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The Distribution of Cod (Gadus morhua L.) in Relation to Oxygen Level and Temperature in the Northern Gulf of St. Lawrence

by

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ABSTRACT

Bottom temperature and oxygen levels were measured in the Gulf of St. Lawrence during a trawl survey in August and September 1991, within a random stratified sampling scheme. Cumulative relative frequencies of temperature and of oxygen level were computed with consideration of the sampling scheme. Cumulative relative frequencies of temperature × cod abundance and of oxygen × cod abundance were also computed with consideration of the sampling scheme. Comparisons of the cumulative relative frequencies of bottom conditions and bottom conditions × fish abundance suggest that: 1) cod select intermediate values within the temperature range of the area sampled; 2) cod tend to avoid areas where the oxygen level is below 3-4 mg/l.

RÉSUMÉ

La température et la teneur en oxygène dissous ont été mesurées dans les eaux de fond du Golfe du Saint-Laurent durant une mission d'évaluation des poissons de fond en août et septembre 1991, dans un plan d'échantillonnage aléatoire stratifié. Les fréquences relatives cumulées de la température et de l'oxygène ont été calculées en fonction du plan d'échantillonnage. Les fréquences relatives cumulées de la température × abondance de morue et de l'oxygène × abondence de morue, ont aussi été calculées en fonction du plan d'échantillonnage. La comparaison des fréquences relatives cumulées des propriétés hydrographiques avec celles des propriétés hydrographiques × abondance de morue, indique que: 1) la morue favorise les températures intermédiaires parmi celles disponibles dans la zone étudiée; et 2) la morue évite les eaux où la teneur en oxygène dissous est inférieur à 3-4 mg/l.

INTRODUCTION

Variations of water temperature provide a thermal landscape which may guide fish in their movements (Smith 1985). For Atlantic cod (*Gadus morhua* L.), it has long been believed that "...the movements [of cod] are the results of many influences, [one of which is] the direct influence of temperature upon the fish themselves..." (Goode 1884). Recent studies have provided empirical evidence linking the displacements of cod with specific thermal regimes at various geographical scales (e.g. Rose and Leggett (1988), Smith et al. (1991)). But temperature is only one of the many natural stimuli which might influence the movements of fish. Another naturally varying stimulus of the aquatic environment which may influence the movements of fish, is the level of dissolved oxygen (Smith 1985). In freshwater and estuarine habitats, where oxygen levels may vary considerably, it is known that the advance of certain species is blocked by poorly oxygenated waters (e.g. Moller and Schloz 1991). In the ocean, the effect of oxygen gradients on the movements of fish has not yet been investigated, even though the question has been raised by Dunbar *et al.*(1980) more than a decade ago.

Atlantic cod is known to exhibit physiological responses to low oxygen levels. Sundness (1957) studied the transportation of live cod in well-boats. He reported that an oxygen concentration of 3.5 mg/l (at 8 °C) was a threshold below which the normal metabolic rate of the fish would decline rapidly. Saunders (1963) performed further analysis on cod respiration. He suggested that at oxygen levels below 3 mg/l, cod would be stressed as the rate of oxygen consumption would not keep pace with the increased metabolic cost of irrigation of the gills. More recently, Claireaux and Dutil (1992) studied the respiratory performance of cod in hypoxic conditions. They noticed strong hyperventilatory responses in mild hypoxic conditions with P_{WO2}=8 kPa ($\approx$ 4 mg/l). They suggested that dissolved oxygen may be a factor influencing movements of cod in the wild.

All of the above threshold values of oxygen concentrations for cod were found in experimental conditions. In the wild, similar and even lower, values of dissolved oxygen are observed. Dunbar *et al.* (1980), in their description of the biogeographic structure of the Gulf of St. Lawrence, reported oxygen concentrations below 4 mg/l at several locations, with minimal values as low as 1.5 mg/l. In this study, the distribution of Atlantic cod in the Gulf of St. Lawrence is studied in relation to bottom temperature and oxygen concentration. The objective of the study was to determine whether both environmental factors have an effect on the distribution of cod.

