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Northwest Atlantic Fisheries Organization

Serial No. N4368 **NAFO SCR Doc. 01/4**

SCIENTIFIC COUNCIL MEETING – JUNE 2001

An Exploration of Virtual Population Analyses for Divisions 3LNO American Plaice

by

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Abstract

The 1999 assessment of Div. 3LNO American plaice incorporated a VPA with a change in natural mortality for all ages from 1989 to 1996. This was a large departure from previous assessments of this stock. This paper explores this formulation of the VPA for this stock based on recommendations made by STACFIS. The formulation accepted in 1999 appears to have no retrospective pattern in the estimates of population numbers. The use of a plus group in the commercial catch at age has little effect on the estimates of population size but does improve the fit of the model to the data. Several analyses indicate that natural mortality did increase for this stock in the late 1980's and remained high until at least the mid 1990's. Estimates of natural mortality that are above 0.6 for this time period produce a stock trajectory that is much different from our current understanding of stock history. It is recommended that the 2001 assessment of Div. 3LNO American plaice use a formulation of VPA that incorporates a 15-21 plus group in the commercial catch at age and sets M=0.2 except M=0.53 for all ages from 1989-1996. Despite circumstantial evidence there has been no clear demonstration that natural mortality increased or why it may have increased. Given the uncertainties around the estimate of M and the risks involved, research into this problem should continue.

Key words: American plaice, VPA, natural mortality, plus group, retrospective

Introduction

At the June 1999 Scientific Council meeting, a variety of formulations of ADAPT were presented for Div. 3LNO American plaice. The best formulation appeared to be one in which natural mortality (M) was set at 0.2 on all ages except from 1989 to 1996 where it was set equal to 0.6 (Morgan et al MS 1999b). This formulation then formed part of the assessment of this stock (Morgan et al MS 1999a). There were a number of recommendations made concerning the VPA presented at that meeting. The change in M was a large departure from previous models and STACFIS **recommended** that *the effect of the increase in natural mortality and estimation of M within the ADAPT framework be explored.* In recent years catch at older ages was low or nonexistent and therefore, STACFIS **recommended** that *the number of ages in the catch-at-age be reduced and the effect of a plus group in the catch-at-age be explored*. Previous VPAs on this stock had a severe retrospective pattern and STACFIS **recommended** that *the current VPA be examined for a retrospective pattern*.

This paper attempts to address some of these concerns. All analyses use the accepted run from the 1999 assessment presented in Morgan et al (MS 1999a) as the base run for comparison. Sequential population analyses were run using ADAPT V2.1 (Gavaris, MS 1999).

<u>Retrospective Pattern</u>

The base formulation of the model was run repeatedly, each time using one less year of catch and survey data. This was done back to 1992 for a comparison of a total of 7 runs.

There was variability in the estimates of population size but no pattern (Fig. 1). In particular estimates of the population number did not decrease progressively as more data was added as has been noted in the analyses of some groundfish stocks (Sinclair et al., 1991). There was somewhat more retrospective variation in the average estimates of F, at least in 1993 and 1994 when the peak in estimates occurred. There is some pattern in this variation with runs including data from 1995 and later giving a higher estimate of F in those years. This resulted in a slight increasing trend in the population estimate for 1993. The estimates of F in other years were very similar among runs. Although not presented here, the formulation in which M=0.2 throughout showed the same patterns in retrospective analyses as the base formulation.

<u>Plus group analyses</u>

The plus group analyses were conducted by specifying or estimating the ratio of the fishing mortality rate (Fratio) for the plus group relative to the next youngest age group. The calculations are as follows:

Let A represent the oldest non-plus group age and A' represent a plus group. Also, let T represent the terminal time in the VPA. All the cohorts in the terminal time must be specified. In addition, the population abundance for the plus group in the terminal time must be specified. Solve for $F_{(A-1)',T-1}$ using $C_{(A-1)',T-1}$ and $P_{A',T}$ in the catch equation. Then

$$F_{A,T-1} = F_{(A-1)',T-1}\left(C_{A',T-1} + aC_{A,T-1}\right) / aC_{(A-1)',T-1}$$

where a is an F ratio which may be assigned or estimated. Now

$$N_{A,T-1} = C_{A,T-1}\left(F_{A,T-1} + M_{A,T-1}\right) / F_{A,T-1}\left(1 - e^{-\left(F_{A,T-1}+M_{A,T-1}\right)\Delta t_j}\right)$$

Also $F_{A',T-1} = aF_{A,T-1}$ therefore $N_{A',T-1}$ can be calculated in a similar manner.
These calculations are repeated for all times moving backwards (taken from: Gavaris, MS 1999).

The base run was compared to runs of the same formulation but with specified plus groups. The plus groups were 15-21 (this group included all catch from 15 to 21), 15-17 (since the base run included only catch to 17) and 14-21 (the plus group including all catch from 14 to 21). In each case the Fratio for the plus group was estimated.

Estimates of population size were very similar for all 4 analyses. Patterns in average F for ages 9-14 were also very similar for the 4 runs except that the peak in 1993 and 1994 for the base run (no plus group) was higher than for runs including a plus group (Fig 2). The fit of the model to the data was somewhat better with lower CV on the population estimates and lower MSE when plus groups were used particularly for 15-21 and 15-17 (Table 1). Residuals from the different formulations were slightly smaller for the runs with a plus group, although the patterns were similar (Fig. 3).

We also compared for the 15-21 plus group the effect of estimating the Fratio vs. setting it equal to 1. The estimated Fratio was 0.5. The two formulations gave similar population numbers in recent years but slightly higher numbers, particularly prior to 1990, for the run where the ratio was estimated. Average F over ages 9-14 tended to be lower in the run where the Fratio was estimated. The lower average F and the lower F on the plus group for the run where the Fratio was estimated results in the slightly higher population estimates for that run. There is no external data to suggest that the selection pattern for American plaice is domed. It may, therefore, be prudent to set the Fratio equal to 1.0.

Exploration of M

Our exploration of M took 4 forms: did natural mortality change, what did it change to, when did it change, and what is the effect of a change in M?

Did M Change?

Z. Estimates of total mortality from the spring and fall surveys indicate that mortality was very high even after the moratorium on fishing was introduced in 1995 (Morgan et al., MS 1999a). The estimates of Z were very high from 1989 through 1996 but decreased substantially in 1997 and 1998 (Fig. 4). Z should approximate M in the absence of fishing indicating that at least during the first years of the moratorium M was higher than 0.2. This pattern in the survey Z's led to the decision to change M in the VPA for the 1989 to 1996 period.

Sinclair R. Simulation studies comparing F from VPA with R from surveys (where R is catch at age in fishery divided by catch at age in the survey, provided the survey is conducted mid-year) showed that there were differences between the two if M varied (Sinclair, 1998). If M increased then there was a trend in F with an increase followed by a decline. An increase in M did not produce any trend in R. Changes in survey catchability or catch misreporting did not produce these relative patterns in F and R. A comparison of average F from the ADAPT formulation where M=0.2 throughout and R from the spring survey was conducted over two age ranges: 5-14 the range of the VPA; and 7-13 ages fairly well represented in all years in both the catch and the survey. In both cases there was an increase followed by a decrease in F with little or no trend in R (Fig. 5). R did decrease in 1995 with the imposition of the fishing moratorium. It is possible that these analyses are confounded by the very low catch levels starting in 1995.

Residuals from VPA. The simulations conducted in Sinclair (1998) showed that if M increased there should be a trend in the residuals from the VPA with an increase followed by a decrease. Although there is some degree of variability in the residuals there is a tendency for the residuals to increase and then decrease in the VPA formulation where M=0.2 throughout (Fig 6).

What is M if not 0.2?

