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Patterns in the annual weight increment for 2J3KL cod and possible prediction for stock projection

by

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Abstract

Annual weight increment data for Div. 2J3KL cod are examined. A general linear model containing division and age effects explained 36% of the variance in the logarithm of annual weight increment. The residuals from this model had a temporal pattern which could in part be explained by variability in the area of the cold intermediate layer (≤ 0°C). Consideration is given to whether a predictive model based on this relationship could be developed which would have utility in stock projections.

Introduction

Predictive relationships between the environment and biological processes associated with fish production, birth rate, body growth rate and mortality rate, have the potential to reduce the uncertainty in stock assessments. This is particularly the case where management measures such as TACs are imposed in year t+1 based on an assessment of the stock in year t using data collected in t-1 and earlier years. However most correlations between the environment and biological processes have had little utility, and in fact have often been shown to be spurious (Walters and Collie 1988). For example, a model in which recruitment in the NAFO Div. 2J3KL cod stock is predicted from spawner biomass and salinity was put forward as an alternative to the convention of using the geometric mean of past values of recruitment for short-term projections in stock assessments (Myers et al. 1993). However, reanalysis using the cross-validated prediction sums of squares from a non-parametric model indicated that the salinity term was only just significant in the original data and with a further year of data the salinity term was found to be not significant (Shelton and *Atkinson* 1994).

Despite the general lack of success in finding useful predictive relationships between environment and processes determining fish production, such pursuits continue. Although environment-recruitment relationships have generally been shown to fail, relationships between the environment and fish body growth may hold more promise. Much of the difference in Atlantic cod growth among stocks is thought to be attributable to variability in ambient temperature (May et al. 1965, Brander 1995). Within Atlantic Canada cod stocks, Millar and Myers (1990), Cárdenas (1994), Campana et al. (1995) have found that a significant amount of the variability in growth in terms of length can be explained by temperature. In the analysis by Cárdenas (1994), the area of the cold intermediate layer (CIL) was used as an indicator of thermal conditions in the habitat of Div. 2J3KL cod. Shelton and Lilly (1995) carried out a data exploration exercise which suggested support for the earlier finding by Cárdenas (1994) by showing a possible relationship between annual average weight increment in Div. 2J3KL cod over the period 1978 to 1994 and water temperature as measured by the average annual area of CIL. This analysis found no support in the post 1977 data for the hypothesis that cod growth is density dependent and no clear relationships were found with capelin abundance estimates or with variables derived from cod stomach content data. Cárdenas (1994) also found that growth in the three cod stocks examined, including the Div. 2J3KL cod stock, did not vary in response to population size. However, in the Cárdenas (1994) study there was evidence that maximum biomass seems to usually be followed by low growth rates. This may imply that biomass declines partly because of reduced growth rate, rather than growth rate declines because of high biomass.

In this paper we look at the annual weight increment data more closely and examine the possible relationship between average annual weight increment and area of the CIL in further detail. Some consideration is given to whether a predictive model could be developed which would have utility in providing scientific advice on TAC levels, and how the predictive ability of such model might be tested.

Methods and Results

Data

The number of cod sampled for which body weight measurements are available and for which age was determined directly from the otolith (rather than an age-length key) varies across years (Table 1). 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 Div. 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 Div. 2J and 3K and in 1990 in Div. 3L, Table 1). It is suspected that there may be a systematic difference between weights obtained at sea and weights obtained after thawing the laboratory, but in the present study any difference has been ignored. The data set for 1978 to 1995 comprises close to 15,000 aged and weighed fish.

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 by areal expansion of the stratified mean catch at length per tow (Smith and Somerton 1981). In this study population mean weight at age by division was obtained by weighting the individual measurements in the biological sample by the ratio of the estimated number in the population in each 3 cm length class to the number of fish sampled in the 3 cm length class. Because of the low number of samples of older fish, particularly in more recent years, cod greater than age 10 were omitted from the analysis. Annual average weight increment was obtained by subtracting the mean weight at age j in year t from the mean weight at age j+1 in year t+1. The weight increment is assigned to age j for year t+1 because the survey is in fall and most of the growth is considered to take place in the spring and summer of the following year.

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 $\leq 0°$ C, have been calculated as an index of thermal conditions within the northern cod habitat (Colbourne 1995). In this study we use the annual average area of the CIL from the three transects for the period 1978 to 1995 (Fig. 1).

Analysis

In order to visually determine possible patterns in the data, the annual weights at age and weight increments at age were plotted for each division by year (see Shelton and Lilly 1995 for more details). Weight at age in 2J for ages 1 to 8 shows both an overall decline over the time period as well as the presence of fast and slow growth cohorts (Fig. 2). Slow growth cohorts include the 1981 and 1982 cohorts and the 1986 and 1987 cohorts. The overall decline in weight at age over the time period is less in 3K, however there are quite clear periods of fast and slow growth cohorts (Fig. 3). It is of interest to note that fish of the 1982, 1983 and 1984 cohorts grew at a rate similar to fish in adjacent cohorts up to age 4 and only showed relatively accelerated growth thereafter. In contrast, fish belonging to the 1978 cohort showed accelerated growth in the first couple of years of life and then maintained this through average growth over the remainder of the period. Generally however, the cohort to cohort difference in growth are determined within the first 5 years (i.e. by immature fish) as might be expected. There is no evidence of an overall decline in growth and little evidence of strong and slow growth cohorts in 3L (Fig. 4).

The general approach taken in the 1992 Multispecies Assessment Working Group (Anon. 1992) for examining growth was adopted for data analysis. Average annual weight increments by cohorts within divisions were calculated so that X_{ijk} is the weight increment for a cohort in division i at age j in year k. Note that because the data are for fall surveys and most of the growth increment will take place in the following summer, k is the survey year incremented by one year.

Annual weight increments for all ages are plotted for the 3 divisions in Figs. 5-7. The declining trend in weight increments is apparent in all ages in 2J and to a lesser extent in 3K. No trend is apparent in the 3L increment data. Both 2J and 3K show some similarity in year effects across several ages in some years, e.g. down in 1985, up in 1987 etc. in 2J and down in 1984 and 1990 in 3K.

There is some similarity in weight increment at age across 2J and 3K, but not 3L. Two examples are plotted - age 3 (Fig. 8) and age 5 (Fig. 9). If anything, year to year differences in increment at age 3 in 3L appear to be negatively correlated with the other two divisions.

A multiplicative model accounting for division and age effects was fitted to the logarithm of the weight increments,

$$Ln(X_{i,j,k}) = \tau + \alpha_i + \beta_j + \varepsilon,$$

where τ is the intercept, α_i is the division effect, β_j is the age effect and ε is normally distributed error. The model explained 36% of the variance in the logarithm of the annual average weight increment (Table 2).

The mean annual residuals from this model are plotted in Fig. 10. The residuals show a clear pattern with positive values between 1979 and 1983, negative values in 1984 and 1985, strongly negative values in 1990, remaining negative to 1993, positive in 1994 and then negative again in 1995. A scatter plot of the residuals against average area of the CIL suggests a negative relationship (Fig. 11). Regression analysis (Fig. 12) indicates that 48% of the variance in the residuals after removing age and division effects can be explained by CIL.

The possible relationship with area of the CIL can also be seen by plotting the average total weight increment by fish in a cohort over the ages 3 to 5 against the average CIL experienced by the cohort over that period of their life (Fig. 13). The CIL shows a near-decadel cycle over the time period. Low growth increments tend to be associated with the peaks in the cycle and high growth increments with the troughs in all three divisions. The declining trend in weight increment is less evident in these plots.

Expanding the general linear model to include the average area of the CIL in year k,

$$Ln(X_{i,j,k}) = \tau + \alpha_i + \beta_j + \gamma CIL_k + \varepsilon,$$

explained 41% of the logarithm of the annual weight increment (Table 3). The significance of the reduction in the fit sums of squares obtained by including CIL was examined by refitting the model a thousand times to the randomly shuffled CIL series. There is only a small probability (0.002) that the reduction in sums of squares obtained by including CIL is due to chance alone (Fig. 14). A more thorough evaluation using the cross-validated prediction sums of squares will need to be carried out if this model is to be used for forecasts.

Assuming that the model including CIL can predict weight increments in Div. 2J3KL cod to some degree and that is found to be more accurate that using average weights at age, how could such predictions be used in the assessment of the stock? Given the time difference between the measurement of the area of the CIL and the forecasted effect of alternative TACs from the current assessment outlined above, it would be necessary to predict the CIL in the forecast year. The time sequence for the analysis, assessment and forecast are illustrated schematically in Fig. 15.

