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Factors influencing weight at age of cod off eastern Newfoundland (NAFO Divisions 2J+3KL)

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Abstract

(ei Gadus morhua ee)
(ei Mallotus villosus ee)

Growth increments and condition factor in the northern cod stock (NAFO Divs. 2J, 3K and 3L) measured from research vessel trawl samples show considerable variability over the period 1978 to 1994. This variability in the data is examined through a variety of plots. Scatter plots of growth and condition data against temperature, cod biomass and capelin abundance in cod stomachs are used to look for possible correlations. A near-decadal scale cycle in the area of the cold intermediate layer (CIL) is correlated with the cycle in cod growth. The generally declining trend in temperature is correlated with the declining trend in growth. Correlations between the abundance of capelin in cod stomachs and cod growth or condition are not easy to interpret and probably require more attention to temporal and spatial patterns of abundance of predator and prey to resolve. Correlations with cod biomass are weak and, with the exception of Div. 3L, are positive, i.e. do not provide evidence of density dependent growth. It is important to take changes in growth into account in future management of this cod stock and predictive models based on variables such as the area of the CIL would be very useful.

Introduction

Growth of Atlantic cod (*Gadus morhua*) varies considerably among stocks, with much of the difference attributable to variability in ambient temperature (Brander 1995). There is also persistent geographic variability within some stocks, such as those around Iceland (Jónsson 1965) and off Labrador and eastern Newfoundland (Fleming 1960; May et al. 1965). Within the latter region there has historically been a cline in growth, from very slow growth off central Labrador to relatively rapid growth on the southwestern Grand Bank.

Annual variability in growth has been reported for many cod stocks, with important implications for fisheries management. Studies of factors responsible for this variability have emphasized temperature, stock size and the abundance of prey. In the stock of cod occupying Northwest Atlantic Fisheries Organisation (NAFO) Divisions 2J, 3K and 3L (commonly called the northern cod stock), changes in length-at-age of cod were found to be affected by both the biomass of the cod stock (Wells 1984, 1986; Millar and Myers 1990) and temperature (Millar and Myers 1990). There has also been concern that cod growth might be affected by changes in abundance of capelin, the most important prey of cod on the Northeast Newfoundland Shelf (Lilly 1987). Declines in capelin abundance have been correlated with reductions in growth rate of cod in waters around Iceland (Steinarsson and Stefánsson 1991) and with a reduction in both growth rate and

somatic condition of cod in the Barents Sea (Mehl and Sunnanå 1991; Jørgensen 1992). However, neither Akenhead et al. (1982) nor Millar et al. (1990) could find a statistically significant relationship between cod growth and capelin abundance off Newfoundland. The lack of statistical significance might reflect weak linkage between cod and its prey, but might also reflect an inability to detect a link because of uncertainty in the timeseries of capelin abundance (Akenhead et al. 1982; Shelton et al. 1991).

In 1990 the ICES Multispecies Assessment Working Group undertook an analysis of growth in cod from four Arctic/boreal systems (Barents Sea, Iceland, Greenland and Newfoundland, Anon 1991). Length at age and length increments were examined for stock density, capelin abundance and temperature effects. A significant residual year effect was found in most of the data sets after accounting for these three factors. At a subsequent meeting of the Working Group (Anon 1992) cod stomach content data for the North Sea, Baltic Sea, Barents Sea, Iceland, Newfoundland and Northeast USA were compiled into a common format and analysed in some detail. At this same meeting further, but preliminary analysis of the cod growth data base was carried out taking into account the information in the cod stomach content data base. It was concluded (Anon 1992) that in the comparison among ecosystems "the relationship between growth and feeding remains confounded by the inter-dependencies of growth, temperature-dependent stomach evacuation and differences in environmental temperature".

Brander (1995) extended the analysis of the temperature effect to 17 cod stocks and concluded that 92% of the variance in the logarithm of mean weight at age for ages 2 to 4 fish among stocks can be explained by a ANCOVA model with age (class) and temperature (continuous) effects. The weight at age data used in Brander's study came mainly from the sampling of the commercial catch. For the stock off Labrador and the east coast of Newfoundland, and possibly for other stocks, the weight at age in the commercial catch is inferred from a constant length-weight relationship. Although the comparisons among cod stocks by Anon (1991, 1992) and Brander (1995) has much merit, we believe that more detailed intra-stock analyses are required if the combined and probably interacting effects of temperature, food, population density and fishing mortality on cod growth are going to be disentangled.

In this paper we return to the problem of explaining cod growth variability off southern Labrador and the east coast of Newfoundland in further detail. In particular we attempt to (i) account for the length-stratified approach to the subsampling of the research trawl catch, (ii) consider thermal measures additional to those made at Station 27, (iii) give greater consideration to weight at age data, (iv) evaluate condition factor data, and (iv) give further consideration to the possible effects of capelin abundance in cod stomachs on cod growth. The approach in this study remains primarily descriptive and exploratory. Formal hypothesis testing and statistical inference leading to predictive models of use in stock assessments have been attempted in the past (e.g. Millar and Myers 1990) and are an objective for future studies by ourselves. Strong signals in ocean temperature data (e.g. Colbourne 1995), cod population size (see Bishop et al. 1995), the abundance of capelin in cod stomachs (Lilly 1993, 1994, 1995), and possibly the abundance of capelin in the ocean (Carscadden 1994) should facilitate statistical inference, however, before proceeding further with such analyses, we believe that a solid base of data description and exploration is required. Although the present paper does not complete this task for the southern Labrador and east coast of Newfoundland region, we hope it is a further step in this direction.

Data sources

Temperature measurements

Temperature profiles from surface to bottom (175m) are routinely taken throughout the year at Station 27 just off St John's (Fig. 1) at the commencement and termination of nearly every research cruise (Colbourne et al. 1994, Colbourne 1995). For this analysis all data for the period 1978 to 1994 have been used to compute annual average water column temperature. In addition, the bottom temperature anomaly from the longterm mean (1961-90), following Millar and Myers (1990), has been considered.

Oceanographic transects across the Hamilton Bank (Seal Island) in Div. 2J, off Bonavista Bay across the Div. 3K/ Div. 3L boundary, and in Div. 3L shorewards from the Flemish Cap along the 47° N latitude have been surveyed regularly in summer since the 1950s (Colbourne et al. 1994, Colbourne 1995). Annual estimates of the area of the cold intermediate layer (CIL), defined as $\leq 0^{\circ}\text{C}$, have been calculated as an index of thermal conditions within the northern cod habitat (Colbourne 1995) and are used in this study.

Estimates of cod abundance

Two sources of information on cod abundance were considered - research vessel (RV) estimates for each division and estimates from sequential population analysis. RV surveys have been conducted by Canada during the fall in Divs. 2J, 3K and 3L since 1977, 1978 and 1981 respectively (excluding 1984 in Div. 3L). All surveys in Divs. 2J and 3K were conducted with the 74 m stern trawler R.V. 'Gadus Atlantica'. Surveys in Divs. 3L were conducted with the 51 m side trawler R.V. 'A. T. Cameron' and the sister 50 m stern trawlers R.V. 'Wilfred Templeman' and R.V. 'Alfred Needler'. The 'Gadus Atlantica', 'Wilfred Templeman' and 'Alfred Needler' deployed an Engel-145 trawl, whereas the 'A. T. Cameron' deployed a Yankee 41-5 trawl. In all instances, a 29 mm meshliner was inserted in the codend. Tows were made at 3.5 knots for 30 min at each fishing station, and catches from the few tows of duration other than 30 min were appropriately adjusted. No adjustments were made for possible between-vessel differences in catching efficiency. Details regarding areas and locations of strata and changes in survey pattern are provided by Bishop et al. (1994), Lilly and Davis (1993) and Bishop (1994). The most notable change in survey coverage was the addition of depths between 100 and 200 m in northwestern Division 3K (St. Anthony Shelf and Grey Islands Shelf) in 1984 and subsequent years. Fishing in all divisions and years was conducted on a 24-h basis. Set allocation within each stratum is random, with the number of sets determined primarily by the area of the stratum. Boundaries to strata correspond to water depth contours. The RV estimates of trawlable biomass by division obtained from the program STRAP (Smith and Somerton 1981) are provided in Bishop et al. (1995).

A version of sequential population analysis, ADAPT, has been routinely applied in northern cod assessments to commercial catch at age data and tuned using the RV estimates of abundance from STRAP. ADAPT estimates of biomass in Divs. 2J3KL combined are provided in Bishop et al. (1993).

Length and weight at age samples from fall RV surveys

The number of cod sampled for which length and body weight measurement are available and for which age was determined directly from the otolith (rather than an age-length key) varies across years and among ages (Tables 1-3). During the early years of the surveys, otoliths for aging were obtained from a sample of 25 cod per 3-cm length-group per division. An additional sample of 5 cod per 3-cm length-group was frozen at sea and thawed in the laboratory, where otoliths were extracted and body weight (both whole and gutted, head-on) was recorded. All fish were measured (fork length, cm) at sea. Additional samples of frozen fish were collected in Div. 2J in 1984 and 1985. The number of frozen fish increased in 1988 and subsequent years, when Divs. 2J and 3K were both subdivided into 2 areas, and a sample of 5 cod per 3-cm length-group was obtained from each area. The number of cod for which weights were available increased dramatically when weighing at sea was initiated (in 1989 in Divs. 2J and 3K and in 1990 in Div. 3L, Table 2). Length-at-age was determined for a total of 30,535 cod (Table 1) over the study period. Body weights were obtained for 13,822 of these cod (Table 2).

The cod for which length and weight at age were determined represent a subsample of the trawl catch at each station. The subsample is length stratified - where possible 25 fish are collected from each 3 cm length interval in each of the three divisions over the course of the survey. From 1989 onwards in Divs. 2J and 3K and from 1990 onwards in Div. 3L body weights have been recorded at sea prior to freezing and these weights have replaced the thawed weight previously entered into the data base. Although these two weights are expected to differ systematically, a correction has not yet been applied (although the data are available to do so) and in the present study the difference has been ignored.

In addition to the subsample, the length frequency of the entire catch for each set, or a random portion of the catch if it is too large to process, is also determined. The sample length frequency is transformed into a population length frequency in each division using the program STRAP (Smith and Somerton 1981). In this study population mean length and weight at age by division were obtained by weighting the individual measurements in the biological sample by the ratio of the sample number per 3 cm length class to the STRAP estimate of the number in the population in each 3 cm length class.

The average number of length and weight samples by age for the period 1978 to 1994 are summarised in Table 3. It is evident that after age 10 the number of length samples is considerably reduced (<20 per year on average). The number of samples for weight is low (<20 per year) after about age 8. For this reason the present analysis was restricted to ages 10 and less for length at age and ages 8 and less for weight at age. Although the number of samples are also low for ages less than 3, there is relatively little variance in length and weight at age among samples within a year, so ages 1 and 2 have been included in the analysis.

Cod condition measurements from fall RV samples of length and weight at age

Condition was expressed as Fulton's condition factor:

$$K = 100 * (W/L^3)$$

where W is body weight (g) and L is fork length (cm). Both whole body (round) weight and gutted (head on) weight were used. Round weight is of greater significance when considering the impact of growth on stock assessments and the TAC. Gutted weight, with liver and gonad weight measured separately, are of greater significance when considering aspects of bioenergetics and are

currently subjects of further study not reported here. Because growth in cod is not isometric, annual variability in condition was compared within specific cod length-groups rather than within age-groups.

