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SPECIAL SESSION ON ENVIRONMENTAL CONDITIONS

Investigation of the Effect of Ice Cover on Cod Catches in the Gulf of St. Lawrence

by

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Abstract

A analysis of results obtained during the winter groundfish surveys in the Gulf of St. Lawrence since 1978 was done by relating the cod (*Gadus morhua*) catch to the distance from ice edge while taking temperature and depth variables into account. This analysis was prompted by recently published data on increased abundance of many taxons related to an upwelling phenomenon in the marginal ice zone as well as anecdotal information that catch rates for cod may be higher in the vicinity of the ice edge. Results indicate that large catches of cod occur in the marginal ice zone when depths are suitable. It is hypothesized that a strong thermal gradient close to the bottom would increase the concentration of fish and thus the catchability of cod.

Résumé

Une analyse des résultats obtenus lors de missions d'évaluation de poissons de fond dans le Golfe du Saint-Laurent depuis 1978 a été faite en reliant la capture de morue (*Gadus morhua*) à la distance de la marge des glaces tout en tenant compte de la température et de la profondeur. Cette analyse résulte d'informations anecdotiques ainsi que des données publiées récemment sur l'abondance accrue de plusieurs taxons dans la zone marginale des glaces causée par un phénomène de remontée d'eau profonde. Les résultats indiquent que les plus grosses captures de morue se retrouvent dans la zone marginale des glaces si la profondeur est adéquate. On pose l'hypothèse que la présence d'un fort gradient thermique près du fond pourrait causer une augmentation de la concentration de poissons et par le fait même la capturabilité de la morue.

1. Introduction

Attempts to correlate environmental conditions to fish populations parameters have flourished recently. One relating ice cover to cod recruitment has been presented in the June session of the Scientific Council of NAFO. Sloth and Buch (1988) have found a significant correlation coefficient (0.71) between the ice concentration in the Greenland sea and the Fylla Bank June and July temperatures. This was observed for depths up to 400 meters. On the other hand, Hansen and Buch (1985) could estimate year class strength of cod on Fylla Bank from the June temperatures in this area (R^2 = 0.72). These studies illustrate the potential benefits of relating environmental conditions to biological processes and in this example, the importance of ice to cod population dynamics.

The marginal ice zone (MIZ) has recently been recognized as being very productive. Large numbers of marine birds and mammals were associated to the MIZ (Alexander and Niebauer, 1981). This situation being caused by a local upwelling of nutrient rich deep waters (Buckley et al., 1979). Two factors may be involved in explaining this situation. First, winds in this area might create a current from the ice edge toward the open waters to be replaced by deeper waters. The second factor is related to the sequences involved in the formation of ice. As cooling of the surface waters takes place, an increase in density is observed. This water mass sinks until it reaches water masses with identical density thus creating a homogeneous mass of cold waters extending from the surface down to a depth of 150 meters (depending on salinity) (Buckley et al., 1979).

Evidence of high abundance of species occurring at the ice-edge from many trophic levels can be found in the literature. Most of it being associated with the advection of nutrients (Buckley et al., 1979). Phytoplankton productivity is high, microalgae, mostly diatoms dominate (Smith and Nelson, 1986; Buck and Garrison, 1983; El-Sayed and Taguchi, 1981; Smith et al., 1985; Garrison et al., 1986; Wilson et al., 1986). The high primary productivity is followed by high densities of zooplankton (Wiborg, 1955; Bradstreet and Cross, 1982). Arctic cod (Boreogadus saida) was found feeding extensively on amphipods and copepods along the ice edge (Bradstreet and Cross, 1982). Finally many seabirds such as fulmars and thick-billed murres (Bradstreet and Cross, 1982), ivory gull (Orr and Parsons, 1982), various petrels (Ainley and Jacobs, 1981; Fraiser and Ainley, 1986) and marine mammals like narwhals, belugas, and ringed seals (Bradstreet, 1982) congregate at the ice edge. The importance of this phenomenon is such that a comprehensive research project called MIZEX (Marginal Ice Zone EXperiment) has been established in 1983 in the Bering and Greenland Seas to investigate the properties of the ice cover, oceanographic, atmospheric, biological and acoustical characteristics of the marginal ice zone. In a more basic ecological context, it is generally recognized that areas of discontinuity show high productivity (Pingree et al., 1975, 1977; Pingree, 1978; Legendre, 1981; Perry et al., 1983). Concentration of marine organisms from various trophic levels at fronts and the underlying mechanisms have been described by Olson and Backus (1985).

The Gulf of St. Lawrence comprises two distinct cod stocks, one in the north (3Pn, 4RS) and another in the south (4T-Vn [Jan.-Apr.]). Both stocks have a similar migration pattern (Fig. 1); the summer distributions being quite homogeneous within the Gulf while a winter migration outside the Gulf to Subdivisions 4Vn [Jan.-Apr.] and 3Pn are associated with higher concentrations of fish. As a result, the winter fishery in Subdivision 3Pn is very intense, catch rates in January and February being the highest, almost twice those observed in September (Fréchet, 1988), (Fig. 2).

Total biomass estimates of cod from the surveys conducted in winter show considerable inter-annual variation (Fig. 3). Although some of the variations may be attributable to changes in stock size, they may also to be related to variations of catchability (q). The seasonal variability in the catchability coefficient has been recognized to be influenced by abundance of prey and a strong thermal gradient which induce cod concentrations near the bottom and thus a larger availability to the trawl (Jean, 1964; Forest and Minet, 1981). Field observations of catch rates during the winter surveys indicate that very successful sets (i.e. over one ton to a maximum of 11 t of cod in a 30 minute set!) were encountered close to the ice edge. This observation is not unknown to experienced fishing masters involved in this fishery. De la Morandière (1966) in a review of the history of the French fishery in Eastern Canada indicates that the fishery in the 18th century was more successful early in the year along the "French Coast" which extends from Cap Ray to Point Riche. Templeman and May (1965) mention "On May, 1963, very large catches of post-spawning cod were obtained on the southeastern slope just south of the ice-edge at 225-280 m (2.8 to 3.0 C)".

The purpose of this paper is to show that catch rates of cod in the frontal ecosystem of the ice edge are higher than those observed in surrounding waters and that this might be a significant factor in the timing and extent of the winter migration of the 3Pn, 4RS cod stock. A case study should provide some information on the processes involved in the aggregation of cod in the MIZ.

2. Material and methods

By 1987 Canada had carried out 9 years of annual winter groundfish trawling surveys aboard the research vessel *Gadus Atlantica* in the Gulf of St. Lawrence (NAFO divisions 4RST and Subdivision 3Pn). These surveys were based on a depth stratified random selection of fishing stations (Doubleday and Rivard, 1981), Fig. 4 shows the stratification scheme used in these surveys. The area was surveyed by towing an Engels Hi-lift otter trawl at a speed of 3.5 knots for a period of 30 minutes. Only sets done in the Subdivision 3Pn and Divisions 4R and 4S were used in this analysis. Most surveys were done during the month of January:

Year	Date start	end (No. of days)	Number of sets
1978	6 Jan.	22 Jan. (17)	122
1979	6 Jan.	15 Jan. (10)	84
1980	27 Jan.	11 Feb. (16)	133
1981	29 Jan.	17 Feb. (20)	146
1983	7 Jan	29 Jan. (23)	207
1984	6 Jan.	26 Jan. (21)	199
1985	5 Jan.	25 Jan. (21)	165
1986	6 Jan.	26 Jan. (21)	184
1987	9 Jan.	28 Jan. (20)	154

The distance separating the 1,374 sets to the ice edge were calculated by plotting each set (according to the latitude and longitude) on a map of ice conditions in the Gulf of St. Lawrence. These maps were provided by the Atmospheric Environment Service of the Canadian Department of Environment and are a composite of information from ships of opportunity, aerial reconnaissance, satellite imagery as well as shore observations. These maps were generally produced every third or fourth day and considered to be representative of the ice conditions at 12:00 hrs of the day of the report. A total of 64 maps were used to cover the surveys. The position of individual sets was plotted on the map with the closest correspondence in time and the distance to the closest ice edge calculated. The surface of the Gulf covered by ice was calculated using an electronic planimeter (Tamaya digitizing area-line meter. Model:Planix 5000).

For every set, average depth trawled (Z), bottom temperature (T) (from a XBT cast), distance from the ice edge (D) and catch (in kg, W) of cod was recorded. Temperature and depth have been shown to be very important factors influencing cod distribution (Beverton and Lee, 1965; Svetlov, 1970; Templeman and May, 1965; Jean, 1964). These four variables were partitioned according to Legendre and Legendre (1983) to generate the multiway contingency table for analysis using a log-linear model (Table 1). Temperature, and catch were split by quartiles. Since the sampling scheme in groundfish surveys are based on depth strata with 50 fathom steps, this was maintained as a basis for delimiting depth intervals. In order to eliminate the possibility that a higher proportion of sets might have been made in the marginal ice zone (i.e. post stratification could bias the interpretation of the catch), the splitting of the distance variable was done by quartiles. For all practical purposes the MIZ is considered to be equal to the third modality of the D variable (D3, ie. 8.6 to 44.0 nautical miles off the ice edge). A cross tabulation (4x4x4x4) of the observed frequency of temperature (T), depth (Z), distance (D) from ice edge and catch (W) of cod is shown in Table 2 and used as input for the log-linear model. This type of analysis was preferred because the variables show a biological response curve that reach a maximum (or a minimum) for intermediate values of the environmental variables (i.e. non-monotonic responses). Analysis was done using the BMDP program P4F for portable computers. As certain cells were zeros, the log-linear parameters could not be calculated so a constant value of 0.5 (Delta) was added to the multidimensional matrix, as recommended (BMDP, 1985).

Data were submitted to a multiple correspondence analysis (Lebart et al., 1977). This analysis is used to compare various modalities of a variable (lines of a contingency table) to the modalities of a second variable (columns of a contingency table). By opposition to the log-linear analysis of multidimensional contingency tables used above, which identifies interactions between variables and not modalities, the correspondence analysis is recommended to visualize how this interaction is made. In order to use the information contained in the multiway contingency table (4x4x4x4), data are reorderd in a table of Burt (16x16). Statistical analysis was done using the SAS program SAS.BICORR available in the public library of Laval University (Quebec).

