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A Review of the Assessments of the American Plaice (*Hippoglossoides platessoides*) Stock in Divisions 3LNO in Relation to the Recent Decline in Stock Abundance

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Abstract

The American plaice stock in NAFO Div. 3LNO declined in the mid-1980s, with recent TACs about half of the long-term average. Both indices of abundance used to calibrate the sequential population analysis, i.e. research vessel survey data and catch-per-unit-effect from the commercial fleet, have shown this decline, but show important differences in the timing and magnitude of the decrease. The assessments of the stock showed that fishing mortality in the terminal year was estimated to be lower than in subsequent assessments. This discrepancy was largest for the assessments in which survey data were excluded from the calculations.

Introduction

American plaice (*Hippoglossoides platessoides*) is a flatfish which occurs on both the eastern and western sides of the North Atlantic. The largest commercial fishery for the species occurs on the Grand Bank, NAFO Div. 3LNO (Fig. 1). This fishery developed in the late-1940s, and was essentially Canadian until the mid-1960s (Pitt, MS 1971). Other countries then entered the fishery and catches peaked at 94,000 tons in 1967 (Brodie *et al.*, MS 1990). Total catches subsequently stabilized at around 50,000 tons, although there was an increase in the mid-1980s as non-Canadian fishing effort increased, mainly in the Tail of the Bank area, before declining in 1988 and 1989 (Fig. 2).

This stock has been regulated by a total allowable catch (TAC) since 1973, and up to 1987, the TACs ranged from 47,000 to 60,000 tons. The TAC was set at 33,585 tons in 1988, lowered to 30,300 tons in 1989 and 24,900 tons in 1990 (Fig. 3). Catches have exceeded the TAC a number of times, with the largest overruns occurring in 1985-87 (Fig. 3). This paper examines the assessment history of the American plaice stock in Div. 3LNO, focusing on the decline in abundance in the mid- to late-1980s. It examines the indices of abundance derived for the stock and the way in which they were interpreted in the annual assessment of stock status, conducted by ICNAF and then NAFO.

Assessment History

The first published assessment of the stock in Div. 3LNO was by Pitt (MS 1971) during ICNAF times. That and most other assessments in the early-1970s used virtual population analysis (VPA) as the main tool, although Pitt (1973) also used a Schaefer model to assess the stock. VPA was the model used throughout the 1970s, giving way to other sequential population analysis (SPA) models as they evolved, e.g. Pope's cohort analysis (Pope, 1972) and most recently the adaptive framework (Gavaris, MS 1988).

Pitt (MS 1975) advocated that the assessment of the stock be done separately by division, and in fact separate VPAs were used from 1971 to 1976 on the data for Div. 3L and 3N. However, ICNAF (1975) noted that this management approach would cause many practical difficulties, and continued to provide advice for Div. 3LNO combined. From 1977 to 1988, data for Div. 3LN were combined to form the basis of the assessments. Data for Div. 30 were excluded from the VPA models during this period, mainly because of the shortness of the catch-at-age time series compared to Div. 3LN (Pitt, MS 1979). However, Brodie and Bowering (MS 1989) recalculated much of the catch-at-age for Div. 30 back to 1974 allowing data for Div. 3LNO combined to be used in the stock assessment. Another change in the treatment of the catch-at-age data for this stock occurred in 1980 when the data for both sexes were combined before being used in SPA (Pitt and Brodie, MS 1980). Prior to this, the analyses were conducted on each sex separately.

Catch-at-age data for this stock exist from 1956 onward, but the data for the earlier years were usually based on fewer samples. For Div. 3LN, the data for 1965 onward have been used in most assessments, while