Z. The value of 0.6 used in the 1999 assessment was based on the average Z from the spring surveys for 1995 and 1996 calculated over ages 5 to 10. These ages are well represented in the survey data over these years. However the fish are not fully recruited to the survey gear until age 6 or 7 in most years of the time series. We chose to calculate an average over ages 7 to 13 as they are fully recruited to the gear and well represented in the survey data. We calculated this average for Z's calculated 1995-96 and 1996-97 for the spring data and for Z's calculated for 1994-95 and 1995-96 for the fall data. The average from the spring surveys was 0.68 and from the fall surveys it was 1.46

Sinclair's Z. Sinclair (In Press) presents a method of estimating Z from surveys using a multiplicative model. The model produces estimates of Z over blocks of 4 years by estimating a separate intercept for each cohort included in the analyses but a common slope across age (the estimate of Z). This produces an estimate of average total mortality over the 4 year period, after accounting for variability in year class strength. This method was applied to the spring survey data ages 7 to 13. For each block of 4 years, only cohorts that occurred twice in the data were included. Total mortality increased from 1987 until the 4 year block beginning in 1992 (Fig 7). After that point Z declined but remained above 0.2. The last 4 year block (1995-1998) was during the moratorium on fishing and the estimate of Z for that period was 0.53. This pattern was similar to that seen for the smoothed age by age survey Z presented in Figure 4.

ADAPT estimates. ADAPT can estimate M over certain blocks of time or ages. Four runs were conducted: 1) estimating M across all ages from 1989 to 1996 (the same block of years and ages for which M was set to 0.6 in the base run), 2) estimating M across the 1981-1988 cohorts (main cohorts occurring in this period), 3) estimating M for 1989 to 1996 for ages 5-10 and 11-17 separately (to examine the possibility that M was different on older and younger ages), 4) estimating M for all ages, 1989 to 1992 and 1993 to 1996 separately (to examine the possibility that M was different in the earlier and later part of this time period).

The estimate of M for all ages 1989 to 1996 was 0.72. For all ages for the 1981-1988 cohorts the estimate was 0.53. For ages 5-10 during the 1989-1996 time period, M was estimated to be 0.78 and for ages 11-17 it was estimated to be 0.68. In the fourth run M was estimated to be 0.62 for 1989 to 1992 and 0.80 for 1993 to 1996.

The estimation of M within ADAPT, at least in this case, was sensitive to the length of the survey time series. M was estimated for all ages from 1989-96 using 4 different length time series. 1) The Campelen run uses only the Campelen or equivalent time series from 1985-1998. 2) The Engel 85-95 run uses the unconverted Engel time series from 1985-1995 and the Campelen time series from 1996-1998. 3). The Engel to 95 run uses the unconverted Engel time series from 1975-1995 and the Campelen time series from 1996-1998. 4). The 'converted' ATC run uses the Campelen or equivalent time series from 1985-1998 and 'converts' the Engel ATC series from 1975-1982 to Campelen equivalents. This 'conversion' was done by determining the ratios of numbers at age in the unconverted series to the numbers at age in the converted series from the 1985-1995 period. The numbers at age in the Engel ATC time series from 1975-1982 were then multiplied by these ratios to produce a 'converted' time series of numbers at age.

The first two runs which have a shorter time series have much higher estimates of M (0.72 and 0.68 respectively) than the last two runs with time series extending to 1975 (0.51 and 0.55, respectively). The two runs with the shorter time series (and higher estimates of M) show an increase in population size to 1989 while the runs with the longer time series show a more continual decline (Fig. 8 top). This sensitivity to the length of the time series is not seen in runs where M is set for this 1989-1996 time period (Fig. 8 bottom). The effect of the length of the index time series may be a result of the fact that the shorter survey series begin close to the period when the M is to be estimated. There is no historical portion of the time series to 'anchor' the estimates. The estimates produced from the two runs with longer time series (average 0.53) may be more reflective of the level of M.

When did M change?

It is very difficult to estimate when M changed. Age by age estimates of Z from the surveys were very high from 1989 to 1996 but declined after (Fig. 4). The disparity between R and F begins in 1989 and lasts until 1995 (Fig. 5). Estimates of Z for blocks of years are high (less than –1.0) starting in the 4 year block beginning in 1989 until the 4 year block beginning in 1993 (Fig. 7). The fit of the VPA is good for the accepted run which had an increased M from 1989 to 1996. It would seem that M increased in the late 1980's and remained high until the mid 1990's. A change over the 1989 to 1996 time period may not be unreasonable.

What is the effect of an increase in M?

Comparison of different levels of M: Population abundance, average F over ages 9-14 and SSB were compared for the formulation with M=0.2 throughout and for various runs where M was varied in the 1989-1996 time period. The formulations where M was not equal to 0.2 throughout were: M=0.6 on all ages in the 1989-1996 period and M=0.2 otherwise; estimating M for all ages, 1989 to 1992 and 1993 to 1996 separately; M estimated at 0.72 across all ages from 1989 to 1996; estimating M for 1989 to 1996 for ages 5-10 and 11-17 separately. As M increases the model estimates higher population numbers and SSB, and lower F (Fig. 9). The trend in population abundance is also different for the different runs. M of 0.2 shows a continuously declining population. Higher M gives a plateau to about 1989 or shows population size rising to a peak in that year for the highest levels of M. Levels of M above 0.6 do not look much like the survey time series. The spring survey series shows a decline from the late 1970's to mid 1980's with a plateau during the mid 1980's followed by a decline from the late 1980's. A similar pattern is seen in the base run where M=0.6 from 1989-1996, except that the initial decline is not as steep. If M is above 0.6 during this time period the population actually increases to reach its highest point in 1989 (Fig. 10). Such a trajectory is not our current understanding of the stock history.

Conclusions

The base formulation of the VPA model does not appear to have a significant retrospective pattern. The fit of the model is improved by using a plus group and the peak in F in 1993 and 1994 is not as high. Of the plus groups examined the best fit appears to be for the 15-17 and 15-21 plus groups. The 15-21 group includes all the catch at age data and may be a better choice.

Based on the analyses presented here, natural mortality may have increased in the late 1980's and remained high until at least the mid 1990's. Estimates of M ranged from 0.5 to 1.5. Estimates produced by ADAPT were sensitive to the length of the survey time series. Estimates produced in ADAPT using time series beginning in 1975 averaged 0.53 (0.51 and 0.55). Formulations in which M was above 0.6 during the 1989 to 1996 period produced trajectories of the population that were very different from the trajectory of the survey. The best formulation at this time would appear to include a 15-21 plus group in the catch-at-age with the ratio of F on the plus group to F on the last true age set at 1.0. For natural mortality the best approach seems to be M=0.2 on all ages except for 1989-1996 when M=0.53. This estimate is in the range of those obtained by the various analyses and is a somewhat more limited intervention than setting M=0.6. The results of this formulation are given in Table 2 and Fig. 11 and 12. This formulation of the model also appears to be without a major retrospective pattern (Fig. 13).

However, there is little external corroboration of an increase in M. The 2+3K population of American plaice also declined by a similar percentage at a time when there was very low exploitation of that stock (Bowering et al., 1997, Morgan et al., MS 2000). This may indicate that there was an increase in M throughout the area. At the same time as these declines were occurring, water temperatures in the area were below normal for the longest continuous period since measurement began in 1946 (Colbourne et al., 1997). These low temperatures may have contributed to an increase in M through a possible effect on fish condition (Morgan, 1992). Despite this circumstantial evidence there has been no clear demonstration that natural mortality increased or why it may have increased. An overestimate of M is problematic for stock management as it will produce large errors in the estimates of stock numbers that will result in much higher exploitation rates than estimated (Clark, 1999). Given the uncertainties around the estimate of M and the risks involved, research into this problem should continue.

Acknowledgements

We thank P. Shelton for many helpful comments on this work. We also are grateful to the helpful discussion during STACFIS and in particular to C. Darby.

References

Bowering, W.R., M.J. Morgan, and W.B. Brodie. 1997. Changes in the population of American plaice (*Hippoglossoides platessoides*) off Labrador and northeastern Newfoundland: a collapsing stock with low exploitation. Fish. Res., 30:199-216.

Clark, W.G. 1999. Effects of an erroneous natural mortality rate on a simple age-structured stock assessment. Can. J. Fish. Aquat. Sci., 56:1721-1731.

Colbourne, E., de Young, B., Narayanan, S., Helbig, J., 1997. Comparison of hydrography and circulation of the Newfoundland Shelf during 1990-93 with the long-term mean. Can. J. Fish. Aquat. Sci., 54(Suppl. 1), 68-80.

Gavaris, S. MS 1999. ADAPT User's Guide. Version 2.1.