3. Results

The ice cover in the Gulf of St. Lawrence usually starts in the lower estuary and in the Strait of Belle-Isle by the end of December (Markham, 1980). The progression is more or less along a diagonal (SW -NE) in a southeast direction to eventually reach the Cabot Strait. Based on 15 years of data, the percent covered of ice in the Gulf for the first of January is around 10% and reaches 80% by February 5th (Markham, 1980). Fig. 5 shows the observed progression of the ice cover when winter surveys were undertaken. This progression is influenced by the direction and velocity of the dominating winds as well as air temperature. Fig. 6 shows the direction and occurrence (calculated as the number of sets with observed wind velocity above 4 on the Beaufort scale to the total number of sets). These origin mainly from the west and northwest. The years 1978 and 1984 do not follow this pattern, the dominating wind being from the northeast. In surveys since 1984, the progression of ice was rapid, 50% coverage being reached in all cases before the 11th of January (Figure 5) and occurrence of strong winds was high (Fig. 6).

The typical distribution of fishing stations in relation to ice edge starts at a maximum distance because hardly any ice is present in the Gulf and because of the starting location (generally in Subdivision 3Pn). With time, sets are closer to the ice edge and eventually fishing operations will be done within the ice area. When the ice thickness prevents either the trawl to sink (because the warps are lying on the ice) or maintaining the towing speed of 3.5 knots the set is considered unsuccessful and eliminated from this analysis. The bridge is then instructed to proceed to more open waters, generally in a southeastern direction. Year to year description of this situation is shown in Fig. 7. The range of distances separating all tows from the ice edge range from -100 to 200 nautical miles (a minus sign indicating that the set was done within the ice cover). It was of concern that the frequency of the ice maps could not be used to accurately describe the progression of the ice edge. No major steps were observed (Fig. 7) in the calculated distance and no interpolation was done. No geographical or temporal considerations are included in this analysis as all distances are made relative to the closest ice edge. The surveys in 1980 and 1981 were mostly done in February at which time the Gulf had over 50% of its area covered by ice, a larger proportion of stations were done within the ice cover (Fig. 7).

A series of multiple X - Y - Z plots relating the occurrence of the four types of catches of cod to the three descriptors (depth, temperature and distance from the ice edge) are shown in Fig. 8. From Fig. 8A, the depth strata in the [100-150] fathoms range (category #2) is the most favorable to large catches of cod. As depth increases (category #3 and #4), the modal catch category shifts towards categories 3 and 2 (less catch). In Fig. 8B, large catches of cod were taken in water temperature in the [3.92-5.31] degree Celsius range (category #2). Finally, in Fig. 8C two different situations occur, when sets were done well within the ice edge (< -15.1 nautical miles, category #1), small catches of cod were very common (< 1.4 kg, category #1). In areas close to the ice edge ([8.6-44.0] nautical miles, category #3) the highest occurrence of large catches were observed (> 105.4 kg, category #4).

Temperature, depth and distance from the ice edge are expected to have an effect on cod catches so [T] [Z] [D] were included in the log-linear model in order to explain the cod catches [W]. On the other hand, the full model (main effects = [TZDW]) cannot be used since all expectations will equal the observed frequencies (Legendre, 1987). As the log-linear models are hierarchical, an interaction is necessarily included with all its corresponding lower order effects. In this case, the starting model is:

$$\ln(E) = [\theta] + [T] + [Z] + [D] + [W]$$

Where E = expected cell frequency
θ = average of the logarithms of the expectations

If this model does not adequately fit the data (X^2 probability <0.01), an interaction term is added to the model on the basis that its coefficient has the lowest probability of including zero (H_0 = 0). Chi-squares as well as degrees of freedom are additive in log-linear models and are the basis on which a interaction term is added to the initial model. Results indicate that the inclusion of the [ZT] interaction improves the fit but not to a point where the model was significant (Table 3). The [WZ] interaction was added to the model over the [WD] interaction because the difference due to the addition of [WZ] was 176.65 while the difference due to the addition of [WD] was 152.04 in the Chi-square for identical degrees of freedom (Df = 9). This would indicate that the depth strata is marginally more significant to explain the frequency distribution of catches than is the distance to the ice edge. Addition of [WD] improved the fit of the model in the next step. Finally with the addition of the [DZ] and [WDZ] interaction, the model was significant (P >0.01). The resulting model is as follows:

$$\ln(E) = [\theta] + [T] + [Z] + [D] + [W] + [ZT] + [ZD] + [WZ] + [WD] + [WDZ]$$

Which is equivalent to having main effects as [WDZ] and [ZT]. All other main effects have a significant probability of including zero, these are [WDTZ], [WTD], [WTZ], [TZD], [TD] and [TW]. The expected cell frequencies are shown in Table 2. Plots of the standardized residuals over the observed and expected counts as well as the normal probability plot are shown in Fig. 9. No apparent trends are found.

These results indicate as expected that the most significant interaction is between the depth and temperature variables [ZT], this relationship is well known by physical oceanographers. The depth component has a significant effect on cod catches [WZ], followed by the distance to the ice edge [WD]. Temperature is included in the model as an interaction term between depth and distance to the ice edge but is not identified as having a significant interaction with cod catches (i.e. [TW] term is not significantly different from 0). The [TW] term is not as significant in explaining variations in catch (W) than is the depth and distance from the ice edge which are considered the most parcimonius model to make the prediction of catch significant.

From the correspondence analysis, the first two factors explained 40% of the variance of all factors. Each modality of the four variables described in Table 4 are plotted in Fig. 10. The factor 1 axis is associated with the temperature -depth relationship which contributes to 84% of the contrast along this axis (Table 4). Modalities T1 and Z1 are located at the extreme positive values of this factor 1 axis, the T2 - Z2 modalities are close together, midway between T1 - Z1 and the cloud formed by T3 - Z3 and T4 - Z4. This means that cold waters are found in shallow depths, waters with intermediate temperatures occur in intermediate depths (favorable to the presence of cod, Fig. 8B), and that the warmest waters are found in deep strata. On the other hand, 86% of the second factor is explained by the relative contribution of the W and D modalities (Table 4). The four modalities of the W variable increase with the factor 2 axis. The D variable follows closely the factor 2 axis but with a slight variation (D1, D2, D4, D3).

Is is not surprising that the first axis is associated with such a well known physical phenomenon of the presence of cold waters in shallow strata (positive X axis) and deep strata with warmer waters (negative X axis). This is often the first axis in multivariate statistical analysis, exploratory in nature, like principal components or correspondence analysis. Positive values of the Y axis illustrate small catches, and tows done well inside the ice cover, negative values of the Y axis are associated with large catches done at the ice edge (D3). The curvature of the W variable shows the interaction brought by the depth on cod catches.

A case study

A series of plots indicating the distribution of catch according to the ice edge by year are shown in Fig. 11. Most sets with large catches of cod are located at or close to the ice edge, 1984 being the extreme case with the highest catch in the 9 year data base (10,985 kg) situated at a distance of 10 nautical miles from the ice edge at a mean depth of 200 meters and temperature of 4.8 degrees Celsius (i.e. W-4, D-3, Z-2 and T-2). These modalities fit with the preferred habitat shown in Fig. 8. Fig. 12 is the echo sounding trace and Fig. 13 the temperature profile of this set. The gear used during these surveys has a vertical opening of 2.5 meters (C. Bishop pers. comm.), this would suggest that a considerable amount of fish was not caught by the gear since fish were detected at 50 meters from the bottom. The temperature profile does not show the typical cold intermediate water present in the Gulf (Markham, 1980) but rather a homogeneous mass of cold water from the surface extending to 80 meters, followed by a second water mass which shows a gradual increase in temperature with depth right up to the bottom of 200 m. Generally, bottom waters at these depths have a stable water temperature.

4. Discussion

Upwelling of deep waters, favorable to the presence of cod has recently been proven to be a determining factor in the success of the trap fishery in the lower North shore (Rose and Leggett, 1988). The upwelling is associated with the presence of longshore winds which generate offshore currents to be replaced by bottom waters. The presence of cod in inshore areas is thus limited by a thermal barrier. The same series of events can explain the strong thermal gradients in depths favorable to the presence of cod along the ice edge. This is supported by the temperature profile of the largest set in the time series. The variation in catchability in the MIZ is consistent with the idea of increased concentration of fish near the bottom caused by a strong thermal gradient (Forest and Minet, 1981; Jean, 1964). This is thought to be a more significant factor to cause variations in catchability than is the presence of prey in the MIZ because cod is not found to be feeding heavily in January. Recently, Chumakov and Savvatimsky (1987) have shown that Greenland halibut concentrations caused by high thermal stratification close to the bottom are found close to the ice edge off the Baffin Island.

Interpretation of the results obtained from the log-linear model is difficult because there is considerable interaction between variables. This was expected given the current knowledge of the influence of temperature and depth on cod distribution. Although the interaction between distance to the ice edge and the cod catch [WD] was not the most significant interaction, the [WZ] interaction was selected only by a marginal probability. The [WDZ] interaction can be explained by the fact that there might be a variation of cod catches caused by landfast ice. Catches in these shallow areas could be expected to be low because the upwelling in shallow waters causes unsuitable conditions for cod. Buckley et. al. (1979) found cold waters (0.0 to 0.2 degrees Celsius) in the upwelling area at the MIZ from the surface to a depth of 150 meters. Evidence of the importance of the MIZ on observed cod catches is found in the results of the correspondence analysis (proximity of the D3 and W4 modalities) but it must be noted that cod catches are not independent from depth conditions.

It is interesting to note that as the highest catch in the time series was observed in the 1984 survey, catch rates experienced by the French fleet (metropolitan France and Saint Pierre and Miquelon vessels) operating in the Gulf were very high (over 22 t per hour in February). This has been noticed in past assessments of this stock, considered anomalously high and removed from the catch rate data base (Gascon and Fréchet, 1985). Anecdotal information from observers aboard the French vessels suggest that the fishery takes place in the MIZ. This possibility could be investigated as all trawling positions were recorded by the observers. On the other hand, the highest catches observed during the 1987 survey are not close to the ice edge (Fig. 11). Tows with the highest catch rate were done in the Subdivision 3Pn and the resulting biomass estimate for the Subdivision was the highest in the series (Fréchet, 1988). Ice is rarely found in this area outside the Gulf (Markham, 1980).

