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The Influence of Salinity on Cod Recruitment in the Newfoundland Region

by

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Abstract

This paper examines the relationship between salinity and recruitment of 2J3KL cod. Recruitment predictions, based upon a previously published regression with salinity, are found to be well correlated with recent recruitment estimates from both virtual population analysis and those derived from research surveys. The addition of spawning stock biomass in the regression significantly increased the percentage of the variance accounted for in the recruitment time series. A similar relationship between recruitment and salinity was found for two nearby stocks (southern Grand Banks and St. Pierre Bank). Oceanographic and food chain mechanisms that might be responsible for a link between salinity and recruitment are discussed.

Résumé

La présente étude porte sur la relation entre la salinité et le recrutement de morue dans 2J3KL. On y dégage une nette corrélation entre les prévisions de recrutement fondées sur une analyse de régression par rapport à la salinité (analyse publiée antérieurement) et les estimations récentes de recrutement établies d'après une analyse de population et des campagnes d'évaluation des stocks. L'ajout de la biomasse de reproducteurs dans la régression augmente considérablement le pourcentage de variation inclus dans la série chronologique sur le recrutement. On a établi une relation semblable entre le recrutement et la salinité dans deux stocks voisins (sud des Grands Bancs et banc de St. Pierre). On discute ici des mécanismes océanographiques et trophiques qui peuvent être à l'origine du lien entre la salinité et le recrutement.

Introduction

In 1992, the low numbers of commercial size cod occupying the waters off southern Labrador, northern Newfoundland, and the northern Grand Banks (Northwest Atlantic Fisheries Organization (NAFO) subareas 2J3KL; Fig. 1) resulted in the Canadian Government imposing a two-year moratorium on its cod fishery. Although the exact causes of the decline in cod abundance are uncertain, it is clear that early predictions of recruitment would facilitate better long-term management of the stock. Present methods rely upon research surveys which forecast recruitment based upon numbers of cod of age 3 or 4, i.e. only two to three years before the fish are fully recruited into the fishery (age 6). The traditional survey methods are unable to provide earlier predictions because of the different behaviour and spatial distributions of the young fish compared to the older adults which are the primary target of the surveys. Earlier predictions may be possible, however, if recruitment can be shown to be related to other, more-easily measured variables.

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

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

where Recruitment_y is the number of cod produced in year y (estimated as 4 year olds) and s_y is salinity in year y. Recruitment is in numbers ($\times 10^6$) although in the original paper it was mistakenly listed as ($\times 10^5$). In the original analysis salinity was assumed to affect survival during the first three years of life. The recruitment series Sutcliffe et al. (1983) used was 1958-1976 from a Virtual Population Analysis (VPA) by Wells and Bishop (1980).

Sutcliffe et al. (1983) suggested that the interannual variability of cod recruitment arose from the variation in its food supply which was linked to fluctuations in mixing within Hudson Strait and the subsequent surface nutrient flux onto the Labrador Shelf. They suggested that high runoff from Hudson Strait "caps" the tidal mixing outside the strait which inhibits nutrient pumping into the surface layer and reduces productivity. This hypothesis thus provided a rationale for the positive relationship between salinity and recruitment. In support of this hypothesis they 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, a time scale consistent with what was known about oceanic advection in the region at that time. They speculated on the possibility of a relationship at interannual time scales but lacked the necessary time series of freshwater discharge from the Hudson Bay region to test this hypothesis directly. Recent studies (Myers et al. 1990) have found that the seasonal and interannual variability in salinity at Station 27 is more closely related to sea-ice extent over the

Labrador and Northern Newfoundland shelves and that Hudson Bay runoff is only weakly correlated with salinity on the Newfoundland Shelf.

In this paper we re-examine the relationship between salinity and recruitment of 2J3KL cod. We first compare the predictions, based upon the regression relationship from Sutcliffe et al. (1983), with the recent VPA recruitment estimates. Since VPA methods tend to smooth the recruitment time series, we further test the relationship using estimates of cod recruitment derived from research surveys. We also investigate the effects of spawning stock biomass on recruitment of 2J3KL cod. The analysis is then extended to three nearby stocks (southern Grand Banks - NAFO Div. 3NO, St. Pierre Bank - NAFO Div. 3Ps, Flemish Cap - NAFO Div. 3M) because it was felt that similar mechanisms may be operating in these regions. Finally, we consider oceanographic and food chain mechanisms that may be responsible for the link between salinity and recruitment.

Data and Statistical Methods

Salinity

The depth-averaged (0-50 m) summertime (July, August and September) salinities at Station 27 (see Fig. 1 for location) were determined each year for the period 1946-1992 using linear interpolation between depths. The interannual variability in the summertime salinity is dominated by a maximum in the mid-sixties, a rapid decline to a minimum in the early seventies followed by variability superimposed upon a steady rise through to 1990 (Fig. 2).

Recruitment Indices

The 1958-1987 recruitment estimates for 2J3KL cod (Fig. 2), based upon the numbers of age 4 cod from a virtual population analysis calibrated with research survey estimates of abundance, were taken from Baird et al. (1992a). Similar VPA estimates were also examined for the 3NO (1959-1986; Baird et al. 1992b), 3Ps (1959-1987; Bishop et al. 1991), and 3M (1956-1984; Wells et al. 1984) (Fig. 2). Note that the recruitment estimate for a given year is determined from the commercial catches 4 years later, e.g. the 1991 catch data provided the recruitment estimate for 1987. Except for direct comparisons with Sutcliffe et al. (1983), we used the recruitment estimated at age 3, which is generally available. Estimates of spawning stock biomass (SSB) were also obtained from VPA (Fig. 2). Age at maturity was not available for all years, therefore we used average ages of maturity. This unfortunately will introduce some errors in the analysis, but they should be relatively small. For 2J3KL cod we used the biomass of fish of age 7 and older at the beginning of the year. For 3NO and 3Ps we used the average maturity at age given in Baird et al. (1986) and Bishop (1984). The beginning of year biomass was used in all cases.

One difficulty in using VPA results is that year-classes of recruitment tend to be smeared together. This can make recruitment studies relying upon year-to-year variability difficult to sort out. Because of this problem, we supplemented the VPA recruitment estimates with indices derived solely from research surveys. To extract the survey effects at age we have used a modification of a multiplicative catch-at-age model developed by Shepherd and Nicholson (1991). A description of the method follows.

