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Environmental overview for the southern Gulf of St. Lawrence in 1993.

by

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Abstract

Several indices of ocean climate relevant to the southern Gulf of St. Lawrence were examined including atmospheric temperature, ice coverage, bottom temperature, extent of cold water area and discharge from the St. Lawrence River. Results indicate that the cold atmospheric conditions of recent years (including 1993) have resulted in extended ice coverage and a high area of the southern Gulf with sub-zero temperatures during the September groundfish surveys. Discharge from the St. Lawrence River was near-average in the early nineties but appears to have increased in 1993. The impacts of these conditions are discussed in relation to southern Gulf of St. Lawrence cod distribution, migration and production.

Résumé

On a examiné plusieurs indices du climat marin du sud du Golfe du St. Laurent, y compris, les températures atmosphériques, l'étendue de la glace, les températures au fond, l'étendue des températures froides au fond ainsi que le débit du fleuve St. Laurent. Les températures atmosphériques en dessous de la normale observées au cours des dernières années (incluant 1993) ont donnés lieu à une couverture de glace supérieure à la normale. De plus, la surface du fond ayant des températures en dessous de zéro lors du relevé des poissons de fond effectué en septembre se maintient à un niveau élevé. Le débit du fleuve St. Laurent se situait près de la moyenne au début des années 1990 mais semble avoir augmenté en 1993. Les impacts possibles de ces conditions sur la distribution, migration et la production de la morue du sud du Golfe du St. Laurent sont discutés.

Introduction

It is widely recognized that environmental conditions have an influence on the production and distribution of fish stocks (e.g. Cushing 1982). In the context of stock assessments, it is important to consider abiotic factors that could influence the productivity of the resources. In this review, we examine several indices of climatic conditions that may be relevant to fluctuations of cod and other groundfish stocks in the Gulf of St. Lawrence . We compare the indices for the recent years with their historical values. The variables examined are far from being exhaustive. For example, time series of salinity and other environmental variables were not readily available and were not examined. However, although the mechanisms involved are not clearly understood, the variables examined (temperature, ice, discharge) are thought to impact significantly on the groundfish resources of the Gulf of St. Lawrence. Some of the potential impacts are discussed.

Material and Methods

Atmospheric Conditions

Local environmental conditions may ultimately be linked to global atmospheric circulation. In the North Atlantic, an important feature of atmospheric circulation is the North Atlantic Oscillation. Variation in this circulation pattern has been quantified as the difference in atmospheric pressure between a high-pressure system located in the Azores-Bermuda area and a low-pressure system in the Iceland-Greenland area. The index is calculated by computing the mean difference in atmospheric pressure between Akureyri, Iceland and Ponta Delgada, Azores. High values of the NAO index usually result in an intensification of winter northwesterly winds in the West Atlantic and hence colder conditions, while low values of the index are associated with warmer winter conditions in the west Atlantic.

Indices of temperature conditions in the Gulf of St. Lawrence were also calculated by taking the average of freezing degree-days, melting degree-days and total degree-days (Anon. 1992) from 6 weather stations

(Gaspé, Sept-Îles, Charlo, Summerside, Îles-de-la-Madeleine and Stephenville) in the Gulf of St. Lawrence. These stations have been consistently monitored on a daily basis since at least 1953. Freezing degree-days are defined as the sum of daily temperatures below 0° C and melting degree-days are the sum of those above 0° C. The average over the period 1953 to 1990 was also computed for each index.

Ice Coverage

The extent of the ice coverage in 1993 and 1994 was compared with the median, maximum and minimum coverage previously described by Côté (1989).

Bottom Temperature in September

A groundfish abundance survey has been conducted in the southern Gulf of St. Lawrence each fall since 1971. This survey has used a stratified random design (Fig. 1). Strata 401-403 have only been included in the survey only since 1984, and are not included in the analyses reported here. Survey timing has varied between 31 August - 24 September in 1987 and 09 September - 06 October in 1978. We report here results for bottom temperature from the 1993 survey (10-30 September) and compare these results to those from earlier surveys. Further details on September bottom temperatures in 1971-1992 are given by Swain (1993).

Near-bottom temperature was measured at 175 random stations in the southern Gulf in September 1993 (Fig. 2). We mapped spatial variation in bottom temperature in 1993 using ordinary point kriging. Variograms were fitted using GEOEAS. We checked for anisotropy parallel versus perpendicular to the Laurentian Channel. We found no evidence of anisotropy between these two directions and fitted an omnidirectional variogram using a spherical model (Fig. 3). We estimated bottom temperature on a 41x41 grid using the MATLAB program COKRI (Marcotte 1991). Interpolations used the five nearest samples within the range (150 km). SURFER was used to smooth the estimated grid to a 201x201 grid using its SPLINE SMOOTH function and to draw contour maps.

To compare the 1993 results to those for 1971-1992, we performed a second kriging analysis for each year. These analyses were the same as those described above, except that stations at depths over 155 m were omitted in all years. This was done to avoid bias relative to results for 1984-1988 (when no data were available for these greater depths; see Swain 1993 for details). We used SURFER to estimate for each year the area within the survey region with bottom temperatures below 0°C and 1°C. The survey region used in this analysis omitted strata 415, 425 and 439 (where all stations are deeper than 155 m). Results reported here for 1971-1992 may differ slightly from those reported by Swain (1993), who used the 10 nearest neighbours in interpolations.

We calculated stratified mean bottom temperature for each year from 1971 to 1993 as described by Swain (1993). We omitted strata 415, 425, 426, 437, 438 and 439 (the strata with a high proportion of stations deeper than 155 m) from these calculations. We also calculated the average bottom temperature within strata and depth zones for each year from 1971 to 1993. We compared conditions in 1993 with two baseline periods, 1980-1990 (the baseline used by Swain 1993) and 1971-1990. The baselines for strata 415, 425, 426, 437, 438 and 439 were calculated omitting the 1984-1988 period.