Although the examination of the largest catch on record provides valuable information on the process by which catchability might be influenced by ice cover, this remains a single case. Further studies integrating all temperature profiles and echo sounder traces might be more instructive. Measurement of more oceanographic and biological variables on a transect type of survey instead of a post-stratification of previous groundfish surveys should also be useful in establishing the exact process(es) involved.

Observation of increased abundance of cod in the MIZ, coupled with the fact that the ice shows a progression from the estuary to the Cabot Strait would be a significant process in the timing and extent of the winter migration of the 3Pn, 4RS cod stock. These findings should be taken into consideration by managers who split the TAC into fleet and seasonal components. A unit of effort in the winter fishery would have a higher instantaneous fishing mortality associated to it than if it was done in the summer because of variation in catchability. If a higher proportion of the total catch is taken during the winter fishery when the catchability is high, this will increase the effective mean catchability of the stock as a whole. Results of the winter surveys, being as they are, could be rationalized by taking the MIZ into account.

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Table 1: Partitionning of the strata, temperature, distance from the ice edge and catch as input for the log-linear model.

VARIABLE Units Symbol	STRATA see Figure 4 Z	TEMPERATURE Celsius T (quartiles)	DISTANCE Nautical miles D (quartiles)	CATCH Kilograms W (quartiles)
Modality				
1	302,[820-832]	< 3.91	< -15.1	< 1.4
2	303,[401-403],[811-819]	[3.92-5.31]	[-15.0-8.5]	[1.5-13.5]
3	304,[404-406],801,[805-810]	[5.32-5.91]	[8.6-44.0]	[13.6-105.3]
4	305,407,[802-804]	> 5.92	> 44.1	> 105.4

Table 2: Multiway cross tabulation (4x4x4x4) of observed cod catch according to distance to the ice edge, depth, and temperature in winter groundfish surveys in the Gulf of St. Lawrence. Predicted cell frequencies from the log-linear model [WDZ], [TZ] are shown in brackets.

TEMP.	DEPTH	DISTANCE	WEIGHT <1.4		[1.5-13.5]		[13.6-105.3]		>105.4		TOTAL	
<3.91	[50-100]	<-15.1	59	(54.8)	9	(9.0)	2	(3.6)	1	(6.0)	71	(73.6)
		[-15.0-0.5]	48	(46.5)	19	(16.5)	6	(7.5)	18	(21.8)	91	(92.3)
		[0.6-44.0]	14	(14.2)	20	(17.3)	7	(9.0)	42	(37.5)	83	(78.1)
		>44.1	3	(5.3)	5	(6.8)	19	(24.0)	48	(48.0)	75	(84.1)
		TOTAL	124	(120.8)	53	(49.5)	34	(44.3)	109	(113.3)	320	(328.0)
	[101-150]	<-15.1	5	(3.8)	4	(2.2)	0	(1.7)	0	(1.3)	9	(9.0)
		[-15.0-0.5]	0	(2.0)	3	(3.4)	0	(3.3)	1	(4.2)	4	(12.9)
		[0.6-44.0]	0	(0.9)	2	(2.5)	1	(3.7)	10	(4.8)	13	(12.0)
		>44.1	1	(0.5)	0	(1.1)	2	(2.8)	4	(2.6)	7	(7.1)
		TOTAL	6	(7.2)	9	(9.2)	3	(11.6)	15	(12.9)	33	(41.0)
	[151-200]	<-15.1	1	(1.3)	1	(1.0)	0	(0.8)	1	(0.5)	3	(4.6)
		[-15.0-0.5]	1	(1.3)	0	(1.6)	1	(1.5)	2	(1.1)	4	(5.4)
		[0.6-44.0]	0	(0.6)	0	(1.2)	2	(1.5)	1	(0.9)	3	(4.3)
		>44.1	0	(0.8)	0	(1.1)	1	(2.6)	1	(1.3)	2	(5.8)
		TOTAL	2	(3.8)	1	(5.7)	4	(6.4)	5	(4.0)	12	(20.0)
	>201	<-15.1	1	(0.8)	1	(1.4)	1	(1.7)	0	(0.3)	3	(4.3)
		[-15.0-0.5]	0	(0.9)	2	(2.1)	0	(1.7)	0	(0.4)	2	(5.1)
		[0.6-44.0]	2	(1.4)	0	(2.0)	1	(1.3)	0	(0.5)	3	(5.2)
		>44.1	4	(2.7)	0	(2.1)	1	(1.3)	0	(0.4)	5	(6.6)
		TOTAL	7	(5.8)	3	(7.6)	3	(6.1)	0	(1.6)	13	(21.0)
[3.92-5.31]	[50-100]	<-15.1	11	(12.4)	1	(2.0)	1	(0.8)	5	(1.4)	18	(16.6)
		[-15.0-0.5]	12	(10.5)	1	(3.7)	2	(1.7)	9	(4.9)	24	(20.8)
		[0.6-44.0]	2	(3.2)	1	(3.9)	3	(2.0)	3	(8.5)	9	(17.6)
		>44.1	0	(1.2)	2	(1.5)	5	(5.4)	8	(10.8)	15	(18.9)
		TOTAL	25	(27.3)	5	(11.2)	11	(10.0)	25	(25.6)	66	(74.0)
	[101-150]	<-15.1	7	(12.9)	5	(7.9)	6	(8.3)	4	(4.8)	22	(32.8)
		[-15.0-0.5]	3	(7.3)	9	(12.6)	9	(12.3)	19	(15.2)	40	(47.4)
		[0.6-44.0]	6	(3.3)	9	(9.3)	14	(13.6)	28	(17.8)	57	(44.0)
		>44.1	1	(2.8)	3	(4.0)	8	(10.3)	11	(8.6)	23	(25.8)
		TOTAL	17	(26.3)	25	(33.8)	37	(42.4)	63	(47.4)	142	(150.0)
	[151-200]	<-15.1	7	(4.6)	6	(6.6)	0	(3.1)	1	(1.6)	14	(16.1)
		[-15.0-0.5]	2	(4.6)	4	(5.5)	3	(5.1)	1	(3.8)	10	(19.0)
		[0.6-44.0]	2	(2.0)	2	(4.2)	7	(5.1)	4	(3.1)	15	(14.4)
		>44.1	2	(2.2)	4	(3.8)	11	(9.3)	6	(5.3)	23	(20.5)
		TOTAL	13	(12.6)	16	(18.6)	21	(23.6)	12	(13.8)	62	(70.0)
	>201	<-15.1	1	(3.5)	6	(7.9)	6	(9.6)	0	(1.7)	13	(22.7)
		[-15.0-0.5]	2	(4.8)	12	(11.9)	8	(8.6)	2	(2.2)	24	(28.4)
		[0.6-44.0]	10	(7.9)	11	(10.9)	8	(7.4)	4	(3.1)	33	(29.3)
		>44.1	15	(15.3)	16	(11.6)	7	(7.6)	1	(2.2)	39	(36.7)
		TOTAL	28	(31.4)	45	(42.3)	29	(34.1)	7	(9.2)	109	(117.0)

Table 2: (continued).

TEMP.	DEPTH	DISTANCE	WEIGHT <1.4		[1.5-13.5]		[13.6-105 .3]		>105.4		TOTAL	
[5.32-5.91]	[50-100]	<-15.1	1	(2.8)	0	(0.5)	0	(0.2)	0	(0.3)	1	(3.8)
		[-15.0-8.5]	0	(2.4)	0	(0.9)	0	(0.4)	0	(1.1)	0	(4.8)
		[8.6-44.0]	1	(0.7)	0	(0.9)	0	(0.5)	1	(1.9)	2	(4.0)
		>44.1	2	(0.3)	0	(0.4)	2	(1.2)	2	(2.5)	6	(4.4)
		TOTAL	4	(6.3)	0	(2.6)	2	(2.3)	3	(5.9)	9	(17.0)
	[101-150]	<-15.1	8	(11.0)	3	(6.3)	6	(5.0)	5	(3.7)	22	(26.0)
		[-15.0-8.5]	13	(5.8)	13	(10.0)	10	(9.7)	10	(12.1)	46	(37.6)
		[8.6-44.0]	1	(2.6)	9	(7.4)	14	(10.8)	10	(14.2)	34	(34.9)
		>44.1	0	(1.6)	2	(3.2)	4	(8.1)	3	(7.6)	9	(20.5)
		TOTAL	22	(21.0)	27	(26.8)	34	(33.6)	28	(37.6)	111	(119.0)
	[151-200]	<-15.1	7	(7.0)	11	(9.9)	3	(4.6)	1	(2.6)	22	(24.2)
		[-15.0-8.5]	9	(7.0)	10	(8.3)	6	(7.6)	3	(5.6)	28	(28.5)
		[8.6-44.0]	3	(3.0)	8	(6.3)	7	(7.6)	6	(4.6)	24	(21.5)
		>44.1	3	(3.3)	1	(5.6)	13	(13.9)	6	(7.9)	23	(30.8)
		TOTAL	22	(20.2)	30	(30.1)	29	(33.8)	16	(20.9)	97	(105.0)
	>201	<-15.1	1	(1.7)	4	(3.9)	7	(4.8)	0	(0.9)	12	(14.0)
		[-15.0-8.5]	3	(2.4)	4	(5.8)	4	(4.8)	0	(1.1)	11	(13.0)
		[8.6-44.0]	0	(3.5)	8	(4.9)	2	(3.3)	1	(1.5)	11	(13.0)
		>44.1	7	(7.5)	4	(5.8)	3	(3.6)	2	(1.1)	16	(18.0)
		TOTAL	11	(15.6)	20	(21.0)	16	(16.9)	3	(4.5)	50	(58.0)
>5.92	[50-100]	<-15.1	0	(3.0)	0	(0.5)	0	(0.2)	0	(0.3)	0	(4.0)
		[-15.0-8.5]	0	(2.6)	0	(0.9)	0	(0.4)	0	(1.2)	0	(5.1)
		[8.6-44.0]	0	(0.8)	0	(0.9)	0	(0.5)	2	(2.1)	2	(4.3)
		>44.1	0	(0.3)	0	(0.4)	4	(1.3)	4	(2.6)	8	(4.6)
		TOTAL	0	(6.6)	0	(2.7)	4	(2.4)	6	(6.2)	10	(18.0)
	[101-150]	<-15.1	20	(13.3)	10	(7.6)	5	(6.0)	3	(4.4)	38	(31.3)
		[-15.0-8.5]	4	(6.9)	11	(12.0)	16	(11.7)	14	(14.5)	45	(45.1)
		[8.6-44.0]	1	(3.2)	7	(8.8)	10	(12.9)	3	(17.0)	21	(42.0)
		>44.1	2	(1.9)	5	(3.8)	15	(9.8)	9	(9.2)	31	(24.6)
		TOTAL	27	(25.3)	33	(32.2)	46	(40.4)	29	(45.1)	135	(143.0)
	[151-200]	<-15.1	4	(6.1)	10	(11.5)	9	(5.4)	3	(3.1)	26	(26.1)
		[-15.0-8.5]	7	(8.1)	9	(9.6)	11	(6.9)	9	(6.5)	36	(33.1)
		[8.6-44.0]	2	(3.5)	7	(7.3)	5	(8.9)	1	(5.4)	15	(25.0)
		>44.1	3	(3.8)	10	(6.5)	15	(16.2)	9	(9.2)	37	(35.8)
		TOTAL	16	(23.5)	36	(35.0)	40	(39.3)	22	(24.2)	114	(122.0)
	>201	<-15.1	3	(2.1)	5	(4.8)	6	(5.9)	2	(1.1)	16	(14.0)
		[-15.0-8.5]	4	(3.0)	7	(7.3)	8	(5.9)	1	(1.3)	20	(17.5)
		[8.6-44.0]	4	(4.8)	4	(6.7)	4	(4.6)	0	(1.9)	12	(18.0)
		>44.1	7	(9.4)	5	(7.3)	4	(4.6)	0	(1.3)	16	(22.6)
		TOTAL	18	(19.3)	21	(26.1)	22	(21.0)	3	(5.8)	64	(72.0)

