	20733.8	13398.6	8432.8	3666.4	795.0	549.1	145.6	10.0
1978	2502.3	11740.1	26143.5	29309.2	8148.2	2770.7	742.0	163.8	76.9	67.6
1979	357.9	9066.6	13625.5	13994.1	15498.3	7870.5	2322.4	829.1	344.9	70.9
1980	442.2	5805.9	15773.3	8585.3	13736.1	10402.5	5246.0	1181.8	311.7	219.5
1981	3719.8	10352.1	16497.2	22143.8	9329.9	8758.6	4958.4	1734.6	421.6	464.2
1982	1481.7	120151.8	108456.7	39359.1	10273.1	6275.9	3512.9	1649.6	403.8	349.7
1983	25613.3	34147.9	110103.3	45900.5	23249.0	10538.1	2271.2	1212.2	304.7	183.8
1984	869.2	16428.4	29251.5	43157.8	32393.0	17040.1	9639.7	1072.7	914.1	239.6
1985	1576.5	3927.1	18962.0	22164.8	22008.3	12247.8	6322.5	2527.9	1075.5	259.4
1986	706.8	3527.2	5615.4	12650.0	8897.6	7650.2	2677.3	1238.5	571.4	367.9
1987	764.2	3692.2	11575.2	14765.6	18439.4	7974.4	6811.0	3200.1	735.8	57.6
1988	112.3	11669.2	17726.1	15355.6	10741.9	7212.8	4171.7	2154.3	620.0	123.1
1989	510.2	19683.4	19262.7	12146.3	9276.4	3358.7	3529.4	990.2	546.2	32.4
1990	159.0	12870.5	42458.7	21212.4	8652.3	3464.3	1308.8	687.9	231.0	174.4
1991	254.3	4245.1	7929.9	15737.0	10610.8	3528.9	1035.9	502.8	418.6	153.7
1992	4022.6	13136.8	15671.3	9091.7	5798.8	1927.2	352.1	185.8	68.9	52.5
1993	212.5	2499.2	16266.8	18225.6	11922.3	7238.1	2252.6	516.5	11.8	31.8
1994	294.2	2934.7	6856.2	5685.4	2569.6	1218.8	1191.7	152.6	89.0	95.0
1995	431.6	1838.9	6254.7	5196.3	4322.1	1797.1	986.4	1167.8	178.9	10.0
1996	988.1	4552.3	4310.7	2300.0	1568.1	832.7	239.3	124.2	13.7	19.8
1997	154.5	1402.3	2117.3	1494.4	632.9	271.4	260.4	90.5	33.8	10.0
1998	462.4	1292.9	5257.2	8416.8	3180.0	829.8	593.8	197.0	10.0	10.0
1999	426.9	5329.8	6717.2	7445.6	3653.9	902.3	81.2	213.3	53.1	10.0
2000	524.7	1160.6	2621.3	1432.6	1276.7	700.2	317.7	91.9	33.7	36.7
2001	540.2	12487.0	9185.4	3435.5	1040.9	313.9	179.4	129.6	10.0	42.8
2002	700.4	1817.0	4367.5	2023.6	403.7	53.8	10.0	10.0	10.0	10.0
2003	130.2	544.7	2582.8	1778.7	2302.3	838.2	213.6	63.7	28.8	73.9
2004	312.5	741.8	3221.1	1951.6	698.9	475.5	373.6	28.3	10.0	10.0
2005	1599.9	1485.3	2369.7	1858.5	771.3	465.6	393.8	220.0	33.4	10.0
2006	599.0	14882.2	21424.0	11052.8	3686.3	442.2	396.8	42.9	10.0	10.0
2007	694.6	2744.9	26041.2	18199.3	5083.1	322.3	546.3	17.7	10.0	10.0
2008	265.5	2997.2	3244.4	2682.6	936.5	975.3	267.3	22.3	87.3	22.3
2009	289.7	2199.5	13161.3	17038.9	23683.8	8041.7	4520.0	427.4	261.7	10.0
2010	663.8	3842.3	8705.6	7286.7	4641.3	5734.1	1962.8	307.0	119.3	10.0
2011	833.9	9482.6	17654.9	8100.8	3716.8	3693.0	881.6	119.1	119.1	10.0

Table S1.3. Estimated abundance (thousands) of Atlantic cod on the eastern Scotian Shelf based on the updated assessment model.

