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American Plaice *Hippoglossoides platessoides* on the Grand Bank (NAFO Divisions 3LNO) – a Review of Stock Structure in Relation to Assessment of the Stock

by

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Abstract

A review of literature relevant to the stock structure of American plaice in NAFO Divisions 3LNO is presented. Information on the fishery, stock distribution, stock definition, assessment history, stock identification, and various aspects of the biology of American plaice on the Grand Bank has been considered. There have been spatial changes in the fishery over time, as well as documented differences in various biological characteristics among fish from various locations in Div. 3LNO. Stock identification studies generally have proved to be inconclusive. Although current abundance and distribution are much different from the historical patterns, this review does not offer evidence to support a change in the current stock definition, i.e. a single stock of American plaice in Div. 3LNO. The paper concludes with a discussion on the implications of single or multiple stocks for the management of American plaice in Div. 3LNO.

Introduction

In the report of its June 2001 meeting, STACFIS recommended "*that studies be initiated to examine the relationship between American plaice in each of Div. 3L, 3N, and 3O. These studies should include examination of historical fishery and biological data disaggregated by Division, any tagging information, and genetic analysis.*" As a start in addressing this recommendation, this paper reviews the basis of the stock definition for Div. 3LNO American plaice, along with some of the relevant material on the assessment history, fishery, distribution, spawning and maturity, growth, tagging, and stock identification. Much of the early research on the biology of American plaice in the Newfoundland area was done by Pitt in the 1960s and 1970s, as were the initial stock assessments. In recent years, the stock assessments and most of the published research have been done by Morgan and other researchers, such as Walsh and Bowering, with DFO in Newfoundland. This review concentrates mainly on these bodies of work, and for the biological studies, the focus was on papers which contained comparisons of American plaice from two or more areas of the Grand Bank.

Distribution of the fishery

The fishery for American plaice on the Grand Bank, NAFO Div. 3LNO (Fig. 1), essentially began in the late-1940s, with the introduction of the otter trawler (Pitt, 1973a). The fishery was mainly Canadian until the mid-1960s, when European trawlers began increasing their activity on the Grand Bank. Catches escalated rapidly, peaking at 94 000 tons in 1967, but were relatively stable around 45 000 to 50 000 tons from 1973-84 (Fig. 2a). Catches declined in the late-1980s, and the stock has been closed to directed fishing since 1994 (Morgan *et al*., 2001). By catches have increased steadily from a few hundred tons in 1995-96 to over 5 000 tons in 2000.

Catches have generally been highest in Div. 3L, and in many years 50% or more of catches on the Grand Bank came from this division (Fig. 2b). On some occasions, such as 1965-66, 1973-75, and 1985-86, along with most recent

years, catches in Div. 3N have exceeded those in Div. 3L. There are numerous reasons for this, including changes in abundance and distribution of American plaice, changes in fishing patterns in the mixed fisheries for American plaice and other widely distributed species such as cod, yellowtail flounder, and skate, and introduction of large amounts of effort from new fishing fleets. Catches from Div. 3O were usually the lowest of the three Divisions in a given year.

Pitt (1967) reported that the largest commercial concentrations of American plaice occurred on the wide northern and northeastern slopes of the Grand Bank, in depths between 73 and 183 m., and on the eastern slope in depths between 73 and 274 m. The fishery on the southern and southeast portions of the Grand Bank usually occurred on concentrations of fish between 64 and 110 m deep. These depths were fished consistently for American plaice over the years, but some American plaice have been caught in deeper waters, particularly as by-catch in the fishery for Greenland halibut which began in Div. 3L in the late-1980s. The majority of catch in recent years has come from shallow water in Div. 3N, mainly as by-catch in the otter trawl fisheries for skate and yellowtail flounder, although by-catches still occur in the deeper areas.

As has been documented on numerous occasions, there are problems with the catch statistics for American plaice in Div. 3LNO. These include unknown discards by Spanish pair trawler and Canadian otter trawler fleets in the early years, unreported and misreported catches in the mid-1980s to early-1990s, and catches for which species composition of flatfish, and/or Divisional breakdowns of catches, and/or vessel flag-state were not reported. In many years, estimates of catch from a variety of sources, including observers and surveillance authorities, have been used by Scientific Council to derive best estimates of catch for its stock assessments. The data presented in Fig. 2a and 2b include these estimates. Catches by Division for 1960-89 were taken from Brodie *et al.* (1993), and estimates of proportions by Division for 1990-99 were taken from catches reported to NAFO. Total catches for 1990-1999 were taken from Morgan *et al.* (2001), where it was also reported that the catch for Div. 3LNO combined in 2000 was 5176 tons. In considering the catches during the 1990's for which no Divisional breakdown was available, it is likely that most of this fish was caught in Div. 3N.

An inshore fishery, conducted mainly by gillnets in the bays of the Avalon Peninsula in Div. 3L, began in the 1960s and catches from 1972-89 ranged from 1 700 to 4 800 tons per year, averaging about 3 500 tons/year during the 1980s (Brodie *et al*., 1990). Catch at age from these catches was included with the data from offshore catches in the assessments of Div. 3LNO American plaice.

Distribution and trends in abundance

American plaice are widely distributed throughout the Northwest Atlantic, with highest densities generally occurring on the Grand Bank (Bowering and Brodie, 1991). In Div. 3LNO, American plaice are found in inshore areas in Div 3L, in the shallowest areas on the Grand Bank (Virgin Rocks, Southeast Shoal), and in all depths including the slopes of the Bank, where they have been found in waters as deep as 1 400 m (Iglesias *et al*., 1994). Brodie *et al*., (1993) compared distribution maps of American plaice from spring surveys in Div. 3LNO from 1978-92. Distributions remained widespread on the Grand Bank during this period, despite a large change in abundance. Analyses in Morgan *et al.* (2001), including data from the 1996-2000 surveys, confirm that American plaice are still distributed throughout Div. 3LNO. A comparison of the distributions in Div. 3LNO from spring surveys in 1978 and 2000 is shown in Fig. 3.

Research vessel survey data are available for this stock from the 1950s to the present, and stratified random surveys have been conducted in Div. 3LNO since 1971. Table 1 and Fig. 4a show the trends in abundance, by Division, from the spring surveys of 1985-2000 (Morgan *et al*., 2001). The sharp decline in abundance shown by the spring surveys in the late-1980s and early-1990s has been well documented in the assessments of this stock, and has been confirmed in other indices, such as USSR/Russian surveys, and Canadian fall surveys. The VPA from the most recent assessment (Morgan *et al*., 2001), which is for Div. 3LNO combined, showed good agreement with the spring surveys, and indicated a fairly steady decline in population size from 1975 to 1995. The American plaice biomass from that assessment was estimated to be about 10% of the levels in the late-1970s and early-1980s.

From the survey results, it is apparent that the decline in abundance has not been uniform over the entire Grand Bank. The decline appears to have been most severe in Div. 3L, intermediate in Div. 3N, and least severe in Div. 3O (Table 1, Fig. 4a). Although the ratio of minimum to maximum survey values in 1985-2000 is less than 11% for all

3 Divisions, recent values in Div. 3L have remained well below the average of these years, while those in Div. 3O are similar to the average (Table 1). In the 1985-89 period, Div 3L accounted for 70% on average of the Div. 3LNO abundance in the spring surveys, declining to less than 40% in subsequent periods (1990-95, 1996-2000, Fig. 4b and 5). Div. 3N accounted for 16-25% on average during these three time periods, while the percentage in Div 3O increased from 14% to 36% to 48% over the three intervals. Although there are seasonal differences in the pattern of American plaice distribution on the Grand Bank (Morgan and Brodie, 1991), results from fall surveys in Div. 3LNO from 1990-2000 generally agreed with those from the spring surveys, in terms of trends in abundance and relative distribution. Spring surveys conducted by Spain in the NAFO Regulatory Area of Div. 3NO (outside the Canadian 200-mile limit) indicate a substantial increase in abundance and biomass of American plaice in this area from 1997-2000 (Duran Munoz *et al*., 2001).

