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QLSPA Estimates of Divisions 3NO Cod Stock Size

by

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Abstract

Sequential population analysis (SPA) is used to estimate the size of the Div. 3NO cod stock. QLSPA (see Cadigan, 1998; Cadigan 2000) is used for estimating SPA parameters. This method is compared with the standard estimation method (ADAPT), and it is shown that the two methods produce nearly identical results when used with the same data and modelling assumptions. An alternative QLSPA formulation, based on fewer modelling assumptions than those used in the comparison analysis, produced an SSB estimate of 15 000 tons in 2001, which is very low compared to historic values.

Introduction

In this paper several SPA formulations for cod in NAFO Div. 3N and 3O are presented. QLSPA (see Cadigan, 1998; Cadigan, 2000) is used for estimating SPA parameters. The data used for estimation are:

1. Canadian Spring Research Vessel Survey (1984-2000, ages 2-12),
2. Canadian Fall Research Vessel Survey, and (1990-2000, ages 2-12)
3. Canadian Juvenile Research Vessel Survey (1989-1994, ages 2-12).

The cohort model is based on commercial catch-at-age data for 1959-2000 and ages 2-12 (no plus group). The SPA m parameter was fixed at 0.2 for all ages and years. The catchability (q) was assumed to be different for each age and survey, but otherwise constant each year.

Comparison Run

The first SPA formulation we consider is nearly identical to the ADAPT approach that has been used for the assessment of 3NO cod. The only difference is that the ADAPT cohort model assumes continuous fishing mortality each year, whereas QLSPA uses Pope's approximation (Pope, 1972). We present this run for comparison purposes. The ADAPT formulation uses survey indices for ages 2-10, and the fishing mortality at age 12 in 1959-1994 was constrained to be equal to the average of the fishing mortality on ages 6-9 in the same year. Other cohort survivors (numbers at age 12 in 1996-2001, numbers at ages 3-11 in 2001) were estimated. We use the same fishing mortality constraints in this QLSPA formulation, and also freely estimate the size of the same cohort.

We cannot directly estimate cohort survivors for the oldest age group in the cohort model using QLSPA. However, we can estimate the ratio of fishing mortalities each year, which can be equivalent to estimating the cohort survivors. More specifically, using QLSPA we can estimate the α parameter in the relationship

$$F_{ay}=\alpha_y F_y,$$

where F_y is an average F for some younger age classes in year y. Freely estimating α_y is equivalent to freely estimating F_{ay} or N_{ay}, because N_{ay} is a one-to-one function of F_{ay}.

Some QLSPA results are presented in Appendix A. The most relevant part of these results is Figure 1, where ADAPT and QLSPA estimates of stock abundance and biomass are compared. The conclusion we reach from this analysis is that ADAPT and QLSPA can produce very similar results when their structures are made similar. Most of the differences are related to the bias correction procedure in ADAPT. This feature is not available in QLSPA.

Preferred Run

This run differs from the comparison run in three aspects:

1.Estimation method.
2.Range of ages in the stock size indices that are used for estimation.
3.Constraints on the fishing mortality at age 12.

QLSPA offers some choice with respect to estimation and inference methods. This is determined by the choice of the SPA variance model. The quadratic variance model (see Cadigan, 2000) seems preferable for 3NO cod because it better describes the SPA variability in the survey indices, as measured by the extended quasi-likelihood function. Extensive unreported simulations suggest that the extended quasi-likelihood function can be used to reliably diagnose the correct variance model. The benefit of using the correct variance model is more accurate and precise stock size estimators, although in some situations the gains in precision and accuracy may not be that large. Values of zero in tuning indices can also be used with no adjustment. This is why we can use the indices at ages 11 and 12 for SPA estimation. The approach of zero-weighting zero's will result in biased stock size estimators, and it should not be used.

QLSPA also allows for "self-weighting", which is equivalent to estimating separate variance models for each set of tuning indices. The potential benefit of "self-weighting" is the ability to discount the influence of noisy indices on inferences; however, the consequences of self-weighting are not well understood in general.

We employ a shrinkage approach to dealing with the fishing mortality constraints at age 12 in the SPA. The basic approach is to estimate the ratio of F_{12} to the average F at ages 9-11. We do this separately each year, except for the historic part of the time series for which there is no data available to estimate the F ratio's with. For these years we simply assume that the F ratio is constant for 1959-1986. This gives three years of data in the Spring survey to estimate the F ratio with. As previously mentioned, estimating the F ratio at age 12 each year is equivalent to estimating N_{12} each year. There can be difficulties (confounding with q's) when separately estimating the size of completed cohorts. Our solution is to penalize the squared differences between the F ratios and one. The penalty weight is determined as that value that results in an increase of four units (arbitrary) in the fit function compared to the un-penalized value. This gives the estimates that fit the data almost as well as un-penalized estimates, but have smaller variations in the F's at older ages. In particular, if there is a "dome" in the un-penalized estimated pr then this approach will result in less "dome", which may be more reasonable.

Results are given in the tables and figures in Appendix B. This run gives an SSB estimate of 15 000 tons, which is 8 000 tons more that the comparison run. The standard errors and cv's for this run have not been properly adjusted for the shrinkage approach to estimation. More research is required to understand how to do this. Nonetheless, this run fits the survey data substantially better than the comparison run. The overall fit function is lower even though more data was used for estimation.

The historic pr (1959-1986) is domed (see Figures 4 and 5) even though the amount of dome was penalized. This suggests that a stock reconstruction with domed F's fit the data substantially better than a reconstruction with flat F's.

The estimated stock-recruit curve (Figure 7) is somewhat different from the comparison run as well. It suggests that low levels of recruitment have been observed historically when SSB is less than 80 000 tons.

There are some patterns in the residuals (Figures 9-14). In particular, there are large residuals in some years, and year effects are also apparent. It would be useful to understand the sensitivity of the SPA estimates to the weight that the indices get in estimation. The residual patterns in the bottom panels of Figures 9-11 suggest that estimating the correct variance model may be difficult for Div. 3NO cod. The small number of large predicted survey values may mean that the variance parameter estimates are overly influenced by a small number of indices. This is because the variance parameter estimates attempt to model how the SPA survey variability changes in terms of the magnitude of the indices, and a small number of large indices may have too much influence on the variance parameter estimates.

Discussion and Conclusions

In all SPA formulations in this paper, the Div. 3NO cod stock is estimated to be much smaller than historic levels.

References

Cadigan, N. 1998. Semi-parametric inferences about fish stock size using virtual population analysis (VPA) and quasi-likelihood theory. *Canadian Stock Assessment Secretariat Res. Doc*., No. 98/25.

Cadigan, N.G. 2000. QLSPA estimates of Greenland Halibut stock size. *NAFO SCR Doc*., No. 23.

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Appendix A: Comparison Run

Log Errors SPA for cod

Cohort model for years 1959 - 2000 , and ages 2 - 12

All index for years 1984 to 2000 , and ages 2 to 10. Var = Log Constant

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Extended Deviance = 750.92 , df = 261 , #Parms = 17
Penalty = 0.00

Var scale = All 0.757

Age	Survivors	CV	95% L	95% U
2	4865.75	0.61	1461.71	16197.13
3	4224.64	0.42	1850.40	9645.24
4	1021.88	0.29	576.47	1811.42
5	213.13	0.26	128.41	353.75
6	503.96	0.30	277.70	914.55
7	365.15	0.28	211.95	629.09
8	136.58	0.26	82.34	226.55
9	67.88	0.27	39.69	116.09
10	342.30	0.27	199.69	586.75
11	537.15	0.31	292.87	985.18

F Constraint	Estimate	CV	95% L	95% U
F10/ave(F6-F9)_1994	0.085	0.370	0.041	0.175
F11/ave(F6-F9)_1994	0.002	0.486	0.001	0.005
F12/ave(F6-F9)_1959-94	1.000	.	.	.
F12/ave(F6-F9)_1997	1.242	0.353	0.621	2.482
F12/ave(F6-F9)_1998	1.300	0.367	0.633	2.671
F12/ave(F6-F9)_1999	0.656	0.390	0.305	1.410
F12/ave(F6-F9)_2000	0.482	0.350	0.243	0.956

Q_CONST	Estm (x1000)	CV	95% L	95% L
FALL_02	1.1483	0.262	0.6795	1.9406
FALL_03	1.1256	0.262	0.6661	1.9022
FALL_04	0.9004	0.262	0.5328	1.5216
FALL_05	0.6834	0.262	0.4044	1.1549
FALL_06	0.5920	0.262	0.3503	1.0004
FALL_07	0.3774	0.262	0.2234	0.6378
FALL_08	0.4002	0.262	0.2368	0.6763
FALL_09	0.3793	0.275	0.2188	0.6576
FALL_10	0.5172	0.275	0.2983	0.8966
JUVN_02	3.5240	0.355	1.7319	7.1706
JUVN_03	1.8772	0.355	0.9226	3.8197
JUVN_04	1.3776	0.355	0.6770	2.8030
JUVN_05	1.1425	0.355	0.5615	2.3247
JUVN_06	0.8521	0.355	0.4187	1.7338
JUVN_07	0.6516	0.355	0.3202	1.3259
JUVN_08	0.5321	0.355	0.2615	1.0827
JUVN_09	0.3612	0.355	0.1775	0.7349
JUVN_10	0.3525	0.355	0.1732	0.7173
SPRG_02	1.1370	0.211	0.7455	1.7340
SPRG_03	1.5402	0.211	1.0100	2.3490
SPRG_04	0.7574	0.211	0.4966	1.1550
SPRG_05	0.4511	0.211	0.2958	0.6880
SPRG_06	0.3116	0.211	0.2043	0.4752
SPRG_07	0.3389	0.211	0.2222	0.5169
SPRG_08	0.3537	0.211	0.2319	0.5394
SPRG_09	0.4786	0.211	0.3138	0.7298
SPRG_10	0.5866	0.211	0.3846	0.8945