Discharge of the St. Lawrence River

Sutcliffe (1973) found significant correlations between landings of some fisheries resources and an index of the freshwater discharge from the St. Lawrence River. He hypothesized that freshwater discharge promoted nutrient enhancement of the top layer waters through mixing and entrainment processes. The index of river discharge used was the sum of monthly mean discharge from several gauging stations on the St. Lawrence River (Lake Ontario, the Ottawa River and the Saguenay River) and is referred to as RIVSUM. In the sixties, the index accounted for about 70% of the total discharge from the St. Lawrence River in the estuary.

Results

Atmospheric Conditions

As high values of the NAO index are usually related to cold conditions, the data were plotted on a reverse y axis (Fig. 4). The NAO index shows high values during the fifties, early seventies, early eighties and the most recent few years. Low values were seen in the sixties and late seventies. As expected, the mean freezing, melting and total degree-days follow the same general trends as the NAO index, with below average temperatures observed in the early seventies, early to mid-eighties and recently (Fig. 5). Conditions were generally warmest in the late sixties and in the early eighties.

Ice Coverage

Ice coverage was above average in recent years and the winters of 1993 and 1994 continued this trend. In Fig. 6 (from Drinkwater 1994), the position of the ice edge in 1993 is compared to the minimum, median and maximum observed in the period 1962-1987. For many dates examined, the maximum coverage shown in Fig. 6 was established in recent years. Ice coverage in 1993 was generally greater than the median and during some periods was close to the maximum observed.

The 1993/94 season also had extensive ice coverage. As of April 1, 1994, coverage appeared to be as extensive as in the previous year (Fig. 7). After April 1, the ice tended to leave the Gulf of St. Lawrence more rapidly than in some of the previous years.

Bottom Temperature in September

Bottom temperature in September 1993 was lowest in the central region of the Magdalen Shallows and increased shoreward and with depth along the Laurentian Channel (Fig. 8). Bottom temperature was less than 1°C over 44% of the survey area and less than 0°C over 25% of the area. Time series plots of the area within the survey region (excluding strata 415, 425 and 439) with bottom temperatures below 0°C and 1°C are shown in Fig. 9. The estimated area with bottom temperatures below 0°C was exceptionally large in 1993; only 1972 and 1984 had larger areas of subzero bottom temperature. The estimated area with bottom temperatures below 1°C was also relatively large in 1993.

The stratified mean bottom temperature (excluding deep strata) was 1.77°C in 1993. This is the fourth lowest value in the 23-year time series (Fig.10). The mean value was lower than the 1993 value in only 1984, 1990 and 1992.

Time series plots of bottom temperature by depth zone are shown in Fig. 11. At depths less than 60 m, bottom temperature tended to be warm early in the time series (1971 to about 1980) and cold in recent years. The 1993 values conform to this pattern, extending the period of relatively cold water for an additional year. Bottom temperature varied less widely in the deeper depth intervals. In the 60-99 m interval, the 1993 value extends the cold trend of recent years; the 1993 value in this depth zone was the second coldest in the time series. Bottom temperature in 1993 increased toward the longterm average value in the

100-149 m depth zone, was relatively high in the 150-199 m zone and was about average in deeper water (>199 m).

Bottom temperature in 1993 is compared to longterm average values by stratum in Fig. 12. The greatest anomalies were for strata 418 (about -3°C) and 433 (about -5°C). All other anomalies were about 1°C or less. Anomalies were negative in 15 of 24 strata. Anomalies were greater than ±0.5°C in 15 cases; in comparisons with the 1971-1990 baseline, 11 of these were negative and 4 were positive; in comparisons with the 1980-1990 baseline, 9 were negative and 6 were positive.

Bottom temperature in 1993 is compared to longterm average values by depth zone in Fig. 13. Anomalies were negative at depths under 150 m and positive at greater depths. In comparisons with the 1971-1990 baseline, the greatest negative anomaly was in the shallowest depth zone and the greatest positive anomaly was in the 150-199 m zone. Comparisons to a 1980-1990 baseline were similar, except that the greatest negative anomaly was in the 60-99 m zone and temperatures at the greatest depths (>199 m) in 1993 were equal to the baseline average.

Discharge from the St. Lawrence River

The RIVSUM index indicates a progressive decline in river run-off from 1950 to the mid sixties (Fig. 14). Discharge subsequently increased to attain its highest level in the mid-1970's then declined slightly and fluctuated in the early eighties. In 1989 and the early nineties, the index was at the levels of the early 1970's but near the average for the period 1950-1990. Discharge in 1993 increased to previously observed high values of the seventies and eighties.

Discussion

Atmospheric Conditions and Ice Coverage

Atmospheric conditions in the southern Gulf of St. Lawrence can be linked to global atmospheric circulation patterns. The patterns of high NAO index generally corresponds to cold atmospheric temperatures over the Gulf of St. Lawrence. This is particularly apparent in the period of the early seventies and the most recent years. Ice formation and coverage is the result of the cooling in winter. The very cold winter temperatures observed in recent years have resulted in extreme ice coverage such that the ice coverage observed in some areas was the largest ever recorded. As seen in the bottom temperatures in September, this cooling is then reflected in bottom temperatures.

Fréchet (1990) found that concentrations of overwintering cod from the northern Gulf stock are virtually absent within the ice field and are found at the marginal ice zone. The increase in ice coverage seen since 1990 was therefore likely responsible for the extended migration of the southern Gulf stock into NAFO unit area 4Vs in recent years (Hanson et al. 1991). Persistence of the ice within the southern Gulf of St. Lawrence also appears to delay the return migration of cod from the Sydney Bight in the spring. Sinclair and Currie (1994) showed that the spring fishery, which targets this return migration, was delayed by 2-3 weeks in recent years. Thus, the cold conditions and resulting ice coverage and persistence appears to have significantly affected the distribution of cod over winter and the migration timing in the spring in recent years.