	Age														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1970	138233	109610	47026	46844	31378	13503	5324	2917	753	299.2	404.1	259.2	103.56	67.86	13.68
1971	149246	95780	69581	25514	20434	16054	8207	3089	1987	474.0	209.4	244.5	187.61	87.87	51.69
1972	122090	102078	55880	40322	13460	12663	10013	4349	984	1172.3	87.5	41.7	60.88	24.26	4.66
1973	120177	80721	55861	28020	17365	5394	5478	6119	2230	580.5	640.5	15.8	31.04	21.89	22.54
1974	139899	76307	43714	29507	13366	6794	1791	1825	1108	443.1	162.7	62.4	6.88	8.51	0.04
1975	148814	85930	41646	16661	9117	5719	4093	1006	712	830.8	260.8	137.2	55.49	6.32	7.81
1976	108185	92712	47431	20407	8004	3775	2087	935	326	177.2	104.9	74.5	8.00	11.62	0.05
1977	90087	71552	59340	29221	9737	3593	1460	679	428	168.0	111.4	84.5	23.19	7.31	6.81
1978	130659	63176	50159	41168	19463	7365	2471	864	429	278.0	121.8	61.5	35.07	10.65	3.80
1979	117417	95183	45957	35554	26519	13109	4236	1516	550	288.4	181.3	81.2	30.21	5.19	0.15
1980	155526	88306	71513	33039	21054	14956	7062	2686	1014	426.1	239.3	154.7	69.75	24.51	4.69
1981	202440	119437	67750	53384	21107	12374	7604	3464	1354	616.2	296.3	168.0	114.61	59.00	22.05
1982	138736	154868	91146	49031	32849	11948	6643	3989	1748	832.8	422.1	199.1	119.62	81.44	50.73
1983	152910	102199	113967	65021	29539	19383	7051	3432	2273	899.5	433.9	227.6	114.08	54.52	20.02
1984	63953	104657	69944	75102	37323	18508	10876	4308	2018	1379.0	567.2	235.6	147.83	76.03	33.06
1985	56140	41127	67302	44635	43663	23069	10371	5642	2480	1199.4	894.8	337.1	140.53	93.25	48.41
1986	64801	36349	26626	43451	27087	28560	12170	4653	2441	1077.4	577.6	479.1	120.63	54.02	58.64
1987	92027	43774	24552	17884	25991	15618	16377	6856	2558	1152.9	570.1	299.1	316.42	38.55	33.99
1988	99130	65373	31095	17416	12017	16129	7786	8310	3166	1230.8	488.7	262.6	131.81	200.62	21.23
1989	41411	72645	47900	22629	11472	7837	9422	3112	4172	1236.4	565.0	159.0	74.41	48.37	152.79
1990	24145	30749	53936	34989	14611	5462	3414	4506	1356	2096.7	547.9	267.4	92.00	33.09	24.94
1991	30665	17678	22514	39241	23681	7849	1948	1222	896	263.0	693.6	138.8	87.65	22.63	12.34
1992	30788	21566	12432	15604	24883	11960	2678	907	357	376.5	140.5	138.4	42.61	8.58	8.02
1993	55053	20124	14095	7667	8255	10051	3236	421	77	89.2	20.2	25.9	4.75	1.67	0.04
1994	24546	33298	12172	8500	4305	4388	5326	1509	149	11.4	46.3	6.5	12.14	1.26	0.21
1995	18994	14337	19450	7110	4962	1954	2019	2426	691	65.6	4.6	21.5	3.00	5.63	0.58
1996	20506	11074	8359	11335	4134	1731	662	703	848	239.9	22.0	1.6	7.61	1.06	1.99
1997	36047	12149	6561	4925	6648	1320	548	206	227	276.4	77.7	7.1	0.53	2.48	0.34
1998	18201	21741	7326	3954	2956	2776	544	217	72	88.5	113.3	30.8	1.71	0.22	0.40
1999	15375	11061	13212	4451	2387	1364	1282	243	92	27.8	40.3	51.4	13.16	0.80	0.09
2000	22794	9217	6631	7920	2653	1006	565	532	97	36.8	9.7	15.8	21.47	5.62	0.34
2001	69122	13432	5432	3904	4661	975	348	199	195	36.0	12.5	3.6	5.91	8.02	2.09
2002	18143	39992	7771	3138	2238	1709	342	119	70	71.1	13.1	4.6	1.33	2.18	2.96
2003	23197	11116	24503	4761	1915	856	661	127	42	26.1	26.5	4.8	1.55	0.51	0.84
2004	29209	15554	7454	16430	3190	732	325	251	47	15.4	9.8	10.0	1.71	0.59	0.19
2005	62504	20761	11056	5298	11678	1074	243	106	83	14.5	4.7	3.1	3.09	0.57	0.19
2006	32637	45509	15116	8049	3857	4374	398	87	38	30.4	5.1	1.6	1.02	1.15	0.21
2007	33359	23734	33094	10987	5844	1590	1808	162	35	15.0	12.3	1.9	0.58	0.36	0.47
2008	23824	24070	17126	23879	7924	2805	754	866	76	16.6	6.8	5.9	0.89	0.27	0.17
2009	32818	17470	17650	12558	17509	4393	1551	413	478	40.5	8.6	3.4	3.28	0.49	0.09
2010	55736	24448	13014	13148	9355	10564	2647	929	245	286.6	23.3	4.0	1.98	1.96	0.29
2011		41757	18316	9750	9850	5875	6632	1656	579	151.9	178.8	13.5	2.45	1.22	1.22