METHODS

Validation of Oxygen Measurements

From May 15 to May 28, 1991, oceanographic measurements were made at station "C" at the mouth of Bay St. Georges (Newfoundland) (Fig. 1). Vertical profiles of temperature, salinity, and dissolved oxygen, were taken with a salinity/temperature/depth (STD) probe, calibrated by the supplier (Applied Microsystems Ltd., Sidney, B.C., Canada) before the cruise. The probe also included a dissolved oxygen sensor with platinum/lead electrodes (supplied by Royce Instrumentation Corporation, New Orleans, LA, U.S.A.) and thermally compensated with the thermistor of the STD probe. The $STDO_2$ probe was stabilized at the surface for 1 minute, and lowered at 1-2 m/s. Measurements were made every meter, and the downcast values were retained for the analysis. Water samples were collected along the downcast with 1,5 l Niskin bottles mounted on a rosette and triggered at precise depths. Levels of dissolved oxygen in water samples collected were measured with a modified Winkler titration where liberated iodine is titrated spectrophotometrically (see Parsons et al. 1984 for a discussion of the method). The spectrophotometer had itself been calibrated with standard thiosulfate Winkler titration (as per Levy *et al.* 1977). The spectrophotometer automatically transformed iodine absorbance values into oxygen, with a constant of 16.1 as the ratio between oxygen levels and absorbance values, at 287.5 nm through a 1 cm quartz cell. A split-beam photometer was used, with an aliquot of the water sample as background. Oxygen levels measured with the probe were regressed against those measured spectrophotometrically.

Cod Distribution and Bottom Conditions

From August 15 to September 10, 1991, 261 stations were occupied, from the mouth to the head of the Gulf of St. Lawrence. At each station, a standard trawl set was carried out. Those stations were part of a regular annual survey within a random stratified sampling grid (see Schwab and Hurtubise (1987) for a description of the stratification scheme, and Gagnon (1991) for the allocation method). The net was a URI 81/114 trawl with 20 mm mesh in the codend, and towed for 20 minutes on the bottom. A second salinity/temperature/depth/oxygen probe was attached to the mouth of the trawl to record bottom temperature and dissolved oxygen level. The total capture of cod at each station was measured to the nearest kg. The cumulative relative frequency plots for temperature and dissolved oxygen levels, as well as the cumulative relative frequency of cod × temperature and cod × dissolved oxygen level, were calculated with consideration of the random-stratified sampling scheme (R.I. Perry, and S.J. Smith, pers. comm.). For the cumulative relative frequency of temperature (or oxygen), the formula used was:

$$F(t)=\frac{\sum_{h=1}^{L}\sum_{i=1}^{n_h}\frac{N_h}{n_h}\Delta(t-Y_{ih})}{\sum_{h=1}^{L}\sum_{i=1}^{n_h}\frac{N_h}{n_h}}, \qquad (1)$$

where

$$\Delta(t-Y_{ih})=\begin{cases}1 & when\,(t-Y_{ih})\geq 0\\ 0 & otherwise,\end{cases}$$

with L = number of strata, N_h = the number of trawl units in the h_{th} stratum (h=1,..., L), n_h=the number of trawl units effectively sampled in stratum h (i=1,...,n_h), Y_{ih}= temperature (or oxygen level) at the i^{th} set in the h^{th} stratum, with t ranging from -2°C to +7°C (with 0.1°C increments) for temperature, and from 1 mg/l to 12 mg/l (with 0.1 mg/l increments) for dissolved oxygen. For the cumulative relative frequency of temperature (or oxygen level) × cod, the formula was:

$$F(t)=\frac{\sum_{h=1}^{L}\sum_{i=1}^{n_h}\frac{N_h}{n_h}X_{ih}\Delta(t-Y_{ih})}{\sum_{h=1}^{L}\sum_{i=1}^{n_h}\frac{N_h}{n_h}X_{ih}}, \qquad (2)$$

where X_{ih} is the catch of cod (in kg) in the i^{th} set of the h^{th} stratum, and with other parameters as above.

RESULTS

Validation of Oxygen Measurements

For oxygen values ranging from 1.07 mg/l to 13.24 mg/l (Table 1), the linear regression between absorbance values and oxygen levels determined with Winkler titrations, had a null intercept, and a slope of 16.1 (s.e.= 0.59). As specified by Parsons *et al.* (1984), the expected slope should be close to 16. The spectrophotometric determination was thus proven accurate, and subsequent absorbance values were transformed into oxygen levels (in mg/l) with the constant 16.1. A total of 275 water samples were titrated spectrophotometrically for dissolved oxygen, and the results . were compared to corresponding dissolved oxygen sensor measurements. A scatter was observed for values above 10 mg/l, which was attributed to the known erratic nature of the spectrophotometric method at levels above 10 mg/l (Parsons *et al.* 1984). For each of the two O_2 probes used, the linear regression of measured oxygen levels regressed against those measured spectrophotometrically, had a null intercept and a slope of 1, with coefficients of determination of 0.69 and 0.87, respectively.