Bottom Temperature in September

September bottom temperatures in the southern Gulf in 1993 were relatively cold compared to long-term average values (1971-1990). Most indices of bottom temperature indicated that conditions in 1993 were similar to or slightly more moderate than those in 1992 (Swain 1993). Stratified mean bottom temperature was similar in the two years. Compared to the 1980-1990 baseline, there were fewer negative anomalies (9 vs 18) and more positive anomalies (6 vs 1) by stratum in 1993 than in 1992 (counting anomalies greater than ±0.5°C). Similarly, anomalies were negative in all depth zones in 1992 but only in shallower depth zones (<150 m) in 1993. On the other hand, the estimated area of subzero bottom temperatures was substantially greater in 1993 than in 1992 and the negative anomaly at intermediate depths (60-99 m) was stronger in 1993 than in 1992.

Discharge from the St. Lawrence River

The discharge from the Gulf of St Lawrence was found to be weakly correlated with an index of survival for the southern Gulf of St. Lawrence cod stock (Chouinard and Fréchet, 1994). Therriault and Levasseur (1986) have shown that the primary productivity of the St. Lawrence estuary was influenced by freshwater discharge. Thórdardóttir (1986) described a similar effect in the Icelandic coastal current. Skreslet (1976) found that the survival of juvenile Arcto-Norwegian cod hatched on the north coast of Norway was positively correlated with freshwater discharge on the south-west coast of Norway the previous year. Bugden et al. (1982) previously examined the effect of the Gulf of St. Lawrence freshwater run-off on year-class variability of cod in the Gulf of St. Lawrence and concluded that the effect was weak. The weak relationship described for the southern Gulf of St. Lawrence cod implies that other factors are likely at play and that the freshwater discharge may be simply a proxy for some other condition such as the degree of nutrient mixing or the amount of primary and/or secondary production.

Several predictions of global warming have been prepared for Canada (Kemp 1991). One prediction which relates to freshwater discharge is that the flow from the Great Lakes basin to the St. Lawrence would be reduced by about 20 per cent (Sanderson 1987). This decrease could potentially affect the production in the southern Gulf of St. Lawrence if the discharge from the St. Lawrence is directly implicated in the fish production mechanisms.

Literature Cited

Anon. 1992. Melting and freezing degree-days 1961-1990 normals. Ice Climatology Services, Environment Canada, Ottawa Ont., 105 p.

Bugden, G. L., B. T. Hargrave, M. M. Sinclair, C. L. Tang, J.-C. Therriault, and P.A. Yeats. 1982. Freshwater runoff effects in the marine environment: The Gulf of St. Lawrence example. Canadian Technical Report of Fisheries and Aquatic Sciences 1078: 89 p.

Chouinard, G. A. and A. Fréchet. 1994 . Fluctuations in the cod stocks of the Gulf of St. Lawrence. ICES mar. Sci. Symp., 198:000-000 (In press).

Côté, P.W. 1989. Ice limits on the eastern Canadian seaboard. Environment Canada, Ottawa. 39 p. (Unpublished manuscript)

Cushing, D. H. 1982. Climate and Fisheries. Academic Press (London) xiv + 373 p.Cushing

Drinkwater, K.F. 1994. Overview of environmental conditions in the Northwest Atlantic in 1993. DFO Atlantic Fisheries Res. Doc. 94/11, 52 p.

Fréchet, A. 1990. Catchability variations of cod in the marginal ice zone. Can. J. Fish. Aquat. Sci. 47 (9):1678-1683

Hanson, J. M., G. A. Chouinard, G. A. Nielsen, and L. G. Currie 1991. Stock status of the southern Gulf of St. Lawrence cod stock (4T and 4Vn (Jan.-Apr.)) in 1991. CAFSAC Res. Doc. 91/49, 70 p.

Kemp, D.D. 1991. The greenhouse effect and global warming: a Canadian perspective. Geography 1991:121-130

Marcotte, D. 1991. Cokriging with Matlab. Computers and Geosciences 17: 1265-1280

Sanderson, M. 1987. Implications of climatic change for navigation and power generation in the Great Lakes, CCD 87-03, Ottawa: Atmospheric Environment Service

Sinclair, A. and L. Currie 1994. Timing of commercial fisheries based on the movement of cod into and out of the Gulf of St. Lawrence, 1986-1993. DFO Atlantic Fisheries Res. Doc. 94/47, 18 p.

Skreslet, S. 1976. Influence of freshwater outflow from Norway on recruitment to the stock of Arcto-Norwegian cod p. 233-237 *In* S. Skreslet, R. Leinebo, J.B.L. Mathews and E. Sakshaug [eds.] Freshwater on the sea, The Association of Norwegian Oceanographers, Oslo 1976

Sutcliffe, W. H. Jr. 1973. Correlations between seasonal river discharge and local landings of American lobster (*Homarus americanus*) and Atlantic halibut (*Hypoglossus hipoglossus*) in the Gulf of St. Lawrence. J. Fish. Res. Board Can. 30:856-859

Swain, D. P. 1993. Variation in September near-bottom temperatures in the southern Gulf of St. Lawrence, 1971-1992. DFO Atl. Fish. Res. Doc. 93/48. 17 p.

