Northwest Atlantic Fisheries Organization

Serial No. N1233

NAFO SCR Doc. 86/106

SCIENTIFIC COUNCIL MEETING --SEPTEMBER 1986

Non-Parametric Prediction of Recruitment from Stock and the Relationship of the Residuals to Water Temperature for Cod in NAFO Divisions 2J+3KL and 3M

by

J. C. Rice and G. T. Evans

Science Branch, Department of Fisheries and Oceans
P. O. Box 5667, St. John's, Newfoundland, Canada A1C 5X1

INTRODUCTION

Recruitment of some cod stocks has been related to environmental influences including salinity (Sutcliffe et al. 1983) and temperature (Hansen and Buch 1986). For cod in NAFO Div. 2J3KL, recruitment is also influenced by stock size, even though traditional stock recruit models do not fit the data well (Rice and Evans 1986). At least for the 2J3KL stock, the effect of stock size on recruitment should be accounted for when influences of environment on recruitment are investigated.

For the 2J3KL cod stock, we use a non-parametric method to predict expected recruitment given spawning stock biomass in a year, for the period 1962-80. We then investigate the association of water temperatures and salinities with the deviations of observed from predicted recruitments for each year. We apply the same methods to stock-recruit data from two periods - 1958 to 1964 and 1969 to 1976 - for the cod stock in NAFO Div. 3M. This stock has a much lower spawning stock biomass than the 2J3KL stock, and a more restricted spatial distribution. The stock-recruit relationship has not been investigated in the same way. Both spawning stocks have changed greatly in the past decades; changes largely related to the fisheries.

METHODS

SPECIAL SESSION ON RECRUITMENT

The data: For NAFO Div. 2J3KL, spawning stock biomass and recruitment were estimated according to methods described in Rice and Evans (1986). From data for Station 27 (Akenhead 1983) we took values for surface (0-20 m) salinities and temperatures in January, March, June, and October for years 1958-81 and deep water (100-170 m) temperatures. We did not examine effects of environmental data in years other than the year of spawning.

For NAFO Div. 3M, in 1979 the size of 50% maturity was 52 cm for females and 50 cm for males (Wells 1979), which corresponded to a weight of approximately 1.2 kg, using the equations in Wells (1982). Length at age has increased from the early 1950's to the 1980's (Wells 1983a), and recently has varied among years (Wells 1983b). Likewise weights at age used in sequential population analysis have varied (Gavaris 1981). Because of uncertainties about the association between the shape of the maturation ogive and the variation in length and weight at age, and uncertainties about weight at age data for the early part of the time series (Wells 1973), midyear 5+ biomass was used as an estimate of spawning stock biomass, although it is unlikely to reflect true spawning stock biomass exactly. The numbers of the year-class at age 3 in the sequential population analyses were used as an estimate of recruitment strength. For both stock and recruitment estimates, data for the 1958-65 year-classes come from Wells (1980), and data for the 1969-77 year-classes come from Gavaris (1981).

Monthly data on temperatures and salinities were not available consistently for NAFO Div. 3M. From Akenhead (1981) we took two temperature measures ($\sum$ April-August and $\sum$ April-May, where $\sum$ means the sum of temperatures over all depths), and two salinity measures (similar summations over the same months) for each year from 1955-1980 (data for 1966 were not available). These measures will not be independent; $\sum$ April-May will be a portion of $\sum$ April-August. The measures are usually based on data from few cruises, and variation in the timing of the cruises across years may affect the temperature and salinity values. Results from both the stock-recruit and the environmental data must be interpreted with these problems in mind.

Predicting recruitment from stock: The predicted recruitment each year was the weighted average of all historic recruitments except the recruitment observed in that year. For example, to predict 2J3KL recruitment in 1970, stock-recruit data from 1962 to 1969 and 1971 to 1980 were used. The weight for each historic year was the value of the function $1/(1+(x/D)^2)$. In the weighting function "x" is the difference between spawning stock biomass in the historic year and spawning stock biomass in the year being predicted. "D" is the width of the influence window; when it is narrow only observations from stocks similar in biomass to the stock in the year being predicted influence predicted recruitment strongly, as it widens the influence of observations from stocks of biomasses more distant from the current stock increases. The motivation for this function follows from arguments presented in detail in Rice and Evans (MS).

Two options were available for calculating predicted recruitments: recruitment per unit stock, or gross recruitment. For recruitment per unit stock, each historic recruitment was converted into recruits per unit stock. The weighted average of these recruitments per unit stock was calculated for each year, and then multiplied by spawning stock biomass in that year to give predicted recruitment. For gross recruitment, the historic record of stock recruit pairs was used directly. The recruitment per unit stock option can provide some protection against distortion in predictions if the largest observed stocks produce the largest observed recruitments. Once a predicted recruitment was obtained, the deviation of that value from the recruitment actually observed that year was calculated.