Water Properties and Cod Distribution

Temperature, salinity, and oxygen measured at station "C" in the vicinity of Cabot Strait in May 1991, varied considerably on the vertical axis (Fig. 2). Temperature was 1.6 °C at the surface, dropped to -1.4°C at 70 m, and then increased progressively to stabilize at 5.2°C near 270 m. Salinity was 31.5 ppt near the surface, and increased rapidly to 34.5 ppt near 270 m, from where it increased slowly to 34.7 at 490 m. Oxygen levels were above 9.5 mg/l in the top 100 m (>80% saturation), and decreased to a minimum of 3.5 mg/l (34% saturation) near 270 m, where σ_t was 27.2. In the deep layer, oxygen level raised to, and stabilized around 4.2 mg/l (41% saturation). Bottom temperature and oxygen levels measured over the Gulf in August/September 1991 also varied in the horizontal plane. Bottom temperature (Fig. 3a) ranged from -1.7°C to 5.3°C according to position and bathymetry. Bottom oxygen level (Fig. 3b) was 4-5 mg/l in Cabot Strait, as in the previous month of May (as seen from Fig. 2); levels were high in the Strait of Belle-Isle (up to 10 mg/l), and as low as 1.7 mg/l off the northern coast of the Gaspé Peninsula.

The frequency plots pertaining to temperature (Fig. 4a) showed that up to 1.9°C, the frequency of temperature alone cumulated to 17.2%, i.e. faster than the frequency of temperature × cod, at 13.5%. However, after 1.9°C, the situation was reversed. From 2°C to 4°C, the frequency of temperature × cod went from 19.3% to 97.8%, while the frequency of temperature alone went from 17.8% to 42.2%. The frequency plots pertaining to oxygen (Fig. 4b) showed that at a level of 3.4 mg/l, 24.3% of the frequency of oxygen alone was cumulated, while only 2.6% of the frequency of oxygen × cod was cumulated. After this level, both frequencies of oxygen alone and of oxygen × cod, augmented in parallel, until they necessarily joined (97% for each) at 10 mg O_2/l.

DISCUSSION

Vertical variations of water temperature and salinity recorded in May Cabot Strait revealed the known three layered structure of the Gulf of St. Lawrence (as reviewed by Koutitonski and Bugden 1991). Vernal warming had begun in the top layer, while the intermediate cold layer rested on deep oceanic water. The vertical oxygen minimum was located at 270 m where σ_t was 27.2; similarly, d'Anglejan and Dunbar (1968) had observed that oxygen minimum values occured in waters with σ_t between 27.03 and 27.56. The decrease on the horizontal axis of the bottom oxygen level is also consistent with the observations of d'Anglejan and Dunbar (1968). They noted that the decrease of oxygen levels toward the western (estuary) and northern

(Strait of Belle-Isle) ends (Fig. 1) of the Gulf of St. Lawrence is the result of the deep waters contributed through Cabot Strait, circulating slowly enough to be affected by local oxydative processes.

When frequencies of temperature and temperature × cod are compared, it is seen that the latter does not increase as fast as the former in cold water, and also that it levels off more rapidly in warmer water. This observation supports the results of previous studies where cod have shown a preference for intermediate water temperatures in the range available in their habitat (e.g Jean 1954; Rose and Leggett 1988; Smith et al. 1991). When frequencies of oxygen and oxygen × cod are compared, it is seen that a certain level of oxygen (3.4 mg/l) must be passed before oxygen × cod frequency begins to cumulate, after which both frequencies augment in parallel until joining. This is consistent with the hypothesis that cod would avoid areas with oxygen concentrations below a threshold, and would have equal preference for any value above that threshold. The threshold of 3-4 mg/l found in this field study is consistent with the known physiological capacities of cod in the laboratory.