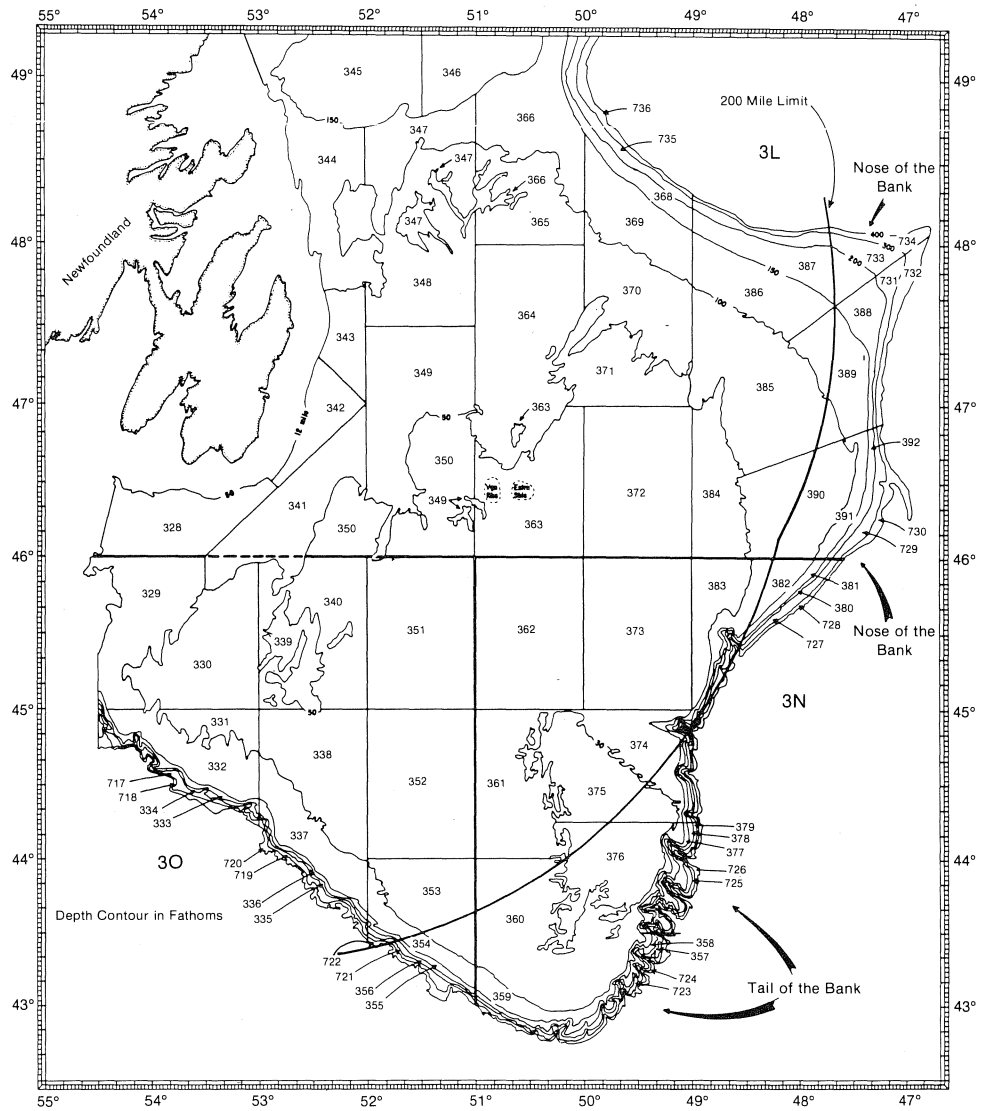

Fig. 1. The Grand Bank, Div. 3LNO, showing the Canadian 200-mile boundary and the depth stratification scheme (fath) used in Canadian research vessel surveys.

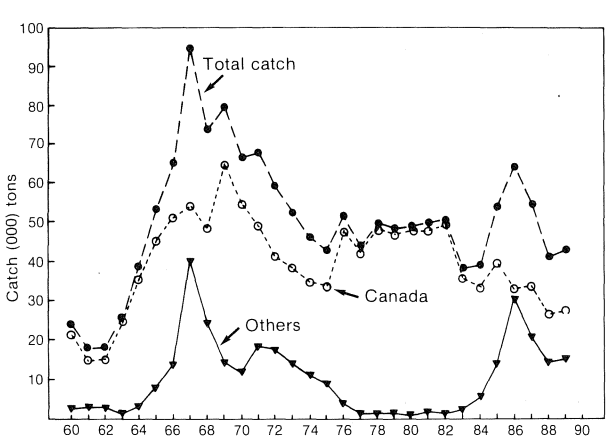

Fig. 2. Catches of American plaice in Div. 3LNO from 1960 to 1989 by Canada and other countries.