Table 3: Partitioning of likelihood chi-square ratios (G^2), for model fitting the data in table 2. Effects included in the model are listed additively.

MODEL	D.F.	G^2	ABBREVIATED MODEL
[W,D,Z,T]	243	1485*	[W,D,Z,T]
Diff.	9	758*	
+ [ZT]	234	727*	[W,D,ZT]
Diff.	9	177*	
+ [WZ]	225	550*	[D,WZ,ZT]
Diff.	9	152*	
+ [WD]	216	398*	[WD,WZ,ZT]
Diff.	9	43*	
+ [DZ]	207	355*	[DZ,WD,WZ,ZT]
Diff.	27	128*	
+ [WDZ]	180	227	[WDZ,ZT]

* prob =< 0.01; G^2 correspond to models having a probability > 0.01 of fitting data.

Table 4: Relative contribution (%) of the various modalities to the three first axis from the correspondance analysis. Lambda and the explained variance (%) associated to a factor are also shown. Symbol refers to those used in Figure 13.

VARIABLE	SYMBOL	UNITS	RANGE	Relative contribution FACTOR 1	2
Distance from	D1	Nautical	< -15.1	0.2	23.7
ice edge	D2	miles	[-15.0 - 8.5]	0.0	0.7
	D3		[8.6 - 44.0]	0.0	11.8
	D4		> 44.1	0.1	3.9
Weight	W1	Kg	< 1.4	4.8	19.7
	W2		[1.5 - 13.5]	2.4	1.9
	W3		[13.6 - 105.3]	5.8	0.8
	W4		> 105.4	2.8	23.6
Depth	Z1	Fathoms	[50 - 100]	29.2	0.0
	Z2		[100 - 150]	3.5	4.0
	Z3		[150 - 200]	6.0	1.9
	Z4		> 200	3.6	1.4
Temperature	T1	Celsius	< 3.91	28.6	0.0
	T2		[3.92 - 5.31]	1.1	4.3
	T3		[5.32 - 5.91]	4.9	0.6
	T4		> 5.92	6.9	1.8
			LAMBDA	0.233	0.118
			%	26.7	13.6
			Cumulative %	26.7	40.2

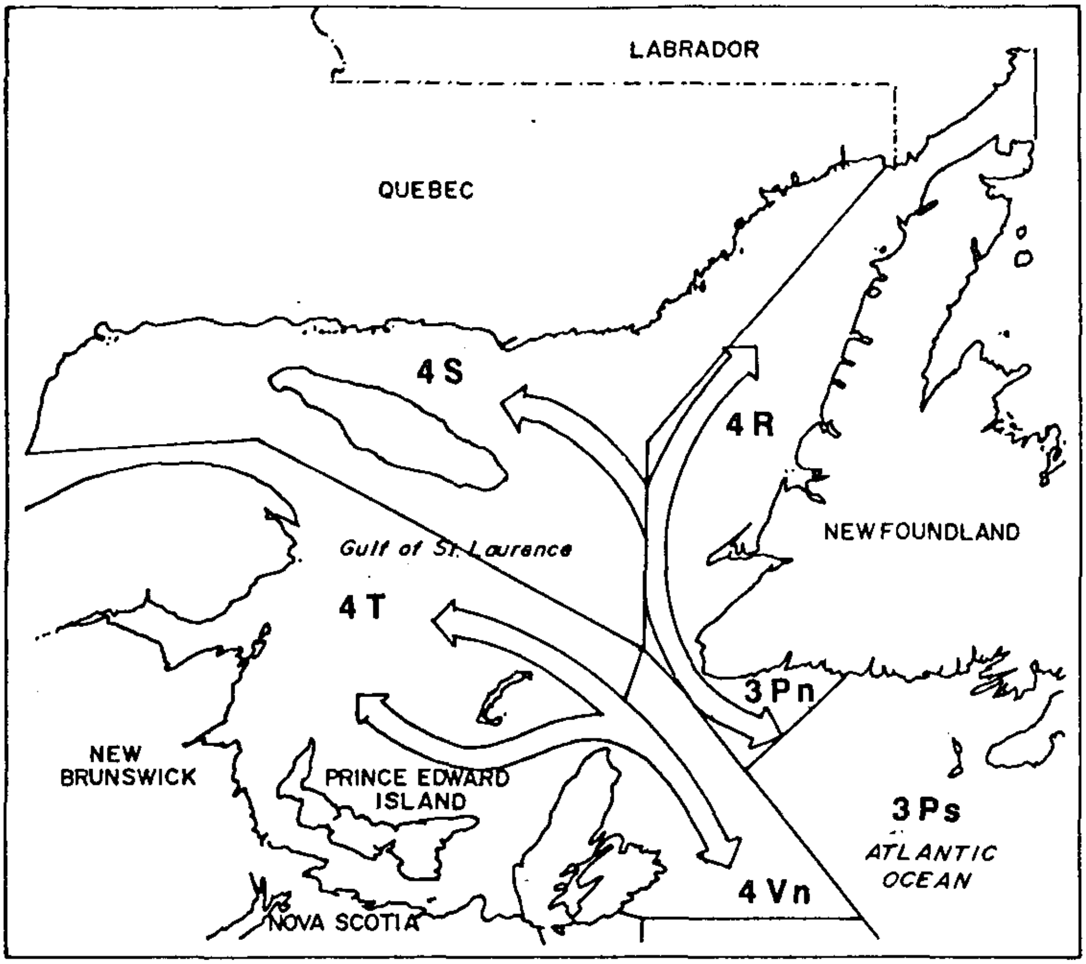


Figure 1: Migration patterns of the cod stocks (3Pn, 4RS and 4T,Vn [Jan. to Apr.]) in the Gulf of St. Lawrence.

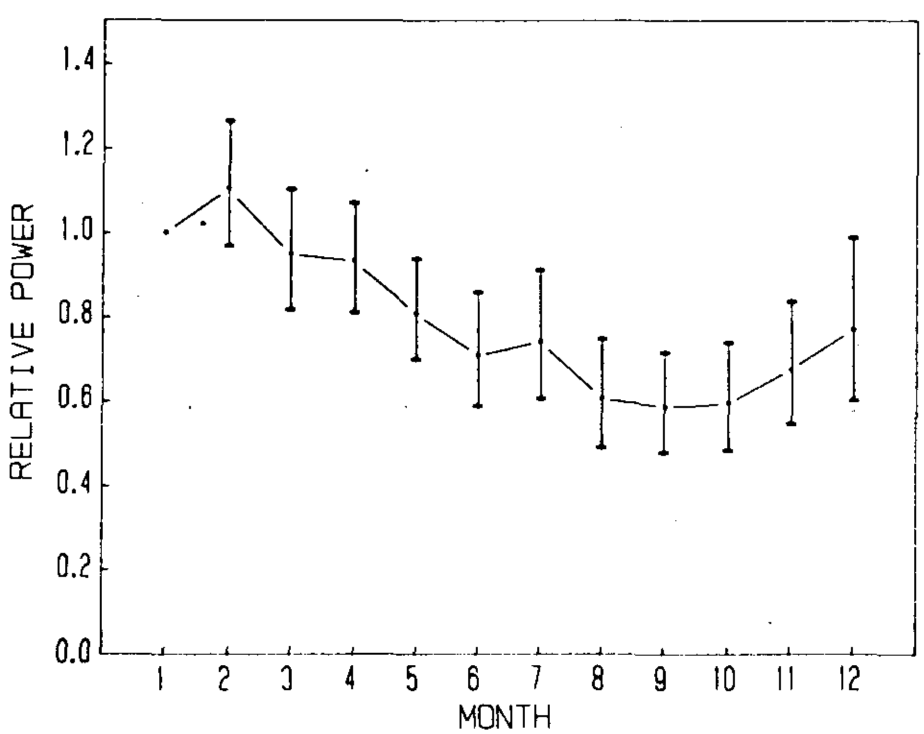


Figure 2: Monthly relative power of commercial catch rates (Fréchet, 1988).