Morgan, M.J. 1992. Low temperature tolerance of American plaice in relation to declines in abundance. Trans. Amer. Fish. Soc., 121:399-402.

Morgan, M.J., W.B. Brodie, and W.R. Bowering. MS 1999a. An assessment of American plaice in NAFO Div. 3LNO. NAFO SCR Doc., No. 99/40.

Morgan, M.J., W.B. Brodie, and D. Maddock Parsons. MS 1999b. Virtual population analyses of the American plaice stock in Div. 3LNO from 1975 to 1997. NAFO SCR Doc., No. 99/58.

Morgan, M.J., W.B. Brodie, and D.W. Kulka. MS 2000. The collapse of 2+3K American plaice: was it overfishing?. Canadian Stock Assessment Secretariat Res. Doc., No. 2000/131.

Sinclair, A.F. 1998. Estimating trends in fishing mortality at age and length directly from research survey and commercial catch data. Can. J. Fish. Aquat. Sci., 55: 1248-1263.

Sinclair, A.F. In Press. Natural mortality of cod (*Gadus morhua*) in the southern Gulf of St. Lawrence . ICES J. Mar. Sci.

Sinclair, A., D. Gascon, R. O'Boyle, D. Rivard, and S. Gavaris. 1991. Consistency of some Northwest Atlantic groundfish stock assessments. NAFO Sci. Coun. Studies, 16: 59-77.

Table 1. Mean square error of the residuals as well as CV's on parameter estimates of population size for the base run from 1999 and runs with three different plus groupings of the catch at age. The average CV for each run is also shown. All plus groups have the Fratio estimated except for 15+ Fratio=1 which has the Fratio set at 1.0.

	base run	15+	15-17	14+	15+ Fratio=1
MSE	0.232	0.156	0.155	0.214	0.162
6	0.503	0.412	0.412	0.483	0.420
7	0.358	0.293	0.293	0.344	0.299
8	0.298	0.244	0.243	0.286	0.248
9	0.281	0.230	0.229	0.269	0.234
10	0.276	0.225	0.225	0.264	0.230
11	0.260	0.212	0.212	0.248	0.216
12	0.257	0.210	0.210	0.246	0.214
13	0.261	0.217	0.217	0.253	0.220
14	0.271	0.233	0.233	0.171	0.235
15	0.290	0.218	0.217		0.173
average	0.306	0.249	0.249	0.285	0.249

Table 2. Results of ADAPT formulation with 15-21 plus group in the catch at age and M=0.2 except M=0.53 on all ages from 1989-1996.

APPROXIMATE STATISTICS ASSUMING LINEARITY NEAR SOLUTION

ORTHOGONALITY OFFSET......... 0.000204
MEAN SQUARE RESIDUALS 0.170912

Parameters in linear scale

		PAR. EST.	STD. ERR.	REL. ERR.	BIAS	REL. BIAS	avg cv
6-15 survivors	6	2.40E+04	1.04E+04	0.432	2.29E+03	0.095	0.259
on Jan 1 1999	7	1.57E+04	4.84E+03	0.307	7.71E+02	0.049	
	8	1.59E+04	4.06E+03	0.256	5.37E+02	0.034	
	9	9.02E+03	2.20E+03	0.244	2.56E+02	0.028	
	10	5.62E+03	1.35E+03	0.241	1.43E+02	0.025	
	11	3.18E+03	7.20E+02	0.227	6.99E+01	0.022	
	12	1.73E+03	3.88E+02	0.225	3.62E+01	0.021	
	13	7.93E+02	1.84E+02	0.232	1.75E+01	0.022	
	14	3.53E+02	8.70E+01	0.247	8.56E+00	0.024	
	15	2.63E+02	4.71E+01	0.179	3.15E+00	0.012	
catchabilities	5	2.63E-03	3.25E-04	0.124	1.48E-05	0.006	
	6	4.62E-03	5.50E-04	0.119	2.47E-05	0.005	
	7	5.75E-03	6.73E-04	0.117	3.16E-05	0.005	
	8	5.18E-03	6.02E-04	0.116	3.05E-05	0.006	
	9	4.50E-03	5.22E-04	0.116	2.84E-05	0.006	
	10	3.41E-03	3.95E-04	0.116	2.23E-05	0.007	
	11	3.28E-03	3.81E-04	0.116	2.20E-05	0.007	
	12	3.90E-03	4.59E-04	0.118	2.71E-05	0.007	
	13	4.01E-03	4.82E-04	0.12	2.94E-05	0.007	
	14	4.51E-03	5.57E-04	0.123	3.46E-05	0.008	

residuals	5	6	7	8	9	10	11	12	13	14
1985	-0.520	-0.363	-0.092	-0.181	-0.358	-0.110	-0.078	-0.259	-0.162	0.057
1986	-0.377	-0.093	-0.082	-0.367	-0.406	-0.389	-0.524	-0.259	-0.009	-0.205
1987	0.323	0.367	0.118	-0.022	-0.323	-0.247	-0.600	-0.188	0.147	0.240
1988	-0.019	0.274	0.080	-0.226	-0.124	-0.332	-0.279	-0.329	-0.001	0.372
1989	-0.044	0.255	0.254	-0.022	-0.030	-0.248	-0.296	-0.149	-0.208	0.121
1990	0.566	0.138	0.276	0.194	0.167	0.300	0.011	0.001	0.327	-0.028
1991	0.646	0.143	-0.131	-0.034	0.133	0.201	0.258	0.164	-0.071	0.280
1992	-0.334	-0.080	-0.303	-0.337	-0.165	0.098	0.094	-0.151	-0.035	-0.491
1993	0.099	0.179	0.271	0.242	0.205	0.766	0.824	0.711	0.067	0.787
1994	-0.164	-0.115	-0.028	0.072	0.156	-0.124	1.087	0.654	1.509	0.702
1995	-0.798	-0.691	-0.286	0.264	0.592	0.455	-0.055	-0.006	-1.147	-0.897
1996	0.470	0.321	0.185	-0.023	-0.144	-0.366	-0.407	0.141	0.485	0.266
1997	0.153	-0.181	0.019	0.046	-0.182	-0.434	-0.431	-0.228	-0.857	-0.333
1998	0.000	-0.152	-0.281	0.393	0.478	0.431	0.395	-0.103	-0.043	-0.869

Table 2. Continued.

Bias adjusted population numbers (000)

	5	6	7	8	9	10	11	12	13	14	15	5+ millions
1975	293985.63	228978.42	190859.52	122611.47	76156.97	43254.62	25040.14	15848.64	10882.56	5939.16	6656.31	1020.21
1976	276666.81	239897.48	184646.77	149745.13	91877.21	54030.55	28301.42	15375.79	8729.20	5515.13	5352.71	1060.14
1977	232202.03	225759.58	192883.20	143250.95	105154.36	60285.18	33144.48	15701.18	7966.21	4436.67	4828.93	1025.61
1978	218522.44	189231.17	178766.59	150028.32	106704.54	73875.98	39316.90	21270.48	9032.01	4396.14	4790.80	995.94
1979	200726.22	177503.83	150895.97	138063.65	113453.28	75878.10	47993.52	23260.93	11295.42	4124.78	3350.67	946.55
1980	193496.93	163205.37	139414.22	111340.43	96147.73	79393.78	50864.18	31382.21	15645.49	7588.53	4955.58	893.43
1981	188424.68	158184.32	130932.95	105544.28	79820.82	66009.48	52210.67	31494.47	18427.63	9455.17	7943.29	848.45
1982	191212.55	154129.97	129009.95	105168.79	82092.69	58210.24	43759.59	30560.85	15154.97	7327.38	5105.23	821.73
1983	189744.43	156527.21	125907.31	103986.20	81773.56	59147.78	36116.65	21672.00	12088.45	5332.23	3807.81	796.10
1984	191344.87	155242.11	127258.54	100327.56	79905.61	59428.97	41482.04	21935.77	11006.66	5789.28	3687.65	797.41
1985	186889.91	156616.57	126742.88	102821.33	79152.18	60141.39	39691.36	22401.40	9940.72	4482.18	4079.26	792.96
1986	159449.72	152745.14	127515.05	101635.36	79082.67	55169.93	35099.92	19483.53	10082.24	4464.49	3648.46	748.38
1987	141464.84	126567.46	116299.10	93079.91	71920.69	52709.31	32703.51	15992.48	6710.81	2971.22	2385.18	662.80
1988	159709.71	113801.45	99164.58	88278.87	66389.95	44616.43	27339.97	16555.43	6849.91	2747.23	2286.19	627.74
1989	182430.69	128133.25	90271.88	76809.27	65720.70	45238.95	27247.25	14083.16	8144.11	3198.92	2227.10	643.51
1990	183790.16	97754.84	66706.30	44532.45	37947.19	28080.33	17407.25	9799.50	4613.78	3280.33	1902.25	495.81
1991	106963.21	96759.75	51731.81	35873.12	22742.49	15861.99	10096.22	5484.16	3086.76	1459.34	1940.44	352.00
1992	75747.94	58346.61	47808.85	24555.78	14161.62	7574.57	4495.20	2720.99	1543.00	1212.65	1368.66	239.54
1993	61964.18	44473.40	33568.14	26181.99	11901.06	5638.46	2856.43	1530.00	952.89	483.22	717.67	190.27
1994	59823.78	35584.36	23375.72	13186.42	6919.61	2832.70	895.42	362.83	188.16	180.13	91.22	143.44
1995	45187.59	31953.45	18054.35	9706.68	4460.19	2029.57	1118.20	182.34	94.37	24.63	98.53	112.91
1996	40217.19	26522.43	18570.06	10283.71	5461.38	2471.54	1145.04	647.87	104.22	55.47	72.12	105.55
1997	22450.74	23534.89	15048.87	10193.35	5710.64	3054.88	1415.45	666.09	375.20	59.60	73.36	82.58
1998	26585.48	18350.94	19020.56	11551.53	7576.22	4295.17	2369.36	1076.41	496.47	285.63	106.24	91.71
1999	43000.00	21756.77	14974.98	15326.44	8765.52	5477.30	3105.97	1688.87	775.55	344.31	260.07	115.48