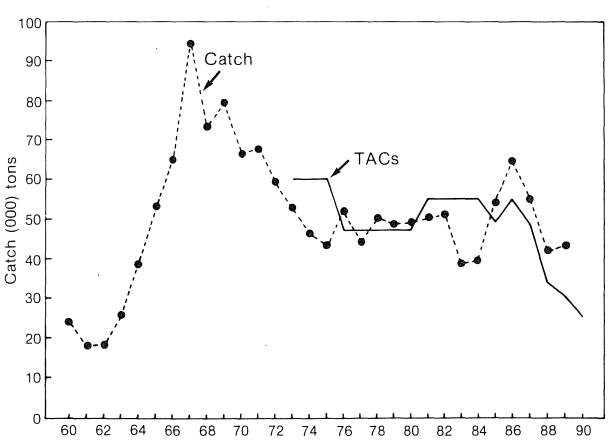

Fig. 3. Catches (1960–89) and TACs (1973–90) of American plaice in Div. 3LNO.

Div. 30 data extends back only to 1974, as noted previously.

Independent indices of abundance

The data used to calibrate the sequential population analyses performed on this stock have come from two sources:

i) **The Newfoundland-based offshore trawler fleet**: Logbooks maintained by this fleet from the 1950s onward have provided catch-per-unit-effort (CPUE) information from the commercial fishery (Pitt, 1973). Up until the mid-1960s, this fleet consisted of side-trawlers, after which time larger stern-trawlers became prominent. In 1989, the fleet contained only a few remaining side trawlers with the vast majority of vessels being stern trawlers (Brodie *et al.*, MS 1990). To standardize the CPUE from the two different vessel classes, Pitt (1973) used a conversion factor of 0.8 applied to the less efficient side trawler effort. This approach was continued until Brodie (MS 1987) used a multiplicative model (Gavaris, 1980) to standardize the catch rates for vessel class, division, month and year.

In some early assessments, both the CPUE from operations where the total catch was American plaice and where operations were directed at American plaice or where American plaice was the main species in the catch, were used as indices of abundance, but only the latter series has been used since 1980. Figure 4 shows the CPUE series in Div. 3LNO, as calculated in the most recent assessment (Brodie *et al.*, MS 1990). An important feature in this series, in relation to the recent stock decline, is the trend in the catch rates from the mid-1980s to the present. With the use of the multiplicative model (1987 onward), the addition of the data for Div. 30 (1989 onward) and most importantly the correction (in 1989) of errors in the effort data from 1984 to 1987, a different perception of the CPUE in the mid-1980s was obtained. Figure 5 shows the CPUE series from 1982 to 1986, as calculated in the 1987 and 1990 assessments, indicating the differences which are mainly in the values for 1984 and 1985. It should be noted that the 1985 and 1986 assessments also used the same data and calculations that were used in 1987.

In the 1990 assessment of the stock, CPUE at age for the Canadian fishery in Div. 3LNO was derived. These data showed that the recent decline in CPUE is more evident at the older ages (Brodie *et al.*, MS 1990).

ii) **Canadian research vessel surveys**: Research vessel surveys have been conducted on the Grand Bank by Canadian ships since at least the early-1940s, with regular line transect surveys beginning in the 1950s (Pitt *et al.*, 1981). However, it was not until after stratified-random surveys were implemented in 1971 (Grosslein and Pinhorn, MS 1971) that survey data became an important part of the stock assessments for American plaice in Div. 3LNO. From 1971 to 1982, the surveys were carried out in the spring of each year onboard the research vessel *A. T. Cameron*, a side trawler equipped with a Yankee 41.5 otter trawl. There was no comparable survey in 1983 and the surveys from 1984 to 1990 were done with the research vessels *W. Templeman* and *A. Needler*, sister stern trawlers which used Engels 145 otter trawls. Gavaris and Brodie (MS 1984) calculated conversion factors to allow comparison of catch numbers from both vessel-gear combinations. To derive an index of abundance which would be comparable in terms of strata covered, a series of selected strata, fished in most years, was chosen (Brodie, MS 1985). This was later replaced (Brodie, MS 1988a) by a series derived from a multiplicative model, which estimated values for strata not fished in each year. This analysis showed, with the exception of Div. 3L in 1984, that most of the estimated values were for surveys prior to 1982, with few strata being omitted in most surveys after 1982.

