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The Influence of Salinity on 2J3KL Cod Recruitment

by

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1 Introduction

We examine the relationship between recruitment of 2J3KL cod and summer salinity at station 27 proposed by Sutcliffe et al. (1983). Sutcliffe et al. (1983) found a strong relationship between depth averaged summer (July-Sept.) salinity at station 27 from 0 to 50 meters and recruitment. The relationship found was

$$Recruitment_y = -26360 + 162s_y + 278s_{y+1} + 406s_{y+2}, \quad (1)$$

where s_y is salinity in year y and recruitment in year y is in numbers ($\times 10^5$) of cod at age 4. This relationship is shown in Fig. 1. The recruitment series they used was from a Virtual Population Analysis (VPA) from Wells and Bishop (1980). The present recuitment series differs substantially from the 1980 assessment because fishing mortality was underestimated in that year.

Sutcliffe et al. (1983) suggested that this freshwater input from Hudson Bay plays an important role in determining the physical characteristics of the water, as well as influencing the production of plankton and fish, on the Labrador and Newfoundland shelves. Sutcliffe et al. (1983) found an inverse relationship between the seasonal cycles in runoff into Hudson Bay and the depth-averaged salinity in the upper 50 m at Station 27 when the salinity lagged the runoff by 4 months. They speculated on the possibility of a relationship at interannual time scales but lacked the necessary runoff data for the Hudson Bay region to test this hypothesis directly. Instead, they used a surrogate data set, the freshwater discharge from the adjacent St. Lawrence River drainage basin. Myers et al. (1990) disproved this hypothesis. They found sea-ice extent over the Labrador and northern Newfoundland shelves was significantly negatively correlated with salinity at a lag of 3 to 4 months, corresponding to the time of minimum salinity at Station 27. It appears that ice-melt over the Labrador-Northern Newfoundland shelf is primarily responsible for the seasonal salinity minimum over the Newfoundland shelf.

Ice melt is not the only source of salinity variation on the Newfoundland-Labrador shelf. Myers et al. (1988) showed that salinity anomalies at Station 27 were significantly positively correlated with salinity variations on the West Greenland Shelf after a lag of 15 months. In particular, the

Station 27 salinity anomaly time series shows a freshening around 1971 that is consistent with the timing of the advection of the "Great Salinity Anomaly" in the north Atlantic (Dickson et al. 1988). This anomaly occured at all depths.

2 Test of Prediction

We have replicated the results of Sutcliffe et al. (Fig. 1). We have also included the results from the results for the estimates of the latest assessment of numbers of age 4 cod in 2J3KL (Baird and Bishop 1992, CAFSAC, not to be cited). The correlation of the new assessment estimates and the prediction from the cod is nominally significant (r=.72, p=0.008, years classes from 1976 to 1987). Note that the test has not been corrected because of loss of degrees of freedom caused by autocorrelation in the time series. This results indicates that the recruitment predicted from salinity may be valid and deserves further investigation.

3 Results using VPA

We begin the reanalysis by a reexamination of the relationship between recruitment and salinity using recruitment from the most recent VPA. If we repeat the regression analysis of Sutcliffe et al. using the most recent data we obtain a highly significant result (p=0.0005); however the results are difficult to sort out because both recruitment from the VPA and salinity are autocorrelated.

One possible limitation of the result is that spawning stock biomass (SSB) decreased at about the same time there was a general decrease in the surface salinity in the region. We thus use a regression approach that includes this information (Table 1).

One difficulty in using VPA results is that year classes are smeared together. This makes recruitment studies relying on year to year variability hard to sort out. The rest of our analysis will use research surveys which smear year classes less than VPA analysis.

4 Summer salinity

We examine the relationship between summer salinity and other environmental variables.

There appears to be a relatively small degree of autocorrelation in the salinity time series (r=0.34) (Fig. 2).

The four panels of Figure 2 are explained below.

4.1 Panel 1

This panel shows the monthly variability of the data.

4.2 Panel 2

This panel shows two smoothed versions of the time series from panel two and theindividual data points are also plotted. The solid line is the lowess smoother developed by Cleveland (1979). Lowess uses robust locally weighted regression for smoothing a scatterplot. Each fitted value is the value of a polynomial fit to the data using weighted least squares. A window is placed about each x value; points that are inside the window are weighted so that nearby points get the most weight. A robust fitting procedure is used that guards against deviant points distorting the smoothed points. The procedure is applied for three iterations. The interval, or window size, is 6 months on each side. Note that when there are missing values in a time series, the series is reconstructed by removing the missing values and the lowess smoother is then applied to this new series.