Population Numbers at age

	2	3	4	5	6	7	8	9	10	11	12	2+
1959	64234	53702	93940	19513	16656	12174	4308	3108	3255	2318	328	273533
1960	1E5	52590	42419	65116	11390	8185	6406	2268	1859	1827	794	293071
1961	132E3	82051	41387	28846	33361	6525	4551	2979	1329	1172	683	334472
1962	95641	108E3	66443	29903	13034	13507	3520	2213	1673	911	937	335518
1963	137E3	78305	87278	50886	22487	9241	7807	2182	1207	978	541	397568
1964	198E3	112E3	63827	66248	31519	14023	5815	2917	733	438	509	496393
1965	257E3	163E3	85992	38182	36599	18640	9424	3757	1675	303	325	613913
1966	224E3	21E4	132E3	63517	24367	17968	6339	3348	2098	242	101	683917
1967	123E3	183E3	171E3	91516	34196	9278	7033	1148	1086	185	88	621796
1968	156E3	101E3	132E3	83720	29398	11242	3276	1549	726	727	87	519220
1969	98118	128E3	67497	56568	24562	7343	3470	1242	812	433	513	388391
1970	103E3	80332	97283	43568	21929	9984	4122	1581	548	400	234	363032
1971	75915	84372	63866	61820	25899	9375	4875	1895	805	314	122	329258
1972	42678	62154	68219	27949	23198	10618	4509	1729	1099	478	166	242796
1973	44565	34942	50825	37940	11763	6839	3370	2166	1158	705	321	194592
1974	28019	36487	19507	16638	17401	4212	3816	1879	1134	728	453	130273
1975	33171	22940	24060	7374	3753	4409	1415	1181	620	317	209	99448
1976	54962	27158	18174	11753	2845	806	844	200	134	91	31	116999
1977	50229	44999	18567	8063	4243	1348	469	476	124	76	63	128657
1978	20994	41124	36293	12967	4311	2117	586	224	200	43	25	118885
1979	23819	17188	32837	25790	8338	2790	1413	388	131	118	28	112839
1980	33265	19501	14007	23422	12783	4308	1485	917	265	92	86	110130
1981	26278	27235	15725	10514	15727	8408	2838	1015	667	189	68	108664
1982	42746	21515	21841	11888	7466	10798	5163	1804	657	461	118	124457
1983	50201	34998	17339	16092	8293	5197	7458	2877	939	347	231	143972
1984	39332	41101	27587	13610	11462	5700	3634	5064	1655	553	211	149910
1985	10663	32202	33598	21681	9867	7282	3563	2324	3315	856	357	125709
1986	7843	8730	26313	24836	12139	5331	3682	2196	1487	2232	465	95255
1987	15727	6422	7009	18951	14522	5984	2997	2157	1293	880	1511	77454
1988	15559	12700	4791	5357	12357	8773	3802	1862	1002	612	361	67174
1989	6207	12507	10147	3634	3004	4374	3604	2200	1012	435	276	47400
1990	6887	4967	8505	6333	1617	1320	1874	1789	1362	618	204	35476
1991	24366	5268	3104	2887	1258	514	699	882	939	718	370	41003
1992	7777	14495	3315	1932	1463	537	165	239	208	314	241	30687
1993	799	6292	7788	1113	825	644	227	78	106	54	119	18046
1994	551	624	3963	3473	335	242	237	119	41	52	0	9636
1995	1168	451	301	1140	1833	161	114	171	90	33	42	5503
1996	1387	957	369	181	915	1464	130	93	139	74	27	5736
1997	461	1134	780	298	146	734	1176	104	74	111	60	5077
1998	1646	377	917	622	234	115	573	922	81	57	86	5629
1999	5213	1346	306	729	490	182	90	444	718	62	43	9624
2000	4866	4225	1022	213	504	365	137	68	342	537	49	12328
2001	3469	3975	3137	530	96	357	280	101	52	268	429	

Spawner Biomass at age

	2	3	4	5	6	7	8	9	10	11	12	2+
1959	0	2	268	1203	10331	25224	13018	11365	14379	11224	1864	88878
1960	0	2	107	4059	6799	15463	19129	8300	8024	9055	4516	75454
1961	0	2	104	1798	19914	12326	13588	10905	5736	5811	3887	74071
1962	0	3	168	1864	7780	25517	10510	8099	7219	4515	5333	71009
1963	0	2	220	3172	13423	17457	23311	7987	5210	4847	3080	78710
1964	0	3	161	4130	18814	26491	17363	10677	3161	2173	2898	85872
1965	0	5	217	2380	21847	35214	28141	13752	7230	1502	1852	112138
1966	0	6	349	4116	15244	35927	21094	15469	11604	1526	737	106072
1967	0	6	484	6212	22230	19433	24768	5908	7584	1492	820	88938
1968	0	4	372	5683	19111	23547	11538	7976	5069	5861	812	79974
1969	0	4	191	3840	15967	15381	12222	6393	5665	3496	4779	67939
1970	0	3	275	2958	14256	20912	14518	8138	3825	3228	2175	70286
1971	0	3	180	4197	16836	19637	17169	9758	5617	2531	1138	77068
1972	0	2	200	1959	14867	21273	14604	8624	7805	3822	1542	74699
1973	0	1	161	2753	7989	15140	11904	10182	8731	6641	3460	66960
1974	0	2	54	1122	11139	8492	15170	10904	6622	6525	4149	64179
1975	0	0	0	164	2834	10593	4880	6003	4357	1698	1612	32141

1976	0	1	80	1177	1964	1694	2921	1053	930	712	253	10786
1977	0	3	66	485	1974	2341	1637	2518	951	769	640	11384
1978	0	0	51	873	3006	5435	2335	1213	1443	391	309	15057
1979	0	2	193	2791	6140	5751	5135	1813	871	895	272	23864
1980	0	15	243	4060	10241	9255	5619	4959	1754	799	859	37805
1981	0	460	1705	4209	18032	19331	11560	6219	5668	1722	704	69611
1982	0	2	119	1534	7008	30335	22118	11399	5205	4362	1237	83318
1983	0	3	96	2225	7683	13149	33001	16519	7304	3087	2404	85473
1984	0	0	35	1205	11858	15057	14238	27713	11134	4698	2245	88185
1985	0	0	47	1396	6425	16531	13242	12031	22950	6961	3559	83141
1986	0	0	31	928	4714	9014	14256	13274	11991	20296	4421	78927
1987	0	2	61	2202	8454	10325	11198	13362	10899	8657	16909	82069
1988	0	1	20	313	4677	10526	10995	9019	7068	5603	3765	51988
1989	0	3	165	972	3589	10143	11539	11363	6600	3515	2953	50842
1990	0	2	101	871	1283	2443	6519	8557	10482	5426	2111	37795
1991	0	16	120	871	1299	1353	2645	4910	6324	7189	4215	28942
1992	0	1	25	378	1788	1338	713	1328	1556	2778	2725	12630
1993	0	0	58	216	813	1410	773	414	697	440	1029	5850
1994	0	2	93	689	303	395	781	534	272	266	2	3336
1995	0	4	8	247	1452	277	208	824	489	278	343	4130
1996	0	1	4	54	873	2619	240	450	752	632	217	5842
1997	0	9	28	89	130	1297	2160	503	403	948	485	6051
1998	0	2	28	207	219	205	1053	4460	436	490	701	7802
1999	0	0	0	6	53	161	146	2109	3880	533	352	7240
2000	0	0	0	2	54	322	222	323	1850	4589	400	7763
2001	0	0	1	4	10	314	455	480	281	2294	3487	7328

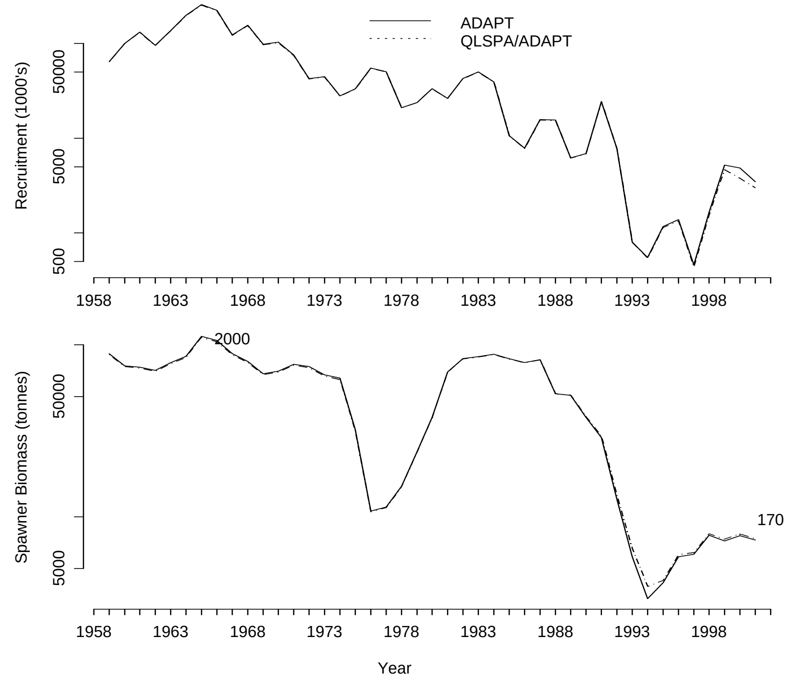

Fig. 1. A comparison of recruitment and SSB estimates from ADAPT and QLSPA. Both SPA formulations are nearly identical, and the same estimation method is used. In the bottom panel we show the difference in SSB estimates in 2001 and the maximum difference over the entire time series.

Appendix B: Preferred Run

Quasi-likelihood SPA for cod

Cohort model for years 1959 - 2000 , and ages 2 - 12

Fall RV index for years 1990 to 2000 , and ages 2 to 12. Var = Quadratic
Juvenile RV index for years 1989 to 1994 , and ages 2 to 12. Var = Quadratic
Spring RV index for years 1984 to 2000 , and ages 2 to 12. Var = Quadratic

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Extended Deviance = 579.51 , df = 313 , #Parms = 28
Penalty = 20.00

Var scale =		
	Fall RV	0.488
	Juvenile RV	0.120
	Spring RV	0.632

Quadratic Var	Beta	Std. Err	95% L	95% U
Fall RV	1.208	0.064	1.066	1.369
Juvenile RV	1.305	0.104	1.064	1.600
Spring RV	1.096	0.039	1.015	1.182

Age	Survivors	CV	95% L	95% U
2	3073.01	0.50	1157.21	8160.45
3	3173.09	0.34	1637.90	6147.18
4	1326.94	0.27	780.16	2256.90
5	178.51	0.27	105.07	303.29
6	389.22	0.29	219.08	691.48
7	299.08	0.28	171.48	521.63
8	215.49	0.26	130.33	356.29
9	127.01	0.28	73.94	218.18
10	662.07	0.23	424.45	1032.72
11	1360.97	0.22	884.86	2093.25

F Constraint	Estimate	CV	95% L	95% U
F10/ave(F7-F9)_1994	0.099	0.526	0.035	0.278
F11/ave(F8-F10)_1994	0.007	0.393	0.003	0.015
F12/ave(F9-F11)_1959-86	0.619	0.341	0.318	1.207
F12/ave(F9-F11)_1987	0.928	0.361	0.458	1.882
F12/ave(F9-F11)_1988	0.781	0.424	0.340	1.791
F12/ave(F9-F11)_1989	0.958	0.307	0.526	1.748
F12/ave(F9-F11)_1990	0.712	0.366	0.348	1.460
F12/ave(F9-F11)_1991	0.628	0.292	0.355	1.112
F12/ave(F9-F11)_1992	0.894	0.316	0.481	1.661
F12/ave(F9-F11)_1993	0.996	0.307	0.546	1.817
F12/ave(F9-F11)_1994	0.018	0.387	0.008	0.039
F12/ave(F9-F11)_1997	0.850	0.267	0.504	1.433
F12/ave(F9-F11)_1998	1.178	0.220	0.765	1.813
F12/ave(F9-F11)_1999	1.257	0.222	0.814	1.943
F12/ave(F9-F11)_2000	0.863	0.250	0.529	1.407