Therriault, J.-C., and M. Levasseur 1986. Freshwater run-off control of the spatio-temporal distribution of phytoplankton in the Lower St. Lawrence Estuary (Canada) p. 251-260 *In* S. Skeslet.[ed.] The role of freshwater outflow in coastal marine ecosystems. Springer-Verlag, Berlin

Thórdardóttir, T. 1986. Timing and duration of spring blooming south and southwest of Iceland. p. 345-360 *In* S. Skeslet.[ed.] The role of freshwater outflow in coastal marine ecosystems. Springer-Verlag, Berlin

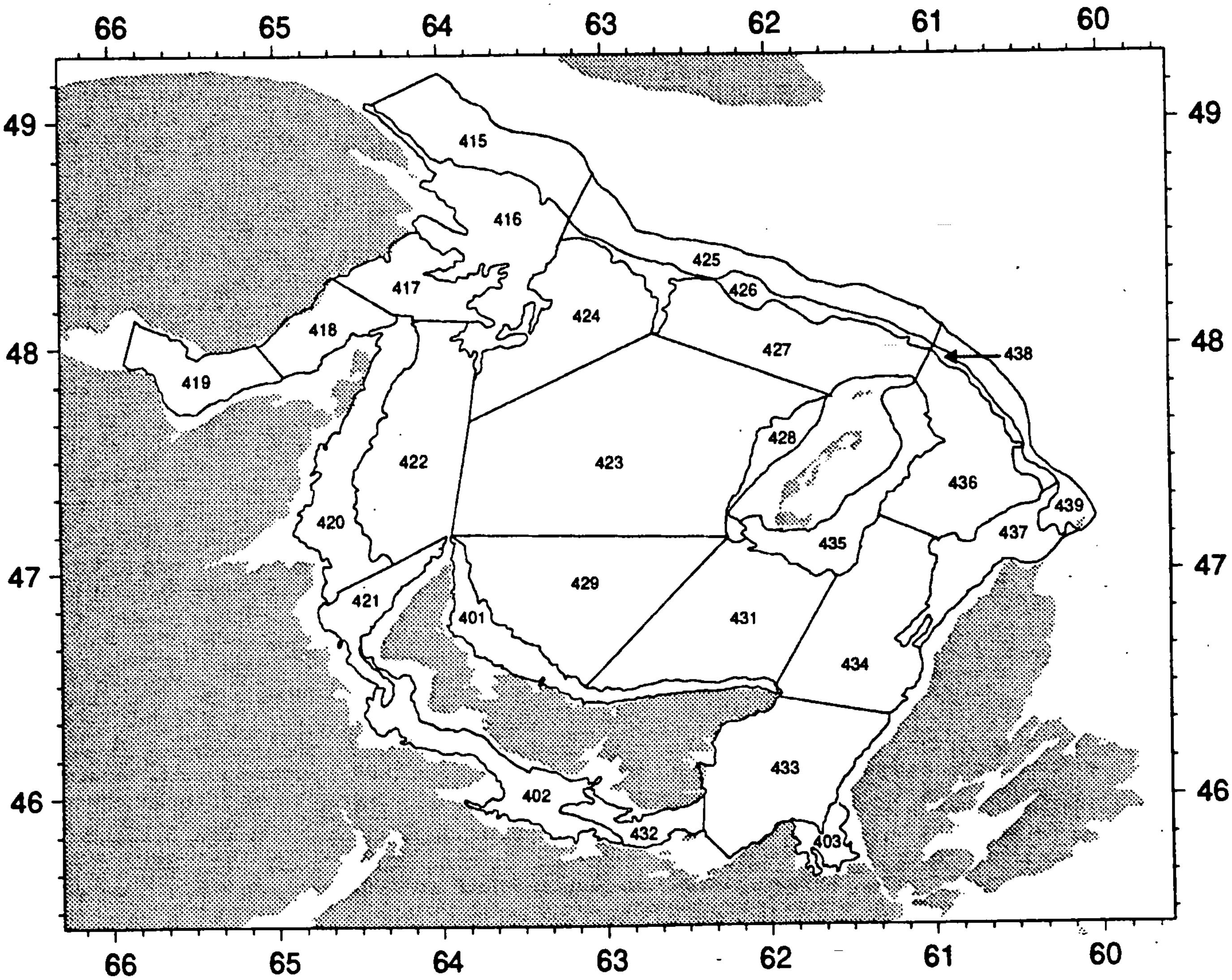

Figure 1. Stratification used in September bottom trawl surveys of the southern Gulf of St. Lawrence.