The line with breaks is produced by means of running medians. The results are produced by applying a method known as 4(3RSR)2H twice (Tukey 1977).

4.3 Panel 3

This panel shows the sample autocorrelation function of each of the time series. It was calculated as follows:

$$r(k) = \frac{1}{s^2 N} \sum_{t=1}^{N-k} (X_t - \overline{X})(X_{t+k} - \overline{X}). \tag{2}$$

The autocorrelation function is only shown for lags up to 12 years; also included are the 95% confidence limits about zero. Note that the autocorrelation at lag 0 is not plotted.

4.4 Panel 4

This panel shows estimates of the spectrum of a time series produced by smoothing the raw periodogram , as well as the autoregressive spectrum estimation. The spectrum is estimated by taking the discrete Fourier transform of the (detrended then tapered then padded) data. The squared modulus of this transform is then smoothed by a sequence of running average using a modified Daniell smoothers. We applied two running averages of length 9. A modified Daniell smoother has all values equal except for the 2 end values which are half the size of the others. Also given is the the bandwidth of the estimate. See Bloomfield (1976) for a discussion of the methods.

An autoregressive model is fit to the data and the autoregressive spectrum is estimated from this fit. The autoregressive fit is of the form:

$$x_t = \alpha_1 x_{t-1} + \alpha_2 x_{t-2} + \ldots + \alpha_p x_{t-p} + \epsilon_t \tag{3}$$

where ϵ_t is white noise process with zero mean and finite variance σ_ϵ^2 The "yule-walker" method is used whereby the autocovariance matrices of the time series are estimated and Whittle's recursion (a multivariate extension of the Levinson-Durbin method) is used to estimate the autoregressive coefficients. The coefficients can also be estimated by using Burg's algorithm, based on the principle of maximum entropy. The estimation is performed using the sample mean of each univariate series as the estimate of the mean. Remember that the coefficients in ar are for the series with the mean(s) removed.

The smoothed spectrum is plotted(solid line), along with a cross in the upper right corner whose vertical component indicate the 95% confidence interval for the spectrum (based on a chi-squared approximation) and whose horizontal element indicates the bandwidth of the estimate.

The autoregressive spectrum estimate is also plotted(dashed line). The spectrum $S(f)$ of an autoregressive process with coefficients $\alpha_1, \ldots, \alpha_p$ is

$$S(f) = \frac{\sigma_\epsilon^2}{|1 - \alpha_1 \exp(-2\pi i f) - \ldots - \alpha_p \exp(-2\pi i f)|^2} \tag{4}$$

where f is the frequency in cycles per unit time and σ_ϵ^2 is the variance of the innovation process ϵ_t.

The spectrum of summer surface salinity appears to be red, i.e. dominated by low frequency variability.

The summer salinity also seems to be highly related to ice formation (Fig. 3), which is in turn related to the NAO . In both relationships there is a puzzling effect that appears to extend to the year after the NAO or icemelt data.

Salinity is also correlated with previous salinities from West Greenland. (Fig. 4)

5 Analysis of recruitment using research data

VPA and related methods will smear year classes together. We will thus examine the relationship in detail using research surveys. We use a multiplicative model to extract the survey effects at age.

In order to provide an alternate recruitment series to the VPA we use a modification of a multiplicative catch at age model developed by Pope (19??), Shepherd and Nicholson (1991), and Cook (1989).

Let the numbers of fish of age a in year y be $N_{y,a}$. We will only consider ages at which commercial fishing mortality is small. Let S_a be the survival to age a, which we assume to be constant. Myers and Cadigan (1992) showed that for cod, haddock, plaice, whiting, and American plaice the interannual variation in juvenile mortality unrelated to density is small. Let the number of recruits in year y be $N_{y,0}$. The numbers at age will then be

$$N_{y,a} = S_a N_{y-a,0}. \tag{5}$$

Let the number of fish of age a in year y estimated from survey i be $R_{y,a,i}$. Assume that the estimate of abundance is proportional to the true abundance, i.e. the catchability of survey i at age a is $Q_{a,i}$. The logarithm of the errors in estimates of abundance is assumed to be normal with constant variance. Thus,

$$R_{y,a,i} = Q_{a,i} N_{y,a} e^{\epsilon_{y,a,i}} \tag{6}$$

$$= Q_{a,i} S_a N_{y-a,0} e^{\epsilon_{y,a,i}}. \tag{7}$$

It will be convenient to use log transformed data. Lower case letters will refer to log transform of parameters and variables. Thus, equation 2 becomes

$$r_{y,a,i} = q_{a,i} + s_a + n_{y-a,0} + \epsilon_{y,a,i}. \tag{8}$$

Note that $q_{a,i}$ and s_a are confounded in the above equation. We only attempt to estimate the sum of these two parameters.