Q_CONST	Estm (x1000)	CV	95% L	95% L
FALL_02	2.0417	0.41	1.2272	2.8561
FALL_03	1.4931	0.31	0.8818	2.1044
FALL_04	1.0459	0.23	0.5951	1.4967
FALL_05	0.7634	0.18	0.4078	1.1190
FALL_06	0.6578	0.16	0.3339	0.9817
FALL_07	0.3709	0.11	0.1499	0.5919
FALL_08	0.2783	0.09	0.0917	0.4649
FALL_09	0.2878	0.10	0.0905	0.4852
FALL_10	0.3030	0.11	0.0918	0.5143
FALL_11	0.3134	0.12	0.0758	0.5511
FALL_12	0.3046	0.14	0.0262	0.5831
JUVN_02	3.1475	0.40	2.3491	3.9459
JUVN_03	1.6034	0.21	1.1915	2.0154
JUVN_04	1.1930	0.15	0.8862	1.4998

JUVN_05	0.9561	0.13	0.6975	1.2147
JUVN_06	0.6814	0.11	0.4682	0.8945
JUVN_07	0.5001	0.09	0.3206	0.6796
JUVN_08	0.3722	0.07	0.2265	0.5179
JUVN_09	0.2611	0.06	0.1457	0.3764
JUVN_10	0.2128	0.05	0.1073	0.3183
JUVN_11	0.3224	0.08	0.1723	0.4725
JUVN_12	0.2667	0.07	0.1214	0.4121
SPRG_02	1.5982	0.30	1.0005	2.1959
SPRG_03	2.0008	0.37	1.2528	2.7489
SPRG_04	1.1713	0.22	0.7260	1.6165
SPRG_05	0.6553	0.13	0.3969	0.9136
SPRG_06	0.4450	0.09	0.2636	0.6263
SPRG_07	0.3802	0.08	0.2183	0.5422
SPRG_08	0.3375	0.08	0.1875	0.4875
SPRG_09	0.3875	0.09	0.2141	0.5608
SPRG_10	0.4454	0.10	0.2455	0.6453
SPRG_11	0.5258	0.12	0.2846	0.7671
SPRG_12	0.5470	0.13	0.2808	0.8132

Population Numbers at age

	2	3	4	5	6	7	8	9	10	11	12	2+
1959	73785	56521	97469	19979	17495	13000	4894	4243	6727	3869	737	298718
1960	104E3	60410	44727	68006	11771	8872	7083	2747	2789	4670	2064	317218
1961	135E3	85213	47789	30736	35727	6837	5113	3533	1722	1933	3011	356411
1962	101E3	11E4	69032	35145	14581	15445	3775	2673	2126	1232	1560	357386
1963	141E3	83063	89429	53006	26778	10507	9393	2392	1584	1349	804	418847
1964	2E5	115E3	67723	68009	33255	17537	6852	4216	904	747	813	515497
1965	257E3	164E3	88595	41372	38040	20061	12301	4606	2739	443	578	630082
1966	224E3	211E3	133E3	65649	26979	19148	7502	5704	2793	1113	215	697649
1967	123E3	184E3	172E3	92558	35941	11416	7999	2100	3015	754	801	633646
1968	157E3	101E3	132E3	84146	30251	12671	5027	2341	1506	2305	553	528754
1969	99074	128E3	67967	56953	24911	8042	4640	2675	1459	1072	1806	396772
1970	105E3	81115	97561	43952	22244	10269	4694	2539	1722	931	756	370488
1971	76554	85725	64507	62048	26214	9633	5109	2364	1589	1275	557	335573
1972	43164	62677	69326	28473	23384	10875	4720	1921	1483	1120	953	248097
1973	45871	35340	51253	38846	12193	6992	3581	2339	1315	1019	846	199594
1974	29380	37556	19833	16989	18144	4563	3941	2052	1275	856	710	135299
1975	37294	24054	24935	7641	4040	5017	1703	1284	762	432	314	107476
1976	59572	30534	19087	12470	3064	1041	1342	436	218	207	126	128095
1977	49162	48774	21331	8810	4830	1527	662	883	317	145	157	136597
1978	23092	40250	39383	15230	4923	2597	733	382	534	201	81	127406
1979	25714	18906	32122	28320	10191	3290	1806	508	260	391	157	121665
1980	35156	21053	15414	22836	14855	5825	1895	1239	363	197	309	119142
1981	28405	28783	16996	11665	15247	10103	4080	1350	931	269	154	117986
1982	43771	23256	23109	12928	8409	10405	6551	2821	932	677	183	133043
1983	51220	35837	18765	17130	9145	5969	7136	4013	1771	572	408	151967
1984	40977	41935	28274	14778	12312	6398	4266	4800	2586	1235	395	157957
1985	10991	33549	34281	22244	10822	7977	4134	2841	3100	1618	915	132474
1986	7949	8999	27416	25395	12599	6114	4252	2664	1911	2055	1089	100443
1987	16176	6508	7229	19854	14980	6361	3637	2624	1676	1227	1367	81639
1988	15974	13067	4861	5537	13097	9147	4110	2387	1383	925	644	71134
1989	6364	12847	10448	3692	3152	4980	3911	2452	1441	748	532	50567
1990	7378	5096	8784	6580	1664	1440	2369	2040	1569	969	460	38349
1991	29350	5669	3209	3115	1459	553	797	1288	1144	887	658	48129
1992	9361	18575	3644	2019	1650	702	197	320	540	483	380	37870
1993	1039	7589	11129	1382	895	797	362	104	172	326	257	24053
1994	813	821	5024	6208	555	300	362	230	62	106	223	14703
1995	989	665	462	2009	4072	342	161	273	181	50	87	9290
1996	1132	810	545	313	1627	3298	278	132	223	148	41	8545
1997	398	925	659	441	254	1316	2677	225	106	180	120	7301
1998	2101	325	746	523	351	203	1050	2151	180	83	143	7856
1999	3929	1719	263	589	410	279	162	834	1724	143	65	10117
2000	3073	3173	1327	179	389	299	215	127	662	1361	116	10921
2001	2938	2507	2276	780	67	263	226	166	100	530	1103	10956

Fishing Mortalities

	2	3	4	5	6	7	8	9	10	11	12
1959	0.000	0.034	0.160	0.329	0.479	0.407	0.377	0.220	0.165	0.428	0.168
1960	0.000	0.034	0.175	0.444	0.343	0.351	0.495	0.267	0.166	0.239	0.139
1961	0.000	0.011	0.107	0.546	0.639	0.394	0.448	0.308	0.134	0.014	0.094
1962	0.000	0.010	0.064	0.072	0.128	0.297	0.257	0.323	0.255	0.227	0.166
1963	0.000	0.004	0.074	0.266	0.223	0.228	0.601	0.773	0.552	0.306	0.337
1964	0.000	0.061	0.293	0.381	0.305	0.155	0.197	0.231	0.513	0.056	0.165
1965	0.000	0.007	0.100	0.228	0.486	0.784	0.569	0.300	0.700	0.522	0.314
1966	0.000	0.004	0.166	0.402	0.660	0.673	1.073	0.438	1.109	0.129	0.346
1967	0.000	0.129	0.514	0.918	0.843	0.620	1.029	0.133	0.068	0.110	0.064
1968	0.000	0.197	0.643	1.017	1.125	0.805	0.431	0.272	0.140	0.044	0.094
1969	0.000	0.073	0.236	0.740	0.686	0.338	0.403	0.241	0.250	0.149	0.132
1970	0.000	0.029	0.253	0.317	0.637	0.498	0.486	0.269	0.101	0.314	0.141
1971	0.000	0.012	0.618	0.776	0.680	0.513	0.778	0.266	0.150	0.091	0.105
1972	0.000	0.001	0.379	0.648	1.007	0.911	0.502	0.179	0.176	0.080	0.090
1973	0.000	0.378	0.904	0.561	0.783	0.373	0.357	0.407	0.229	0.161	0.164
1974	0.000	0.210	0.754	1.236	1.085	0.786	0.922	0.791	0.881	0.804	0.511
1975	0.000	0.031	0.493	0.714	1.156	1.119	1.162	1.574	1.105	1.033	0.766
1976	0.000	0.159	0.573	0.748	0.496	0.254	0.218	0.118	0.208	0.072	0.082
1977	0.000	0.014	0.137	0.382	0.420	0.534	0.351	0.303	0.257	0.375	0.193
1978	0.000	0.026	0.130	0.202	0.203	0.163	0.167	0.184	0.112	0.045	0.070
1979	0.000	0.004	0.141	0.445	0.359	0.352	0.177	0.135	0.075	0.035	0.050
1980	0.000	0.014	0.079	0.204	0.185	0.156	0.139	0.086	0.099	0.046	0.048
1981	0.000	0.020	0.074	0.127	0.182	0.233	0.169	0.171	0.118	0.184	0.098
1982	0.000	0.015	0.099	0.146	0.143	0.177	0.290	0.265	0.288	0.307	0.178
1983	0.000	0.037	0.039	0.130	0.157	0.136	0.197	0.240	0.161	0.170	0.118
1984	0.000	0.002	0.040	0.112	0.234	0.237	0.206	0.237	0.269	0.100	0.125
1985	0.000	0.002	0.100	0.368	0.371	0.429	0.240	0.197	0.211	0.196	0.125
1986	0.000	0.019	0.123	0.328	0.483	0.319	0.283	0.263	0.243	0.208	0.147
1987	0.013	0.092	0.067	0.216	0.293	0.237	0.221	0.440	0.394	0.444	0.395
1988	0.018	0.024	0.075	0.364	0.767	0.650	0.316	0.305	0.415	0.353	0.279
1989	0.022	0.180	0.262	0.597	0.583	0.543	0.451	0.247	0.197	0.285	0.233
1990	0.063	0.262	0.837	1.306	0.902	0.391	0.410	0.378	0.370	0.188	0.222
1991	0.257	0.242	0.264	0.435	0.531	0.830	0.714	0.669	0.663	0.648	0.415
1992	0.010	0.312	0.769	0.613	0.527	0.462	0.444	0.419	0.304	0.431	0.344
1993	0.036	0.212	0.384	0.712	0.895	0.589	0.256	0.310	0.288	0.181	0.259
1994	0.000	0.375	0.717	0.222	0.286	0.420	0.083	0.039	0.018	0.000	0.000
1995	0.000	0.000	0.189	0.011	0.011	0.006	0.000	0.004	0.000	0.000	0.000
1996	0.002	0.005	0.010	0.011	0.012	0.008	0.012	0.017	0.015	0.007	0.000
1997	0.003	0.014	0.031	0.028	0.022	0.026	0.019	0.025	0.043	0.031	0.028
1998	0.001	0.010	0.036	0.045	0.032	0.028	0.030	0.021	0.025	0.054	0.040
1999	0.014	0.059	0.189	0.215	0.114	0.057	0.042	0.031	0.037	0.016	0.035
2000	0.004	0.132	0.332	0.774	0.194	0.081	0.064	0.035	0.022	0.010	0.019