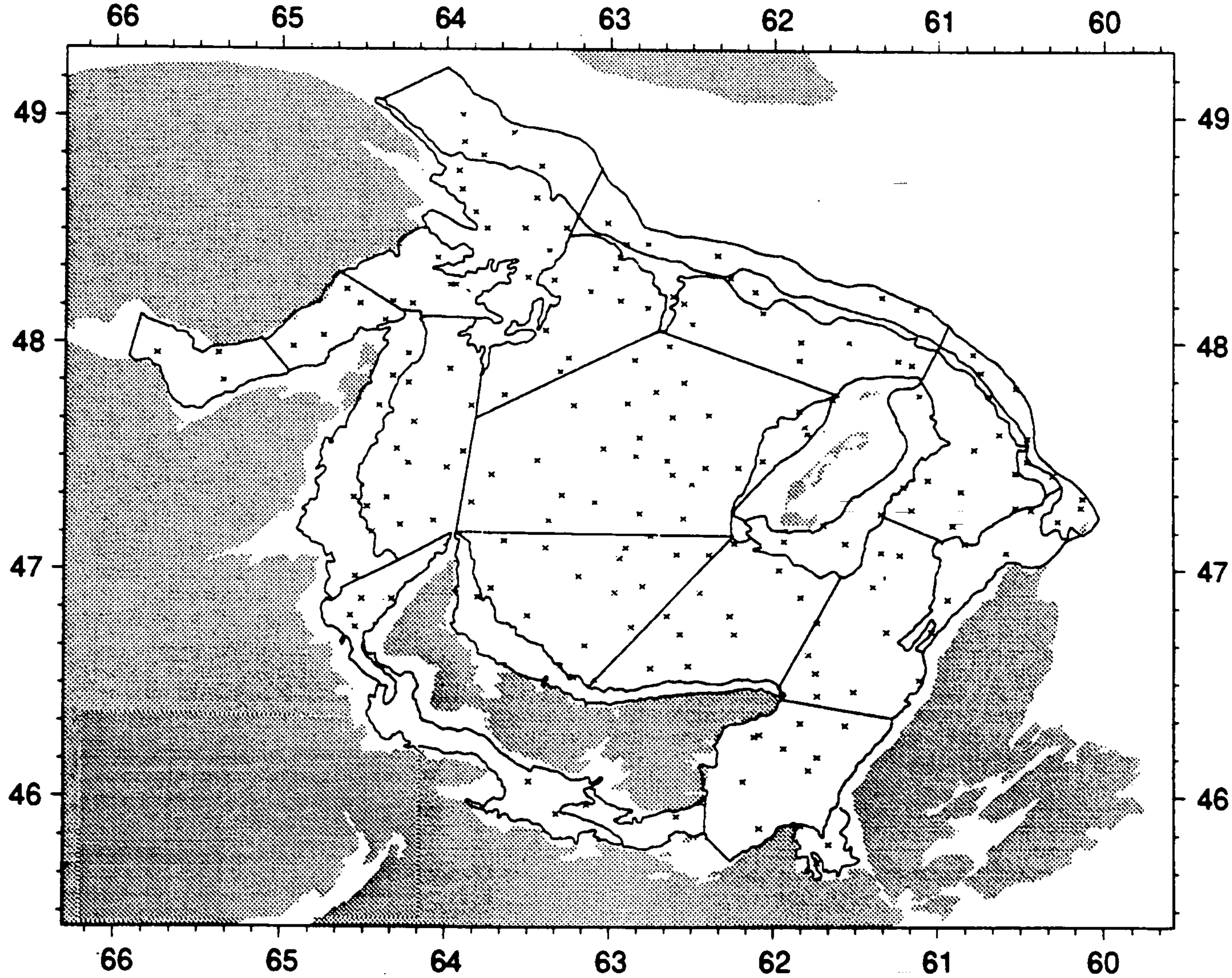

Figure 2. Stations sampled during the September 1993 groundfish abundance survey in the southern Gulf of St.Lawrence.

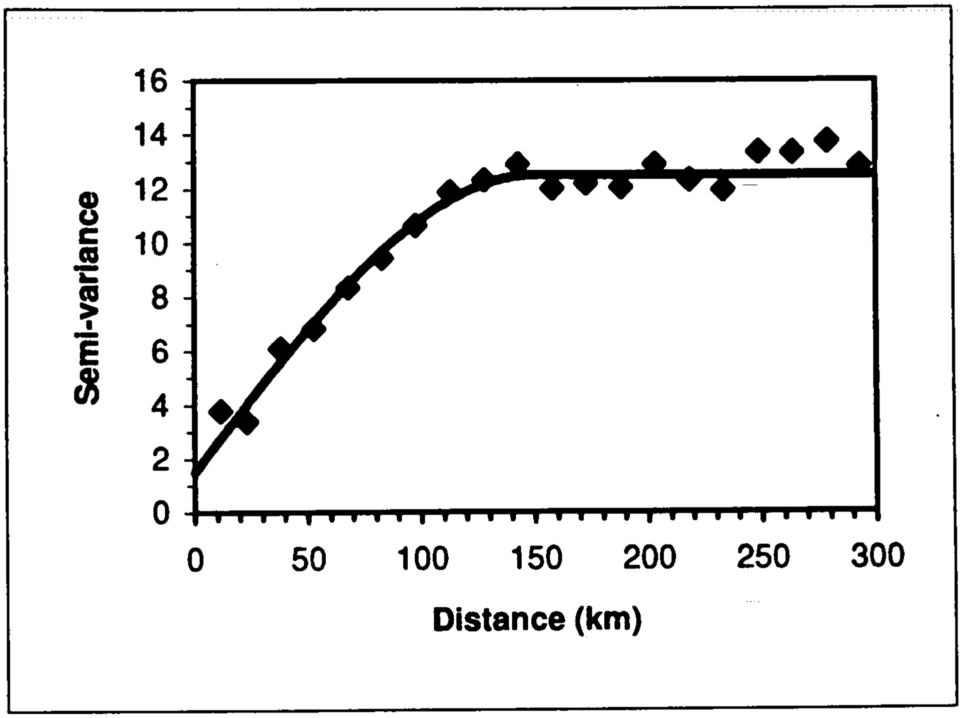

Figure 3. Variogram for bottom temperature in the southern Gulf of St. Lawrence, September 1993