Note that the above equation is a simple analysis of variance with year class and age effects. If the error variance is approximately constant the year class effects can be estimated using any standard analysis of variance programs. The year effects will be used here as the estimate of recruitment.

The first and the last year classes in the series will be the least reliable. Less emphasis should be put on these time series.

We will use age 2 to 6 for the analysis for fall surveys and 2 to 7 for spring surveys. (Age 1 to 3 was used for the Russian 3M data)

For 2J we analyze the Federal Republic of Germany fall survey series from 1972 to 1983, and the Canadian fall surveys from 1977 to 1991. There is excellent agreement in these surveys during the period of overlap (Fig. 5).

For 3K there are only the Canadian fall surveys from 1978 to 1991. They are in excellent agreement with the 2J surveys (Fig. 5).

For 3L there are Canadian spring surveys from 1977 to 1991, with 1983 and 1984 missing, and fall surveys from 1981 to 1991. There was a change in research ships in the spring survey; we estimated different sets of age effects for each ship. The 3L recruitment surveys are very similar to each other; however, there are consistent differences with the 2J and 3K surveys.

The southern Grand Banks (3NO) was surveyed in the spring by Canada from 1971 to 1990. There was a change in research ships in the survey; we estimated different sets of age effects for each ship. The results for 3NO are very similar to those for 3L, and similar to those for 2J. (NOTE: The first and last two year class estimates were deleted.)

The St. Pierce Bank (3Ps) was surveyed in the spring by Canada from 1972 to 1991 and by France from 1972 to 1989. There was a change in research ships in the Canadian survey; we estimated different sets of age effects for each ship. There appears to be little relationship of 3Ps with other regions.

The Flemish Cap area (3M) was surveyed by Russia from 1962 to 1982. There appears to be little relationship of 3M with other regions.

6 Analysis of salinity and recruitment using research data in 2J3KL

The results for the simple correlations confirm that salinity at age 0+ and 1+ appear to confirm the suspected correlation (Fig. 6).

If anything the salinity when the age 1+ cod appears to have a stronger effect on recruitment than salinity at 0+. Salinity when the cod are 2+ appears to have no affect and will be ignored for the rest of the analysis.

7 Analysis of salinity and recruitment using research data in 3M, 3NO and 3Ps

We also investigated the relationship for divisions 3M, 3NO and 3Ps.

For 3NO and 3Ps the results for the simple correlations confirm that salinity at age 0+ and 1+ appear to confirm the suspected correlation. If anything the salinity when the age 1+ cod appears to have a stronger effect on recruitment than salinity at 0+. (Fig. 7 & Fig. 8)

For 3M the there appears to be no significant relationship. (Fig. 9)

NOTE: See Table 2 for results of stepwise regressions.

8 Analysis of ice and recruitment using research data

The relationship of the residuals from a power stock recruitment relationship with ice cover south of 55 *degrees latitude from 1962 to 1984* is consistent with the hypothesis that ice is responsible for the larval and/or 1+ juvenile mortality (Fig. 10). The stongest relationship is found with May ice cover. If mortality is occuring during the larval phase this is the month that would be most likely to be affected.

The ice data was provided by John Walsh.

9 Discussion

There appears to be a clear relationship with recruitment and summer salinity when cod are one year old. The mechanism is unclear.

9.1 Food Effects

Dickson et al. (1984) proposed a salinity-temperature mechanism for the great salinity anomaly. However, salinity is if anything anticorrelated with primary production for the region (Mertz and Myers, in preparation).

9.2 Direct Mortality

Ice death could explain mortality in the larval phase. Fletcher et al. (in press) demonstrated that larval death could result from freezing. This is a possible reason for the relationship in the year the larvae are 0+ with summer salinity or ice cover in May or June.

The relationship with salinity during 1+ is more difficult to understand. One possible cause is death from ice contact and freezing during the first winter of life when the juveniles are not completely settled.

9.3 Advection from Region

Summer salinity may be correlated with probablity of being advected from the nursery grounds. There is no evidence for such a relationship.

9.4 Changes in Predator Density

There is no known relationship with salinity and predator density.

10 Conclusion

There is strong evidence that summer salinity is strongly correlated with recruitment in the 2J3KL, 3NO and 3Ps. The mechanism responsible is not clear.