Cod stomach contents from fall RV surveys

Stomachs were collected from up to 3 randomly selected cod per 10-cm length-group per station in 1980-1982 and 3 per 9-cm length group in 1983-1994. Stomachs were not collected from fish which showed signs of regurgitation, such as food in the mouth or a flaccid stomach. Stomachs were individually tagged and excised. In 1978-1993, the stomachs were fixed and preserved in 4% formaldehyde solution in seawater prior to examination of their contents in the laboratory. In 1994, the stomachs were frozen prior to examination.

Examination involved separation of food items into taxonomic categories. Fish and decapod crustacea were identified to species, but most other groups were assigned to higher order taxa. Items in each taxon were placed briefly on absorbent paper to remove excess liquid, and then counted and weighed to the nearest 0.1 g.

The quantity of capelin in the stomachs of the cod from a specified sample was expressed as a mean partial fullness index (Fahrig et al. 1993):

$$PFI_c = \frac{1}{n} \sum_{j=1}^n \frac{W_{cj}}{L_j^3} \cdot 10^4$$

where W_{cj} is the weight (g) of capelin in fish j , L_j is the length (cm) of fish j , and n is the number of fish in the sample. This index is based on the assumption that stomach capacity is a power function of length, and is analogous to Fulton's condition factor. Mean total fullness index was calculated as

$$TFI = \frac{1}{n} \sum_{j=1}^n \frac{W_{tj}}{L_j^3} \cdot 10^4$$

where W_{tj} is the total weight of prey in fish j .

For simplicity, the present analysis was restricted to cod within the 36-71 cm length range, and all cod within this range were pooled. Cod smaller than about 30-35 cm cannot feed on the largest capelin and cod larger than about 70 cm tend to feed to an increasing extent on groundfish and crabs (Lilly 1991).

Capelin abundance estimates

Estimates of capelin biomass from hydroacoustic surveys conducted by Canada and Russia during the fall in Divs. 2J and 3K are available intermittently from 1974 onwards (Miller 1994). Considerable uncertainty exists regarding some of the estimates, particularly those in recent years (see for example Carscadden 1994).

Data description

Temperature

Water temperatures on the shelf off Labrador and Newfoundland have been below the longterm mean for most of the period since 1980, with two unusually cold periods in the mid-1980s and early 1990s (Colbourne et al. 1994). These recent two cold periods separated by a warmer period can be clearly seen in the annual average water column temperature and bottom temperature anomaly plotted in Fig. 2. Underlying this near-decadel scale variability is longer period variability apparent as a downward trend in temperature over the study period with current values well below the relatively warm 1950s and 1960s (Colbourne 1995). The near-decadel scale variability is clearly illustrated in the annual variability in the area of the CIL calculated along the three transects within the study area Fig. 3). As well, the upward trend in the area of the CIL, corresponding to the cooling trend in Fig. 2, can be seen.

Capelin

Estimates of capelin biomass from hydroacoustic surveys conducted by Canada and Russia during the fall in Divs. 2J and 3K declined to very low levels in the early 1990s with the Canadian series showing a very abrupt drop between 1989 and 1990. Low levels of capelin in the acoustic fall survey in Divs. 2J and 3K, as well as in the spring survey in Div. 3L have persisted in subsequent years. The 1983 and 1986 capelin year classes are thought to have been particularly strong (Carscadden 1994).

Peaks in capelin PFI in cod stomachs (Fig. 5) in Div. 2J occur in the mid 1980s and in the late 1980s, corresponding to the high values in the Canadian hydroacoustic survey. Subsequently the capelin PFI dropped to a very low level and there was a corresponding drop in TFI. In Div. 3K capelin PFI increased over the 1980s and was fairly constant over the early 1990s, dropping to a low level only in the most recent year for which data are available (1994). The capelin PFI in Div. 3L increased in 1990 and has remained at a high level up to and including the most recent survey. It is clear that there is little compensation in the contribution of other food in the diet of cod and that the trends in TFI are therefore driven mostly by the capelin contribution (Lilly 1991).

It is important to consider changing geographic patterns of cod and capelin abundance in the interpretation of these data (Lilly 1994). Despite the apparent low abundance of capelin in the 1990s, cod in Divs. 3K and 3L had a relatively high capelin PFI, at least partly because the capelin changed their distribution and occupied the restricted area where bulk of the remaining cod population was encountered during the fall RV survey. The low capelin PFI in Div. 2J corresponds to a very low abundance of cod in this division after 1989.

Cod abundance

The time series of cod abundance in fall RV surveys and from the ADAPT estimates are illustrated in Figs. 6 and 7. The RV estimates fluctuated with no apparent trend up to 1988. High estimates in 1986 in Divs. 2J and 3K relative to estimates before and after are not easily interpreted. The progressive decline in Div. 2J, Div. 3K and Div. 3L in the late 1980s and 1990s to the current low biomass is clearly seen. The ADAPT time series is smoother and suggests that the biomass rose to a peak in 1984 following extension of jurisdiction and then declined monotonically to 1992,

after which sequential population analysis has not been applied. These perspectives on the changes in cod stock size, although not independent because of the tuning exercise, are somewhat different and both have been considered in the data exploration exercise that follows.

Cohort length at age

The cohort length at age for Divs. 2J, 3K and 3L are plotted in Fig.8 for ages ≤ 10 . Note that because the point estimates are from the fall of each year and growth is slow over the winter, most of the increment in length or weight is occurring in the following year. Cohorts are taken back to age 0 at which age length is assumed to be 0 to facilitate the identification of cohorts in the plots. Lines roughly parallel to the x-axis identify the ages whereas lines roughly parallel to the y-axis indicate cohorts. Ridges corresponding to fast growing cohorts and valleys corresponding to slow growing cohorts can be clearly seen in the plot for Div. 2J and to a lesser extent in the plot for Div. 3K. The Div. 3L "surface" is relatively flat.

The ridges in the cohort growth correspond to fast growing 1976-78 cohorts and fast growing cohorts from the early to mid 1980s. The elevated length increment does not occur in all ages in these cohorts but by age 4 the effect of the cumulative increment is clear and remains distinct to age 6, after which the general slowing down in growth and increasing measurement error tend to obscure the pattern. The valleys correspond to slow growing cohorts from the mid 1970s, late 1970s-early 1980s and late 1980s. The most marked declines in growth in these cohorts (lowest points to the valleys) occurred in the mid 1980s and early 1990s, primarily within ages 2 to 5, particularly in Div. 2J but also in Div. 3K. Year-to-year variability is much less pronounced in the Div. 3L data.

In addition to these cohort and year effects in the growth, it is evident that there is an overall decreasing trend in length at age in Divs. 2J and 3K illustrated by the downward slope of the iso-age lines with time. A similar trend is not apparent in the Div. 3L data.

Cohort weight at age

The cohort weight at age plots (ages ≤ 8) for the 3 divisions (Fig. 9) show similar pattern of ridges and valleys to those described above for the cohort length at age plots. The overall downward trend in weight at age in Divs. 2J and 3K is also quite marked, illustrated by the decrease in area of the rectangles bounded by age and cohort lines in the right portion of the plots. There is some indication of an increase in weight at age for the 1989+ cohorts in the older ages and most recent years.

Year effects in length and weight increments

In an attempt to see the year effects in length and weight increments more clearly, the general approach taken in the 1992 Multispecies Assessment Working Group (Anon 1992) was adopted. A multiplicative model accounting for age and year effects were fitted to the logarithm of the annual increments for each division separately,

$$\text{Ln}(X_{ij}) = \alpha_i + \beta_j + \varepsilon$$

where X_{ij} is the length or weight in a particular division at age i in year j , α_i is the age effect, β_j is the year effect and ϵ is normally distributed error. The vector β_j for both length and weight is plotted for each division in Fig. 10. The year effects for both length and weight increments in Divs. 2J and 3K have a similar pattern and are compatible with the downward trend and near-decadel scale variability described in the cohort plots. As explained above, the effect ascribed to year t occurs mainly in year $t+1$, requiring that these year effect estimates be lagged by one year in the subsequent data exploration exercises described below.

Condition

Annual variability in condition based on round weight was similar among cod length-groups, but differed among divisions (Fig. 11). In Div. 2J, average condition based on round weight increased slowly but irregularly in the 1980s before declining abruptly in the early 1990s. There is some indication of an increase in the most recent two years. In Div. 3K, condition fluctuated without trend until the mid-1980s, when it increased for about 4 years before dropping back to the earlier level. In Div. 3L, there was a small increase in the 1990s.

Condition based on gutted weight (Fig. 12) was less variable than condition based on round weight. In Div. 2J, there was no trend until a rapid decline in the early 1990s, followed by some improvement in recent years. In Div. 3K, condition based on gutted weight did not rise as prominently in the mid-1980s as did condition based on round weight. In Div. 3L, condition based on gutted weight was variable but without trend. Similar patterns in annual variability in condition based on gutted weight are apparent when the data are presented by age-group (Bishop and Baird 1994; Taggart et al. 1994; Bishop et al. 1995).

Data exploration

A data exploration exercise was carried out to compare the patterns described above for cod growth and the "environmental" variables. The primary tool adopted for doing this was scatter plot analysis and the construction of 95% bivariate normal density ellipses. Correlation in the variables is seen by the collapsing of the ellipses along the diagonal. If the ellipses is fairly round and not orientated along the diagonal then the variables are not correlated. In this exercise correlations are not taken to indicate cause and effect, but to suggest possible relationships that could be examined further.

Correlations with capelin

The PFI for capelin in cod stomachs is plotted against cod length increments, weight increments and condition factor in Fig. 13. Correlations with length and weight increments are generally weak. The Div. 2J PFI for capelin show little correlation with cod length and weight increments but is positively correlated with condition factor in Divs. 2J and 3K and negatively correlated with condition in Div. 3L. Div. 3K capelin PFI is negatively correlated with length and weight increments in all divisions but in some cases the correlation is very weak. There is no correlation with condition factor. Capelin PFI for Div. 3L is weakly negatively correlated with length and weight increments. However there is a relatively tight ellipses indicating negative

correlation in the scatter plot with Div. 2J and 3K condition factors and a positive correlation with Div. 3L condition.

The generally negative correlations, albeit weak, between capelin PFI and cod length and weight increments are unexpected. Increased consumption of capelin, and hence generally increased total consumption, might rather be expected to translate into increased growth increment. The positive correlation between capelin PFI in Div. 2J and cod condition in Divs. 2J and 3K is reassuring. The differing correlations between capelin PFI and condition between Divs. 2J/3K and Div. 3L might suggest that good feeding conditions in the north occur at the expense of fish in the south, and vice versa. It is of interest that the intermediate area, Div. 3L shows virtually no correlation with any of the growth or condition data.

Correlations with cod biomass

The RV survey biomass estimates for the three divisions and the ADAPT estimate of 3+ biomass are plotted against the growth and condition data in Fig. 14. With few exceptions, the correlations are weakly positive. Correlations with Div. 3L condition are negative. The tightest positive correlations are between weight increment estimates in Div. 2J and RV estimates in Div. 2J as well as ADAPT estimates. Correlations with population size are generally anticipated to be negative because of density dependent effects, however in this study period the correlations are consistent with a growth contribution to the observed biomass changes.