Relating deviations in observed and predicted recruitment to environmental influences: Because the water temperature and salinity measures were likely to be interrelated, these environmental attributes were first ordinated onto a smaller number of axes. Principal components analysis was appropriate for this purpose. The environmental principal components were determined from data of more years than we had stock-recruit data for. This provides better determination of the major axes, and causes no later difficulties.

The factor scores for each year on each component were then used as environmental measures to be associated with the stock-recruit data. To investigate linear relationships, a second principal component analysis was performed, using the appropriate factor scores from the environmental data set, spawning stock biomass, observed recruitment, and the deviations of observed from predicted recruitments. Because non-linear relationships of recruitment and environment were possible, two other analyses were done. Spearman rank-order correlations of the attributes were calculated. Also, the environmental axes, recruitment, and deviations were divided into quartiles, and cross-tabulated. These tables were too sparse for valid statistical analysis, but were scanned for patterns.

RESULTS

2J3KL (Southern Labrador Sea, Northern Grand Bank):

For this stock, the relationship of recruitment to stock size is apparent (Fig. 1a). Recruitments predicted from stock usually corresponded closely to observed recruitments. In the 19 years, only 5 predictions were more than one standard deviation from the observed recruitment; given stock size, recruitment was exceptionally high in 1963 and 1978, low in 1969, 1970, and 1971 (Fig. 1b). The change in stock size over the period is also apparent; another reason to account for the stock-recruit relationship when examining relationships of environment to recruitment.

The 12 environmental measures reflect four independent axes, according to the principal components analysis (χ^2 = 171.2, df = 66, P<0.001; Bartlett's test). The pattern of loadings of the original measures on the principal components suggest the linear components reflect the underlying patterns reasonably (Fig. 2). The first axis reflects a gradient in water temperature at the surface in January and deep from January to June; years with low values on the axis were cold, years with high values were warm. The second axis reflects a gradient in surface water temperature in March and June, and March salinity as well: again cold (and relatively fresh) years would have low scores, warm and saline years would have high scores. The third axis reflects a gradient in fall surface temperature, which correlates inversely with January salinity. Here warm years would have low scores, however, and cold years would have high scores. The fourth and smallest axis reflects temperatures in deep water in October; variation independent of any other measures except fall salinity.

When the stock, recruitment, and deviation of observed from predicted recruitments are factored along with the environmental factor scores, significant internal structure is again present (χ^2 = 64.12, df = 21, P<0.001). The change in stock size dominates the first component, and is associated with a similar trend in observed recruitment and January water temperatures. Functionally, this factor indicates recruitments were larger when the stock was larger, and winters were somewhat warmer in those years. This factor should not be interpreted to suggest that the marked changes in stock size from the 60's to the late 70's are consequences of changing winter water temperatures, however. Impacts of the fishery on the stock were substantial during that period.

The second component of this analysis directly addresses the effect of the environment on recruitment (Fig. 3). The deviations of observed recruitments from those predicted given stock size correlate well with this axis, and observed recruitment is also correlated, although somewhat less well. Note that any effect of stock on recruitment has been removed from both the deviations (by the method of prediction) and from the residual variation in observed recruitment (that not associated with the first component, which accounts for the changes in stock size). The second environmental factor also correlates with this axis, but negatively. Functionally, deviations were large and positive (predicted recruitments were too low) when March and June surface waters were relatively cold and saline; deviations were large and negative (predicted recruitments were too high) when waters were warmer and fresher. Later components do not reflect variation in the stock or recruitment attributes.

These relationships are not dependent on the use of linear ordination methods. Rank-correlations of stock size, observed recruitment, and deviations of observed and predicted recruitment show similar patterns (Table 1). Deviations correlate with recruitment but not the March-June temperature and salinity component. This indicates that although especially large deviations are associated with atypically warm or cold spring and summer waters, the pattern does not persist at intermediate, more typical, conditions. Recruitment itself correlates with both stock (and the January environmental factor) and deviations.

3M (Flemish Cap):

Predictions of recruitment from stock sizes were poorer for this stock than for the 2J3KL stock. The influence of the occasional very large recruitments (Fig. 4a) meant that predictions of recruitments for most years were too high (negative deviations), whereas the predicted recruitments were markedly low for those strong year-classes. Years with large failures did tend to occur together, however, as did the infrequent years with positive deviations (Fig. 4b).

Because predictions were often poor, we tried predicting with the gross recruitment method rather than the recruitment per unit stock method. Deviations of observed from predicted recruitments were generally smaller than with the recruitment per unit stock option, but were still large (Fig. 5a), and generally in the same direction for each year (Fig. 5b). This suggests that recruitment is much less influenced by stock size for this stock.