It must be pointed out that the use of a probe to measure oxygen levels, albeit practical during a fast-paced groundfish survey, is not ideal to determine the precise level of oxygen blocking the advance of the fish. In this study, the regressions used to validate the methods all had the expected theoretical slopes and intercepts. However, a scatter was evident, as examplified by the relatively low coefficients of determination. On the average, our measurements of oxygen levels are reliable, but precise Winkler titrations will be needed to measure the exact levels of oxygen at specific locations, to determine the exact boundaries between sufficiently and insufficiently oxygenated water.

CONCLUSION

The temperature and oxygen level of bottom waters in the Gulf of St. Lawrence vary considerably. The environmental landscape provided by both may set the extent of the distribution of cod, and interannual variations in the geographic extent of this landscape could cause interannual variations in the distribution of the fish. As described by Bugden (1991), the Gulf of St. Lawrence is a sampler of the waters at the edge of the continental shelf. This water at the edge of the shelf is made up of warm water from the Atlantic, with oxygen levels as low as 3.6 mg/l (Fuglister 1963), and of cold Labrador Sea water with oxygen levels as high as 8 mg/l (Lazier 1973). Decadal fluctuations in the relative proportion of both water masses could result in changes in temperature of 2°C (Bugden 1991), and changes in oxygen level of the order of 1 mg/l, in the water entering the Gulf of St.Lawrence through the Laurentian Channel. Such variability in temperature and oxygen levels could cause variations in the extent of the zones thermally adequate and sufficiently oxygenated for cod inside the Gulf of St. Lawrence. Further, fluctuations or trends in the oxydative mechanisms responsible for the gradual horizontal and vertical depletion of oxygen in water along the direction of transport could also cause variations in the geographic extent of waters suitable for cod.

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Table 1. Absorbance units of colorimetric determinations of liberated iodine (following Parsons *et al.* 1984) and corresponding oxygen levels (in mg/l) determined with Winkler titrations (following Levy *et al.* 1977) on seven samples of seawater.

Sample no.	Absorbance units	Oxygen level (mg/l)
1	0.069	1.07
2	0.065	1.16
3	0.390	6.15
4	0.401	6.06
5	0.447	6.87
6	0.570	9.86
7	0.831	13.24

