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Cold Water and Recruitment in 2J3KL Cod

by

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Abstract

We tested the hypothesis that the extent of the cold intermediate layer (CIL) is negatively correlated with recruitment of cod in NAFO Div. 2J3KL. First, we tested the proposed relationship using VPA estimates of recruitment and a CIL index for the years before 1978. Second, we used an alternative index of environmental conditions which is strongly correlated with the CIL, i.e. bottom temperature at Station 27. Third, we constructed independent estimates of recruitment for the 2J3KL stock and nearby stocks (NAFO Divs. 3NO and 3Ps) from research surveys. We also constructed indices for each survey of 2J3KL on a divisional basis. Fourth, we compared the relationship between recruitment and the CIL index with proposed relationships for salinity. On the basis of our results we could not confirm the hypothesis that recruitment of 2J3KL cod was negatively correlated with the areal extent of the CIL.

Résumé

Nous avons éprouvé l'hypothèse selon laquelle l'étendue de la couche froide intermédiaire (CFI) est anticorrélée avec le recrutement de morue dans les divisions 2J3KL de l'OPANO. En premier lieu, nous avons d'abord cherché à vérifier la relation proposée en utilisant des estimations de recrutement fondées sur l'APV et un indice CFI pour les années antérieures à 1978. En deuxième lieu, nous avons utilisé un autre indice des conditions environnementales en étroite corrélation avec la CFI, soit la température des eaux profondes à la station 27. En troisième lieu, nous avons établi des estimations indépendantes du recrutement dans le stock de 2J3KL et dans les stocks adjacents (divisions 3NO et 3Ps de l'OPANO) d'après les campagnes d'évaluation. Nous avons aussi établi des indices par division d'après chaque campagne d'évaluation dans 2J3KL. Enfin, nous avons comparé la relation entre le recrutement et l'indice CFI à la relation proposée en ce qui concerne la salinité. Il ressort de nos résultats que nous ne pouvons confirmer l'hypothèse d'une corrélation négative entre le recrutement de morue dans 2J3KL et l'étendue aréale de la CFI.

Introduction

It has recently been suggested by NAFO (Report of the Special Meeting of the Scientific Council, 1992) that the cold water temperatures off Northeast Newfoundland have a negative impact on recruitment of cod in NAFO Divisions 2J3KL. This hypothesis was based upon a significant negative correlation between cold water temperatures, as given by the extent of the cold intermediate layer (CIL) on the Bonavista transect and recruitment in the latest VPA (Virtual Population Analysis) of 2J3KL cod. Following recommendations that this proposed relationship be examined in more detail, we tested the hypothesis by using alternative estimates of recruitment from research surveys, by using alternative measures of cold water, and by including the effects of spawning stock biomass (SSB) in the analysis.

Recruitment Data

The recruitment at age 3 (Fig. 1) and SSB for 2J3KL cod were obtained from the most recent VPA (Baird, Bishop, and Murphy 1992). Because of the smoothing effect inherent in the VPA, we supplemented these with estimates of cod recruitment from research surveys (Fig. 2) using a multiplicative model with age and cohort effects for ages 2-6. We obtained such estimates for the combined Canadian fall 2J3KL surveys, for the Canadian fall surveys in 2J, 3K, and 3L separately, for the Canadian 3L spring surveys and for the German 2J surveys. We also used the Canadian spring 3NO and 3Ps surveys to examine if there were large scale effects of cold water on recruitment. Details of the methods used to estimate recruitment from the research surveys can be found in Myers, Drinkwater, and Bown (1992).

Oceanographic Data

The CIL time series that NAFO (1992) used is an index of the area of water with temperature below zero degrees through the Bonavista transect off the Northeast coast of Newfoundland in August and September for the period 1978-1991 (Petrie et al. 1992). Petrie et al. (1992) showed that this time series is very highly correlated with bottom water temperature from Station 27. We thus constructed a time series of yearly average near-bottom temperature anomalies (175 m) at Station 27. The correlation with the CIL index is good ($r=-0.78$, $p=0.001$). The CIL index and the summer surface salinity index in the following year, the index investigated in detail in Myers, Drinkwater, and Bown (1992), were also correlated ($r=-0.56$, $p=0.046$).