In both spring and fall surveys, Morgan *et al*. (2001) showed that the largest concentration of fish in each year since 1996 has been in the southeast portion of Div. 3O, often extending into Div. 3N (Fig. 3). Furthermore, the spring surveys show that the proportion of American plaice biomass located north of 45 degrees N latitude on the Grand Bank has declined from about 85% in 1985-89 to about 40% in surveys since 1993, and is only 31% in 2001 (Fig. 6). Thus the conclusion that the current distribution of American plaice on the Grand Bank is located more to the south, particularly in southeastern Div. 3O, than it was in the 1980s and earlier. Nevertheless, abundance in many areas of the Grand Bank is much reduced compared to levels in the late-1970s and early- to mid-1980s. Not surprisingly, the trends in catches over time have generally followed the trends in abundance and distribution, although there have been some exceptions.

There is also evidence that American plaice have been distributed in deeper, warmer waters since at least the early-1990s, during a period of lower than average bottom temperatures (Morgan 2001, Colbourne *et al*., 1997). An earlier paper by Walsh and Brodie (1988) showed that unusually large catches (e.g. 3.75 tons in a 30 minute tow) of American plaice were found in depths around 500 m in a small area of Div. 3L during a research vessel survey in 1987. The authors noted that this concentration of American plaice in the depth observed was most unusual, and that there was no survey or commercial fishery data to suggest that this had occurred previously. Wells *et al*. (1988) examined distribution of Div. 3LNO American plaice from surveys during 1977-87, and found that catches from the deeper, warmer waters were usually low, and often zero. Iglesias *et al*. (1994) reported on trends in the distribution of American plaice by-catches in the Spanish deepwater fishery for Greenland halibut in Div. 3L in the early-1990s.

Original stock definition and assessment history

Pitt (1971) considered that there were two main stocks, one in Div. 3L, and the other in a relatively small area along the southeast and eastern slope of the Grand Bank, (in Div. 3N). This was based on the location of the fishery, on tagging studies that showed minimal migration between the northern and southern parts of the Bank, and on differences in growth rates and age compositions of the fish in the 2 areas. Pitt (1973a) did note, however, that although Div. 3L and 3N were dealt with separately, there was a strong possibility that recruitment in Div. 3N depended on Div. 3L, probably as pelagic larvae. In a review of the delineation of American plaice stocks, emphasizing Div. 3LNO, Pitt (1975b) said that it appeared that plaice on the Grand Bank occurred in relatively isolated groups, instead of large aggregate populations. He stated that conservation of the Div. 3LNO stock would be enhanced by possibly assigning separate TACs to the three Divisions, or possibly a combination such as Div. 3L and Div. 3NO. He expressed concerns that assigning a TAC for all of Div. 3LNO potentially could allow over-exploitation within an individual Division. He also felt that accuracy of assessments would be improved by reporting data in units smaller than ICNAF Divisions, noting that the definition of ICNAF Divisions in the early-1950s pertained more to the reporting of cod, haddock, and redfish catches.

The first documented assessments of American plaice on the Grand Banks occurred in ICNAF in the early-1970s (Pitt, 1970, 1971), and the first TAC was established by that organization, for the fishery in 1973, was 60 000 tons for Div. 3LNO combined. The value of 60 000 tons was arrived at by adding values of 32 000 for Div. 3L, 20,000 for Div. 3N, and 8 000 for Div. 3O, although the rationale for the combined TAC was not specified (ICNAF, 1972). The first assessments were carried out on the Div. 3L and 3N components separately, by sex, using virtual population analysis, although Pitt (1973b) also used a Schaefer model. Brodie (1990) reviewed the assessments of the stock up to 1989, and Table 2 shows how the assessments evolved up to the present time. From 1980 onward, assessments were done with sexes combined, although the catch at age and survey indices were calculated for each sex, and then added together. From 1979-88, data from Div. 3O were not included in the analyses, due mainly to

lack of commercial sampling data from earlier years, and TACs for Div. 3LNO were arrived at by adding a value for recent mean catch from Div. 3O to the projected catches from assessment of Div. 3LN data. The most recent assessment within NAFO (Morgan *et al*., 2001) uses the ADAPT framework, is calibrated with data from the spring and fall Canadian surveys, and treats all catch at age and indices as Div. 3LNO combined.

Spawning and nursery areas

Pitt (1966) examined sexual maturity and spawning of American plaice on the Grand Bank and adjacent areas, concluding that there were no specific spawning grounds for this species. He found that the areas with the largest concentrations of American plaice in the northwest Atlantic, which were in Div. 3L, were also the areas of greatest spawning activity. Based on data from numerous research vessel surveys, Pitt concluded that the spawning of American plaice was widely distributed. In an earlier paper, Pitt (1964) found no significant differences in the fecundity-length relationships of American plaice from three areas - the southern and northern slopes of the Grand Bank and from St. Mary's Bay. Zamarro (1990, 1992) also examined fecundity, although his studies were limited to fish from the southern Grand Bank and Flemish Cap.

Nevinsky and Serebryakov (1973) reported on icthyoplankton studies done by research vessels from PINRO from 1959-1970, as well as observations on maturity stages of American plaice collected from 1954-1970, on the continental slope from Labrador to the Scotian Shelf. They concluded that the most intensive spawning occurred on the northern part of the Grand Bank, and that spawning seemed to be less intensive on the southern parts of the Bank. Spawning of American plaice was found to be widespread on most of the continental shelf from Labrador to the Gulf of Maine. The authors found that larvae of American plaice were generally observed in the same habitats as eggs, at or near the spawning locations, and given what they said were "low current velocities at the Grand Bank spawning locations", they suggested that American plaice in the early stages of development do not drift far from the spawning grounds.

Morgan (2001) examined times and locations of American plaice spawning in Div. 3LNO from Canadian survey data collected during 1971 to 1999. Her analysis was consistent with the previous studies, in that spawning appeared to be widespread, without specific spawning locations. She found little interannual variation, except that in recent years spawning occurred in deeper waters and that spawning females were more abundant in Div 3NO than in Div. 3L. She noted that these changes reflect changes in stock distribution which began in the early-1990s. American plaice in Div. 3L spawned later than those in Div. 3NO, and there was a significant trend towards later spawning in the 1990s.

Walsh (1994a) compared life history traits and spawning characteristics of American plaice on both sides of the Atlantic Ocean, and concluded that with the exception of the Barents Sea population, no spawning migration or large scale spawning aggregation occurs in this species. His summary of numerous studies was that spawning appeared to occur throughout the range occupied by the various populations. It is interesting to note that of the 6 areas he examined to compare early life history traits, only the Grand Bank had no available information on egg size, hatch size, and hatch time.

Pitt (1967) noted that large quantities of young American plaice lived on the shallow parts of the Grand Bank, and that these locations probably acted as nursery areas for the large commercial concentrations along the seaward slope of the Grand Bank. Walsh (1982) proposed that juvenile American plaice were concentrated in certain areas of the Grand Bank, often overlapping with the distribution of adults. Based mainly on a series of research vessel surveys specifically designed to measure juvenile flatfish abundance and distribution, the location of specific "oceanic nursery sites" was subsequently identified (Walsh, 1991). These were fairly large geographic areas where most of the young American plaice on the Grand Bank were located. The areas are best described as the north/northeast slope of the Grand Bank in Div 3L, most of the southern Grand Bank outside the Canadian 200 mile limit, and the area in Div. 3O encompassing the southwest slope of the Bank, as well as Whale Deep (Walsh *et al*., 1995). However, Walsh *et al*. (2001b) noted that there have been shifts in the spatial pattern of juvenile distribution on the Grand Bank during the 1990's, and that this may be related to reductions in stock size. The areas of formerly high densities of American plaice juveniles, on the Tail of the Bank and northern slope, now contain few juveniles, with most of the young fish in recent surveys being found in Div. 3O.