Let the numbers of fish of age a in year y be $N_{y,a}$ and consider only ages at which commercial fishing mortality is small. Let P_a, the survival to age a, be constant. Myers and Cadigan (1991) showed that for cod, haddock, plaice, whiting, and American plaice the interannual variation in juvenile natural mortality unrelated to density was small. Let the number of recruits in year y be $N_{y,0}$. The numbers at age will then be

$$N_{y,a} = P_a N_{y-a,0}. \tag{2}$$

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, $\epsilon_{y,a,i}$, in estimates of abundance is assumed to be normal with constant variance. Thus,

$$\begin{aligned} R_{y,a,i} &= Q_{a,i} N_{y,a} e^{\epsilon_{y,a,i}} && (3) \\ &= Q_{a,i} P_a N_{y-a,0} e^{\epsilon_{y,a,i}}. && (4) \end{aligned}$$

Using a log transformation, and letting lower case letters represent the log transform of parameters and variables, the last equation becomes

$$r_{y,a,i} = q_{a,i} + p_a + n_{y-a,0} + \epsilon_{y,a,i}. \tag{5}$$

Note that $q_{a,i}$ and p_a are confounded in the above equation, and therefore we only attempt to estimate the sum of these two parameters. If the same survey vessel was used throughout the survey period, we estimated a year-class effect for each year-class, $n_{y-a,0}$, and age effect for each age used in the analysis, which is the sum of $q_{a,i}$ and p_a. In the Canadian spring surveys for 3L, 3NO, and 3Ps there was a change in survey vessel in year 1983. We estimated separate age effects for each survey vessel because they did not fish with the same efficiency.

The above equation is a simple analysis of variance with year-class and age effects. If the error variance is approximately constant then the year-class effects can be estimated using any standard analysis of variance programs. The estimates of the year-class effects, $n_{y,0}$, (on a log scale) are used as relative recruitment indices (Shepherd and Nicholson 1991). Ages 2 to 6 were used from the fall surveys and ages 2 to 7 from the spring surveys. The exception was the USSR (3M) survey for which only ages 1 to 3 were available.

Data from a variety of research vessel surveys covering NAFO subareas 2J, 3K and 3L were available (Fig. 3). For 2J, we analyzed the Federal Republic of Germany (1972-1983) and the Canadian (1977-1991) autumn surveys. There is excellent agreement between the two during the period of overlap. For 3K, Canadian autumn surveys were available from 1978 to 1992. These match closely the 2J indices. For 3L, there were Canadian surveys during both the spring (1977-1982, 1985-1992) and autumn (1981-1991). The 3L recruitment indices derived from the different seasonal surveys are similar; however, there were consistent differences with the 2J and 3K surveys. For example, the 1978 year-class was strong in 3L but not in 2J.

We also obtained research vessel survey data for other NAFO subareas (see Fig. 1 for locations). The southern Grand Banks (3NO) was surveyed each spring by Canada from 1971 to 1992. Both Canada (1972-1992) and France (1972-1989) have conducted spring surveys in the vicinity of St. Pierre Bank (3Ps). The survey-derived recruitment indices for both 3NO and 3Ps show similarities with those for 3L and 2J (Fig. 3). The Flemish Cap area (3M) was surveyed by the USSR from 1962 to 1982 but it showed different recruitment trends from those in the other regions. The short research survey series of the Flemish Cap by Canada (1978-1982) and by the EEC (1989-1992) were not used in our analysis.

Results

Comparison of Predicted and VPA Estimated Recruitment for 2J3KL Cod

The 2J3KL cod recruitment estimates based upon the salinity regression in Sutcliffe et al. (1983) are shown in Fig. 4 together with the VPA population estimates from the 1980 and 1992 assessments. The 1980 VPA estimates were those used by Sutcliffe et al. (1983) to establish the regression. The salinity-derived estimates are divided into two periods; the regression years (1958-76) and the predicted years (1977-1987).

There is a close relationship between the predicted recruitment and the population estimates. The correlation (0.70) was nominally significant ($p=0.05$); the significance levels have been corrected for autocorrelation according to Bayley and Hammersley (1946) and Garrett and Toulany (1981). Note that the population values for 1970 to 1976 used by Sutcliffe et al. (1983) are larger than the 1992 estimates. This is due to underestimates of the fishing mortality in the 1980 assessment. The overestimates of the populations in the 1970's are believed to have led, in part, to the absolute difference between the predicted and 1992 VPA estimated recruitment. Another factor that may explain this difference is the decline in spawning stock biomass that occurred after 1970.

Effects of Spawning Stock Biomass on 2J3KL Cod Recruitment

To examine the possible influence of SSB we performed a stepwise regression with recruitment being a function of SSB and salinity (Table 1). We log transformed the recruitment and SSB estimates to stabilize variance and to linearize the stock-recruitment relationship. The recruitment time series covered the period 1962-1988 (birth dates). Correlations between SSB and salinity, either in the year of hatch or at ages +1 or +2, were low ($r < 0.3$) and non-significant.

The SSB for 2J3KL cod was high in the 1960's, declined sharply in the early 1970's and has fluctuated about relatively low levels during the last two decades (Fig. 2). Regressing the log recruitment against SSB resulted in an r^2 of 0.38. The relationship was primarily due to extremes (Fig. 2), i.e. when SSB was high (low), recruitment was high (low). The best one variable model in terms of recruitment variance accounted for was, however, with salinity at age +1 ($r^2 = 0.42$). Salinity in the year of hatch ($r^2 = 0.32$) and at age +2 ($r^2 = 0.13$) accounted for less variance. Only the correlation with salinity at age +1 was significant at the $p < 0.1$ level after correcting for autocorrelation in the time series.

Combining the SSB and salinity at age +1 accounted for 68% of the recruitment variability. Using salinity only (at age +1 and in year of hatch) accounted for 50% of the recruitment variability. The relatively small increase in variance accounted for using the 2 years of salinity instead of salinity at age +1 alone is because of the strong autocorrelation in the salinity time series (e.g. $r = 0.5$ at a lag of one year). The three variable models using SSB, salinity at age +1 and salinity in year of hatch accounted for 71% of the recruitment variability but this is not statistically better than the two variable model with SSB and salinity at age +1 because of the loss of degrees of freedom by adding an extra variable.