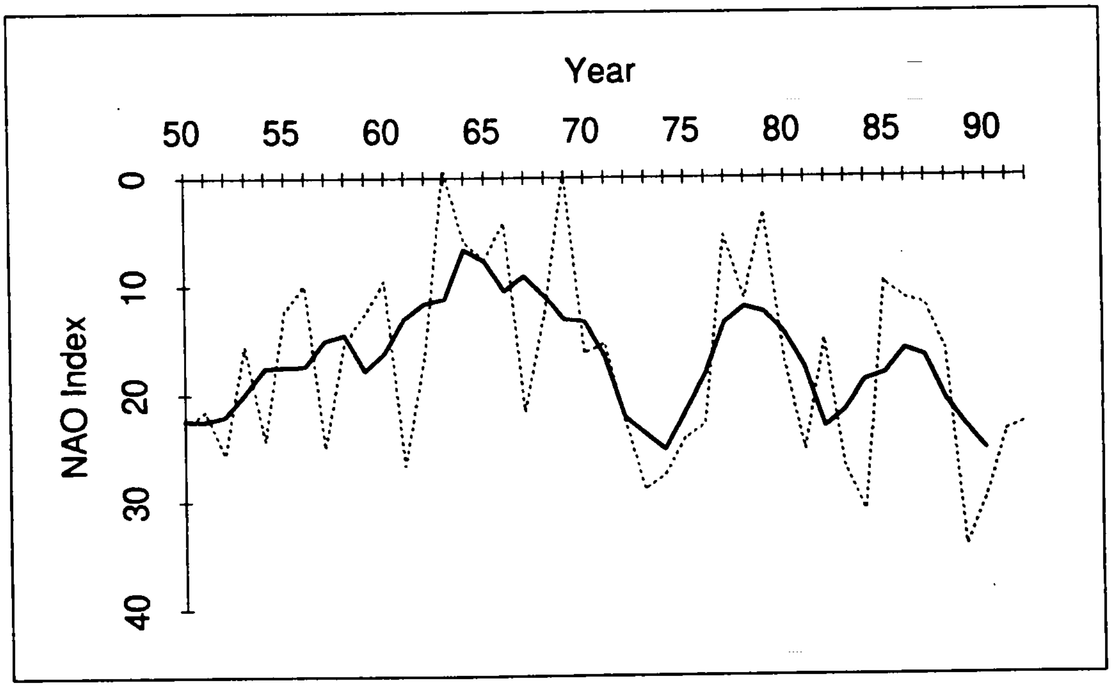

Figure 4. North Atlantic Oscillation (NAO) index for the period 1950-1992 (Solid line is the 5-year running average).

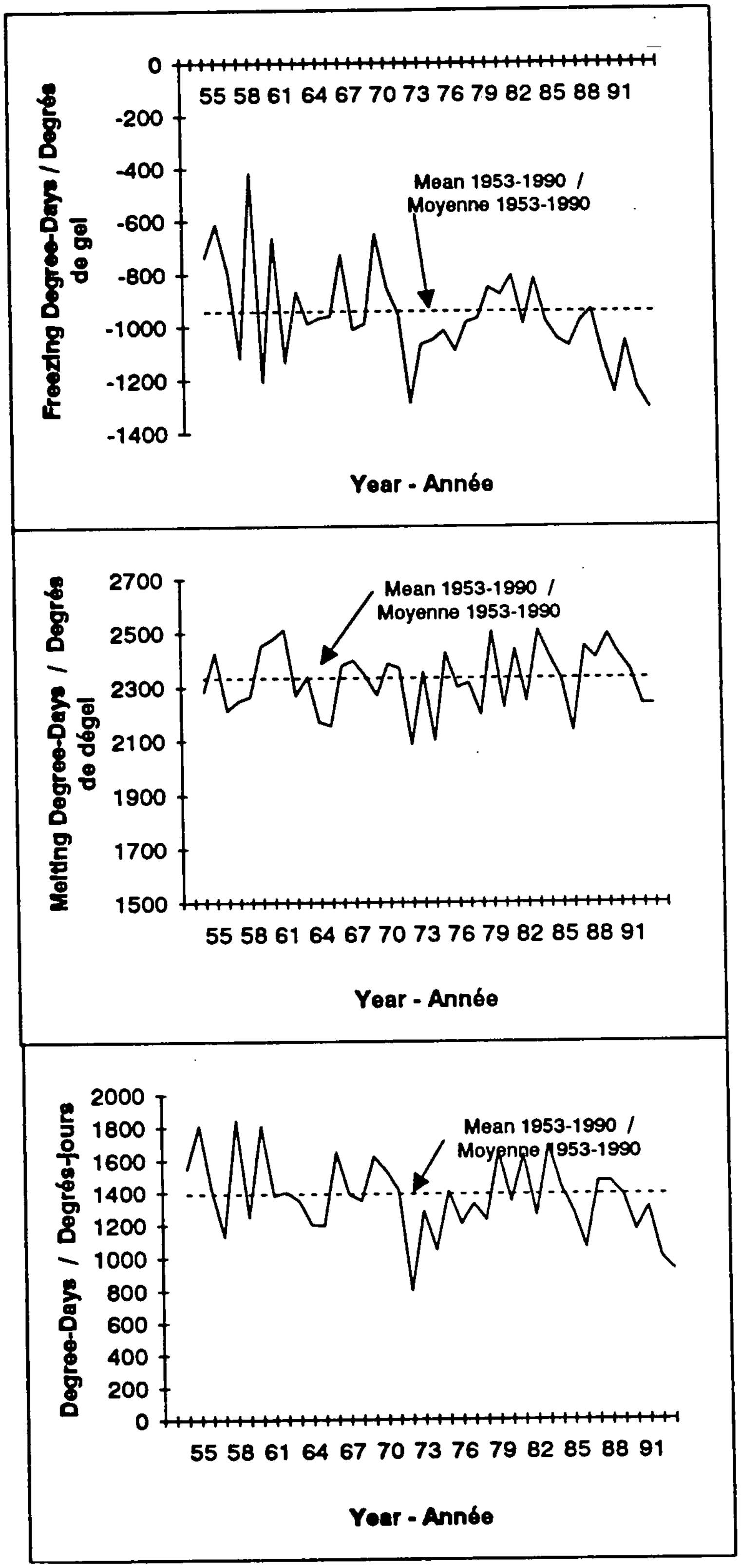

Figure 5. Average freezing (top), melting (middle) and total atmospheric degree-days for 6 weather stations in the Gulf of St. Lawrence (see text for details).