Tagging studies

There have been two tagging programs directed at American plaice on the Grand Bank by researchers working out of St. John's, NF. The first, reported on by Pitt (1969), tagged 4653 American plaice with Petersen discs at 6 locations on the Grand Bank and 1 in St. Mary's Bay, at various times in 1954, 1959, and 1961. The second, reported on by Morgan (1996), tagged 9715 juvenile and 3154 adult American plaice, also with Petersen discs, in four research vessel trips from 1990 to 1993. The results of both studies indicate that American plaice on the Grand Bank are generally rather sedentary, and do not appear to undergo long distance migrations for any reason.

Pitt's study found that most returns were within 30 n. miles of the tagging site, even up to 7 years after tagging. There were, however, a number of tags recovered more than 60 n. miles from the tagging locations. He concluded that "the Grand Bank apparently has a large number of relatively sedentary stocks of this species". He also stated that St. Mary's Bay probably supported a resident population, despite the fact that only 7 of 499 tagged fish were recovered, and of these seven, four were recaptured outside St. Mary's Bay, one of which was caught on the eastern Grand Bank. However, one of the difficulties in interpreting the inshore tagging, which occurred in 1954, was the low level of inshore landings of American plaice prior to the mid-1960s.

Morgan's study indicated that recaptures of juvenile American plaice were found at an average distance of 34 n miles from the tagging site, and that the average distance for adults was 52 n. miles. She also found no evidence of large-scale migrations, but that unlike the earlier tagging, many of the fish released in Div. 3L were recaptured in Div. 3NO, indicating mixing between these areas. However, she noted that the Div. 3L tagging positions in Pitt's study were along the eastern edge of the Grand Bank, while the Div. 3L releases in the 1990s were more on top of the Bank.

Other stock identification studies

A few studies have been directed at stock differentiation of American plaice in the Northwest Atlantic, including the Grand Bank. Pitt (1963) noted that no significant differences existed in vertebral numbers between any of the Grand Bank samples, but that averages for the Grand Bank were significantly higher than averages for nearby areas, such as Gulf of St. Lawrence, Flemish Cap, and Labrador Shelf. He cited differences in the time of spawning, larval drift, and inclusion of numerous year-classes in the samples as possible explanations for the low degree of variability over the whole area. He found no significant differences in anal fin ray counts taken from Div. 3K, many areas of the Grand Bank, St. Mary's Bay, and St. Pierre Bank (Pitt, 1975b). He concluded that vertebral and fin ray counts were not very useful in delineating American plaice stocks. Based on these studies, and other information from tagging and growth, he also concluded that there was probably considerable intermingling of pre-metamorphosis individuals over the whole of the Grand Bank, but likely very little mixing between different groups after the fish had settled and undergone metamorphosis.

Bowering *et al*. (1998) looked at morphometric characteristics of American plaice from 18 sampling locations in the Newfoundland and Labrador area of the northwest Atlantic, including 13 from the Grand Bank. Their analyses indicated that all samples were statistically different from each other, including samples taken from the same general area in different seasons. They rejected the notion that this suggested the presence of so many separate stocks, and concluded that morphometric data are very limited in their usefulness for stock identification of American plaice. This latter conclusion agreed with Pitt's view of the meristic characters he studied, noted in the previous paragraph.

Biological studies

In examining the age and growth of this species in Div. 3LNO, Pitt (1967) found that fish from the southern Grand Bank were the largest, and fish from St. Mary's Bay the smallest at comparable ages. For the 12 areas in his study, he found a positive association between lengths at ages 5 and 15 years and the average bottom temperature for each area. He showed that growth curves for four areas of the Grand Bank increased in mean length at age from north to south, specifically (in increasing order) northeast, east, southeast, and southwest. Otolith samples, collected on research vessel surveys from 1957-63, showed little similarity in the age compositions of American plaice in these four areas, although it was also difficult to follow year-class strengths in the samples from any one area on the Grand Bank during this time. Pitt (1975b) found that growth curves from American plaice caught in Div. 3L and those caught in Div. 3O between 45 and 46 degrees latitude were almost identical. Fish from the northern part of

Div. 3N were intermediate in growth rate between the Div. 3L/northern 3O samples and those taken in Div. 3NO south of 45 degrees.

Pitt (1973c) studied the food of American plaice on the Grand Bank, from samples collected between 1964 and 1971. He found that capelin (*Mallotus villosus*) and sand launce (*Ammodytes dubious*) comprised up to 85% of the weight of the diet in Div. 3N, compared to 55% in Div. 3L. Echinoderms (brittle stars, sand dollars, sea urchins) occurred in significantly greater proportions in Div. 3L than in Div. 3N. Zamarro (1991) also confirmed the importance of sand launce and capelin in the diet of American plaice on the southern Grand Bank, noting that there were seasonal differences in the diet in this area.

Walsh (1994b) looked at recruitment variability of American plaice (also known as long rough dab) populations throughout the Atlantic Ocean. Using survey data on abundance of age 4 fish from the Grand Bank, he found a significant positive correlation between 3L and 3O, but no significant correlations between Div. 3L/3N or Div. 3N/3O. Based on comparisons of numerous populations, Walsh described two life history patterns: "southern populations are characterized by faster growing, early maturing winter-spring spawners exhibiting low stock-dependent responses and low recruitment variability; northern populations are characterized by slow growing, late maturing spring-summer spawners exhibiting strong stock-dependent responses and high recruitment variability."

Abundance at age data from the 1985-2000 spring surveys in Div. 3LNO were re-examined, given that there has been a change in the survey trawl (Engel to Campelen) since Walsh's analysis, and the pre-Campelen data (1985-1995) have been converted into Campelen equivalents (Morgan *et al*., 1998). Using data for ages 4 and 5 separately, it was found that correlations were significant at both ages for Div. 3O *vs* 3N, not significant at both ages for Div. 3L vs 3O, and significant at age 4 but non-significant at age 5 for Div. 3L *vs* 3N (Fig. 7). All 6 relationships had positive slopes, but of the 6 correlations, only one (Div. 3O *vs* 3N, age 5) produced an r^2 value above 0.36. These results, as well as those of Walsh (1994b) may be confounded by using data aggregated to the level of NAFO Division, if in fact there are true spawning populations distributed across divisional boundaries.

The most recent assessment of the Grand Bank stock (Morgan *et al*., 2001) used a value of 0.53 for natural mortality for the period 1989-96, compared to 0.2 for the remaining years. Studies of adjacent stocks of American plaice in the Newfoundland-Labrador region have shown changes in distribution and abundance similar to those seen in Div. 3LNO, and raised the possibility that natural mortality may have been higher than normal. For the stock to the north of the Grand Bank, in Subarea 2 + Div. 3K, Bowering *et al*. (1997) showed severe declines in abundance since the mid-1980s, along with a shift to deeper water in the 1990s. That study, along with Morgan *et al*. (2002 in press) concluded that these declines were not likely to have resulted only from fishing. Similar findings came from an examination of the American plaice stock in Subdiv. 3Ps (Bowering *et al*., 1996).

Work by Morgan on the sexual maturity of American plaice, contained in assessments of the Div. 3LNO American plaice stock (eg. Brodie *et al* 1994), showed trends in the age at 50% maturity (A_{50}), by Division and sex. This indicated declines in A_{50} throughout the 1980s in all 3 Divisions, to about the lowest observed levels in the late-1980s. Some evidence of an increase was observed for females in Div. 3N and 3O in the early-1990s, but not in Div. 3L, where the most severe declines had occurred. Earlier work by Pitt (1975a) showed declines in A_{50} for males and females in both Div. 3L and 3N from the early-1960s to the early-1970s, in relation to exploitation of the stock.