Based on our analysis using the VPA estimates, the regression that provides the most reliable prediction of recruitment is

$$\log(\mathrm{Recruitment}_y) = -40.4289 + 0.4281 \log(\mathrm{SSB}_y) + 1.3741 s_{y+1}$$

where recruitment in year y is in millions of cod at age 3, SSB in year y is in thousands of metric tonnes, and s_{y+1} is salinity in year $y + 1$. Note that natural logarithms are used. We have used this relationship and recent salinity and SSB estimates to predict cod recruitment during 1989-91. These are estimated to be weak with the 1991 recruitment to be the lowest on record.

We also investigated the relationship between salinity at age +1 and recruitment for subareas 3M, 3NO and 3Ps. For 3NO and 3Ps the correlations were positive but significant only for 3Ps. Recruitment was regressed against salinity at age +1 for the 3NO and 3Ps stocks and the results are plotted in Fig. 5.

Research Survey Estimates of Recruitment

We repeated the stepwise regression for the research survey recruitment indices but did not include the effects of SSB because the indices were generally available only after the large decline in biomass in the early 1970's (Table 2). Salinity at age 1+ was the most important variable in each of the 9 surveys considered for the 2J3KL, 3NO, and 3Ps stocks. Salinity at other ages did not enter at a nominal significance level of 0.15. For 3M the relationship was negative, low, and not significant. Table 1 clearly show that the results for 2J3KL cod using the VPA are not caused by artifacts or errors in the assumptions of the VPA because they are replicated by 5 independent surveys as well as the combined 2J3KL fall surveys. It is to be expected that the r^2 using the research survey estimates are lower than those using the VPA estimates because the former have greater sampling variability.

Although the results for the southern Grand Bank (NAFO 3NO) are positive, the r^2 is so low that the analysis brings into question the results for the stepwise regression using the VPA. The r^2 for St. Pierre Bank (NAFO 3Ps) are both higher, and lend support for the results in Table 1.

Possible Mechanisms

Our results have confirmed the relationship between 2J3KL cod recruitment and salinity found by Sutcliffe et al. (1983) but the question of the underlying mechanism remains. We examine two possibilities.

Food Chain Hypotheses

Sutcliffe et al. (1983) suggested that the link between salinity and recruitment was through the food chain with high salinity corresponding to high nutrients, high primary and secondary production, and hence more food for cod. However, recent examination of historic continuous plankton recorder (CPR) data (Robinson et al. 1973) has shown that salinity is, if anything, negatively correlated with phytoplankton biomass for the Labrador, Newfoundland region (Mertz and Myers 1993). The correlation of the CPR index of phytoplankton biomass off the Labrador coast with summer surface (0-20 m) salinity at Station 27 from 1961 to 1971 was negative ($r = -0.54$, $p = 0.107$, $n = 10$), as was the correlation with phytoplankton in the Grand Banks region ($r = -0.41$, $p = 0.21$, $n = 11$). Although this analysis cannot rule out the food chain hypothesis in the region, we note that the hypothesis is not consistent with the limited data available.

Larval Freezing Hypothesis

Interannual variability in summer and autumn salinities at Station 27 is strongly related to ice coverage (Myers et al. 1990) and the amount of ice is in turn linked to the ocean temperatures (Petrie et al. 1992). Large quantities of ice are usually accompanied by cold, fresh conditions. Valerio et al. (1993) demonstrated that larval death could result from freezing at temperatures of $-1.35°$C. Thus, another possible explanation for the apparent relationship between recruitment and salinity is through freezing of cod larvae.

For this hypothesis to be valid, the near surface temperature has to be below the freezing temperature for larval fish plasma during the time the larvae are present. In order to investigate this, surface temperatures (Drinkwater and Trites 1986) and the time of peak larval concentrations (Myers et al. 1993) were plotted for several areas

(Fig. 6). It appears that this is not a valid hypothesis for any stocks except perhaps the northern components of the 2J3KL stock. In all other stocks near surface water very seldom goes below freezing when cod larvae are present.

We continue the analysis by using the sea-ice coverage south of 55° along the Labrador and east coast of Newfoundland as an index of freezing. These estimates were derived from two data sets provided by Peterson and Prinsenberg (1990) from 1963 to 1991 and Walsh and Sater (1981) from 1953-1984. The area covered by ice was summed over the region and time of interest to arrive at the index. The Peterson and Prinsenberg (1990) data was used from 1963 to 1991, and the Walsh data was used from 1953 to 1962. The two time series were calibrated by a linear regression (Fig. 2). The two time series are very highly correlated ($r > .9$). Our *a priori* belief was that May ice cover would be the month most closely connected to recruitment because this is the only month with significant ice cover in which larvae might be present.

A negative relationship between the residuals from a power stock recruitment relationship with ice cover south of 55° latitude (Fig. 7) supports the hypothesis that ice may be responsible for the larval and possibly 1+ juvenile mortality in 2J3KL. The strongest relationship was found with May ice cover. If mortality is occurring during the larval phase, May is the month during which the larvae would be expected to be most susceptible since they would have just recently hatched. Consistent with the salinity-recruitment relationship, summer salinities at Station 27 depend upon the spring ice coverage in southern Labrador (Myers et al. 1990). The relationship with salinity during age 1+ is more difficult to understand. Although it is possible that juveniles die from ice contact and freezing during the first winter of life, this seems unlikely given that they have high levels of antifreeze (Fletcher et al. 1993).

We repeated the stepwise regression described in Table 1 for 2J3KL cod with the inclusion of May ice cover. May ice cover did not enter significantly into the regression ($p < 0.15$).

There also appeared to be a fairly strong relationship between May ice cover and recruitment in 3NO cod ($r = -0.56$) and a weaker one for 3Ps cod ($r = -0.18$). These relationships are unlikely to be caused directly by ice, but may be caused by an indirect relationship May ice cover and some other environmental variable.

Thus, it appears that larval death by freezing may account for some of the interannual variability in recruitment in 2J3KL cod but is is an unlikely mechanism for the other stocks considered.

Conclusions

A reexamination of the regression relationship between recruitment of 2J3KL cod and upper layer salinity at Station 27 has confirmed that the recruitment trends in the years since it was first published by Sutcliffe et al. (1983) were accurately predicted. This is remarkable since most previously published relationships between recruitment and environmental variables when reexamined with new data, usually (Drinkwater and Myers 1987) but not always (Myers and Drinkwater 1989) break down. A positive relationship between summer salinity and recruitment appears to hold not only for the 2J3KL stock complex, but also for St. Pierre Bank (3Ps) and possibly southern Grand Banks (3NO) 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 we confirmed the relationship using 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, aging 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 salinity at age 2 in their analysis which was not found in recent VPA data nor in the research vessel data.