Acknowledgments

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Table 1. Results of a stepwise regression appoach to regressing log transformed VPA recruitment estimates on log transformed Spawning Stock Biomass (SSB), salinity in the year of birth (sal), next years salinity (sal1) and the next year after salinity (sal2) for divisions 2J3KL, 3NO, 3Ps and 3M.

Division	Variables	Year Classes	R^2	Nominal P-value
2J3KL	SSB sal1	1962-1989	0.490	0.0002
3NO	sal1	1959-1986	0.247	0.0071
3Ps	sal1	1959-1987	0.566	0.0001
3M	sal2	1956-1984	0.034	0.3566

Table 2. Results of a stepwise regression appoach to regressing year class estimates on salinity in the year of birth (sal), next years salinity (sal1) and the next year after salinity (sal2). Note that for the Canadian surveys 3L spring, 3NO and 3Ps there was a change in research ships in the survey; we estimated different sets of age effects for each ship.

Division	Variables	Year Classes	R^2	Nominal P-value
Canadian 2J	sal1	1970-1988	0.240	0.0332
German 2J	sal1	1965-1980	0.534	0.0013
Canadian 3K	sal1	1971-1988	0.493	0.0012
Canadian 3L Spring	sal1	1971-1988	0.240	0.0391
Canadian 3L Fall	sal1	1974-1988	0.072	0.3354
Canadian 2J3KL	sal1	1971-1988	0.393	0.0054
Russian 3M	sal	1961-1982	0.157	0.0680
Canadian 3NO	sal1	1967-1985	0.131	0.1285
Canadian 3Ps	sal1	1966-1988	0.266	0.0118
French 3Ps	sal1	1972-1988	0.360	0.0108

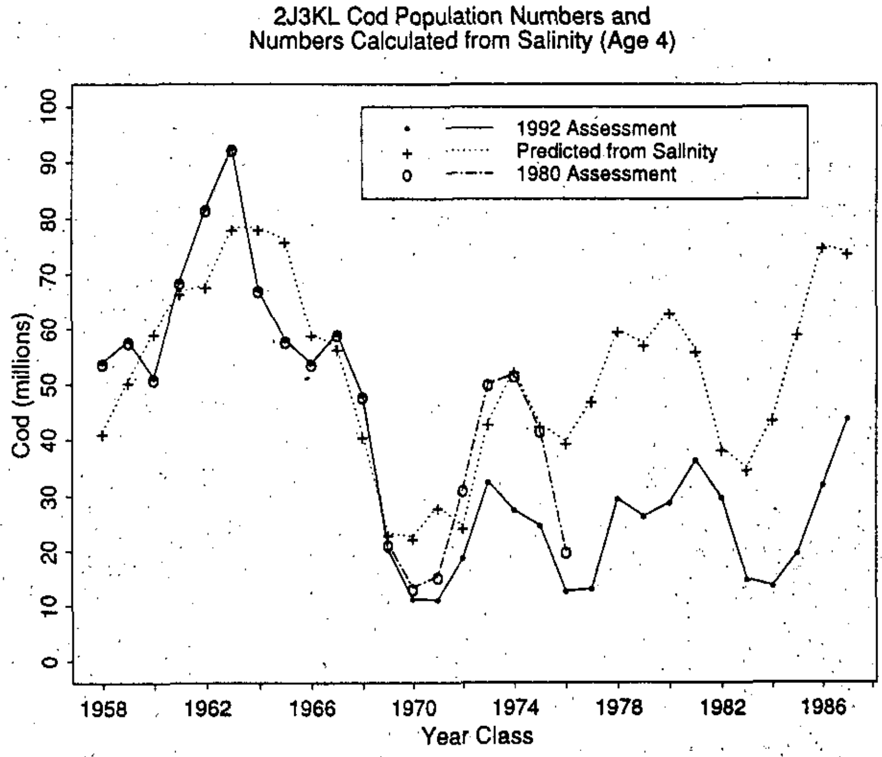

Fig. 1. The original relationship proposed by Sutcliffe et al. between their their regression for cod from summer salinity at station 27 and the 1980 assessment of recruitment of age 4 cod. Also shown in the 1992 assessment of cod.

