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Part II of American Plaice Div. 3LNO Research Recommendations: Data Explorations with ADAPT Analyses with Varying Natural Mortality

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Abstract

In 2005, NAFO STACFIS recommended that several aspects of the analytical assessment formulation for the Div. 3LNO American plaice stock (NAFO 2005) be reviewed and studied in further detail. A VPA using the ADAPTive framework (Gavaris, 1999) is used to assess this stock and the same formulation was used from 2001 to 2006. After some of the recommendations had been addressed it was decided to include the Spanish Div. 3NO survey series in the assessment (Dwyer *et al*. 2007a; Dwyer *et al*., 2007b). This paper gives a summary of the issues that were examined in 2007 and describes the results of analyses used to address the outstanding issues from the recommendation. Based upon these analyses, it is recommended that the next assessment of this stock should consider two distinct series for the Canadian spring RV survey and discontinue using a single time series with "converted" data (to account for a change in survey gear after the spring of 1995). In addition, we advocate use of a natural mortality (M) value of 0.7 at all ages for 1989-1996. This formulation gave the best overall model fit out of the several alternatives considered.

Introduction

In 2005, STACFIS made the following recommendation for American plaice Div. 3LNO (NAFO 2005):

STACFIS noted that it had been some time since alternative formulations of the population model for this stock had been explored. Therefore STACFIS recommends that a number of ADAPT formulations be explored for Div. 3LNO American plaice, including shortening or splitting the tuning indices in conjunction with varying natural mortality that is included in the current model. In addition, further comparisons between the Canadian surveys of Div. 3LNO and the Spanish Div. 3NO survey in the NRA of Div. 3NO should be carried out, including comparisons of trends in overall abundance, age by age abundance and a comparison of retrospective patterns in recruitment for VPA formulations including and excluding the Spanish Div. 3NO survey.

Morgan *et al*. (1999a) and Morgan and Brodie (2001) looked at several issues regarding the formulation of the ADAPT for this assessment, particularly the uncertainties around the appropriate value of natural mortality (M). This paper re-analyses the work of Morgan and Brodie (2001) and examines some new information.

Summary from Part I (2007)- NAFO SCR 07/62

To investigate the "*shortening or splitting the tuning indices*" portion of the research recommendation, several alternative input datasets were explored using the same model formulation as in the 2005 assessment (Dwyer *et al*. 2005), using data to 2005 only. These focused on the treatment of the Canadian survey data, collected using an

Engel 145 hi-rise trawl from 1983 through to the spring of 1995, which was subsequently replaced by a Campelen 1800 shrimp trawl. (See Morgan *et al*. (1998) for details of the comparative fishing experiments used to "convert" the Engel time-series into Campelen units equivalents.). The datasets considered were:

1) Exclusion of converted data set (Campelen data only from Canadian surveys)
2) No conversion of survey data – separate survey series for:
    - 1985-1995 Canadian RV spring survey using an Engel trawl,
    - 1996-2005 Canadian RV spring survey using a Campelen 1800 shrimp trawl
    - 1990-1994 Canadian RV fall survey using Engel gear, and
    - 1995-2005 Canadian RV fall survey using the Campelen trawl
3) Inclusion of Spanish Div. 3NO summer survey, 1998-2005.

All three alternates showed reasonably good fits to the data, but separating or shortening the converted time series data did not greatly improve the fit of the model to the data. The analysis including the Spanish Div. 3NO survey did not show any strong residual patterns for this index; the magnitude of the residuals for this index were similar to that of the Canadian spring and autumn surveys (Dwyer *et al.* 2007b).

A comparison between the trends in biomass and abundance of the Spanish Div. 3NO survey and the Canadian spring survey was carried out. Generally, both surveys indicate an increase over the time series examined (1997-2005). The exploratory data analysis package (FLEDA) of the Fisheries Library in R software (FLR; http://flr-project.org), was used to plot comparisons of standardized abundance at age values for all the surveys and results indicated that all surveys show the same age-by-age trends in abundance. Concern was expressed regarding the inclusion of an index that covers such a small proportion (10% of Div. 3LNO) of the entire stock distribution (Dwyer *et al.*, 2002). It was also noted that inclusion of the Spanish Div. 3NO survey to the ADAPT base formulation caused an increase in the retrospective pattern, which may be due to higher estimates of the 1998 cohort from the Spanish Div. 3NO survey at ages 5 and 6, relative to estimates of these cohorts in the Canadian surveys at these ages.

STACFIS agreed that the Spanish Div. 3NO survey would be added to the tuning indices input into the 2005 ADAPT model (current model in Table 1 and associated statistics) with the caveat that this data series be examined periodically to ensure it continues to show the same trends as the Canadian Div. 3LNO series (Dwyer *et al*. 2007b).

As part of the 2005 recommendation, it was also noted that 'varying natural mortality (M)' in conjunction with the above issues was still questionable. More research was recommended into the timing of a potential change in M, and the value of M. This was looked at with respect to changes in the formulation and analyses of the 2007 work. It was also noted that the conclusions from 2005 could change depending on outcome of work on M.

Note on Canadian RV Fall 2004 data

In 2007, Dwyer *et al.* (2007a) removed the Canadian RV Autumn 2004 survey value from the analytical assessment. Although shown to produce very little change in the outcome of the assessment, it was suggested that the age by age abundance of the missed strata from that survey be examined. Results by percent abundance at age can be seen in Table 2. About 6% (ranging from zero to 22%) of ages 5-14 (those ages used in the VPA) were found in the missing strata over the past 10 years when expressed as a percentage of abundance of Div. 3LNO by age. Although on average the percentage of age 5-14 found in the missing strata was low, for some years/ages it was 10% or more; these strata were especially important in 1999. The fall 2004 survey should not be included in the calibration of the VPA for 3LNO plaice.

Natural Mortality (M) in American Plaice

Natural mortality (M) estimates are difficult to obtain but are one of the most important values used in fisheries science. M is generally assumed to be 0.2 for most stocks but this does not take into consideration changes in life history over time, effects of fishing pressure or longevity of the species. For American plaice, M has been estimated at 0.13-0.26 (Pitt 1972).

It has long been suspected that there has been an increase in M for American plaice during the late 1980s and early 1990s. Although there has been little in the way of external corroboration of an increase in M, the Div. 2+3K American plaice stock declined by a similar percentage as the decline in Div. 3LNO American plaice during the early 1990s when there was a very low exploitation of that stock (Morgan *et al.* 2000; Bowering *et al.* 1997). There is also an increase in M suspected in 3Ps American plaice at that time (Bowering *et al.* 1996). In the early 1990s, water temperatures in Div. 3LNO were low for the longest continuous time since 1946 which might have led to increased mortality. Most importantly, estimates of total mortality from the Canadian RV spring survey indicate that for Div. 3LNO, M continued to be high even after the fishing moratorium was imposed in 1995.

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. Also it affects SR relationships, reference points and current perception of stock.

There are several methods for estimating M or changes in M (Vetter, 1988; DFO 2007/002):

- empirical methods based on longevity, growth and maturation characteristics (Beverton-Holt life history characteristics);
- analysis of survey data;
- analysis of tagging or telemetry data;
- estimation using population models.

In this paper, both analysis of survey data and estimation of parameters using population models such as ADAPT are used to estimate M and the period of high M. Though tagging data exists for American plaice from the early 1990s, returns were limited and the data have never been used to estimate M (Morgan 1996).

Analyses from Morgan and Brodie (2001)

Morgan and Brodie (2001) focused on analysis of survey data and estimation using population models in order to determine whether there was a change in M, the period of change in M and the value of M. They carried out their analyses based on the 1999 assessment which utilized the following information:

- Catch at age from 1975-1998 for ages 5-17;
- F at ages 15-17 set as average of average of ages 12-14
- Canadian RV spring survey (converted data + Campelen units) 1985-1998 Ages 5-14;
- M = 0.6 during 1989-1996.

In this section we address the analyses of Morgan and Brodie (2001) and update some of these analyses where possible, using the same input data and PR structure as in the 2007 assessment (Table 1)**.** The fall survey was added as a tuning index to the VPA formulation in 2001 (Morgan *et al.* 2001) and the Spanish Div. 3NO survey was added in 2007 (Dwyer *et al.* 2007a).