The four environmental measures were highly intercorrelated, such that a single axis resulted from the principal component analysis (χ^2 = 66.33, df = 6, p<0.001). Cool, fresh years received low scores on this axis; warm saline years received high scores (Fig. 6). Years from 1971 to 1974 and 1978 were ones with low scores; the early 60's and late 70's were relatively high.

Two components resulted from analysis of the environmental factor along with stock size, observed recruitment, and the deviation of observed from predicted recruitment (χ^2 = 54.52, df = 6, p<0.001). The first component reflects variation in stock size and the environmental factor; the second reflects variation in recruitment and the deviations (Fig. 7). Big recruitments produce large underestimates in predicted recruitment, whereas recruitment failures produce large overestimates. Both the recruitments and the errors in prediction are independent of the environmental factor, however.

The inability to relate recruitment to either stock or the environmental component led us to repeat the analysis using recruitment predicted from the gross recruitment method, rather than the recruitment per unit stock method, and using the actual temperature and salinity April-August measures, rather than the principal component scores of the environmental analysis. All the analyses produced similar results: deviations and recruitment size covaried, as did stock and the environmental measures (Fig. 8). It was warmer in the early '60's when the stock was large, and colder in the late '70's, when stocks were depressed. Neither influence had systematic effects on recruitment, however.

The rank-correlations show the same independence of recruitment from stock size and water characteristics (Table 2). Likewise, the magnitude and direction of errors in predicted recruitments are uncorrelated with stock or environmental measures, although naturally correlated with observed recruitment.

Even when only the upper and lower quartiles of recruitments are considered, no relationship with environmental influences are seen (Table 3a-c). Relatively large year-classes have been produced in both cold, fresh years and warm, saline ones. Although recruitment failures have not been observed in warm, saline years, fitting 4 points into 3 cells provides a high likelihood of an empty cell by chance. Certainly there is little evidence that cold, fresh conditions enhance the probability of a recruitment failure.

DISCUSSION

For the cod stock in NAFO Div. 2J3KL, recruitment is clearly influenced by the size of the spawning stock. Implications of this relationship for management of the stock are discussed elsewhere (Rice and Evans 1986). Furthermore, the extent to which recruitment deviates from that expected given the stock size is associated with water conditions in the spring and early summer. The run of markedly poor recruitments in 1969 to 1971 correspond to three consecutive years of relatively warm temperatures in both March and June. Years warm in one month, but not the other, do not appear to have recruitments which were noticeably too low. The large recruitment in 1978 occurred with an average March temperature, but cold June; the 1963 year-class was produced in a year of average temperatures in both months, but relatively high salinity. Given such interrelated influences, single factor analyses and explanations of recruitment processes are likely to err, as will investigations which ignore the influence of spawning stock size.

In contrast to the clear patterns in the recruitment data from NAFO Div. 2J3KL, no relationships were detected in the data from NAFO Div. 3M. It is certainly possible that recruitment processes are completely different for this stock. Before this conclusion is drawn, however, more attention must be given to obtaining the best possible estimates of spawning stock biomass and recruitment, and measures of environmental factors.

For example, using the weight-at-age information in Gavaris (1981), in 1972 a mean weight-at-age of 1.2 kg was not reached until age 6, whereas in 1975 and 1976 the size was attained at age 4. Hence, if the 50/52 cm size at 50% maturity remained fixed, 5+ biomass underestimated spawning stock for 1975 and 1976, and overestimated it for 1972. Our weighted average estimate of recruitment was too high in 1975 and 1976, and too low in 1972, however; just the opposite of the pattern expected from systematic errors in estimating spawning stock biomass. Although this refinement in spawning stock biomass estimation doesn't appear to help, better data are still desirable, and may result from this meeting.

REFERENCES

Akenhead, S. A. 1981. Local sea-surface temperature and salinity on Flemish Cap. NAFO SCR Doc. 81/120, Ser. No. N426. 7 p.

Gavaris, S. 1981. Assessment of the cod stock in Division 3M. NAFO SCR Doc. 81/12, Ser. No. N276. 17 p.

Hansen, H., and E. Buch. 1986. Prediction of year-class strength of Atlantic cod (Gadus morhua) off West Greenland. NAFO Sci. Coun. Studies, 10: 7-11.

Rice, J. C., and G. Evans. 1986. Re-examining target spawning biomass for the cod stock in NAFO Div. 2J+3KL. NAFO SCR Doc. 86/30, Ser. No. N1144. 5 p.

Sutcliffe, W. H., Jr., R. H. Loucks, K. F. Drinkwater, and A. R. Coote. 1983. Nutrient flux onto the Labrador Shelf from Hudson Strait and its biological consequences. Can. J. Fish. Aquat. Sci. 40: 692-1701.