Correlations with Station 27 temperature data

Average annual water column temperature and annual bottom temperature anomaly are plotted against the growth and condition data in Fig. 15. Correlations vary in strength but are generally positive with growth and condition data for Divs. 2J and 3K but negative with the Div. 3L data. Correlations are weakest with respect to Divs. 2J and 3K length increments. With the exception of Div. 3L, these correlations are consistent with warm water conditions causing enhanced growth.

Correlations with area of the CIL

Annual estimates of the area of the CIL for the three sections as well as the average area for all three sections combined are plotted against growth and condition data in Fig. 16. Correlations are generally negative, with the exception of Div. 3L, and in some cases are quite strong. For example, weight increments in Divs. 2J and 3K are considerably smaller when the area of the CIL is large. Div. 2J length increment data are also negatively correlated with area of the CIL but the relationship with Div. 3K length increment data is not clear.

Further exploration of the correlation with area of the CIL

To examine the correlation in growth increments with the average area of the CIL from the three sections more closely, the total length and weight increment in each cohort from the beginning of age 2 to the end of age 5 was plotted against the average area of the CIL experienced by the cohort over that period (Fig. 17). For the CIL data this is equivalent to a 3 year running mean and brings out the near-decadal scale cycle very clearly. Evaluating the growth increment over the three

years of the cohort's life when most of the growth is occurring and for which most of the data are available brings out the near-decadel scale of variability in growth more clearly than can be seen by plotting year effects in the increments. This is probably at least in part because the year to year errors in the sample estimates cancel. Warren (1993) applied the Kalman Filter technique to the cod growth data for Divs. 2J, 3K and 3L for a longer time period. This technique appears to be particularly useful in picking out both the downward trend and the near-decadel cycle in growth. For the time periods that overlap the pattern is very similar in the study by Warren (1993) and in the present study.

In the case of both length and weight increments, but most clearly with respect to weight, the increments decline when the area of the CIL increases and increase when the area of the CIL declines. The overall declining trend in growth, particularly strong with respect to weight, is also apparent, corresponding to the increasing trend in CIL, most easily seen in the plots in Fig.3.

Discussion and Conclusions

Cod growth has varied considerably over the time period considered in this study. There appears to be at least two components to this variability: (i) a downward trend over the entire period and (ii) an approximately decadel cycle in growth. The combined effect, as illustrated in Fig. 17 is that the weight increment by cohorts between the ages of 2 and 5 reached a minimum in Divs. 2J and 3K in the 1986 and 1987 cohorts. The decline in weight increment is quite substantial and could perhaps be referred to as a "collapse in growth". The 1976 and 1977 cohorts benefited from being at both the high end of the trend and the high point in the approximately decadel cycle, and increased by nearly 1.6 kgs over ages 2 to 6. In comparison, the 1986 and 1987 cohorts were at the low end of the trend and the low point in the cycle and increased by only about 400 g in Div. 2J and 700 g in Div. 3K. Thus the weight increment over these ages decreased by more than 1 kg for cod in Div. 2J. The timeseries for Div. 3L is less complete but shows much less evidence of a similar trend or cycle.

Isolating the causes for the trend and cycle in cod growth in Divs. 2J and 3K would have important implications for management of the northern cod stock from both the TAC-fishing mortality aspect and from a spawner stock per recruit point of view. Several variables examined in this study show weak to strong correlation with these changes, but causation is still a matter of speculation. Relationships with temperature, particularly the area of the CIL, may have the most promise with respect to explaining the near-decadel cycle in cod growth. The downward trend in cod growth is correlated with the overall downward trend in ocean temperature over the period of the study. However, other factors, such as the generally increasing fishing mortality over the study period may also be important. Fishing mortality could progressively weed out the fast growing genotypes from the population leaving only genotypes with a low growth capacity.

The effect of capelin on cod growth, while anticipated to occur, is not easy to isolate in the current data. It is thought that the 1983 and 1986 year classes were strong (Carscadden 1994, leading to biomass peaks about two years later in the hydroacoustic surveys (Fig. 4). Cod growth was in fact low following the 1983 year class, however two years after the 1986 capelin yearclass cod growth rate was high and/or increasing. Capelin in cod stomachs in Div. 2J increased in the late 1980s when cod growth rate and condition were high and then decreased sharply to very low levels after 1990, coincident with the abrupt decline in the weight increment and the condition factor, although the overall correlation of capelin PFI with weight is weak. The general increase in capelin in cod stomachs in Divs. 3K and 3L over the time period is not compatible with changes in

growth and condition in Div. 3K, but is consistent with the trend of improving condition in Div. 3L. At this stage the capelin effect on cod growth and condition should be interpreted as equivocal. It seems almost certain that resolution of the temporal and spatial patterns of abundance of cod and capelin are an essential prerequisite to the interpretation of capelin effects on cod (see Lilly 1994 for more insight into this).

Density dependent effects on cod growth rate have been suggested in the past, particularly when the pattern in the residuals are examined after removing the predominant temperature effect (e.g. Millar and Myers 1990). In this data visualization and exploration exercise there is no evidence of density dependent growth in northern cod in Divs 2J and 3K, although there are correlations compatible with density dependent growth in Div. 3L. In Divs. 2J and 3K cod growth and condition are in fact generally positively correlated with biomass estimates supporting the interpretation of an accelerated growth component to the increase in biomass following extension of jurisdiction in 1977.

Difference in the sign of the correlations between Divs. 2J/3K and Div. 3L with respect to the variables considered in this study suggest that fish on the Labrador and north east Newfoundland shelves are responding differently to those on the northern Grand Bank. This is particularly evident with respect to the increasing condition factor in Div. 3L in the late 1980s and early 1990s at a time when condition factor was dropping precipitously in Divs. 2J and 3K. Reasons for the spatial differences over the range of northern cod stock need to be examined in more detail.

The cod stock in NAFO Divs. 2J3KL are presently under a fishery moratorium following the very large decline in biomass in the late 1980s and early 1990s. This decline coincided with rapidly increasing fishing mortality which must be considered to be the major cause. However what amounts to a collapse in growth in cohorts entering the fishery at this time amplified the fishing mortality effect considerably and reduced the biomass and yield per recruit. While it is important to resolve the various contributors to the decline in the northern cod stock, the isolation of predictive relationships between cod growth and, for example, temperature and capelin consumption, could have considerable value in adjusting future fisheries management for changes in cod growth rate.

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Table 1. Number of fish sampled from RV surveys by NAFO division for which both length and age have been determined.

YEAR	NAFO			TOTAL
FREQUENCY	2j	3k	3l	
78	453	457	0	910
79	460	510	0	970
80	600	706	0	1306
81	650	687	614	1951
82	844	747	882	2473
83	725	800	797	2322
84	1055	844	0	1899
85	987	659	801	2447
86	569	670	699	1938
87	819	681	743	2243
88	852	1000	742	2594
89	891	1055	713	2659
90	853	971	706	2530
91	546	764	578	1888
92	263	540	494	1297
93	95	355	378	828
94	62	92	126	280
TOTAL	10724	11538	8273	30535

Table 2. Number of fish sampled from RV surveys by NAFO division for which both weight and age have been determined.

YEAR	NAFO			TOTAL
FREQUENCY	2j	3k	3l	
78	132	120	0	252
79	113	119	0	232
80	140	156	0	296
81	145	141	138	424
82	135	160	51	346
83	173	156	152	481
84	532	167	0	699
85	506	143	147	796
86	119	130	142	391
87	104	132	161	397
88	200	249	156	605
89	890	1055	142	2087
90	852	970	706	2528
91	546	764	576	1886
92	263	538	494	1295
93	95	355	377	827
94	62	92	126	280
TOTAL	5007	5447	3368	13822

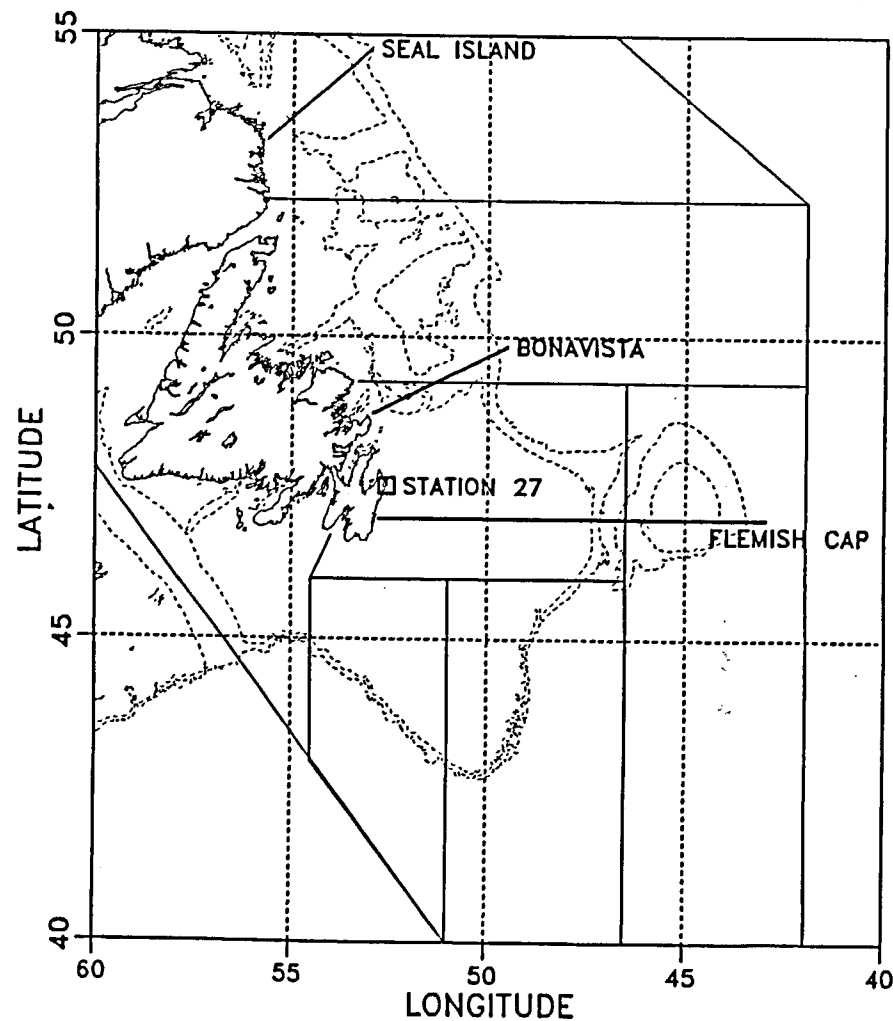
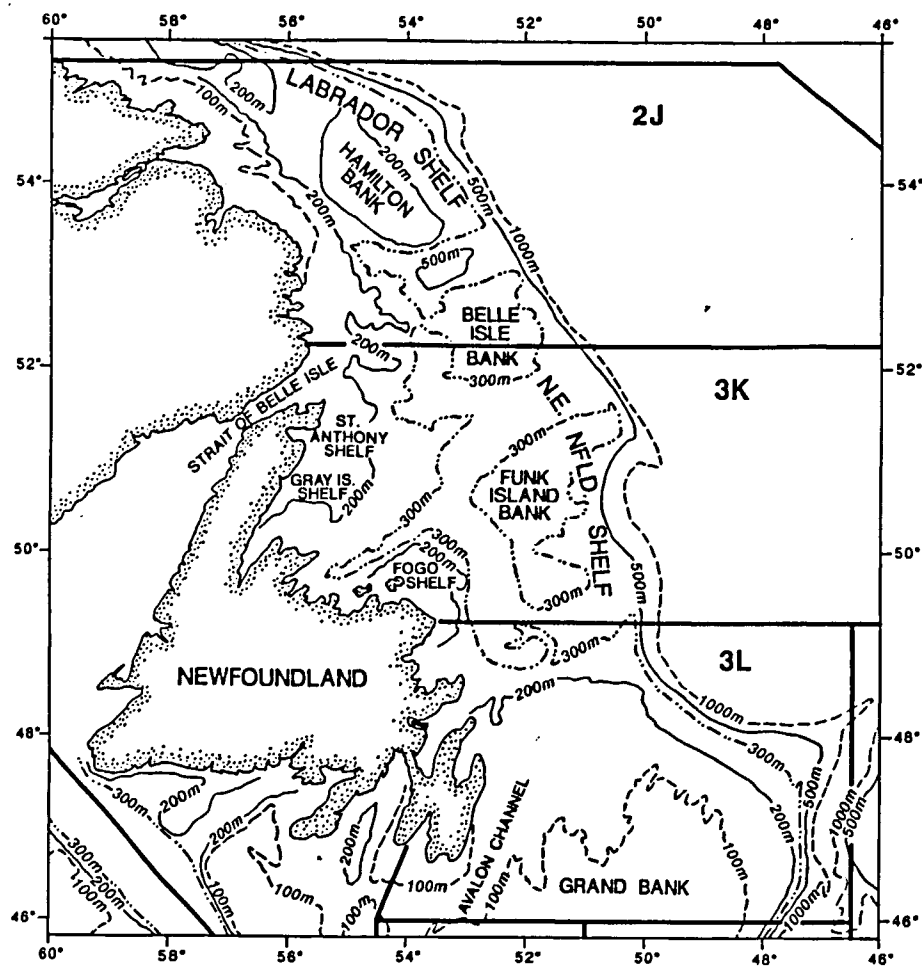