Table S1.4. Estimated instantaneous rate of fishing mortality of Atlantic cod on the eastern Scotian Shelf based on the updated assessment model.

	Age														
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1970	0.011	0.099	0.256	0.474	0.600	0.428	0.474	0.314	0.393	0.287	0.432	0.253	0.094	0.202	0.360
1971	0.016	0.175	0.182	0.276	0.408	0.402	0.565	1.073	0.457	1.619	1.544	1.320	1.975	2.865	1.582
1972	0.021	0.210	0.297	0.449	0.842	0.765	0.420	0.595	0.455	0.532	1.641	0.222	0.950	0.000	1.086
1973	0.013	0.172	0.197	0.299	0.860	1.024	1.021	1.631	1.538	1.194	2.250	0.751	1.216	6.121	1.722
1974	0.012	0.130	0.489	0.699	0.765	0.423	0.493	0.858	0.204	0.446	0.087	0.034	0.002	0.001	0.267
1975	0.013	0.134	0.253	0.273	0.795	0.921	1.390	1.041	1.305	1.983	1.167	2.755	1.477	4.815	1.575
1976	0.006	0.039	0.077	0.332	0.712	0.861	1.035	0.692	0.573	0.375	0.127	1.078	0.001	0.446	0.251
1977	0.000	0.000	0.011	0.052	0.188	0.283	0.433	0.367	0.340	0.230	0.502	0.788	0.687	0.562	0.366
1978	0.000	0.002	0.028	0.123	0.300	0.458	0.394	0.356	0.303	0.333	0.310	0.617	1.815	4.182	0.322
1979	0.000	0.001	0.045	0.239	0.474	0.520	0.357	0.303	0.157	0.088	0.060	0.053	0.110	0.002	0.074
1980	0.000	0.001	0.029	0.184	0.427	0.571	0.607	0.580	0.393	0.258	0.249	0.195	0.062	0.000	0.253
1981	0.000	0.002	0.056	0.218	0.455	0.508	0.531	0.570	0.372	0.264	0.283	0.225	0.227	0.037	0.274
1982	0.000	0.001	0.032	0.201	0.399	0.398	0.532	0.433	0.535	0.523	0.489	0.428	0.657	1.274	0.506
1983	0.000	0.000	0.038	0.176	0.319	0.429	0.344	0.382	0.351	0.312	0.462	0.283	0.257	0.352	0.387
1984	0.000	0.000	0.008	0.101	0.309	0.407	0.484	0.380	0.348	0.260	0.348	0.345	0.289	0.279	0.304
1985	0.000	0.000	0.003	0.065	0.230	0.445	0.607	0.644	0.639	0.537	0.430	0.834	0.762	0.270	0.484
1986	0.000	0.000	0.006	0.122	0.343	0.349	0.367	0.391	0.543	0.429	0.451	0.208	0.934	0.256	0.440
1987	0.000	0.000	0.001	0.056	0.263	0.482	0.464	0.559	0.517	0.644	0.561	0.605	0.242	0.382	0.603
1988	0.000	0.000	0.007	0.107	0.207	0.317	0.696	0.468	0.719	0.558	0.902	1.040	0.781	0.051	0.730
1989	0.000	0.000	0.016	0.140	0.508	0.597	0.504	0.597	0.454	0.580	0.514	0.313	0.576	0.429	0.547
1990	0.000	0.000	0.006	0.079	0.361	0.771	0.767	1.355	1.380	0.846	1.113	0.855	1.142	0.726	0.980