Wells, R. 1973. Virtual population assessment of the cod stock in ICNAF Division 3M. ICNAF Res. Doc. 73/105, Ser. No. 3068. 6 p.

Wells, R. 1979. Observations on the distribution, abundance, growth, mortality and sex and maturity of cod from the Flemish Cap. ICNAF Res. Doc. 79/63, Ser. No. 5404. 20 p.

Wells, R. 1980. Changes in the size and age composition of the cod stock in Division 3M during 1959-79. NAFO SCR Doc. 80/28, Ser. No. N060. 18 p.

Wells, R. 1983a. Changes in average length-at-age of cod on the Flemish Cap. NAFO SCR Doc. 83/42, Ser. No. N699. 3 p.

Wells, R. 1983b. Distribution and abundance of cod on the Flemish Cap, 1977-83. NAFO SCR Doc. 83/29, Ser. No. N681. 8 p.

Table 1. Spearman Rank Correlation coefficients of environmental factors with stock, observed recruitment, and deviations of observed and predicted recruitments for cod in NAFO Division 2J3KL.

	Stock	Observed recruitment	Deviations Obs.-Pred. recruitment
Envt. PC I	0.69[b]	0.50[a]	0.13
Envt. PC II	-0.12	-0.28	-0.14
Envt. PC III	-0.47	-0.35	0.04
Envt. PC IV	-0.01	0.19	0.23
Stock	1.00	0.65[b]	-0.14
Obs. Recruitment	.65[b]	1.00	0.53[a]
Deviations	-0.14	0.53[a]	1.00

[a]$p < 0.05$.

[b]$p <$ 001

Table 2. Spearman Rank Correlation coefficients of environmental factors with stock, observed recruitment, and deviations of observed and predicted recruitments for cod in NAFO Division 3M.

	Stock	Observed recruitment	Deviations Obs.-Pred. recruitment
Envt. PC I	0.56[a]	0.38	-0.09
Salinity Ap - Aug.	0.55[a]	0.16	-0.27
Temp. Ap - Aug.	0.54[a]	0.32	-0.06
Stock	1.00	0.26	-0.52
Obs. Recruitment	0.26	1.00	0.64[b]
Deviations	-0.42	-0.64[b]	1.00

[a]$p < 0.05$.

[b]$p <$ 001

Table 3. Cross tabulation of middle half plus lower and upper quartiles of observed recruitment by middle half plus lower and upper quartiles of environmnetal factor, April-August salinity and April-August temperatures for cod in NAFO Division 3M.

	Lower (cold, fresh)	Middle	Upper (warm saline)
A) Environment Factor:			
Lower (failure)	1	3	0
Middle (Average)	1	4	3
Upper (Success)	2	1	1

	Lower (fresh)	Middle	Upper (saline)
B) Salinity			
Failure	1	3	0
Average	1	4	3
Success	2	1	1

	Lower (cold)	Middle	Upper (warm)
C) Temperature			
Failure	2	2	0
Average	1	4	3
Success	1	2	1

Fig. 1A) Recruitment as a function of spawning stock biomass for cod in NAFO Div. 2J3KL from 1962 to 1980.

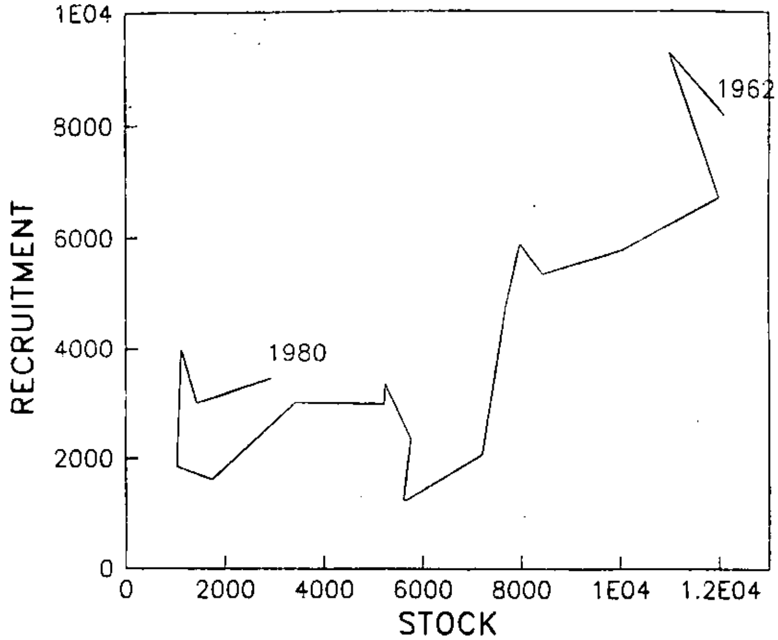


Fig. 1B) Changes in spawning stock biomass, observed recruitment and predicted precruitment over years, for cod in NAFO Div. 2J3KL.