Analysis of the autocorrelation in the CIL data, for example data from Bonavista transect for the period 1948 to 1995, showed that only the lag-1 correlation, explaining 64% of the variation, is significant (Fig. 16). The implication is that the CIL data can be adequately modelled by a first order autoregressive process. This is demonstrated by subtracting the mean from the data, setting the initial value Y_t to the 1948 value and modelling the remainder of the series by recursively calculating Y_{t+1} applying

$$Y_{t+1} = r\,Y_t + \varepsilon,$$

where r is the lag-1 regression coefficient (0.8) and ε is normally distributed random noise with standard error equal to the standard error of the data having first subtracted the mean. Y_{t+1} is then added to the mean to obtain the realization. Realizations were randomly generated and compared to the measured time series. Two examples are given in Fig. 17. It is clear that the Bonavista transect CIL can be adequately modelled by a lag-1 autocorrelation model.

Analysis of the autocorrelation in the 2J weight at age for an example age (5) also indicates significant lag-1 autocorrelation, explaining 61% of the variation (Fig. 16). The lag-1 autocorrelation for the logarithm of the weight increment for age 5 is less strong, explaining only 15% of the variation.

Discussion

The literature on the effect of environment on Atlantic cod growth can be divided into two main categories - those papers that examine the effect of geographical differences in average ambient temperature and those that examine temporal changes in ambient temperature within a specific geographic area. With respect to geographic differences in ambient temperature, Brander (1995) examined the growth of Atlantic cod (derived mainly from commercial catch data) in 17 stocks, and concluded that 92% of the variance among stocks in the logarithm of mean weight at age for ages 2 to 4 fish could be explained by an ANCOVA model with age and temperature effects. Brander (1993) considered that the effect was big enough to have significant consequences for assessments with respect to catch forecasts. Brander's research was preceded by that of Sager et al. (1988) and two ICES studies of cod growth in four Arcto/Boreal systems (Barents Sea, Greenland, Iceland and Newfoundland (Anon 1990), later extended to three other cod systems (Gulf of Maine, Georges Bank and North Sea (Anon 1992). These three references are not cited in the Brander study. Although the primary aim of the ICES studies was to examine the impact of food consumption on growth, across ecosystem differences are attributable in part to ambient temperature. Campana et al. (1995) attribute growth differences on Georges Bank, eastern Scotian Shelf and southern Gulf of St Lawrence to ambient temperature. Shackell et al. (1995) suggest that differences in cod growth among the Scotian shelf and adjacent areas are due to differences in the hydrographic regime.

Studies of geographic variability within cod stocks have been carried out in Iceland (Jónsson 1965), off Labrador and eastern Newfoundland (Flemming 1960; May et al. 1965), between Norwegian fjordic systems (Berg et al. 1993) and in post-larval cod off southwestern Nova Scotia (Suthers et al. 1989). These studies suggest that substantial changes in cod growth can take place with respect to geographic location within ecosystems. In the present study, NAFO Division accounted for a significant portion of the variability in the logarithm of annual weight increment when included in a model with age effects (Table 2).

Annual variability in growth has been reported for many cod stocks. Studies of factors responsible for this variability have generally emphasised temperature as the main causative factor. Some of the stocks for which temperature effects on growth rate have been suggested include cod on the Scotian shelf (Campana et al. 1995, Shackell et al. 1995), Div. 2J3KL cod (Millar and Myers 1990, Warren 1993, Cárdenas 1994, Shelton and Lilly 1995) southern Gulf of St Lawrence cod (Beacham 1983), Iceland (Jónsson 1965, Steinarsson and Stefánsson 1991, Cárdenas 1994), North-east Arctic cod (Loeng 1986, Loeng and Gjøesaeter 1990, Jørgensen 1992, Nakken 1994, Nakken and Raknes 1987, Ohzigin et al. 1994, Cárdenas 1994) and West Greenland (Hermann and Hansen 1965). In the analysis of interannual variation in cod growth in Barents Sea, Greenland, Iceland and Newfoundland (2J3KL) cod stocks, Anon (1990) concluded that the overwhelming presence of year effects in the data indicates the existence of a strong environmental effect in cod growth. Significant temperature effects in the Barents Sea, Iceland and Newfoundland stocks were apparent over a variety of analyses.

The present study adds to the body of evidence that cod growth is influenced by the environment. A general linear model fit to the weight increment data that includes age, NAFO Division and average CIL effects explains 41% of the variance. Although a significant amount of the variation in growth is explained in the fit, how useful is this in a predictive sense? The utility of this model in predicting weight increment for use in stock projections still needs to be examined. Because of the lag between the analysis (up to and including year t-1), the assessment (year t) and the projection (year t+1), the model has to be able to make useful 2 year projections. To do this, CIL has to be predicted in year t and year t+1, however there is only a lag-1 autocorrelation in the CIL data. How can this be overcome? How do alternative models with and without CIL compare with each other and with a base model (mean weight at age)? Is it possible to decrease the projection period by reducing the time between the assessment and the prediction? Further work to examine the cross-validated prediction sums of squares for a variety of different weight increment models is planned.

Acknowledgements

We acknowledge the considerable efforts of DFO personnel who collected the samples on which this analysis is based. Our recently retired colleague Claude Bishop and his predecessors in the Gadoids Section in particular have done much to ensure that a comprehensive biological data base is available for northern cod.

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Table 1. Number of individual fish sampled in each year in each division for which both body weight was taken and age determined from the otolith.

YEAR	NAFO			
Frequency	2J	3K	3L	Total
78	132	120	0	252
79	113	120	0	233
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	144	2089
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
95	401	468	236	1105
Total	5408	5916	3606	14930

Table 2. Results of the general linear model in which age and division effects were fitted to the logarithm of the annual weight increment data.

Number of observations	396
R-Square	0.363696
Residual Sums of Squares	182.738248

Type III Sums of Squares

	DF	Type III SS	Mean Square	F value	Pr > F
Age	9	92.3464291	10.2607143	19.88	0.0001
NAFO	2	14.6590163	7.32950814	14.2	0.0001

Table 3. Results of the general linear model (ANCOVA) in which age, division and CIL effects were fitted to the logarithm of the annual weight increment data.

Number of observations	366
R-Square	0.414445
Residual Sums of Squares	168.163602

Type III Sums of Squares

	DF	Type III SS	Mean Square	F value	Pr > F
AGE	9	89.5618553	9.95131726	20.89	0.0001
NAFO	2	14.9518262	7.47591309	15.69	0.0001
AVECIL	1	14.574646	14.574646	30.59	0.0001