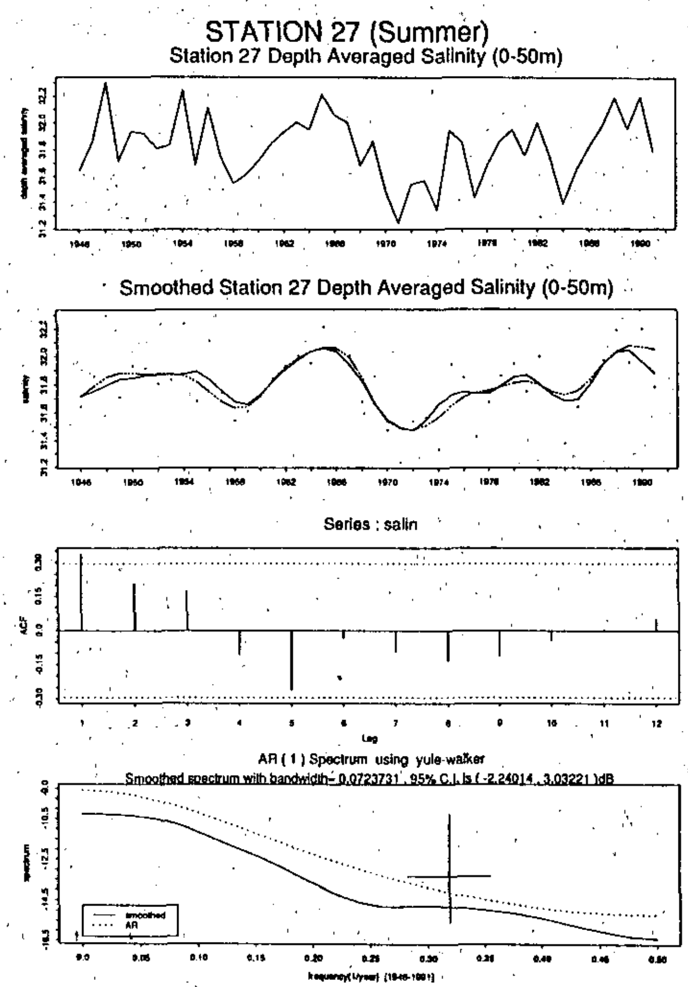

Fig. 2. The depth averaged summer (July-Sept.) salinity at station 27 from 0 to 50 meters.

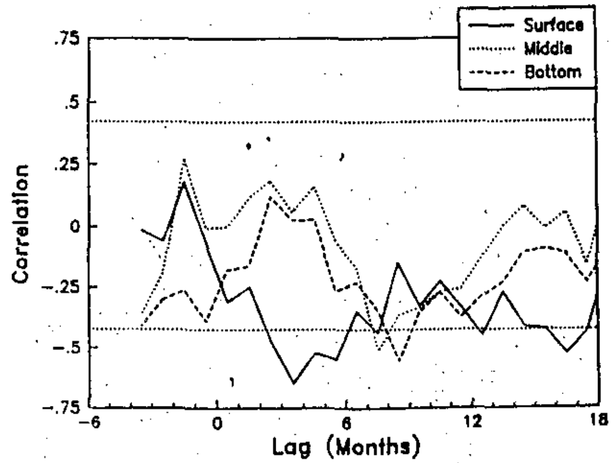

Fig. 3. The correlation of the area of Labrador ice between 47°N and 65°N from March to June with lagged salinity anomalies at Station 27 for three depth zones, plotted against lag referenced to May 1.

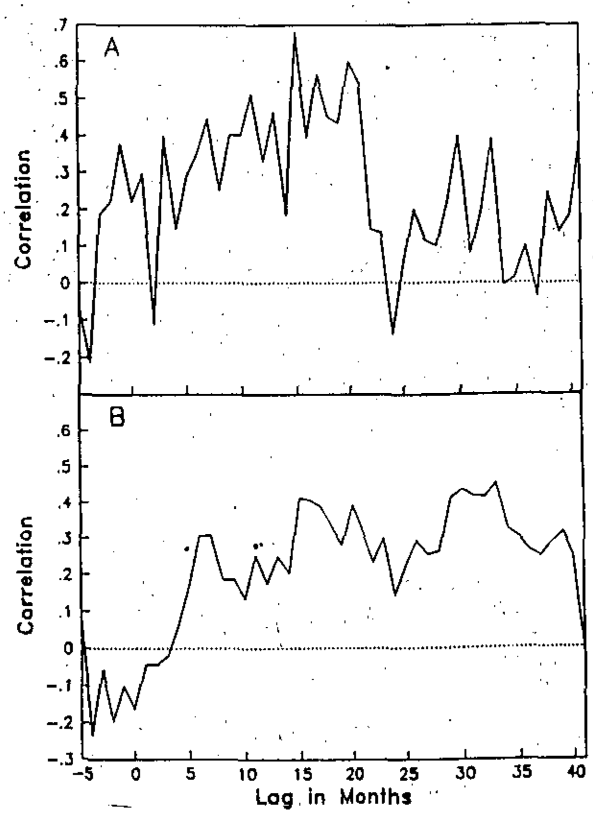

Fig. 4. The correlation of July salinity at Fyllas Bank with the lagged salinity (A) and temperature (B) residuals at Station 27.

