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An assessment of the Northwest Atlantic mackerel (*Scomber scombrus* L.) with XSA (Extended Survivors Analysis)

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Table 1. Standardized stratified mean catch per set in numbers and weight (kg) for Atlantic mackerel in the NEFSC spring research vessels bottom trawl surveys conducted from 1968 to 2008*.

	SPRING SURVEY BACKTRANSFORMED GEOMETRIC MEAN	
YEAR	No/Set	Wt/Set
1968	17.921	1.831
1969	0.190	0.033
1970	2.908	0.972
1971	3.154	1.023
1972	2.566	0.657
1973	3.490	0.885
1974	3.444	0.866
1975	1.200	0.232
1976	1.353	0.345
1977	0.535	0.209
1978	1.068	0.482
1979	0.405	0.231
1980	0.797	0.368
1981	4.606	1.978
1982	1.112	0.396
1983	0.611	0.121
1984	2.819	0.971
1985	3.036	1.005
1986	1.334	0.484
1987	14.006	3.676
1988	7.095	2.469
1989	4.321	0.713
1990	4.104	0.883
1991	6.577	1.477
1992	12.719	2.267
1993	9.767	2.674
1994	15.604	3.045
1995	15.668	2.865
1996	15.555	2.669
1997	6.679	1.248
1998	13.389	1.736
1999	24.723	3.723
2000	30.193	3.446
2001	59.106	6.022
2002	11.387	2.615
2003	44.151	5.177
2004	32.741	3.063
2005	7.761	1.611
2006	38.982	4.917
2007	15.602	2.606
2008	9.166	1.893

* Data from G. Shepherd and J. Deroba, NEFSC, Woods Hole, pers. comm.

Table 2. Standardized stratified mean catch per set at age (numbers) of Atlantic mackerel in the NEFSC spring research vessels bottom trawl surveys conducted from 1968 to 2008*.

	AGE (yr)									
YEAR	1	2	3	4	5	6	7	8	9	10+
1968	**12.94**	0.4150	0.1890	0.0520	0.0160	0.0000	0.0000	0.0000	**0.0000**	0.0000
1969	0.0300	**0.1420**	0.0170	0.0060	0.0000	0.0010	0.0010	0.0010	0.0000	**0.0000**
1970	0.2800	0.1850	**1.3910**	0.6120	0.1810	0.0620	0.0550	0.0880	0.0830	0.0470
1971	0.3280	0.9410	0.4380	**1.1250**	0.3930	0.0620	0.0140	0.0070	0.0060	0.0080
1972	0.8720	0.3080	0.5930	0.2260	**0.3250**	0.0580	0.0110	0.0010	0.0020	0.0000
1973	0.3510	0.3400	0.1760	0.2340	0.1260	**0.2850**	0.1820	0.1520	0.0460	0.1020
1974	0.3480	0.1800	0.2360	0.0480	0.0990	0.0600	**0.2080**	0.0910	0.0590	0.0230
1975	**0.6540**	0.2300	0.0410	0.0230	0.0060	0.0070	0.0040	**0.0040**	0.0030	0.0000
1976	0.0960	**0.3870**	0.0710	0.0140	0.0020	0.0010	0.0030	0.0000	**0.0020**	0.0010
1977	0.0100	0.0470	**0.0850**	0.0450	0.0150	0.0050	0.0030	0.0070	0.0040	**0.0140**
1978	0.0500	0.1100	0.1030	**0.1940**	0.0960	0.0280	0.0110	0.0030	0.0150	0.0180
1979	0.0110	0.0040	0.0070	0.0130	**0.0500**	0.0140	0.0100	0.0060	0.0060	0.0480
1980	0.0230	0.1880	0.0070	0.0050	0.0230	**0.0490**	0.0110	0.0110	0.0070	0.0280
1981	0.3360	0.1370	0.4290	0.0480	0.0460	0.1610	**0.4040**	0.2300	0.1390	0.4020
1982	0.4320	0.1950	0.0220	0.0980	0.0180	0.0100	0.0250	**0.0970**	0.0440	0.0840
1983	**0.2360**	0.2870	0.0220	0.0020	0.0040	0.0010	0.0000	0.0010	**0.0020**	0.0020
1984	0.2600	**1.8010**	0.6060	0.0420	0.0050	0.0430	0.0040	0.0030	0.0160	**0.0840**
1985	0.3380	0.0850	**1.8510**	0.2350	0.0280	0.0110	0.0470	0.0030	0.0100	0.1860
1986	0.1300	0.4500	0.0780	**0.5910**	0.1180	0.0080	0.0010	0.0200	0.0000	0.0470
1987	1.4840	1.7950	0.8740	0.3720	**2.9450**	0.4970	0.1430	0.0160	0.1380	0.2560
1988	0.6340	0.4580	0.3670	0.3360	0.3750	**1.7690**	0.4430	0.0510	0.0480	0.2230
1989	**1.5830**	1.6410	0.0710	0.2840	0.0090	0.0110	**0.0670**	0.0090	0.0050	0.0180
1990	1.3000	**1.3850**	0.5010	0.0160	0.0130	0.0060	0.0000	**0.0760**	0.0090	0.0160
1991	1.6700	0.8890	**1.4840**	0.5370	0.2400	0.1140	0.0580	0.0000	**0.2690**	0.0030
1992	2.9790	2.6422	0.5558	**1.1593**	0.7247	0.1156	0.1304	0.0199	0.0488	**0.3450**
1993	1.2070	2.6595	1.0091	0.3813	**1.0544**	0.7203	0.1492	0.1330	0.3325	0.6099
1994	4.1386	1.7436	2.1139	0.8699	0.2815	**0.6019**	0.2070	0.0512	0.0105	0.2251
1995	3.1701	3.4871	0.5893	1.1824	0.7122	0.2848	**0.7191**	0.2258	0.0655	0.1310
1996	4.0058	3.2257	1.3258	0.1481	0.6175	0.4196	0.1927	**0.2800**	0.1539	0.1317
1997	**2.9998**	1.1619	0.4485	0.2247	0.0254	0.1244	0.1149	0.0452	**0.0702**	0.0066
1998	5.6474	**3.1195**	0.6787	0.2863	0.1211	0.0171	0.0867	0.0634	0.0179	**0.0240**
1999	4.9932	4.1347	**2.9206**	0.9221	0.4061	0.1784	0.0498	0.0819	0.0436	0.0145
2000	**14.7693**	2.4561	1.1156	**0.7272**	0.2514	0.1189	0.0500	0.0000	0.0236	0.0194
2001	12.4608	**26.5956**	1.7582	0.3622	**0.2115**	0.0375	0.0114	0.0093	0.0042	0.0012
2002	1.2662	2.9770	**5.7418**	0.4438	0.1229	**0.0494**	0.0192	0.0014	0.0000	0.0000
2003	9.1159	8.3906	2.9148	**3.2997**	0.4028	0.1207	**0.0555**	0.0000	0.0000	0.0000
2004	**21.9188**	3.0060	0.3165	0.1166	**0.1516**	0.0121	0.0020	**0.0000**	0.0000	0.0000
2005	1.7745	**3.7293**	0.9319	0.1697	0.1354	**0.3667**	0.0258	0.0050	**0.0000**	0.0000
2006	**4.4389**	9.5737	**6.2724**	0.6548	0.1372	0.0521	**0.1267**	0.0120	0.0000	**0.0000**
2007	1.9963	**6.9564**	1.2098	**1.2239**	0.1565	0.0135	0.0224	**0.0320**	0.0062	0.0000
2008	3.2617	1.6649	**1.6213**	0.2450	**0.2289**	0.0000	0.0000	0.0000	**0.0305**	0.0000

* Data from G. Shepherd and J. Deroba, NEFSC, Woods Hole, pers. comm.

** Bold and underlined figures represent dominant year-classes seen in the commercial catch at age

Table 3. Extended Survivors Analysis (XSA) formulation for **Run 1**: Catchability independent of stock size for all ages and independent of age for ages ≥ 7; last true age in the catch at age is 9 (10^+ is present).

FLEET	FIRST YEAR	LAST YEAR	FIRST AGE	LAST AGE	Alpha	Beta
Spring Survey:	1968	2008	1	9	0.333	0.417

Time series weights :	Tapered time weighting applied Power = 3 over 20 years
Catchability analysis :	Catchability independent of stock size for all ages Catchability independent of age for ages >= 7
Terminal population estimation :	Survivor estimates shrunk towards the mean F of the final 5 years or the 5 oldest ages
	S.E. of the mean to which the estimates are shrunk = .500
	Minimum standard error for population estimates derived from each fleet = .300
	Prior weighting not applied Tuning converged after 11 iterations

Mean log catchability and standard error of ages with catchability independent of year class strength and constant w.r.t. time

Run 1:	Age	1	2	3	4	5	6
	Mean Log q	-15.267	-15.014	-15.585	-16.052	-16.218	-16.431
	S.E(Log q)	0.641	0.733	0.657	0.628	0.959	0.894
	Age	7	8	9			
	Mean Log q	-16.228	-16.228	-16.228			
	S.E(Log q)	1.257	0.759	1.122			

Regression statistics :
Ages with q independent of year class strength and constant w.r.t. time.

Run 1:	Age	Slope	t-value	Intercept	RSquare	No Pts	Reg s.e
	1	1.22	-0.709	15.93	0.5	20	0.8
	2	1.73	-1.667	17.22	0.34	20	1.18
	3	1.27	-0.859	16.64	0.51	20	0.84
	4	1.14	-0.544	16.77	0.6	20	0.74
	5	3.54	-2.843	31.24	0.11	20	2.65
	6	1.23	-0.668	17.98	0.49	19	1.13
	7	1.56	-0.966	20.38	0.25	18	1.97
	8	1.15	-0.509	17.2	0.65	15	0.89
	9	1.43	-1.593	18.94	0.72	15	0.98

Residual mean squared (log) : 1.13

Table 4. Extended Survivors Analysis (XSA) formulation for **Run 2**: Catchability dependent on stock size for ages < 3 and independent of age for ages ≥ 7; last true age in the catch at age is 9 (10^{+} is present).

FLEET	FIRST YEAR	LAST YEAR	FIRST AGE	LAST AGE	Alpha	Beta
Spring Survey:	1968	2008	1	9	0.333	0.417

Time series weights :	Tapered time weighting applied Power = 3 over 20 years
Catchability analysis :	Catchability dependent on stock size for ages < 3 Regression type = P Minimum of 5 points used for regression Survivor estimates not shrunk to the population mean Catchability independent of age for ages >= 7
Terminal population estimation :	Survivor estimates shrunk towards the mean F of the final 5 years or the 5 oldest ages
	S.E. of the mean to which the estimates are shrunk = .500
	Minimum standard error for population estimates derived from each fleet = .300
	Prior weighting not applied Tuning converged after 11 iterations

Mean log catchability and standard error of ages with catchability independent of year class strength and constant w.r.t. time

Run 2:	Age	3	4	5	6	7	8	9
	Mean Log q	-15.582	-16.052	-16.217	-16.431	-16.228	-16.228	-16.228
	S.E(Log q)	0.657	0.629	0.959	0.894	1.256	0.758	1.122

Regression statistics :
Ages with q dependent on year class strength

Run 2:	Age	Slope	t-value	Intercept	RSquare	No Pts	Reg s.e
	1	0.60	-2.10	14.08	0.49	20.00	0.56
	2	0.57	-1.67	13.73	0.33	20.00	0.69
Ages with q independent of year class strength and constant w.r.t. time.							
	3	0.64	-1.788	14.17	0.51	20	0.6
	4	0.68	-1.817	14.42	0.6	20	0.57
	5	0.39	-1.741	12.62	0.11	20	0.88
	6	0.6	-1.958	13.7	0.49	19	0.79
	7	0.38	-2.753	11.68	0.25	18	0.98
	8	0.75	-1.149	14.09	0.65	15	0.72
	9	1.03	0.115	15.72	0.72	15	0.83

Residual mean squared (log): 1.09

Table 5. Extended Survivors Analysis (XSA): Recruits at age 1 (thousands of fish), fishing mortality (average ages 3-5) and spawning stock biomass (metric tons) calculated from the outputs of XSA **Run 1** and **Run 2**.

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YEAR	RECRUITS AGE 1 (thousands of fish)		FISHING MORTALITY (average ages 3-5)		SPAWNING STOCK BIOMASS (metric tons)	
	RUN 1	RUN 2	RUN 1	RUN 2	RUN 1	RUN 2
1962	371 131	371 131	0.072	0.072	175 878	175 878
1963	198 465	198 465	0.122	0.122	207 482	207 482
1964	264 301	264 301	0.043	0.043	238 059	238 059
1965	301 995	301 995	0.039	0.039	272 654	272 654
1966	727 223	727 223	0.034	0.034	321 062	321 062
1967	1 896 746	1 896 746	0.068	0.068	393 760	393 760
1968	5 127 975	5 127 975	0.259	0.259	779 768	779 768
1969	1 998 853	1 998 853	0.178	0.178	1 097 396	1 097 396
1970	2 458 808	2 458 809	0.211	0.211	1 195 723	1 195 723
1971	1 281 043	1 281 043	0.346	0.346	1 346 896	1 346 897
1972	1 415 964	1 415 965	0.330	0.330	1 455 240	1 455 240
1973	1 126 161	1 126 162	0.484	0.484	1 116 250	1 116 250
1974	1 550 555	1 550 556	0.491	0.491	881 642	881 643
1975	1 690 570	1 690 573	0.487	0.487	743 107	743 107
1976	291 108	291 109	0.681	0.681	588 300	588 301
1977	52 029	52 030	0.258	0.258	438 063	438 064
1978	25 925	25 925	0.077	0.077	460 508	460 510
1979	171 974	171 975	0.064	0.064	403 059	403 060
1980	47 299	47 300	0.138	0.138	380 430	380 432
1981	105 347	105 348	0.126	0.126	301 717	301 719
1982	411 831	411 833	0.154	0.154	273 569	273 572
1983	2 115 758	2 115 782	0.147	0.147	332 700	332 703
1984	102 984	102 987	0.115	0.115	392 369	392 371
1985	137 199	137 201	0.152	0.152	651 264	651 271
1986	96 351	96 352	0.163	0.163	578 250	578 258
1987	99 604	99 605	0.201	0.201	467 850	467 857
1988	277 166	277 177	0.331	0.331	391 047	391 054
1989	461 951	462 011	0.278	0.278	348 538	348 549
1990	99 823	99 834	0.334	0.334	294 096	294 115
1991	169 352	169 362	0.329	0.329	294 005	294 030
1992	149 678	149 681	0.192	0.192	231 132	231 158
1993	26 116	26 121	0.159	0.159	196 845	196 867
1994	138 003	138 003	0.224	0.224	155 592	155 615
1995	183 692	183 692	0.204	0.204	136 760	136 779
1996	130 739	130 740	0.383	0.383	137 836	137 855
1997	183 906	183 906	0.346	0.346	122 572	122 587
1998	90 877	90 877	0.559	0.559	108 376	108 386
1999	158 032	158 031	0.567	0.567	91 323	91 327
2000	1 268 238	1 268 220	0.260	0.260	198 983	198 984
2001	177 888	177 888	0.318	0.318	331 448	331 446
2002	141 433	141 434	0.263	0.263	346 236	346 232
2003	358668	358 658	0.419	0.419	319928	319924
2004	600679	599 932	0.558	0.558	276187	276163
2005	172297	172 347	0.546	0.546	230803	230708
2006	300370	296 083	1.034	1.034	197265	196923
2007	100503	114 376	0.993	0.995	151046	150226
2008	241682	246 575	0.703	0.713	102457	103504

Table 6. Extended Survivors Analysis (XSA): Mohn's Rho statistic for recruits (age 1), population abundance, and fishing mortality (average ages 3-5) calculated from the outputs of XSA **Run 2**.