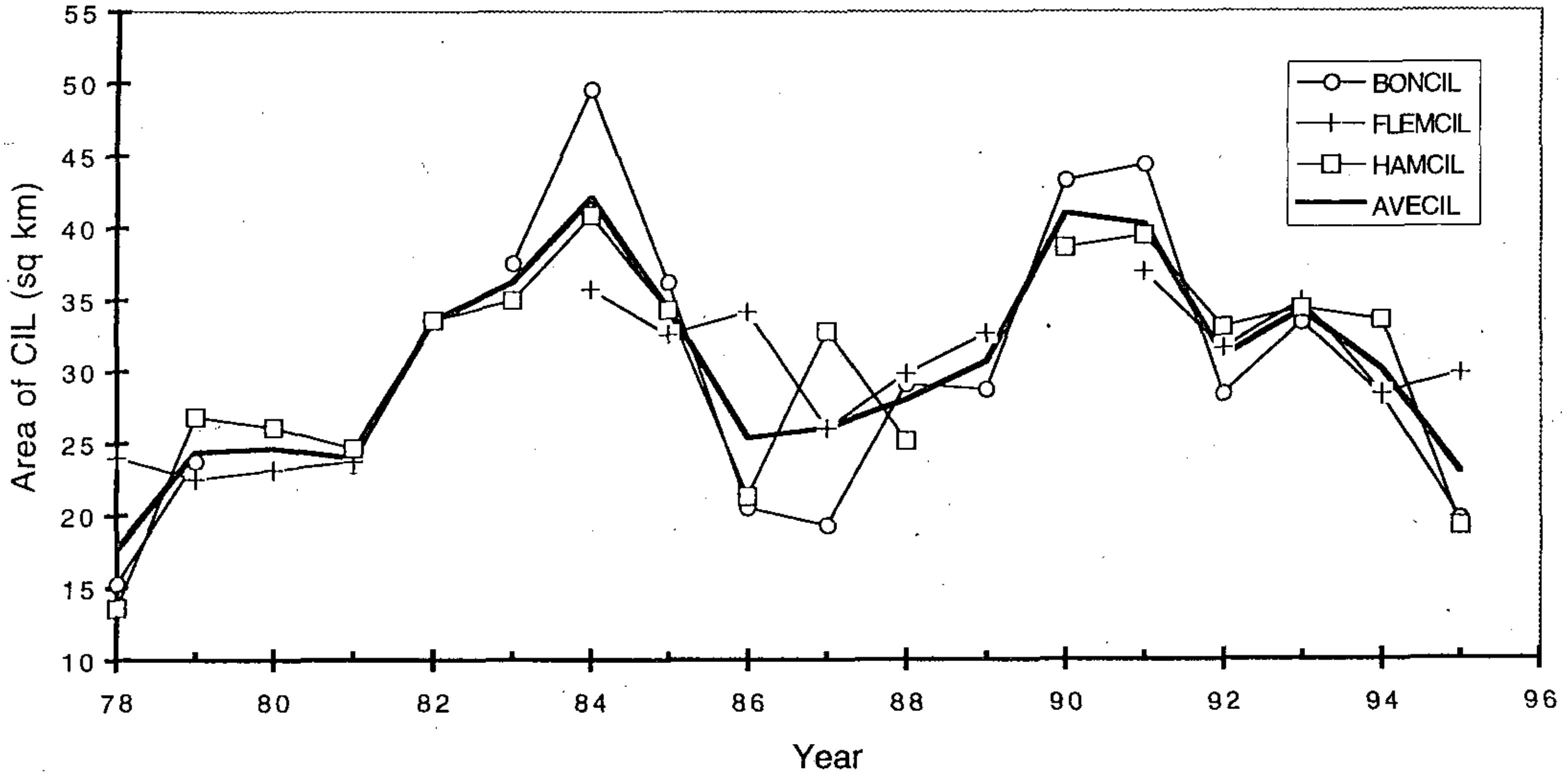


Fig. 1. Annual area of the cold intermediate layer (CIL) in summer on the Hamilton Bank, Bonavista and Flemish Cap sections, together with the annual average for all three sections.

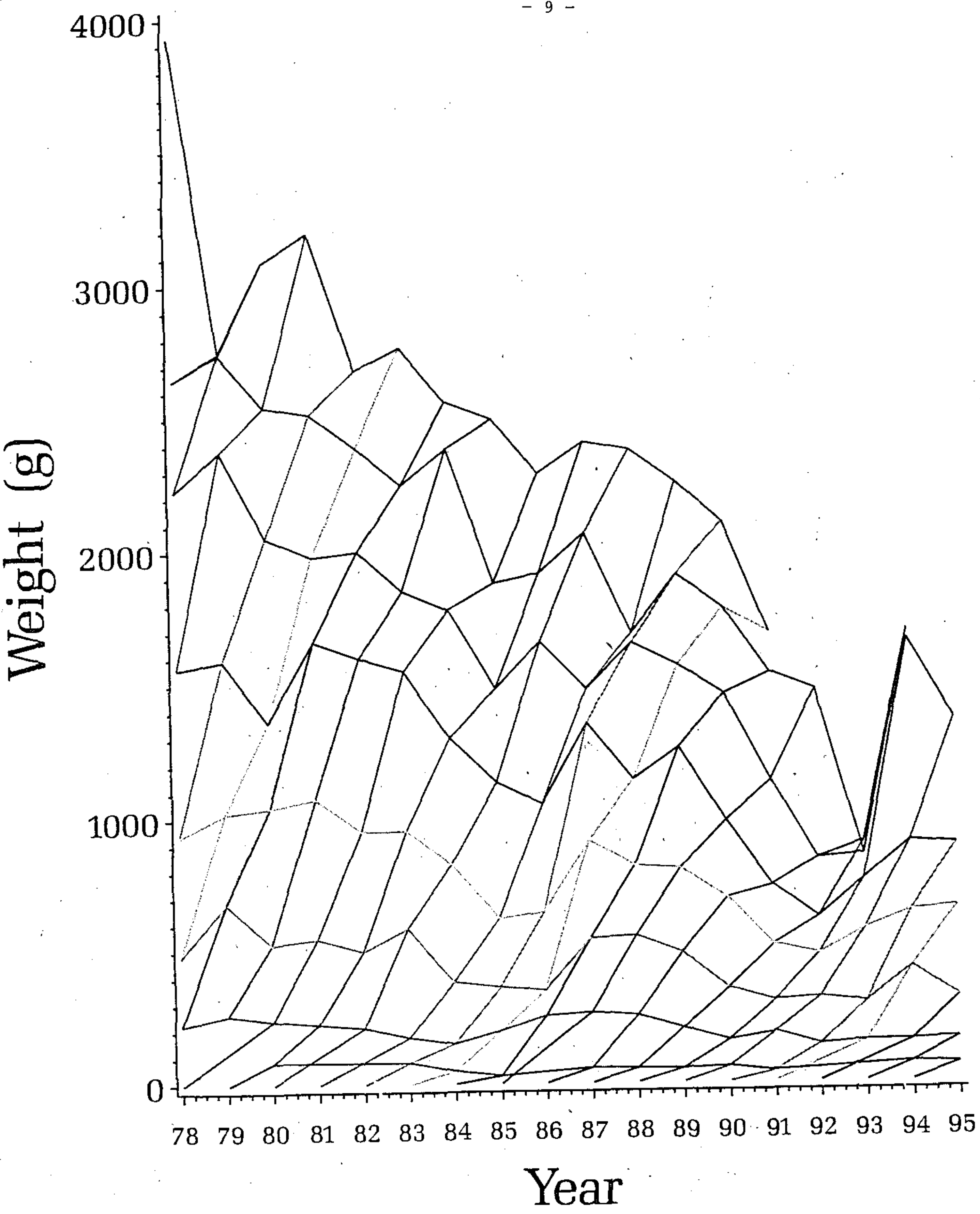


Fig. 2. Cohort lengths at age in Division 2J for ages 8 and less. Lines orientated roughly parallel to the x-axis denote ages. Length at age 0 is taken to be 0 so that lines orientated roughly parallel to the y-axis denoting cohorts intercept the x-axis to give the year in which the cohort arose.

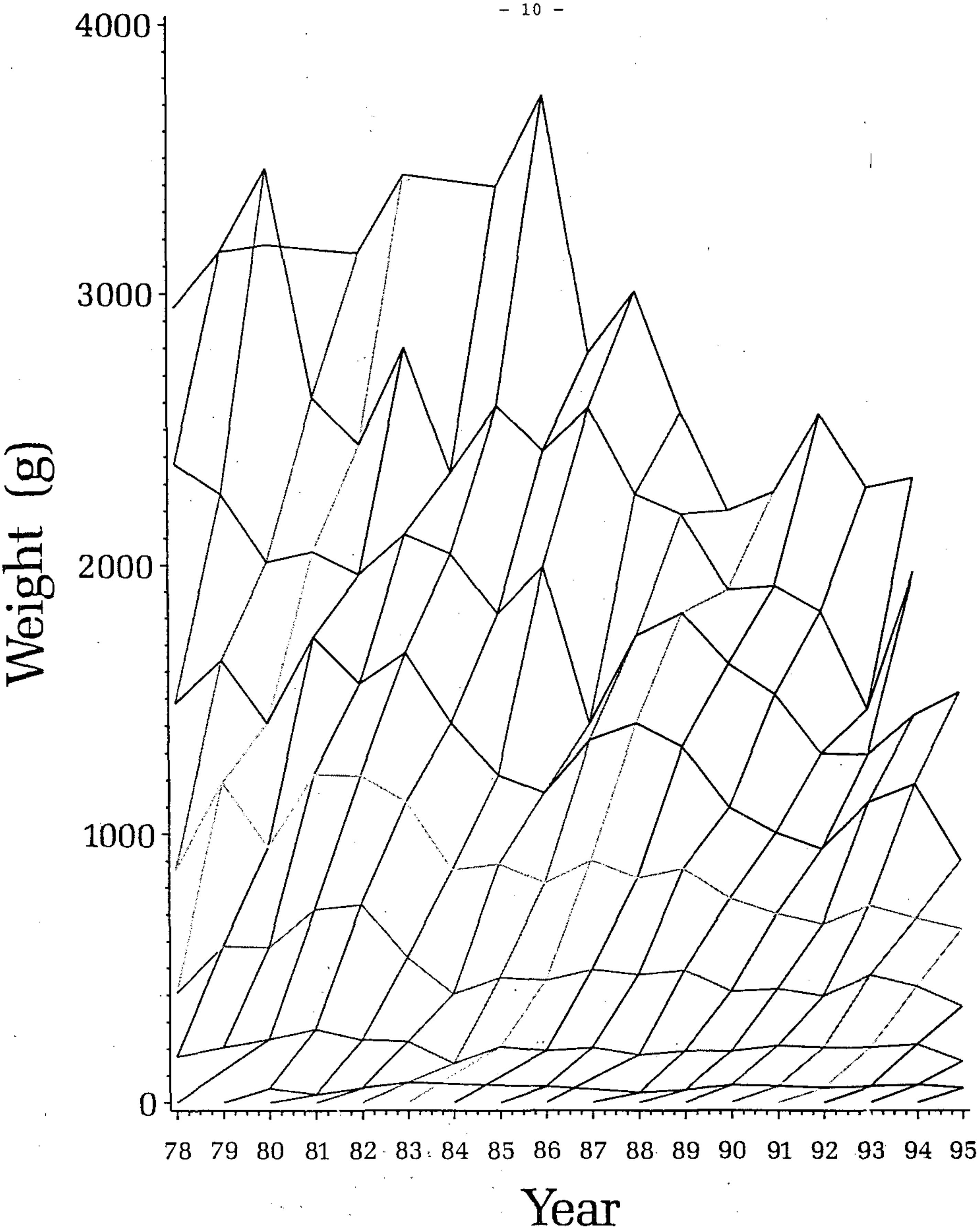


Fig. 3. Cohort lengths at age in Division 3K for ages 8 and less.