Bias adjusted fishing mortalities

	5	6	7	8	9	10	11	12	13	14	15	avg 9-14
1975	0.003	0.015	0.043	0.089	0.143	0.224	0.288	0.396	0.480	0.656	0.656	0.364
1976	0.003	0.018	0.054	0.154	0.221	0.289	0.389	0.458	0.477	0.611	0.611	0.407
1977	0.005	0.033	0.051	0.095	0.153	0.227	0.244	0.353	0.394	0.460	0.460	0.305
1978	0.008	0.026	0.058	0.079	0.141	0.231	0.325	0.433	0.584	0.809	0.809	0.420
1979	0.007	0.042	0.104	0.162	0.157	0.200	0.225	0.197	0.198	0.211	0.211	0.198
1980	0.002	0.020	0.078	0.133	0.176	0.219	0.279	0.332	0.304	0.257	0.257	0.261
1981	0.001	0.004	0.019	0.051	0.116	0.211	0.336	0.531	0.722	1.026	1.026	0.490
1982	0.000	0.002	0.016	0.052	0.128	0.277	0.503	0.727	0.845	0.983	0.983	0.577
1983	0.001	0.007	0.027	0.063	0.119	0.155	0.299	0.478	0.536	0.708	0.708	0.382
1984	0.000	0.003	0.013	0.037	0.084	0.204	0.416	0.591	0.698	0.643	0.643	0.439
1985	0.002	0.006	0.021	0.062	0.161	0.338	0.512	0.598	0.600	0.653	0.653	0.477
1986	0.031	0.073	0.115	0.146	0.206	0.323	0.586	0.866	1.022	1.024	1.024	0.671
1987	0.018	0.044	0.076	0.138	0.277	0.456	0.481	0.648	0.693	0.651	0.651	0.535
1988	0.020	0.032	0.055	0.095	0.184	0.293	0.463	0.509	0.561	0.615	0.615	0.438
1989	0.094	0.123	0.177	0.175	0.320	0.425	0.493	0.586	0.379	0.518	0.518	0.454
1990	0.112	0.106	0.090	0.142	0.342	0.493	0.625	0.625	0.621	0.452	0.452	0.526
1991	0.076	0.175	0.215	0.399	0.569	0.731	0.781	0.738	0.404	0.380	0.380	0.601
1992	0.003	0.023	0.072	0.194	0.391	0.445	0.548	0.519	0.631	0.750	0.750	0.547
1993	0.025	0.113	0.404	0.801	0.905	1.310	1.533	1.566	1.136	2.048	2.048	1.416
1994	0.097	0.149	0.349	0.554	0.697	0.400	1.061	0.817	1.503	0.483	0.483	0.827
1995	0.003	0.013	0.033	0.045	0.060	0.042	0.016	0.029	0.001	0.005	0.005	0.026
1996	0.006	0.037	0.070	0.058	0.051	0.027	0.012	0.016	0.029	0.023	0.023	0.026
1997	0.002	0.013	0.064	0.097	0.085	0.054	0.074	0.094	0.073	0.024	0.024	0.067
1998	0.000	0.003	0.016	0.076	0.124	0.124	0.139	0.128	0.166	0.210	0.210	0.148

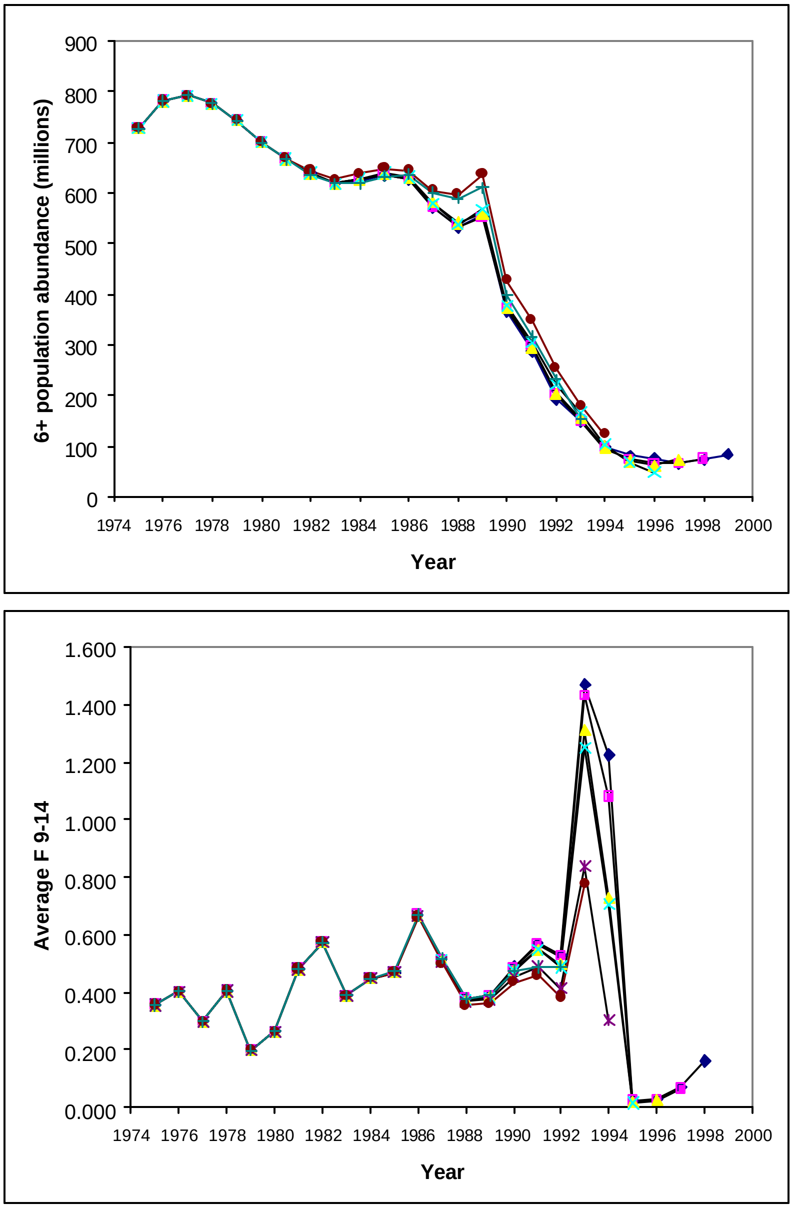


Figure 1. Results of retrospective analyses for ADAPT formulation used in the 1999 assessment of Div. 3LNO American plaice.