Commercial catch

	2	3	4	5	6	7	8	9	10	11	12
1959	0.000	1711	13036	5068	6025	3935	1392	757.0	926.0	1220	103.0
1960	0.000	1846	6503	22050	3095	2377	2504	583.0	387.0	898.0	242.0
1961	0.000	812.0	4400	11696	15258	2014	1672	847.0	196.0	25.00	245.0
1962	0.000	1026	3882	2206	1581	3594	773.0	668.0	433.0	226.0	216.0
1963	0.000	313.0	5757	11210	4849	1935	3840	1165	608.0	322.0	208.0
1964	0.000	6202	15555	19496	7919	2273	1109	788.0	328.0	37.00	112.0
1965	0.000	1013	7611	7619	13258	9861	4827	1081	1248	163.0	141.0
1966	0.000	753.0	18413	19681	11795	8486	4467	1829	1694	122.0	57.00
1967	0.000	20086	62442	50317	18517	4774	4651	236.0	180.0	71.00	45.00
1968	0.000	16359	56775	48608	18485	6337	1592	505.0	178.0	90.00	45.00
1969	0.000	8154	12924	26949	11191	2089	1393	518.0	292.0	134.0	202.0
1970	0.000	2105	19703	10799	9481	3646	1635	541.0	149.0	227.0	90.00
1971	0.000	950.0	26900	30300	11700	3500	2500	500.0	200.0	100.0	50.00
1972	0.000	69.00	19797	12289	13432	5883	1686	285.0	216.0	78.00	74.00
1973	0.000	10058	27600	15098	5989	1971	972.0	707.0	243.0	137.0	116.0
1974	0.000	6425	9501	10907	10872	2247	2147	1015	676.0	428.0	257.0
1975	0.000	671.0	8781	3528	2505	3057	1059	921.0	461.0	252.0	152.0
1976	0.000	4054	7534	5945	1084	211.0	238.0	44.00	37.00	13.00	9.000

1977	0.000	607.0	2469	2531	1500	572.0	177.0	209.0	65.00	41.00	25.00
1978	0.000	920.0	4337	2518	818.0	354.0	102.0	58.00	51.00	8.000	5.000
1979	0.000	72.00	3827	9208	2784	883.0	265.0	58.00	17.00	12.00	7.000
1980	0.000	266.0	1055	3812	2275	761.0	222.0	92.00	31.00	8.000	13.00
1981	0.000	505.0	1091	1262	2297	1902	574.0	192.0	94.00	41.00	13.00
1982	0.000	305.0	1978	1591	1012	1528	1492	595.0	211.0	162.0	27.00
1983	0.000	1179	647.0	1893	1204	686.0	1152	774.0	238.0	81.00	41.00
1984	0.000	58.00	1000	1411	2324	1220	720.0	918.0	551.0	106.0	42.00
1985	0.000	57.00	2953	6203	3036	2519	797.0	459.0	533.0	261.0	97.00
1986	0.000	153.0	2865	6423	4370	1512	948.0	558.0	373.0	349.0	135.0
1987	195.0	516.0	422.0	3491	3445	1213	653.0	845.0	494.0	398.0	404.0
1988	256.0	277.0	318.0	1527	6347	3955	1009	567.0	425.0	249.0	142.0
1989	127.0	1917	2182	1502	1260	1887	1284	485.0	233.0	168.0	100.0
1990	410.0	1064	4505	4341	895.0	422.0	721.0	581.0	439.0	150.0	83.00
1991	6028	1103	673.0	995.0	544.0	282.0	368.0	568.0	502.0	383.0	202.0
1992	83.00	4508	1769	837.0	612.0	235.0	64.00	99.00	128.0	153.0	100.0
1993	33.00	1314	3209	637.0	479.0	321.0	74.00	25.00	39.00	49.00	53.00
1994	0.000	232.0	2326	1117	125.0	93.00	26.00	8.000	1.000	0.030	0.070
1995	0.000	0.000	72.00	20.00	40.00	2.000	0.000	1.000	0.000	0.000	0.000
1996	2.000	4.000	5.000	3.000	17.00	25.00	3.000	2.000	3.000	1.000	0.000
1997	1.000	12.00	18.00	11.00	5.000	31.00	45.00	5.000	4.000	5.000	3.000
1998	1.000	3.000	24.00	21.00	10.00	5.000	28.00	41.00	4.000	4.000	5.000
1999	48.00	89.00	41.00	103.0	40.00	14.00	6.000	23.00	56.00	2.000	2.000
2000	10.00	356.0	339.0	87.00	62.00	21.00	12.00	4.000	13.00	12.00	2.000

Biomass at age

	2	3	4	5	6	7	8	9	10	11	12	2+
1959	0	17013	64720	19999	28377	33435	15312	15573	29727	18737	4194	247086
1960	0	18183	26255	68822	18375	20805	21900	10090	12038	23149	11744	231360
1961	0	25649	28052	31104	55769	16033	15809	12977	7431	9584	17135	219544
1962	0	33219	40522	35567	22761	36217	11673	9819	9177	6108	8880	213944
1963	0	25002	52495	53642	41801	24640	29043	8784	6838	6687	4578	253510
1964	0	34635	39754	68825	51910	41123	21186	15484	3901	3703	4628	285149
1965	0	49381	52005	41869	59381	47043	38035	16919	11819	2197	3290	321940
1966	0	60457	82041	69063	44137	47526	25852	26442	15453	7002	1580	379553
1967	0	64514	113E3	102E3	61099	29681	29172	10850	21049	6083	7453	444764
1968	0	35484	86926	92729	51427	32944	18333	12091	10515	18595	5149	364196
1969	0	44989	44654	62762	42349	20909	16923	13820	10189	8646	16811	282051
1970	0	28471	64098	48435	37815	26700	17119	13114	12020	7506	7040	262319
1971	0	30090	42381	68377	44563	25047	18632	12211	11094	10281	5180	267855
1972	0	21185	47280	32403	39192	27047	15832	9613	10528	8958	8828	220865
1973	0	14030	37671	45761	21654	19213	13099	11033	9915	9598	9131	191104
1974	0	18928	12792	18603	30372	11422	16224	11948	7450	7674	6502	141918
1975	0	6952	15235	7389	6460	12448	5874	6524	5351	2320	2423	70975
1976	0	7511	11223	13966	5291	2740	4772	2297	1514	1622	1023	51958
1977	0	17266	15081	10228	9032	4368	2597	4747	2432	1464	1612	68826
1978	0	16905	30483	18961	8984	7911	2949	2067	3844	1836	999	94939
1979	0	11665	26982	34210	18344	8360	6719	2376	1729	2970	1539	114895
1980	0	10821	12670	29390	27689	16175	7521	6732	2404	1718	3102	118223
1981	0	15284	16146	16133	32507	30098	18096	8449	7935	2455	1601	148704
1982	0	18349	23710	17841	16918	33400	28307	17824	7382	6402	1930	172063
1983	0	30210	19684	25336	18162	17256	31850	23049	13780	5088	4242	188656
1984	0	30655	27963	19640	25425	18093	16736	26272	17396	10485	4207	196871
1985	0	25397	28248	27916	19037	21715	15544	14712	21458	13154	9119	196300
1986	0	2979	19082	29027	21670	16354	17829	16195	15408	18692	10353	167588
1987	0	1751	4092	22753	24987	15890	14825	16442	14136	12068	15293	142236
1988	0	4482	3403	5891	19972	18478	13568	11785	9777	8472	6730	102558
1989	0	8299	8849	4671	5540	12045	12538	12669	9402	6038	5701	85753
1990	0	1845	6307	7830	3335	3561	8717	9814	12078	8515	4753	66755
1991	0	2506	2195	3947	2673	1714	3106	7188	7710	8886	7496	47421
1992	0	9399	2179	1916	2792	1789	850	1778	4041	4267	4291	33301
1993	0	1632	5642	1295	1251	1796	1233	553	1131	2638	2223	19395
1994	0	261	2045	5227	824	551	1223	1035	414	546	1813	13939
1995	0	302	106	1045	4003	612	297	1321	979	427	703	9795
1996	0	264	125	163	1599	5906	511	638	1206	1265	333	12010
1997	0	301	151	230	249	2358	4926	1087	575	1535	978	12391

1998	0	106	171	272	345	364	1931	10403	972	712	1159	16437
1999	0	560	60	306	403	499	298	4034	9338	1225	525	17249
2000	0	1034	304	93	383	536	397	614	3586	11631	940	19516
2001	0	817	521	405	66	470	416	801	544	4532	8971	17543

Spawner Biomass at age

	2	3	4	5	6	7	8	9	10	11	12	2+
1959	0	2	278	1232	10851	26935	14787	15518	29721	18737	4194	122256
1960	0	2	113	4239	7027	16760	21149	10055	12035	23149	11744	106273
1961	0	3	121	1916	21326	12916	15267	12932	7429	9584	17135	98628
1962	0	3	174	2191	8704	29177	11273	9785	9175	6108	8880	85470
1963	0	3	226	3304	15985	19850	28047	8754	6836	6687	4578	94269
1964	0	3	171	4240	19850	33129	20460	15430	3901	3703	4628	105514
1965	0	5	224	2579	22707	37898	36730	16860	11817	2197	3290	134308
1966	0	6	353	4254	16878	38287	24965	26349	15449	7002	1580	135124
1967	0	6	485	6283	23364	23911	28171	10812	21045	6083	7453	127615
1968	0	4	374	5712	19666	26540	17704	12049	10513	18595	5149	116306
1969	0	4	192	3866	16194	16844	16342	13771	10187	8646	16811	102859
1970	0	3	276	2984	14461	21510	16532	13068	12017	7506	7040	95396
1971	0	3	182	4212	17041	20178	17993	12168	11092	10281	5180	98329
1972	0	2	203	1996	14987	21789	15289	9579	10526	8958	8828	92157
1973	0	1	162	2819	8280	15478	12650	10995	9913	9598	9131	79026
1974	0	2	55	1146	11614	9202	15668	11907	7449	7674	6502	71219
1975	0	0	0	170	3051	12053	5873	6524	5351	2320	2423	37764
1976	0	2	84	1249	2115	2188	4644	2294	1514	1622	1023	16732
1977	0	3	75	530	2247	2651	2308	4676	2430	1464	1612	17996
1978	0	0	55	1026	3433	6669	2918	2066	3844	1836	999	22847
1979	0	2	189	3065	7504	6784	6564	2374	1729	2970	1539	32721
1980	0	16	267	3959	11901	12514	7170	6701	2404	1718	3102	49753
1981	0	486	1842	4670	17482	23230	16619	8276	7907	2454	1601	84569
1982	0	2	126	1668	7892	29232	28066	17822	7382	6402	1930	100522
1983	0	3	104	2369	8472	15102	31579	23047	13780	5088	4242	103786
1984	0	0	36	1308	12738	16899	16714	26272	17396	10485	4207	106055
1985	0	0	48	1432	7047	18110	15364	14709	21458	13154	9119	100442
1986	0	0	32	949	4893	10337	16462	16099	15406	18692	10353	93224
1987	0	2	63	2307	8720	10975	13592	16251	14125	12068	15293	93397
1988	0	1	20	324	4957	10976	11887	11560	9763	8472	6730	64690
1989	0	3	170	987	3765	11547	12521	12669	9402	6038	5701	62803
1990	0	2	105	905	1321	2666	8243	9759	12074	8515	4753	48343
1991	0	18	124	940	1507	1455	3018	7169	7710	8886	7496	38322
1992	0	1	28	394	2017	1748	850	1778	4041	4267	4291	19415
1993	0	0	83	268	883	1745	1233	553	1131	2638	2223	10756
1994	0	3	118	1232	501	489	1193	1030	413	546	1813	7338
1995	0	6	12	435	3227	588	295	1319	979	427	703	7991
1996	0	1	6	94	1553	5899	511	638	1206	1265	333	11506
1997	0	7	23	132	227	2327	4917	1087	575	1535	978	11809
1998	0	1	23	174	329	362	1931	10403	972	712	1159	16068
1999	0	0	0	5	44	245	263	3967	9319	1225	525	15594
2000	0	0	1	1	42	263	350	604	3578	11627	940	17408
2001	0	0	1	6	7	231	367	787	542	4531	8971	15445