Fig. 1. Maps showing NAFO division boundaries, the location of Station 27 and the position of the three sections. The Seal Island section crosses the Hamilton Bank and is referred to in the text as the Hamilton Bank section.

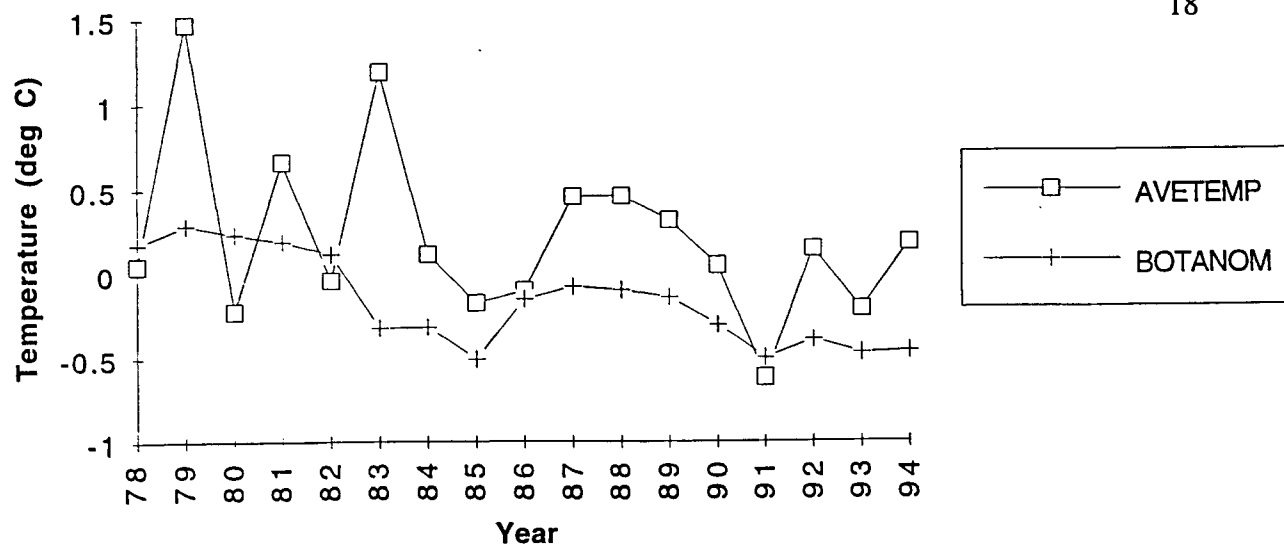


Fig. 2. Time series of Station 27 average annual water column temperature and the bottom (175 m) temperature anomaly from the 1961 - 1990 mean.

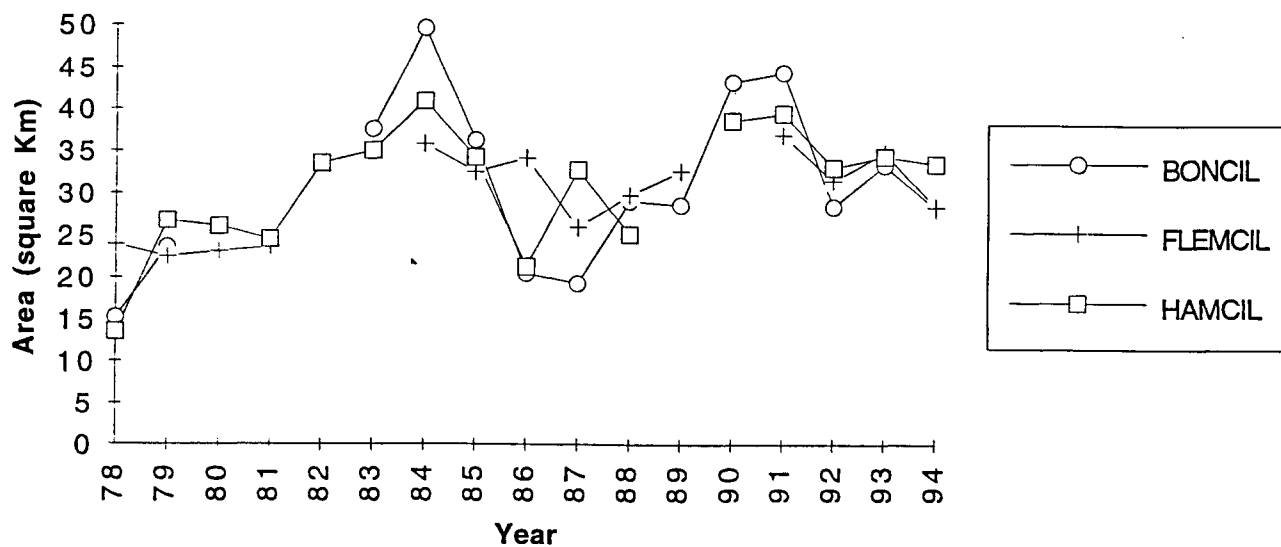


Fig. 3. Annual area of the cold intermediate layer (CIL) on the Hamilton Bank, Bonavista and Flemish Cap sections.

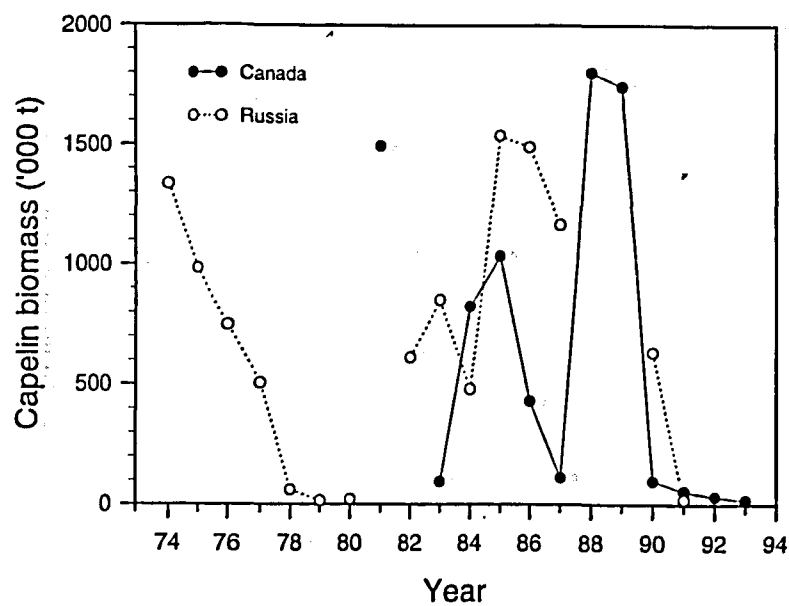


Fig. 4. Canadian and Russian fall capelin hydroacoustic estimates.

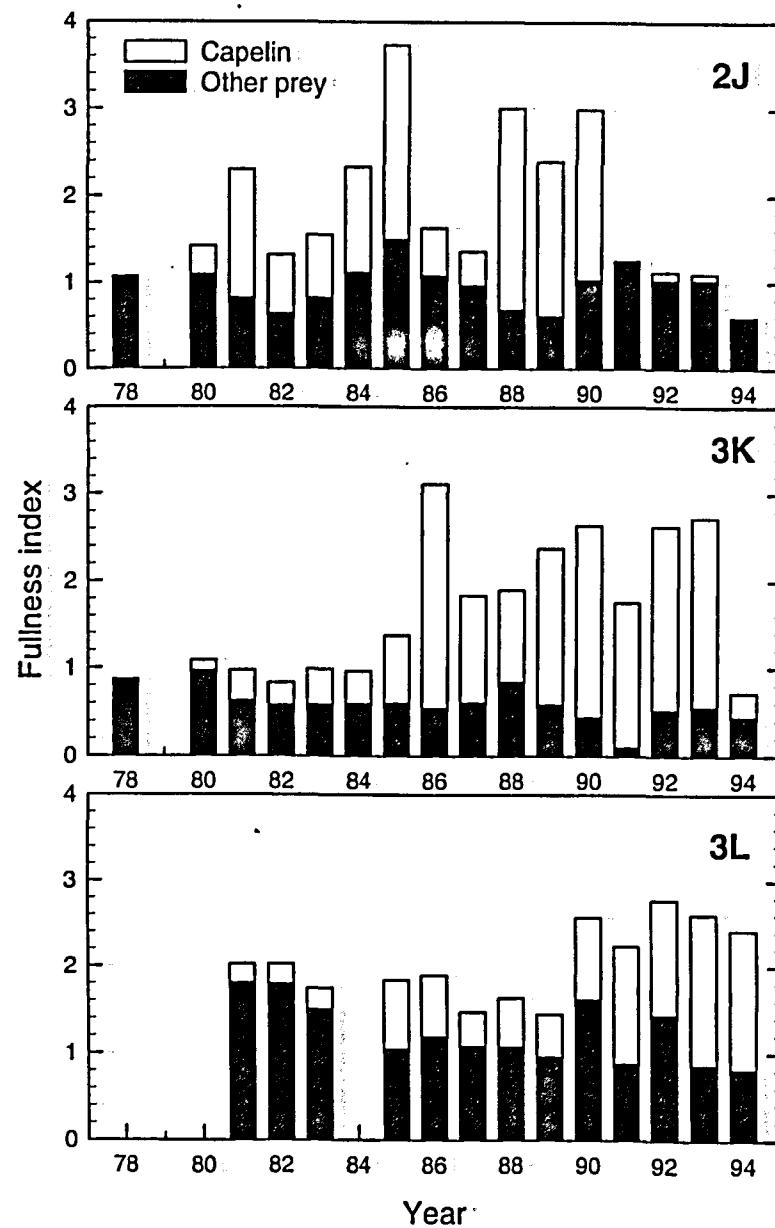


Fig. 5. Partial fullness indices (PFI) for capelin in cod stomachs in the fall RV survey, together with the PFI for other prey, by division.