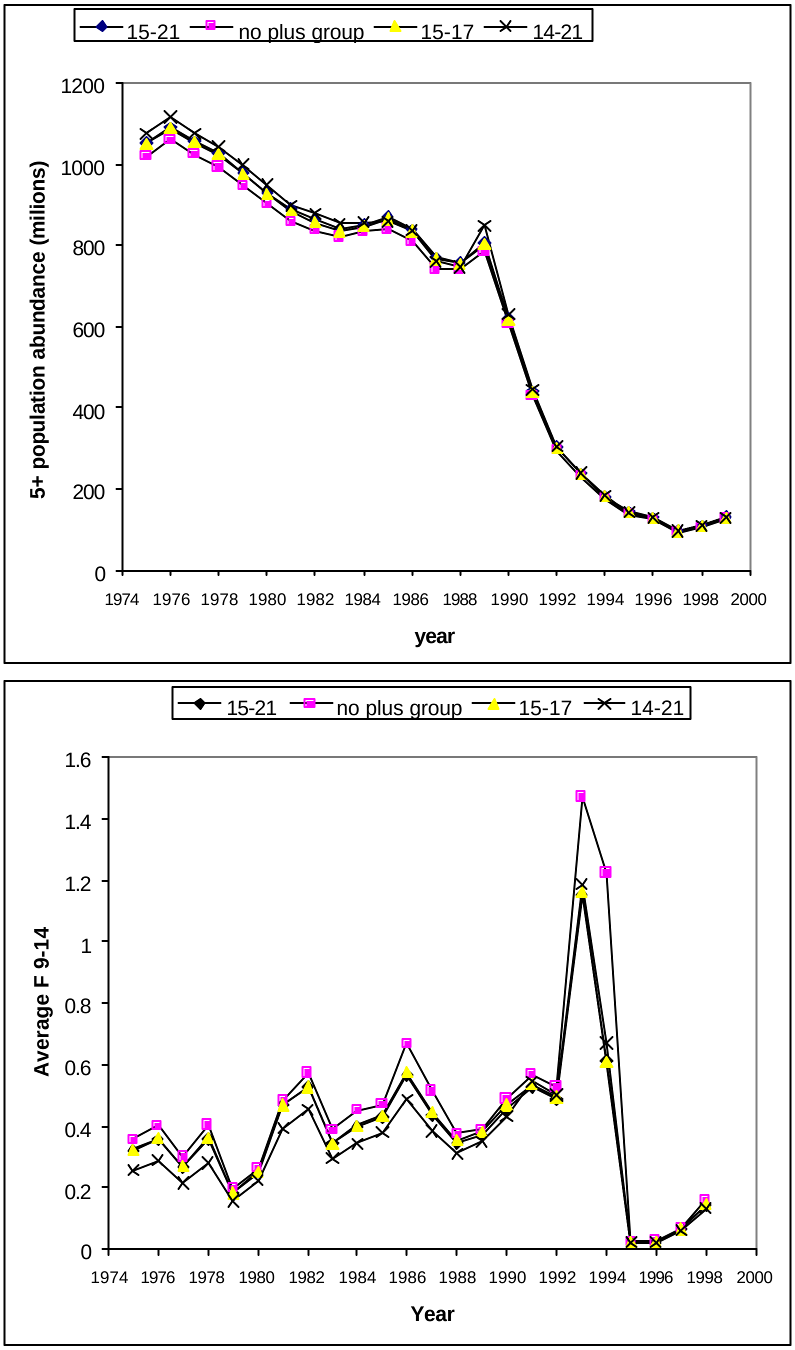


Figure 2. Results of comparison of different plus groups in the commercial catch at age. 5+ population abundance and average fishing mortality are shown.

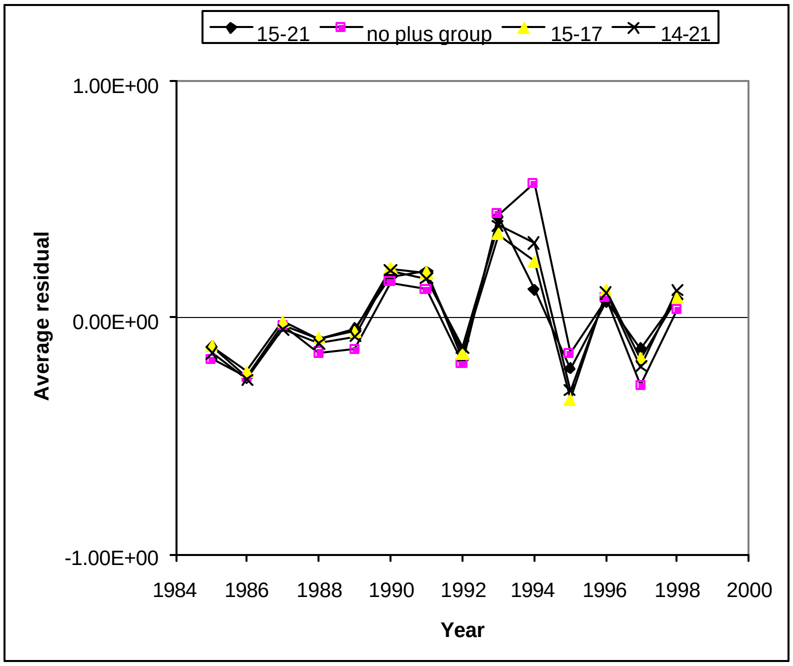


Figure 3. Average residuals from the ADAPT formulations using different plus groups in the commercial catch at age.

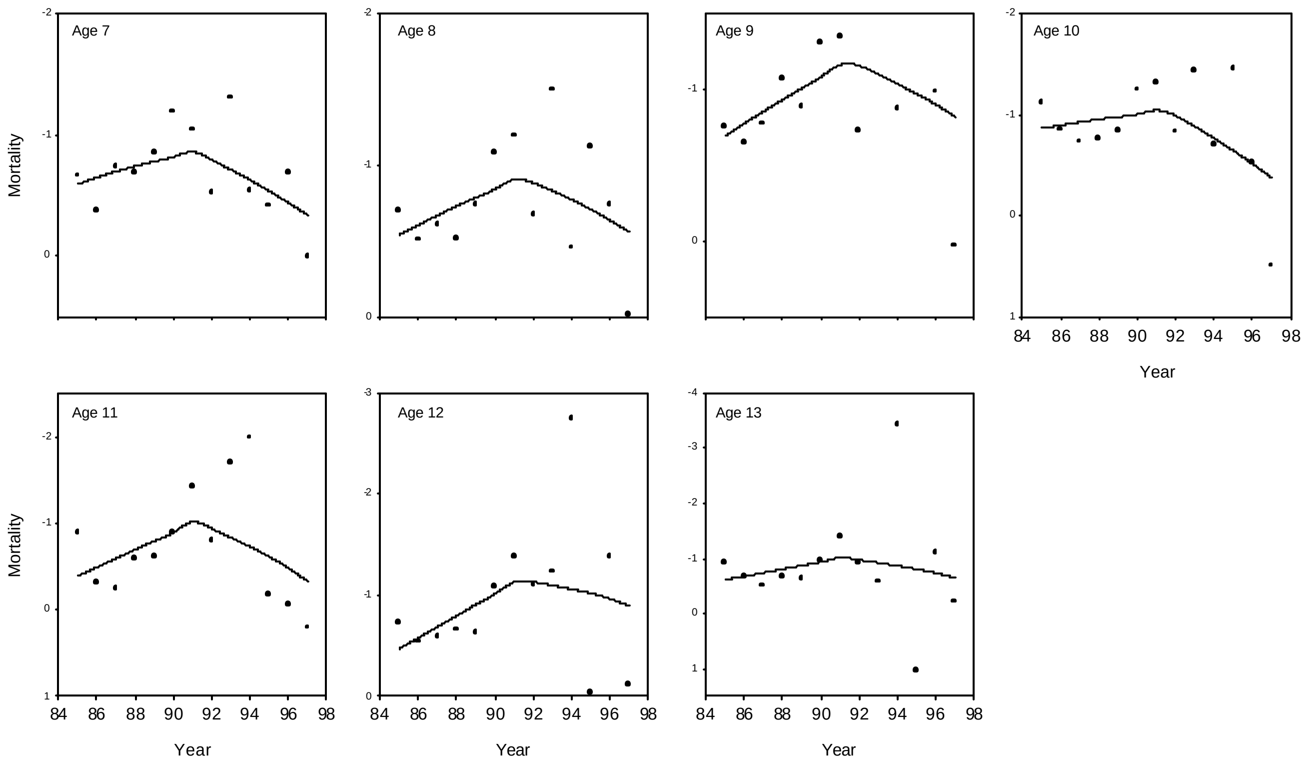


Figure 4. Estimates of mortality for ages 7 to 13 for Canadian spring surveys from 1985 to 1998.