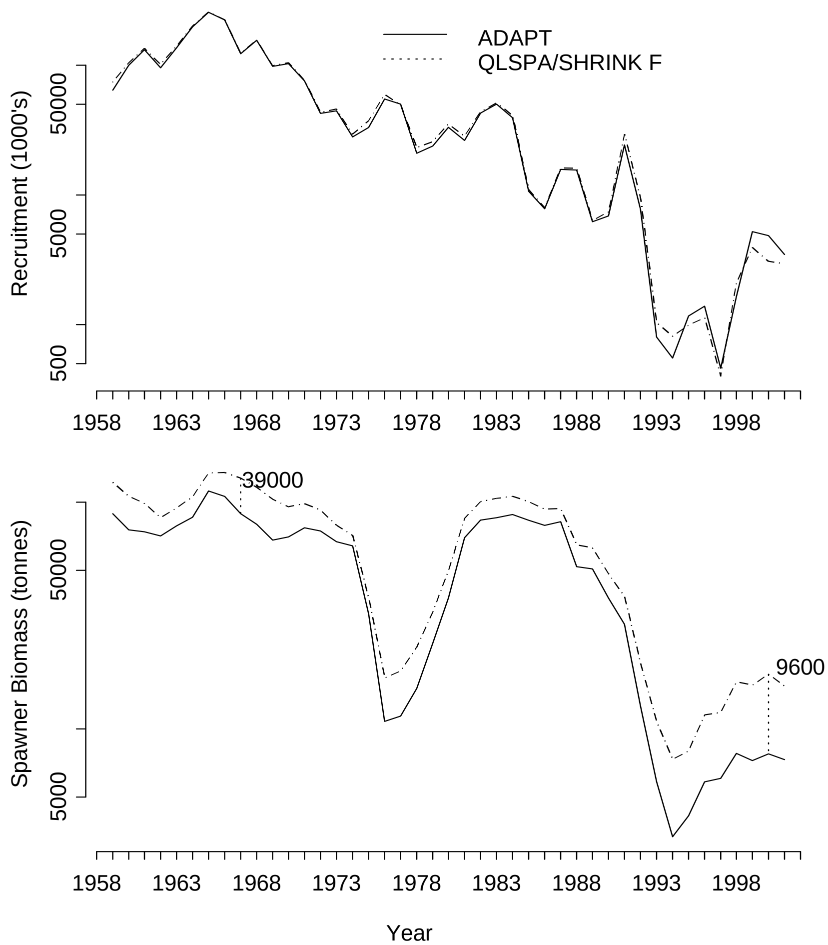

Fig. 2. A comparison of QLSPA estimates of recruitment and SSB from the comparison and "preferred" runs. In the bottom panel we show the difference in SSB estimates in 2001 and the maximum difference over the entire time series.

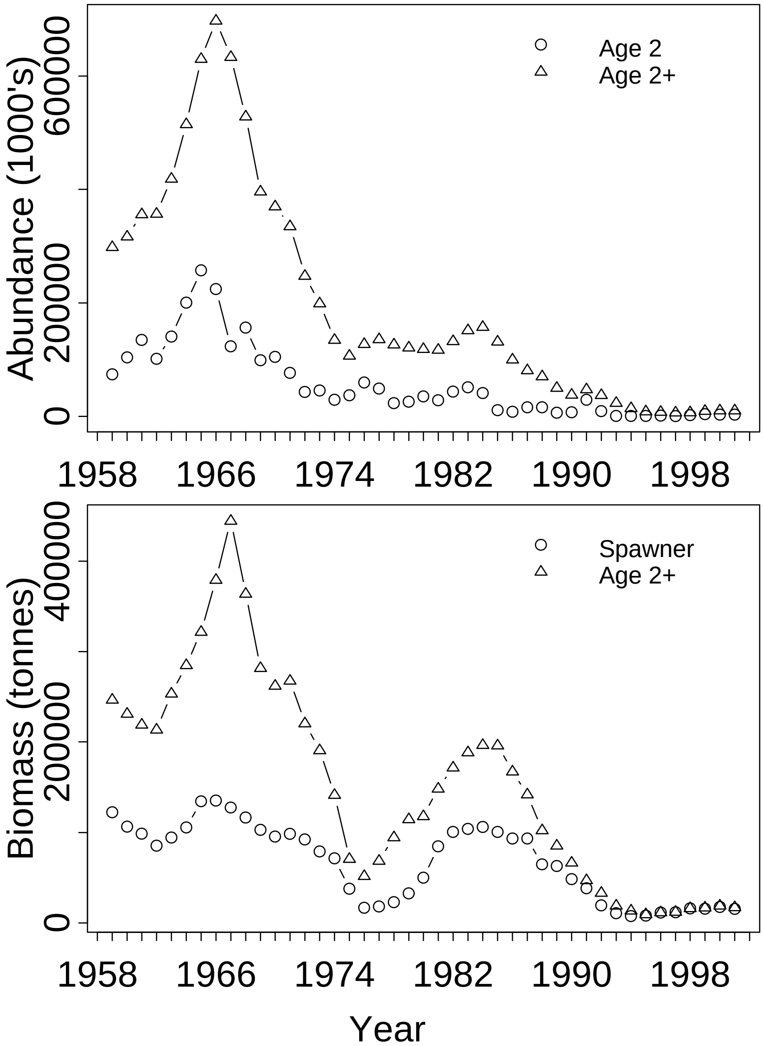

Fig. 3. Stock size estimates from the QLSPA "preferred" run.

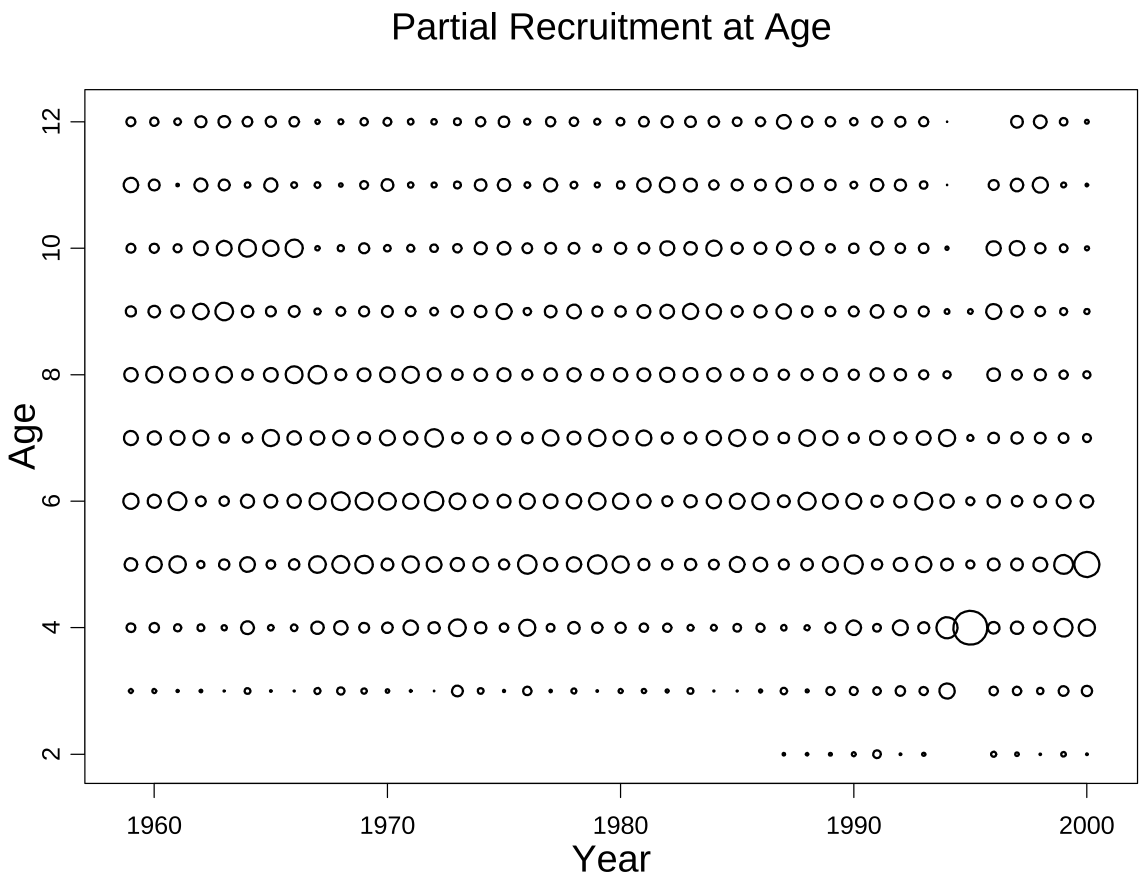

Fig. 4. Time series of partial recruitment (pr) estimates. The bubble area is proportional to the pr value.

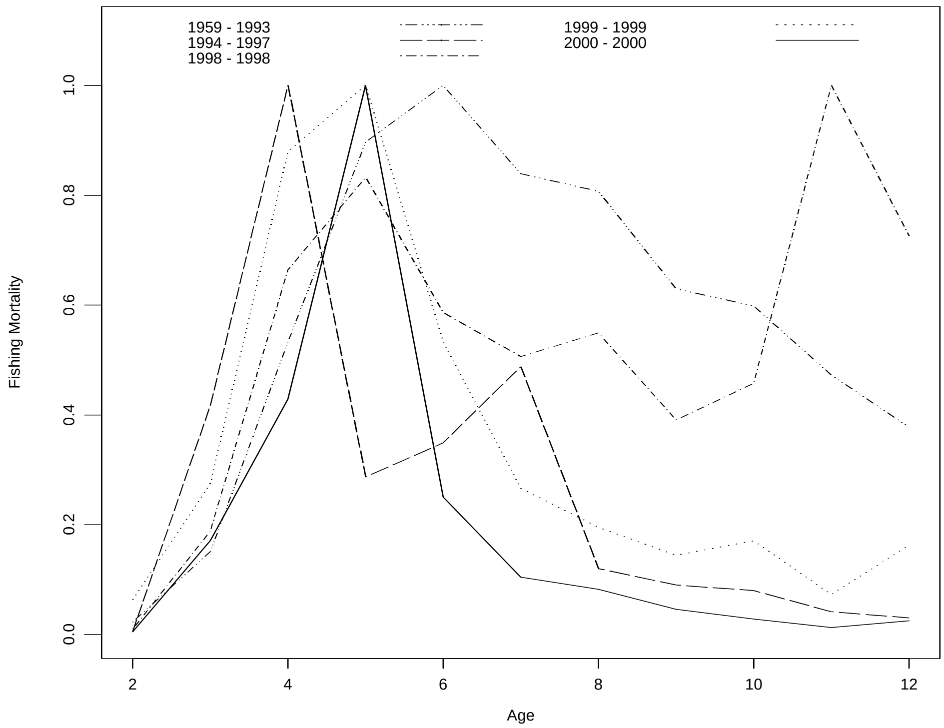

Fig. 5. Partial recruitment curves for some recent years, as well as the historic average.