If the Sutcliffe et al. (1983) regression had been used for predictions during the late 1970's and early 1980's, recruitment would have been greatly overestimated. This is believed to be primarily because of the decline in spawning stock biomass which they did not take into account. This should serve as a caveat to fisheries scientists, that even given a relationship between environmental variables and recruitment, it still may not produce the best predictions. Given this caveat, we predict on the basis of our regression relationship that the 1990 and 1991 year-classes of 2J3KL will be low (Fig. 5). Indeed, the 1991 year-class is predicted to be the lowest on record. Similar low levels of recruitment are predicted for the southern Grand Banks and St. Pierre Bank for 1990 and 1991. It should also be noted that under the present SSB levels and the historical salinity range, the regression predicts that recruitment will never reach the high levels observed in the early to mid-sixties. The regression also provides an alternative to the geometric mean of the historical recruitment for making short-term projections of future recruitment levels.

The mechanism underlying the relationship between salinity and recruitment remains elusive. The original hypothesis suggested by Sutcliffe et al. (1983) was that a nutrient flux from Hudson Strait controlled production on the Labrador Shelf so that high salinities (indicative of more mixing, and higher nutrient concentrations) favored biological production. Existing data on phytoplankton standing stocks do not support the hypothesis since they are negatively correlated with salinity (Mertz and Myers 1993). However, the lack of interannual estimates of phytoplankton and zooplankton production time-series limit our ability to adequately test any food-chain hypothesis.

We also tested the hypothesis that larval freezing could reduce recruitment. While this could possibly explain the relationship for the more northern stocks it cannot do so for the remaining stocks, although the relationship with salinity was also high for these stocks. Since the eggs and larvae do not all originate in the north, the freezing hypothesis appears unlikely. Other possible explanations for the salinity recruitment relationship include links through advection related processes or stability arguments. These are presently being explored.

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Tables

Table 1. Results of a stepwise regression of log transformed VPA recruitment estimates on log transformed Spawning Stock Biomass (SSB), salinity in the year of hatch (sal), salinity in the following year (sal1) and the salinity two years later (sal2) for divisions 2J3KL, 3NO, 3Ps and 3M.

Division	Variables	Year Classes	R^2	Nominal P-value
2J3KL	sal1 SSB	1962-1988	0.680	0.0001
3NO	sal1	1959-1986	0.258	0.0071
3Ps	sal1	1959-1987	0.537	0.0001
3M	sal2	1956-1984	0.034	0.3566

Table 2. Results of a stepwise regression of year-class estimates from research surveys on salinity in the year of hatch (sal), salinity in the following year (sal1) and the salinity two years later (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

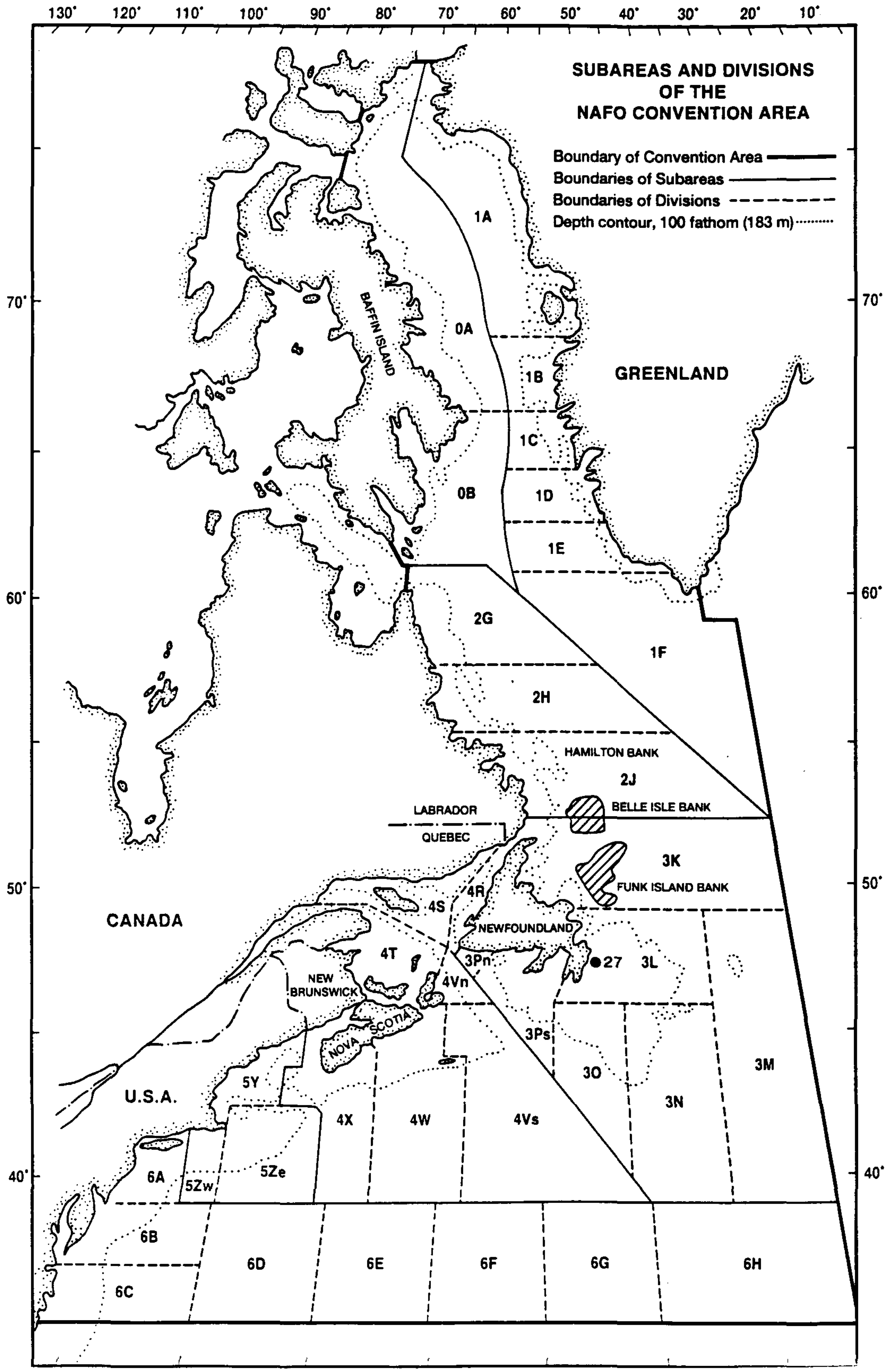

Fig. 1. Location of the NAFO divisions and Station 27. Funk Island Bank and Belle Isle Bank are conveniently delineated by the 300 m isobath, as indicated here (hatched areas).