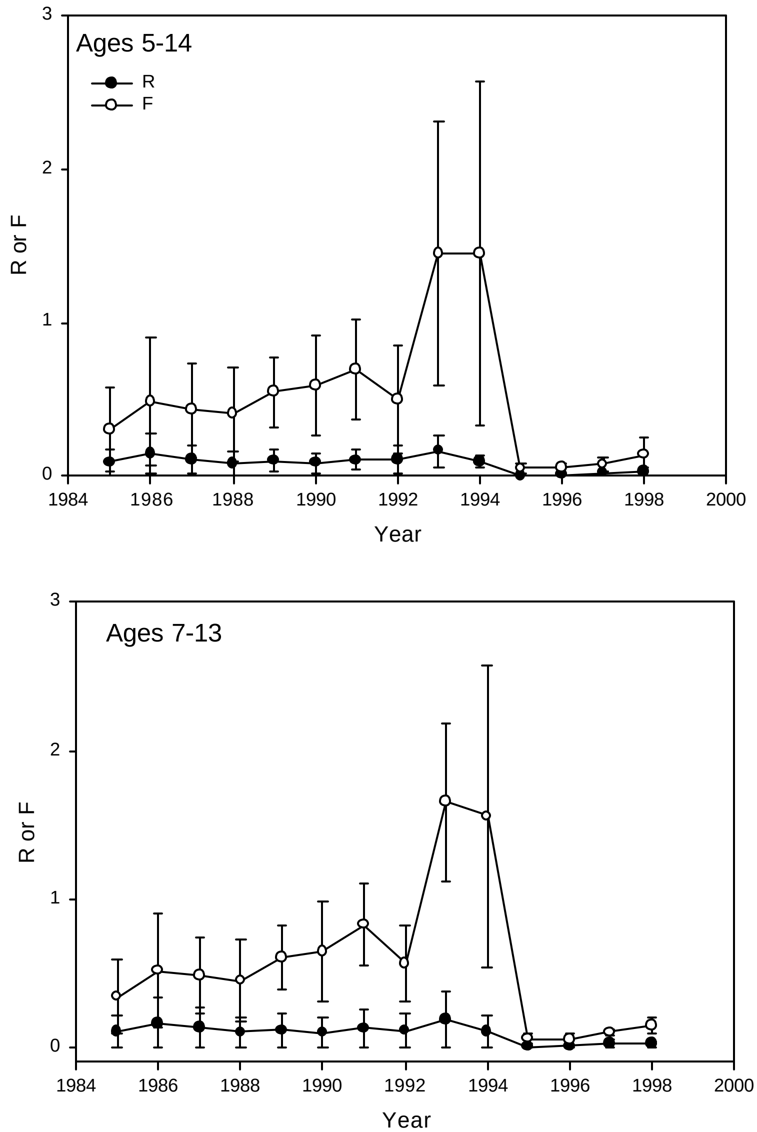


Figure 5. Average (± S.D.) of R calculated from survey and commercial catch at age and of F from ADAPT. Averages are calculated over ages 5-14 and ages 7-13.

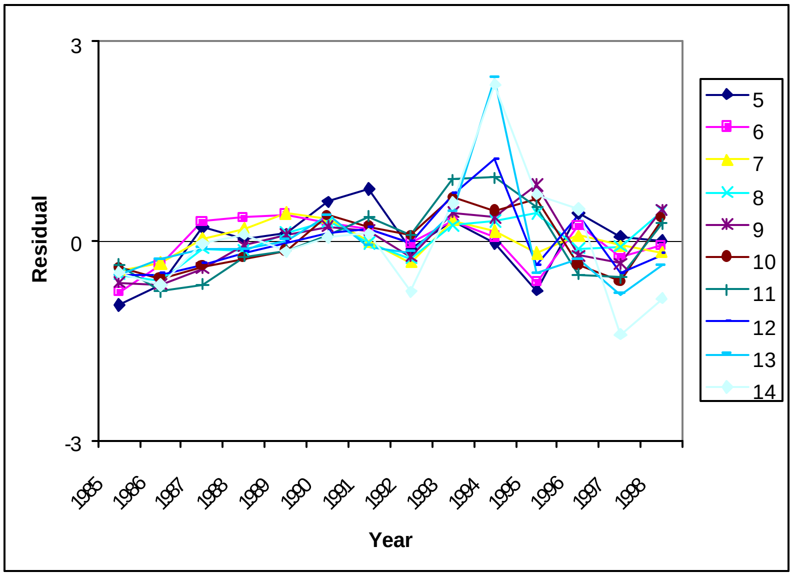


Figure 6. Log residuals from ADAPT for Canadian spring research vessel survey for formulation where M=0.2 for all ages in all years.

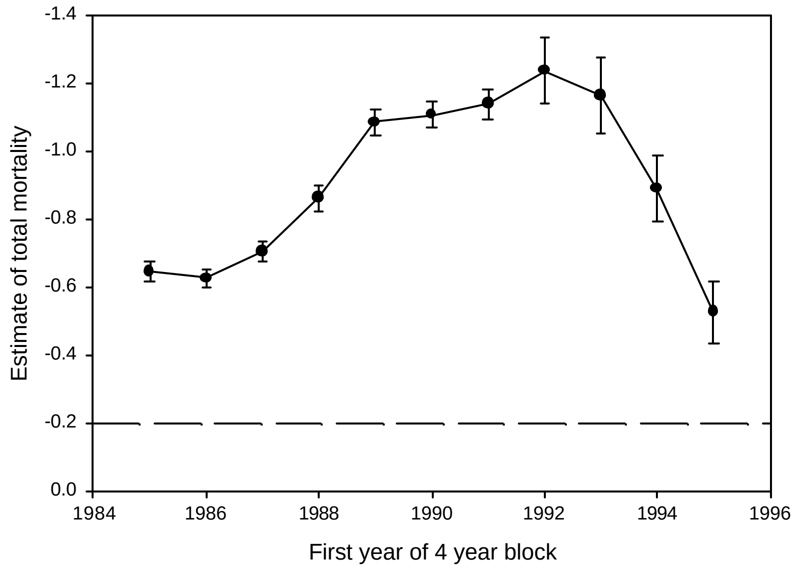
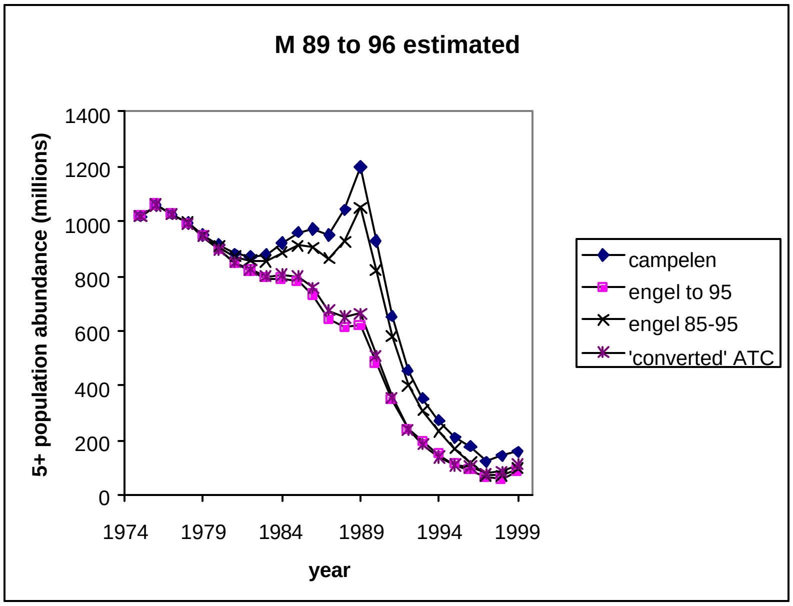


Figure 7. Estimates of total mortality from survey data calculated for ages 7 to 13 over running blocks of 4 years.