In computing the survey mortality for fall surveys, the mortality estimate for year y+1 refers to the survival of numbers at age a in year y to age a+1 in year y+1.

Total mortality (Z) from RV surveys

Morgan and Brodie (2001) looked at Zs by age for the Canadian Campelen-converted RV spring survey and concluded that Z was high even after moratorium. Estimates of Z were high from 1989-1996 but decreased substantially in 1997 and 1998. Morgan and Brodie (2001) concluded that Z should approximate M in absence of fishing in the first years of the moratorium.

For ages 8-10 in the Zs calculated from the spring surveys, Zs were high from 1989-1996 (Figure 1). This is not as clear for other ages; in some it seems Z for 1987-88 are as large as the values for 1994-96. However, for each age, the highest Z points of the time series fall within the 1989-1996 period. For fall, the high M period starts at the beginning of the series (1991) for most but not all of the ages; for some ages there appear to be 2 increases but the second increase is not as large and may be due to higher F in recent time period (Figure 2).

When survey Zs from the Canadian spring Engel are examined at age, there is an increase in Zs for most ages starting at about 1988 (Figure 3) but for some ages, the increase is continuous from the beginning of the time series and therefore it is difficult to say when it actually began. Certainly it was high from the last 5-7 years of the time series. The Engel series ends in 1995 and so cannot be used to infer M during the period of the moratorium.

Plots of age-aggregated average annual Zs (Figure 4) and proportion of fish dying indicate that Canadian spring and fall RV Zs show the same pattern, a high total mortality increasing in the period from 1989-1996 and afterwards decreasing again. For fall, this is 1991-1996. The Engel age-aggregated average annual Zs show an increase around 1988-89 (Figure 5).

Morgan and Brodie (2001) also compared trends in fishing mortality (F) from the VPA with R from surveys (where R is relative fishing mortality (R) = commercial catch/survey at age provided survey is conducted mid year) in order to determine whether there was an increase in M during the 1989-1996 period. Sinclair (1998) showed that there would be differences in between the two if M increased. When F and R are compared using ages 5-14 (and also ages 7-13) there is an increasing trend in F followed by a decline and no trend in R; this departure can be seen in 1989 and continues until 1995.

Another piece of evidence which indicated an increase in M is the pattern of residuals in the VPA when a constant M = 0.2 is used for all ages throughout the time series. If there is an increase in M, the residuals should increase and then decrease at that time (Sinclair 1998). This can be seen in VPA outputs from the ADAPT runs using 2007 data, in both spring and fall Canadian RV survey residuals. The spring residuals are positive from about 1988 to 1993 (except for 1991 point) and then are all negative from 1994-1996. After this period they show less of a pattern. For fall residuals, all residuals are positive from 1990 until 1995, after which the 1996 residual is very negative. Table 6 shows the statistics from an ADAPT analysis with constant M (0.2) throughout the time series.

Morgan and Brodie then (2001) attempted to determine the value of M during the period of increase. In the 1999 assessment, M was assigned a value of 0.6 which was the average Z from spring surveys for 1995 and 1996 (ages 5-10). They proposed that Z would equal M after the imposition of the moratorium. The average Z calculated from spring surveys (1995-6 and 1996-7) is 0.68 and for fall surveys (1994-5 and 1995-6) is 1.46 (see values below in Figure 4 and 5). It should be noted that the fall survey was not included in the final assessment run at this time, presumably due to a poor fit resulting from a short time series.

Another way of estimating Z in order to approximate M in absence of fishing mortality is to use a multiplicative model that examines 4-year blocks of time and estimates a separate intercept for each cohort but a common slope across age (Z) (Sinclair 1999). This produces an estimate that takes into account variability in year class strength. This analysis was carried out for spring and fall surveys (both Engel and Campelen units) aged 7-13 (most represented in the fishery). Z was higher than -1.0 from the four year block of 1989 to the four year block of 1994. It increased from the 1987 four-year block to the 1992 four year block.

The 4 year block from 1995-1998 in spring was during the moratorium on fishing and Z = 0.53 and for fall (4 year block 1994-1997) was 1.09. Both spring and fall show the same patterns (Figure 8) but, as with the Zs estimated above, there does appear to be a 1-year time lag for fall when the actual time frame estimated is taken into account (see comment above on how fall mortality is computed).

ADAPT model runs

Finally, Morgan and Brodie (2001) used ADAPT to attempt to estimate the value of M within the 1989-1996 time period. Population models, such as ADAPT, can treat M as a parameter to be estimated for years, ages, or cohorts, the number of additional estimable parameters depending on the degrees of freedom (DFO 2007/002). Morgan and Brodie (2001) ran a number of ADAPTs in order to determine a reasonable estimation of M during the proposed period of increase.

The authors ran 4 ADAPTs to obtain an estimate of M:
1) estimating a common value of M across all ages from 1989-1996;
2) estimating M across 1981-88 cohorts (main cohorts occurring in this period);

3) estimating M for 1989-1996 for ages 5-10 and 11-17 separately (to examine the possibility that M different on older and younger ages); and
4) estimating M for all ages, 1989 to 1992 and 1993 to 1996 separately.

See Table 3 below for M estimates.

All of the ADAPT runs done from Morgan and Brodie (2001) were repeated in this paper using the VPA formulation from the current assessment and all available data (Table 1 and Dwyer *et al.* 2007a for formulation and Table 4 for output). For the converted time series runs, it is noted that estimates of M by ADAPT are lower in all cases than those estimated from Morgan and Brodie (2001), most likely due to the fact that the data used in the 1999 assessment had less information (only the Canadian spring RV survey was used) about unfinished cohorts, whereas the most recent assessment has more information on the cohorts affected by the increase in M and as the cohorts are finished. Also there are more tuning indices used in the current runs.

Morgan and Brodie (2001) also found that the estimation of M by ADAPT was sensitive to length of time series. Morgan and Brodie (2001) estimated M during 1989-1996 using:

1) Converted time series 1985-1998;
2) Engel 85-95/Campelen 96-98;
3) Engel 75-95 and Campelen 96-98;
4) Campelen converted 85-98 and 'Campelen converted' ATC 75-82 (conversion done by taking ratio of unconverted/converted series in 85-95 period).

The output from these runs produced by Morgan and Brodie (2001) are shown in Table 3. The first 2 runs (which have 1985 as the first year of survey data) have higher estimates of M (0.72 and 0.68) than last 2 runs (0.51 to 0.55). It is suggested that because the shorter time series is so close to the period when M is estimated, there is no historical portion of the time series to 'anchor' the estimates. The survey data prior to 1985 provide information on several cohorts which are in the population during 1989-1996 when M is being estimated. Morgan and Brodie (2001) suggested taking an average of the two longer runs (0.53) and this was used as their estimate of M. Though estimates of M from their analyses ranged from 0.5 – 1.5, they felt results using M>0.6 produced trajectories of the population which were very different than the trajectory of the survey.

Some of the runs with differing time periods in this paper were attempted with the current VPA formulation (Table 5) for comparison. The 'Campelen converted' run was not attempted as the conversion from Yankee to Campelen is not real and conclusions from this run would be limited. ADAPT analyses were conducted using:

1) converted Campelen data from 1985-2005 (spring), fall data (1990-2006) and Spanish Div. 3NO survey (1998-2006) - ages 5-14;
2) nonconverted Engel data 1985-1995 (spring), Campelen data 1996-2005 (spring), nonconverted Engel data 1990-1994 (fall), Campelen data 1995-2006 (fall; no 2004) and Spanish Div. 3NO (1998-2006) – ages 5-14; and
3) Yankee converted to Engel data 1973-1984 (no 1974 or 1983) plus the datasets in #2 – ages 5-14.

The first year of survey data in both Run 1 and 2 is 1985, whereas Run 3 includes survey data back to 1973. Both Run 1 and 2 as well as Run 3 gave comparable estimates of M to those obtained by Morgan and Brodie (2001).

When Run 2 is carried out (using nonconverted data back to 1985), M is estimated by ADAPT for the 1989-1996 period to be 0.7 which is much higher than estimated when converted data is used (Table 5). This is likely due to the difference in catchabilities (*q*s) when data is converted.

An ADAPT run attempting to use only the Campelen time series for Canadian spring and fall RV surveys (plus Spanish Div. 3NO survey) did not allow an estimation of M during the 1989-1996 time period.