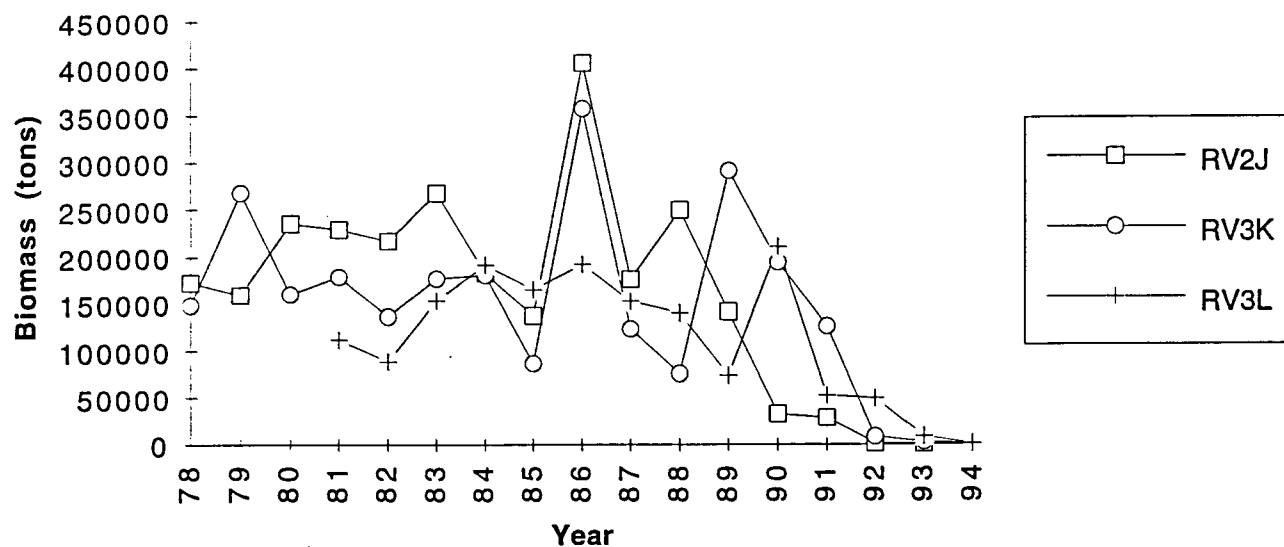


Fig. 6. Annual biomass estimates by division from the fall RV trawl survey.

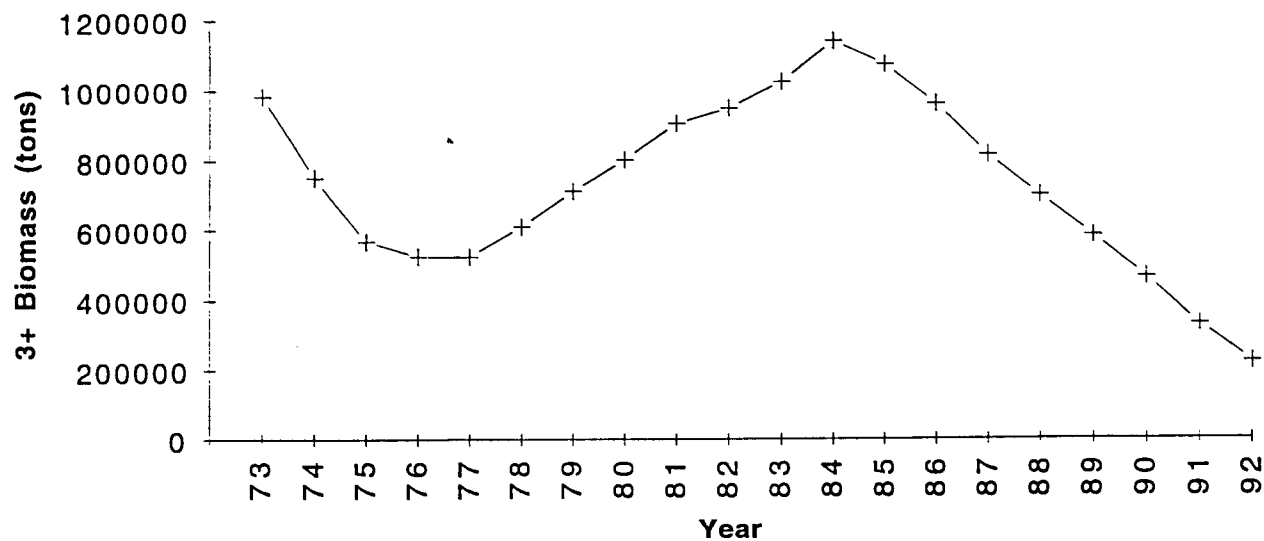
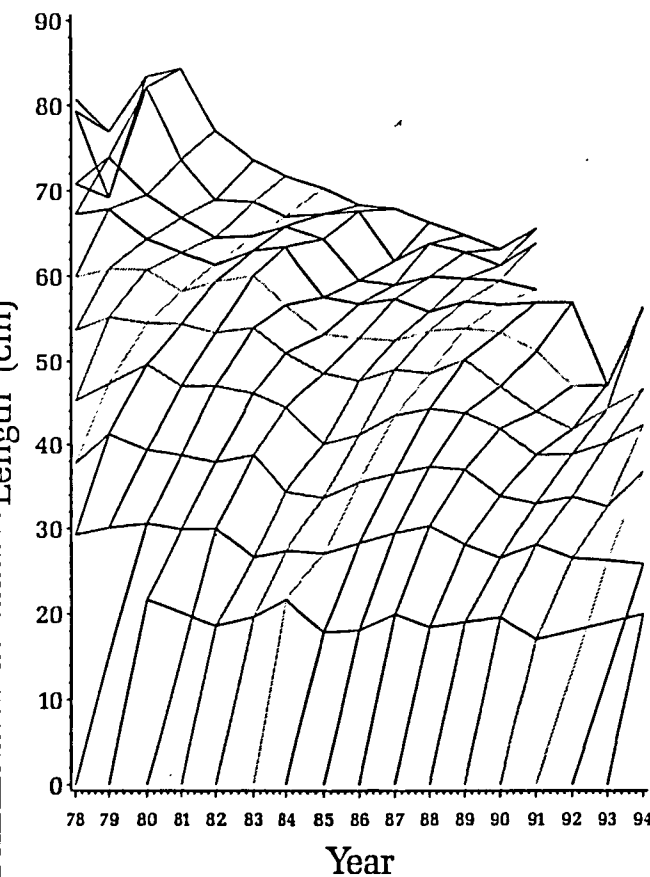
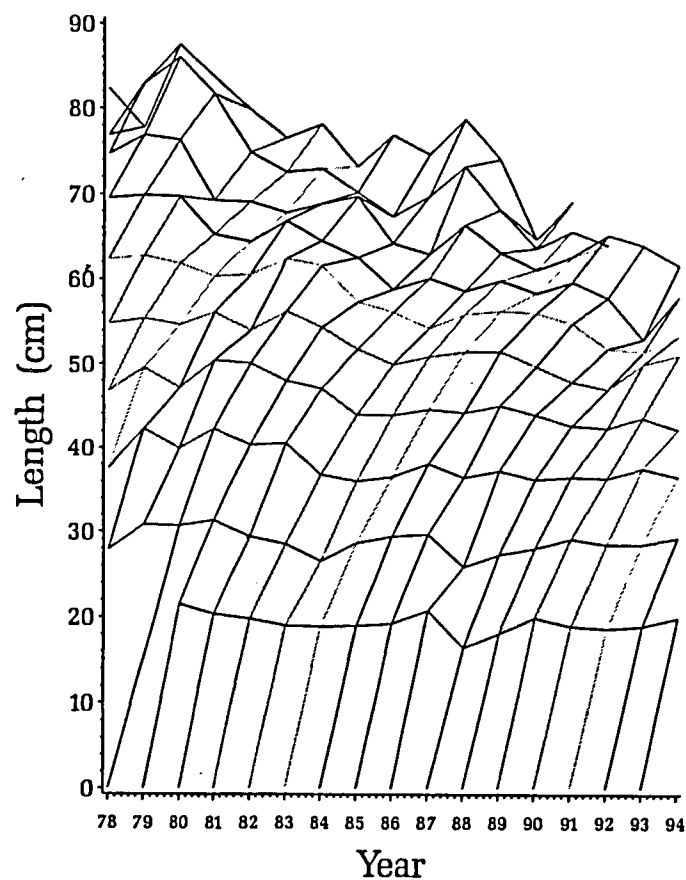


Fig. 7. ADAPT estimates of the 3+ beginning of year biomass in NAFO Divs. 2J3KL combined.