TERMINAL YEAR	RECRUITS AGE 1	POPULATION ABUNDANCE	FISHING MORTALITY (3-5)
2000	-0.697	-0.651	0.323
2001	0.278	-0.458	0.076
2002	0.601	-0.267	0.372
2003	-0.112	-0.091	0.009
2004	0.804	0.505	-0.155
2005	0.811	0.250	-0.195
2006	0.262	0.392	-0.540
2007	-0.563	0.108	-0.425
AVERAGE:	0.173	-0.026	-0.067
TOTAL	1.383	-0.212	-0.537

Table 7. Input data for the yield per recruit (YPR) and projection (AGEPRO[1]) analyses. Recruits at age 1 for all year-classes (n=47) and selectivity data (partial recruitment) are from the outputs of XSA **Run 2**.

AGE	SELECTIVITY [2]	NATURAL MORTALITY	STOCK WEIGHT [3]	CATCH WEIGHT [4]	SPAWNING STOCK WEIGHT	FRACTION MATURE [5]
1	0.1260	1	0.118	0.147	0.118	0.154
2	0.4329	1	0.184	0.237	0.184	0.807
3	0.8941	1	0.283	0.337	0.283	0.986
4	0.9973	1	0.364	0.403	0.364	0.999
5	0.9887	1	0.435	0.467	0.435	1.000
6	1.0000	1	0.492	0.512	0.492	1.000
7	0.9827	1	0.557	0.589	0.557	1.000
8	1.0000	1	0.603	0.613	0.603	1.000
9	1.0000	1	0.619	0.604	0.619	1.000
10	1.0000	1	0.650	0.650	0.650	1.000

[1] Recruit model = empirical CDF; harvest strategy = F at 40%

[2] From Fs (3-5), average 2004-2008

[3] Rivard's method (NOAA Fisheries Toolbox 2009a), average 2004-2008

[4] Average 2004-2008

[5] Canadian data, average 2004-2008

Table 8. Yield per recruit analysis (YPR) results (F at 40% as a proxy of F_{msy}). Selectivity data (partial recruitment) used in this analysis are from the outputs of XSA **Run 2**.

	PARAMETERS						
	F	Y/R	SSB/R	TB/R	Mean Age	Mean Gen. Time	Expected Spawnings
F-0	0	0	1.752	2.067	5.517	8.146	3.075
F-0.1	0.258	0.162	0.624	0.901	3.006	4.731	1.589
F-Max	0.819	0.187	0.236	0.478	2.040	3.095	0.716
F at 40%	0.217	0.154	0.701	0.982	3.185	5.009	1.731

Table 9. Biological reference points: MSY and B_{msy} as deterministic points estimated by the YPR analysis; msy and B_{msy} were also estimated from stochastic bootstrapped projections (AGEPRO). Recruits and selectivity data (partial recruitment) used in YPR and AGEPRO are from the outputs of XSA **Run 2**.

RECRUITS	Analytical		Stochastic		$F_{(3-5)\ 2008}$ / Fmsy	$SSB_{\ 2008}$ / Bmsy	
(average 1961-2008)	msy (t)	B_{msy} (t)	msy (t)	B_{msy} (t)	Analytical	Analytical	Stochastic
627 919	96 517	440 021	94 553	431 020	3.284	0.235	0.240

Table 10. Extended Survivors Analysis (XSA) formulation for **Run 3**: Catchability independent of stock size for all ages and independent of age for ages ≥ 5; last age in the catch at age is 6 (no 7^{+}).

FLEET	FIRST YEAR	LAST YEAR	FIRST AGE	LAST AGE	Alpha	Beta
Spring Survey	1968	2008	1	6	0.333	0.417

Time series weights : Tapered time weighting applied
Power = 3 over 20 years

Catchability analysis : Catchability independent of stock size for all ages
Catchability independent of age for ages >= 5

Terminal population estimation : Survivor estimates shrunk towards the mean F of the final 5 years or the 5 oldest ages

S.E. of the mean to which the estimates are shrunk = .500

Minimum standard error for population estimates derived from each fleet = .300

Prior weighting not applied
Tuning converged after 25 iterations

Mean log catchability and standard error of ages with catchability independent of year class strength and constant w.r.t. time

Run 3:	Age	1	2	3	4	5	6
	Mean Log q	-15.428	-15.2129	-15.8634	-16.4715	-16.8652	-16.8652
	S.E(Log q)	0.613	0.7456	0.6255	0.5928	0.8557	0.9987

Regression statistics :
Ages with q independent of year class strength and constant w.r.t. time.

Run 3:	Age	Slope	t-value	Intercept	RSquare	No Pts	Reg s.e
	1	1.11	-0.383	15.77	0.53	20	0.71
	2	1.72	-1.489	17.41	0.3	20	1.22
	3	1.13	-0.437	16.38	0.53	20	0.73
	4	1.04	-0.164	16.67	0.63	20	0.65
	5	2.63	-2.498	26.65	0.19	20	1.85
	6	1.01	-0.03	17.52	0.62	19	0.83

Residual mean squared (log) : 1.12

Table 11. Extended Survivors Analysis (XSA): Recruits at age 1 (thousands of fish), fishing mortality (average ages 3-5) and spawning stock biomass (metric tons) calculated from the outputs of XSA **Run 3**.

NORTHWEST ATLANTIC MACKEREL
- NAFO Subareas 2-6 -

YEAR	RECRUITS AGE 1 (thousands of fish)	FISHING MORTALITY (average ages 3-5)	SPAWNING STOCK BIOMASS (metric tons)
1962	395 040	0.028	525 170
1963	185 480	0.022	583 896
1964	200 980	0.017	637 818
1965	374 380	0.023	641 503
1966	1 049 960	0.038	311 611
1967	2 980 910	0.063	354 999
1968	6 073 980	0.228	836 365
1969	2 738 520	0.110	1 250 403
1970	2 806 330	0.135	1 499 151
1971	1 503 070	0.206	1 754 294
1972	1 633 880	0.236	1 950 380
1973	2 336 340	0.347	1 436 061
1974	2 782 770	0.354	1 051 635
1975	2 030 590	0.253	1 071 041
1976	342 060	0.228	954 074
1977	114 630	0.087	954 345
1978	61 530	0.029	987 298
1979	451 280	0.041	693 084
1980	82 020	0.065	471 775
1981	161 430	0.045	284 549
1982	809 650	0.056	250 692
1983	3 666 390	0.063	425 725
1984	155 500	0.055	564 964
1985	247 170	0.072	991 505
1986	185 360	0.078	994 665
1987	182 470	0.106	866 675
1988	551 640	0.157	713 155
1989	845 890	0.109	304 645
1990	149 010	0.117	362 454
1991	266 270	0.122	433 976
1992	264 230	0.080	366 311
1993	37 700	0.083	351 918
1994	202 300	0.118	257 321
1995	255 100	0.111	162 798
1996	172 700	0.196	171 645
1997	290 770	0.177	161 758
1998	132 980	0.249	158 366
1999	196 620	0.240	159 899
2000	1 400 280	0.117	274 473
2001	202 120	0.177	407 185
2002	148 250	0.180	417 726
2003	373 890	0.303	371 131
2004	636 930	0.456	315 916
2005	186 050	0.445	266 398
2006	327 500	0.825	186 102
2007	110 990	0.727	165 059
2008	264 110	0.501	122 439

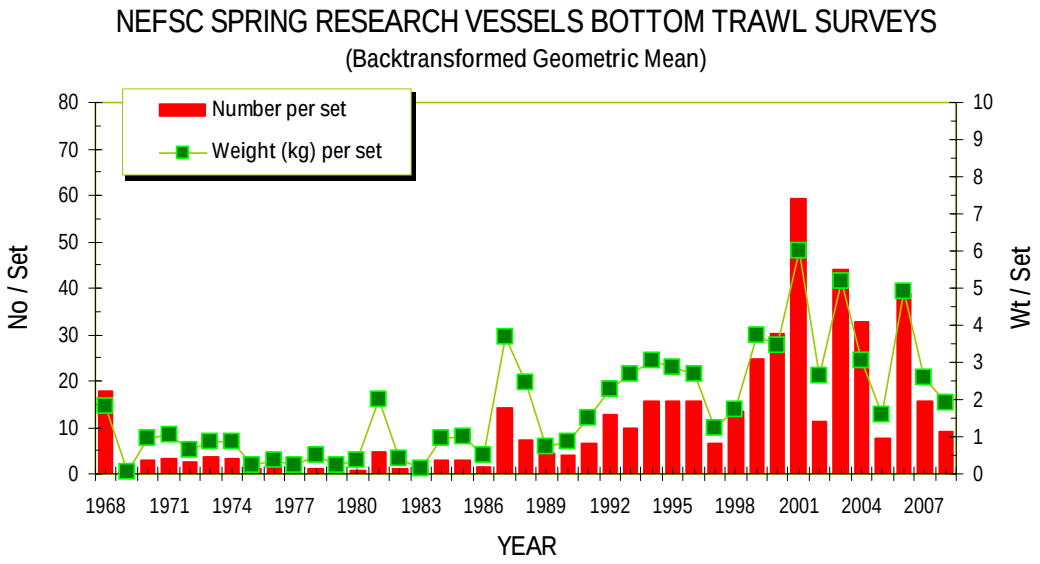

Figure 1. Mean catch per set in numbers and weight (kg) for Atlantic mackerel in the NEFSC spring research vessels bottom trawl surveys conducted from 1968 to 2008.

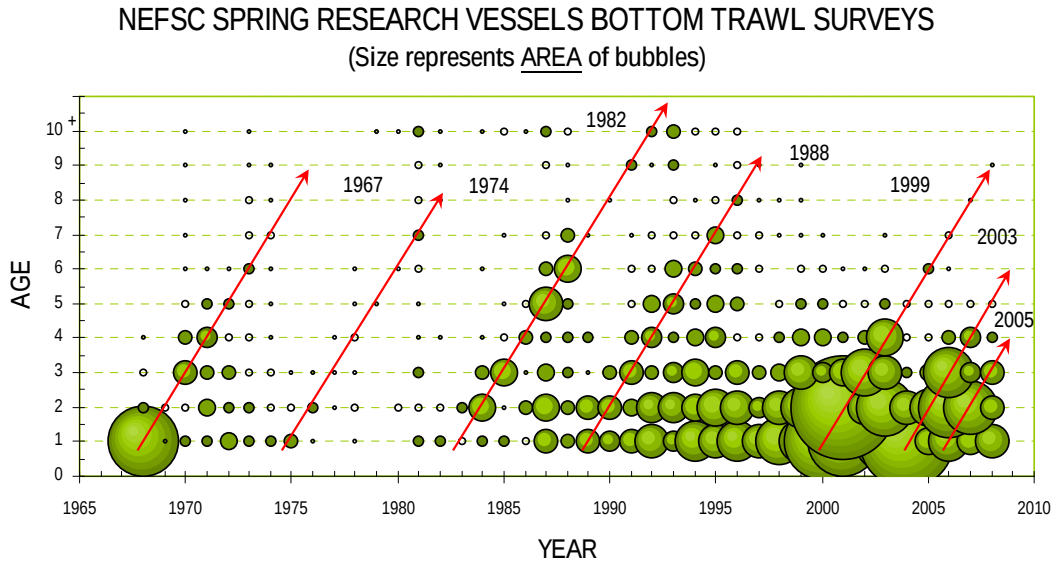

Figure 2. Mean catch per set at age (numbers) of Atlantic mackerel in the NEFSC spring research vessels bottom trawl surveys conducted from 1968 to 2008 (the strong year-classes observed in the commercial catch at age are indicated).

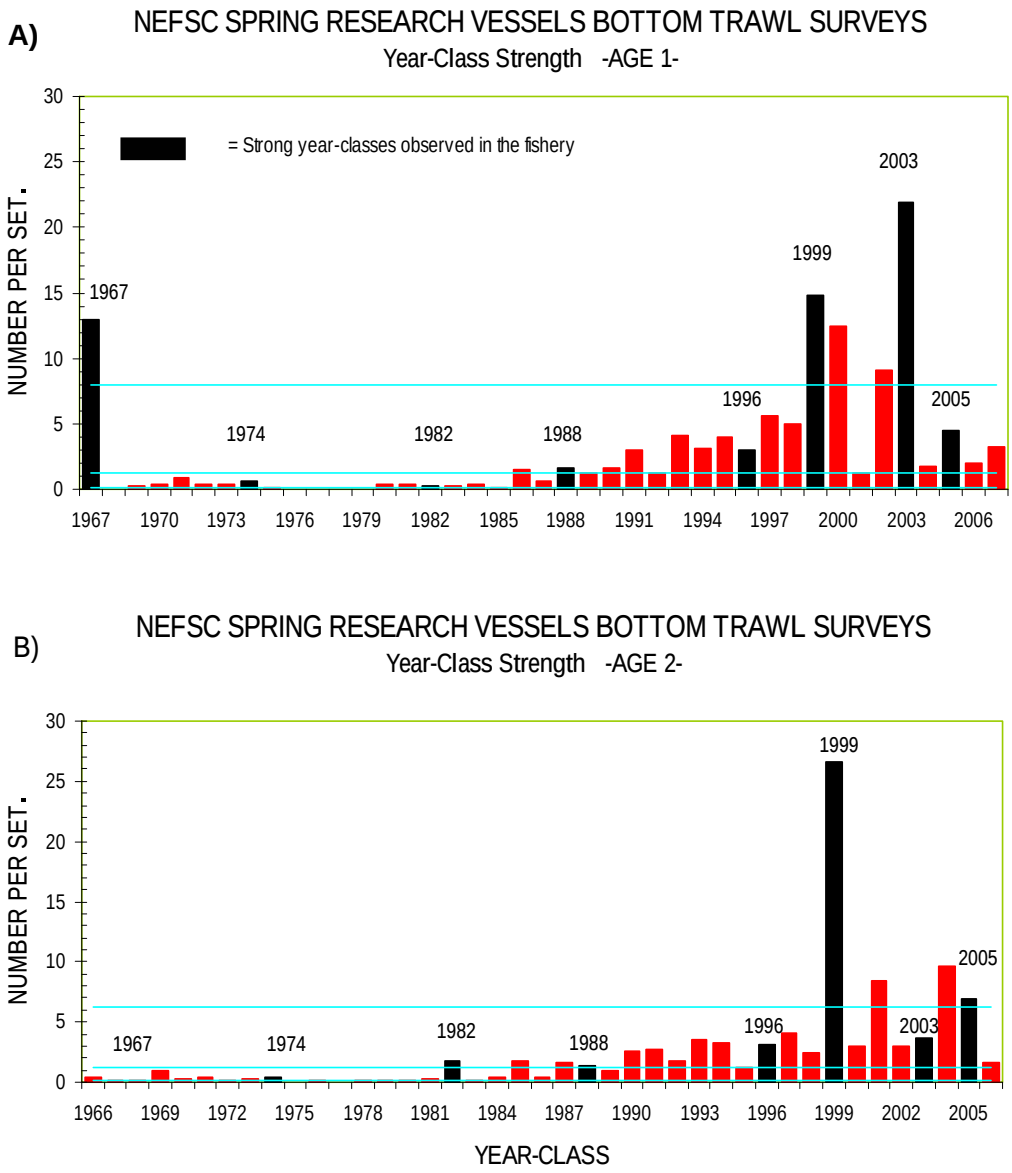

Figure 3. Year-class strength of age 1 (A) and age 2 (B) of Atlantic mackerel in the NEFSC spring research vessels bottom trawl surveys conducted from 1968 to 2008. The horizontal lines represent three levels of abundance: low, average and high.