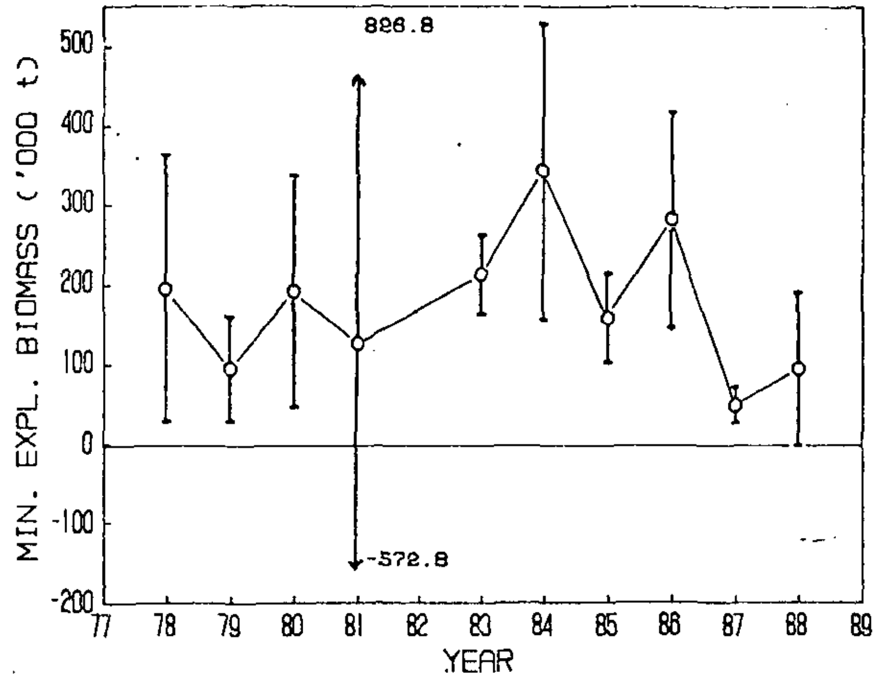


Figure 3: Minimum exploitable biomass from winter groundfish surveys for the 3Pn, 4RS cod stock.

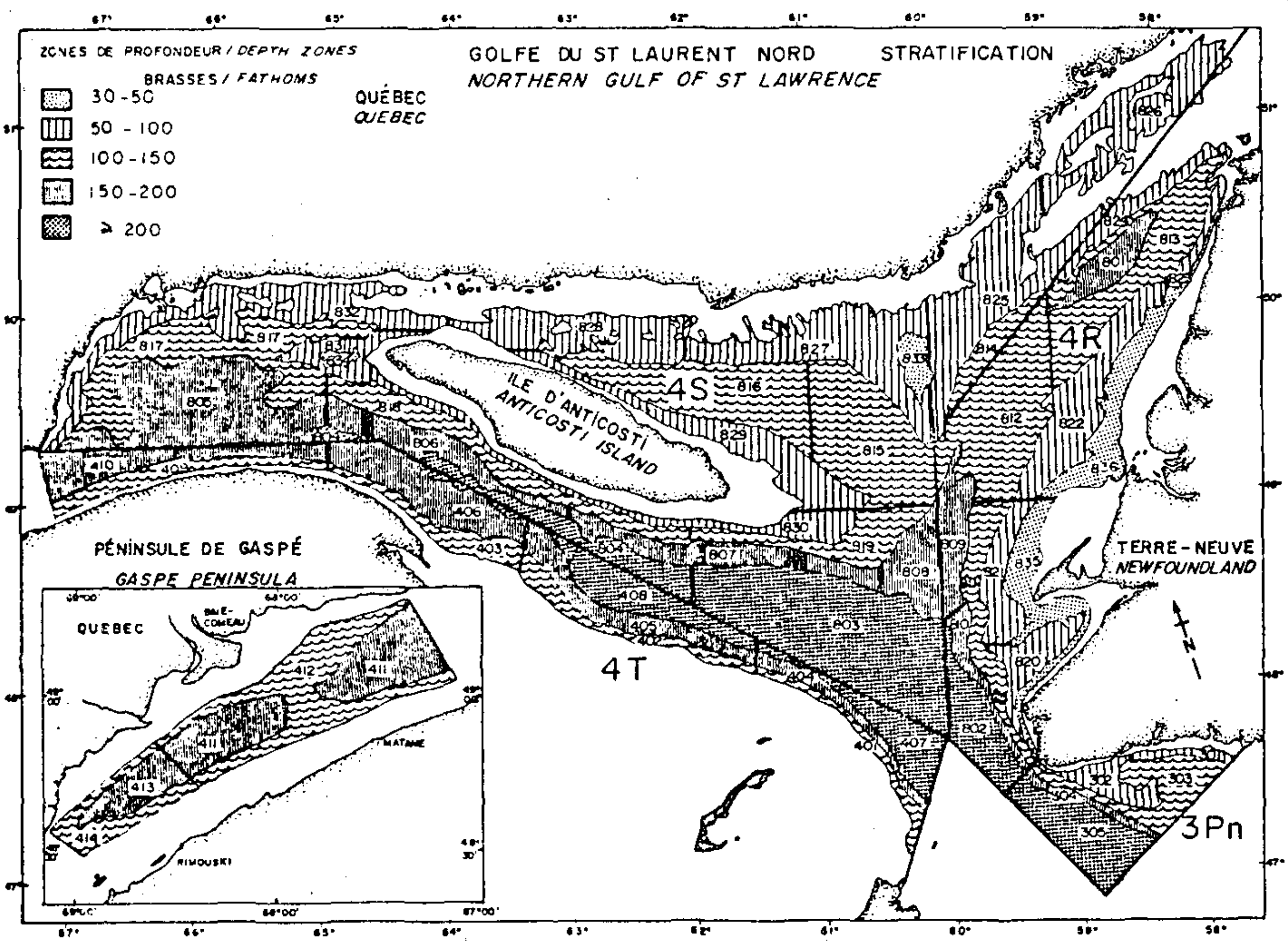


Figure 4: Stratification scheme used in the winter groundfish surveys.

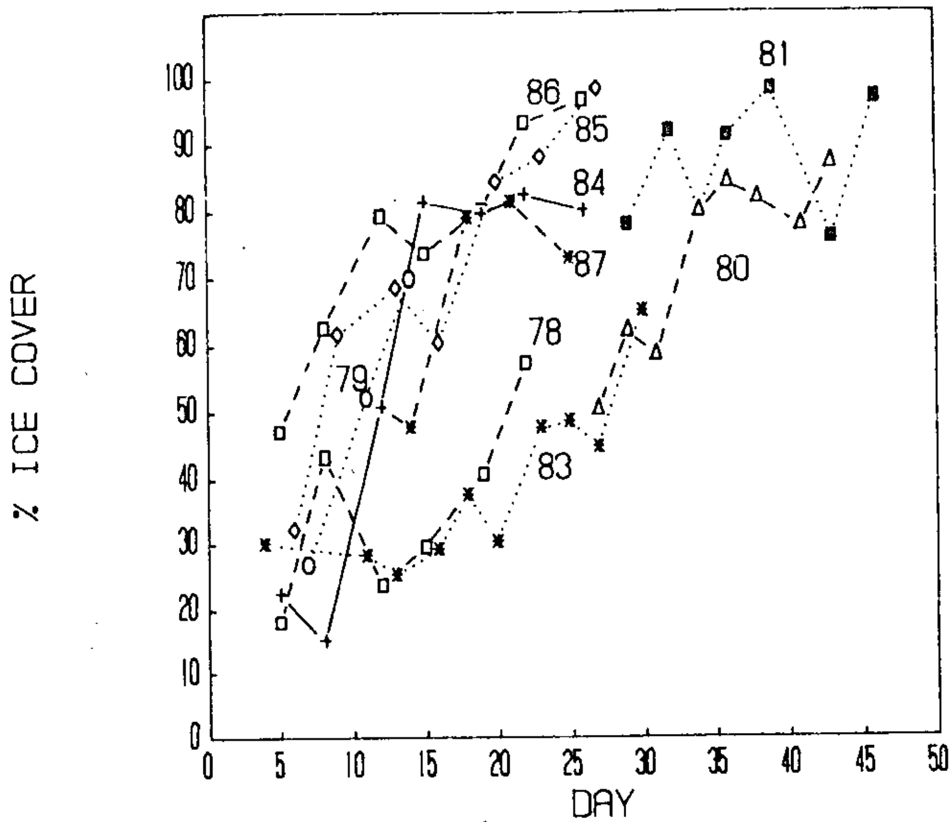


Figure 5: Julian calendar day of the area covered by ice in the Gulf of St. Lawrence where groundfish surveys were done. Every point was calculated from a map provided by the Atmospheric Environment Service of the Canadian Department of Environment.

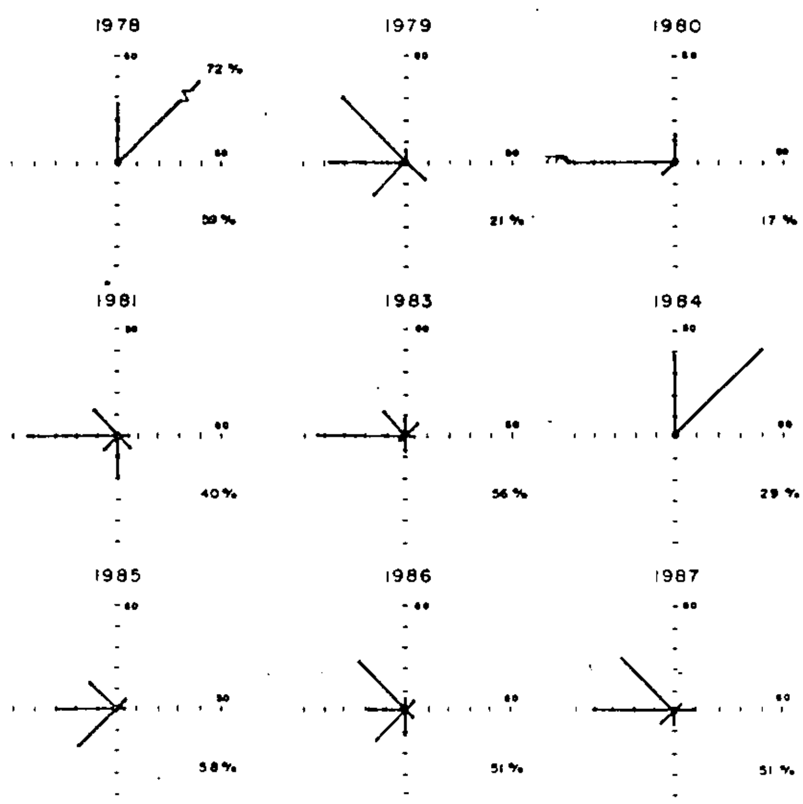


Figure 6: Direction of observed winds above 4 on the Beaufort scale during the winter groundfish surveys (north is the top). Occurence of these winds (one observation per set) during the survey is shown in the second quadrant.