Div 2J cohort length at age



Div 3K cohort length at age



Div 3L cohort length at age

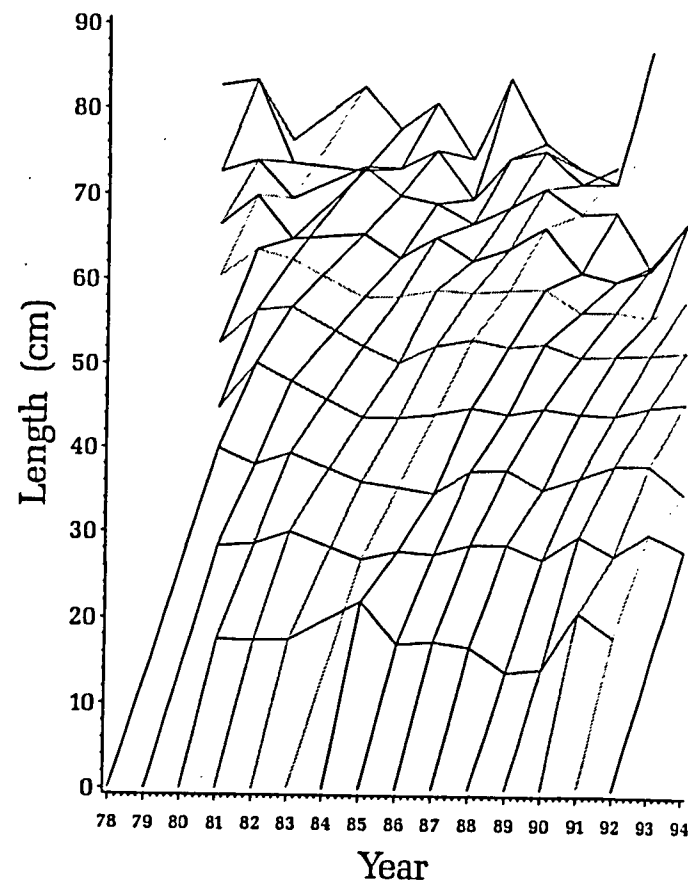
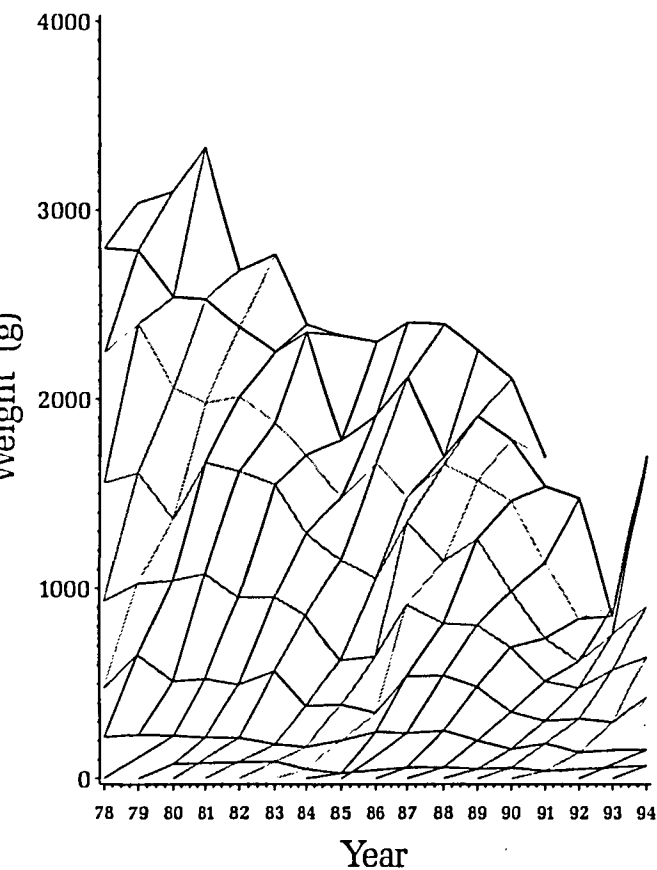
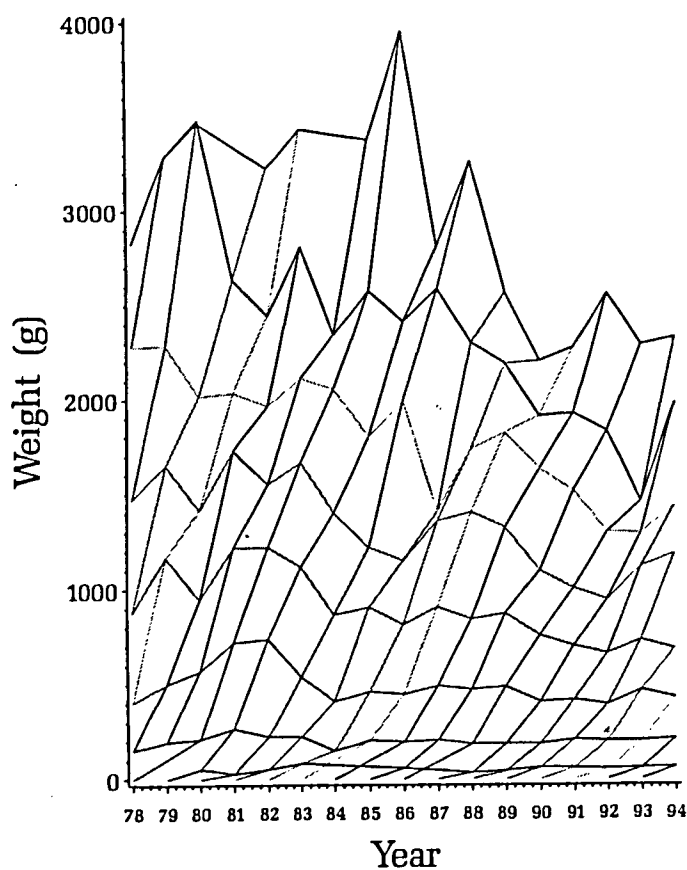


Fig. 8. Cohort lengths at age for each division for ages 10 and less. Lines orientated roughly parallel to the the x-axis denote ages. Length at age 0 is taken to be 0 so that the lines orientated roughly parallel to the y-axis denoting cohorts intercept the x-axis to give the year in which the cohort arose.

Div 2J cohort weight at age



Div 3K cohort weight at age



Div 3L cohort weight at age

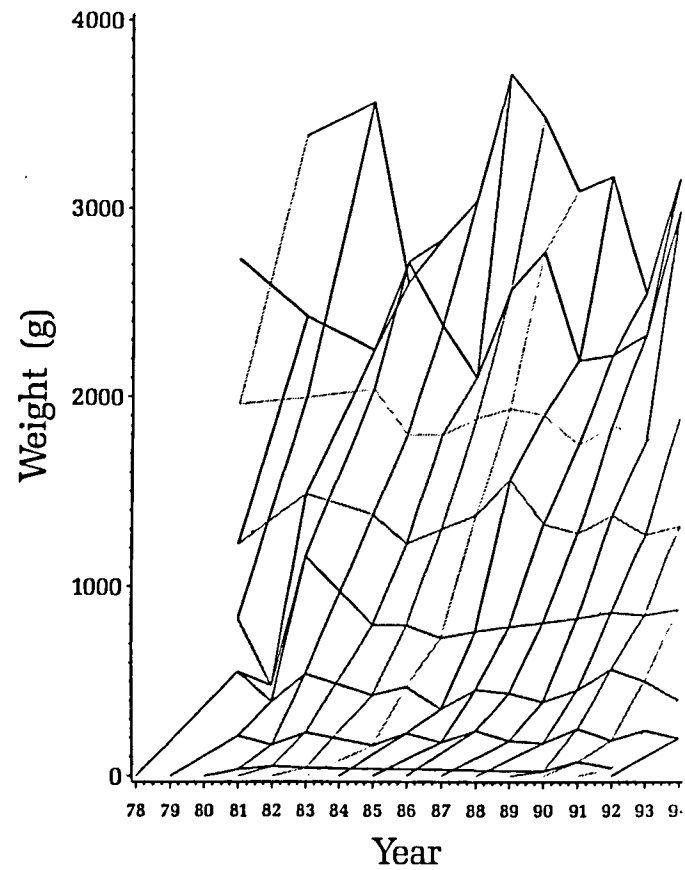


Fig. 9. Cohort weights at age for each division for ages 8 and less.

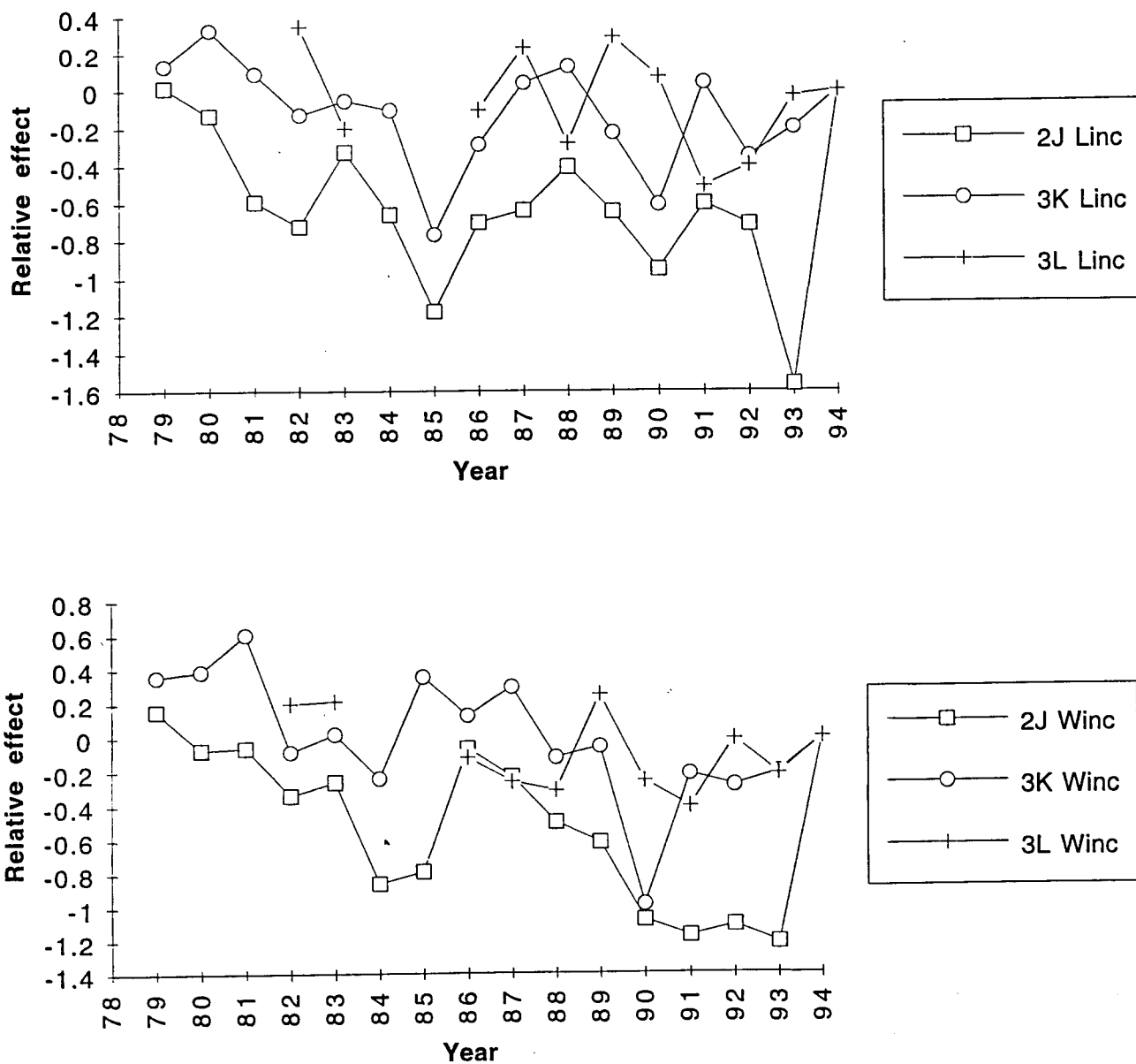


Fig. 10. Relative year effects in cohort length and weight increments in each division, all ages combined.