Further Analyses

Because there were differences in whether converted versus nonconverted data (Engel and Campelen split) was used it was decided that this should be explored further. Therefore several ADAPTs were run with a range of M values (from M = 0.2 to M = 0.9 during the 1989-1996 period) for both converted and nonconverted data (Table 6):

1) Run A (Converted time series): Canadian Spring RV 1985-2005; Fall RV 1990-2006 plus Spanish Div. 3NO 1998-2006 (ages 5-14);
2) Run B (Non-converted time series): Canadian Spring Engel 1985-1995; Spring Campelen 1996-2005; Fall Campelen-converted data 1990-2005 (no 2004 value); plus Spanish Div. 3NO 1998-2006 (ages 5-14).

These runs are the same as those used to determine the effect of length of time series on the estimate of M during the 1989-1996 period, except Campelen-converted fall data was used in these runs as it was initially thought that splitting the data into Engel and Campelen might not be useful, considering the fall Engel time series had only 5 years. However there are some runs presented later that split both spring and fall into Engel and Campelen units.

Firstly, the mean squared error (MSE) from the nonconverted data runs (Run B) is lower overall than the converted data runs. Considering several analysis with fixed M starting with M=0.2 in the converted runs (Run A, Table 6), the MSE value decreases until M = 0.45, and begins to increase again when M >0.6. For the converted data, the fit (examining residuals and observed/predicted values) for the fall series increases as M increases but the fit for the spring series decreases as M increases. MSR on ages decreases as M decreases. Although as M increases the 'bad residual pattern' around the 1989-1996 period in the spring series decreases, the magnitude of the residuals at the beginning of the time series 1985-1988 (residuals are all negative) increases (Figure 9). The residuals from the Spanish Div. 3NO survey are worse from the M = 0.2 runs and the higher M runs than the M = 0.33-M=0.53 runs.

For the nonconverted data (using fall converted data for these runs, Run B), MSE value decreases until M = 0.6 but then increases after M >0.7 (Run B, Table 6). In general, as the value for M increases, both the fit of the fall and spring series improved. In fact, in the run with M = 0.7 the pattern in the early spring Engel series almost entirely disappeared (residuals in Figure 10).

For both the Runs A and B, as M increases so do the population numbers and SSB during the period from 1980 to 1996. When using the converted series, there are larger differences in the recent period with M = 0.2 which is likely due to survey qs (larger for some ages in converted but smaller for others). The population abundance, SSB and F estimated from the ADAPT runs using the converted time series and nonconverted time series looked similar (Figures 11 and 12). Within each, as M increases the model estimates higher population numbers and SSB and lower F (Figures 11 and 12). When M=0.2 is assigned throughout all years, the population decline is continual after 1978, but with all other estimates there is a plateau from 1980 to 1985, a small decline and then a rapid decline after 1989. When the nonconverted time series is used there is virtually no difference in population estimates in the recent period (Figure 12). As M increases the population estimates, SSB and biomass all increase during the 1980-1995 time period, and F decreases as M increases. Morgan and Brodie (2001) did not feel the trajectory for ADAPT output runs reflected how they perceived the stock based on survey indices (Figure 12). However, when 5+ abundance from the VPA output is compared with abundance (ages 5-14) from the surveys standardized by each series' mean (Figure 13), there are similarities with the output from even the high M runs.

Two runs using split spring (Campelen and Engel) and split fall (Campelen and Engel) along with Spanish Div. 3NO survey data using M = 0.6 and M = 0.7 show MSE values of 0.24. The run using M = 0.7 again showed a marked decrease in the residual pattern at the beginning of the time series for the spring Engel data.

Summary on M

There was a period of high total mortality (Z) in the late 80s and early 90s for American plaice in Divs. 3LNO. This is assumed to be due to an increase in natural mortality (M) as fishing mortality cannot explain the high Z values, especially after the fishing moratorium in 1995 and 1996. The questions surrounding M are compounded by the fact that around the same time, there may have been misreporting of catches and as well, there was an increase in survey coverage.

With regards to survey coverage, there was an expansion of the Canadian RV survey depths in 1991 to 366 m which confounds the issue of M. It is possible that fish surveyed after 1991 in these deeper strata were present but not surveyed prior to the survey change which would be problematic, but we would suggest this is not the case. It has been suggested that American plaice in Div. 2+3K began to shift their distribution into deeper water around the same time as there was an extreme cold period over the Grand Banks (Colbourne *et al.*, 1997; Morgan *et al.*, 2002). It is not unlikely the same happened to Div. 3LNO American plaice. Also, few American plaice were found in these survey depths in 1991, and only began appearing there in 1992, reaching a maximum in 1995 (especially in Div. 3L) and after 1996 (the first year the Campelen gear was used) this decreased again; since 2003, there have been few American plaice in these deeper strata (from Tables in Dwyer *et al.*, 2007a). Also, in 1985 there were sets deeper than 366 m but not a large percentage of biomass found there. The biggest percentage of biomass in the deeper strata is in Div. 3L, and as a percentage of the entire stock, this number is fairly low. In addition, in terms of the VPA, the issue is whether or not there is an impact of extending the survey on abundance at age. This does not appear to be true and there is no evidence of a systematic shift in age composition with the extension of the survey to deeper water. This will be examined further, however, to determine whether this data should be treated differently within the VPA.

Though the value of M in the proposed time period is high, increasing M in the analyses merely makes an adjustment for unaccounted deaths in the population, whatever the cause, or could account for changes in catchability. Similar methods were examined for the Gulf of St. Lawrence cod stocks (DFO 2007/002) when the issue of increasing the value of M was addressed but cautioned that the use of ADAPT to estimate M can be confounded by changes in survey catchability and catch reporting as well as sensitivities to assumptions and constraints applied in the ADAPT estimation procedure.

For American plaice, though no model is a clear ‘winner’, there is sufficient evidence to suggest that setting the value of M higher than 0.2 during the 1989-1996 period is justified. Based on the findings of Morgan and Brodie (2001), some updates to those analyses, and additional ADAPT runs, we agree with the findings that M increased substantially around 1989-1990 and decreased again after 1996 (Table 7). In fact, the vast majority of the estimates of M from survey Zs and from ADAPT estimates indicate that M is higher than the value (0.53) used in the current assessment (Table 8). The most appropriate value of M depends on whether converted or nonconverted data is used and these are in general agreement with estimates from survey Zs. When ADAPT estimates M for the 1989-1996 time period for the converted data, the estimate of M is 0.56 (MSE = 0.28) and when estimated for nonconverted data M = 0.70 (MSE=0.24). These values give the best model fit. In addition, the residuals from the early part of the spring series, although improved for the 1989-1996 period when M >0.2, do not improve when M is increased for the converted data but improve substantially when M = 0.7 using nonconverted data. Thus we recommend, for several other reasons (time period is now long enough for each series, possible imprecision with conversions, more consistent survey coverage within each time series if separated), that Canadian spring RV Engel (1985-1995) and Campelen (1996-2007) data are treated as independent data series in tuning the VPA. Using this structure, the value of M = 0.7 gives the best fit to the model.

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Table 1. Current 2007 formulation using ADAPT for Div. 3LNO American plaice.

Stock	Catch at age	Tuning Indices	M values	Other
American Plaice Div. 3LNO	1960-2006 Ages 5-15 (15 a plus group)	Converted Canadian RV spring survey – Ages 5-14 for 1985-2005 Converted Fall RV survey – Ages 5-14 for 1990-2006 (no 2004) Spanish Div. 3NO (NRA) spring survey – Ages 5-14 for 1998-2006	M = 0.2 for all years except M = 0.53 for 1989-1996	F on plus group equal to F of last true age (Fratio = 1.0) All tuning indices equally weighted Proportional model used for catchability

Statistics	MSE	Rel Error Pop Ests	Rel Error *q*s
Final 2007 run (M = 0.53 1989-1996)	0.28	0.21-0.39	<0.22

Table 2.

Percent of abundance index of American Plaice in Div. 3LNO observed in strata that were not surveyed during 2004 fall for ages 5-14.