An alternative analysis of the CIL along the Bonavista transect in summer was presented by Naranayan (1992). This time series covers a longer time period, although some recent years are missing. The correlation of the two CIL series during the overlapping period is very good ($r=0.97$, $p=0.000001$, $n=11$). A single time series was constructed for a stepwise regression analysis (Fig. 1). The CIL index from Naranayan (1992) was regressed on the index from Petrie et al. (1992), and the missing values from the latter were replaced by the predicted values from the regression.

Results

The correlation between the Petrie CIL index and all indices of recruitment in the 2J3KL region were negative and usually nominally significant (Table 1), consistent with the results published by NAFO (1992). Note that in Table 1 we have not corrected the statistical tests for autocorrelation in the time series; therefore, the probability values are generally overestimates.

We repeated the above analysis using the Station 27 bottom temperature from 1978 onward (Table 2). The purpose of this analysis was to test if we could replicate the CIL results with the Station 27 bottom temperature. In general, the correlation results were similar to those for the CIL. Note that the weak correlation between the Station 27 bottom temperature and the 3K surveys is not surprising; this survey has the largest error variance of any survey (Baird, Bishop, and Murphy 1992).

To test the hypothesis we applied the above analysis to the complete bottom temperature time series (Table 3). When we did this there were no significant correlations. Furthermore, the absolute value of the correlations was small.

In the above analyses the effects of spawning stock biomass (SSB) were not considered. To redress this, we applied the following multiple regression model to the data:

$$\log(\text{recruitment}) = a \log(\text{SSB}) + b(\text{environmental index}). \tag{1}$$

For this analysis we used only the VPA estimates of recruitment. The results again showed no evidence of a strong relationship between cold water and recruitment if data before 1978 were included in the analysis (Table 5).

In our final analysis we tested whether the Naranayan alternative CIL index was significantly related to recruitment before 1978. Neither the multiple regression with SSB and the CIL (Table 5, model 4) nor the simple correlations with any of the 2J3KL recruitment series was significant (Table 4).

Alternative Environmental Variables

The recruitment variability of 2J3KL cod recruitment has been related to salinity at Station 27, a hydrographic site off St. John's, Newfoundland. Sutcliffe et al. (1983) found a strong correlation between recruitment and the 0 to 50 m depth-averaged summer (July-September) salinity at Station 27. They cast the relationship in terms of a multiple linear regression, i.e.,

$$\text{Recruitment}_y = -26360 + 162 s_y + 278 s_{y+1} + 406 s_{y+2}, \tag{2}$$

where s_y is salinity in year y and recruitment in year y is in numbers ($\times 10^5$) of cod at age 4. The recruitment series they used was from a VPA by Wells and Bishop (1980) for the years 1958-76.

Myers, Drinkwater, and Bown (1992) reexamined this regression relationship and confirmed that the recruitment trends in the years since it was first published were accurately predicted. A positive relationship between summer salinity and recruitment appears to hold not only for the 2J3KL stock complex, but also for the southern Grand Banks (3NO) and St. Pierre Bank (3Ps) stocks as well. The positive relationship is not an artifact of the method of analysis of commercial catch at age data, e.g., virtual population analysis, because it also holds using recruitment estimates from research vessel surveys undertaken by Canada, France, and Germany. The salinity-recruitment relationship appears to hold for each of the three regions of the 2J3KL stock complex considered. However, ageing errors in the original VPA analysis used by Sutcliffe et al. (1983) could have introduced artificial autocorrelations in the recruitment estimates (Bradford 1991). This may account for the strong relationship they found with age 2 in their analysis which Myers, Drinkwater, and Bown (1992) could not confirm. The relationship investigated by Myers, Drinkwater, and Bown (1992) appeared strongest for salinity when cod were at age 1.

In order to test whether the CIL improved the regression, we repeated the stepwise regression used by Myers, Drinkwater, and Bown (1992) . We regressed log recruitment from the VPA with log SSB, salinity at age 0, salinity at age 1, and the CIL index. The strong relationship of log recruitment with log SSB and salinity at age 1 found by Myers, Drinkwater, and Bown (1992) was reproduced. The CIL index did not enter significantly into the stepwise regression (nominal $p=0.1446$) (Table 6).

We repeated the analysis using the average bottom temperature at Station 27 instead of the CIL index in the stepwise regression. There was virtually no improvement in the regression when bottom temperature was included (Table 7).