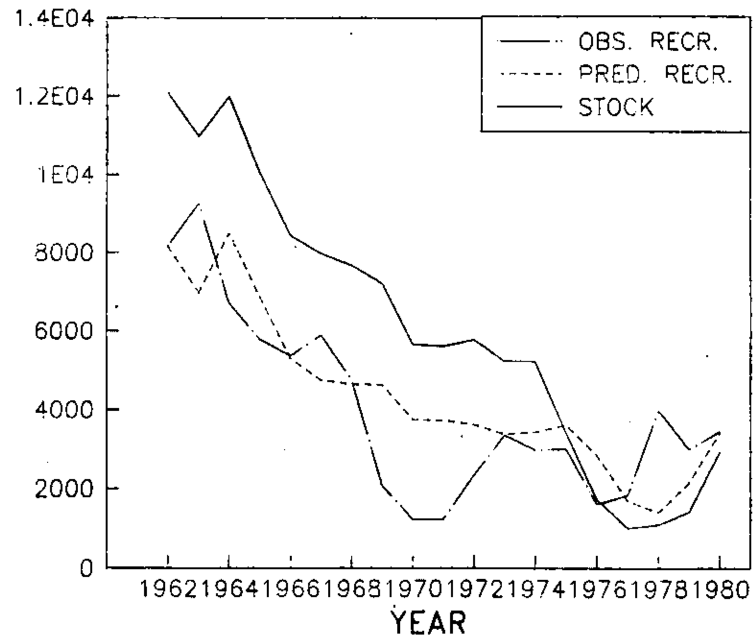
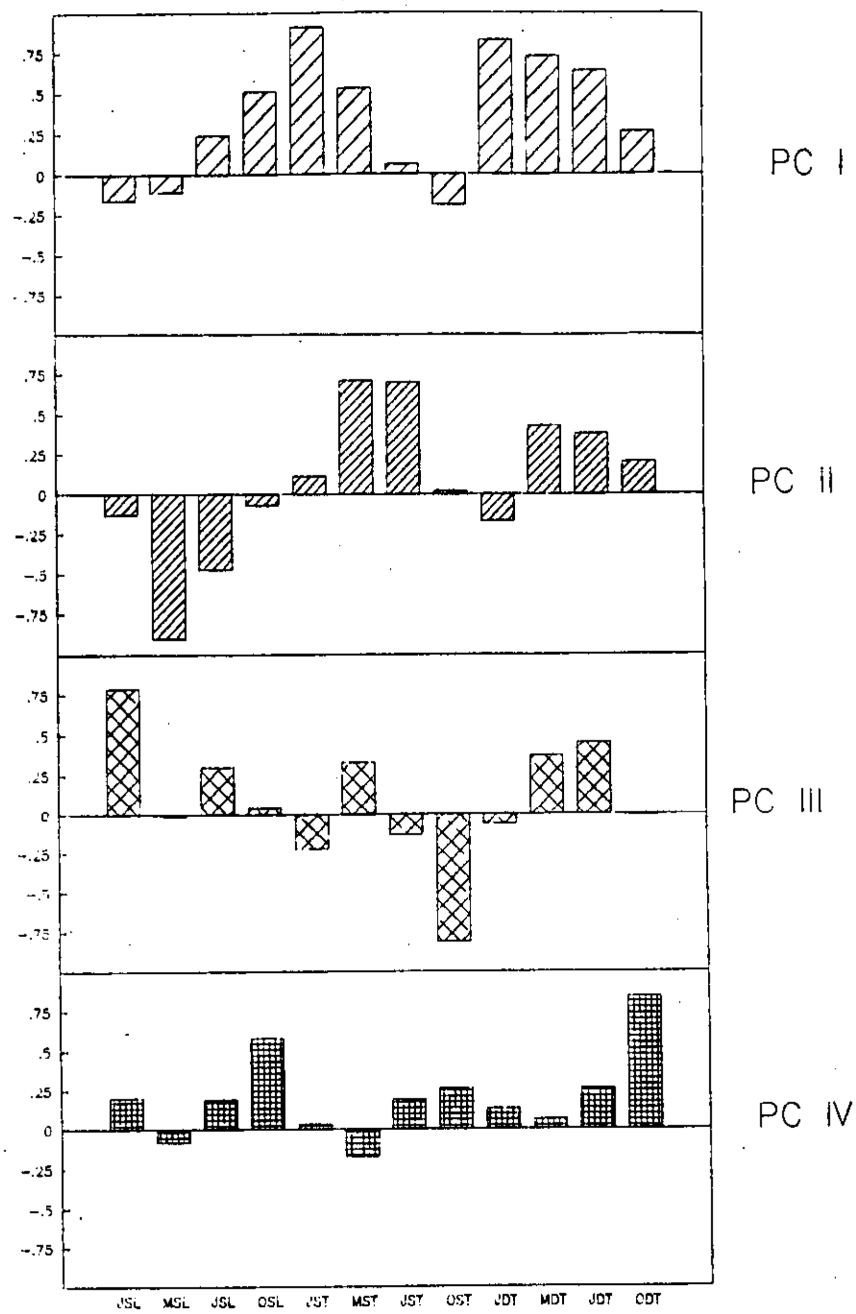