Age	1997	1998	1999	2000	2001	2002	2003		2005	2006		Average
5	8	11	22	3	6	4	4		7	9		8
6	11	12	21	6	7	5	4		6	10		9
7	11	8	20	6	8	6	5		5	12		9
8	11	5	14	4	9	8	6		5	10		8
9	10	3	10	3	8	9	9		5	9		7
10	9	2	6	2	6	7	9		5	8		6
11	8	2	5	1	3	5	8		4	7		5
12	6	1	2	0	1	2	5		4	7		3
13	2	0	1	0	1	1	4		4	6		2
14	1	0	1	0	0	0	1		3	5		1

Table 3. Estimates of M from ADAPT runs by Morgan and Brodie (2001).

ADAPT runs (Morgan and Brodie (2001))	Estimate of M	
Est M across all ages 1989-1996	0.72	
Est M across 1981-1988 cohorts	0.53	
Est M for ages 5-10 and 11-17 during 1989-1996	0.78	0.68
Est M all ages 1989-1992, 1993-1996 separately	0.62	0.80

Table 4. ADAPT runs re-run from Morgan and Brodie (2001) using the 2007 formulation (except where noted) for American plaice Div. 3LNO

Description of run	MSE	Relative error on population numbers	Relative errors on qs	Estimate of M (plus relative error)	
Allowing ADAPT to estimate M across all ages from 1989-1996	0.28	0.19-.039	<0.19	0.56 (0.06)	
Allowing ADAPT to estimate M for 1981-1988 cohorts	0.32	0.20-0.42	<0.2	0.29 (0.15)	
Allowing ADAPT to estimate M for ages 5-10 and 11-15 separately for 1989-1996	0.27	0.19-0.39	<0.19	0.64 (0.07)	0.44 (0.15)
Allowing ADAPT to estimate M across all ages for 1989-1992 and 1993-1996 separately	0.26	0.19-0.39	<0.19	0.41 (0.13)	0.68 (0.06)

Table 5. Effect of length of time series on estimates of M (for 1989-1996) from current (2007) ADAPT formulation for American plaice Div. 3LNO. ADAPT was allowed to estimate M over the 1989-1996 time period.

Description of run	Length of time series	MSE	Relative error on population numbers	Relative errors on qs	Estimate of M (plus relative error)
Converted time series as in final 2007 run (see above)	1985+	0.28	0.19-.039	<0.19	0.56 (0.06)
Nonconverted time series: -Can. RV spring Engel 1985-1995 -spring Campelen 1996-2005 - Can RV fall Engel 1990-1994 - fall Campelen 1995-2006 (no 2004) - Spanish Div. 3NO 1998-2006	1985+	0.23	0.18-0.37	<0.28	0.70 (0.09)
Nonconverted series plus ATC series: - ATC 1973-1984 converted data plus above series - Spanish Div. 3NO 1998-2006	1973+	0.23	0.18-0.36	<0.27	0.66 (0.10)

Table 6. Runs with converted (Run A) and non-converted (Run B) data and output from a range of set M values during 1989-1996, see text for details.

	Run A			***Run B***		
	MSE	**Rel err Pop**	**Rel err Qs**	**MSE**	**Rel err Pop**	**Rel Err Qs**
M = 0.2	**0.33**	**0.21-0.43**	**<0.22**	**0.32**	**0.20-0.42**	**<0.2**
M = 0.33	**0.3**	**0.2-0.41**	**<0.2**	**0.28**	**0.19-0.40**	**<0.19**
M = 0.45	**0.28**	**0.19-0.4**	**<0.19**	**0.26**	**0.18-0.38**	**<0.19**
M = 0.53	**0.28**	**0.21-0.39**	**<0.22**	**0.25**	**0.18-0.37**	**<0.18**
M = 0.6	**0.28**	**0.19-0.39**	**<0.19**	**0.24**	**0.18-0.37**	**<0.18**
M = 0.7	**0.29**	**0.19-0.4**	**<0.2**	**0.24**	**0.17-0.36**	**<0.18**
M = 0.8	**-**	**-**	**-**	**0.24**	**0.18-0.37**	**<0.18**
M = 0.9	**-**	**-**	**-**	**0.25**	**0.18-0.38**	**<0.19**

Table 7. Summary of evidence leading towards an increase in M over 1989-1996.

	Survey Z			Sinclair R	Residuals		Sinclair Z (4-year block)	
	Spring	Fall	Engel	Spring	Spring	Fall	Spring	Fall
Estimate of period of increased M	1990-1996	1991-1996	↑	1989-1994	1989-1996	1990-1995(6)		
Estimate of M	0.68	1.46					0.55	1.09

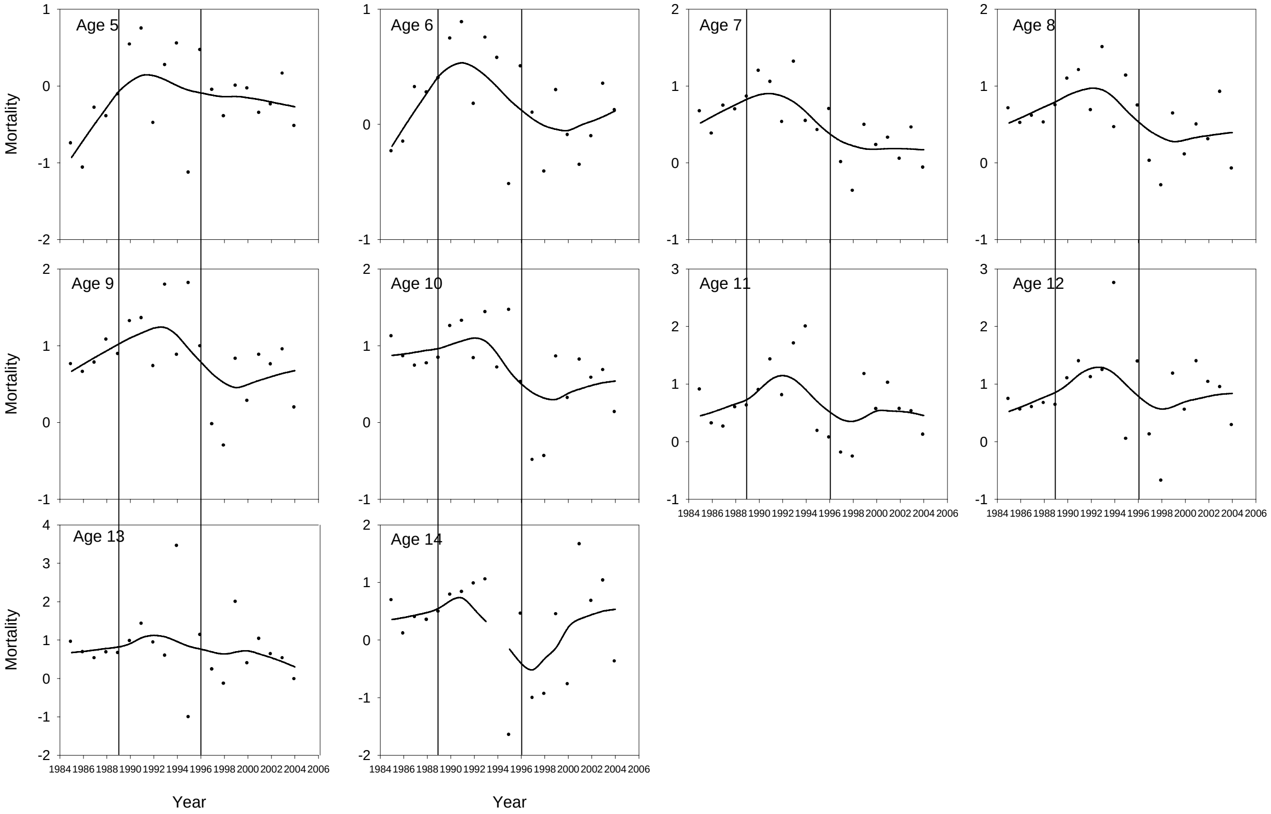

Figure 1. Survey Zs for Canadian converted spring RV series with loess smoother. Vertical lines indicate period of proposed mortality change (1989-1996).