1991	0.000	0.000	0.015	0.104	0.372	0.764	0.454	0.919	0.556	0.316	1.301	0.870	2.013	0.726	0.808
1992	0.000	0.000	0.058	0.211	0.515	0.916	1.459	2.077	0.995	2.536	1.300	2.980	2.849	4.937	1.918
1993	0.000	0.000	0.003	0.074	0.100	0.104	0.232	0.510	1.377	0.124	0.603	0.225	0.796	1.524	0.364
1994	0.000	0.000	0.000	0.001	0.023	0.010	0.020	0.015	0.051	0.138	0.000	0.002	0.001	0.012	0.069
1995	0.000	0.000	0.000	0.003	0.015	0.045	0.018	0.013	0.020	0.053	0.004	0.001	0.006	0.003	0.028
1996	0.000	0.000	0.006	0.010	0.023	0.032	0.046	0.013	0.003	0.009	0.008	0.011	0.002	0.017	0.008
1997	0.000	0.000	0.001	0.005	0.010	0.024	0.064	0.188	0.078	0.028	0.061	0.564	0.030	0.969	0.045
1998	0.000	0.000	0.000	0.007	0.022	0.021	0.052	0.106	0.201	0.033	0.039	0.099	0.009	0.070	0.036
1999	0.000	0.000	0.000	0.006	0.035	0.053	0.050	0.093	0.085	0.227	0.107	0.044	0.022	0.038	0.167
2000	0.000	0.000	0.001	0.001	0.016	0.078	0.060	0.020	0.006	0.094	0.002	0.001	0.001	0.003	0.048
2001	0.000	0.000	0.001	0.009	0.008	0.052	0.074	0.044	0.014	0.014	0.001	0.005	0.003	0.002	0.008
2002	0.000	0.000	0.000	0.004	0.016	0.005	0.044	0.088	0.044	0.044	0.063	0.149	0.012	0.007	0.053
2003	0.000	0.000	0.000	0.001	0.005	0.009	0.011	0.036	0.059	0.025	0.012	0.070	0.010	0.032	0.019
2004	0.000	0.000	0.000	0.000	0.001	0.016	0.033	0.013	0.088	0.106	0.073	0.090	0.010	0.030	0.090
2005	0.000	0.000	0.000	0.000	0.000	0.012	0.042	0.038	0.028	0.058	0.111	0.113	0.005	0.029	0.085
2006	0.000	0.000	0.000	0.002	0.005	0.002	0.017	0.034	0.059	0.021	0.129	0.105	0.164	0.014	0.075
2007	0.000	0.000	0.000	0.000	0.002	0.014	0.004	0.019	0.012	0.060	0.001	0.008	0.025	0.041	0.030
2008	0.000	0.000	0.000	0.000	0.000	0.003	0.014	0.005	0.045	0.070	0.096	0.002	0.015	0.500	0.083
2009	0.000	0.000	0.000	0.000	0.000	0.001	0.008	0.018	0.006	0.049	0.247	0.042	0.008	0.027	0.148
2010	0.000	0.000	0.000	0.000	0.000	0.001	0.004	0.008	0.011	0.007	0.082	0.035	0.013	0.006	0.045
2011		0.000	0.000	0.000	0.000	0.001	0.002	0.004	0.005	0.012	0.010	0.010	0.010	0.010	0.010

Table S1.5. Estimated spawning stock biomass (SSB, thousand tonnes) and instantaneous rates of natural mortality of Atlantic cod on the eastern Scotian Shelf based on the updated assessment model.