The population numbers as derived from the surveys in Div. 3LNO (Brodie *et al.*, MS 1990), showed an increase in abundance up to the early-1980s followed by a sharp decrease (Fig. 6). It should be noted that in 1983, which was a key year in evaluating the magnitude

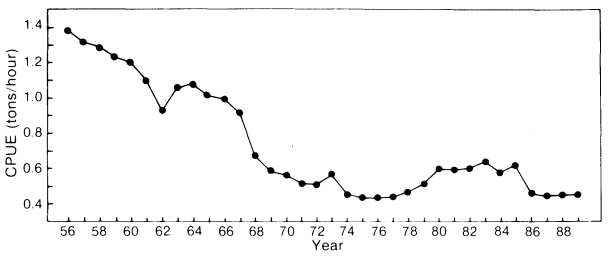

Fig. 4. Index of catch-per-unit-effort from Canadian commercial otter trawlers directing for American plaice in Div. 3LNO from 1956 to 1989.

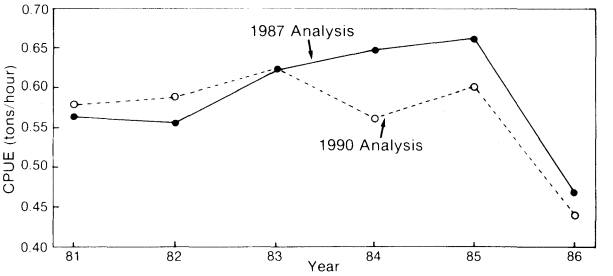

Fig. 5. Catch-per-unit-effort of American plaice in Div. 3LNO for the years 1981-86, as calculated in 1987 and 1990.

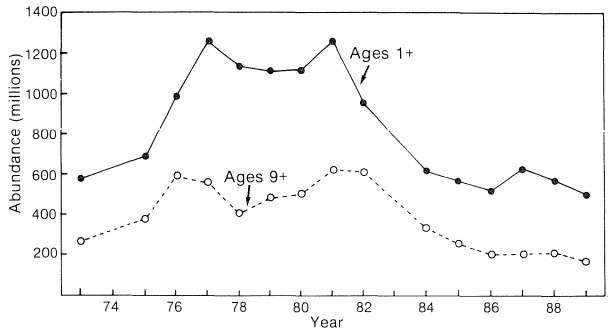

Fig. 6. Indices of abundance of American plaice, from Canadian research vessel surveys in Div. 3LNO from 1973-89. The indices are for all three divisions combined and for ages 1+ and 9+.

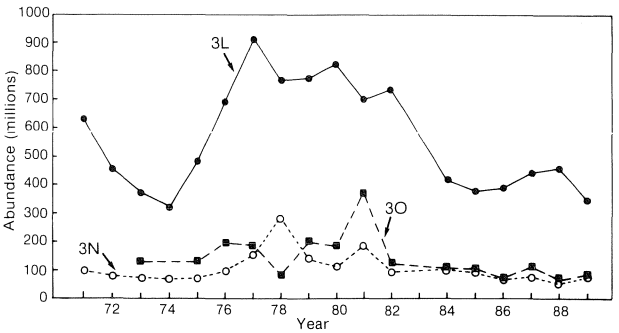

Fig. 7. Indices of abundance of American plaice aged 1+, from Canadian research vessel surveys in Div. 3L and 3N from 1971 to 1989 and Div. 3O from 1973 to 1989.

of the decline, no spring survey was done in Div. 3LNO. Figure 7 indicates that the decline occurred in all three divisions and that recent values are among the lowest in the time series. These data also show that the largest portion of the Grand Bank American plaice population occurs in Div. 3L. In addition to the spring survey series in Div. 3LNO, there have been a number of seasonal surveys conducted by Canadian research vessels in Div. 3L since 1981. These data also show a decrease in the abundance from the early-1980s to the present (Fig. 8). USSR stratified-random surveys on the Grand Bank also showed the same pattern as the Canadian surveys, with peak abundance in the late-1970s and early-1980s followed by a decline to levels similar to those in the early-1970s (Bowering and Chumakov, MS 1990).