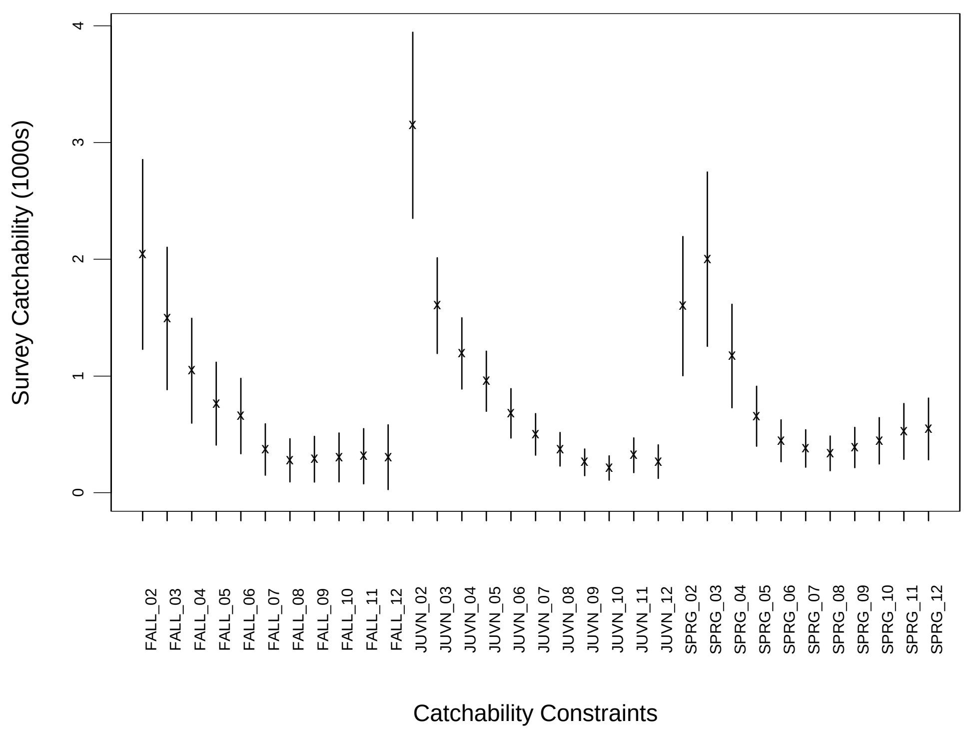

Fig. 6. QLSPA estimates of survey catchabilities.

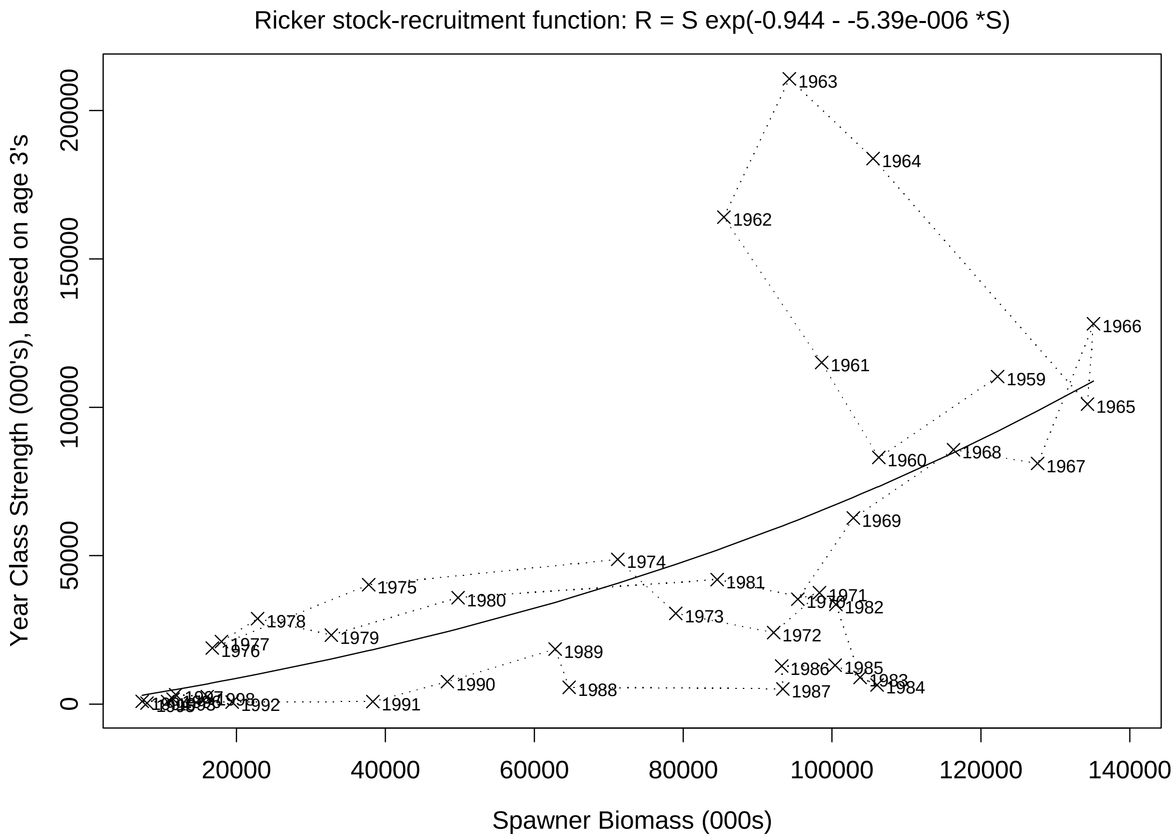

Fig. 7. Stock-recruit relationship for Div. 3NO cod.

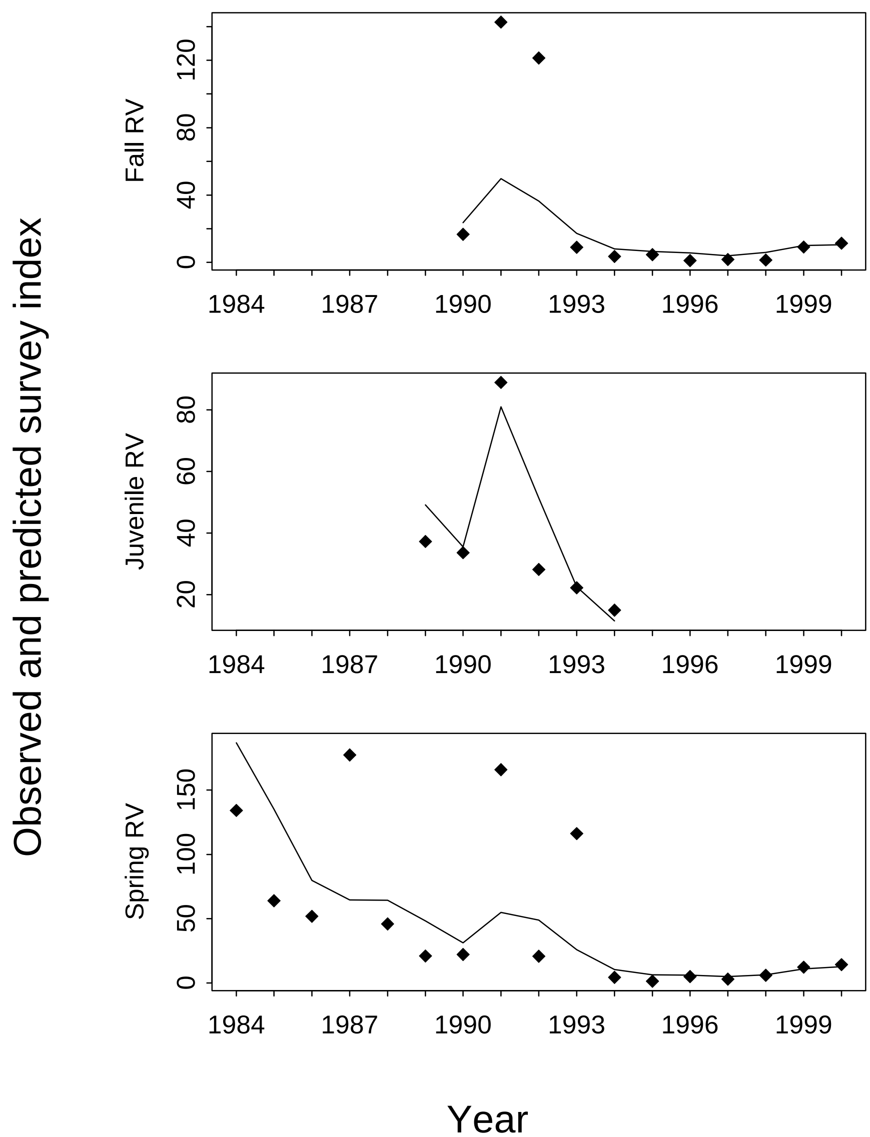

Fig. 8. Model fit to 2+ survey indices.