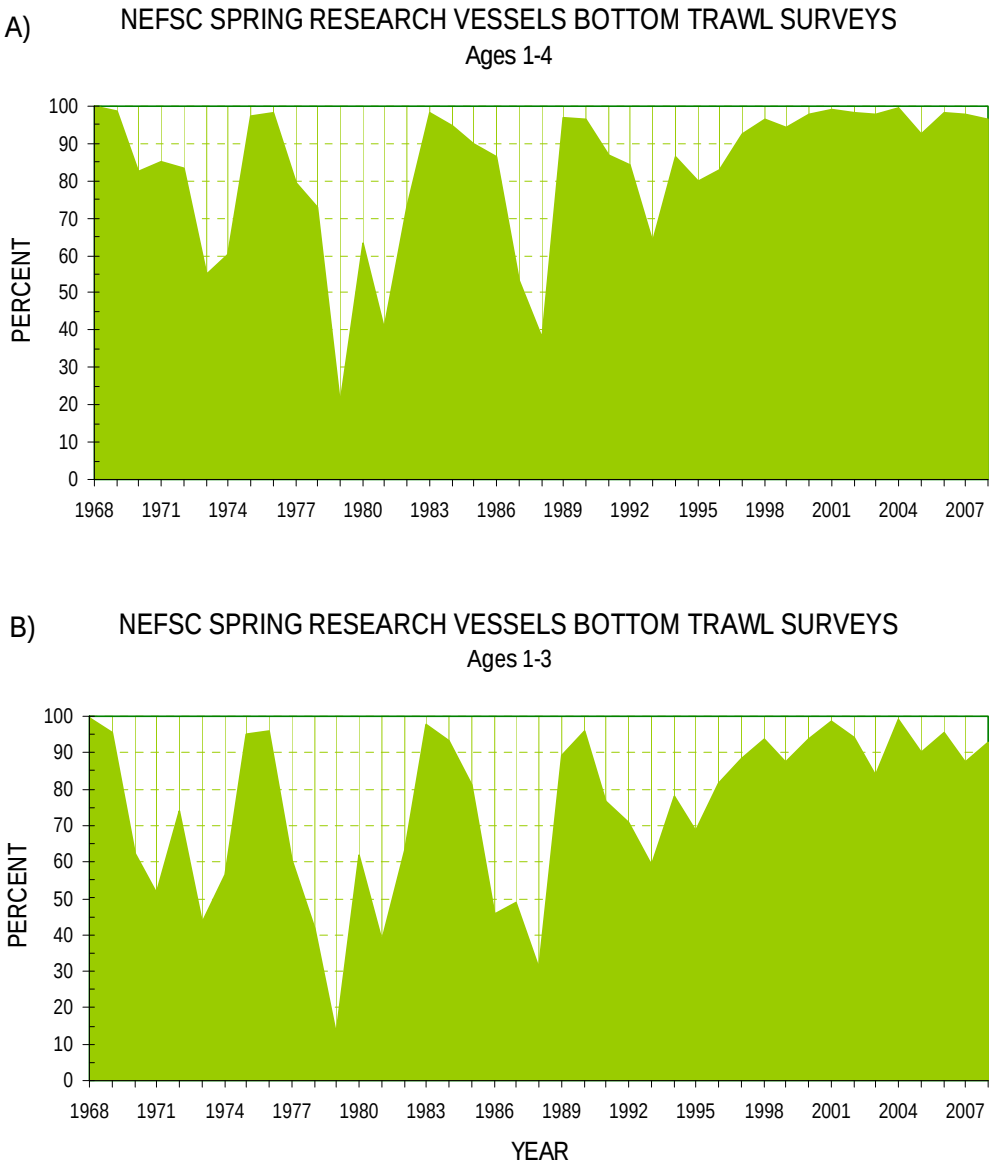

Figure 4. Percentage at ages 1-4 (A) and ages 1-3 (B) of Atlantic mackerel in the NEFSC spring research vessels bottom trawl surveys conducted from 1968 to 2008.

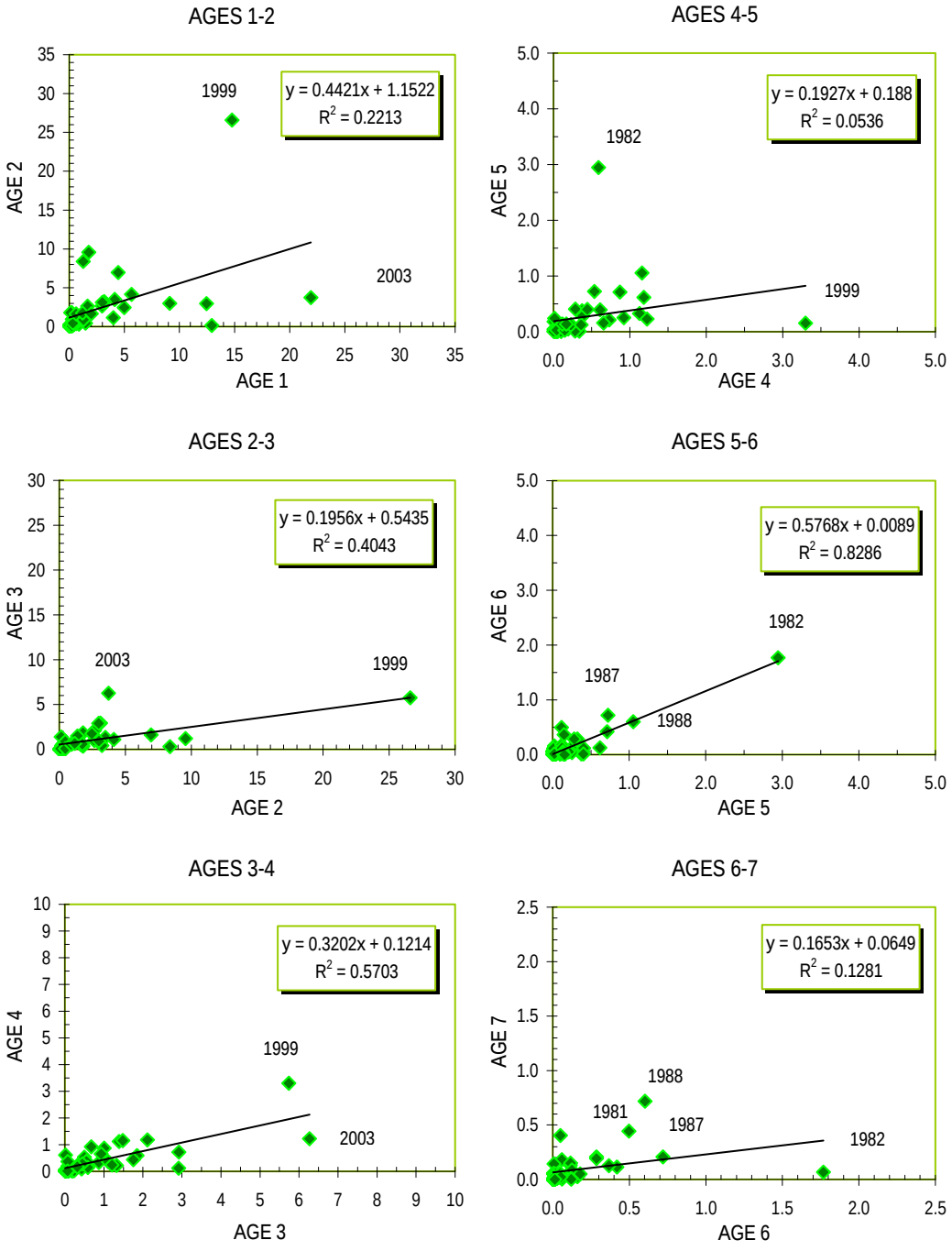

Figure 5. Comparison between NEFSC spring research vessels bottom trawl surveys indices (shifted) at age and the indices of the same year-class one year later.

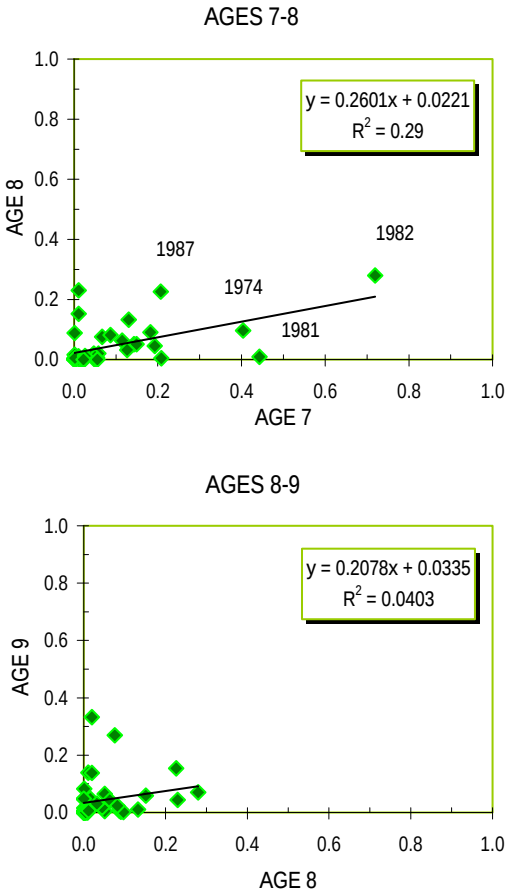

Figure 5. (Continued).

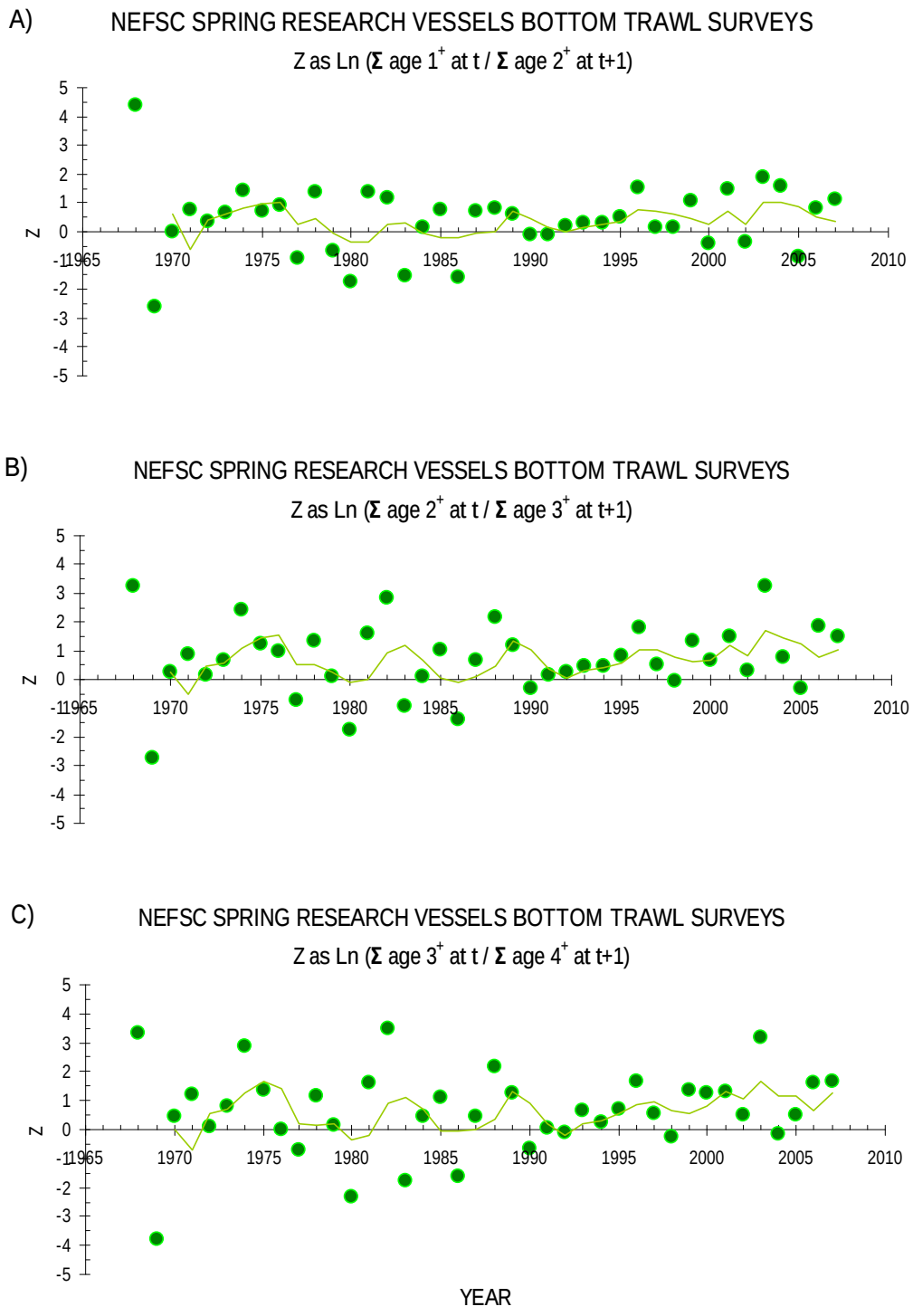

Figure 6. Estimates of instantaneous rate of total mortality (Z) derived from the NEFSC spring research vessels bottom trawl surveys fit with a 3-year moving average over the time series and blocks of ages: A) ln(Σ age 1^+ at t / Σ age 2^+ at t+1); B) ln(Σ age 2^+ at t / Σ age 3^+ at t+1); C) ln(Σ age 3^+ at t / Σ age 4^+ at t+1); D) ln(Σ age 4^+ at t / Σ age 5^+ at t+1); and E) ln(Σ age 5^+ at t / Σ age 6^+ at t+1).