Pitt (1972, 1973a) made reference to preliminary results from biochemical research on this stock. However, he gave no reference for this study, and there does not appear to be a subsequent publication dealing with such a study, so it is not clear what work was being referred to. The author is not aware of any published work on genetic studies of this species in the Newfoundland area. A recent initiative saw American plaice samples collected from a number of locations on the Grand Bank and inshore in Div. 3L during the spring of 2000, but no funding was made available for subsequent genetic analysis.

Discussion

The picture of American plaice stock structure on the Grand Bank is certainly not a clear one. The distribution of American plaice is continuous along the continental shelf, slope, and inshore regions of Newfoundland and Labrador. If one considers the definition of a population to be dependent on a discrete spawning unit, then this widespread distribution of spawning fish, combined with the lack of obvious spawning aggregations make it very

difficult to imagine where the lines between such populations would be drawn. The currents on the Grand Bank, influenced mainly by the north-to-south Labrador Current, suggest that some eggs and larvae from Div. 3L could be carried into Div. 3N or 3O, particularly along the eastern edge of the Grand Bank, but that the reverse would appear to be less likely. There are large-scale oceanic nursery areas in each Division, and there are indications of some synchrony in cohort strengths among divisions, although the relationships are not particularly strong in most cases. Little is known about American plaice in the inshore area of Div. 3L, with the exception of some studies on St. Mary's Bay, mainly by Pitt.

There are well-documented differences in biological characteristics such as growth and maturity, throughout the American plaice found on the Grand Bank. These alone do not indicate the presence of different stocks, given that environmental factors also influence the biological ones, and that wide differences in habitat, temperature, and prey occur over the range of American plaice distribution in Div. 3LNO. Stock discrimination studies based on meristic and morphometric characters have not shed much light on the stock structure. Tagging suggests that large-scale migrations do not occur, and most tagged fish have been recovered relatively close to the tagging site. There have been a few long-distance movements as well as some fish recaptured in a different division than the tagging site.

Pitt obviously believed that there were differences in the fish found in Div. 3L compared to Div. 3N, and that the American plaice in St. Mary's Bay were probably separate from the Grand Bank population(s). This was based on his tagging results, and differences in numerous biological characteristics. He did recognize that larvae from spawning in Div. 3L were likely to contribute to recruitment in Div. 3N. His statement that separate TACs should be established for each Division, or at least for Div. 3L and Div. 3NO, resulted mainly from concerns that an overall TAC for Div. 3LNO could be fished in any one division and lead to overexploitation in an area.

Declines in abundance, which were most severe in Div 3L, do not appear to be as severe in the southern Grand Banks. The reasons for this are not known, but drastic declines in abundance for many stocks of this species (and numerous others) occurred in the 1980s and 1990s throughout the northwest Atlantic. In general, these declines appeared to be worse in the north, similar to the situation on the Grand Bank. At present, about half of the abundance of American plaice on the Grand Bank, as measured by surveys, is in Div. 3O with 3L comprising only about 33% in recent years, compared to 70% in the mid- to late-1980s. It is this point which is underlying the current interest in examining stock structure, particularly in light of increasing by-catch, primarily in fisheries on the southern Grand Bank.

Although the present abundance and distribution of American plaice on the Grand Bank are much different from the historical patterns, the review of literature carried out here does not support a change in the current stock definition, i.e. a single stock of American plaice in Div. 3LNO.

Implications of a single, or multiple, stocks

It is perhaps worthwhile to consider possible courses of action and associated consequences and risks for the two different hypotheses: that American plaice on the Grand Bank is one stock, or the alternative, that it is comprised of 2 or more stock components. This approach has been considered for cod in Div. 2J3KL, where questions exist as to the relationship of inshore and offshore distributions of fish (Lilly *et al*., 2001).

At present, American plaice in Div. 3LNO is treated as one stock, and is assessed to be at a very low level, with further decline likely to occur if current fishing mortality is maintained (Morgan *et al*., 2001). If there is just one single stock then it should not matter what the distribution of fish is, or whether the decline in one area is worse than in other areas. The assumption is that a fishery on remaining fish in any areas would impede recovery of the overall stock. If there is more than 1 stock, then the effects of a fishery on one component should be minimal on other components, or at worst indirect, depending on the level of interchange (migration, drift of eggs and larvae, etc.). However, the sustainability of catches from each component would be unknown, and assessments of the individual components would be required to determine this. Thus maintaining an overall moratorium in Div. 3LNO could result in the loss of some yield from individual components, although such catches would undoubtedly be small relative to the long term catches from Div. 3LNO combined.

If a decision was made to split the stock into components, and this proved to be incorrect, the risk of allowing a fishery on any one component is that it would impede recovery of the overall stock. While it may be possible to

sustain some relatively low level of catch from an area, the likelihood that the overall stock would recover to its former levels would be reduced, or the recovery time would be increased. This would be particularly true if the recovery of the stock was dependent on the eventual spread of fish from the current areas of higher density (e.g. southern Grand Bank) into the areas of lower density (central and northern Grand Bank), as was seen with the recent recovery of the Div. 3LNO yellowtail flounder stock (Brodie *et al*., 1998; Walsh *et al*., 2001a).

Ultimately, any management decision should weigh the risks of adopting a stock structure and then following a course of action. For example, if separate components are adopted, and a fishery allowed on some of these, there are risks that the unit stock will not recover, if in fact there are not separate components. If a single stock is assumed, and a moratorium on fishing maintained, there are risks that yield will be lost, if in fact separate components actually exist at a level that would allow some sustainable harvest. Again, if a single stock is incorrectly assumed, and fishing is eventually allowed, there is risk that one or more of the separate stocks could be overfished. Even if the northern and southern areas contain separate populations, it is possible that fish from Div. 3NO could repopulate Div. 3L if their abundance was allowed to increase.

If further studies show that there are indeed 2 or more stocks of American plaice in Div. 3LNO, much of the current assessment data will need to be disaggregated into the appropriate units. Fishery data would pose a particular problem, as the reporting (or in many cases estimation) of catch and effort data for stock assessments has not always been at a scale smaller than NAFO Division, and sometimes even stock area. Survey data would pose somewhat less of a problem, although numerous time series of abundance and biological indices from the spring and fall surveys would have to be recalculated, especially if the new stock units did not follow divisional boundaries. Regardless, substantial revisions to the current assessment database would be required. Eventual decisions on whether to open fisheries on these components would likely depend on development of biomass-based reference points, under the precautionary approach proposed by NAFO Scientific Council (Serchuk *et al*., 1997). There was some discussion of a biomass-based limit reference point in the 2001 NAFO SC assessment of Div. 3LNO American plaice, although there are no accepted reference points for the stock at this time.

It is not immediately evident which studies could be recommended to address hypotheses of stock structure of American plaice on the Grand Bank. Traditional methods such as meristics and morphometrics have not proved fruitful, and authors of previous studies have questioned the use of these data with available methodologies for this species in the Newfoundland area. Tagging would be of limited use as the stock is currently under moratorium, and despite substantial catches in recent years, there are some areas of the Grand Bank which receive little or no fishing effort for groundfish at present. Genetic studies would seem to offer some possibilities, although interpretations of such studies would likely be difficult, based on recent work on other species.

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Table 1. Abundance indices of American plaice, from spring surveys in Div. 3LNO. Data from 1996-2000 are from Campelen trawl, and prior to 1996 are in Campelen equivalent units. The minimum and maximum values in each column are highlighted.