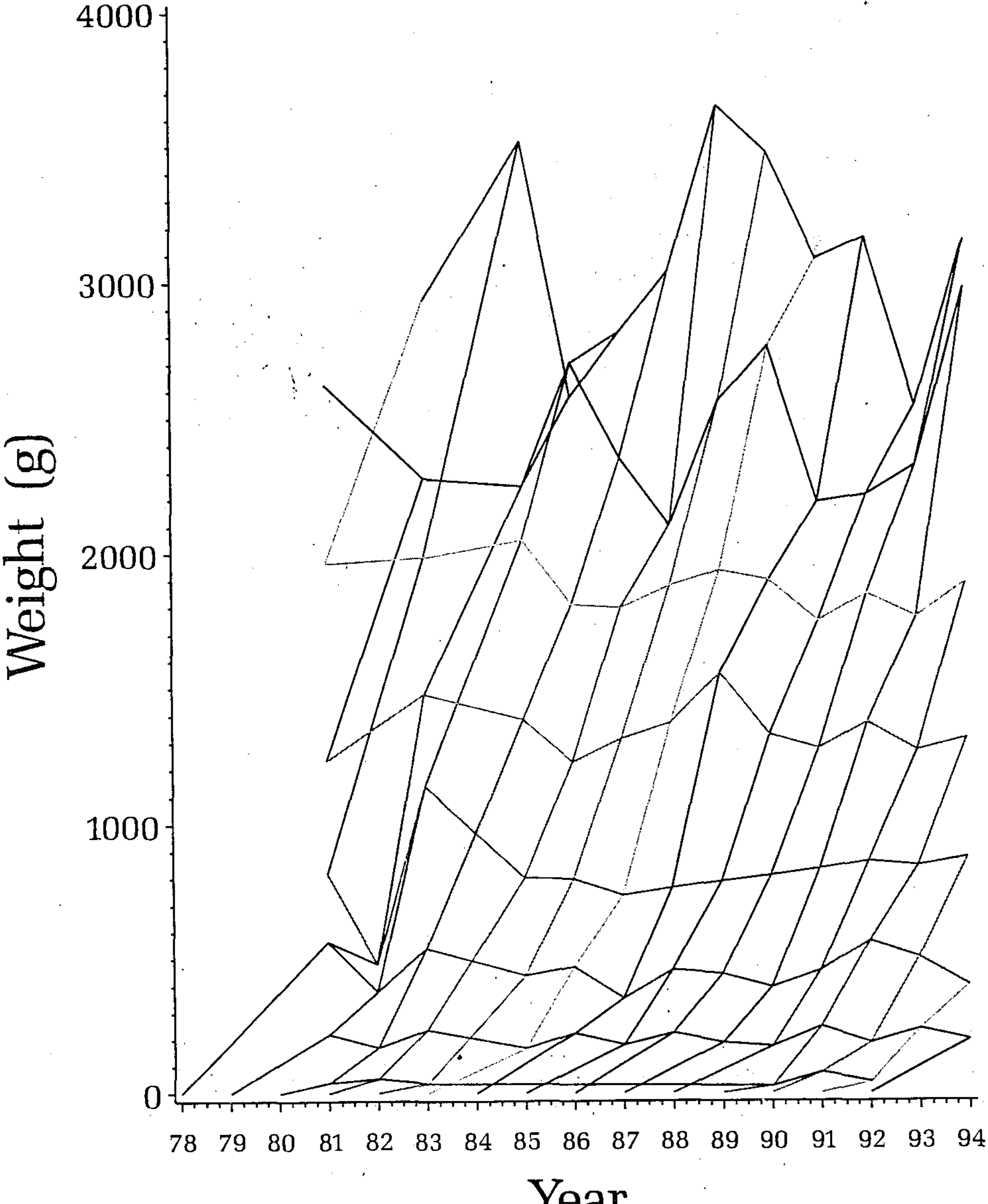


Fig. 4. Cohort lengths at age in Division 3L for ages 8 and less.

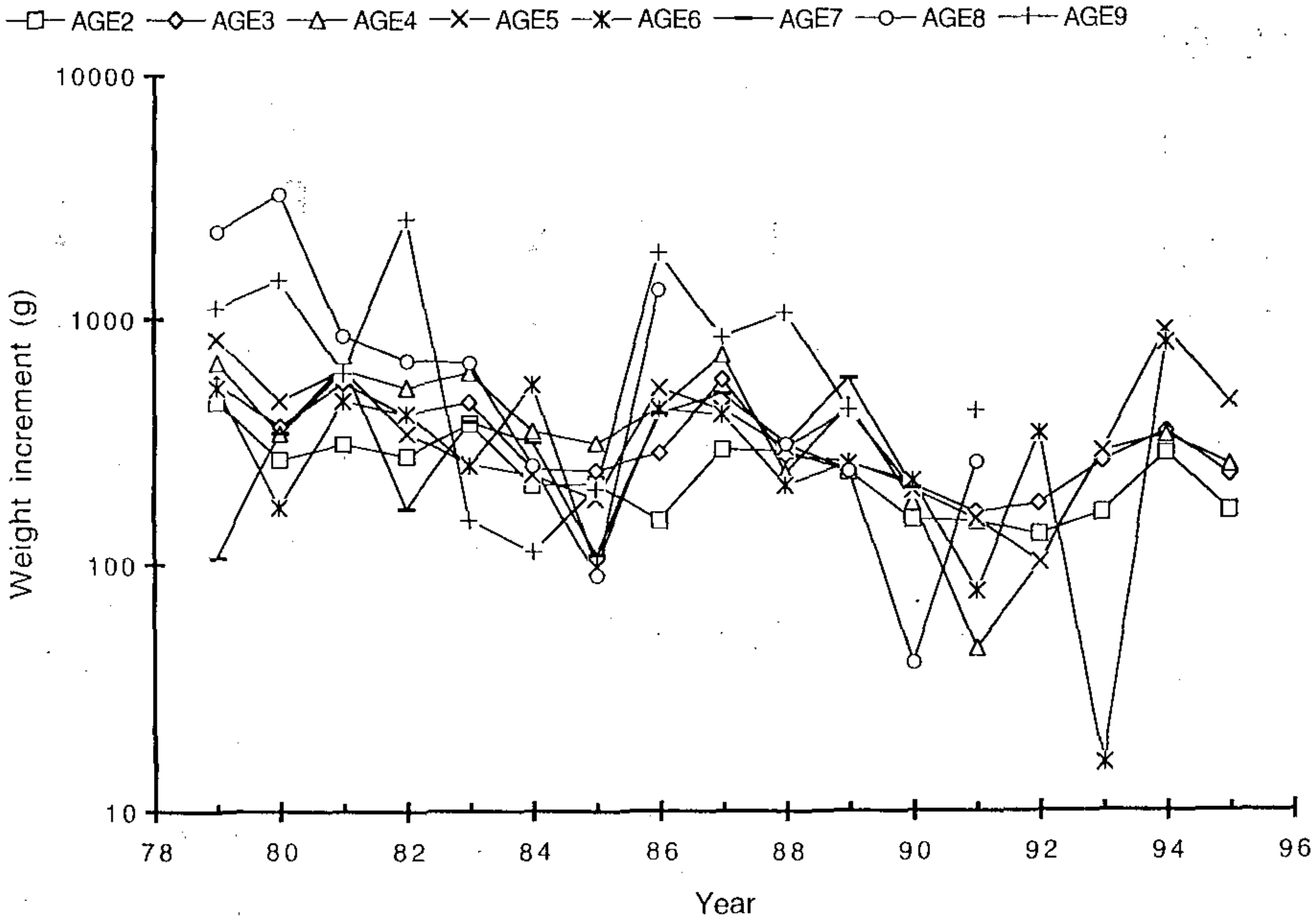


Fig. 5. Annual weight increment (g) for ages 2 to 9 in Division 2J.