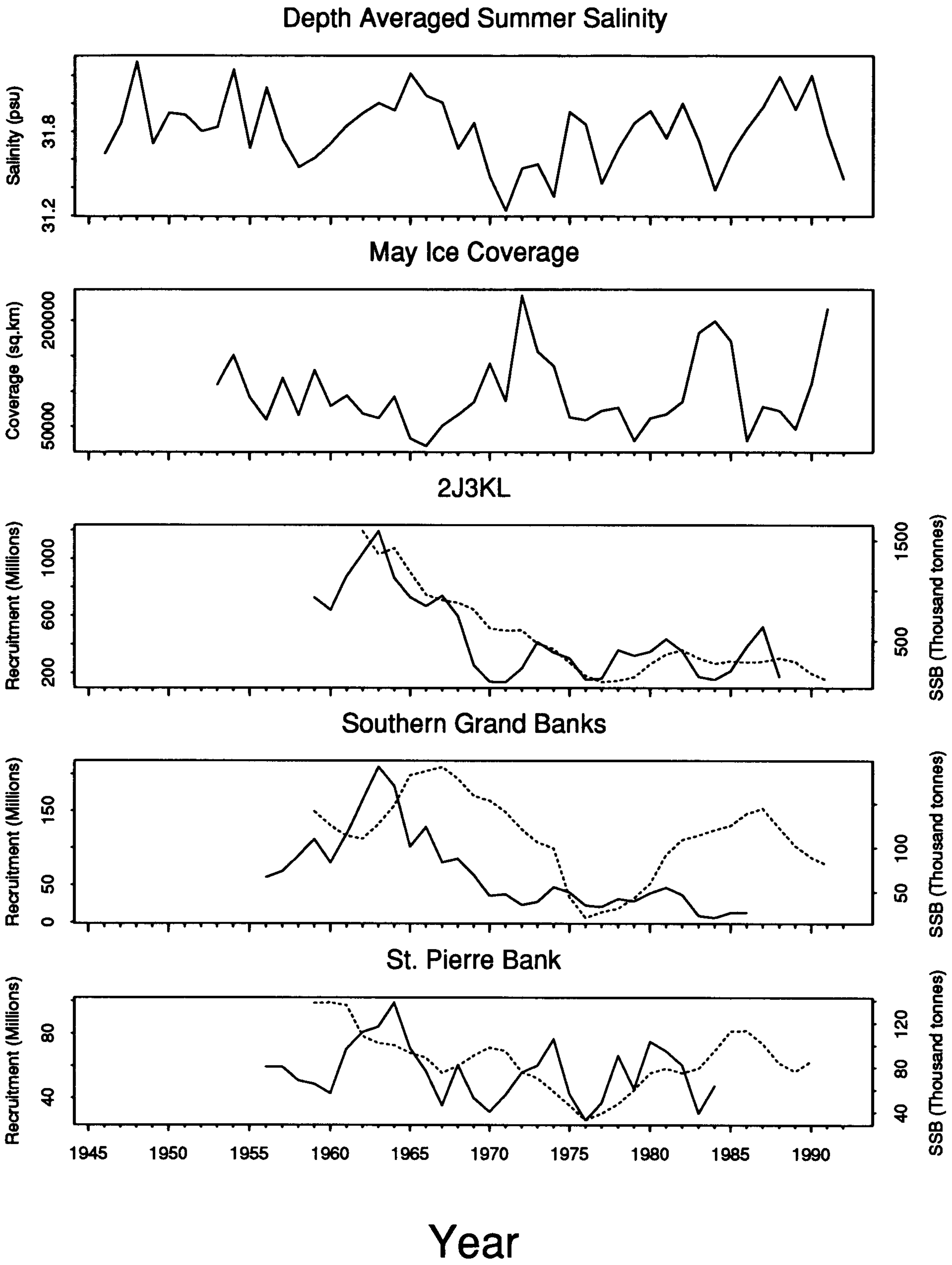

Figure 2. (a) The yearly depth-averaged summer (July-September) salinity at Station 27 from 0 to 50 metres. (b) The ice cover south of 55 N along the Labrador-Newfoundland coast in May. (c) Recruitment (solid line) and spawning stock biomass (dotted line) from VPA for 2J3KL cod. (d) Recruitment (solid line) and spawning stock biomass (dotted line) from VPA for southern Grand Banks cod. (e) Recruitment (solid line) and spawning stock biomass (dotted line) from VPA for St. Pierre Bank cod.