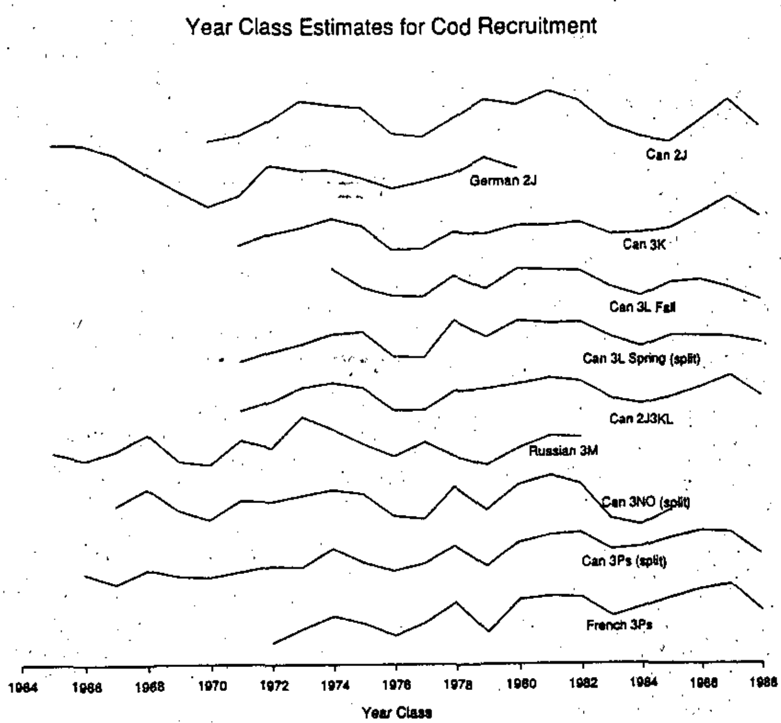

Fig. 5. Recruitment time series for various research surveys around Newfoundland. The series show relative changes in log. (base e) recruitment. The data is based on cohort effects in a year class by age analysis of variance.

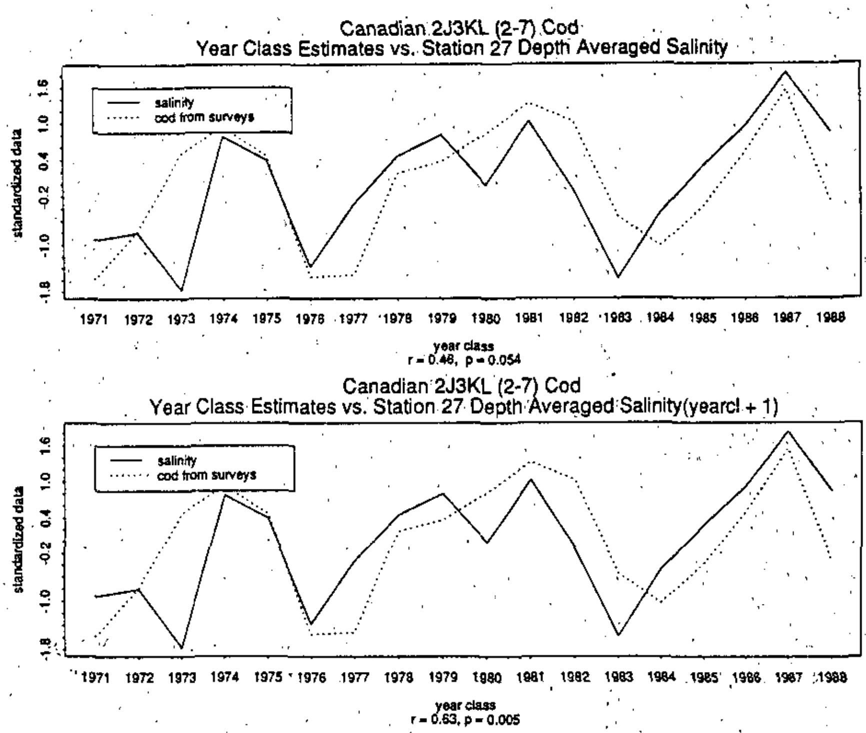

Fig. 6. Relationship between summer salinity and log (base e) recruitment from research surveys in 2J3KL.