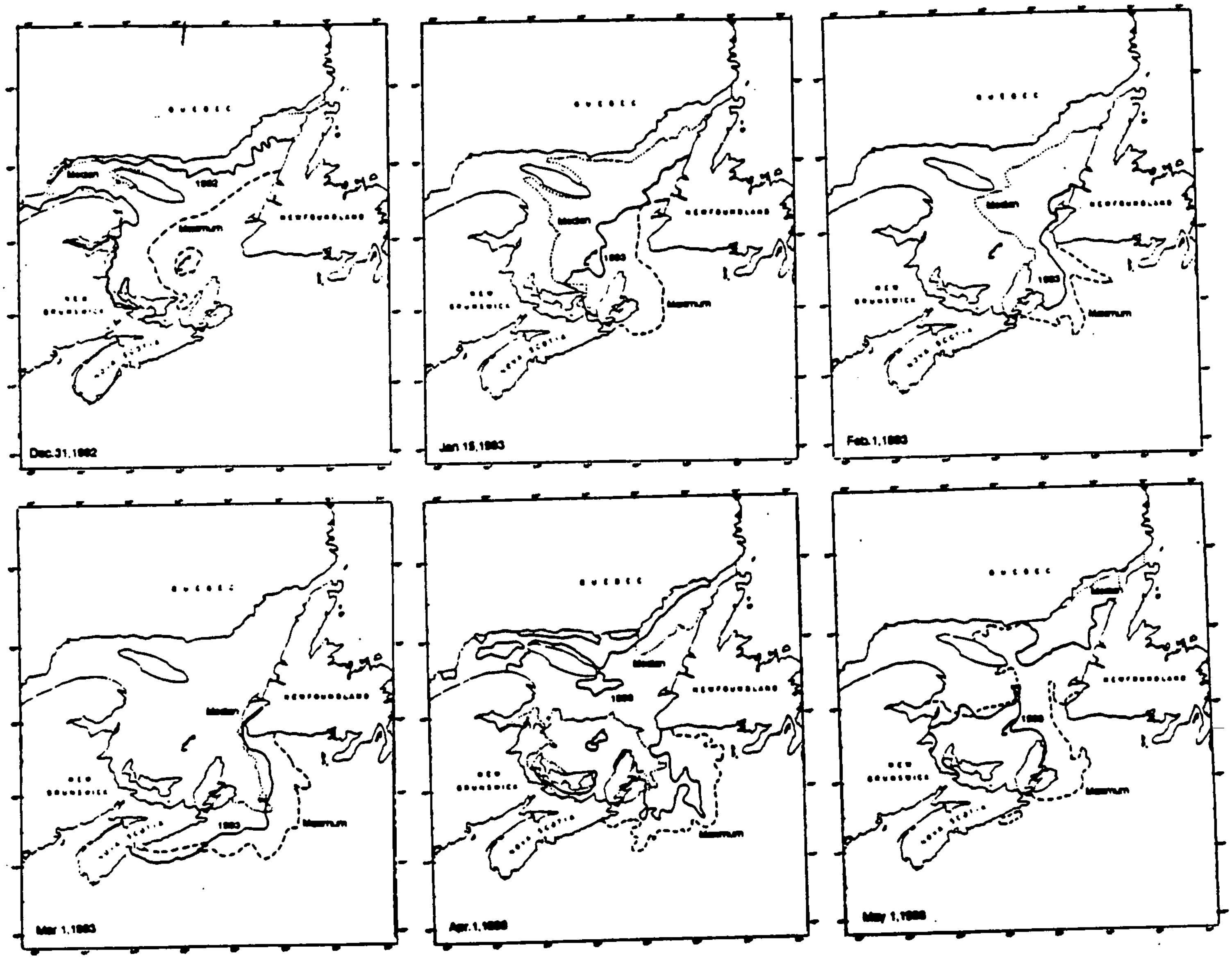

Figure 6. Location of the ice edge (concentrations >10%) in the Gulf of St. Lawrence between December 1992 and May 1993. The historical (1962-1987) median and maximum extent are also shown (From Drinkwater 1994).