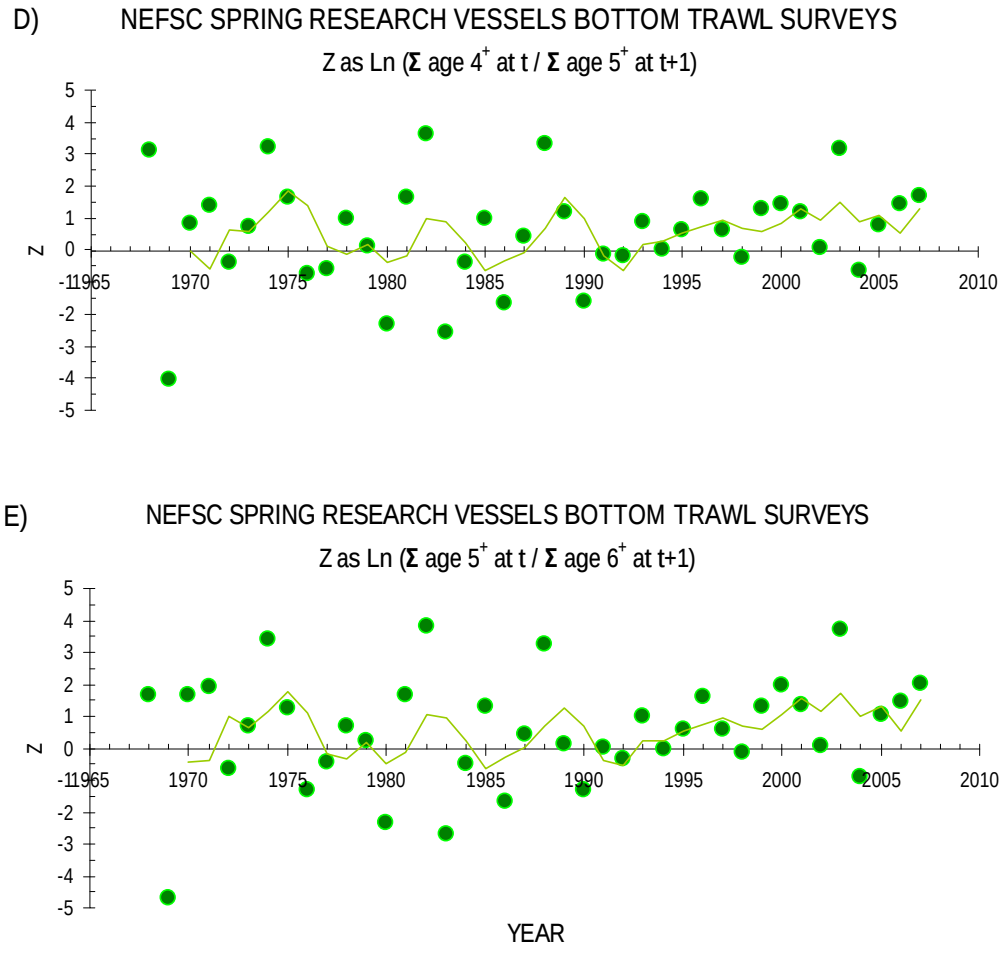

Figure 6. (Continued).

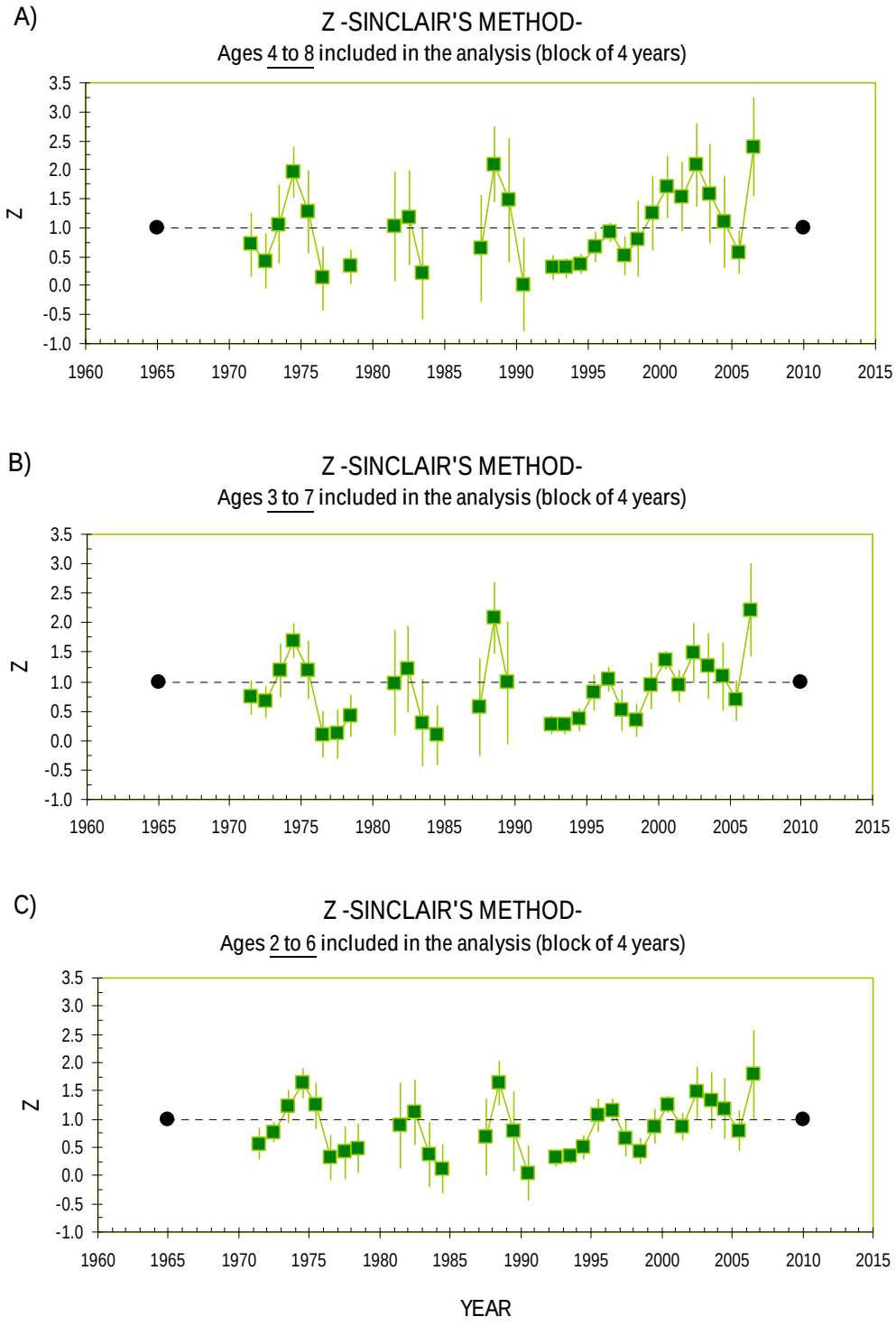

Figure 7. Estimates of instantaneous rate of total mortality (Z) derived from the NEFSC spring research vessels bottom trawl surveys and fit according to the Sinclair's method (Sinclair 1998) for blocks of 4 years and different groups of ages: A) ages 4 to 8; B) ages 3 to 7; and C) ages 2 to 6. The horizontal lines represent Z=1.0.

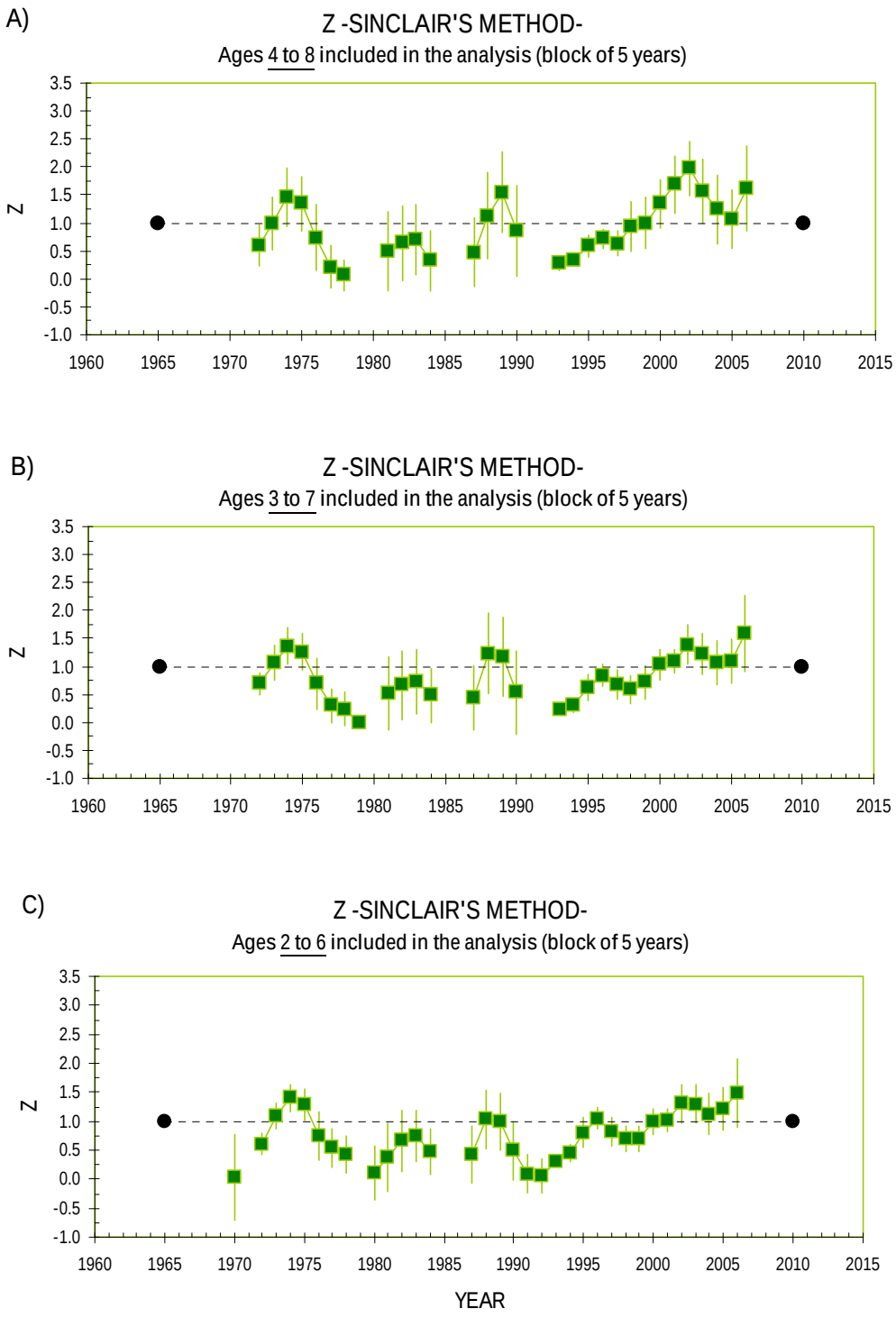

Figure 8. Estimates of instantaneous rate of total mortality (Z) derived from the NEFSC spring research vessels bottom trawl surveys and fit according to the Sinclair's method (Sinclair 1998) for blocks of 5 years and different groups of ages: A) ages 4 to 8; B) ages 3 to 7; and C) ages 2 to 6. The horizontal lines represent Z=1.0.

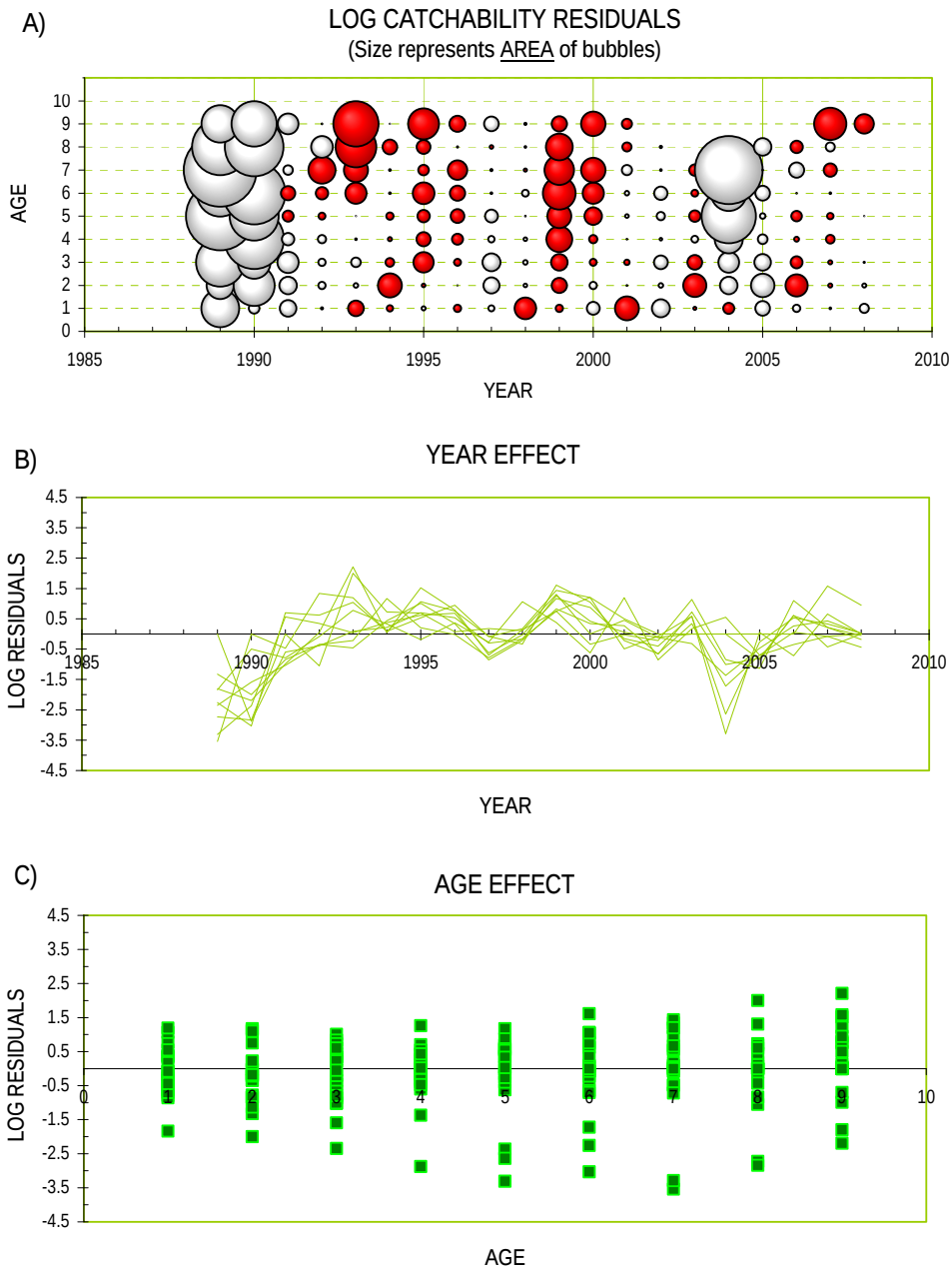

Figure 9. Extended Survivors Analysis (XSA) diagnostics for **Run 1**: A) log of catchability residuals at year and age (negative values are in white); B) plotted against time (year effect); and C) plotted against age (age effect).