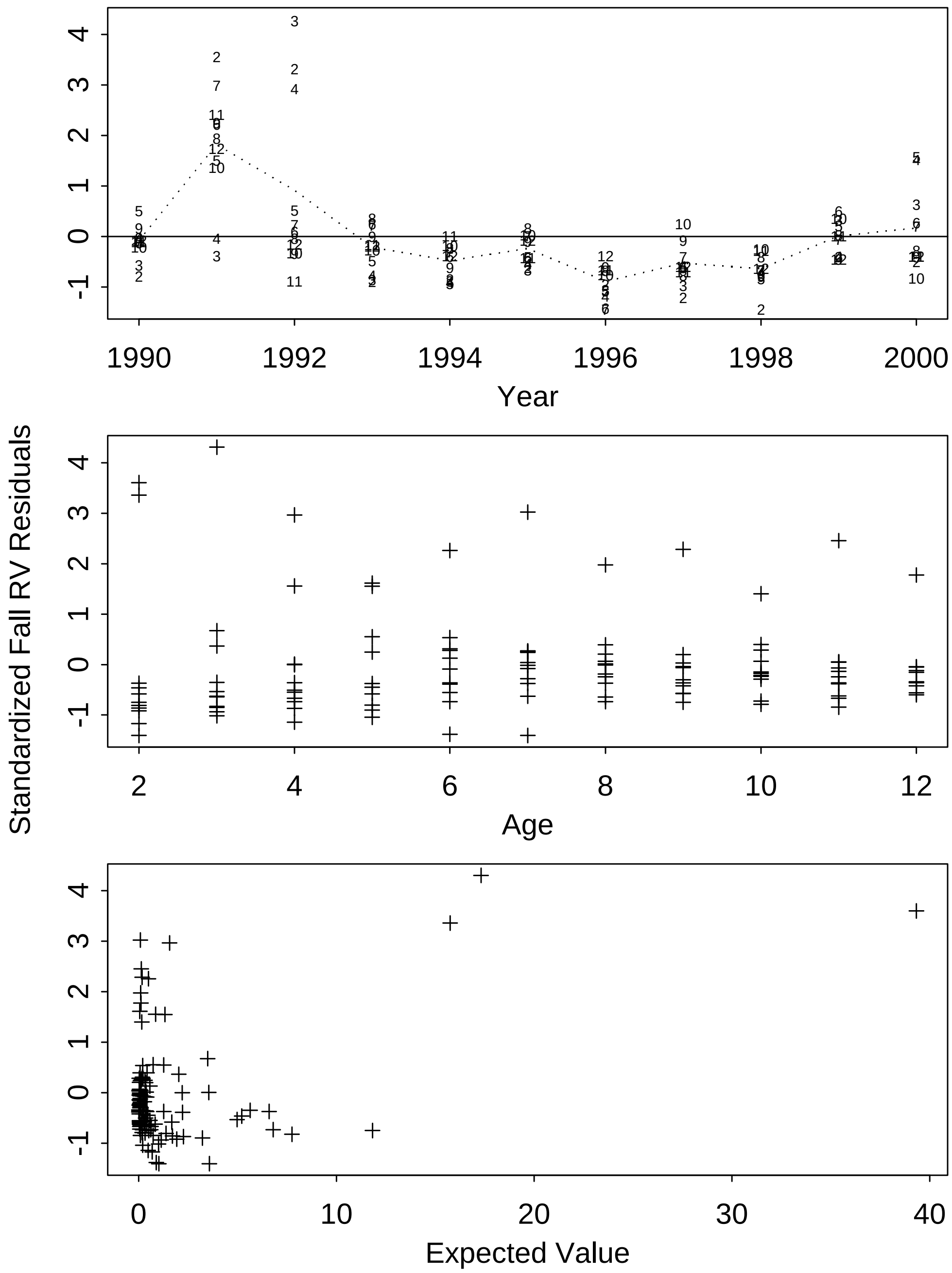

Fig. 9. Model diagnostics for the fall research survey indices.

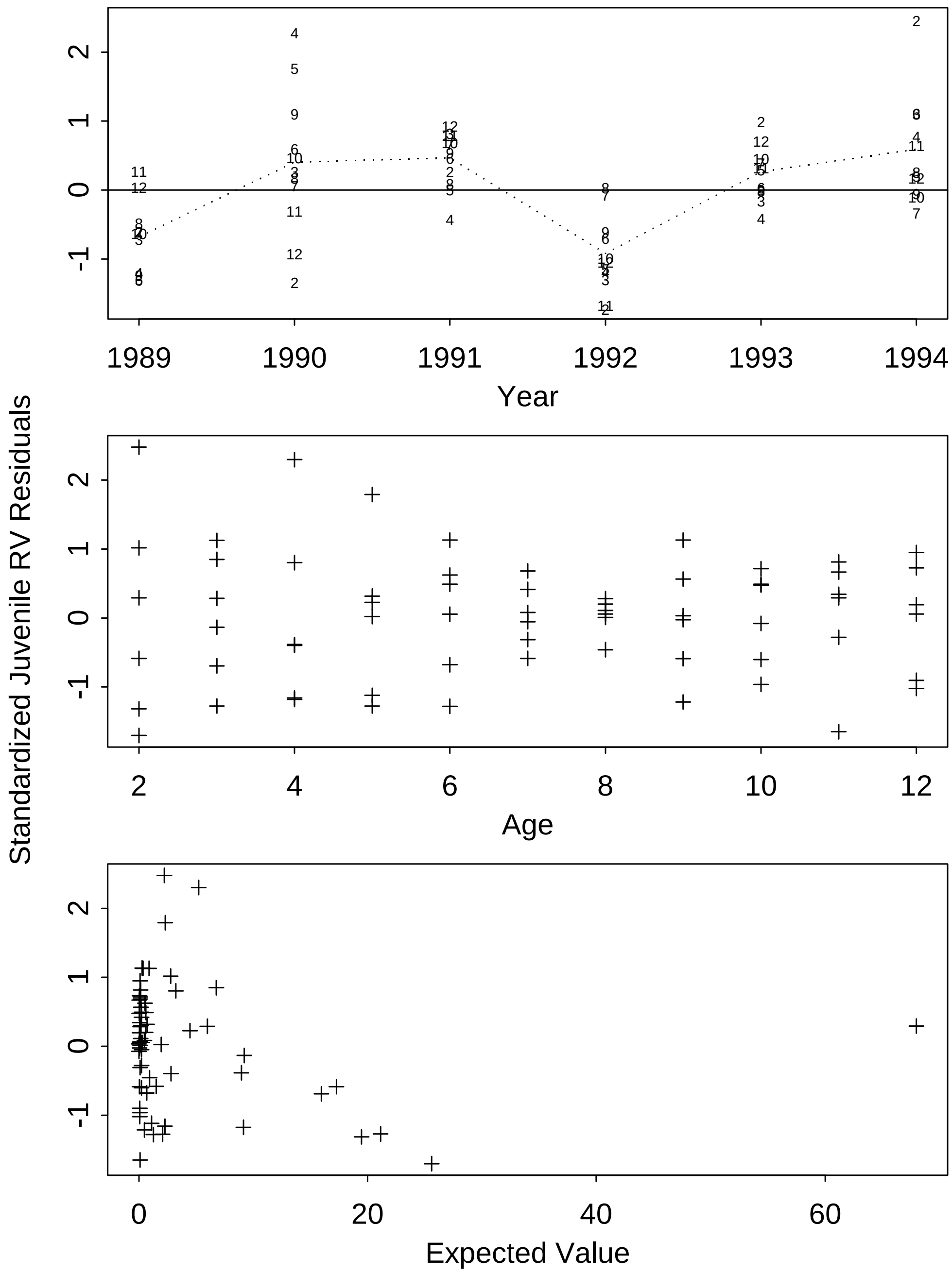

Fig. 10. Model diagnostics for the juvenile research survey indices.

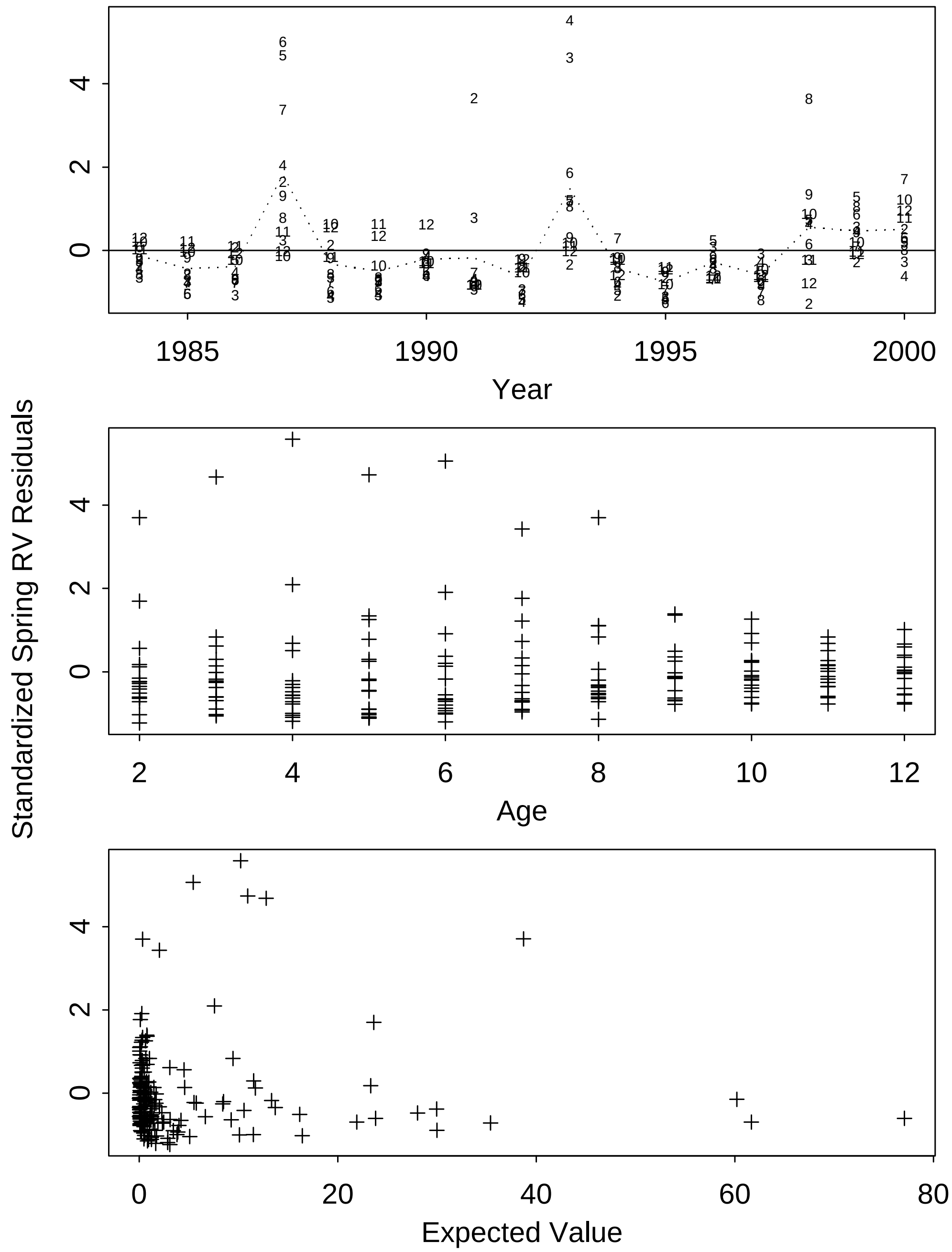

Fig. 11. Model diagnostics for the spring research survey indices.