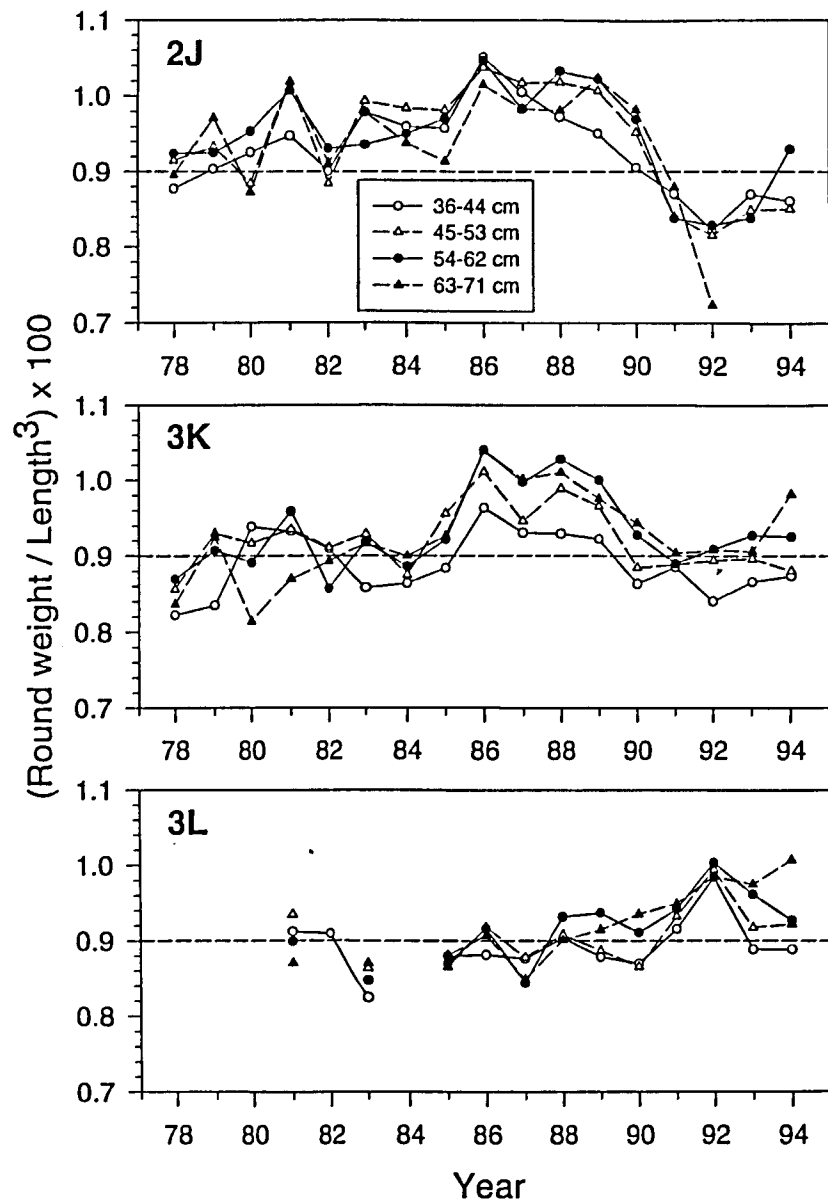


Fig. 11. Average condition (round weight) of cod by division in 9 cm length groups from samples taken in the fall RV surveys. A condition factor of 0.9, which is sometimes assumed to be generally applicable to cod (eg. Brander 1995), is shown for reference.

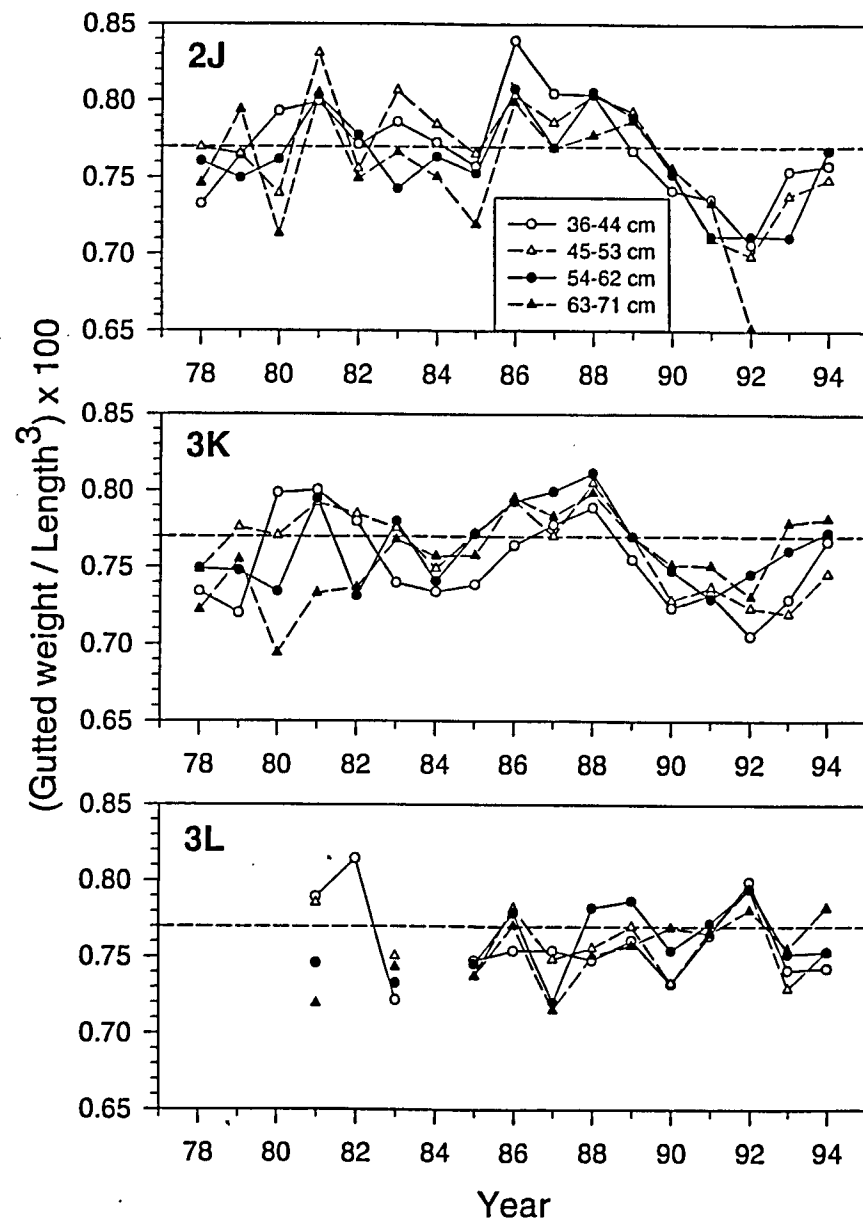


Fig. 12. Average condition (gutted weight, head on) of cod by division in 9 cm length groups from samples taken in the fall RV surveys. A condition factor of 0.77, which is the overall average reported by Taggart et al. (1994), is shown for reference.

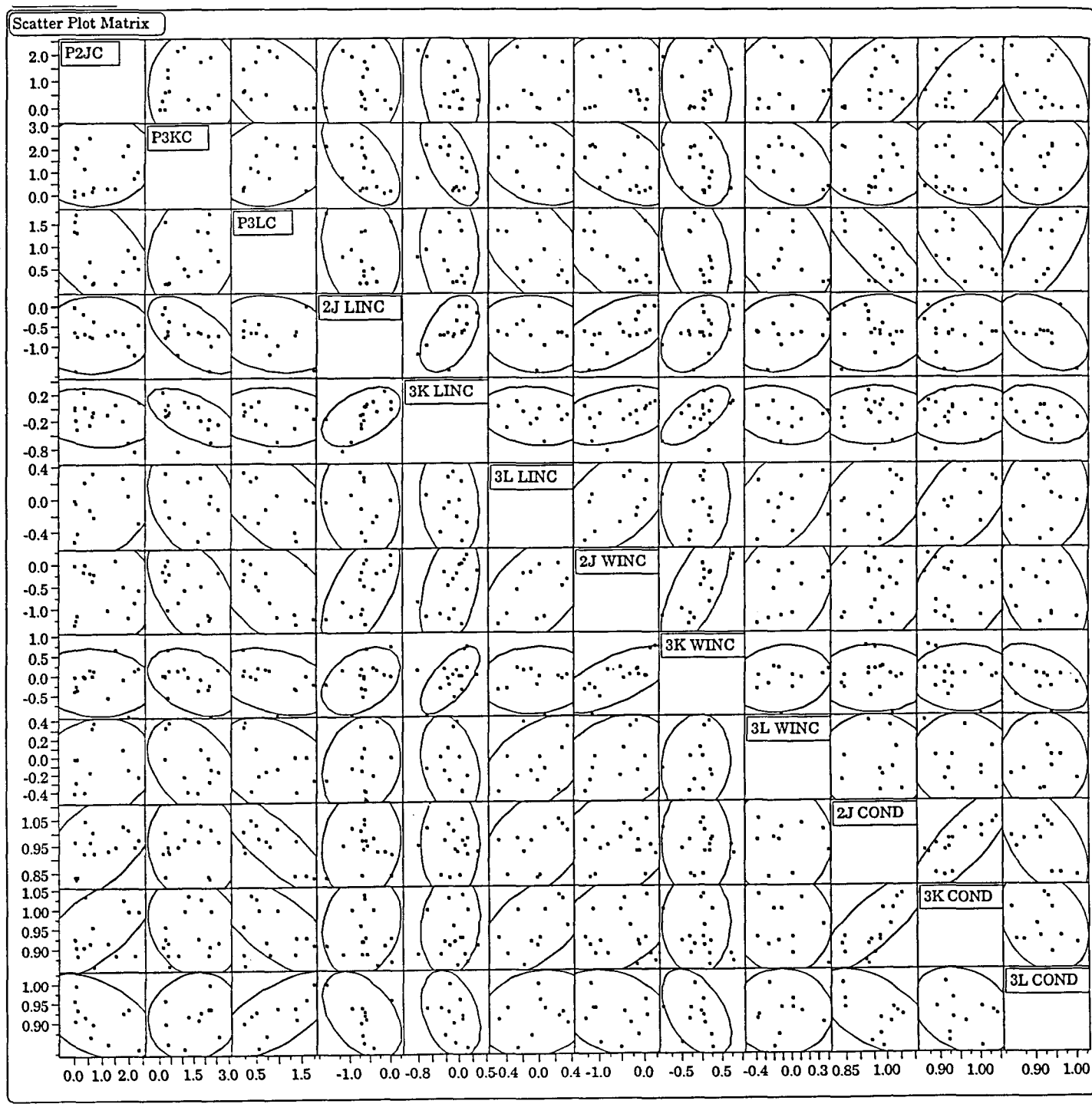


Fig. 13. Scatter plot matrix of the partial fullness index of capelin in each division (P2JC, P3KC, P3LC) against the relative annual length increments for all ages combined (2J LINC, 3K LINC, 3L LINC), relative annual weight increments for all ages combined (2J WINC, 3K WINC, 3L WINC) and round weight condition factor for cod in the 54 - 62 cm length class (2J COND, 3K COND, 3L COND).