		Natural Mortality	
Year	SSB	Ages 1-4	Ages 5+
1970	131.707	0.356	0.070
1971	99.686	0.364	0.070
1972	95.260	0.393	0.073
1973	76.615	0.441	0.078
1974	53.342	0.476	0.084
1975	61.432	0.460	0.087
1976	36.278	0.408	0.089
1977	43.020	0.355	0.092
1978	82.193	0.316	0.095
1979	104.044	0.285	0.099
1980	111.573	0.264	0.105
1981	116.172	0.268	0.114
1982	121.909	0.306	0.129
1983	143.194	0.379	0.149
1984	150.830	0.441	0.172
1985	155.525	0.435	0.194
1986	148.627	0.392	0.207
1987	130.369	0.342	0.214
1988	104.630	0.311	0.221
1989	92.657	0.298	0.234
1990	66.310	0.312	0.260
1991	52.020	0.352	0.311
1992	47.807	0.425	0.392
1993	22.969	0.503	0.531
1994	21.980	0.538	0.767
1995	13.819	0.540	1.038
1996	11.463	0.523	1.119
1997	12.985	0.506	0.863
1998	9.059	0.498	0.752
1999	7.755	0.512	0.829
2000	7.180	0.529	0.984
2001	7.509	0.547	0.995
2002	7.257	0.490	0.945
2003	4.412	0.400	0.958
2004	5.106	0.341	1.088
2005	14.531	0.317	0.982
2006	10.583	0.319	0.882
2007	9.559	0.326	0.732
2008	19.563	0.310	0.589
2009	27.162	0.294	0.505
2010	46.906	0.289	0.465
2011	52.053	0.286	0.441

Table S1.6. Mean weight (kg) at age of Atlantic cod on the eastern Scotian Shelf. Missing values replaced by the long term average for that age.