Fig.2) Loadings of environmental measures on the first 4 principal components, from analysis of data from Station 27, 1958 to 1981.



JMJO= January,March,June,October
SL= Salinity; ST=Surface Temperature; DT=Deep Temperature

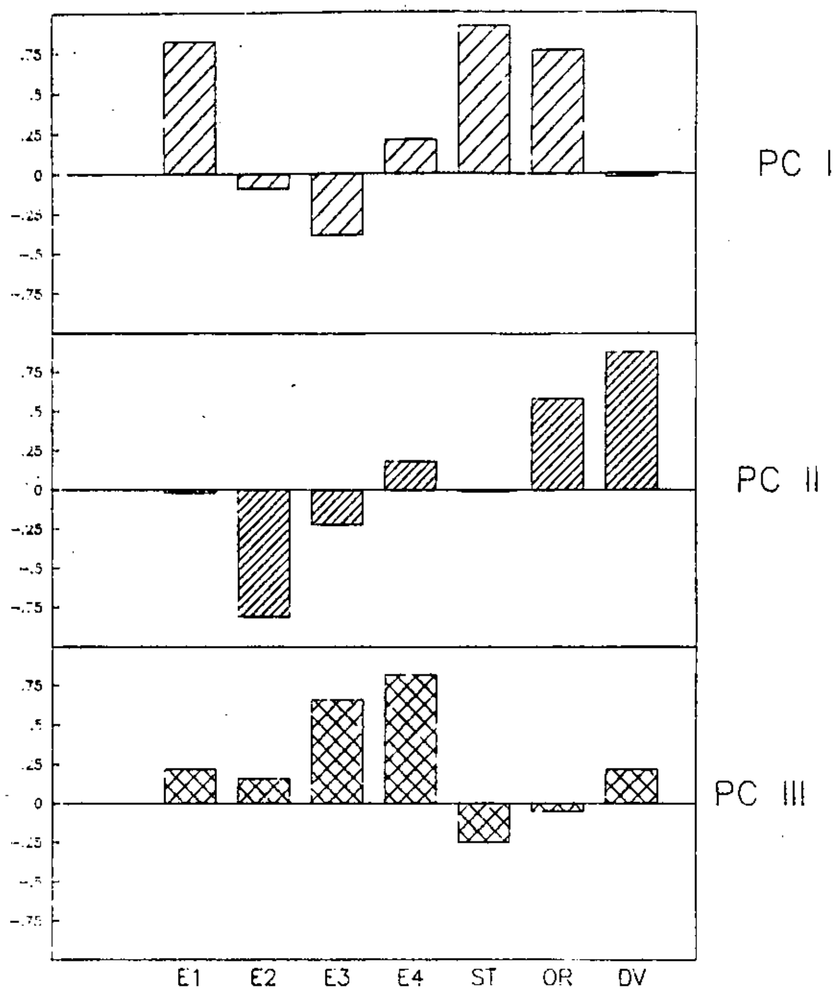


Fig. 3) Loadings of environmental components (E1 to E4), stock (ST), observed recruitment (OR), and deviations of observed from predicted recruitments (DV), for principal components analysis of data from cod in NAFO Div. 2J3KL from 1962 to 1980.

Fig. 4A) Recruitment as a function of spawning stock biomass for cod in NAFO Div. 3M.