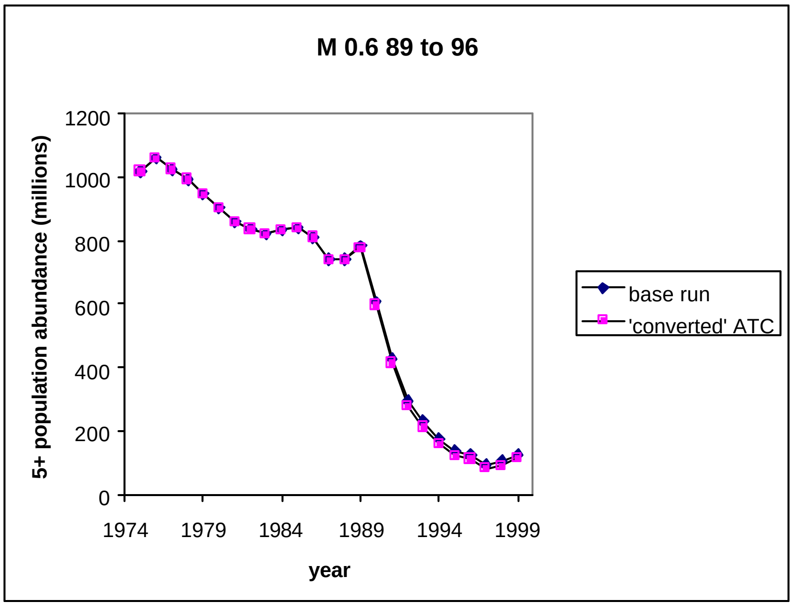


Figure 8. Effect of length of survey index time series on population estimates when M is estimated (top) and when M is fixed (bottom).

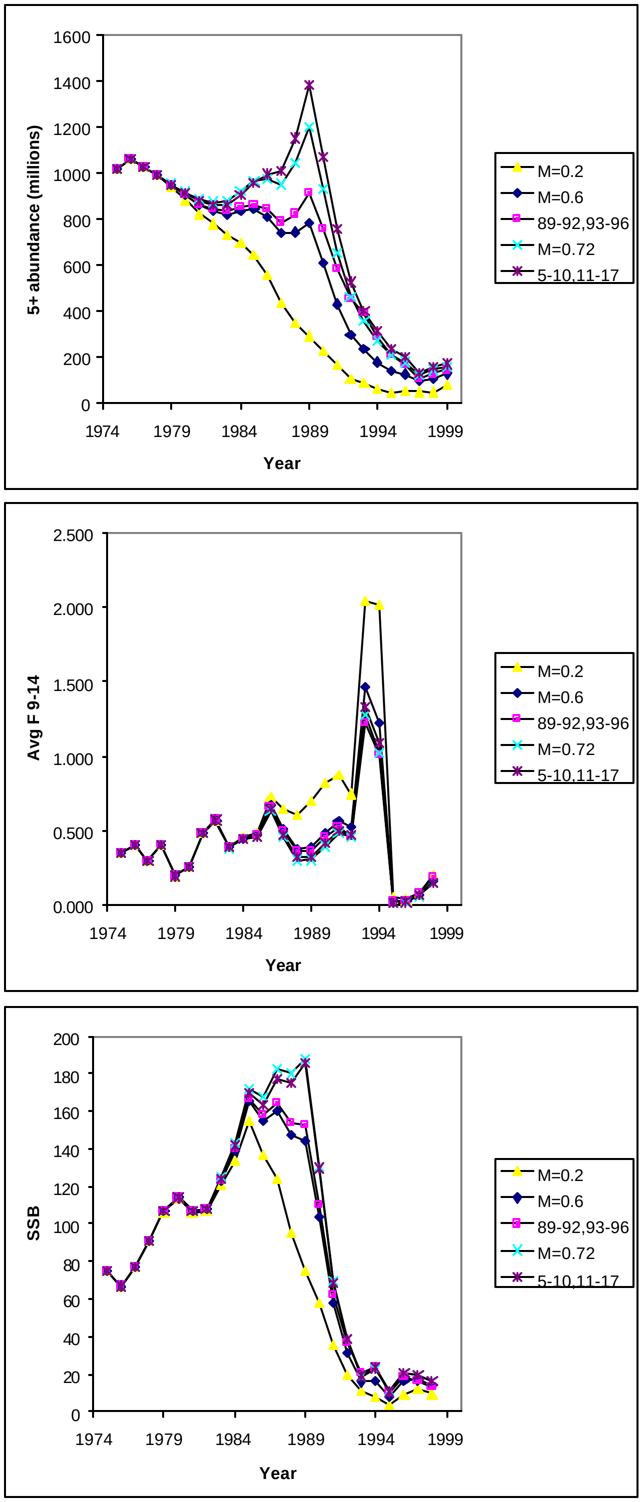


Figure 9. Effect of different levels of M in the 1989-1996 period on estimates of population abundance, average fishing mortality and spawning stock biomass.

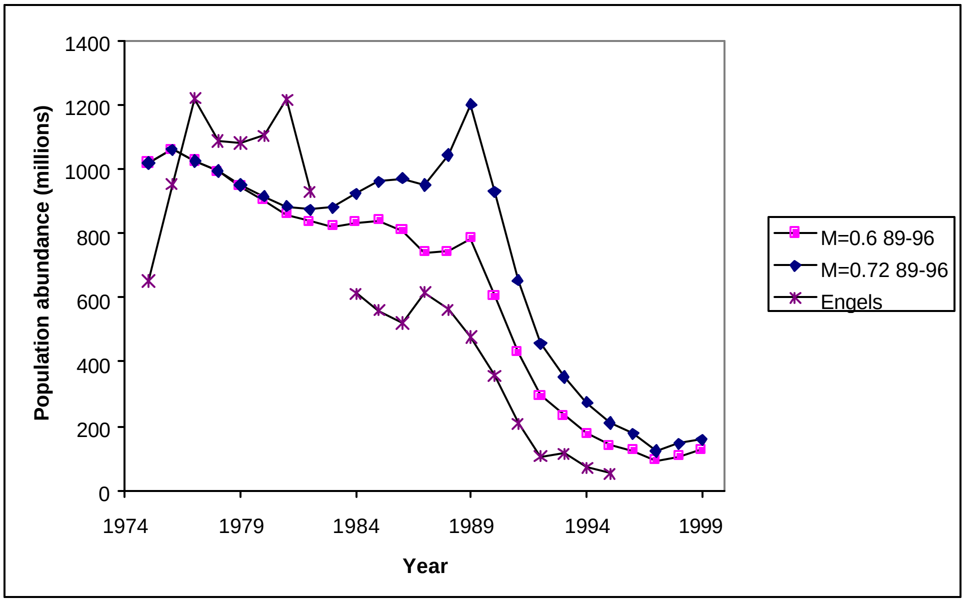


Figure 10. Estimates of population abundance from ADAPT when M is set at two different levels in the 1989-1996 period and from Canadian spring research vessel surveys using the Engel bottom trawl.