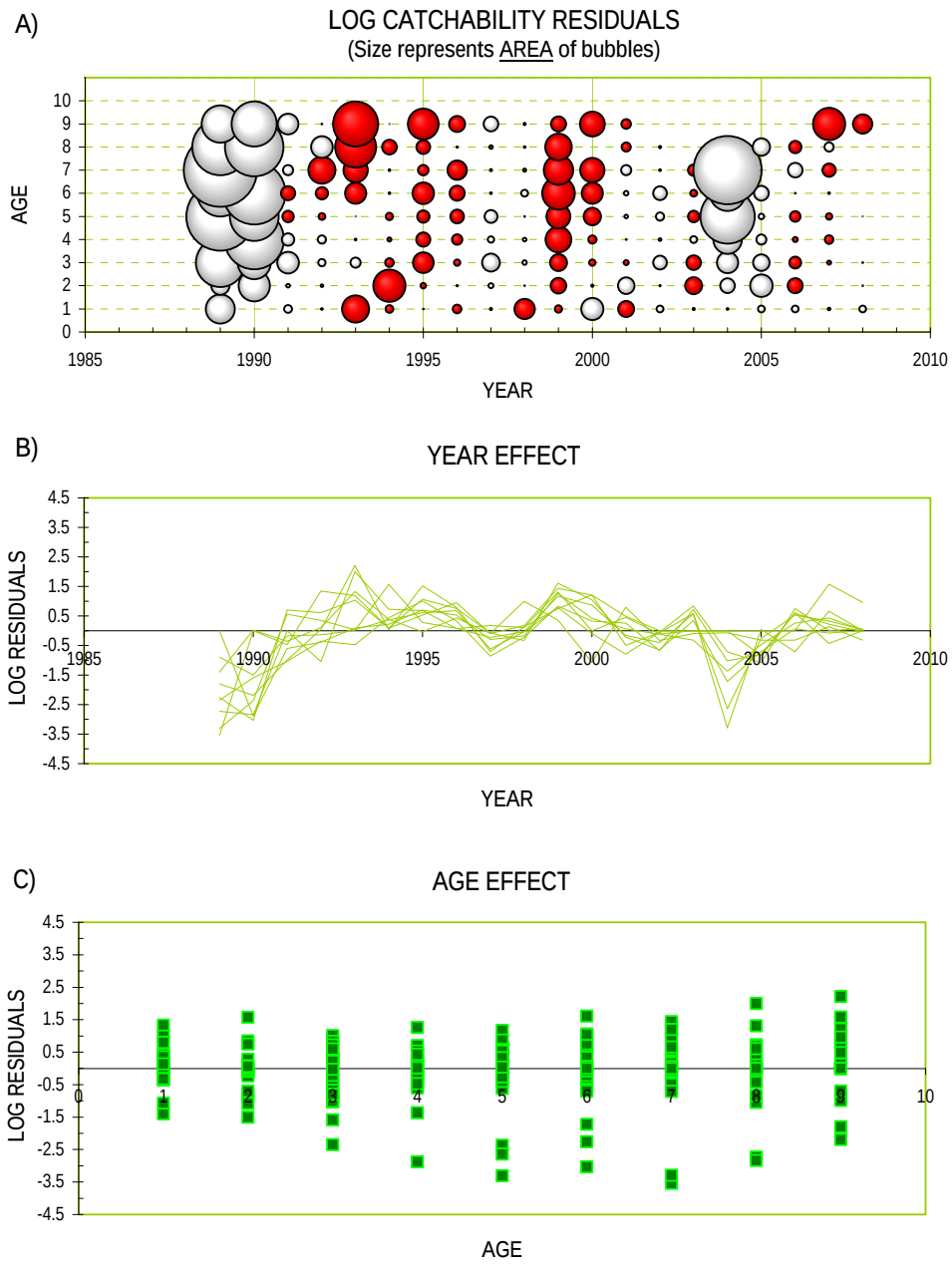

Figure 10. Extended Survivors Analysis (XSA) diagnostics for **Run 2**: A) log of catchability residuals at year and age (negative values are in white); B) plotted against time (year effect); and C) plotted against age (age effect).

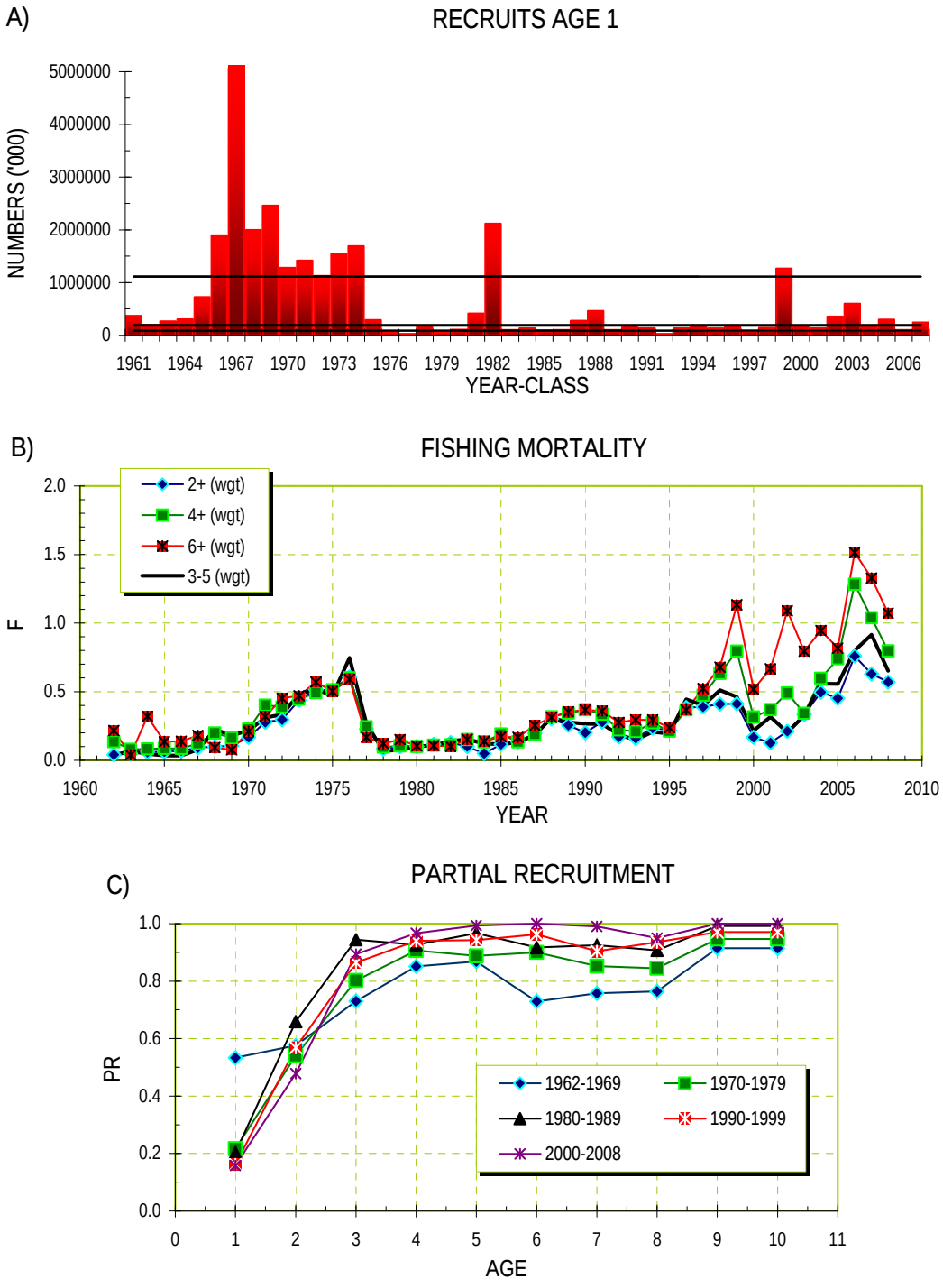

Figure 11. Extended Survivors Analysis (XSA) results for **Run 1**: A) Recruits at age 1 (thousands of fish); B) fishing mortality (weighted by abundance); and C) partial recruitment (from fishing mortalities) for the Northwest Atlantic mackerel. The horizontal lines in A) represent three levels of recruitment: low, average and high.

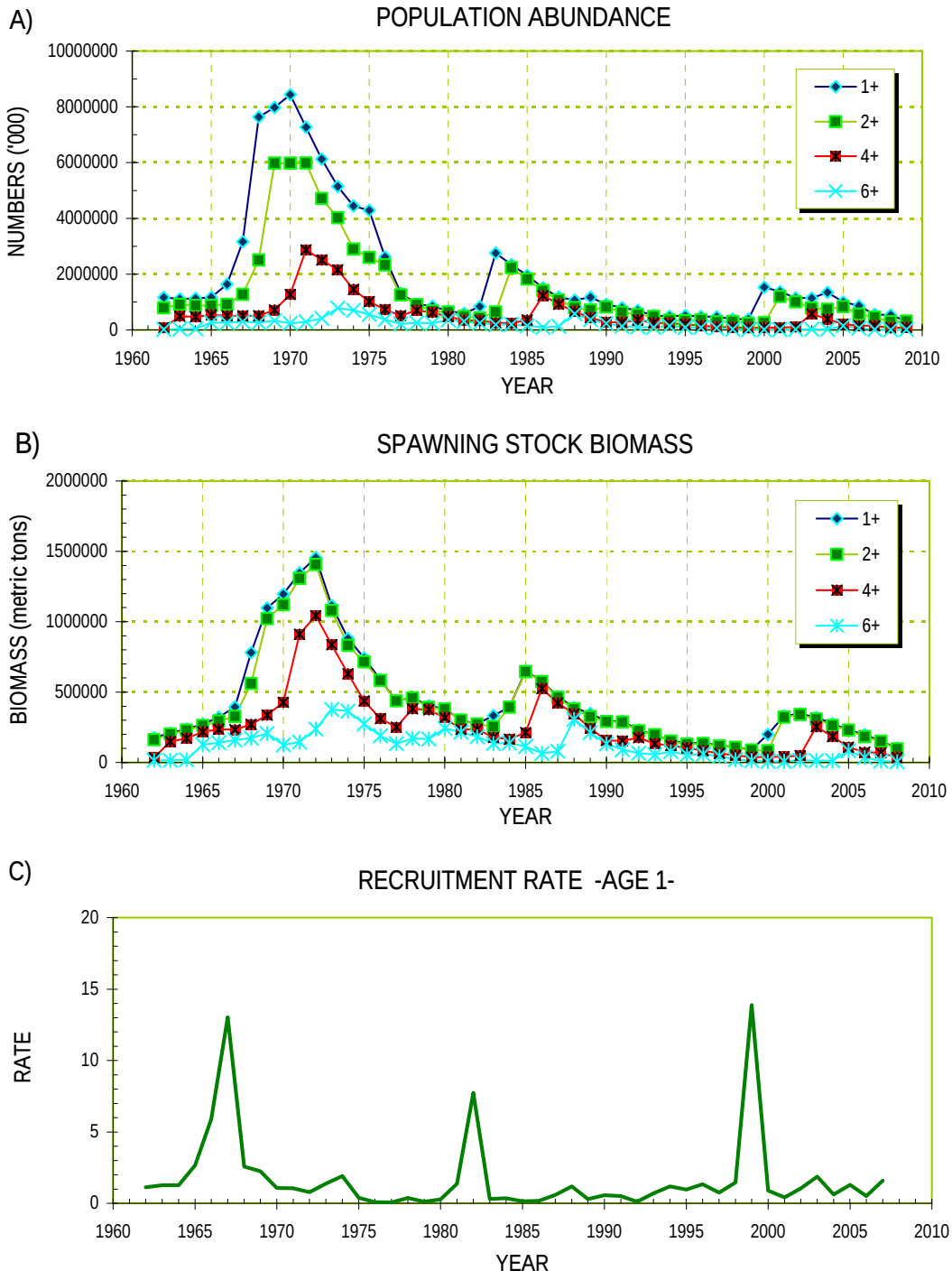

Figure 12. Extended Survivors Analysis (XSA) results for **Run 1**: A) Population abundance (thousands of fish); B) spawning stock biomass (metric tons); and C) recruitment rate at age 1 for the Northwest Atlantic mackerel.