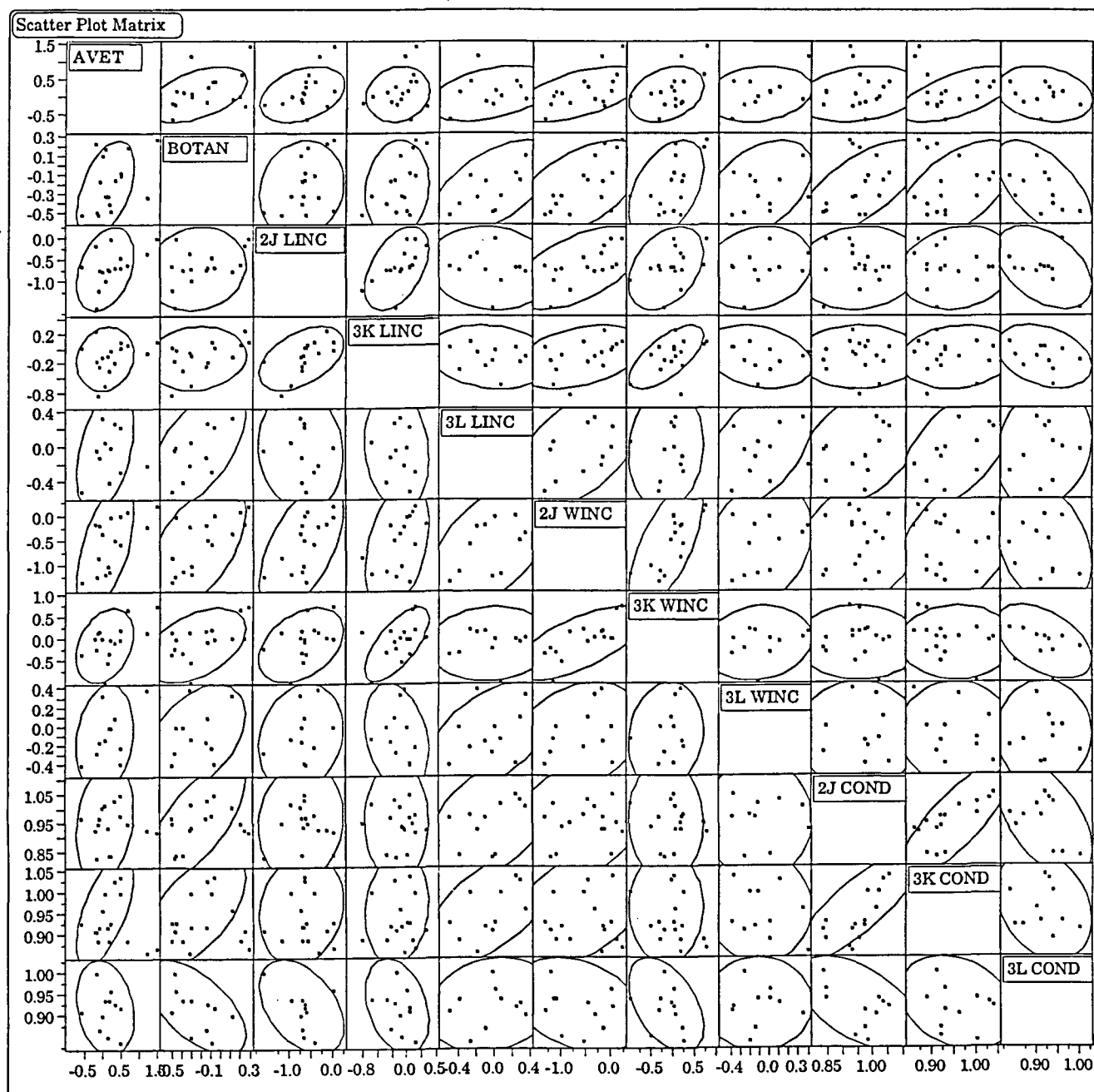


Fig. 15. Scatter plot matrix of average annual water column temperature (AVET) and bottom temperature anomaly (BOTAN) from Station 27 measurements against growth and condition data (same abbreviations as in Fig. 13).

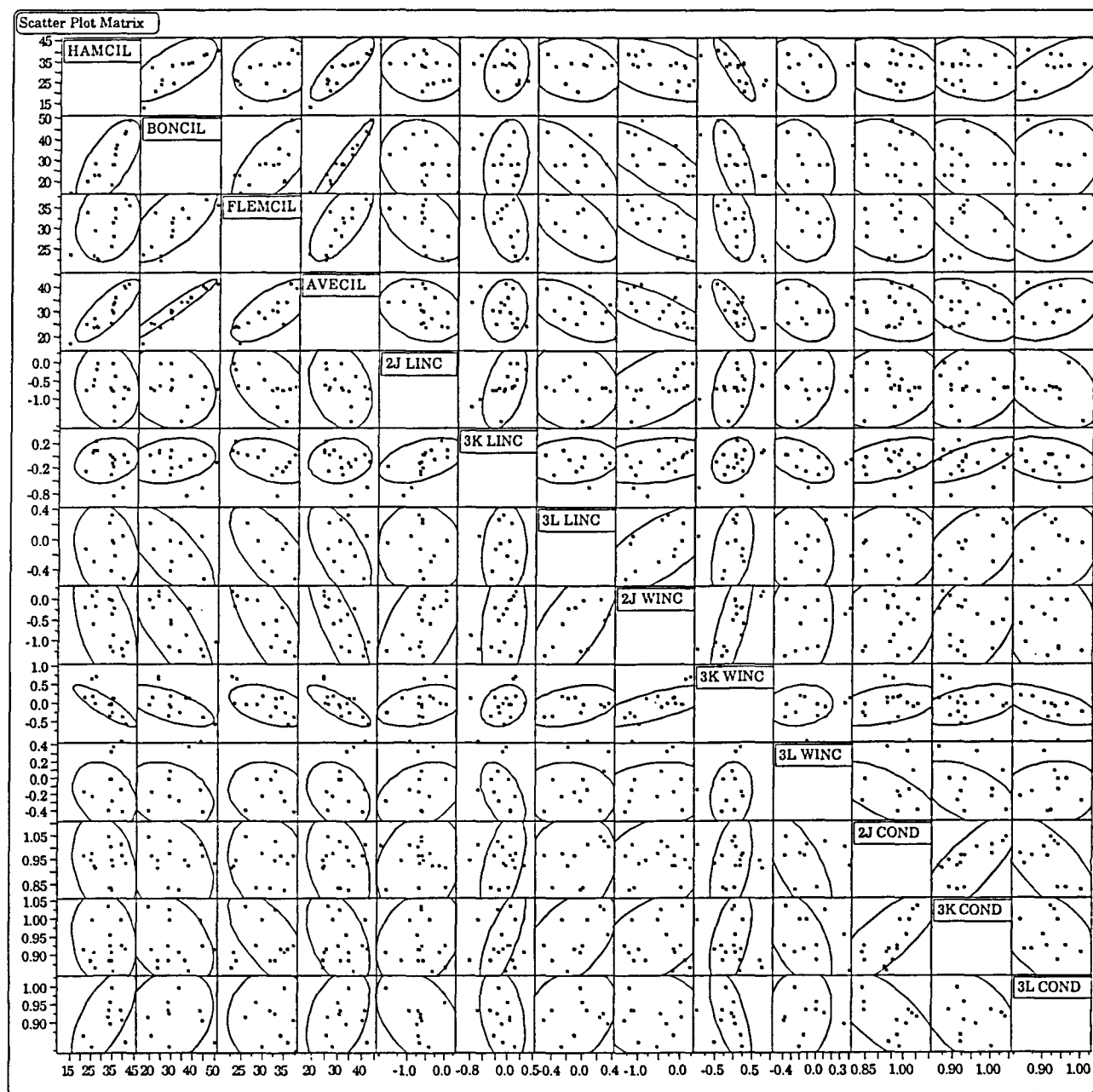


Fig. 16. Scatter plot matrix of average annual area of the cold intermediate layer on the Hamilton Bank (HAMCIL), Bonavista (BONCIL) and Flemish Cap (FLEMCIL) as well as the annual average of all three (AVECIL) against growth and condition data (same abbreviations as in Fig. 13).

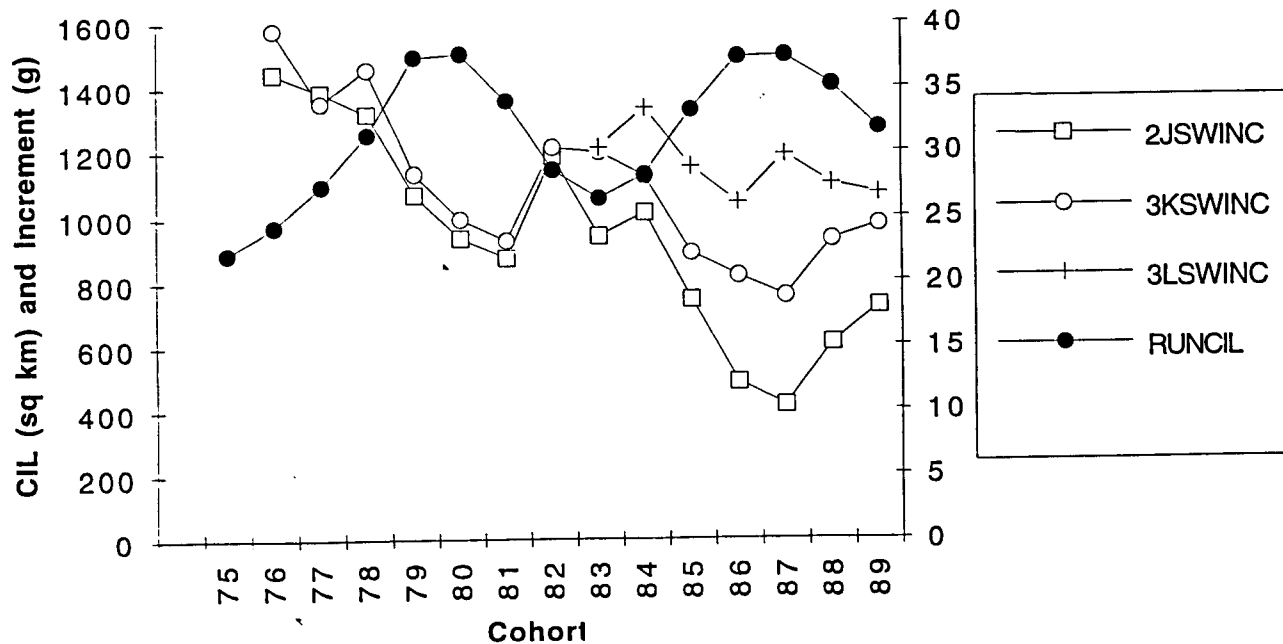
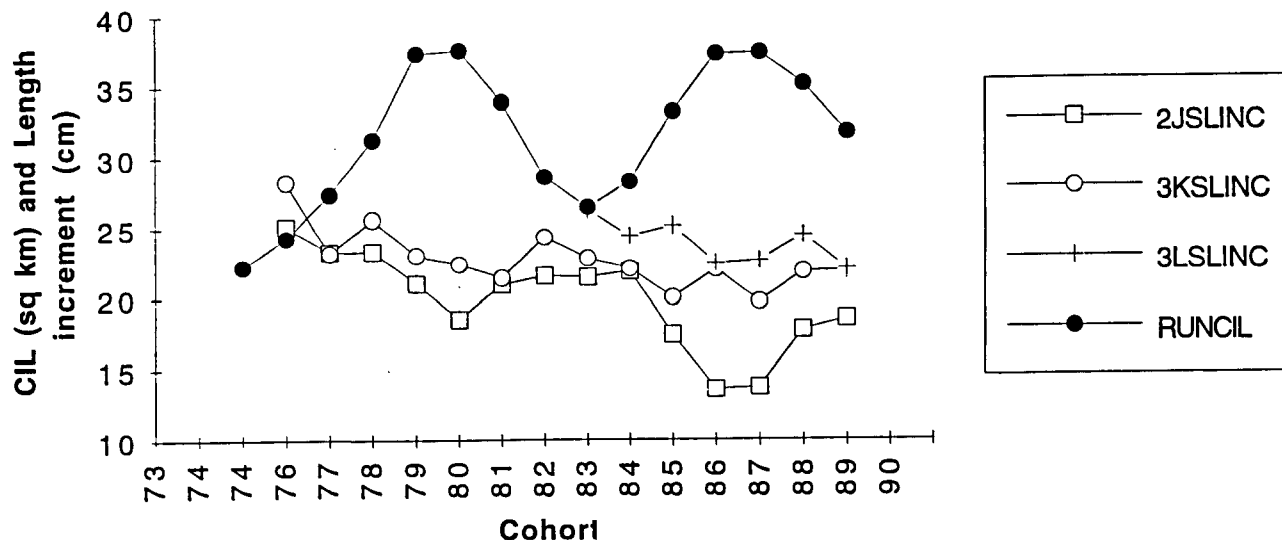


Fig. 17. The total increment in length and weight in each cohort from the beginning of age 2 to the end of age 5 plotted together with the average area of the CIL over that period (all three sections combined).