	Age														
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1970	0.09	0.28	1.09	1.39	1.88	2.34	3.72	3.08	6.03	5.34	3.96	12.30	3.08	10.62	15.13
1971	0.05	0.22	0.49	1.19	1.51	1.80	2.13	2.71	3.62	2.70	2.60	11.00	3.10	10.62	15.13
1972	0.07	0.37	0.83	1.01	1.66	1.88	2.10	3.22	7.58	4.08	6.54	9.27	9.23	10.62	15.13
1973	0.10	0.27	0.68	1.05	1.38	2.27	2.32	2.31	2.35	7.43	5.06	9.27	9.23	10.50	6.80
1974	0.13	0.32	0.56	1.16	1.54	2.10	3.03	3.47	2.76	4.23	8.30	5.50	9.23	10.62	14.50
1975	0.09	0.27	0.53	1.02	1.55	2.53	3.86	4.82	4.89	5.95	6.54	10.00	9.23	10.62	15.13
1976	0.08	0.28	0.53	1.05	1.56	2.47	3.45	3.67	3.96	6.05	4.90	9.27	11.25	10.62	15.13
1977	0.15	0.32	0.69	1.14	1.96	2.80	3.83	5.41	5.02	5.62	6.27	5.00	9.23	10.62	15.13
1978	0.07	0.43	0.76	1.27	1.98	3.14	3.13	5.15	6.74	12.73	6.54	9.27	9.23	10.62	15.13
1979	0.05	0.24	0.47	0.95	1.46	2.32	4.06	5.81	6.07	8.85	9.04	14.20	8.80	10.62	15.13
1980	0.09	0.31	0.61	0.98	1.49	2.20	2.71	4.71	6.93	8.26	10.76	9.27	9.23	10.62	15.13
1981	0.10	0.35	0.64	1.18	1.74	2.00	2.65	3.95	6.47	8.71	8.90	11.00	11.00	10.62	12.00
1982	0.06	0.28	0.50	0.79	1.44	2.15	2.53	3.08	3.98	6.20	7.51	9.27	9.23	9.30	15.13
1983	0.07	0.20	0.52	1.02	1.45	2.17	3.02	3.34	4.95	4.68	10.97	13.00	14.00	10.62	15.13
1984	0.09	0.28	0.58	0.93	1.51	1.84	2.19	3.67	3.27	3.43	6.58	14.00	6.00	11.50	15.13
1985	0.06	0.16	0.44	0.76	1.18	1.67	2.18	3.00	3.81	4.21	6.96	4.48	9.23	10.62	26.00
1986	0.08	0.28	0.63	0.84	1.28	1.67	2.20	2.75	4.20	5.05	7.01	9.27	9.60	10.62	15.13
1987	0.06	0.18	0.48	0.85	1.32	1.54	1.79	2.33	3.85	4.06	6.17	8.07	17.20	10.62	16.34
1988	0.08	0.23	0.42	0.80	1.39	1.72	1.92	2.39	3.00	5.40	6.58	7.35	9.23	13.29	15.13
1989	0.09	0.28	0.53	0.82	1.36	1.57	2.50	2.83	3.06	7.12	9.90	11.58	8.30	10.62	15.13
1990	0.07	0.23	0.41	0.72	1.10	1.65	2.03	3.25	3.08	3.76	6.54	9.27	9.23	10.62	15.13
1991	0.08	0.23	0.43	0.70	1.02	1.37	1.75	2.06	4.37	4.22	5.18	10.00	9.23	10.62	15.13
1992	0.05	0.13	0.36	0.51	0.83	1.11	1.54	2.42	4.73	8.23	6.54	9.27	9.23	8.49	15.13
1993	0.02	0.20	0.34	0.62	0.86	0.96	1.30	1.86	9.00	1.75	6.54	9.27	9.23	10.62	15.13
1994	0.07	0.22	0.34	0.51	0.78	1.05	1.85	2.18	2.16	4.51	7.15	9.27	9.23	10.62	15.13
1995	0.07	0.22	0.38	0.54	0.70	1.07	1.34	1.63	1.32	5.62	6.54	9.27	9.23	10.62	15.13
1996	0.07	0.24	0.39	0.61	0.86	1.02	1.52	1.82	3.75	1.62	6.54	9.27	9.23	10.62	15.13
1997	0.13	0.21	0.45	0.73	1.07	1.57	1.86	1.89	0.92	5.62	6.54	9.27	9.23	10.62	15.13
1998	0.06	0.18	0.48	0.84	0.98	1.19	1.69	1.96	3.96	5.62	3.70	9.27	9.23	10.62	15.13
1999	0.08	0.24	0.34	0.56	0.84	1.16	1.92	2.42	2.32	5.62	3.73	9.27	9.23	10.62	15.13
2000	0.08	0.19	0.41	0.66	0.92	1.45	1.64	2.06	6.30	4.96	6.54	9.27	9.23	10.62	15.13
2001	0.06	0.16	0.35	0.65	0.89	1.29	1.49	1.70	3.96	5.50	6.54	9.27	9.23	10.62	15.13
2002	0.08	0.22	0.42	0.60	0.82	2.02	2.23	2.93	3.96	5.62	6.54	1.53	9.23	10.62	15.13
2003	0.04	0.15	0.28	0.57	0.80	1.31	1.70	1.50	2.18	4.03	6.54	9.27	9.23	10.62	15.13
2004	0.07	0.14	0.29	0.50	0.98	1.02	1.38	1.38	3.96	5.62	6.54	9.27	9.23	10.62	15.13
2005	0.07	0.14	0.32	0.56	1.03	1.24	2.03	2.26	2.69	5.62	2.70	9.27	9.23	10.62	15.13
2006	0.08	0.21	0.44	0.65	0.83	1.43	1.05	3.53	3.96	5.62	6.54	9.27	9.23	10.62	15.13
2007	0.07	0.21	0.49	0.66	0.86	1.25	1.07	1.64	3.96	5.62	6.54	9.27	9.23	10.62	15.13
2008	0.09	0.21	0.41	0.67	1.20	1.60	1.96	4.25	1.90	9.90	6.54	9.27	9.23	10.62	15.13
2009	0.06	0.20	0.55	0.73	0.99	1.27	1.36	2.09	1.99	5.62	6.54	9.27	9.23	10.62	15.13
2010	0.09	0.23	0.44	0.74	1.26	2.12	2.81	3.26	1.58	5.62	6.54	9.27	9.23	10.62	15.13