Conclusion

We have tested the *a priori* hypothesis that the extent of the cold intermediate layer (CIL) is negatively correlated with recruitment of cod in NAFO Div. 2J3KL. This hypothesis was suggested when it was noted that there was a strong negative relationship between the VPA estimate of recruitment and the extent of the CIL for the yearclasses from 1978 to 1988. No mechanism was proposed to explain this relationship.

We used four approaches in an attempt to confirm the hypothesis. First, we used VPA estimates of recruitment and a CIL index for the years before 1978. The resulting relationship was of the correct sign but was weak and not statistically significant (Table 5, model 4).

Second, we used an alternative index of environmental conditions which is strongly correlated with the CIL, i.e. bottom temperature at station 27. In this case the result was marginally statistically significant for the years since 1978 if we ignored the reduction of the effective degrees of freedom caused by autocorrelation in the time series (Table 5, model 3) but not statistically significant if all years were included (Table 5, model 4).

Third, we constructed independent estimates of recruitment for the 2J3KL stock and nearby stocks (NAFO Div. 3NO and 3Ps) from research surveys. We also constructed indices for each survey of 2J3KL on a divisional basis. We found that the correlations with the CIL were generally strong after 1978 (Table 1), but weak before 1978 (Table 4). The relationship with station 27 bottom temperature is weaker than for the CIL after 1978 (Table 2) and close to zero when all data is used (Table 3).

Fourth, we compared the relationship between recruitment and the CIL index with proposed relationships for salinity. In a stepwise regression the CIL index was not significant.

In summary, the tests using longer CIL time series or proxy variables such as bottom temperatures at Station 27 have failed to confirm any statistically significant relationship between the cold intermediate layer and recruitment in 2J3KL cod. Based on our findings we recommend that the CIL-recruitment relationship should not be used to predict recruitment. If there is a link between the cold intermediate layer and recruitment it is not a simple one.

We are left with two alternative explanations of the strong correlation of strong correlation from 1978-1988, and the lack of a relationship during the earlier times. First, it could be a statistical fluke of no biological importance. Second, it may be that the CIL extent only has an effect when the CIL extent is extreme. Note that the high CIL values around 1979 were not observed before. If the second case is true, then recruitment for the 1990 and 1991 year classes will be very low.

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TABLES

Table 1. Correlations between CIL and RV indices along with p-values, for 1978-1988 (n=11).

	r	p-value
2J	-0.680	0.021
3K	-0.443	0.172
3L (spring)	-0.572	0.066
3L (fall)	-0.458	0.156
2J3KL	-0.763	0.006
3NO	-0.451	0.191
3Ps	-0.195	0.566

Table 2. Correlations between Station 27 yearly bottom temperature anomalies and RV indices along with p-values, for 1978-1988 (n=11) and after.

	r	p-value
2J	0.848	0.001
3K	-0.012	0.971
3L (spring)	0.646	0.032
3L (fall)	0.494	0.123
2J3KL	0.647	0.031
3NO	0.675	0.032
3Ps	-0.161	0.637

Table 3. Correlations between Station 27 yearly bottom temperature anomalies and RV indices along with p-values, for all data.

	r	p-value	n
Can 2J	0.144	0.558	19
Germ 2J	0.149	0.582	16
3K	-0.148	0.557	18
3L (spring)	0.251	0.315	18
3L (fall)	0.157	0.578	15
2J3KL	0.127	0.616	18
3NO	0.334	0.119	23
3Ps	-0.409	0.052	23

Table 4. Correlations between CIL and RV indices along with p-values, for data before 1978. (Naranayan's CIL, year < 1978)

	CIL	p-value	n
Can 2J	0.019	0.964	8
Germ 2J	-0.276	0.411	14
3K	-0.130	0.781	7
3L (spring)	-0.210	0.652	7
3L fall	-0.753	0.247	4
2J3KL	-0.144	0.758	7
3NO	-0.169	0.640	13
3Ps	-0.394	0.294	12

Table 5. Results of multiple regressions of log transformed VPA estimates of recruitment on log transformed spawning stock biomass (SSB) and environmental variables for 2J3KL cod.