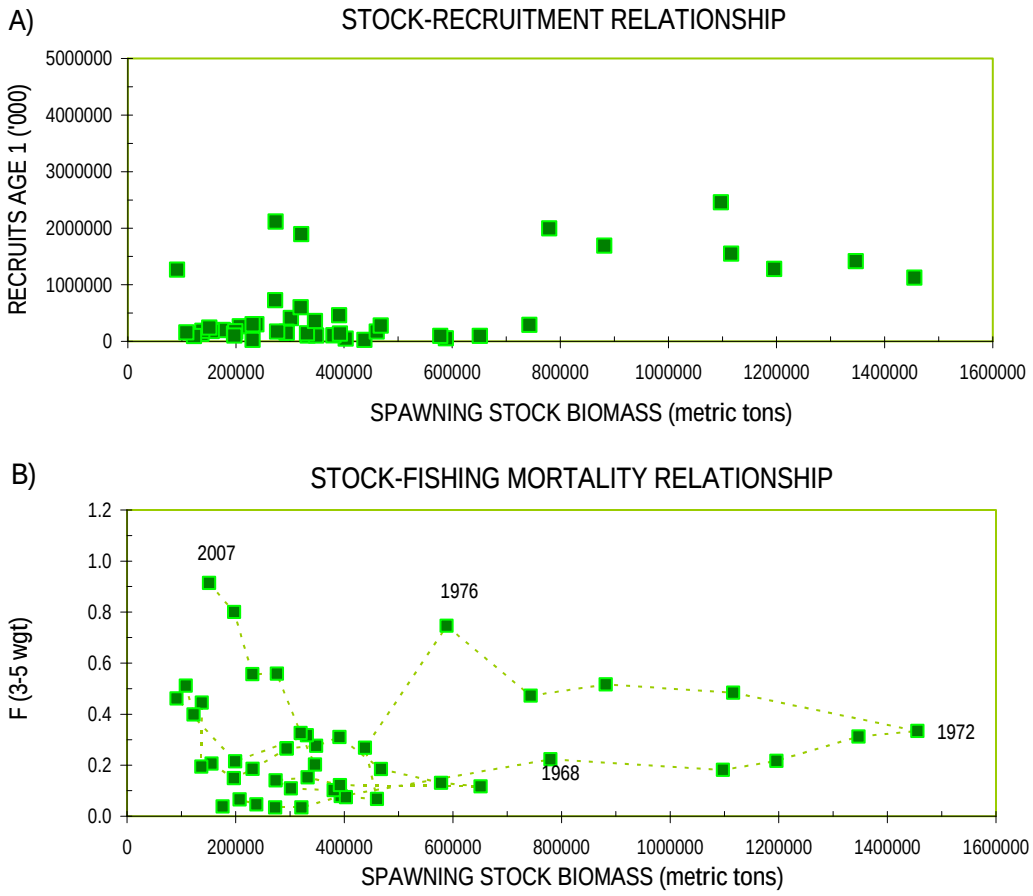

Figure 13. Extended Survivors Analysis (XSA) results for **Run 1**: A) Stock-recruitment relationship; and B) stock-fishing mortality relationship for the Northwest Atlantic mackerel (some years are indicated).

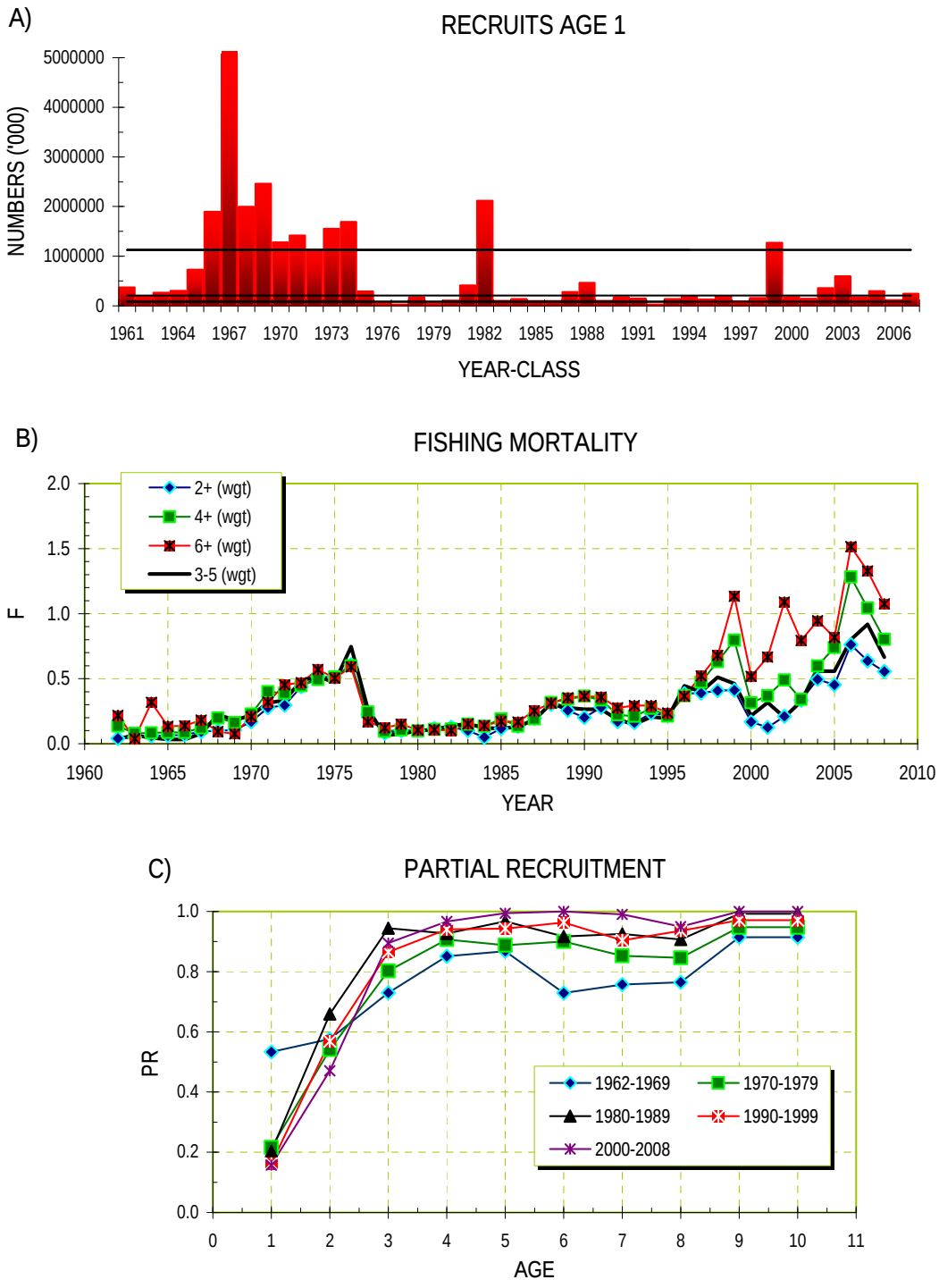

Figure 14. Extended Survivors Analysis (XSA) results for **Run 2**: A) Recruits at age 1 (thousands of fish); B) fishing mortality (weighted by abundance); and C) partial recruitment (from fishing mortalities) for the Northwest Atlantic mackerel. The horizontal lines in A) represent three levels of recruitment: low, average and high.

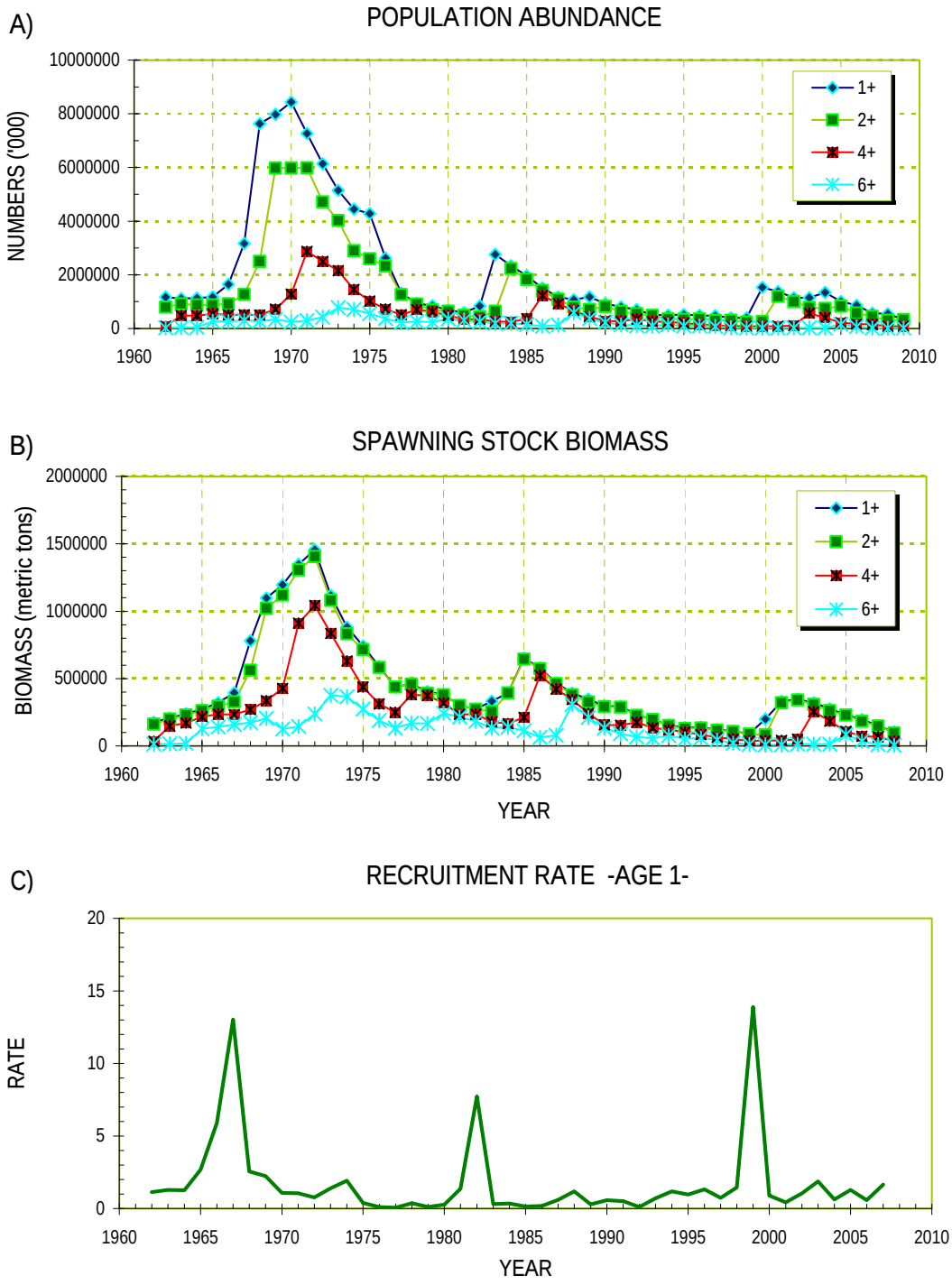

Figure 15. Extended Survivors Analysis (XSA) results for **Run 2**: A) Population abundance (thousands of fish); B) spawning stock biomass (metric tons); and C) recruitment rate at age 1 for the Northwest Atlantic mackerel.

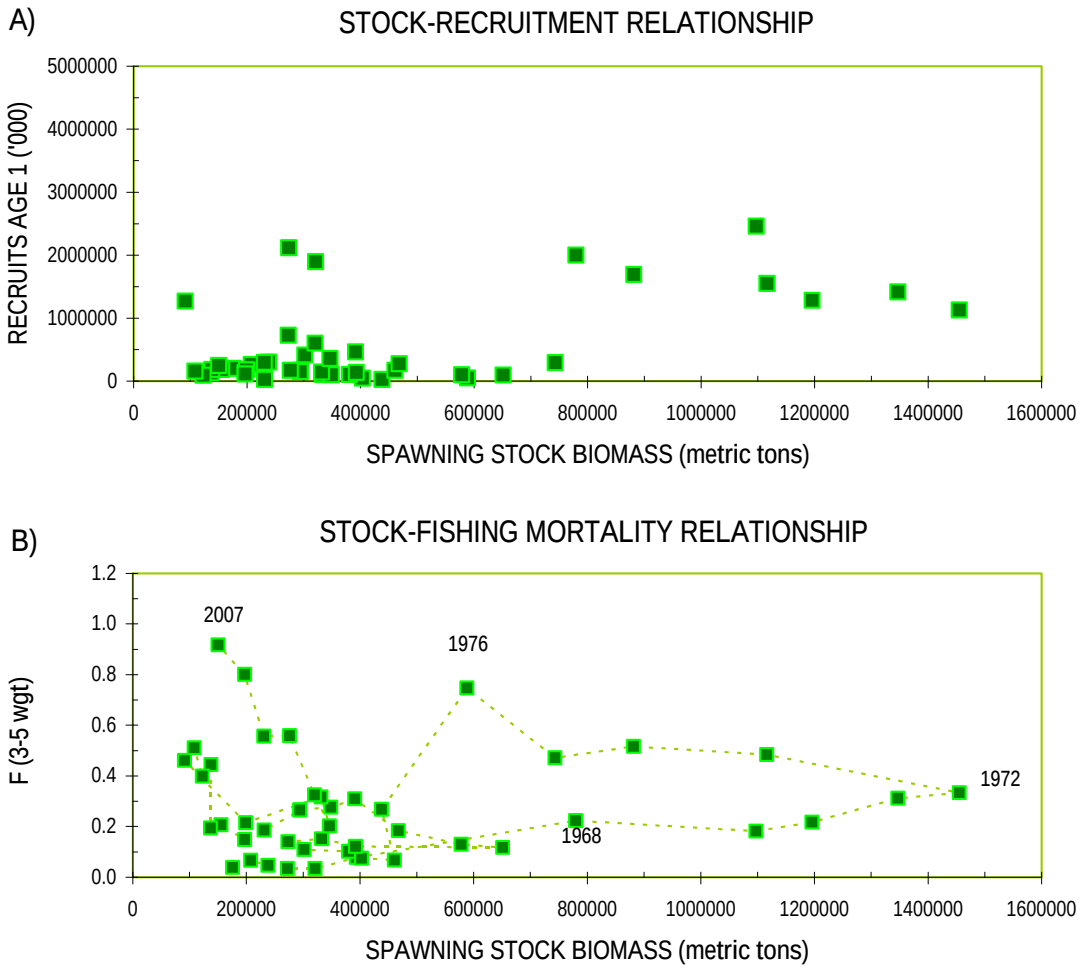

Figure 16. Extended Survivors Analysis (XSA) results for **Run 2**: A) Stock-recruitment relationship; and B) stock-fishing mortality relationship for the Northwest Atlantic mackerel (some years are indicated).