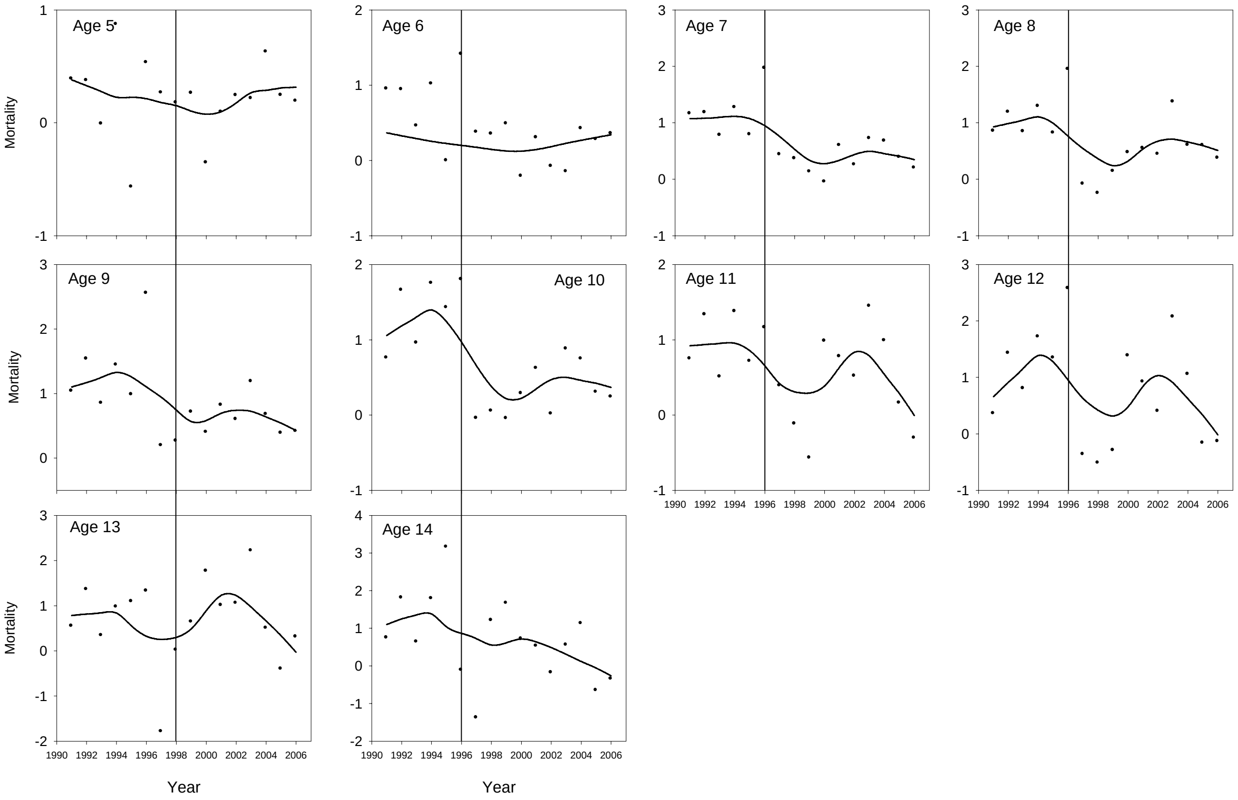

Figure 2. Survey Zs for Canadian converted fall RV series. Line indicates end of proposed mortality change (1996).

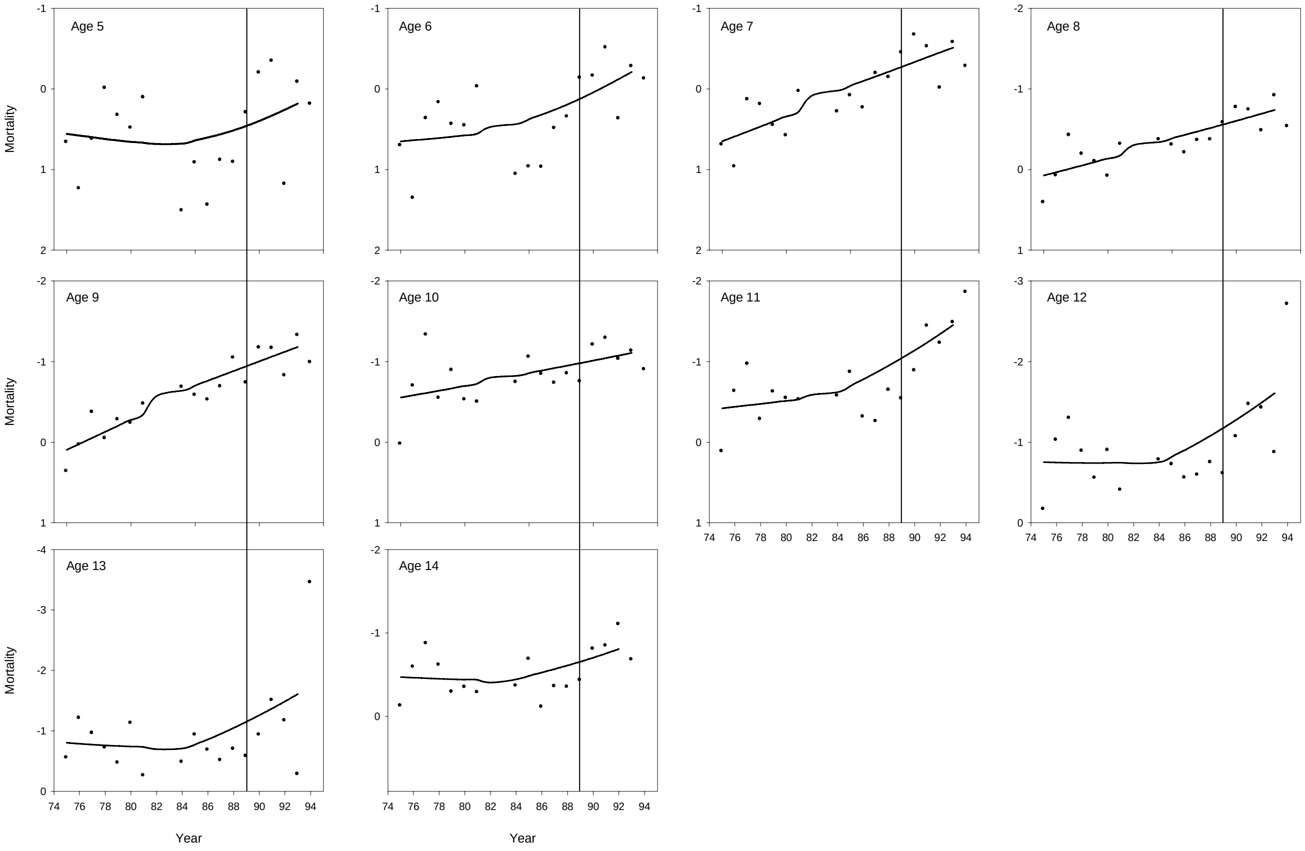

Figure 3. Survey Zs for Engel series. Line indicates start of proposed mortality change (1989).

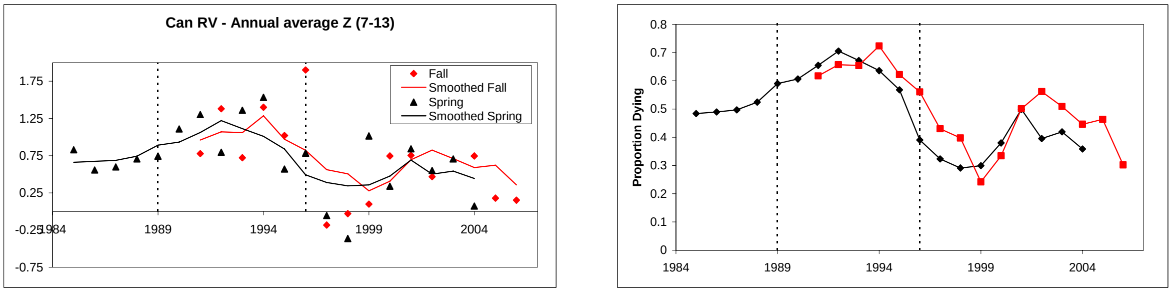

Figure 4. Annual average survey Zs by year for spring and fall, and plot of proportion dying over time.