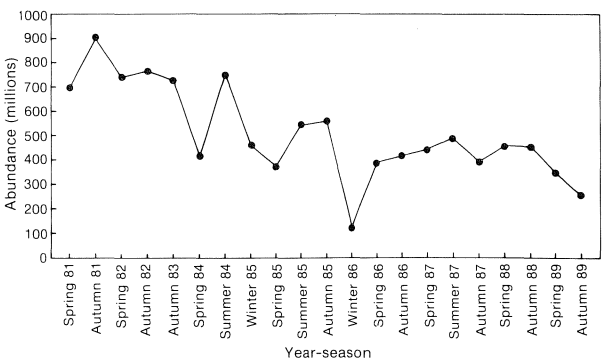

Fig. 8. Index of abundance of American plaice, from Canadian research vessel surveys in Div. 3L at various times of the year from 1981 to 1989.

It is clear from all available indices that the stock declined in the mid-1980s. The CPUE shows a sudden drop from 1985 to 1986 followed by stability, while the surveys indicate an earlier decline, probably from 1982 to 1984, followed by stability. However, these two indices do not show the same magnitude of decline. Although they both indicate that the stock size in the mid-1970s and late-1980s was about the same, the degree of increase in the late 1970s and subsequent decrease in the mid-1980s is greater in the survey series (Fig. 9). The data also show that there was a succession of strong year-classes in the late-1960s and early-1970s, which supported the high CPUE in the fishery. Following these, however, were a number of weaker year-classes which led to the drop in the CPUE (Fig. 10).

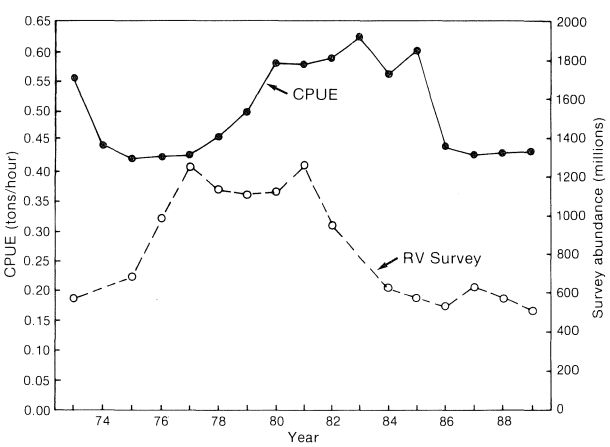

Fig. 9. Comparison of catch-per-unit-effort and research vessel survey indices of abundance for American plaice in Div. 3LNO from 1973 to 1989.

Calibration of SPA

In all of the early assessments of this stock, the linear relationship between fishing mortality (F) from SPA and fishing effort derived from CPUE data was used to determine the value for F in the most recent year. It was not until 1980 that research vessel survey data came into use as a calibration tool (Table 1), as a sufficient time series was available by that time (Pitt and Brodie, MS 1980). Also at this time, the relationship between aggregate biomass and CPUE was used to tune the SPA. In later years exploitable, or fishable, biomass from SPA replaced aggregate biomass in the CPUE calibration, because aggregate biomass included a portion of the population which was not

measured by the CPUE index. In the 1985 and 1986 assessments, the relationship between population numbers from SPA and surveys was examined but not used in deciding on terminal F, as there was no 1983 survey and the 1984 survey in Div. 3L was incomplete. The survey data was again used after the 1986 assessment, and in 1989 the Adaptive Framework (ADAPT) was used in calibrating the SPA, representing the first time that age-disaggregated data has been used in the tuning process for this stock (Brodie and Bowering, MS 1989). ADAPT was again used in 1990 with all data, both CPUE and survey being used age-disaggregated in one formulation of the model (Brodie *et al.*, MS 1990). One of the features of the ADAPT methodology is that it provides parameters estimates with statistical properties which can be evaluated to determine the best fit of the model (Gavaris, MS 1988). This is a clear advantage over the *ad hoc* tuning methods, in which the best fit for a particular relationship was often determined by evaluating several aspects of a least-squares regression (correlation coefficient, residual pattern, intercept) without well-defined and objective criteria as to what actually constituted the best fit. The selection of an appropriate terminal F was often made more difficult by the existence of several such relationships, as indicated for several assessments of this stock (Table 1).

TABLE 1. Chronology of SPA calibration methods used in the assessments of American plaice in Divisions 3LNO.