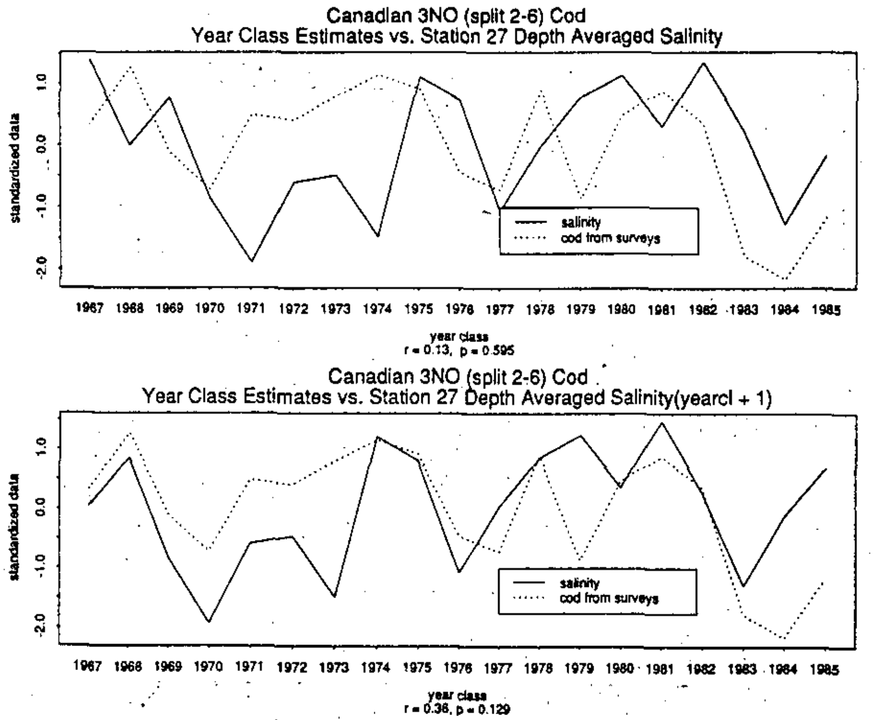

Fig. 7. Relationship between summer salinity and log (base e) recruitment from research surveys in 3NO.

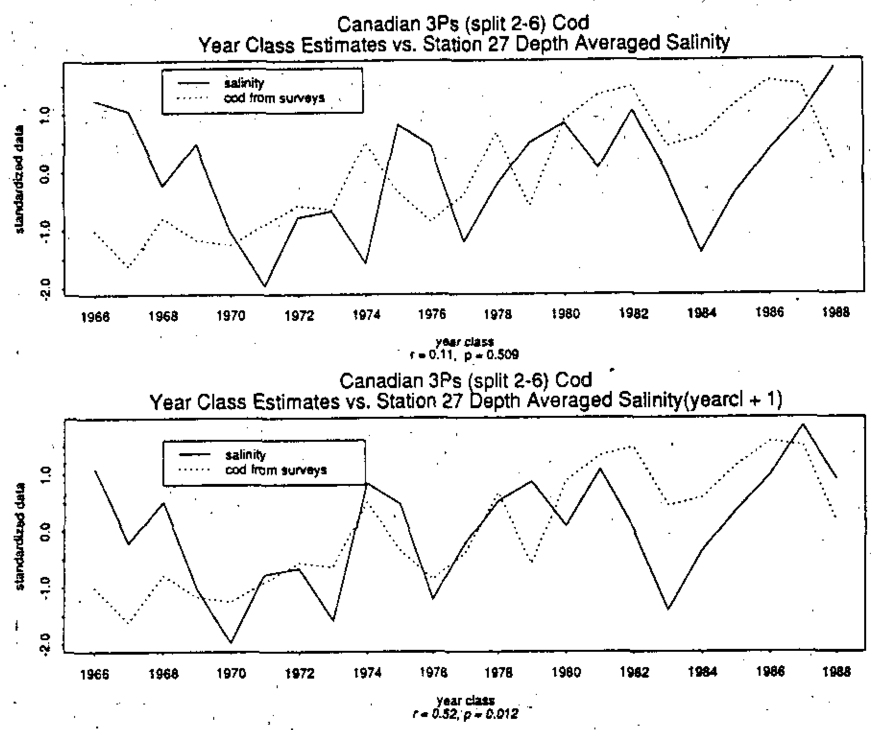

Fig. 8. Relationship between summer salinity and log (base e) recruitment from research surveys in 3Ps.