	Division			
Year	3L	3N	3O	Total
1985	1689	398	358	2445
1986	1644	353	267	2264
1987	2019	450	552	3021
1988	2038	296	221	2554
1989	1507	590	445	2542
1990	1068	568	638	2271
1991	574	267	494	1332
1992	268	154	268	689
1993	156	326	286	766
1994	152	76	163	391
1995	118	50	94	262
1996	300	90	309	699
1997	103	78	229	410
1998	134	66	252	452
1999	289	147	289	724
2000	169	178	330	677
Mean	764	255	325	1344
min/max	0.051	0.078	0.110	0.087

Table 2. Summary of assessments of the Div. 3LNO American plaice stock within ICNAF/NAFO.

Years	Aggregation of Data	Assessment Method
1971-76	Div. 3L, 3N separate; sexes separate	VPA, calibrated with F on effort
1977-79	Div. 3LN, 3O separate; sexes separate	VPA, calibrated with F on effort
1980-88	Div. 3LN; sexes combined. TAC for 3LNO calculated by adding Recent average catch for 3O to 3LN catch projections.	1980-83: VPA cal. with F *vs* effort, biomass *vs* CPUE, Pop #'s from VPA *vs* #'s from RV surveys
		1984: VPA cal. with VPA fishable biomass *vs* CPUE, Pop #'s from VPA *vs* #'s from RV surveys
		1985-86: VPA cal. with VPA fishable biomass *vs* CPUE
		1987-88: VPA cal. with VPA fishable biomass *vs* CPUE, Pop #'s from VPA *vs* #'s from RV surveys
1989 on	Div. 3LNO; sexes combined	1989: ADAPT – 2 formulations: Fully rec. biomass *vs* CPUE; SPA #'s *vs* RV #'s (age –disaggregated)
		1990: ADAPT – 1 formulation: SPA #'s vs CPUE #'s at age; SPA #'s *vs* RV #'s (all age –disaggregated)
		1991: no VPA accepted. Assessment based on analysis of surveys.
		1992: ADAPT and Laurec-Shepherd tuning, using SPA #'s *vs* RV #'s and CPUE #'s at age
		1993: ADAPT and L-S tuning, using SPA nos *vs* RV #'s
		1994-98: No VPA. Assessments based on analysis of survey data.
		1999: ADAPT, using SPA #'s *vs* spring and fall RV #'s at age. Change in m to 0.6 for 1989-96
		2000: Stock monitored – no full assessment
		2001: ADAPT, using SPA #'s *vs* spring and fall RV #'s at age. Change in m to 0.53 for 1989-96

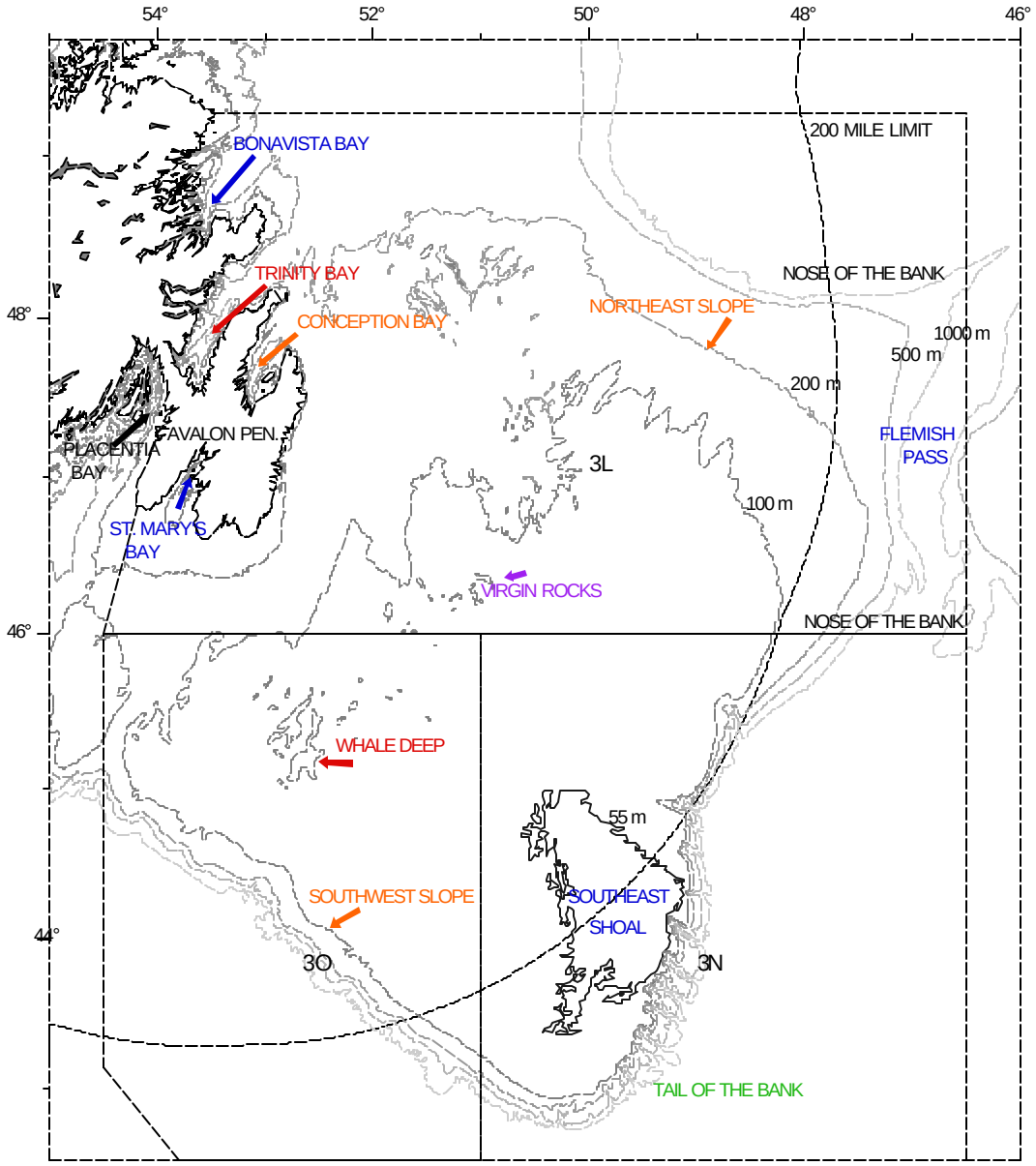

Fig. 1. Map of Grand Bank, NAFO Div. 3LNO, with some place names referred to in the text.

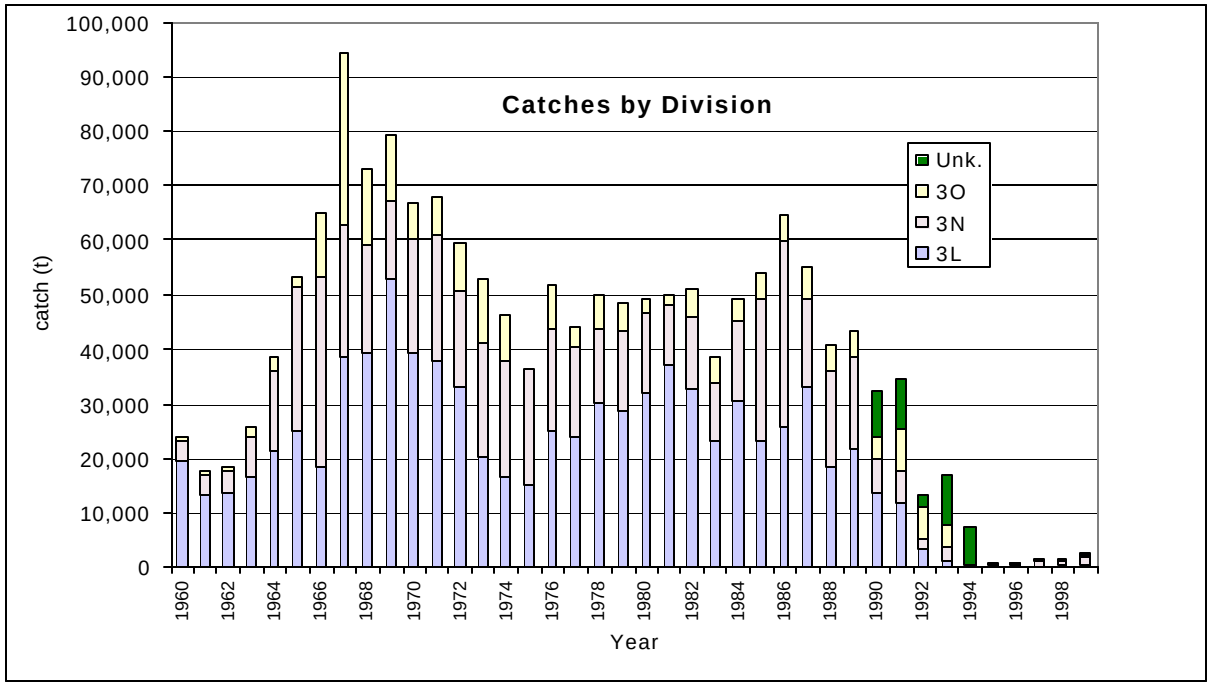

Fig.2a. Catches of 3LNO American plaice, by Division, 1960-99.