MODEL 1: Log(Rec) = int + a*Log(SSB) + b*CIL (Petrie's CIL, year >= 1978)

Residual Standard Error = 0.2182, Multiple R-Square = 0.7801
N = 11, F-statistic = 14.1887 on 2 and 8 df, p-value = 0.0023

	coef	std.err	t.stat	p.value
Intercept	12.5290	0.9663	12.9665	0.0000
log(SSB)	0.2277	0.1839	1.2382	0.2508
CIL	-0.0418	0.0079	-5.2609	0.0008

MODEL 2: Log(Rec) = int + a*Log(SSB) + b*bottemp (Stn. 27 bottom temp, year >= 1978)

Residual Standard Error = 0.3488, Multiple R-Square = 0.4382
N = 11, F-statistic = 3.1205 on 2 and 8 df, p-value = 0.0996

	coef	std.err	t.stat	p.value
Intercept	12.8027	1.5408	8.3093	0.0000
log(SSB)	0.1463	0.2962	0.4939	0.6347
bottemp	1.0429	0.4270	2.4427	0.0404

MODEL 3: Log(Rec) = int + a*Log(SSB) + b*bottemp (Stn. 27 bottom temp, all years)

Residual Standard Error = 0.5168, Multiple R-Square = 0.4003
N = 27, F-statistic = 8.0088 on 2 and 24 df, p-value = 0.0022

	coef	std.err	t.stat	p.value
Intercept	10.1893	0.9550	10.6697	0.0000
log(SSB)	0.4649	0.1372	3.3874	0.0024
bottemp	0.2960	0.2967	0.9977	0.3284

MODEL 4: Log(Rec) = int + a*Log(SSB) + b*CIL (Naranayan's CIL, year < 1978)

Residual Standard Error = 0.5504, Multiple R-Square = 0.587
N = 13, F-statistic = 7.1058 on 2 and 10 df, p-value = 0.012

	coef	std.err	t.stat	p.value
Intercept	10.1096	1.6524	6.1182	0.0001
log(SSB)	0.5591	0.1987	2.8131	0.0184
CIL	-0.0325	0.0250	-1.3006	0.2226

Table 6.

Stepwise regression of log. recruitment from VPA using summer salinity at age 0 (SAL), salinity at age 1 (SAL1), CIL index (CIL), and log SSB (LOGSSB).

Summary of Stepwise Procedure for Dependent Variable LOGREC

Step	Variable Entered	Variable Removed	Number In	Partial R**2	Model R**2	C(p)	F	Prob>F
1	SAL1		1	0.4593	0.4593	17.2920	18.6896	0.0003
2	LOGSSB		2	0.2146	0.6739	4.4937	13.8156	0.0013
3	CIL		3	0.0337	0.7076	4.1692	2.3050	0.1446

N = 24 Regression Models for Dependent Variable: LOGREC

Number in Model	R-square	Variables in Model
1	0.45932174	SAL1
1	0.34023786	CIL
1	0.31150545	LOGSSB
1	0.29703377	SAL
2	0.67387454	SAL1 LOGSSB
2	0.53612223	LOGSSB CIL
2	0.52532061	SAL1 CIL
2	0.51314591	SAL SAL1
2	0.49050760	SAL LOGSSB
2	0.47055221	SAL CIL
3	0.70757667	SAL1 LOGSSB CIL
3	0.69479933	SAL SAL1 LOGSSB
3	0.61801311	SAL LOGSSB CIL
3	0.56731193	SAL SAL1 CIL
4	0.72452851	SAL SAL1 LOGSSB CIL

Table 7.

Stepwise regression of log. recruitment from VPA using summer salinity at age 0 (SAL), salinity at age 1 (SAL1), bottom temperature (TEMP), and log SSB (LOGSSB).

Summary of Stepwise Procedure for Dependent Variable LOGREC

Step	Variable Entered	Removed	Number In	Partial R**2	Model R**2	C(p)	F	Prob>F
1	SAL1		1	0.4193	0.4193	20.7806	18.0501	0.0003
2	LOGSSB		2	0.2603	0.6796	3.1531	19.5030	0.0002