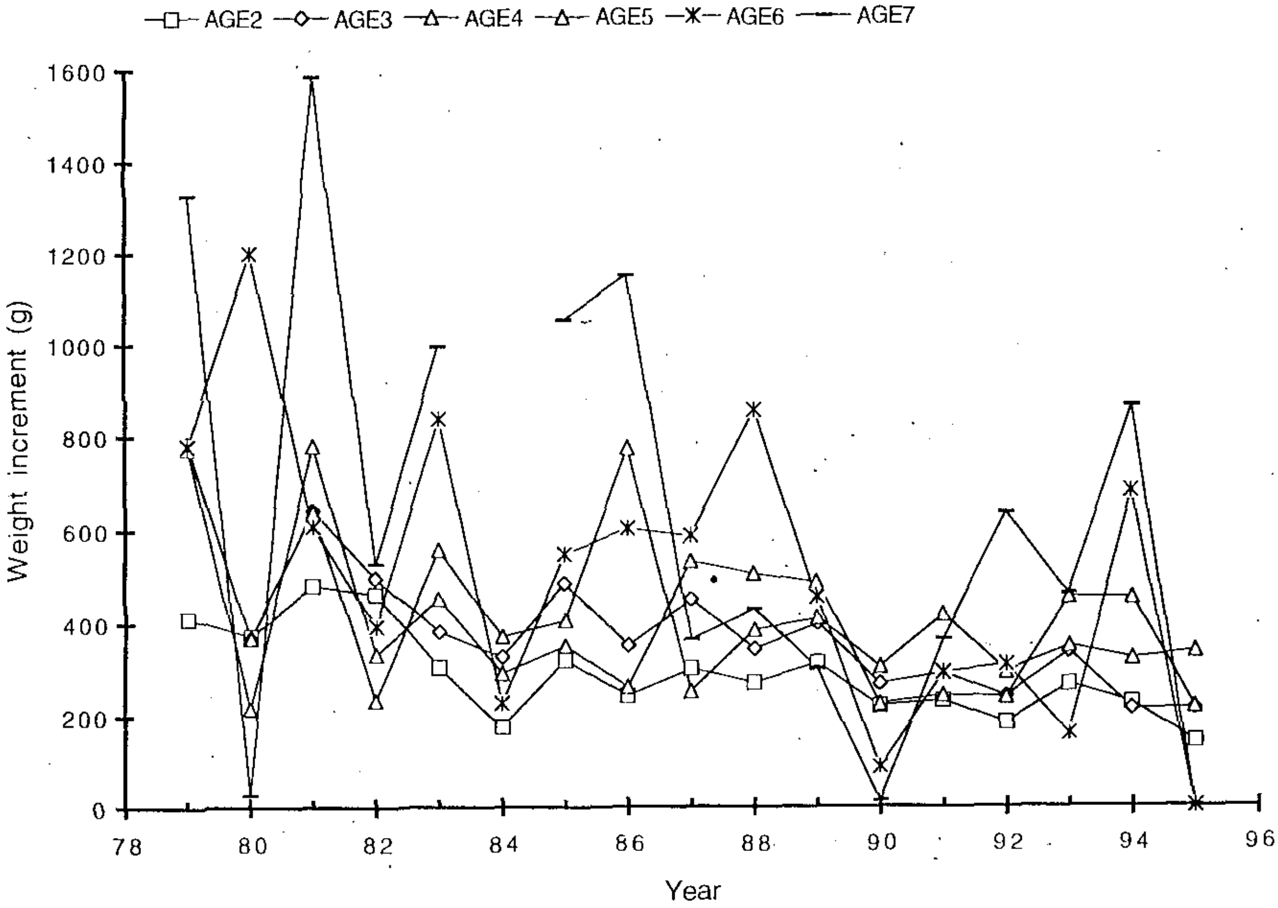


Fig. 6. Annual weight increment (g) for ages 2 to 7 in Division 3K.

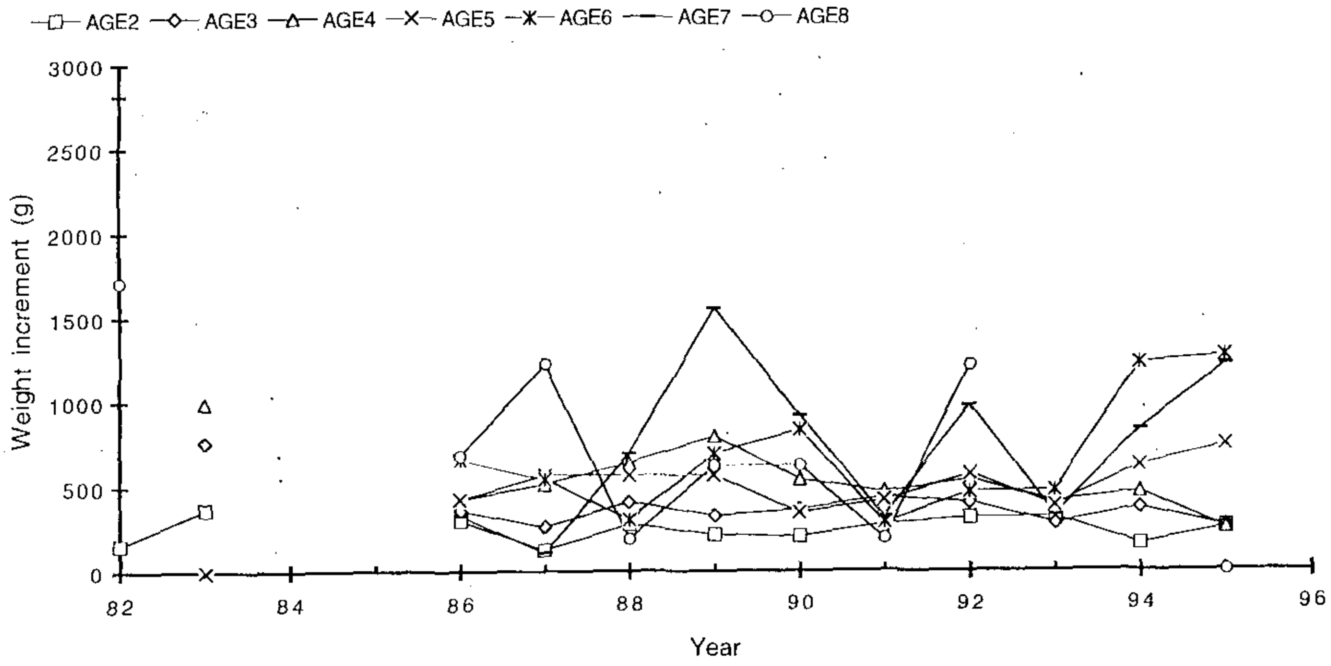


Fig. 7. Annual weight increment (g) for ages 2 to 8 in Division 3L.

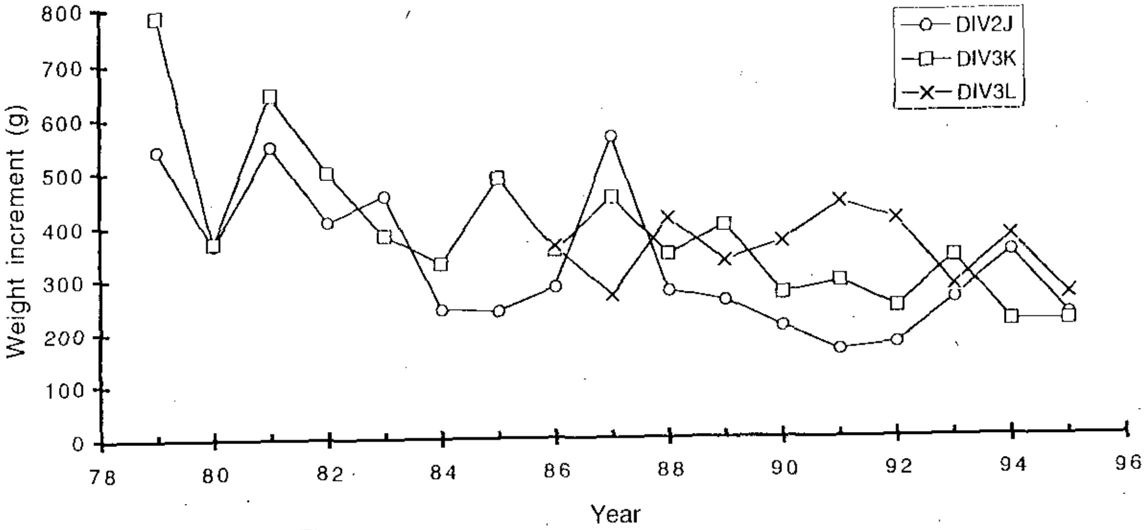


Fig. 8. Annual weight increment at age 3 by division.