Period	Calibration techniques
1971-79	Fishing mortality from SPA *vs* fishing effort.
1980-83	F *vs* effort, biomass from SPA *vs* CPUE, population numbers from SPA *vs* population numbers *vs* RV surveys.
1984	Fishable biomass from SPA *vs* CPUE, SPA numbers *vs* RV numbers.
1985-86	Fishable biomass from SPA *vs* CPUE.
1987-88	Fishable biomass from SPA *vs* CPUE, SPA numbers *vs* RV numbers.
1989	ADAPT- 2 separate formulations: fully recruited biomass *vs* CPUE, and SPA numbers *vs* RV numbers (age-disaggregated).
1990	ADAPT-1 formulation: SPA numbers *vs* CPUE at age, SPA numbers *vs* RV numbers (age-disaggregated).

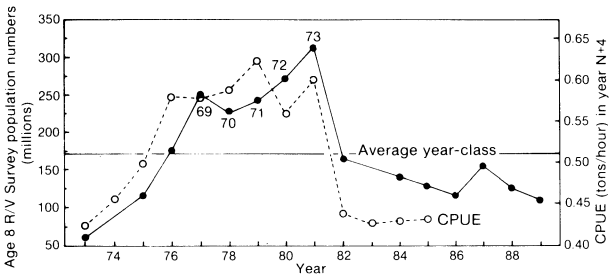

Fig. 10. Abundance of American plaice at age 8, as measured by research vessel surveys in Div. 3LNO in year n, compared with catch-per-unit-effort from the commercial fleet in year n+4. The 1969-73 year-classes are noted and the horizontal line indicates the mean abundance at age 8.

Examination of SPA results

i) **Current**: The 1990 assessment of this stock showed the population size at ages 5+ to be relatively stable in recent years, at about three quarters of the population size of the mid-1970s (Fig. 11). However, these data also showed that the stability had been caused by a slight increase in recruitment, as the population at the older ages (9+) had declined. The SPA showed a more gradual decline in population size, and did not reflect the sudden declines in the survey series (1981-84) or the catch rate (1985-86) (Brodie *et al.*, MS 1990).

Figure 12 displays the trends in fishing mortality (F) and yield, as taken from the 1990 assessment (NAFO, 1990). The values of F from 1965 to 1973 are for Div. 3LN only and were taken from the 1988 assessment, as the current data set for Div. 3LNO extends back only to 1974. As in previous years, mean fishing mortality at ages 9+, weighted by population numbers from SPA, was the measure of

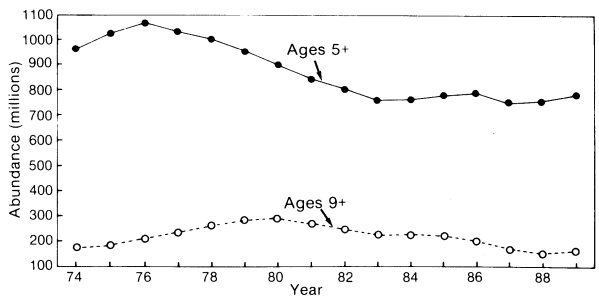

Fig. 11. Population numbers at ages 5+ and 9+, from sequential population analysis in 1990, for American plaice in Div. 3LNO from 1974 to 1989.

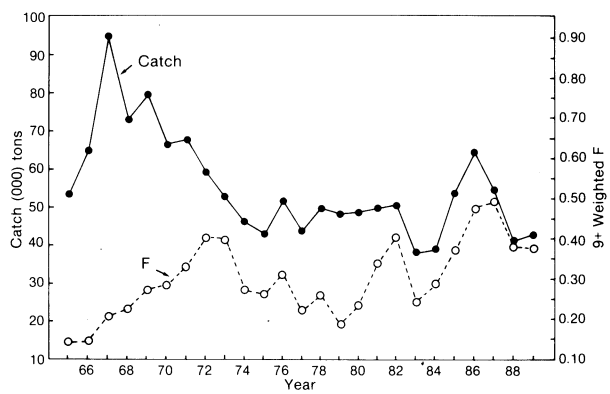

Fig. 12. Catch and mean fishing mortality (weighted by age 9+ population numbers) of American plaice in Div. 3LNO from 1965 to 1989. Fishing mortality estimates for 1974 to 1989 are from SPA in the 1990 assessment.