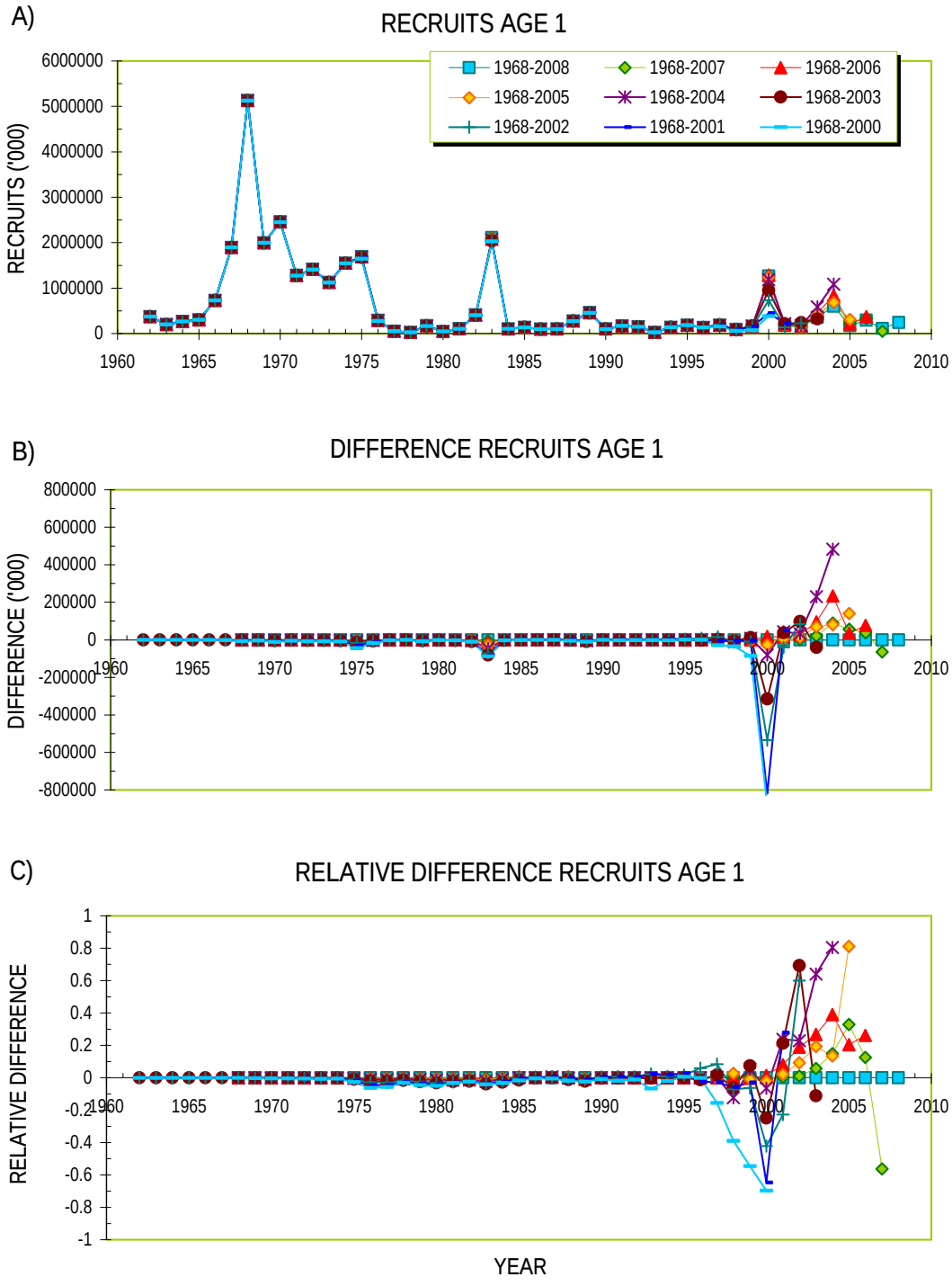

Figure 17. Extended Survivors Analysis (XSA) results for **Run 2**: A) Retrospective analysis of age 1 recruitment; B) difference; and C) relative difference to the terminal year (Mohn's Rho statistic: Average = 0.173; total = 1.383).

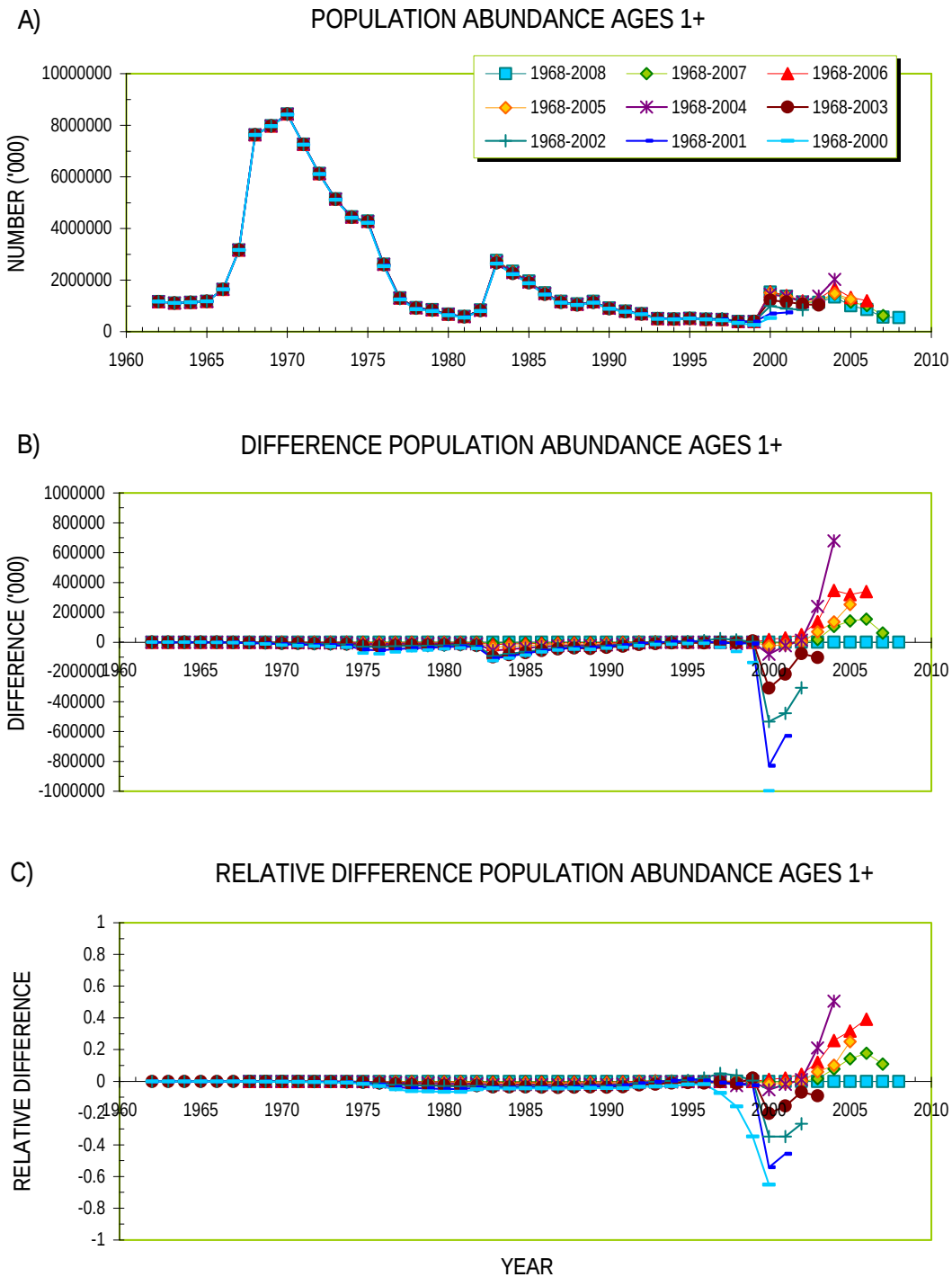

Figure 18. Extended Survivors Analysis (XSA) results for **Run 2**: A) Retrospective analysis of population abundance ages 1^{+}; B) difference; and C) relative difference to the terminal year (Mohn's Rho statistic: Average = -0.026; total = -0.212).

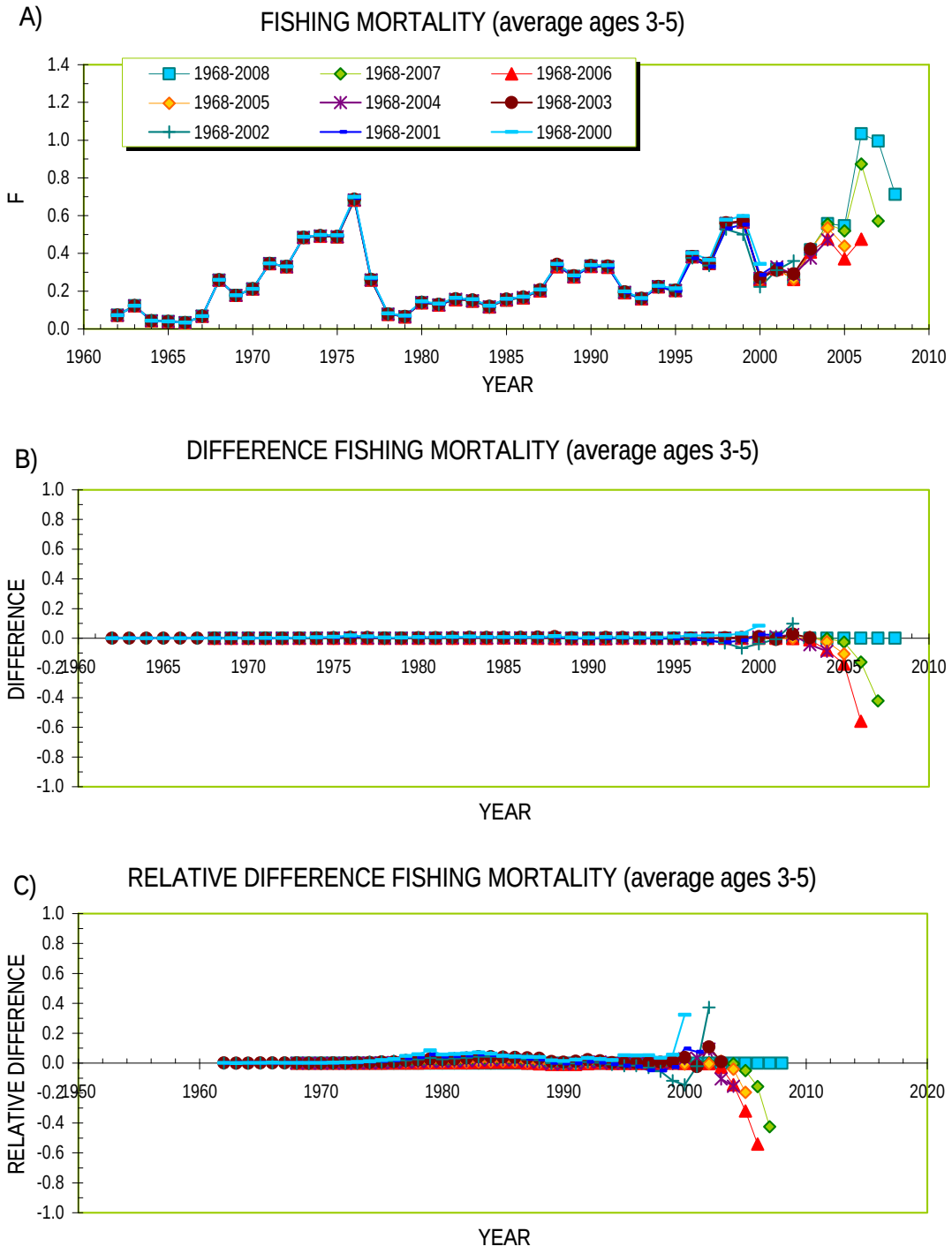

Figure 19. Extended Survivors Analysis (XSA) results for **Run 2**: A) Retrospective analysis of fishing mortality (average ages 3-5); B) difference; and C) relative difference to the terminal year (Mohn's Rho: Average = -0.067; total = -0.537).

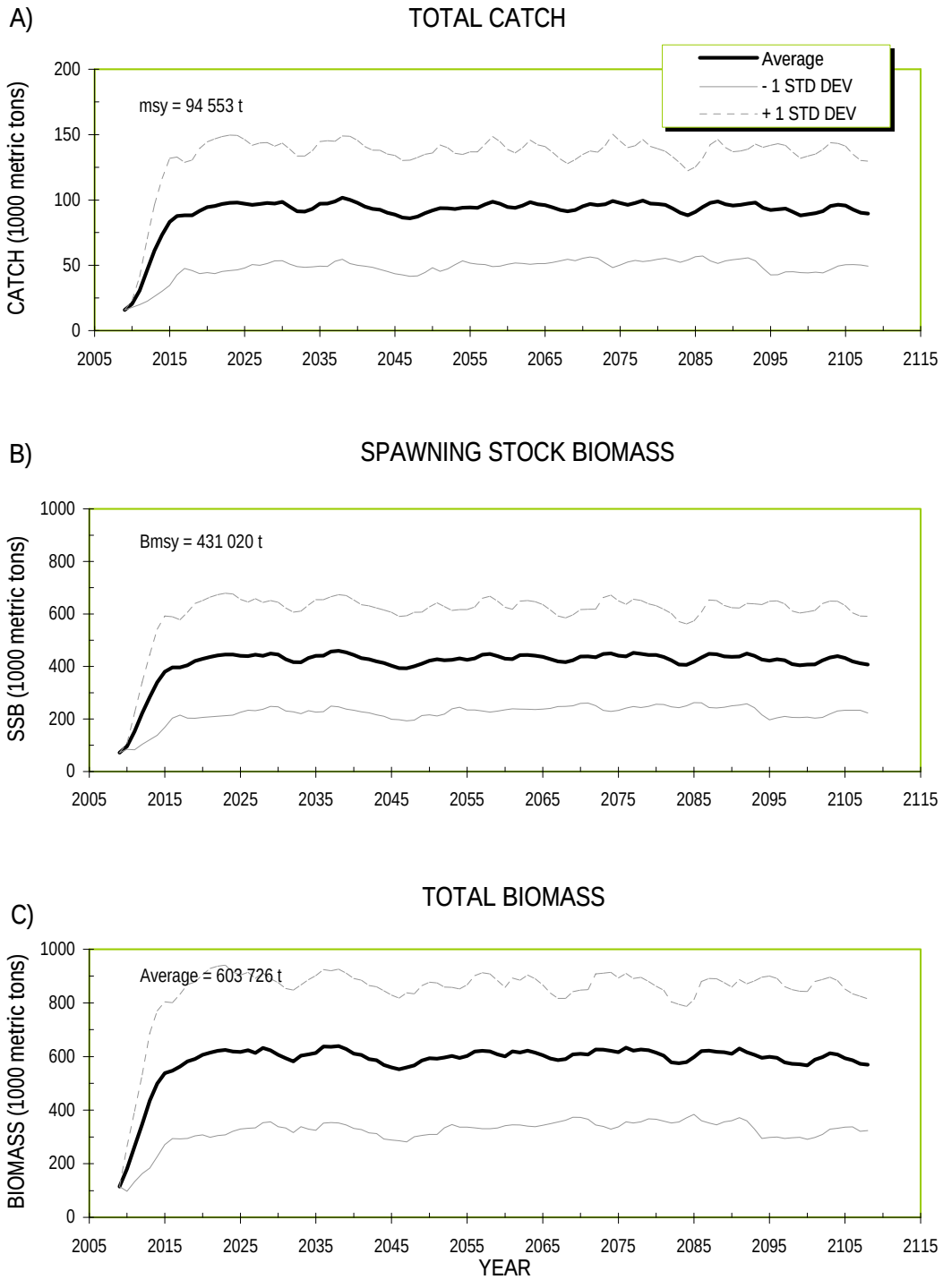

Figure 20. Stochastic bootstrapped projections (AGEPRO) of: A) total catch (thousands of metric tons); B) spawning stock biomass (thousands of metric tons); and C) total biomass (thousands of metric tons) with F at 40% as the harvest strategy. MSY and B_{msy} in A) and B) are calculated as the averages of the 2020-2108 period. Data used in this analysis are from the outputs of XSA **Run 2**.