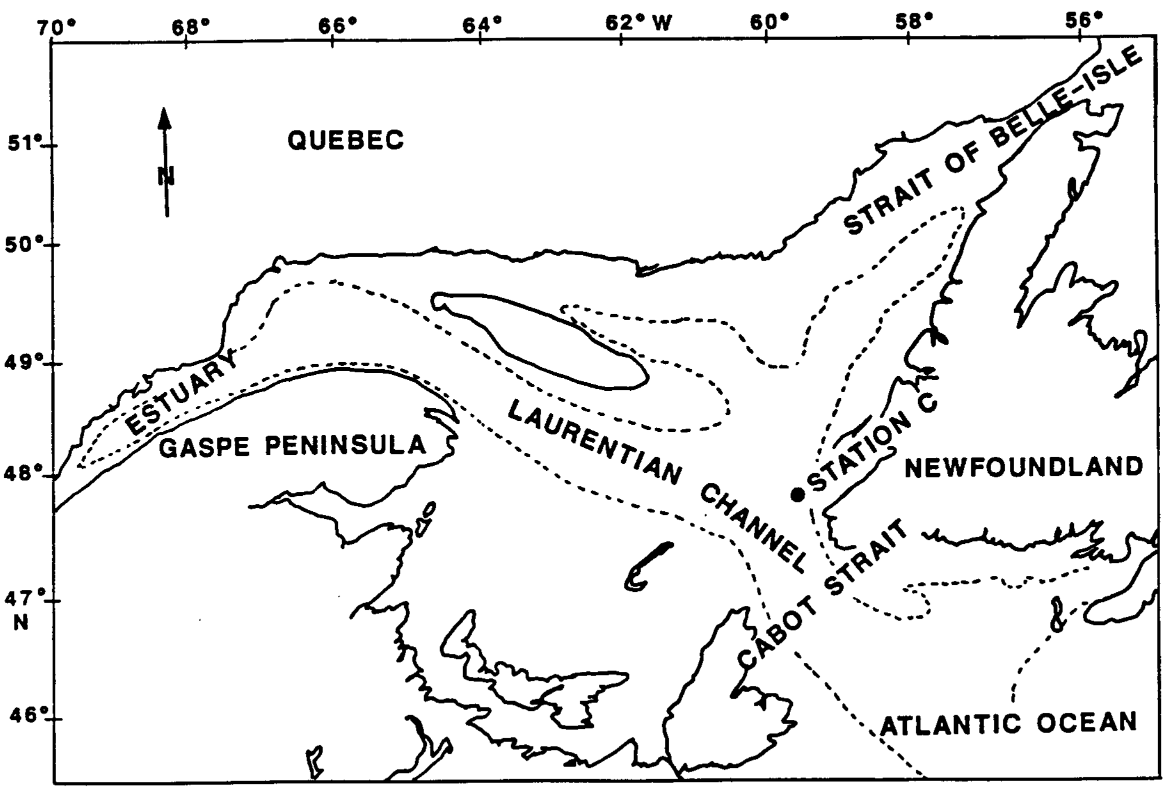


Figure 1. Map of Gulf of St. Lawrence.

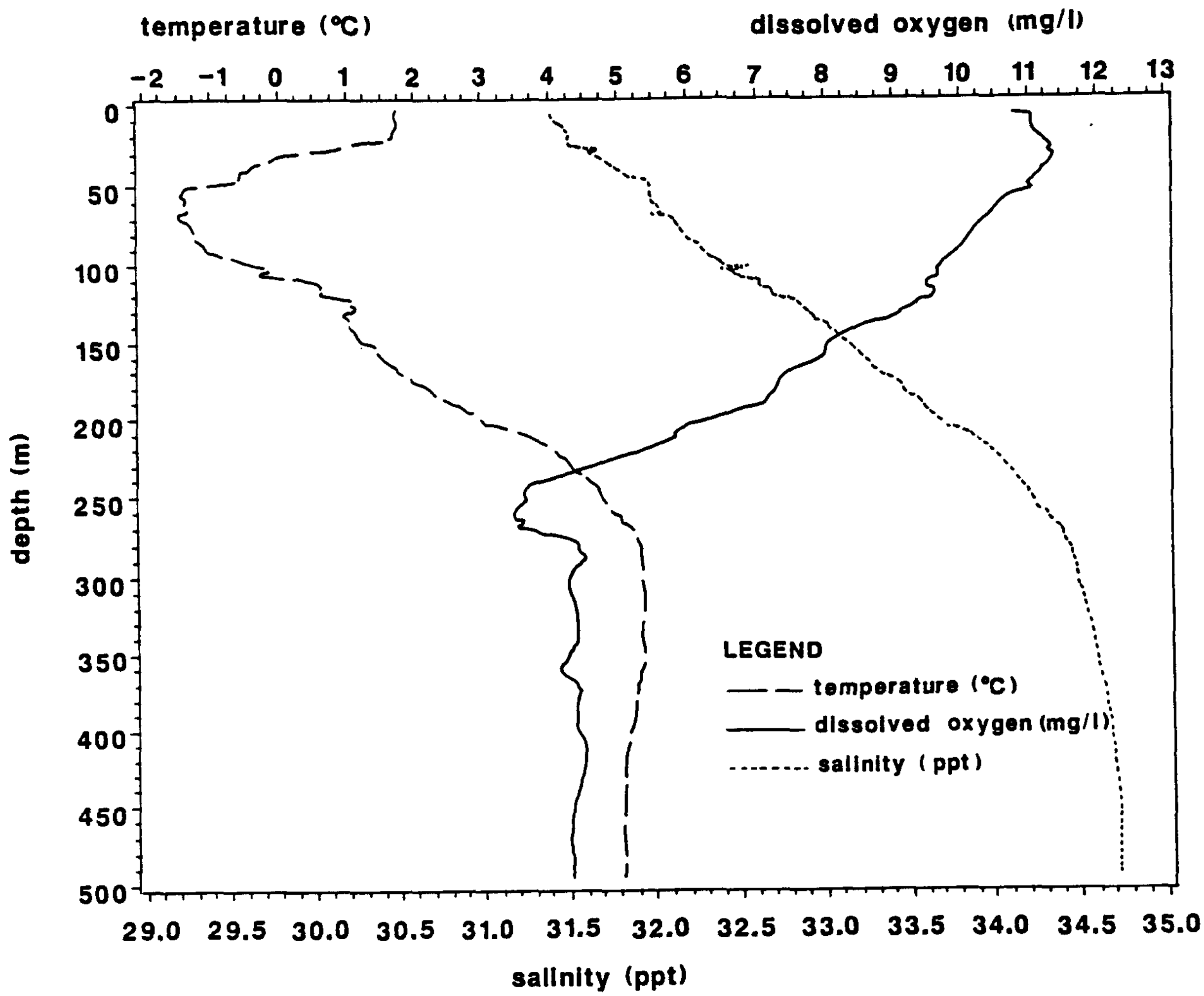


Figure 2. Vertical profiles of temperature, salinity, and dissolved oxygen at station "C".