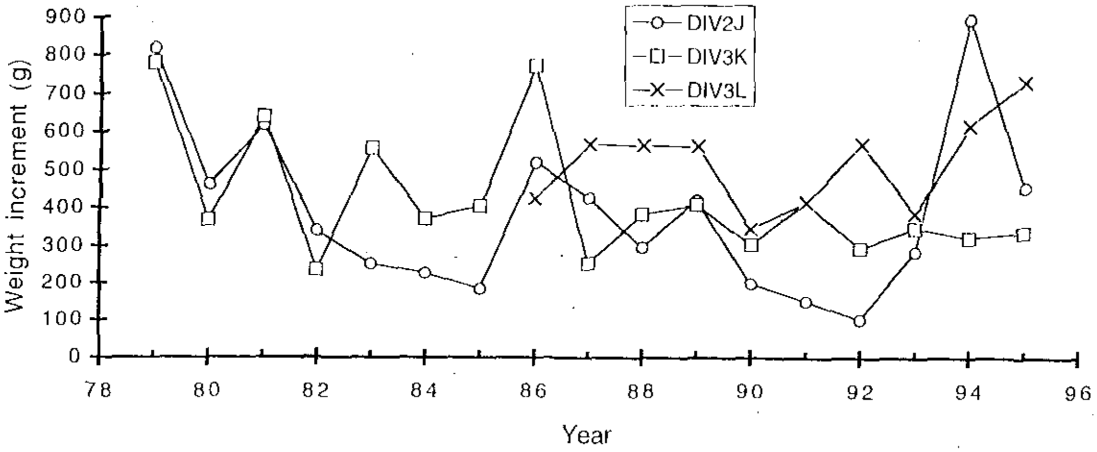


Fig. 9. Annual weight increment at age 5 by division.

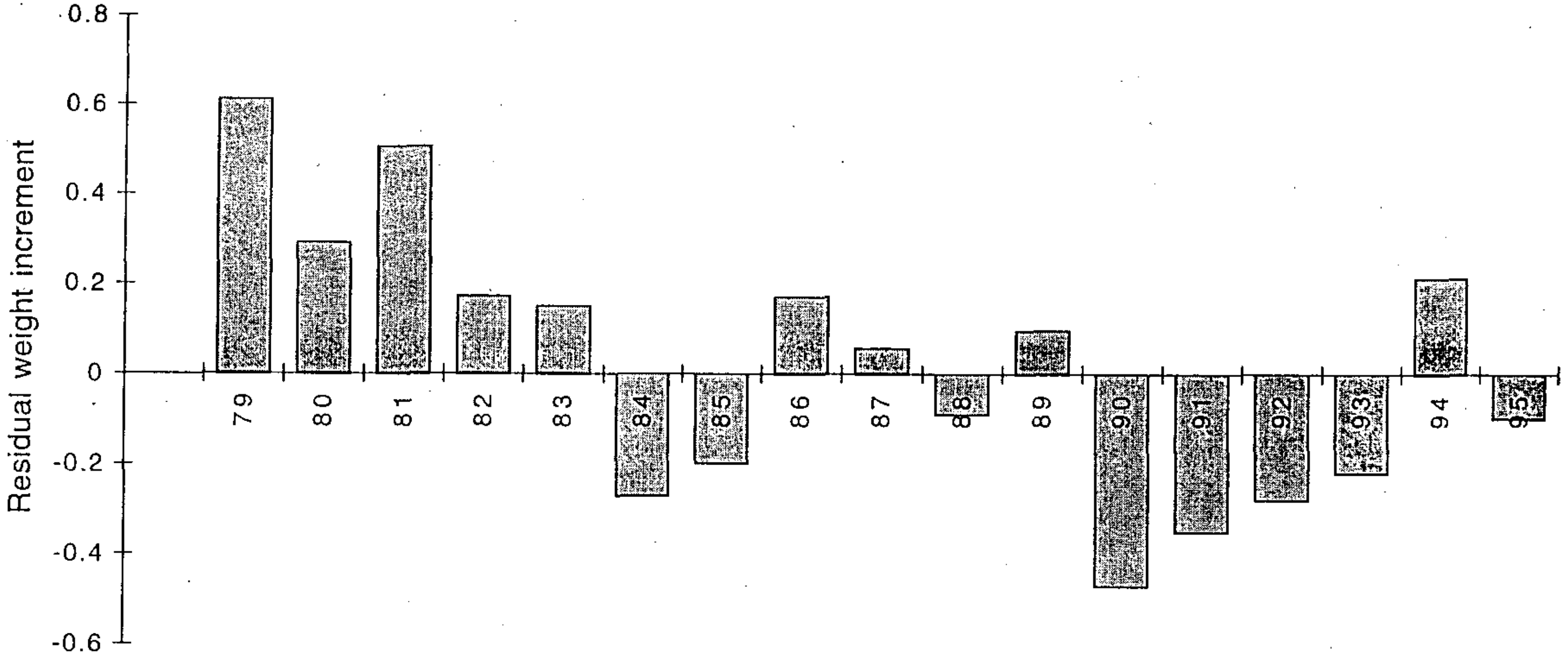


Fig. 10. Annual mean residuals in the weight increment data after removing age and division effects.

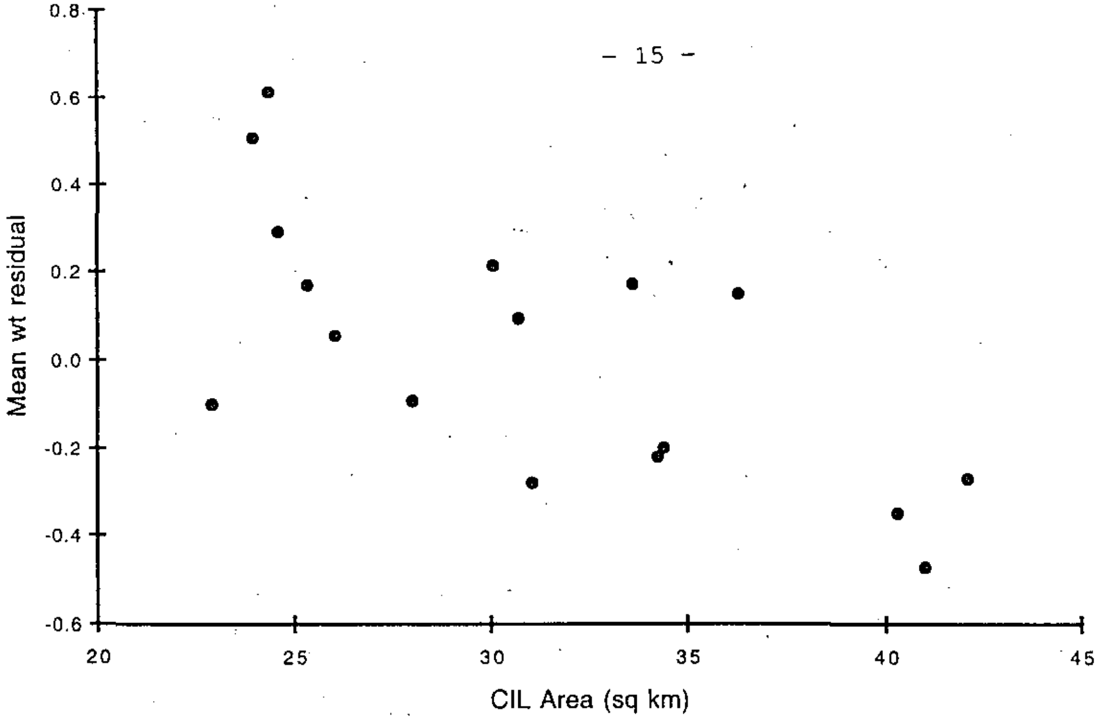
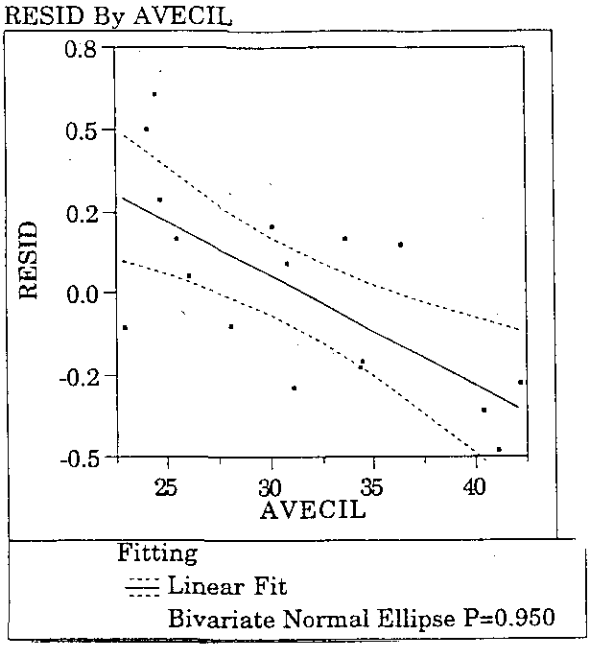


Fig. 11. Residuals in the weight increment data after removing age and division effects, plotted against annual mean area of the CIL.