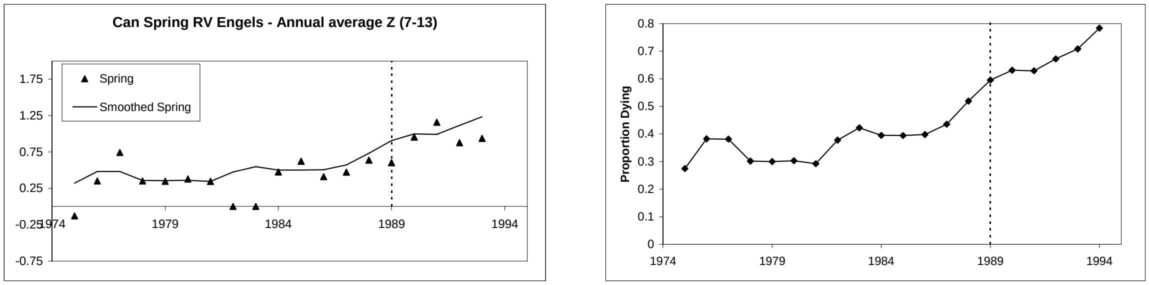

Figure 5. Annual average survey Zs for spring Engel series, and plot of proportion dying over time.

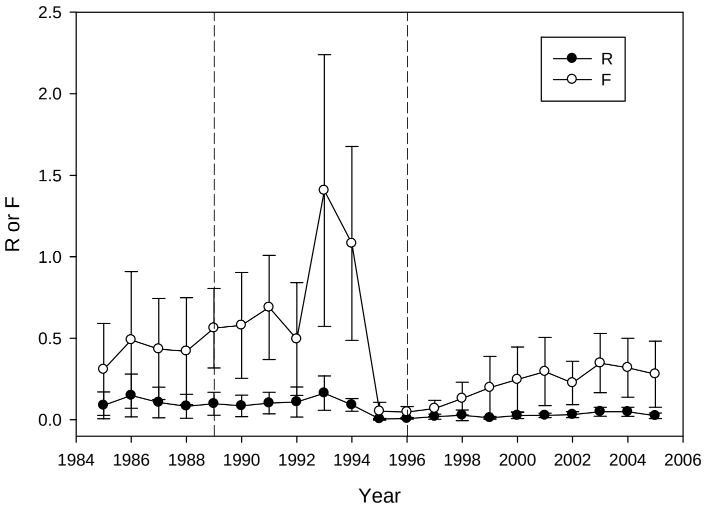

Figure 6. Discrepancy between Sinclair R (commercial catch at mid-year/survey) and fishing mortality from run with M = 0.2. Dashed line is period of presumed increase in mortality. All ages (5-14). Pattern same as ages 7-13.

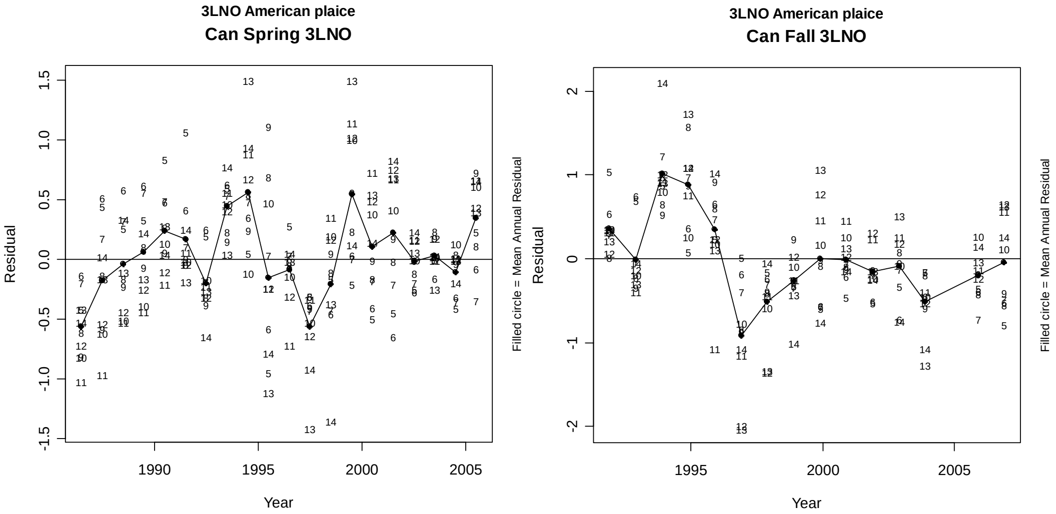

Figure 7. Residuals from VPA output where M=0.2 throughout. Plot on left indicates Canadian spring RV survey and plot on right indicates Canadian fall RV survey (converted data).

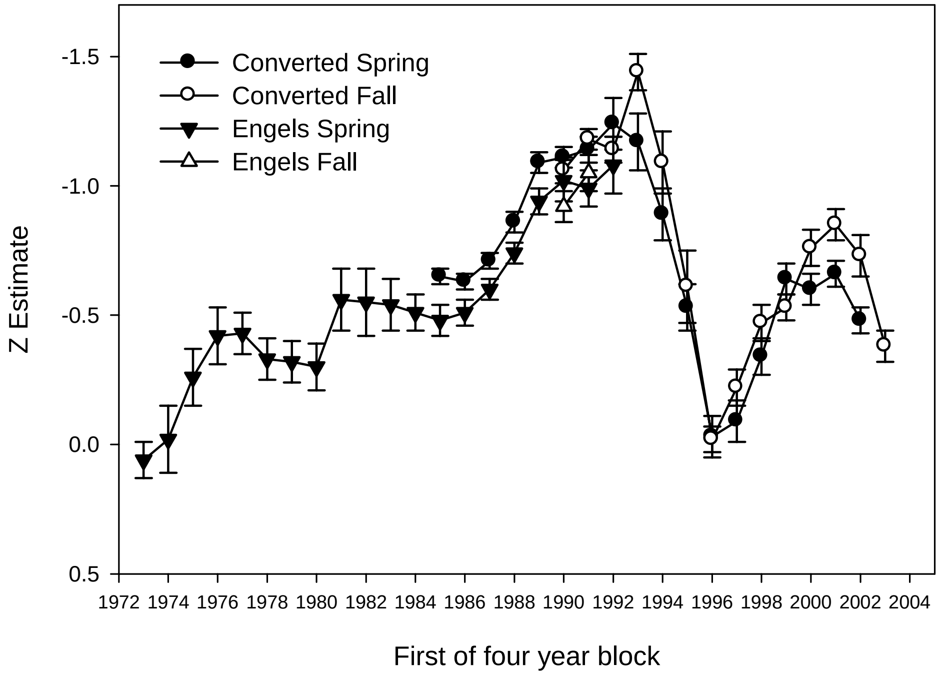

Figure 8. Similar trend as from survey Zs above (as expected). On ages 7-13. Z would = M in absence of fishing 1995-1996.