F chosen. This was selected over fully recruited F (ages 11+) to account for some of the large proportion of fishing mortality from the partially recruited age groups (Brodie *et al.*, MS 1990). These data show an increase in F in the mid-1980s as catches rose, with recent F values being double those in the late-1970s.

ii) **Retrospective**: As with many other stocks assessed with sequential population models (CAFSAC, 1987), American plaice in Div. 3LNO shows a consistent pattern of underestimated F in the previous assessments compared to the most recent. This can be seen in Fig. 13, which contrasts the estimates of F from the 1989 and 1990 assessments. Although the estimates converge quite rapidly, there is a discrepancy of 20–30% for 1987–89, not all of which can be accounted for by the upward revision of the nominal catches for these years in the 1990 assessment. This level of difference has not been uncommon, as illustrated in Fig. 14, which compares the F values for 1979–88 from the 1990 assessment with the values as they were calculated in each year, e.g. the 1988 value as calculated in the 1989 and 1990 assessments. The largest discrepancies were in the 1985 and 1986 assessments, when estimated Fs were less than 50% of the values indicated in the 1990 assessment (Fig. 15). As noted previously, these 2 years were the only assessments since 1980 which did not use survey data for calibration, because of the gap in the survey series, and the 1984 assessment did not have a point in the survey series for the most recent year. Figure 16 shows that the Fs for 1983 were substantially underestimated in 1984–86, before increasing in subsequent assessments. Translated into population sizes, these discrepancies in F meant the difference between the 1984–86 assessments and the current value was about double.

Discussion

In the assessments during the 1982–84 period, there was good agreement in the calibrations with the CPUE and survey data (Brodie and Pitt, MS 1984). Therefore, there was no apparent cause for concern when the 1985 and 1986 assessments did not use the spring survey series in calibrating the SPA, particularly when fall surveys in Div. 3L in 1983–84 showed relative stability in the population size (Fig. 8). Subsequent assessments, however, began to show a discrepancy in the calibrations, with the survey data consistently indicating a higher value for F in the terminal year. For example, the 1988 assessment indicated a fully-recruited F about 25–30% higher in the survey calibrations compared to the CPUE tuning. The problem was further compounded by the trend in the catch-rate series, which showed an increase up to a 17-year high in

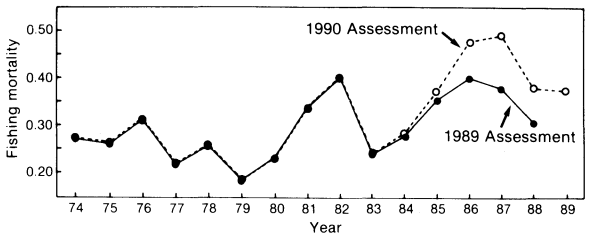

Fig. 13. Comparison of mean fishing mortality (weighted by age 9+ population numbers) from the 1989 and 1990 assessments of the American plaice stock in Div. 3LNO, for the years 1974–88.

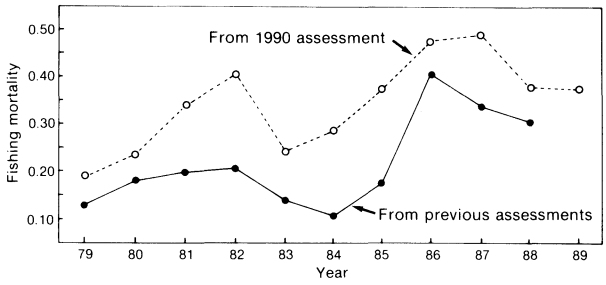

Fig. 14. Comparison of mean fishing mortality (weighted by age 9+ population numbers) from the 1990 assessments and the terminal year of previous assessments, for American plaice stock in Div. 3LNO from 1979 to 1989.

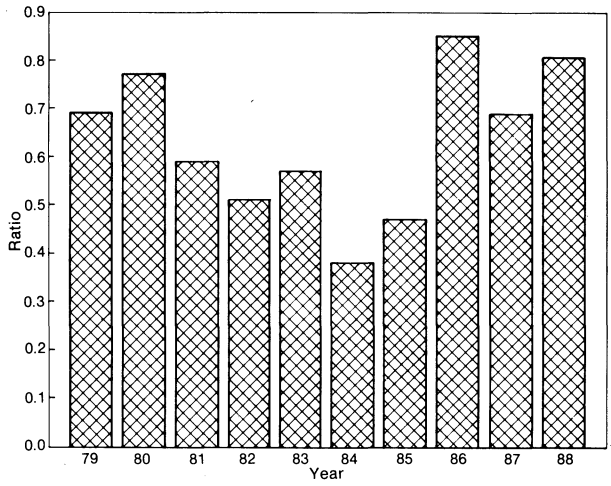

Fig. 15. Ratio of fishing mortality in the 1990 assessment to fishing mortality in the terminal year of previous assessments, for American plaice in Div. 3LNO from 1979 to 1988.