Supplementary Appendix S2: Stock-recruit relationship of Atlantic cod on the eastern Scotian Shelf and the effect of pelagic fish biomass

Ricker and Beverton-Holt spawner-recruit relationships were fit for eastern Scotian Shelf cod using the Nonlinear Least Squares (NLS) function in the R software package. The Ricker model was expressed as:

$$R = aSe^{bS} \quad (1)$$

where R is age-1 recruits in millions and S is spawning stock biomass in 1000 t. The Beverton-Holt model was expressed as:

$$R = aS/(b+S) \quad (2)$$

Analyses used the 1970-2009 year-classes, based on the population model results given in Supplementary Appendix S1. Fits of the two models to the stock-recruit data were similar, though parameter estimates were more significant for the Ricker model (Table S2.1, Fig. S2.1). Residuals from both models were unrelated to the bottom-trawl survey index of biomass of three dominant pelagic forage fishes, Atlantic herring, capelin and northern sand lance (Fig. S2.2).

Stock-recruit models were also fit including pelagic fish biomass as a covariate. The Ricker model was expressed as:

$$R = aSe^{(bS+cP)} \quad (3)$$

where P is the biomass index in million t for pelagic forage fishes.The Beverton-Holt model was expressed as:

$$R = aSe^{cP}/(b+S) \quad (4)$$

For both the Ricker and the Beverton-Holt models, addition of the pelagic fish covariate did not improve the model (P= 0.28 and 0.21, respectively, based on a likelihood ratio test) and the parameter for the effect of pelagic fish biomass was not significant (Table S2.2).

Table S2.1. Stock-recruit relationships for Atlantic cod on the eastern Scotian Shelf.

Parameter	Estimate	SE	*t* value	*P*
A. Ricker, RSE=38.79				
a	2.884	0.578	4.990	<0.0001
b	-0.00977	0.00196	-4.978	<0.0001
B. Beverton-Holt, RSE=39.92				
a	138.64	26.05	5.322	<0.0001
b	35.17	19.43	1.811	0.078

Table S2.2. Stock-recruit relationships for Atlantic cod on the eastern Scotian Shelf, including pelagic fish biomass as a covariate (parameter c).

Parameter	Estimate	SE	*t* value	*P*
A. Ricker, RSE=38.68				
a	3.370	0.787	4.280	0.0001
b	-0.01082	0.00215	-5.029	<0.0001
c	-0.10282	0.09826	-1.046	0.30
B. Beverton-Holt, RSE=39.59				
a	128.93	21.20	6.082	<0.0001
b	19.61	16.06	1.221	0.23
c	-0.1267	0.1103	-1.149	0.26