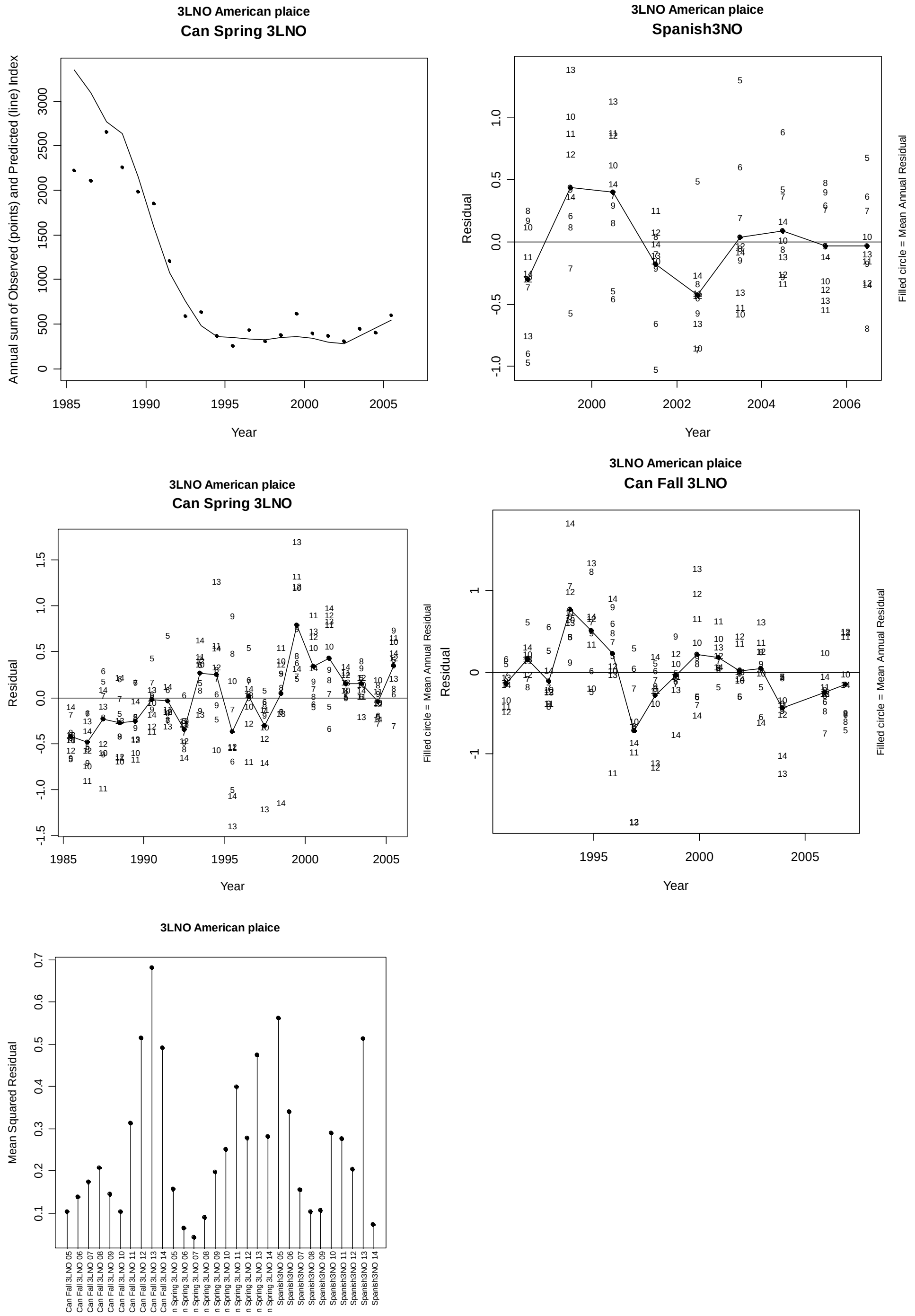

Figure 9. Sum of observed versus predicted index for converted data run M = 0.53 (2007 assessment, see text), residuals by survey and mean squared residuals by age by survey.

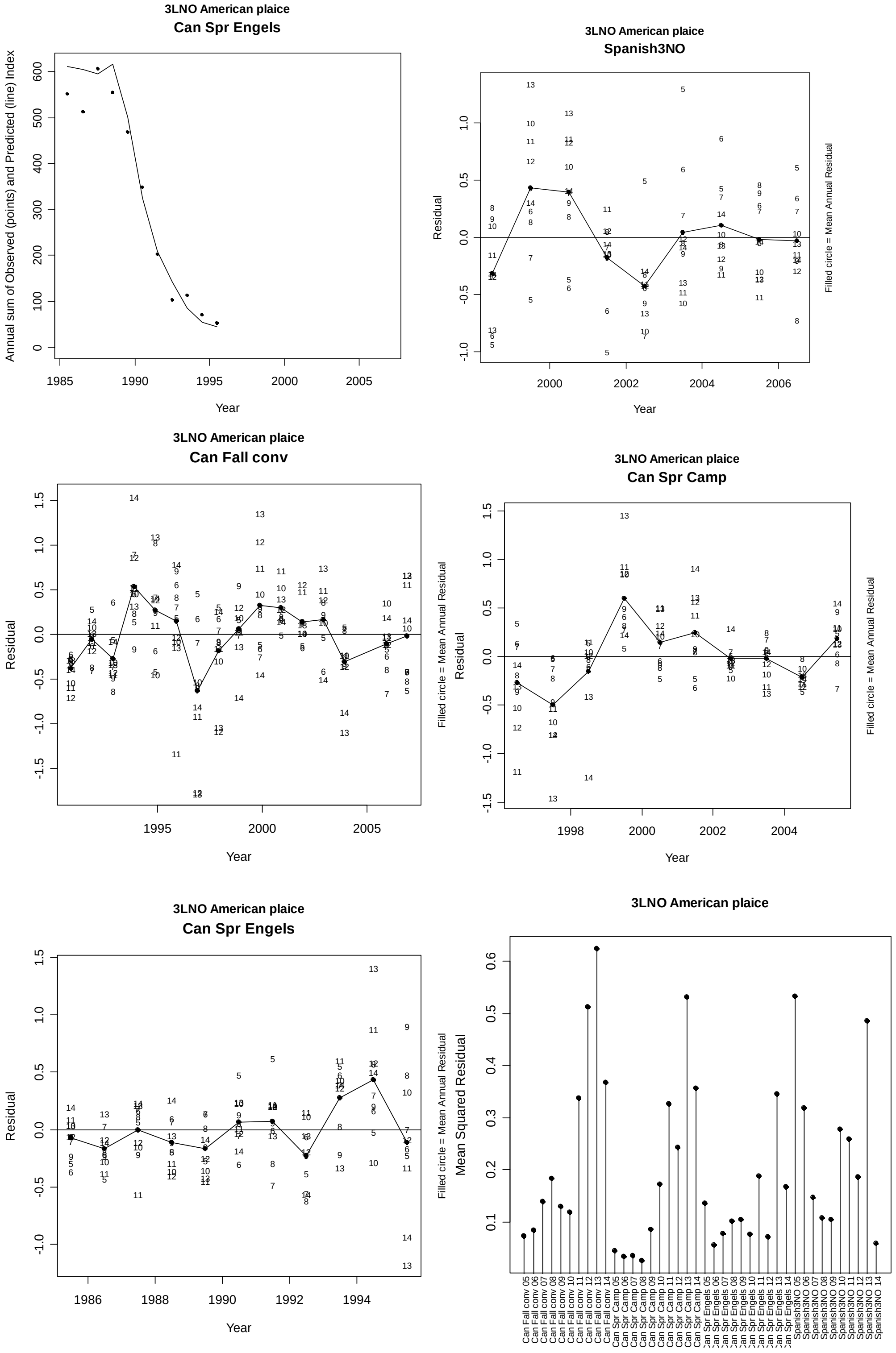

Figure 10. Sum of observed versus predicted index for nonconverted data run M = 0.7, residuals by survey and mean squared residuals by age by survey.