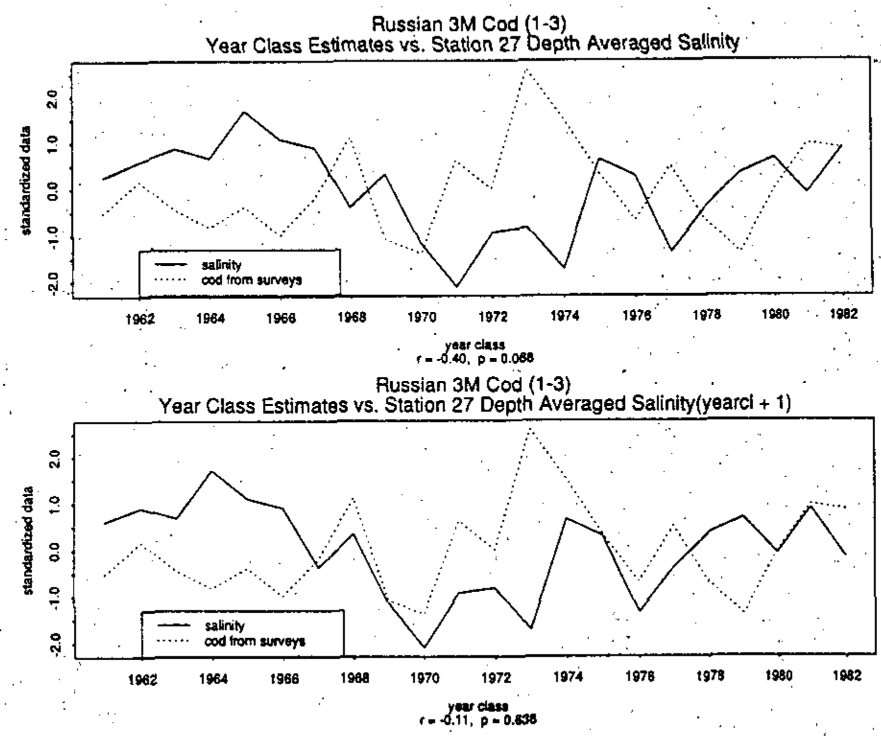

Fig. 9. Relationship between summer salinity and log (base e) recruitment from research surveys in 3M.

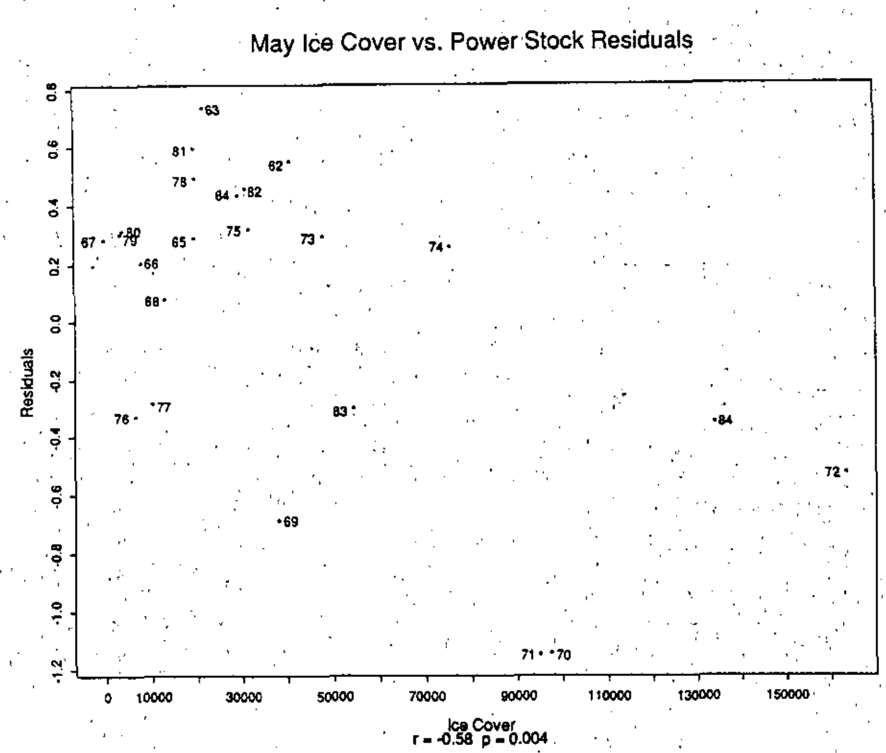

Fig. 10. Relationship between May ice cover south of 55 degrees latitude and recruitment residuals from a power stock recruitment curve.