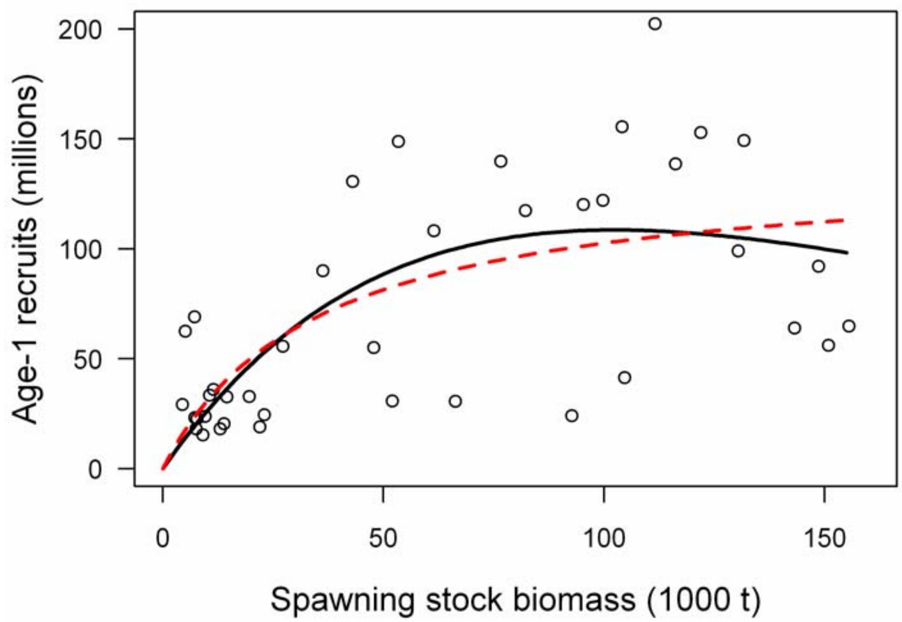

Figure S2.1. Ricker (solid black line) and Beverton-Holt (dashed red line) stock-recruit relationships for Atlantic cod on the eastern Scotian Shelf, 1970-2009 year-classes.

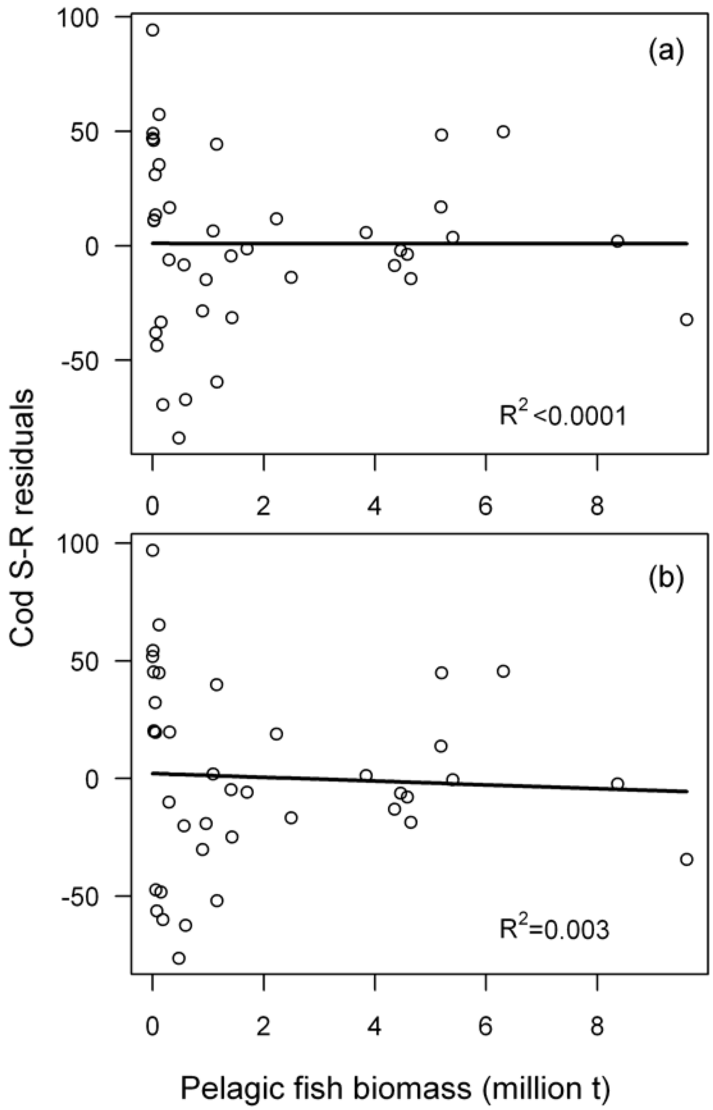

Figure S2.2. Relationships between the residuals from the Ricker (a) and Beverton-Holt (b) stock-recruit relationships for eastern Scotian Shelf cod and the biomass index for pelagic fish in the year that each year-class was produced. Lines show the linear regression of recruitment residuals on pelagic fish biomass.