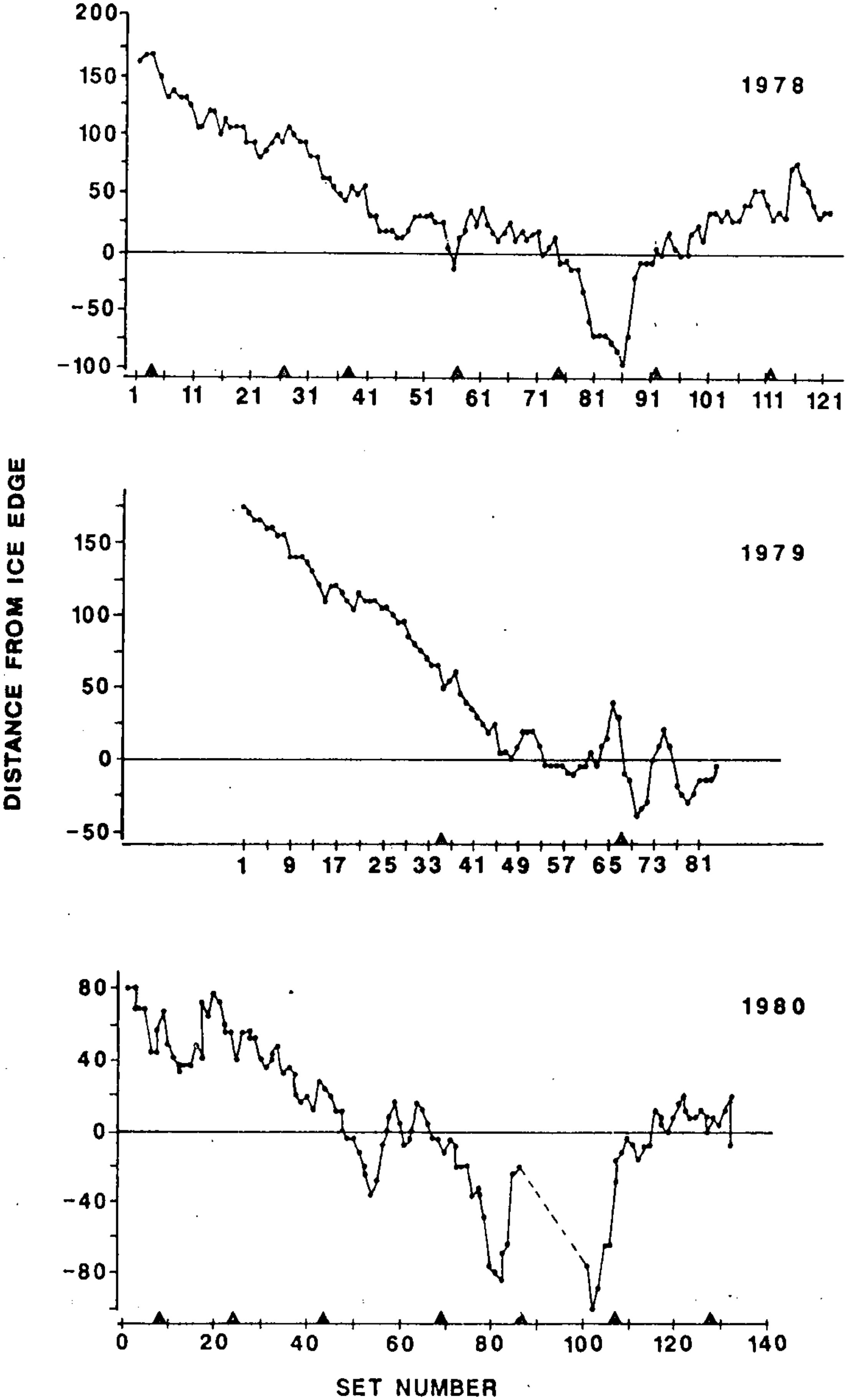


Figure 7: Distance separating each tow from groundfish surveys in the Gulf of St-Lawrence to the ice edge (straight line at zero). Triangles on the abscise represent the transition point at wich a new ice map was used to calculate the distance from the ice edge.

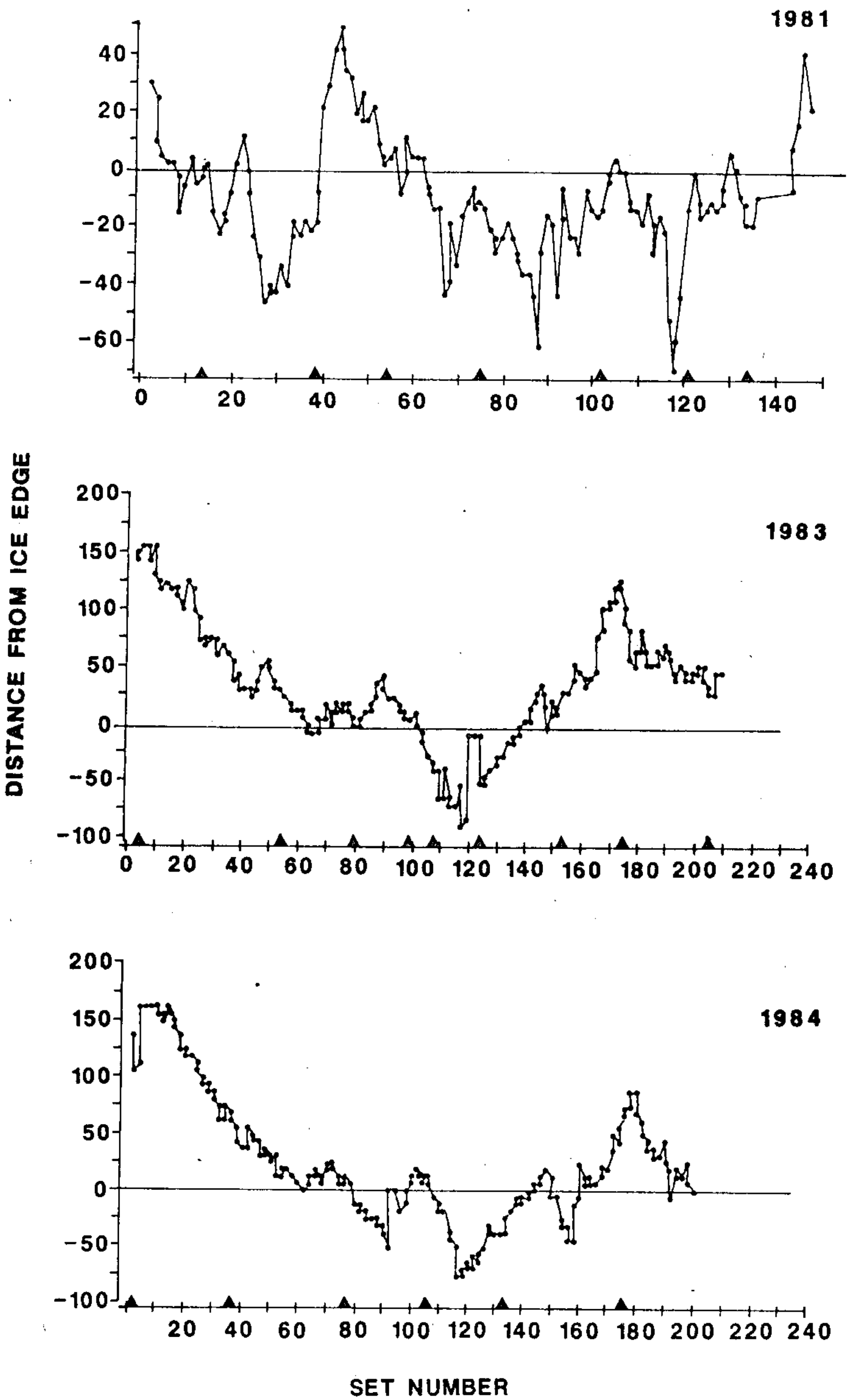


Figure 7 (Continued).