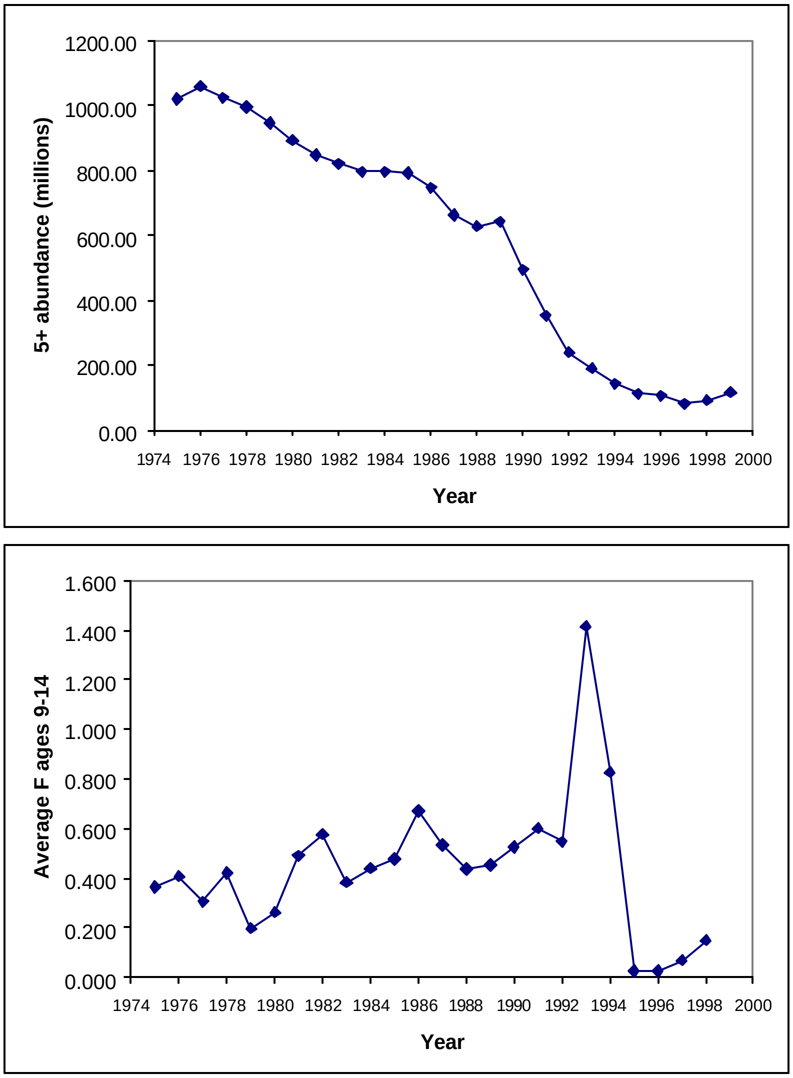


Figure 11. Population abundance and average fishing mortality for Div. 3LNO American plaice from an ADAPT formulation where a 15-21 plus group in the commercial catch at age was used and where M=0.2 except M=0.6 for all ages from 1989-1996.

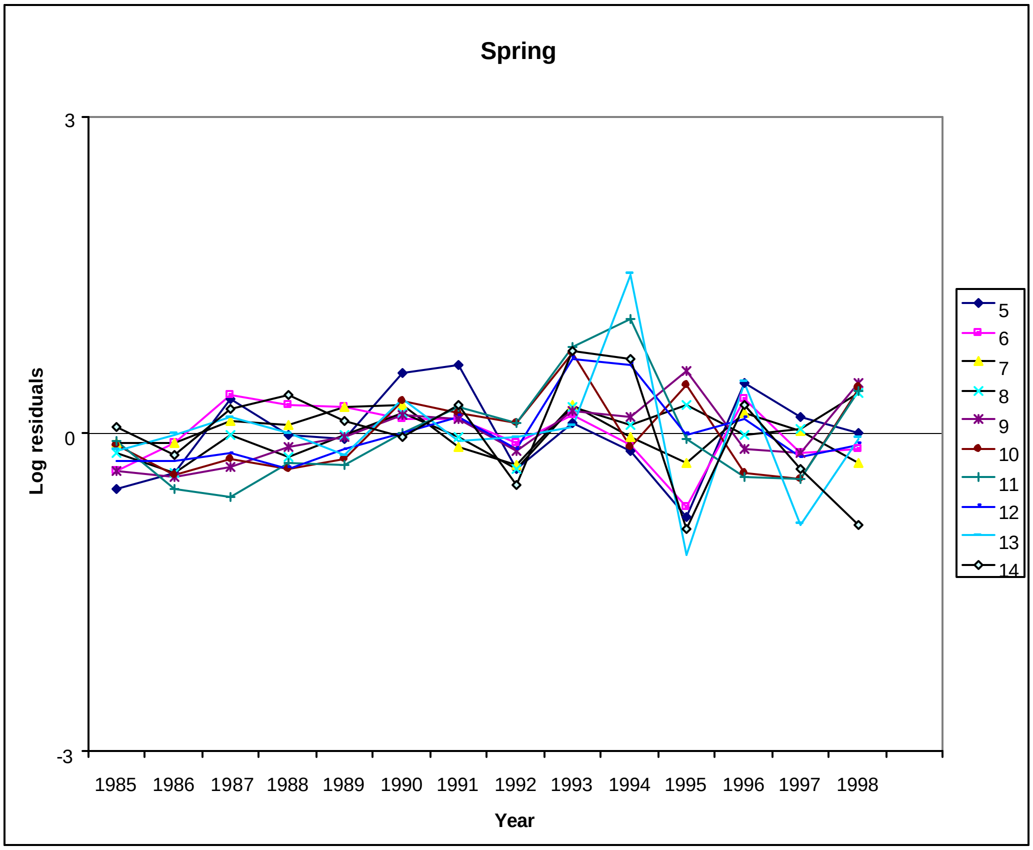


Figure 12. Log residuals from ADAPT for Canadian spring research vessel survey. ADAPT formulation used a 15-21 plus group in the catch at age and M=0.2 except M=0.6 for all ages from 1989-1996.

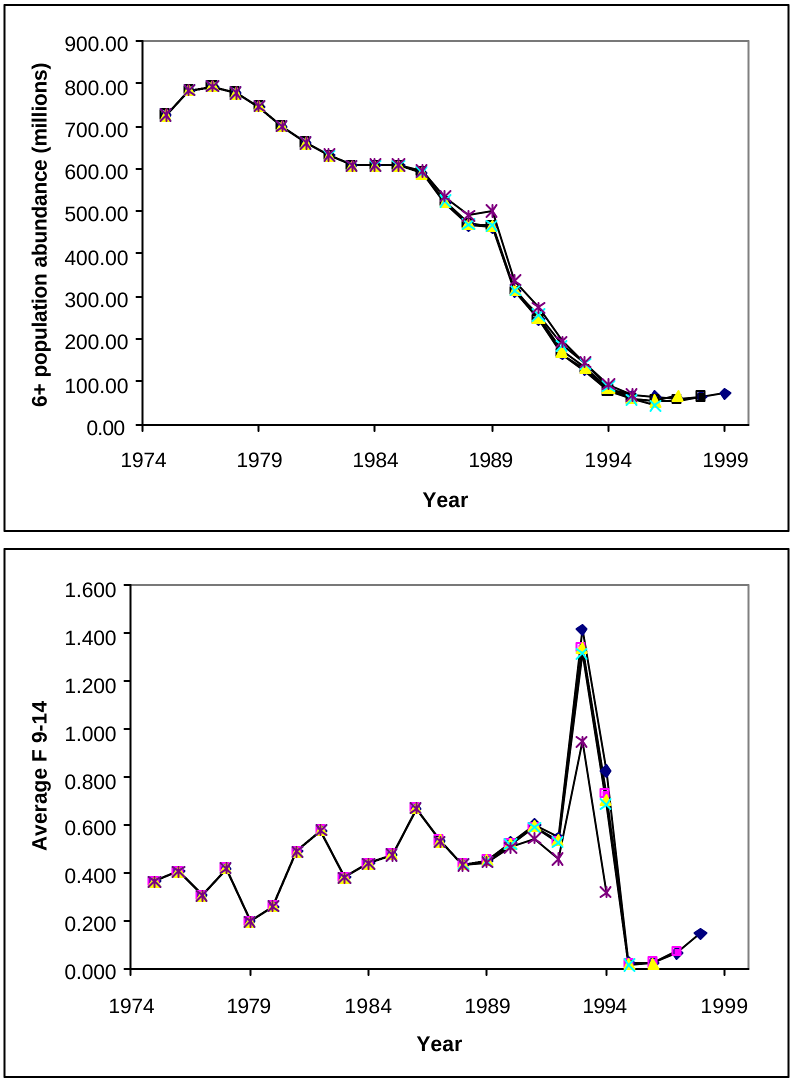


Figure 13. Results of retrospective analyses for ADAPT formulation using 15-21 plus group in the commercial catch at age and M=0.2 except M=0.6 for all ages from 1989-1996.