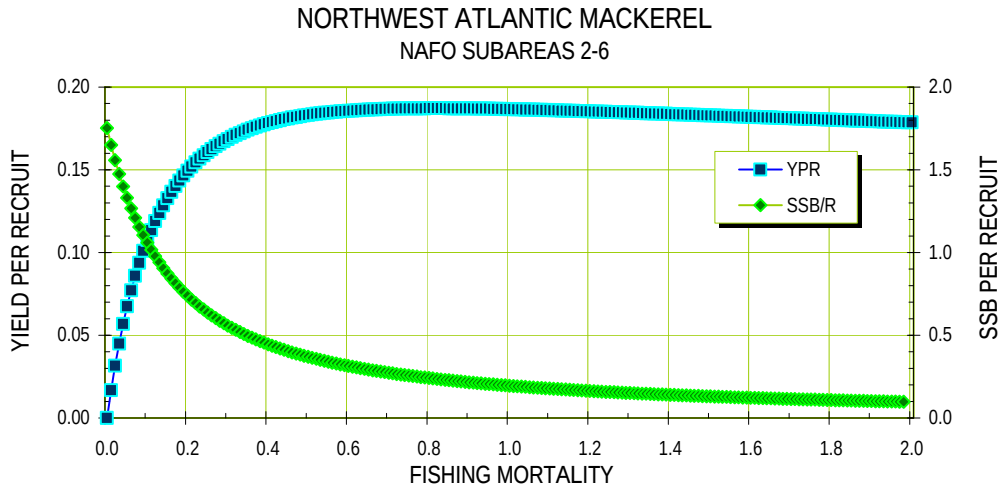

Figure 21. Yield- and spawning stock biomass per-recruit analyses for the Northwest Atlantic mackerel ($F_{0.1}$ = 0.258, F_{max} = 0.819 and $F_{40\%}$ = 0.217). Data used in these analyses are from the outputs of XSA **Run 2**.

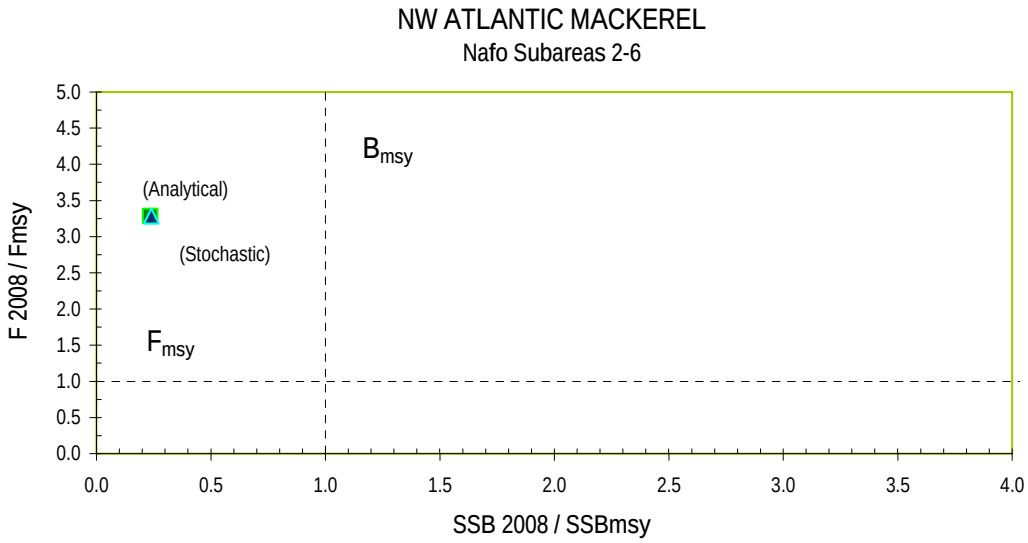

Figure 22. Status of 2008 fishing mortality (F) and spawning stock biomass (SSB) of the Northwest Atlantic mackerel to F_{msy} and SSB_{msy}. Data used in this analysis are from the outputs of XSA **Run 2**.

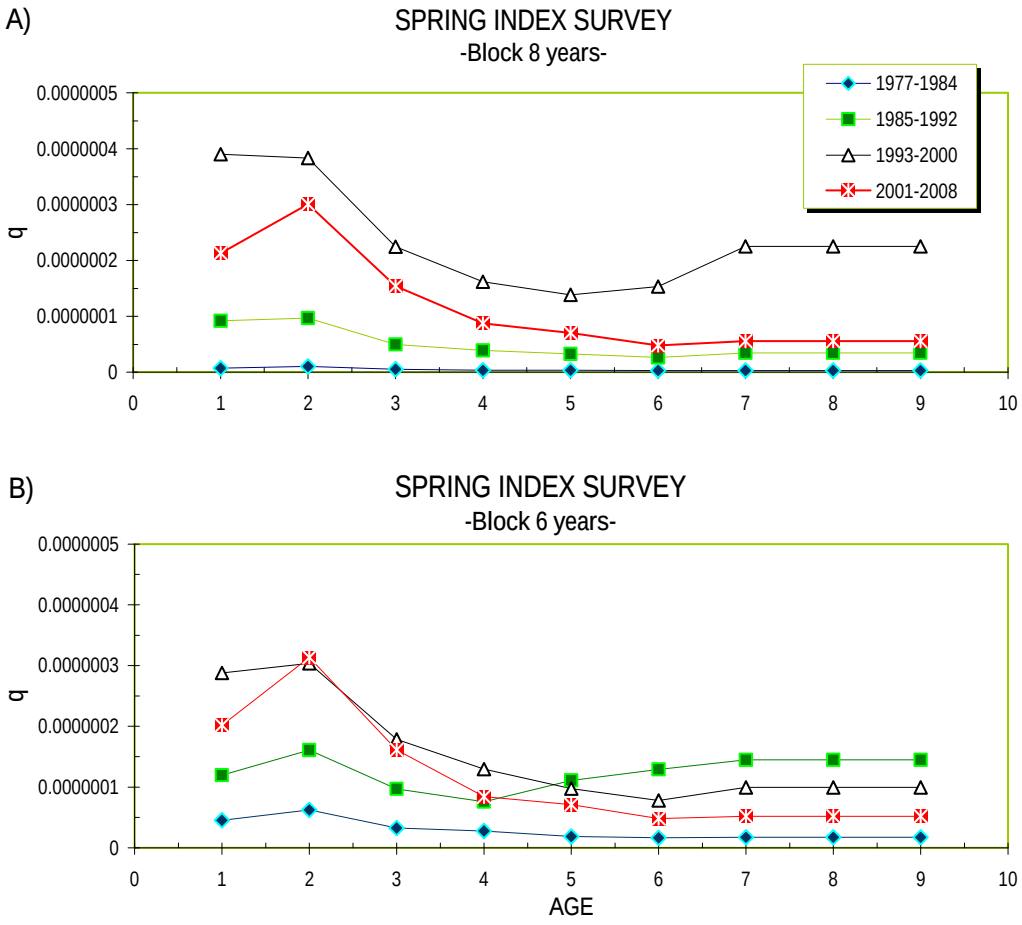

Figure 23. Coefficients of catchability calculated for blocks of 8 (A) and 6 (B) years.

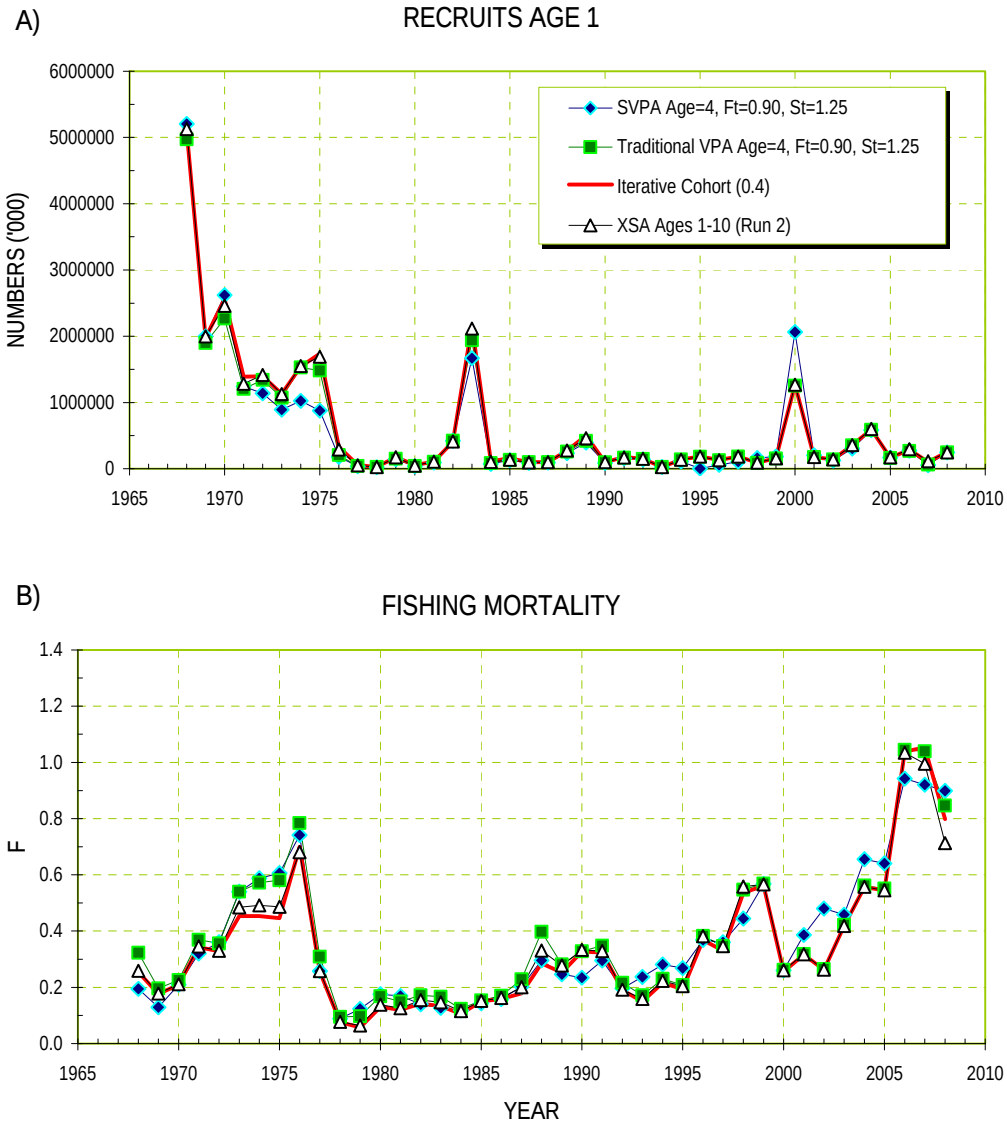

Figure 24. Assessment of the Northwest Atlantic mackerel from Separable VPA (SVPA), traditional VPA, iterative cohort and Extended Survivors Analysis (XSA): A) recruits at age 1 (thousands of fish); B) fishing mortality (average ages 3-5); C) population abundance ages 1^{+} (thousands of fish); and D) spawning stock biomass (metric tons).

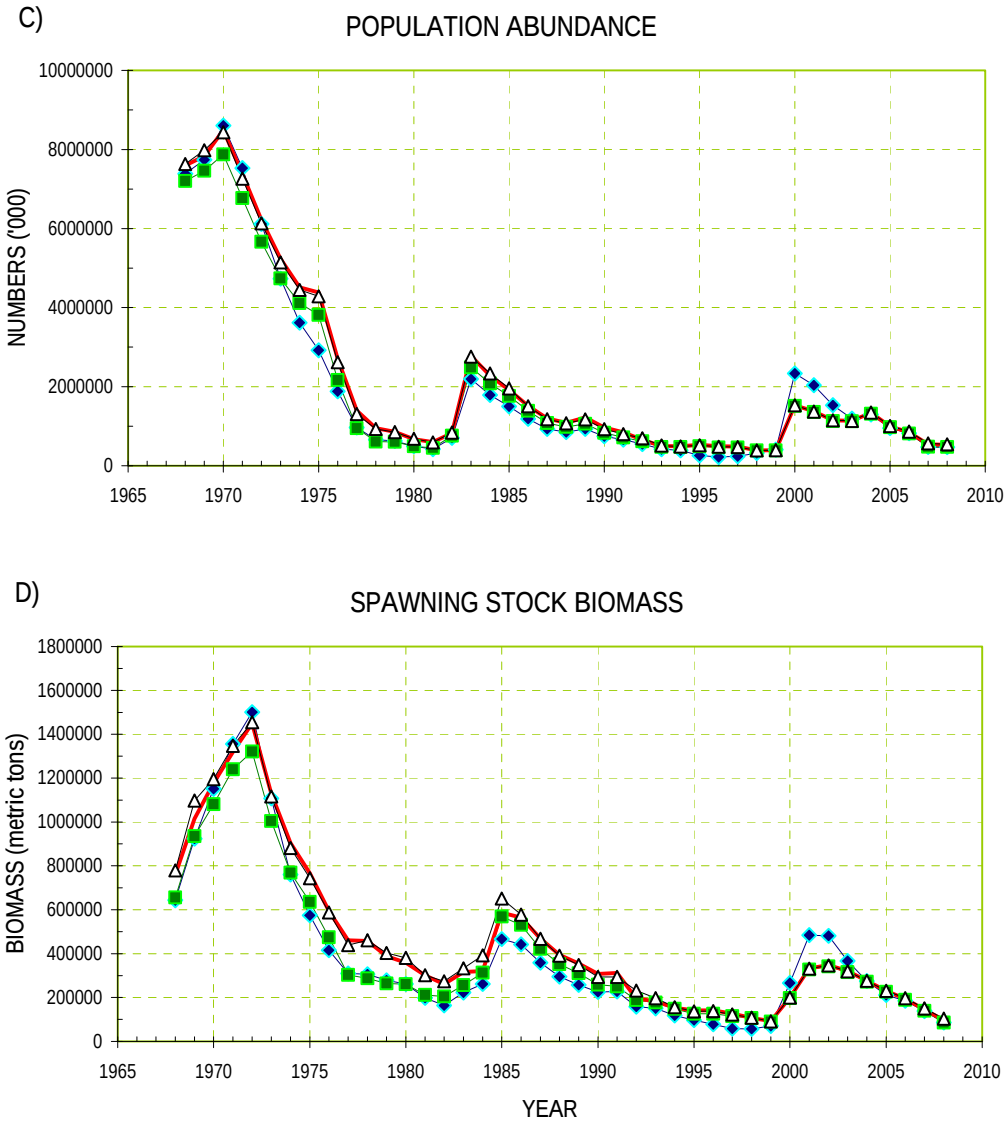

Figure 24. (Continued).