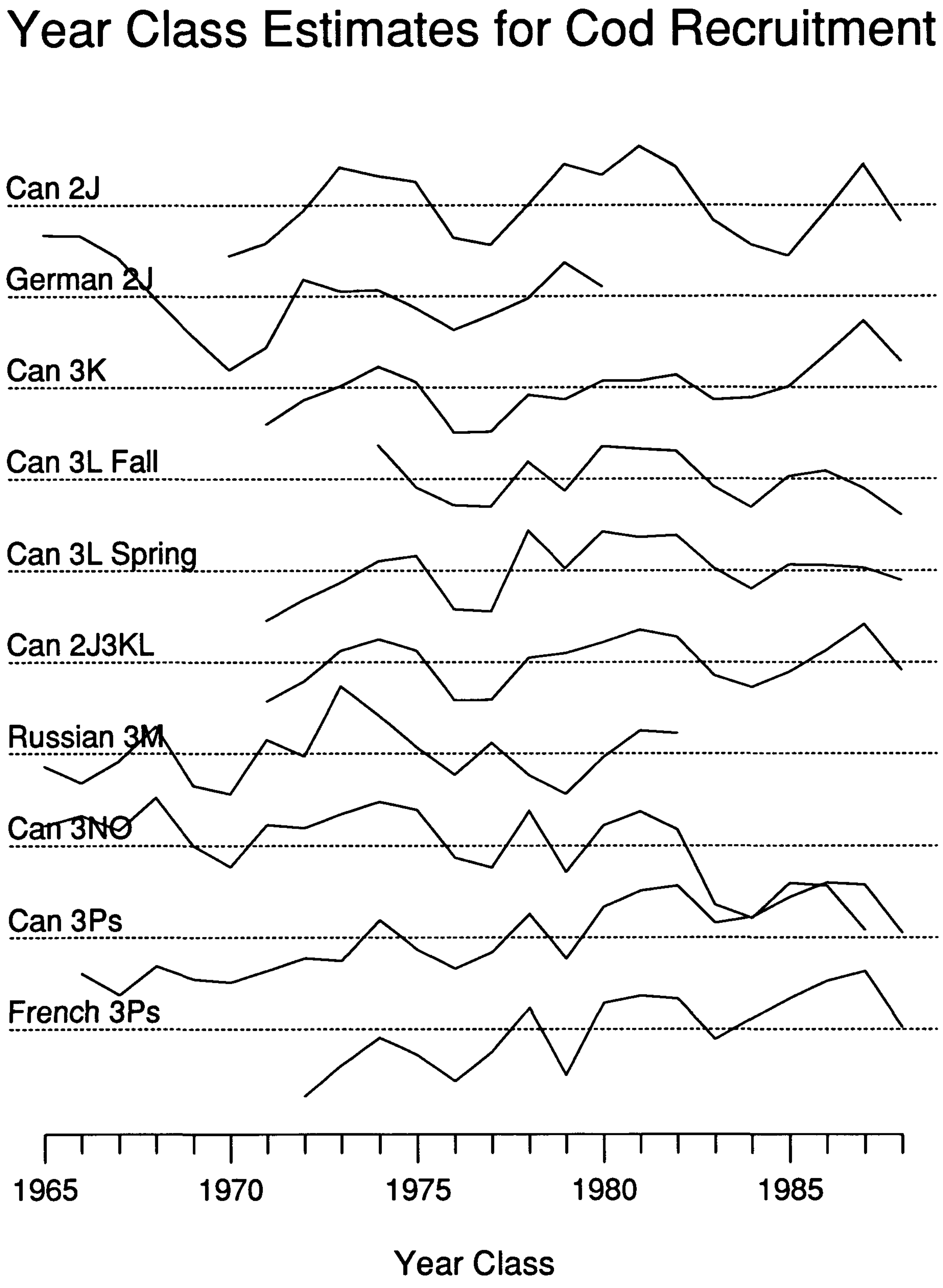
Year Class Estimates for Cod Recruitment

Figure 3. Recruitment time series for various research surveys around Newfoundland. Estimates of numbers at age in a year-class are logarithmical 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.

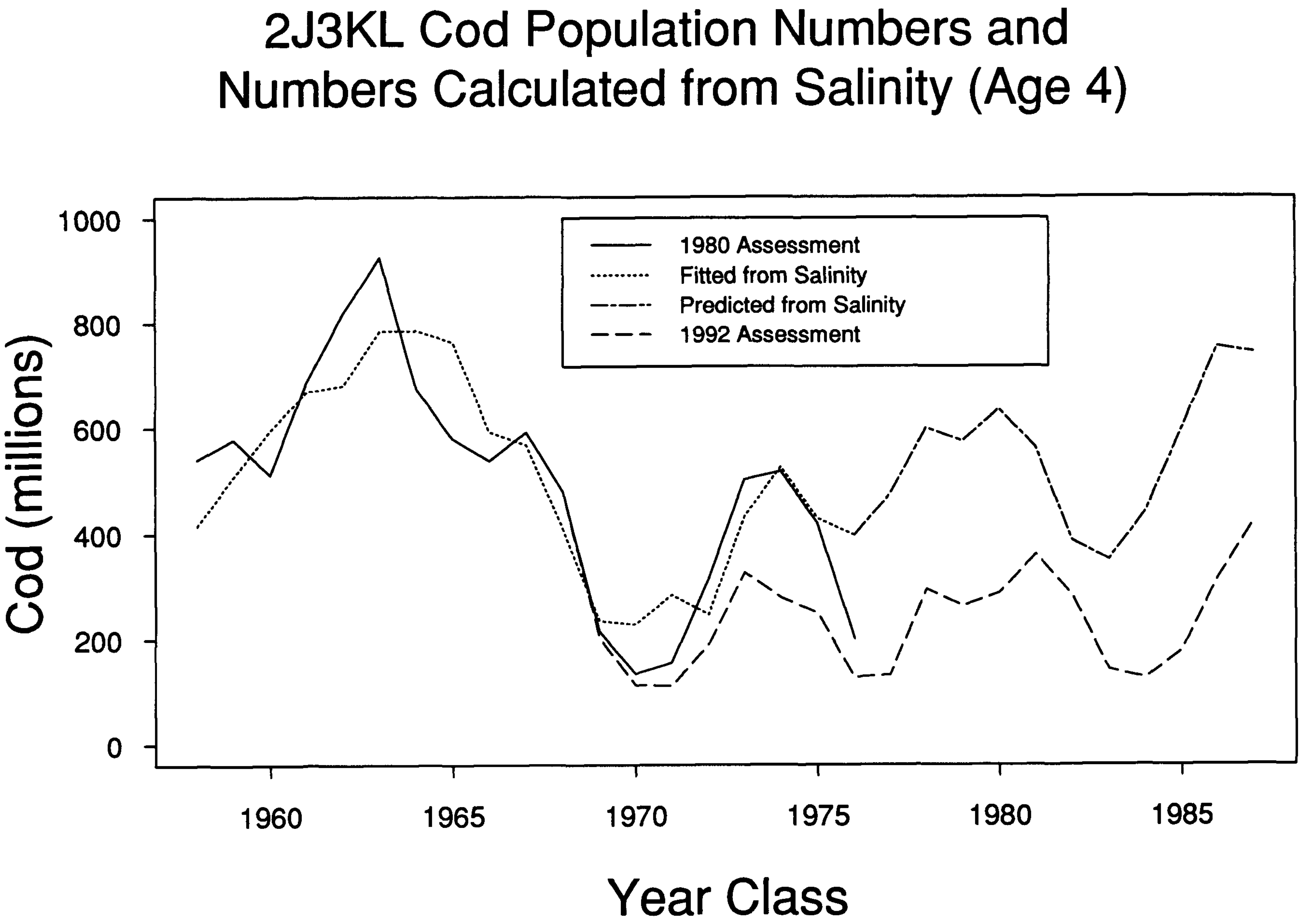

Figure 4. The 1980 assessment estimates for 2J3KL cod recruitment at age 4 (solid line) and the fitted values in the original regression (Eq. 1) proposed by Sutcliffe et al. (1983) with summer salinity at Station 27 (dotted line). Also shown is the 1992 assessment of cod (long dash line) and the predicted recruitment from 1975 to 1987 (dash-dot line).