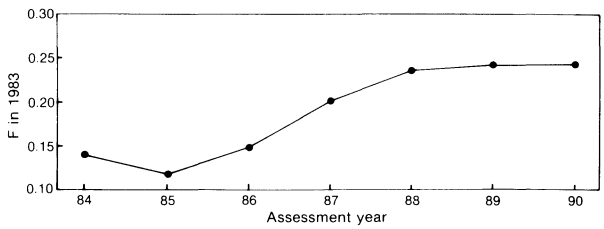

Fig. 16. Mean fishing mortality (weighted by age 9+ population numbers) for 1983 from the 1984 to 1990 assessments of American plaice in Div. 3LNO.

1985, as well as the previously noted error in the CPUE calculation (Fig. 5). By the time the survey data were again included in the calibration (in 1987), the CPUE had also declined sharply (from 1985 to 1986), which resulted in a totally different perception of stock status. The estimate of F for 1985 in the 1987 assessment was 72% higher than the estimate in the 1986 assessment. However, even when the 1987 assessment indicated these results, there was some doubt as to their validity. It was noted that this stock had a long-term history of stable catches, essentially due to relatively stable recruitment, and that the sudden changes in the indices of abundance may have been due in part to changes in availability rather than in population size (NAFO, 1987). These doubts were caused by some changes noted in the distribution of American plaice on the Grand Bank after the extremely low bottom temperatures which had been observed in 1984–86 (Wells *et al.*, MS 1988). However, subsequent assessments showed that the indices of abundance stabilized at the lower levels, and that in fact the stock size was smaller.

There has been much speculation as to the reasons for the severe decline in the stock in the mid-1980s. For a stock not subject to large variations in recruitment, containing fish of about 15 year-classes in the commercial catches, the sudden decreases observed in the indices are difficult to comprehend, as one would expect to see much more gradual changes in such a stock. Although the recruitment was lower and catches were higher than the $F_{0.1}$ reference level, as indicated by the retrospective analysis, neither of these factors fully explain the decreases. One theory was that the very cold water found on the Grand Bank throughout the mid-1980s produced an increase in natural mortality (m), which was not accounted for in the SPA, where a constant value of m for all years and age-groups had been used in all assessments. Brodie (MS 1987) demonstrated a positive relationship between bottom temperatures and survey catches for American plaice in Div. 3L, and the effect of low water temperatures in 1962–63 on the mortality of sole in the North Sea has been discussed by many authors (De Veen, MS 1975). In addition, there was a large decline in the biomass of the adjacent American plaice stock (Subarea 2 + Div. 3K) in the mid-1980s, with the largest decrease occurring in the area where commercial catches were negligible (Brodie, MS 1988b). At present, however, the effects of low temperatures on the American plaice population on the Grand Bank are not known, and studies are under way to attempt to quantify this.

In interpreting the assessments as they exist, it is clear that the difference in the timing and the severity of the decline between the CPUE and survey indices caused discrepancies in the SPA calibrations. The survey data produced a much more pessimistic view of the resource, a feature common to many stocks where both CPUE and survey data are used. In fact, for many stocks, CPUE data have been eliminated from calibration of SPA, as rapidly developing fisheries and technological changes have made trends in catch-rate data difficult, if not impossible, to relate to stock abundance. However, it has long been argued that the offshore fishery for the Grand Bank American plaice stock has not varied greatly over its 40 year existence, with the major change (from side to stern trawlers) being quantifiable. Nonetheless, differences continue to exist in the calibrations with the two indices (Brodie *et al.*, MS 1990). As further indices of abundance are added (e.g. juvenile flatfish surveys) when time series become long enough, and as methods of analyzing the indices and quantifying their variability continue to improve, differences in calibration should be more readily explainable. The use of such techniques as age-disaggregated indices, within the Adaptive framework, are certainly viewed as improvements in terms of SPA calibration. Whether these changes will eliminate the pattern of consistent underestimation of F in the current year remains to be seen.

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