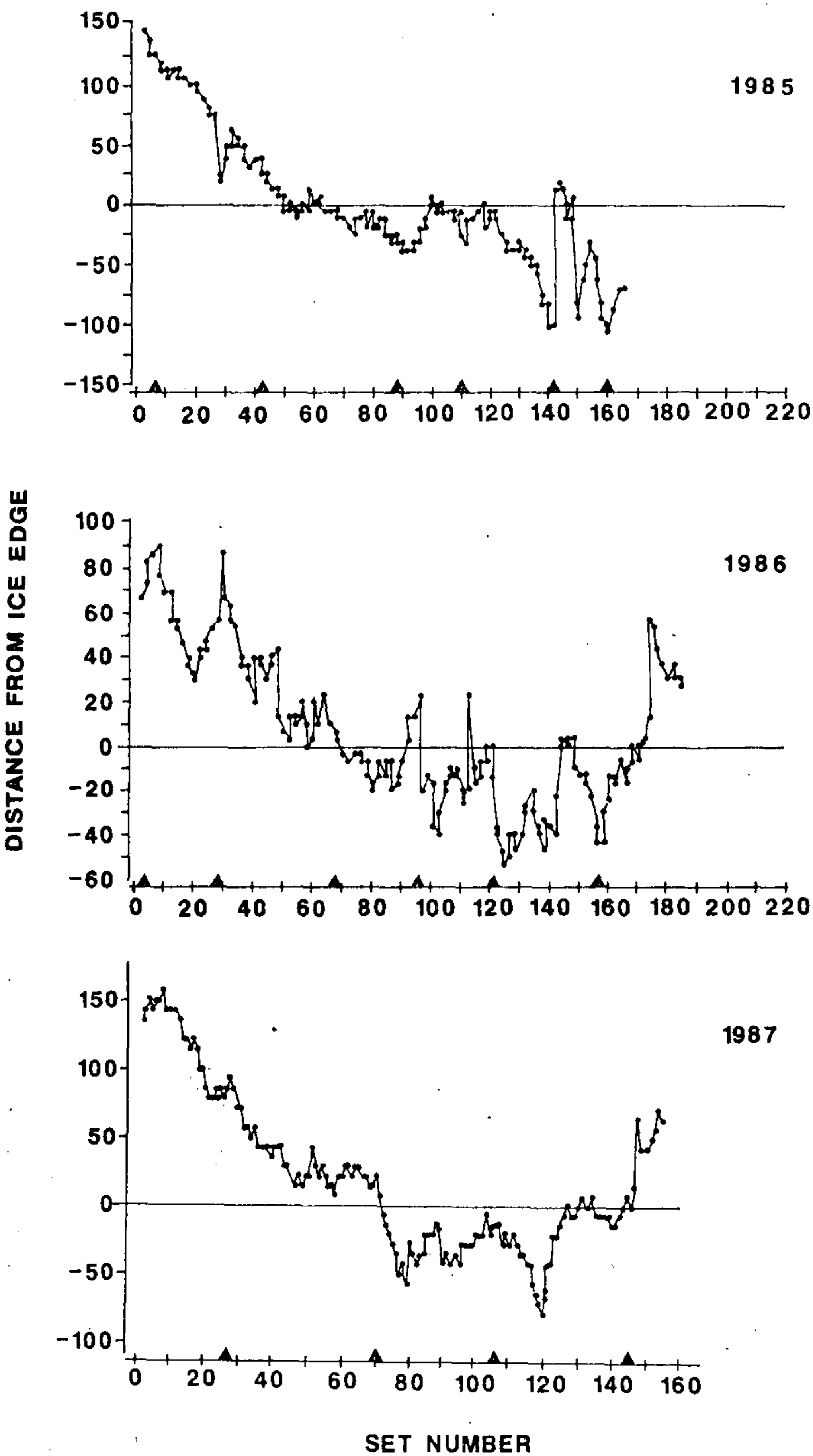
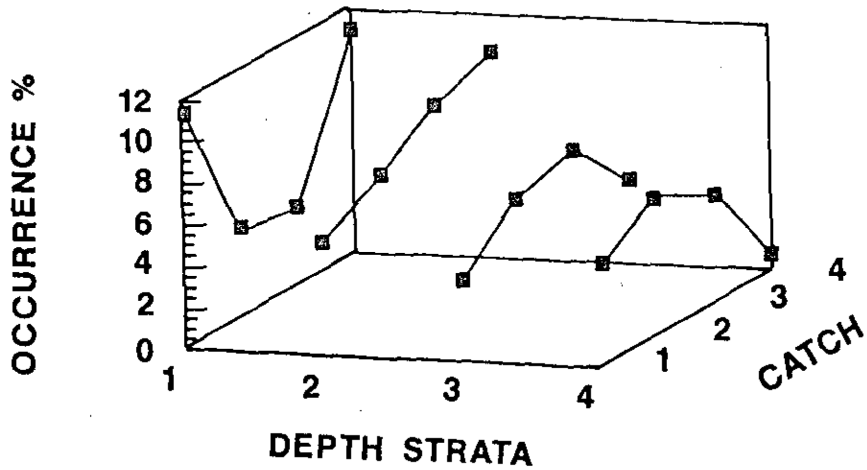
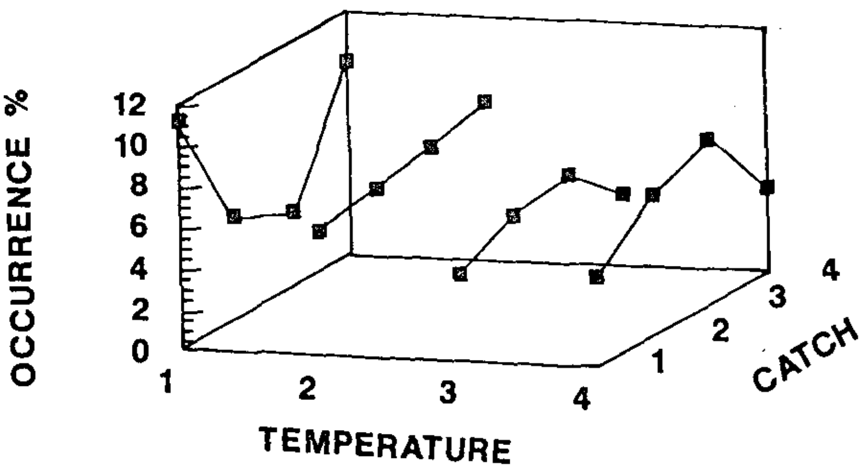


Figure 7 (Continued).

A)



B)



C)

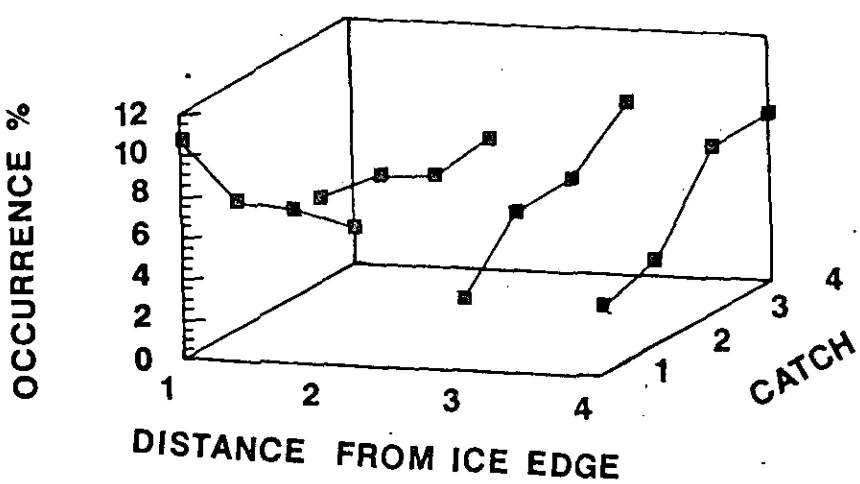


Figure 8: Occurrence (%), of catch categories according to depth (A), temperature (B), and distance from ice edge (C). See Table 1 for a description of modalities.

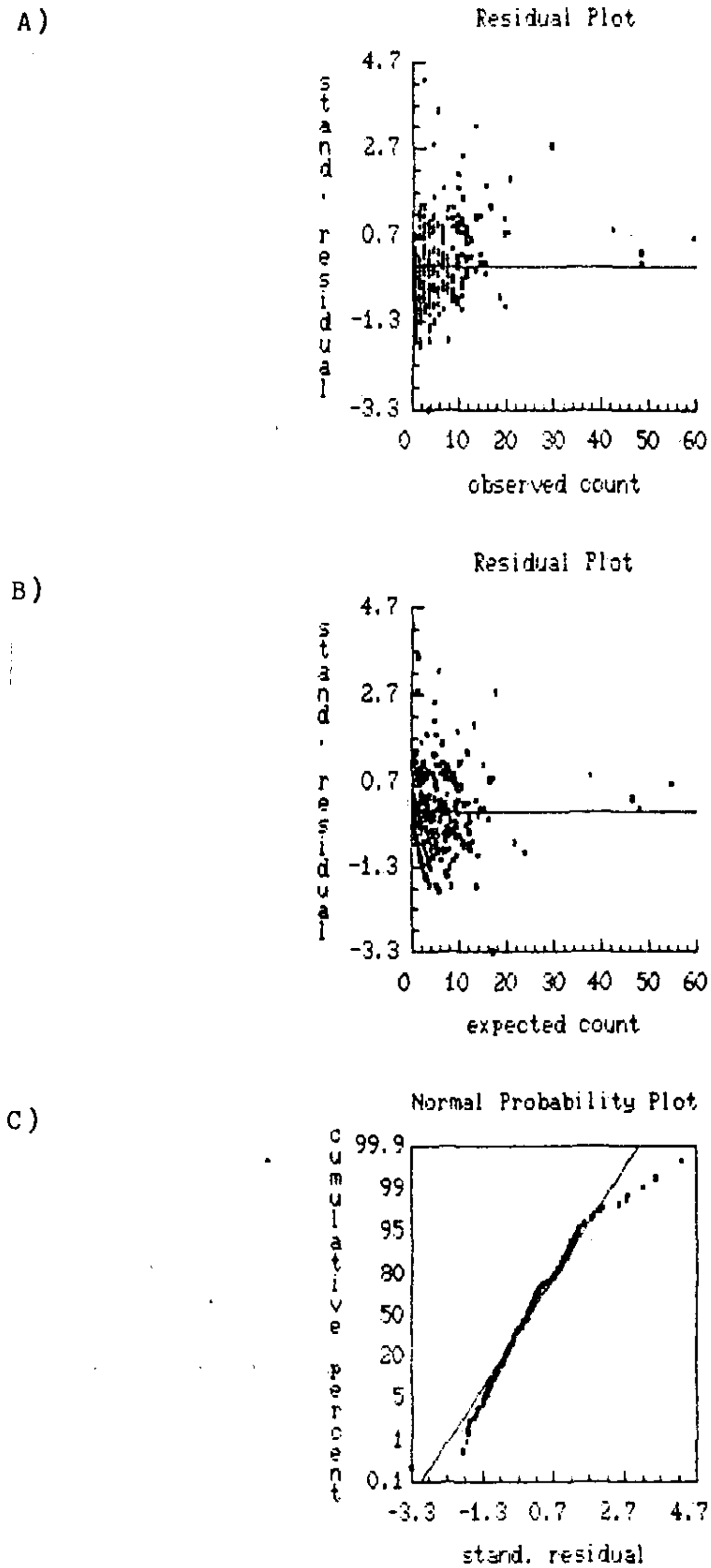


Figure 9: Plots of standardized residuals obtained from the log-linear model [WDZ], [TZ] against the observed count (A), the expected count (B) and the normal probability plot of the standardized residuals (C).