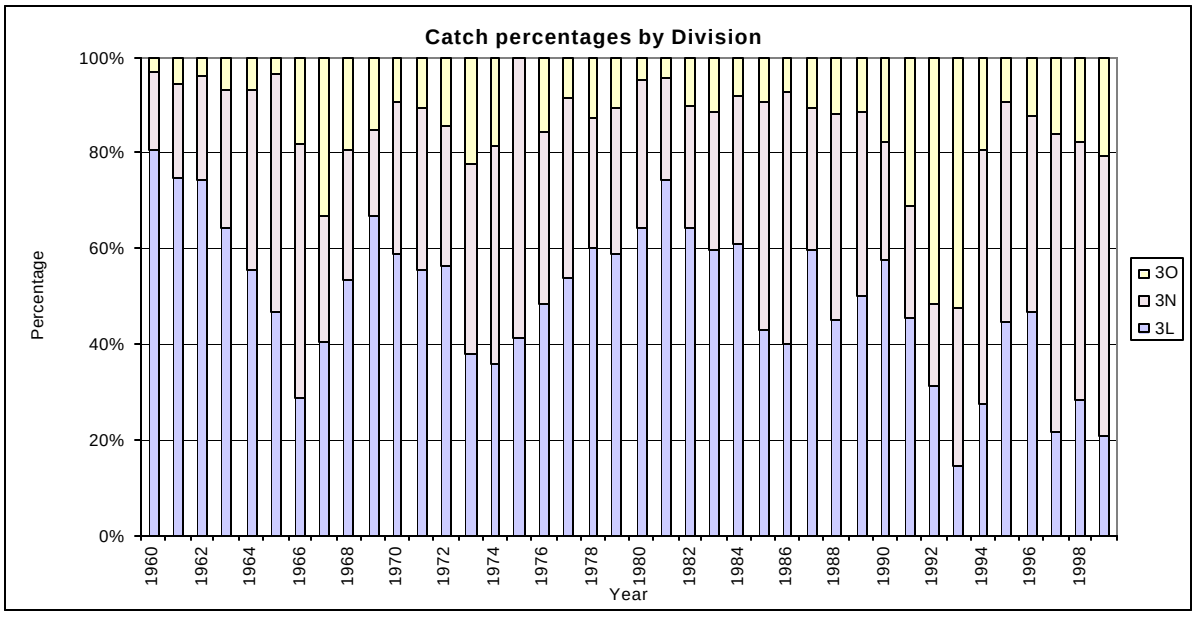

Fig.2b. Catch percentages of 3LNO American plaice, by Division, 1960-99.

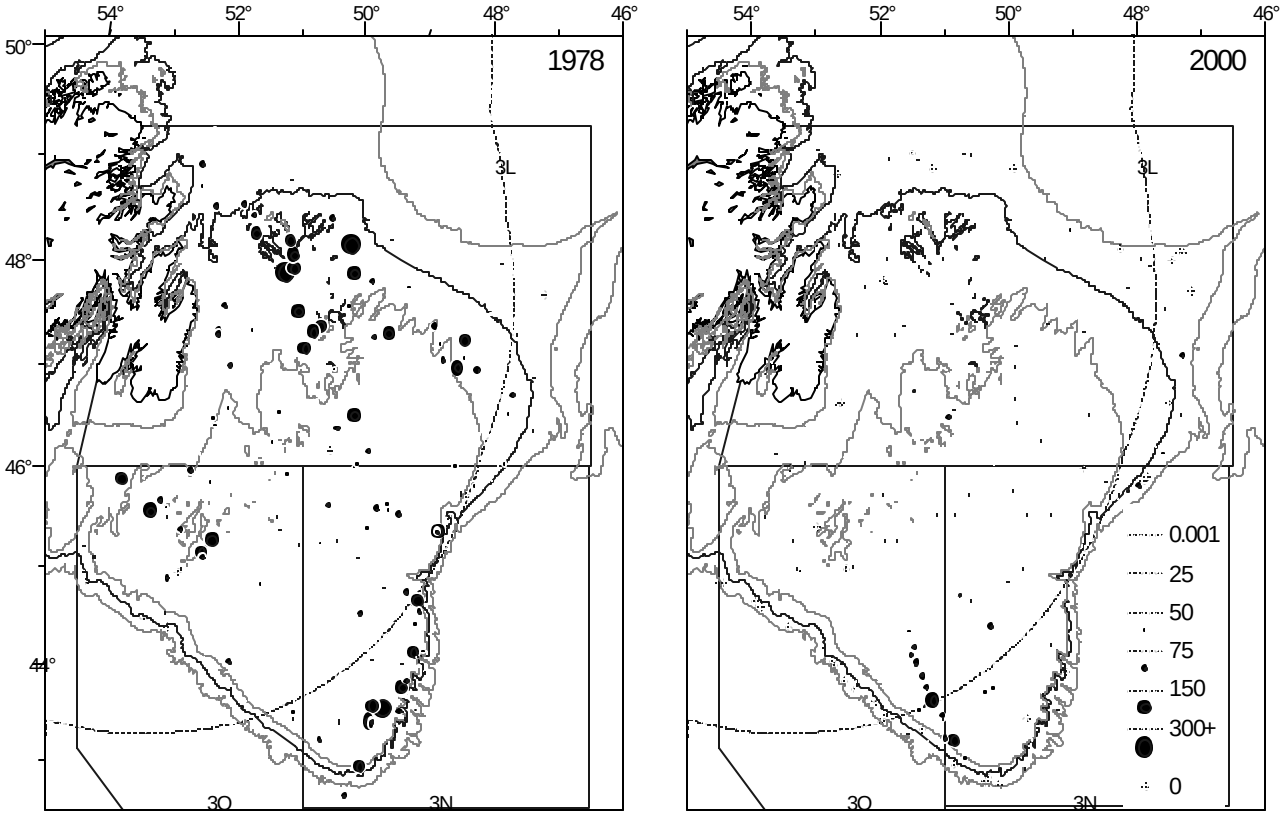

Fig. 3. Distribution of American plaice catches (1978 data is kg per standard 1.8 Nm tow and 2000 data is kg per standard 0.8 Nm tow) from research vessel surveys conducted in 1978 and 2000.