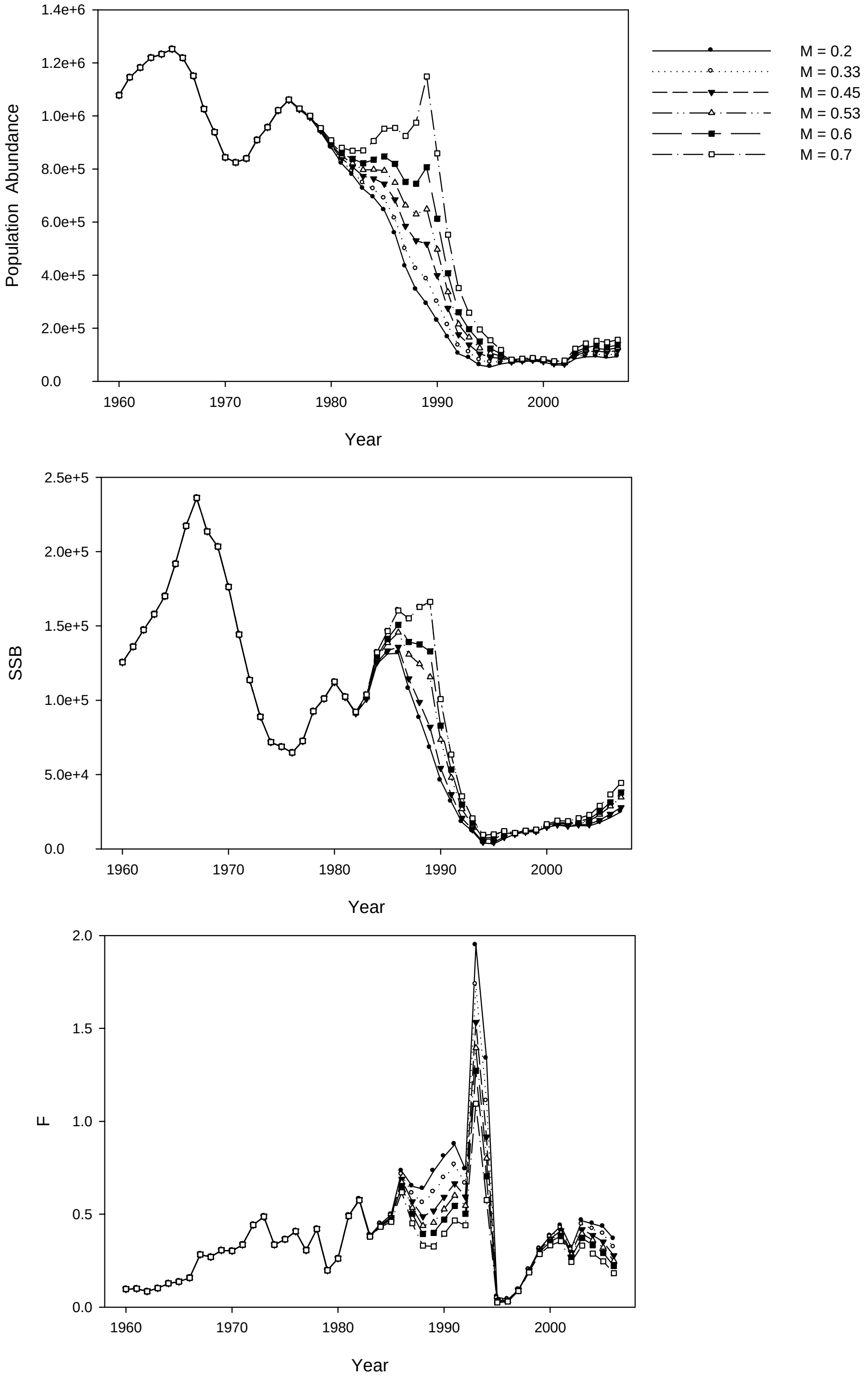

Figure 11. Population abundance (5+), spawning stock biomass, and fishing mortality (F) from ADAPT output using converted time series and varying the natural mortality during 1989-1996.

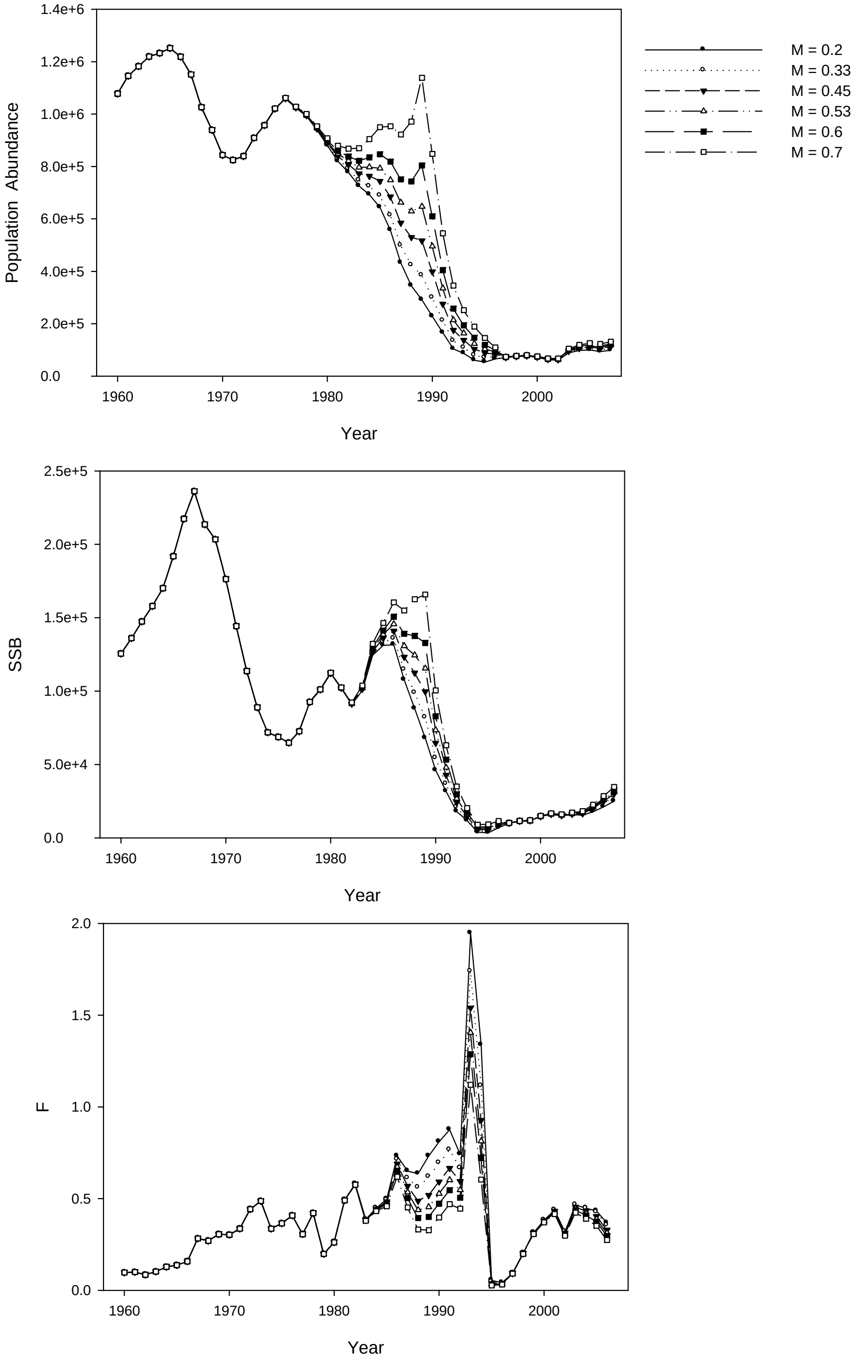

Figure 12. Population abundance (5+), spawning stock biomass, and fishing mortality (F) from ADAPT output using non-converted spring time series and converted fall time series and varying the natural mortality during 1989-1996.

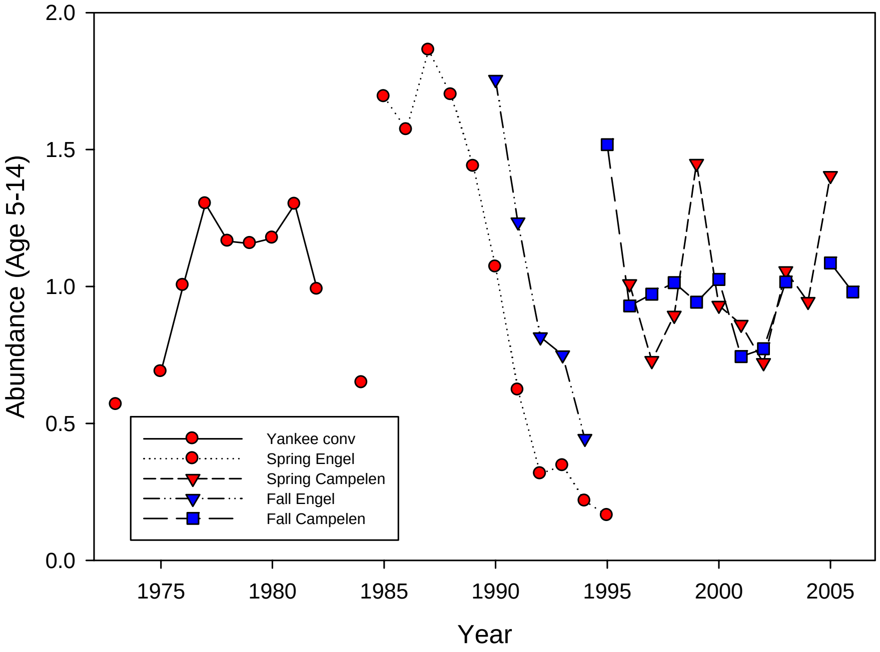

Figure 13. Abundance for ages 5-14 from surveys, standardized by the mean of each series.