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Linear Fit

Summary of Fit
Rsquare                        0.482397
Root Mean Square Error         0.224272
Mean of Response               0.016706
Observations (or Sum Wgts)           17

Analysis of Variance
Source      DF   Sum of Squares   Mean Square   F Ratio
Model        1        0.7031556      0.703156   13.9798
Error       15        0.7544720      0.050298   Prob>F
C Total     16        1.4576275                  0.0020

Parameter Estimates
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Fig. 12. Linear regression of the residuals in the weight increment data after removing age and division effects, against annual mean area of the CIL.

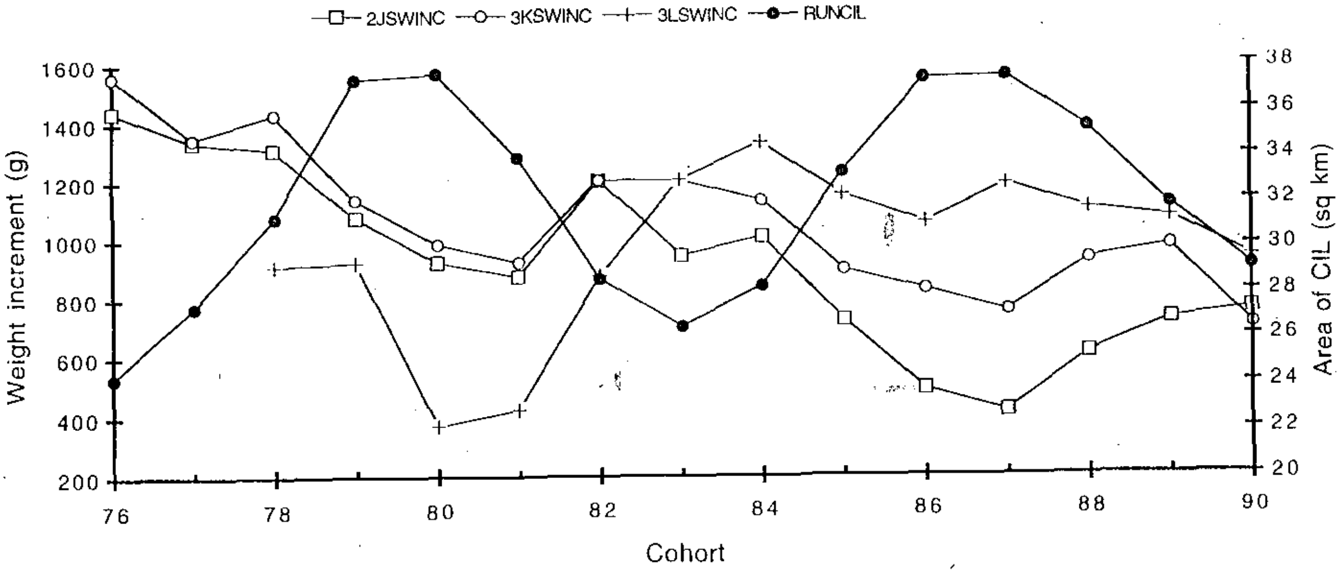

Fig. 13. The total increment in length and weight in each cohort from the beginning of age 3 to the end of age 5 plotted together with the average area of the CIL over that period (equivalent to a 3-year running mean CIL).

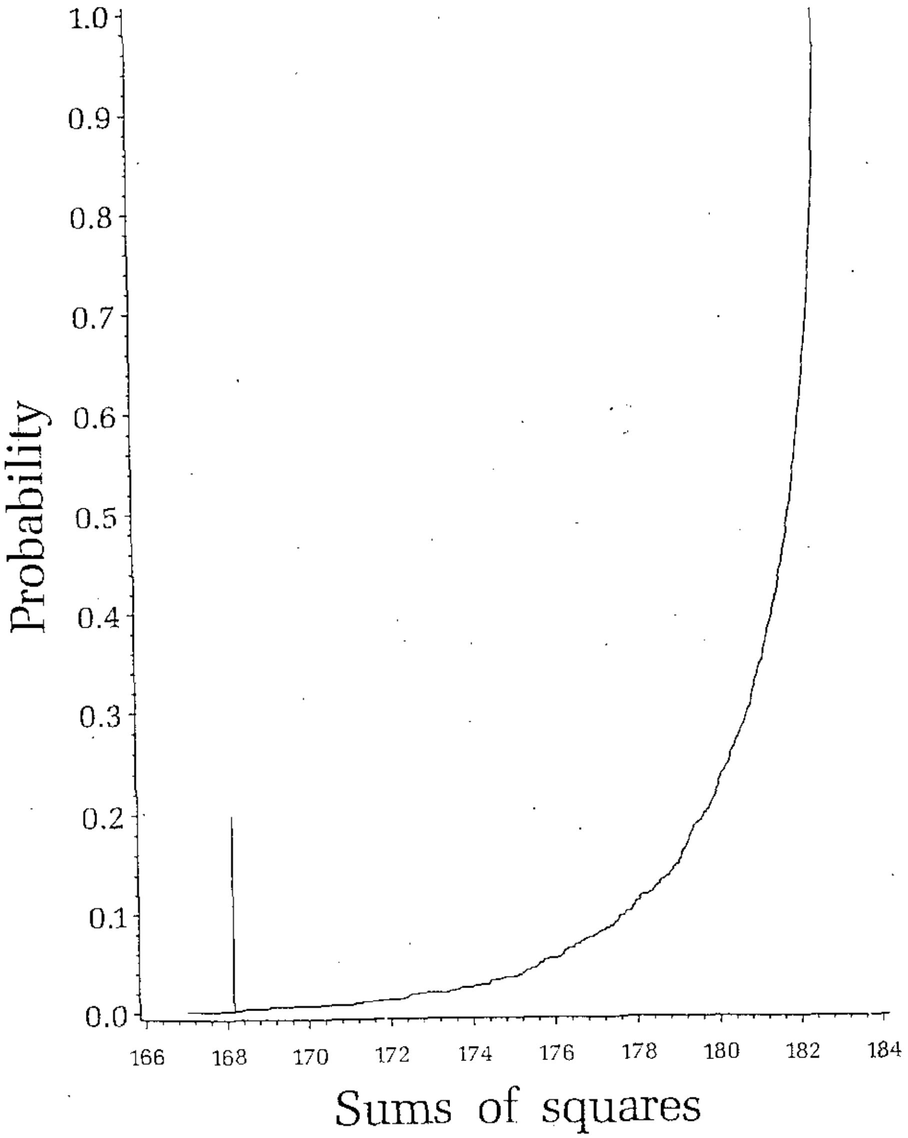

Fig. 14. Randomization results giving the cumulative probability of obtaining a value for fit sums of squares, by including a CIL term, due to chance alone (randomly shuffled CIL data). Vertical line indicates the fit sums of squares obtained in the general linear model including age, division and CIL effects (unshuffled CIL data).