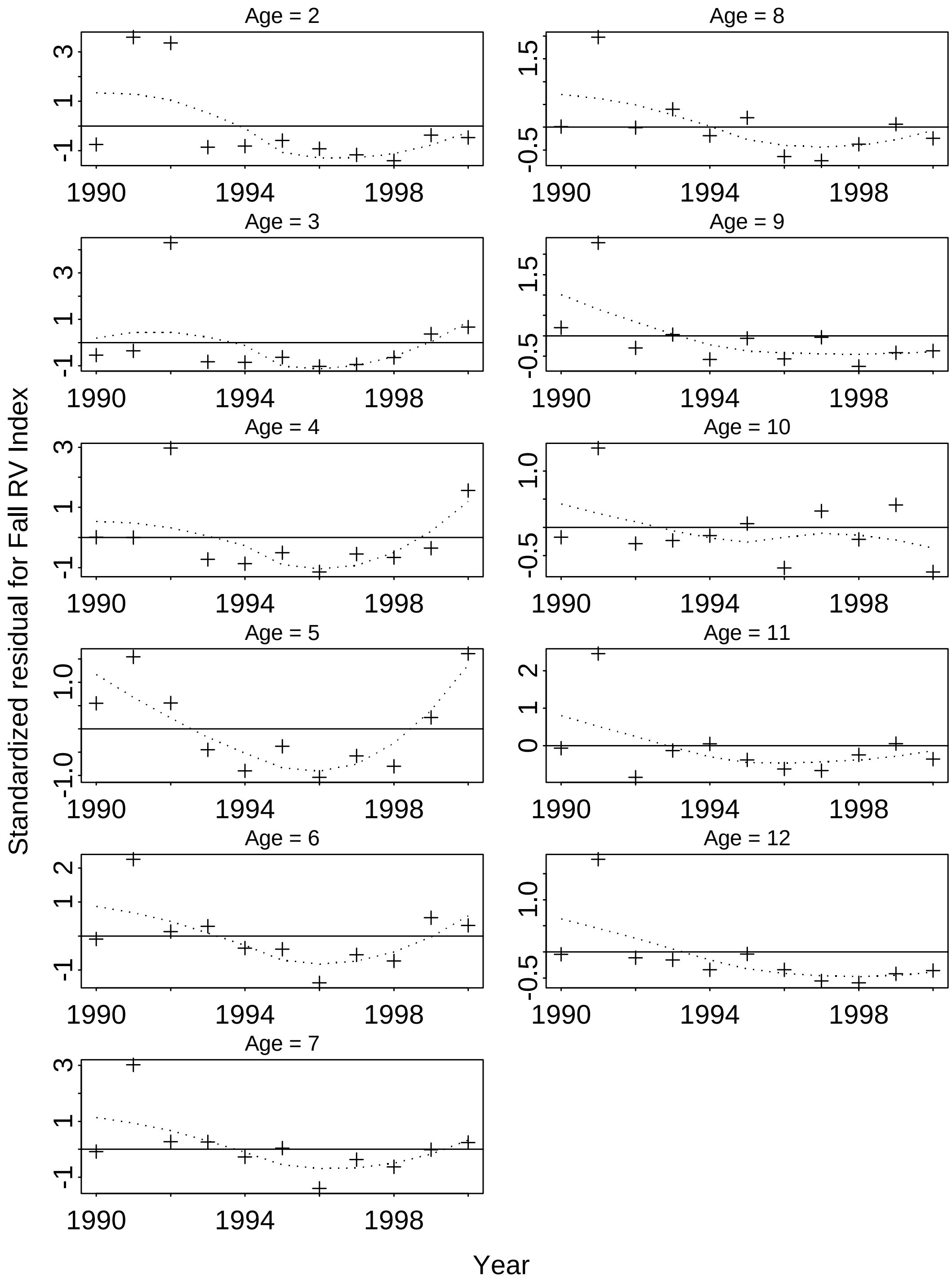

Fig. 12. Time series of standardized residuals for the fall research survey indices.

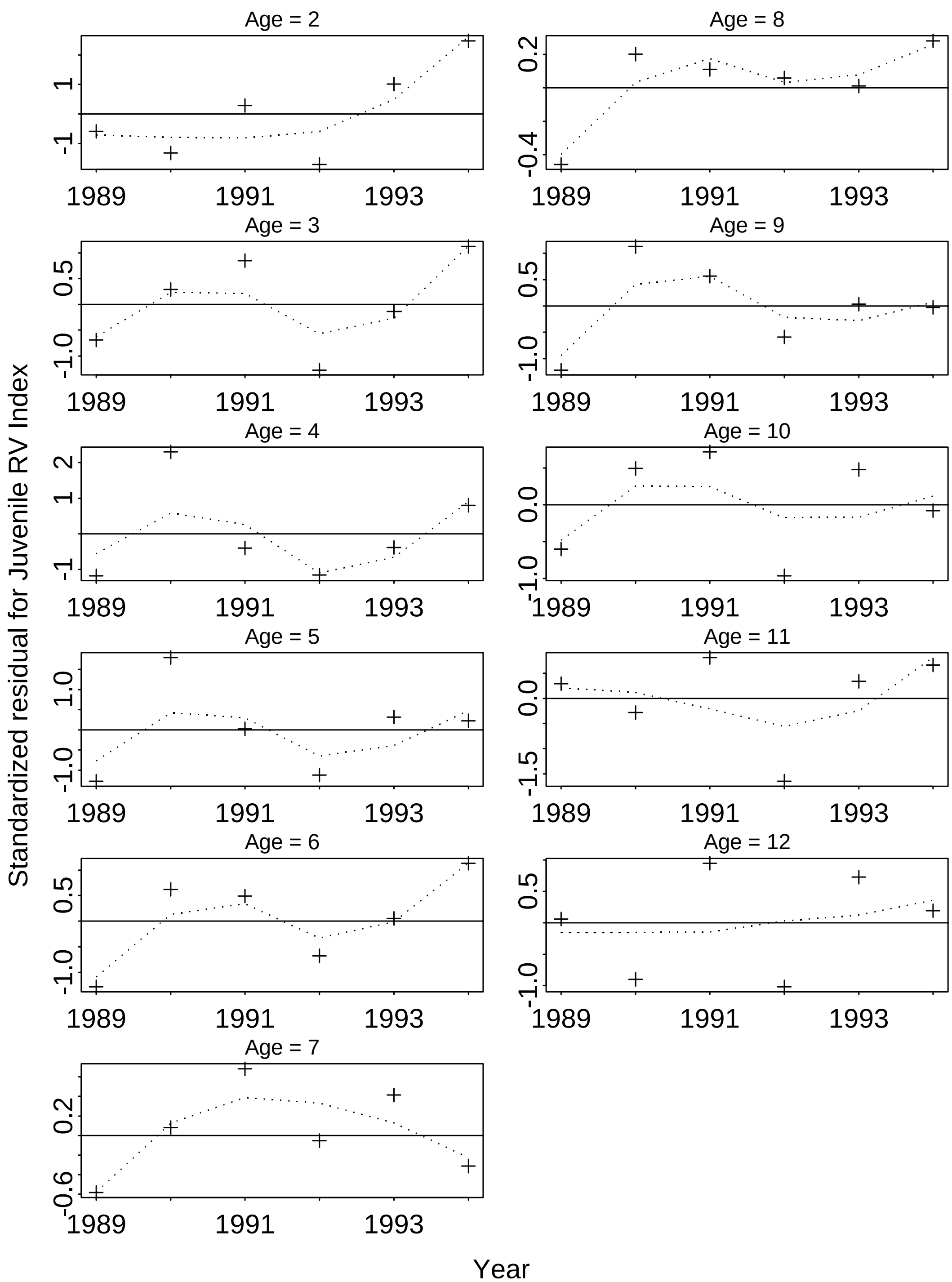

Fig. 13. Time series of standardized residuals for the juvenile research survey indices.

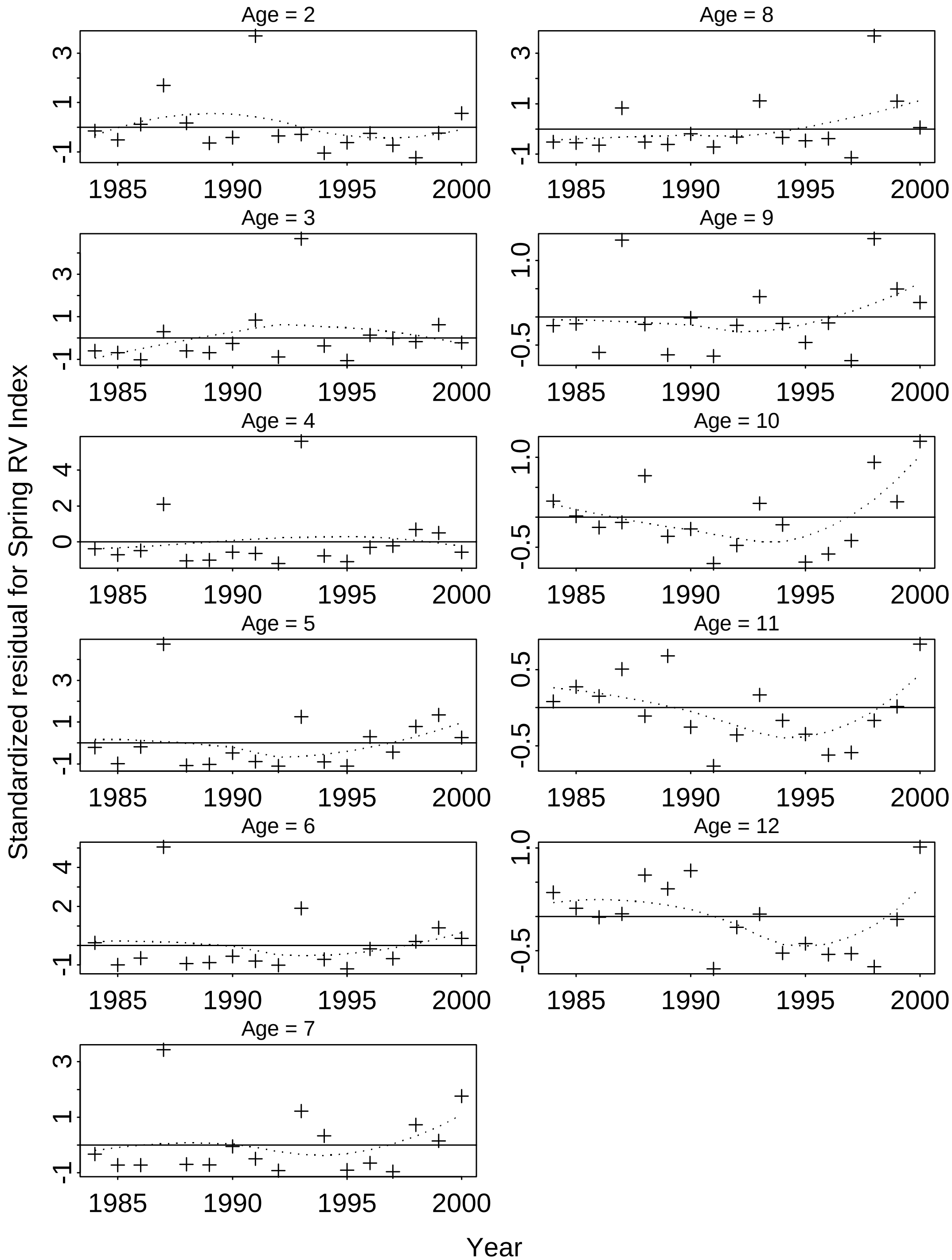

Fig. 14. Time series of standardized residuals for the spring research survey indices.