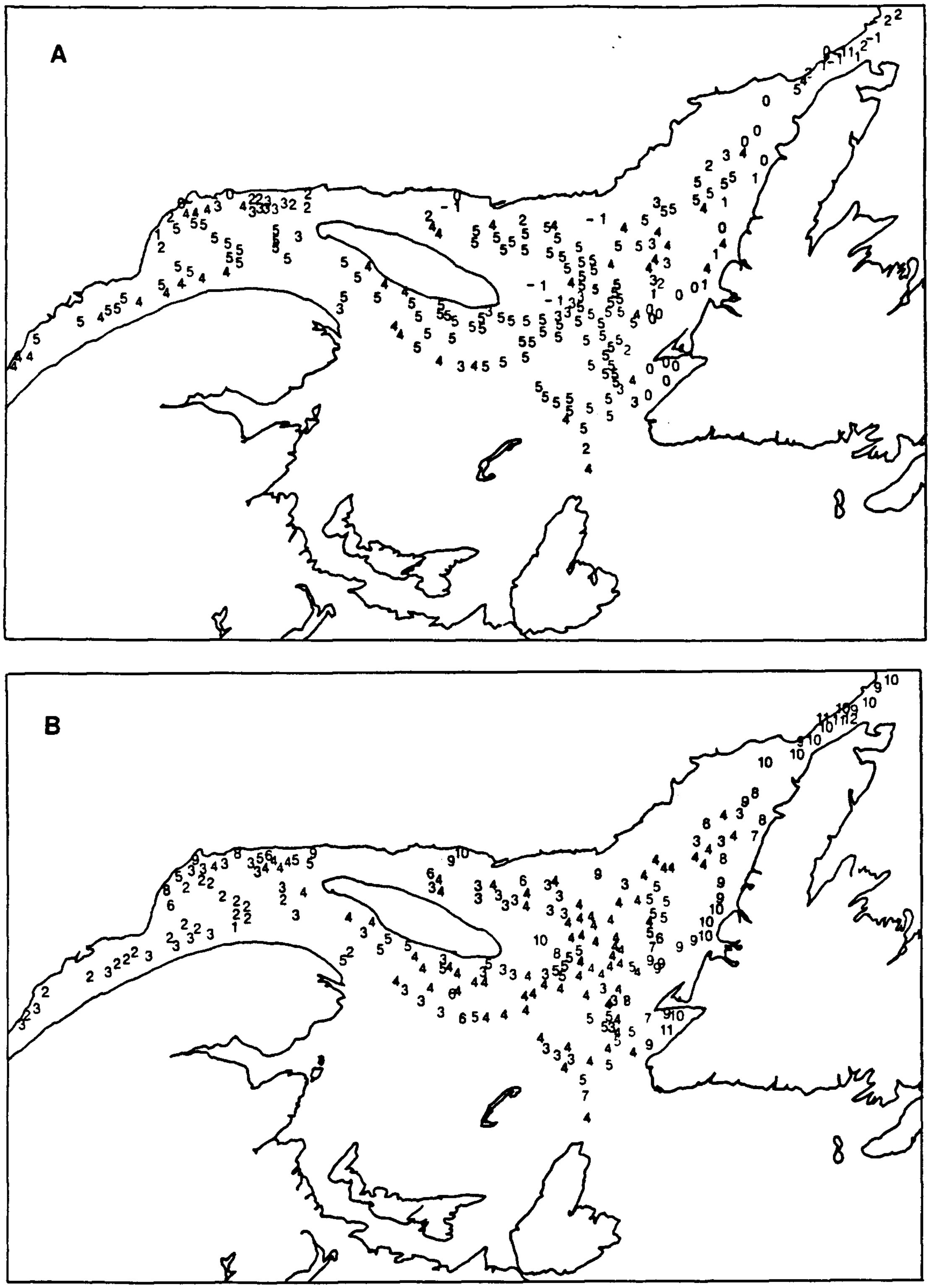
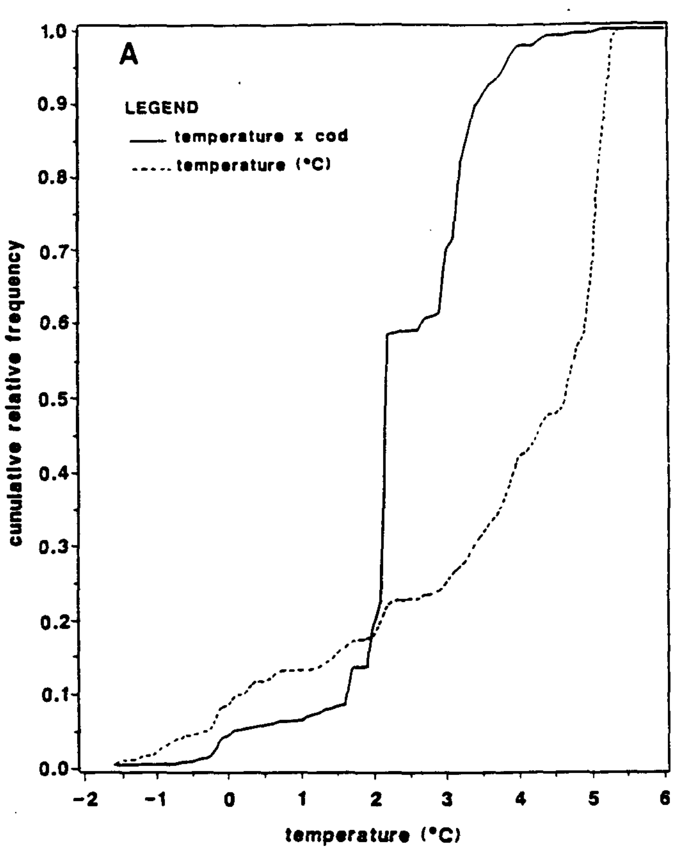