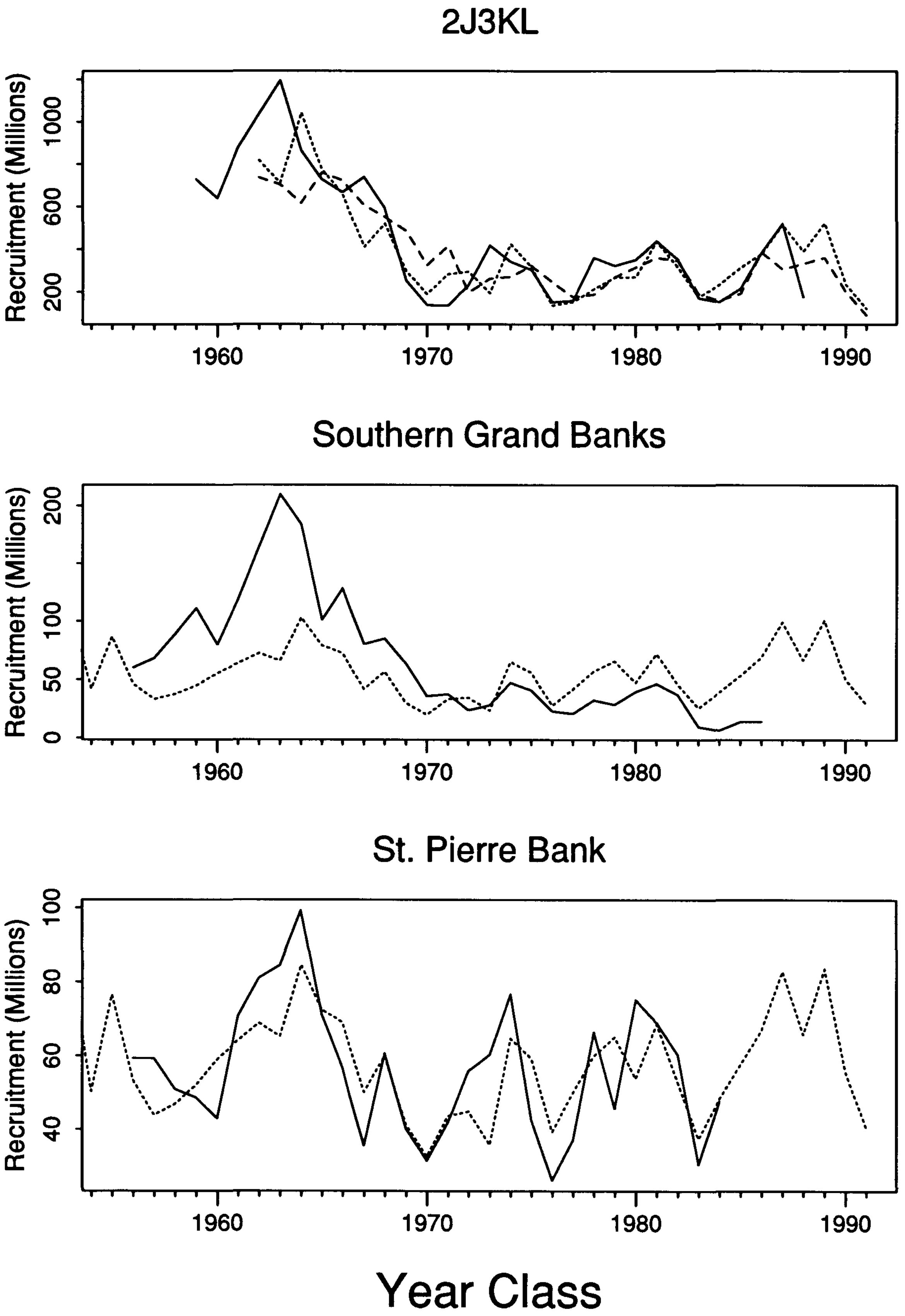

Figure 5. Recruitment at age 3 estimated from VPA (solid line) and the results from the regression of log recruitment on log SSB and salinity at age 1 (dotted line) for 2J3KL cod, and salinity at age 1 for 3Ps and 3NO cod. For 2J3KL we also show the regression results for log SSB and May sea-ice cover south of 55 N (dashed line).