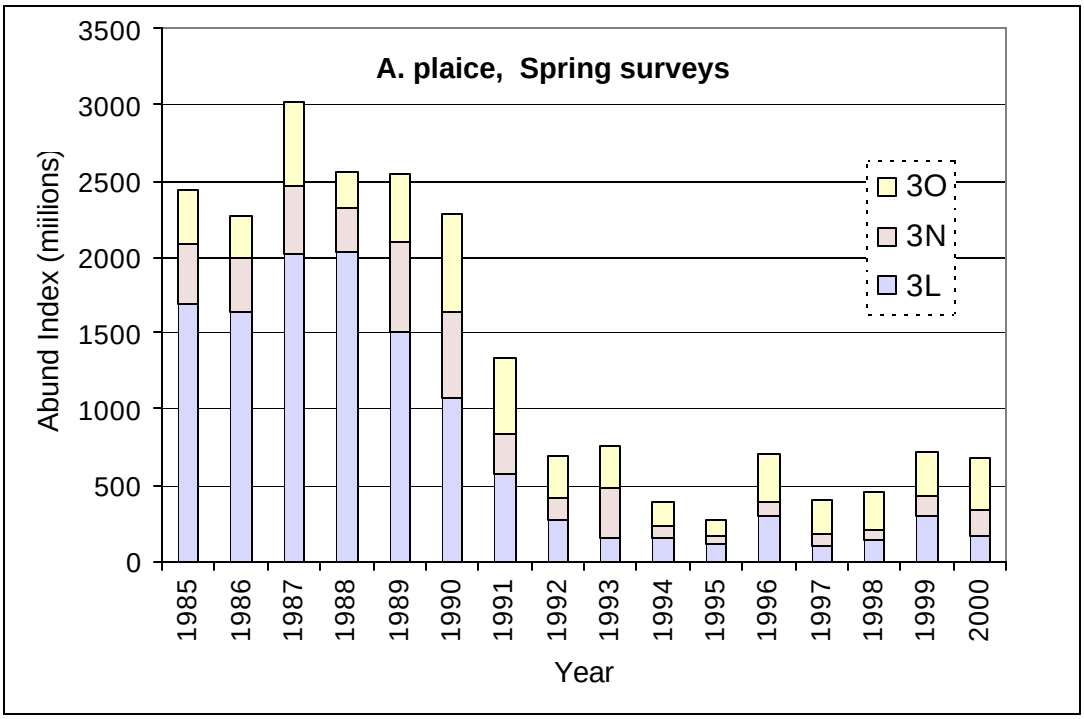

Fig. 4a. Abundance indices from spring surveys in Div. 3LNO. Data are in Campelen trawl equivalents and are taken from Morgan *et al*, 2001.

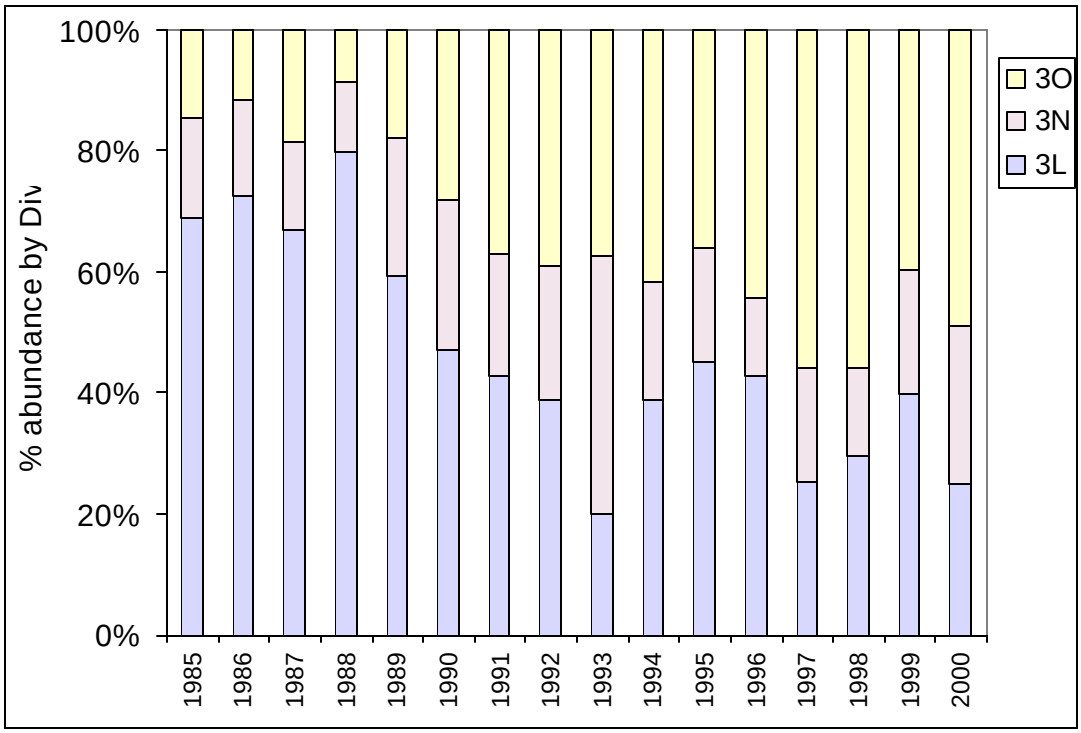

Fig. 4b. Abundance indices from spring surveys in Div. 3LNO, expressed as Divisional percentages. Data from the previous figure.

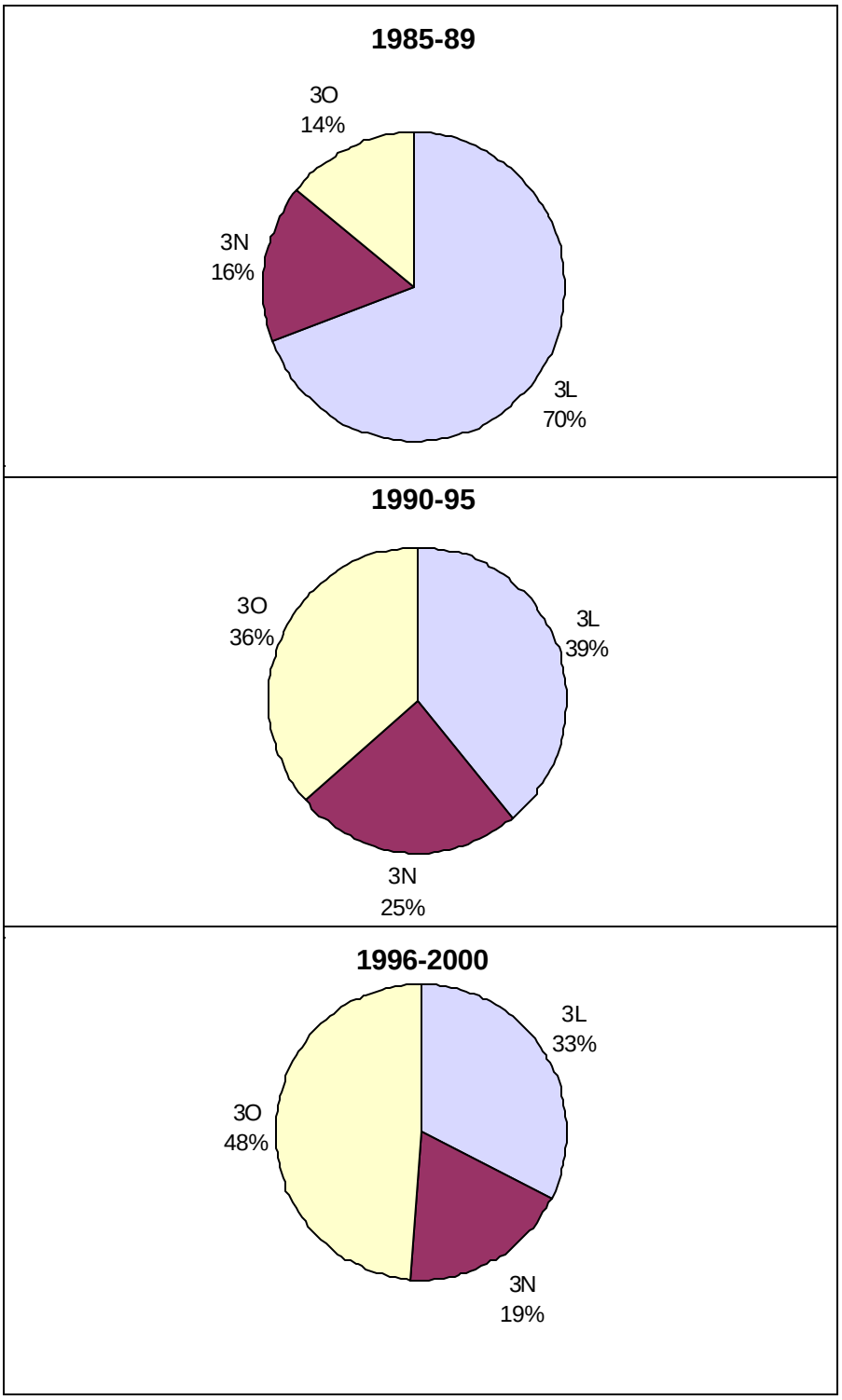

Fig 5. Mean percentage abundance of American plaice, by Division, for three time periods.