Figure 3. A) Bottom temperature (°C) and B) Bottom oxygen levels (mg/l), recorded at each station during the groundfish survey of August/September 1991 in the Gulf of St. Lawrence. (position of numbers on the map immediately above position of corresponding stations; rounded values).



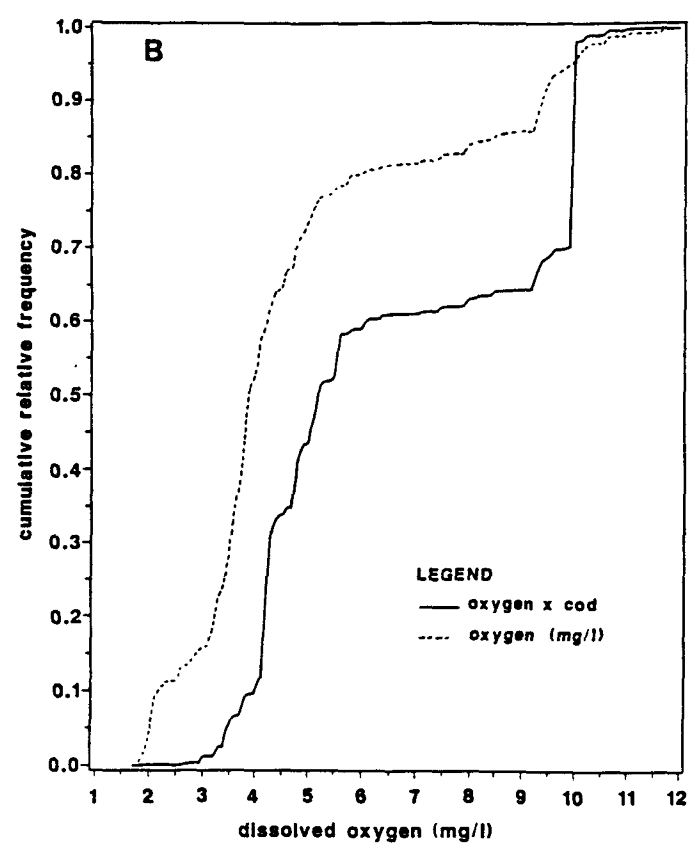


Figure 4. A) Cumulative relative frequencies of temperature and temperature × cod, for all stations over all strata. B) Relative cumulative frequencies of oxygen and oxygen × cod, for all stations over all strata.