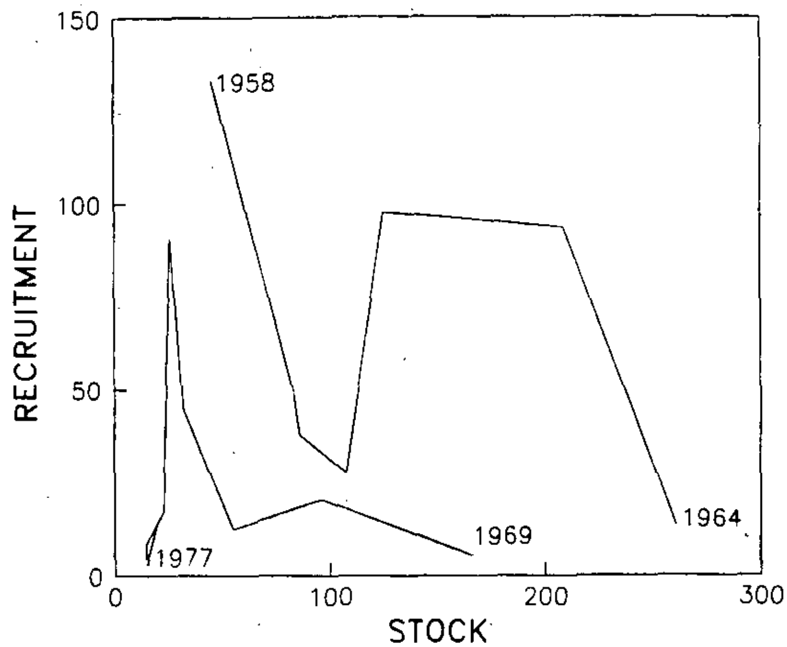


Fig. 4B) Changes in spawning stock biomass, observed recruitment and predicted recruitment over years, for cod in NAFO Div. 3M. Predicted recruitment used recruitment per unit stock option.

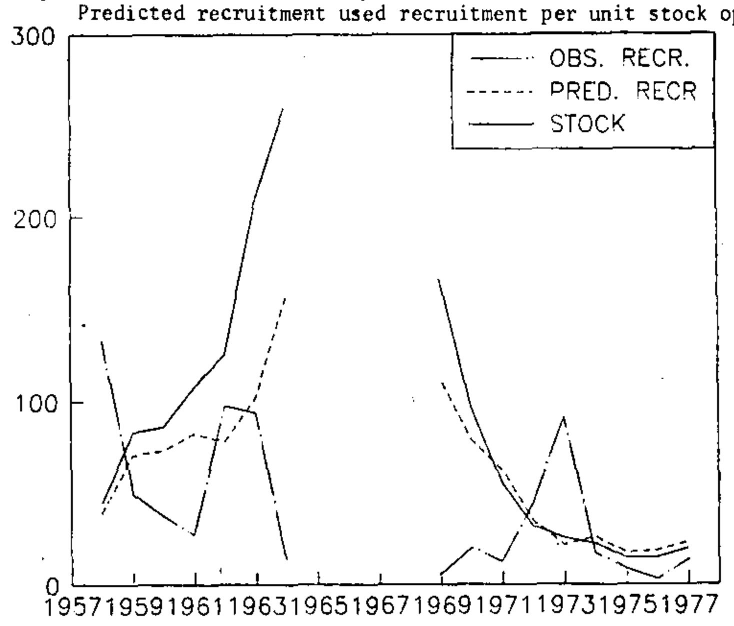


Fig. 5A) Changes in spawning stock biomass, observed recruitment and recruitment predicted using gross recruitment option, for cod in NAFO Div. 3M.

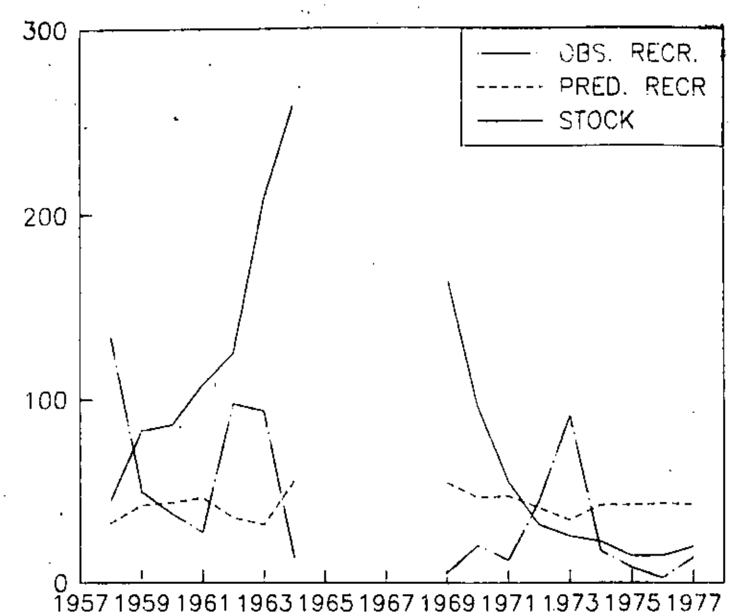


Fig. 5B) Deviations of observed recruitment from recruitment predicted with recruitment per unit stock and gross recruitment options, for 1958 to 1977.