N = 27 Regression Models for Dependent Variable: LOGREC

Number in Model	R-square	Variables in Model
1	0.41928166	SAL1
1	0.37539295	LOGSSB
1	0.31528548	SAL
1	0.11353406	TEMP
2	0.67962594	SAL1 LOGSSB
2	0.53919916	SAL LOGSSB
2	0.49518403	SAL SAL1
2	0.47587018	SAL1 TEMP
2	0.40026500	LOGSSB TEMP
2	0.33380340	SAL TEMP
3	0.70570366	SAL SAL1 LOGSSB
3	0.68886221	SAL1 LOGSSB TEMP
3	0.54017018	SAL LOGSSB TEMP
3	0.51821265	SAL SAL1 TEMP
4	0.70818565	SAL SAL1 LOGSSB TEMP

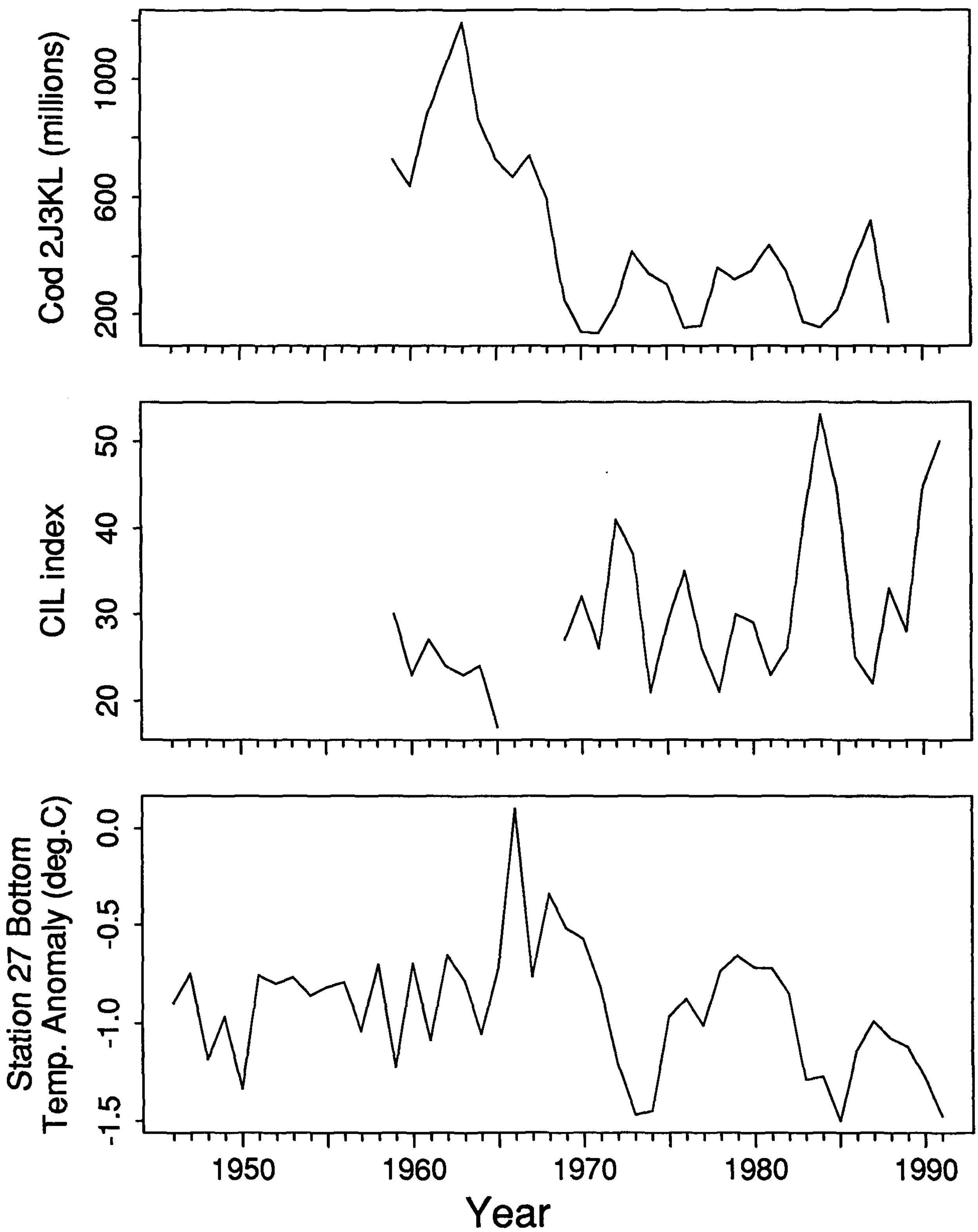

Figure 1 Recruitment at age 3 of 2J3KL cod, combined CIL index, and yearly average Station 27 temperature anomalies at 175 m.