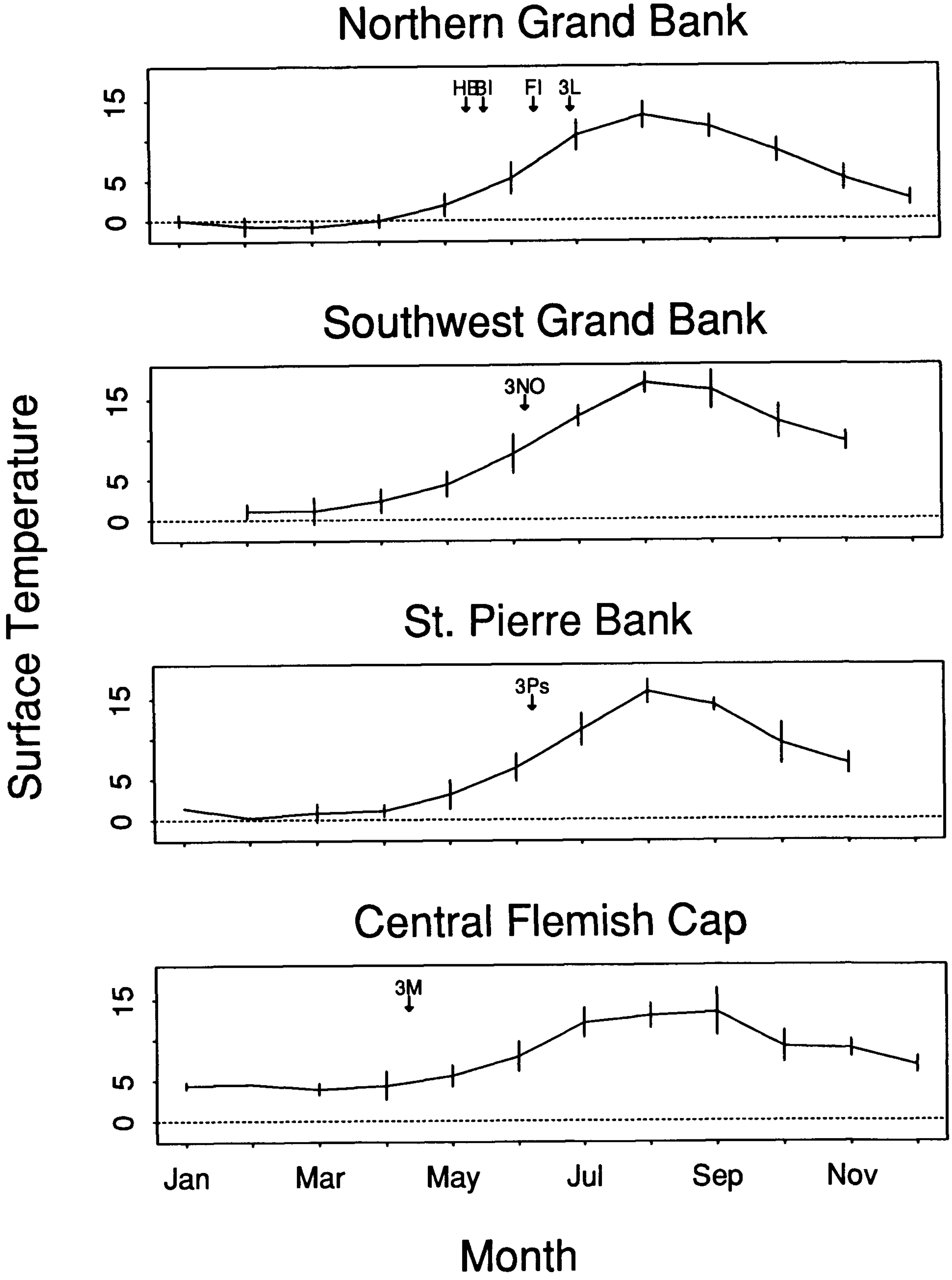

Figure 6. Sea surface temperature versus month for several subareas. Peak larval days for various regions are also indicated with arrows and the following labels: HB - Hamilton Bank, BI - Belle Isle Bank and the NAFO region labels.

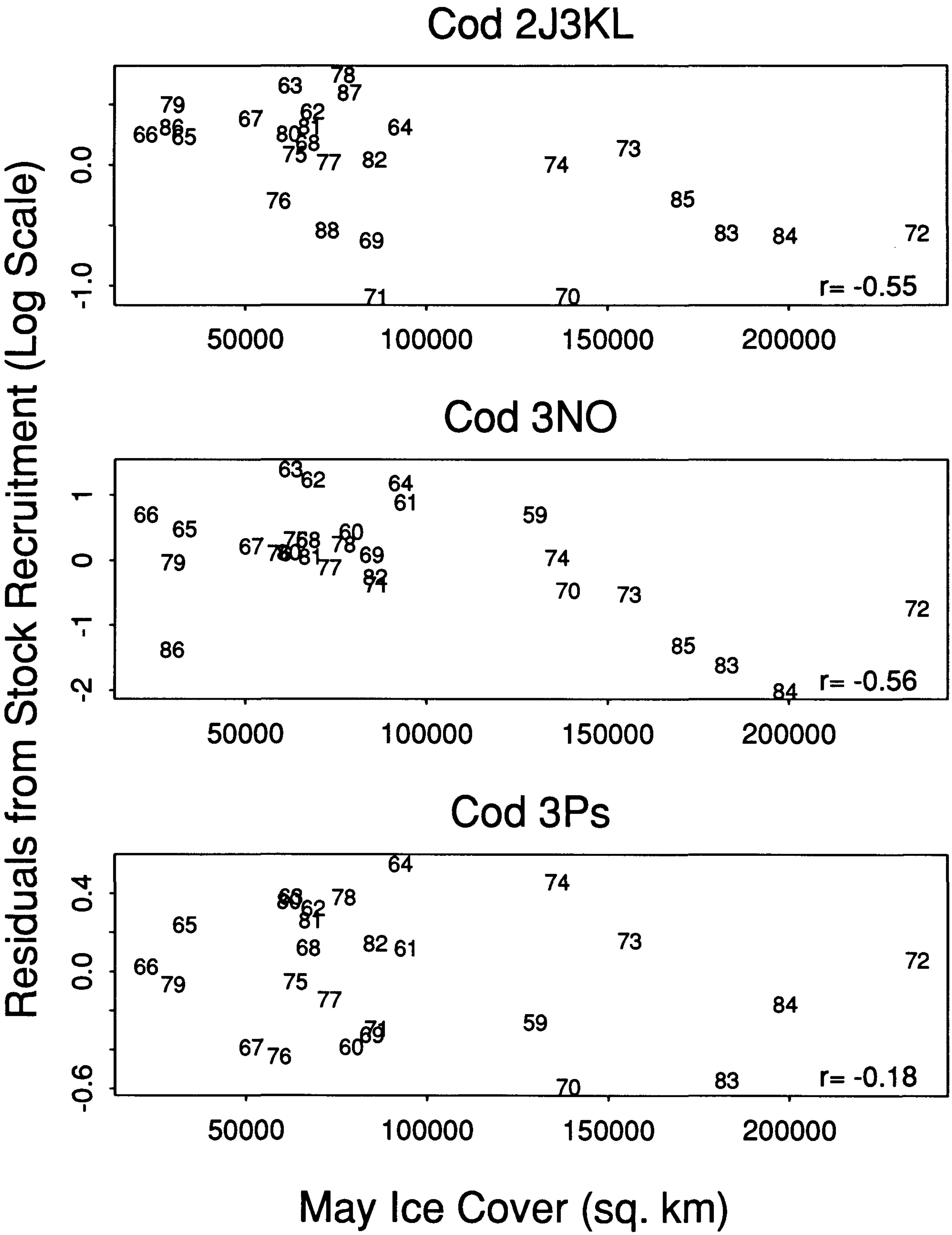

Figure 7. May ice cover south of 55 N and recruitment residuals from a a power stock recruitment curve. The correlation is given in the lower right hand corner.