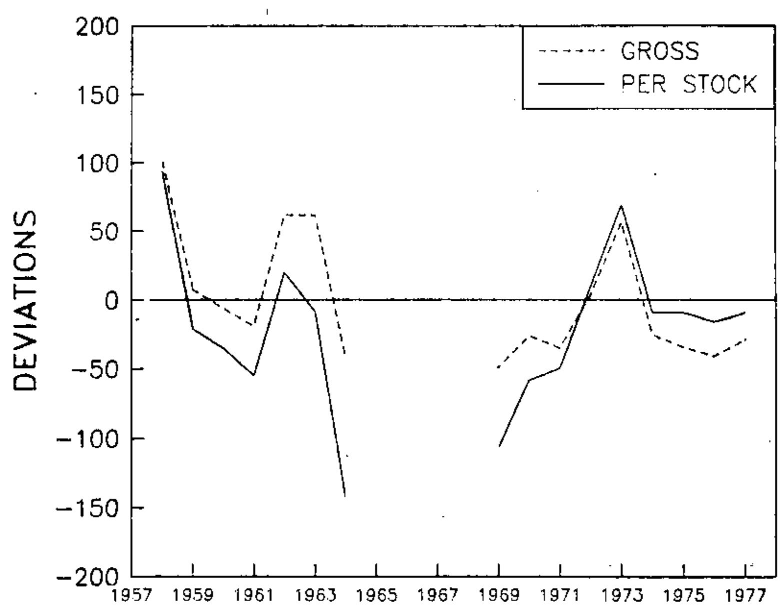


Fig.6) Loadings of April-August (AA) and April-May (AM) salinities (S) and temperatures (T) on first principal component of data from NAFO Div. 3M, 1956 to 1980.

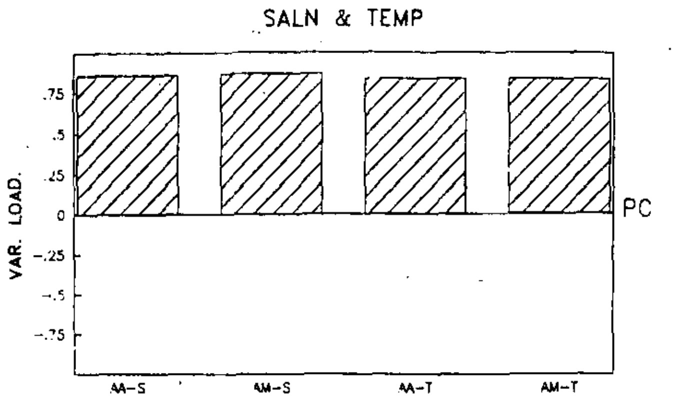


Fig. 7) Loadings of the environmental component, stock, observed recruitment (ob. recr.) and deviations of observed from predicted per unit stock recruitment (dev), for data on cod from NAFO Div. 3M.

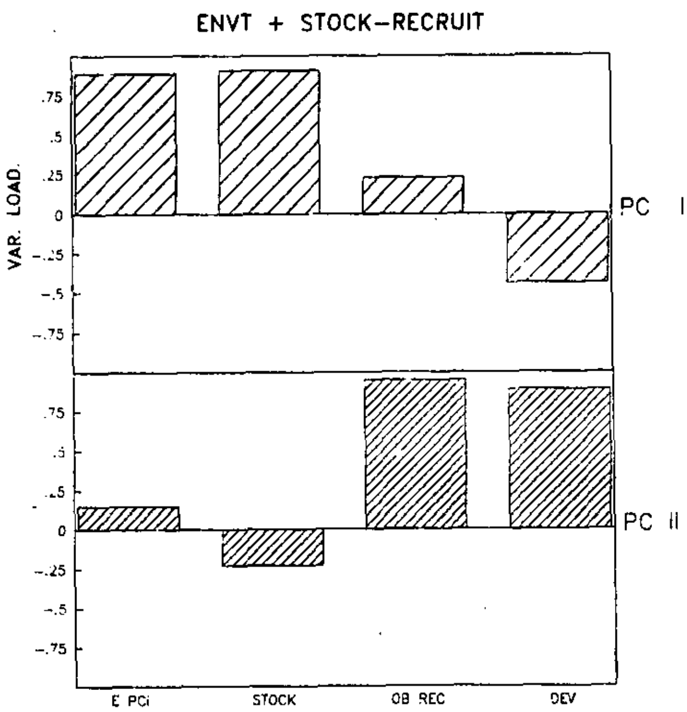


Fig. 8) Loadings of environmental component, stock, observed recruitment, and deviations of observed reruitment from recruitment predicted with gross recruitment option, for data from cd in NAFO Div. 3M. Abberviations as in Fig. 7.