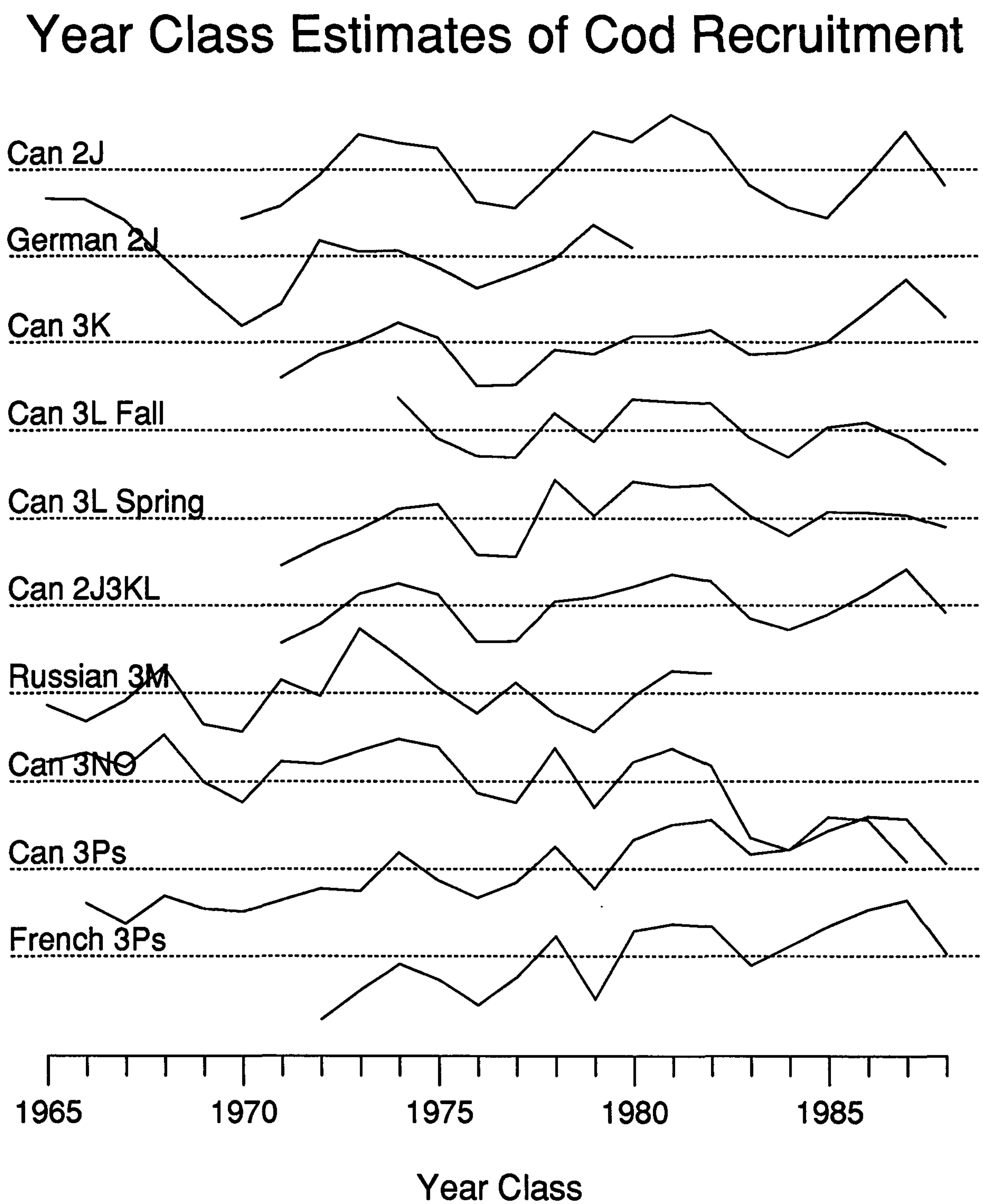

Figure 2 Recruitment time series for various research surveys around Newfoundland. Estimates of numbers at age in a year class are logarithmically transformed (base 10) with the mean removed. The mean of each series is separated by 1 unit, i.e. a factor of 10, from the one below. Thus the distance between the dotted lines gives the vertical scale.