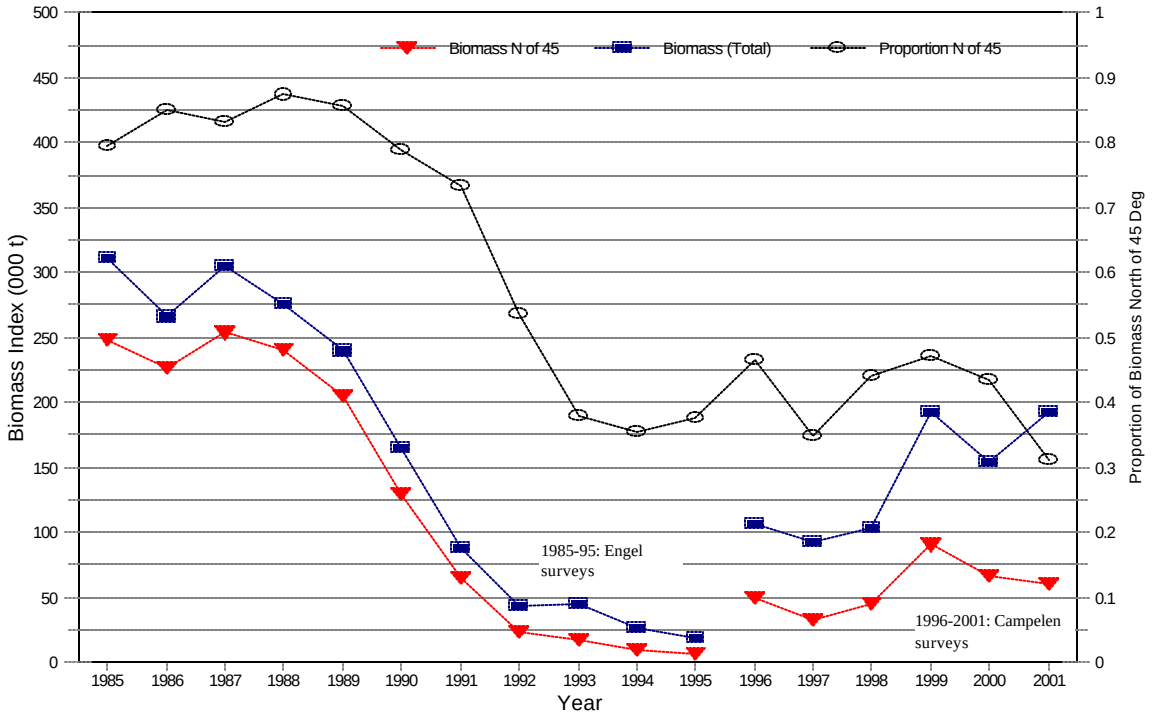

Fig. 6. Proportion of American plaice biomass in Div. 3LNO found north of 45 degrees N latitude, as measured by spring surveys.

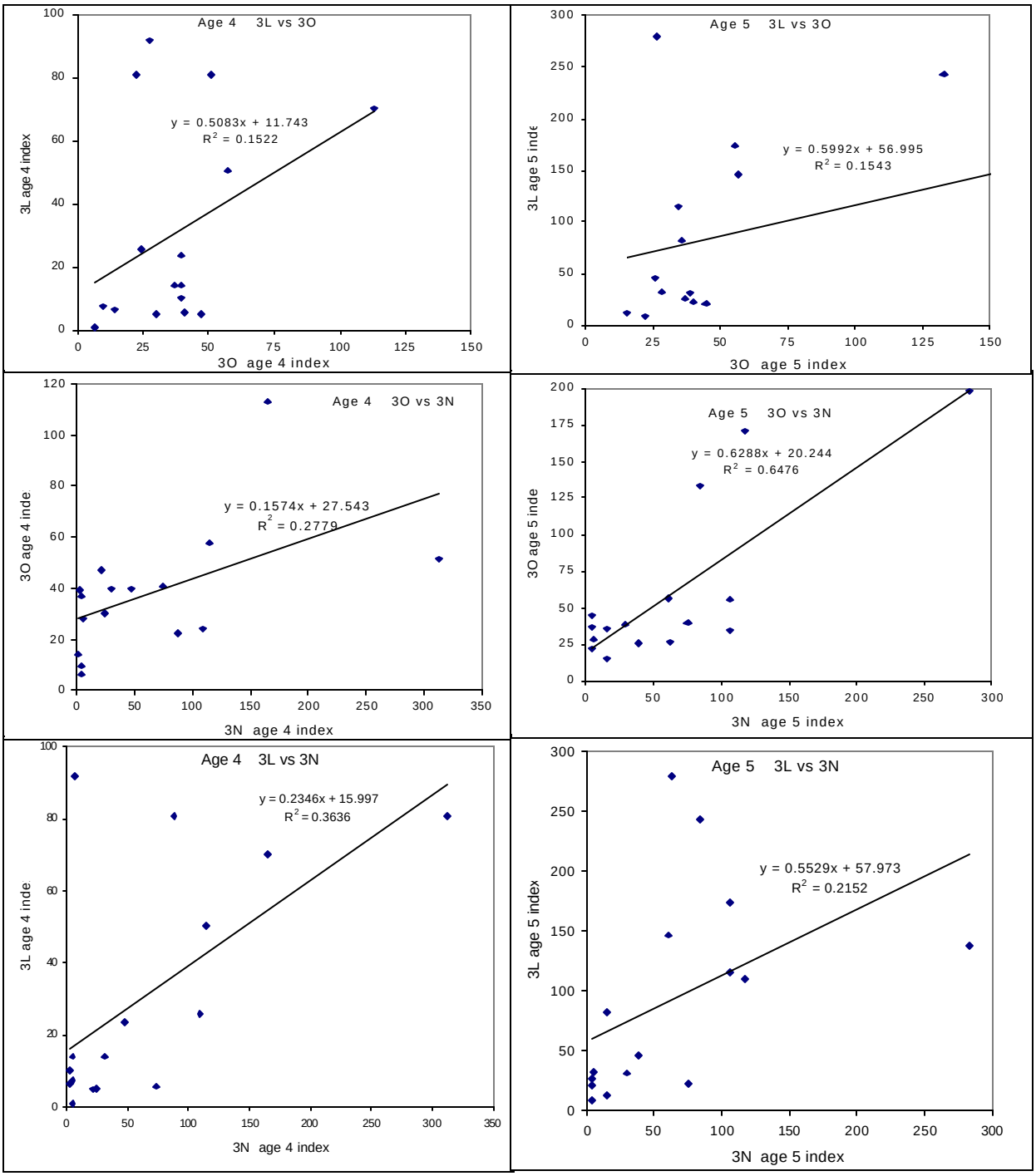

Fig. 7. Correlation of abundance estimates from spring surveys, ages 4 and 5, by Division.