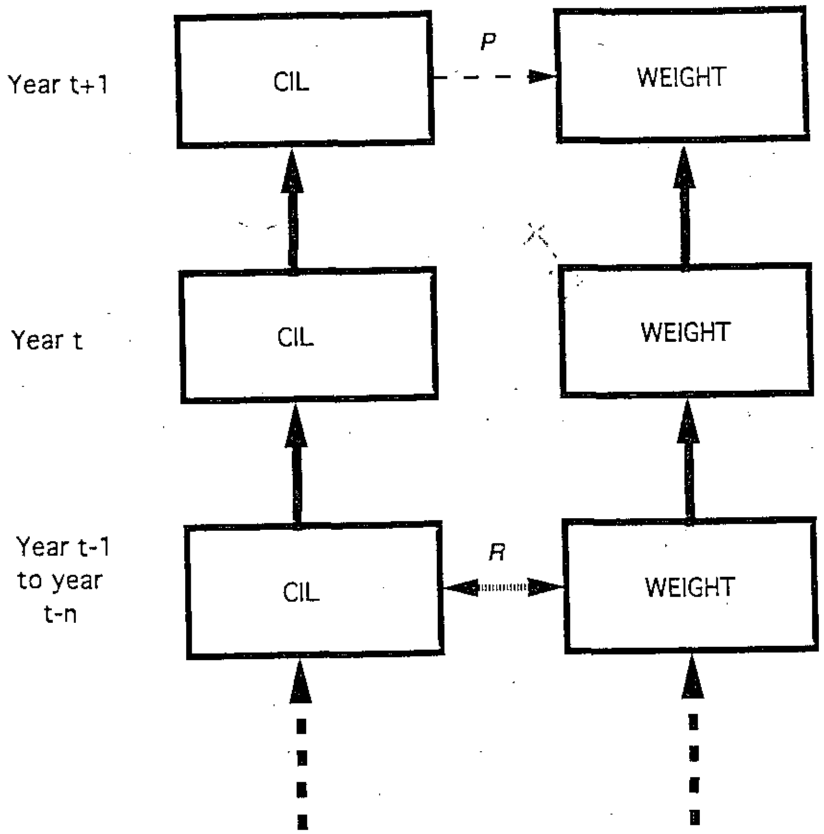

Fig. 15. Schematic indicating the the temporal sequence of events associated with attempting to predict the weight of fish in year t+1 from a predictive growth model which includes CIL fit to data up to and including year t-1, when used during the assessment carried out in year t..

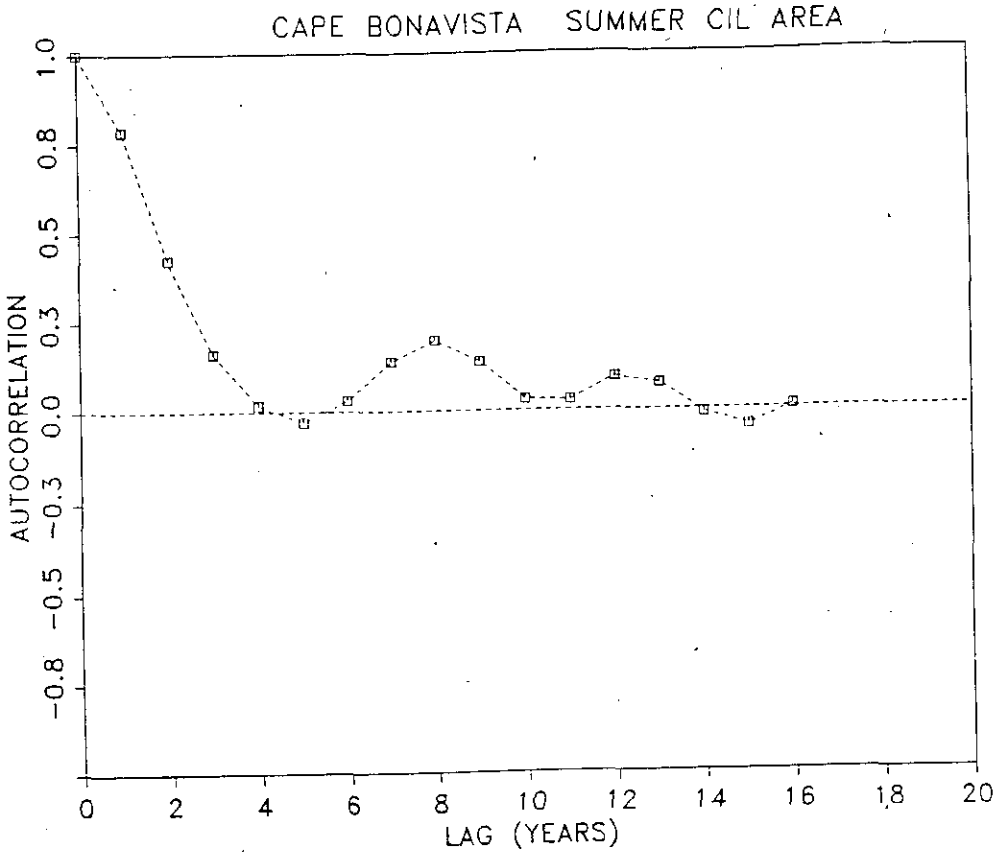

Fig. 16. Autocorrelation in the Bonavista CIL data shown for a range of lags.

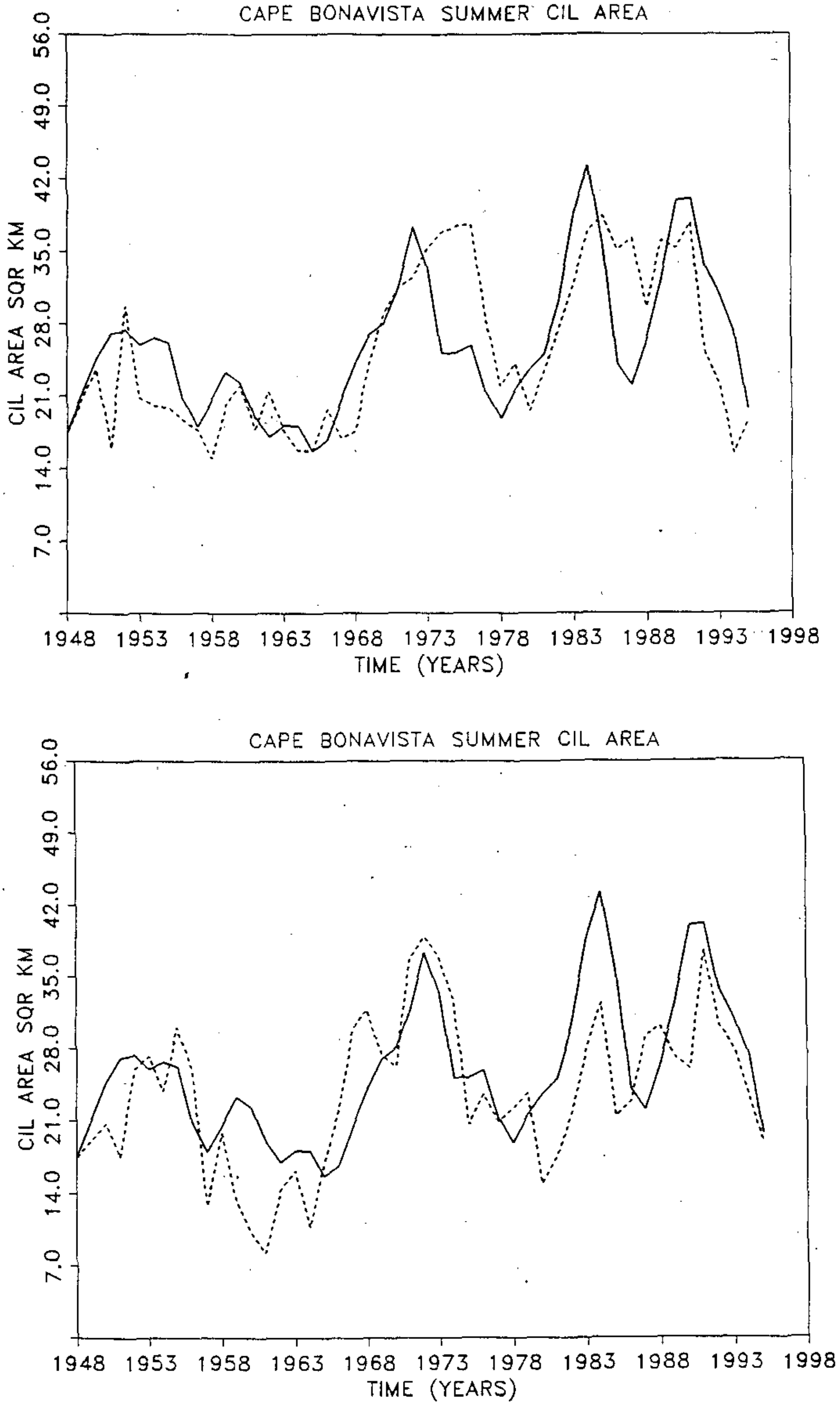

Fig. 17. A sample of two CIL time series generated using the observed lag-1 autocorrelation in the Bonavista CIL data together with a random noise component (broken line) compared with the observed CIL time series (solid line).