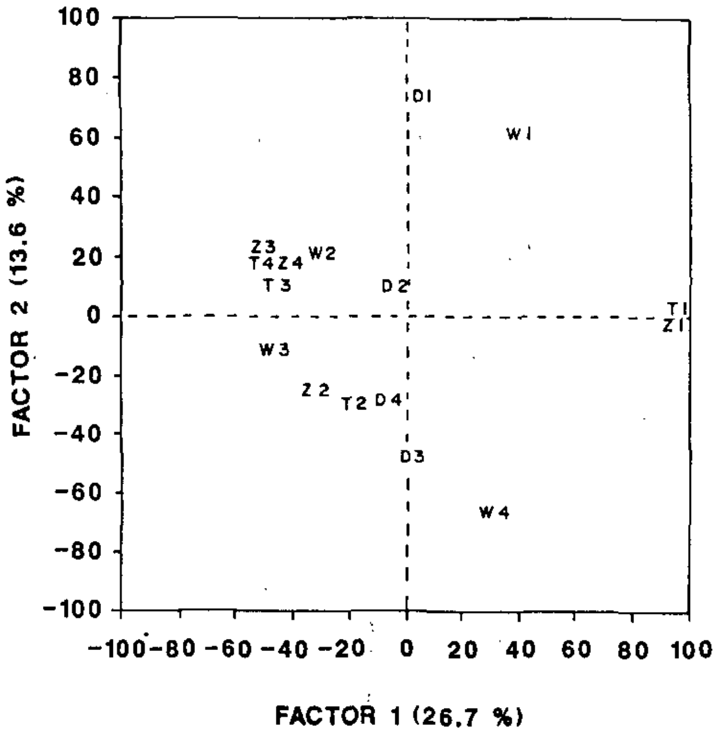


Figure 10: Projection of the first and second factors from the correspondence analysis. Percentage of the explained variance from each axis are in brackets. See Table 4 for a description of the symbols used.

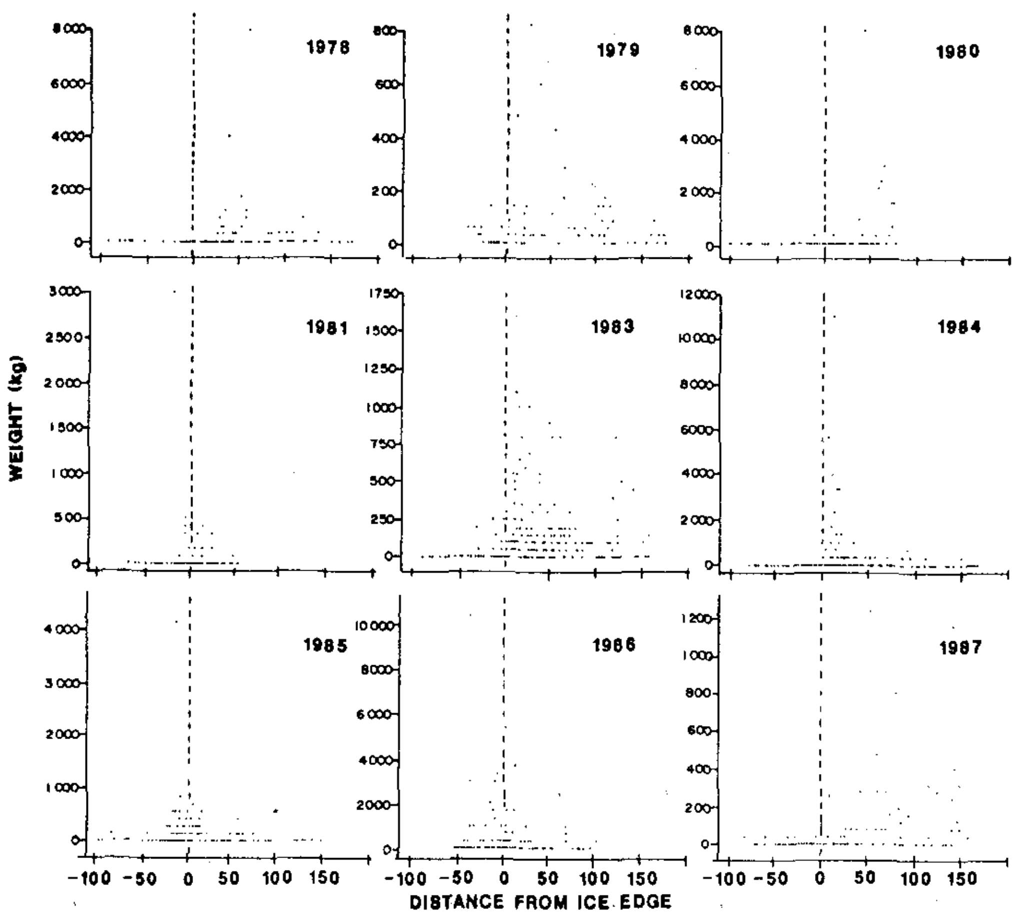


Figure 11: Catch (kg) of cod from winter groundfish surveys relative to the ice edge (dotted line at zero). One point may represent more than one set.

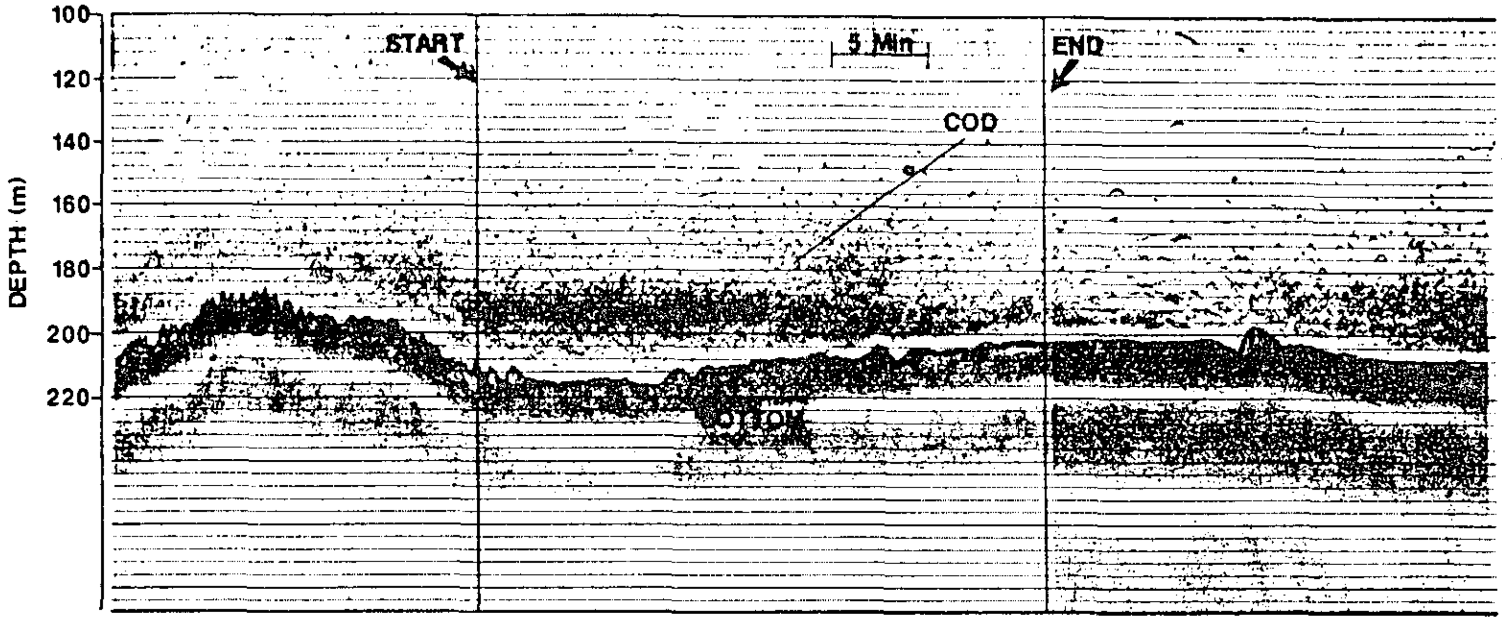


Figure 12: Echo sounding trace of the largest catch (10,985 kg/30 min.) observed in the 9 year winter surveys in the Gulf of St. Lawrence.

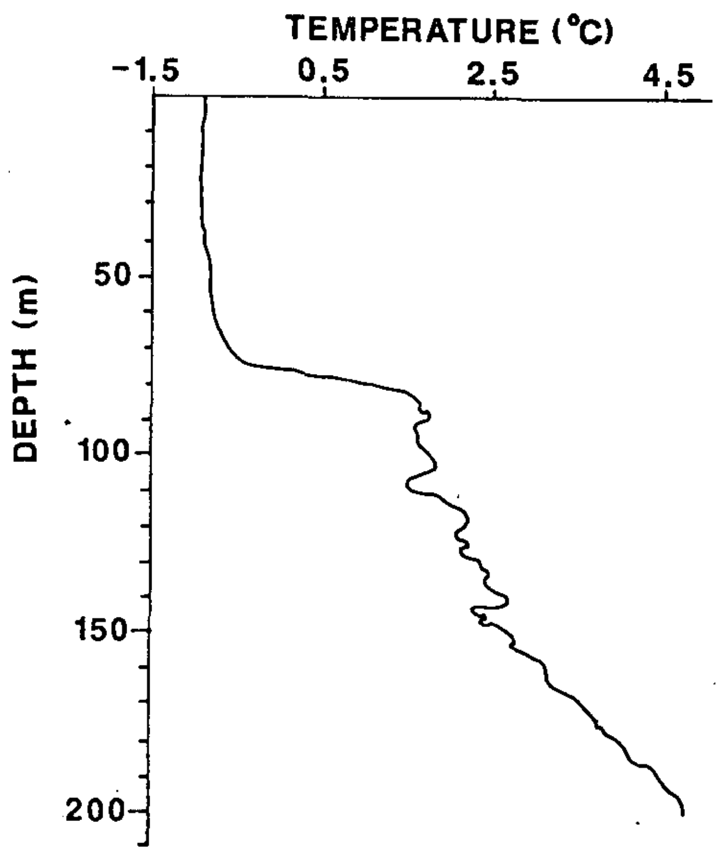


Figure 13: Temperature profile of the largest catch observed in the 9 year winter surveys in the Gulf of St. Lawrence.