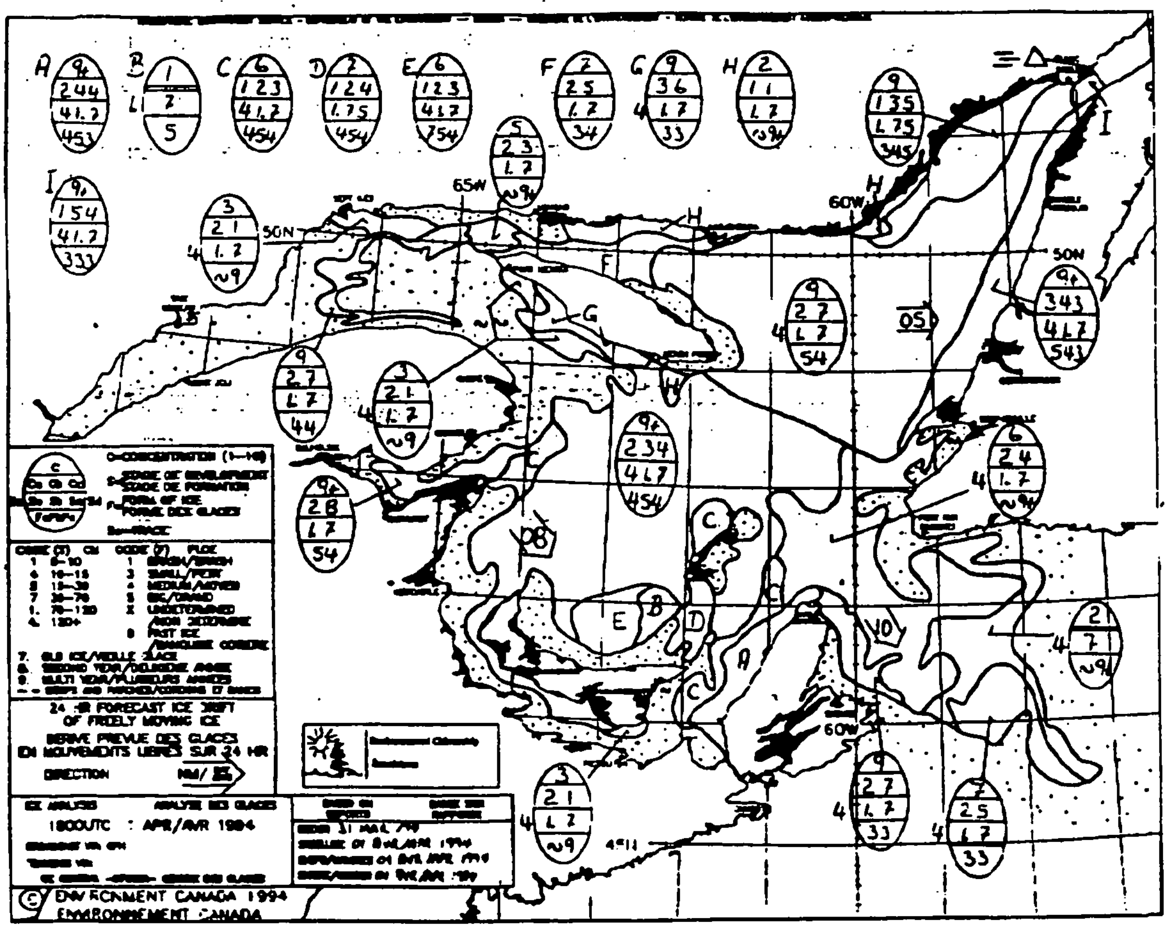

Figure 7. Ice chart for April 1, 1994 showing the extent of ice coverage in the Gulf of St. Lawrence. Dotted areas are ice-free waters.

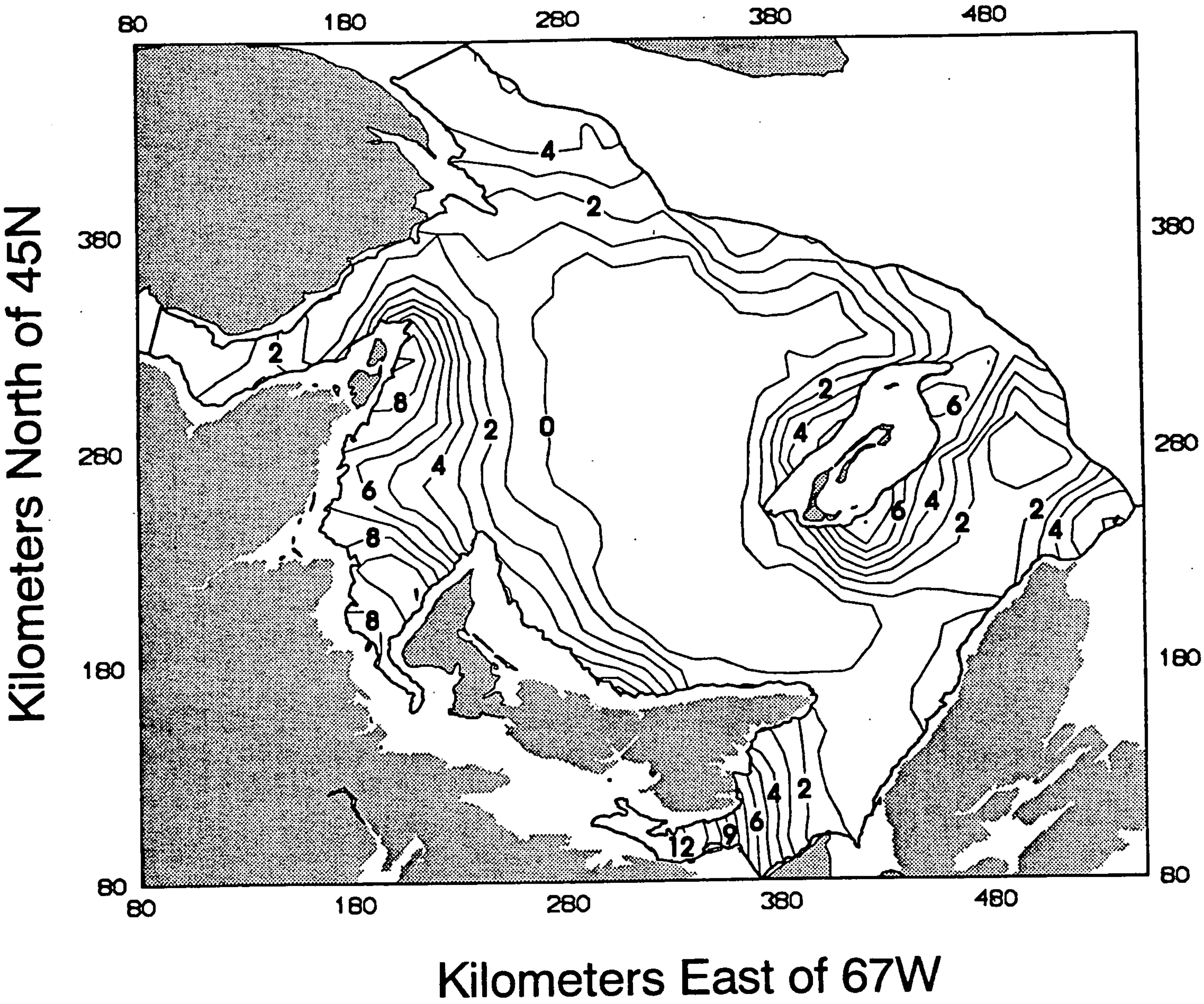

Figure 8. Bottom temperature in the southern Gulf of St. Lawrence, September 1993. Contour interval is 1° C.

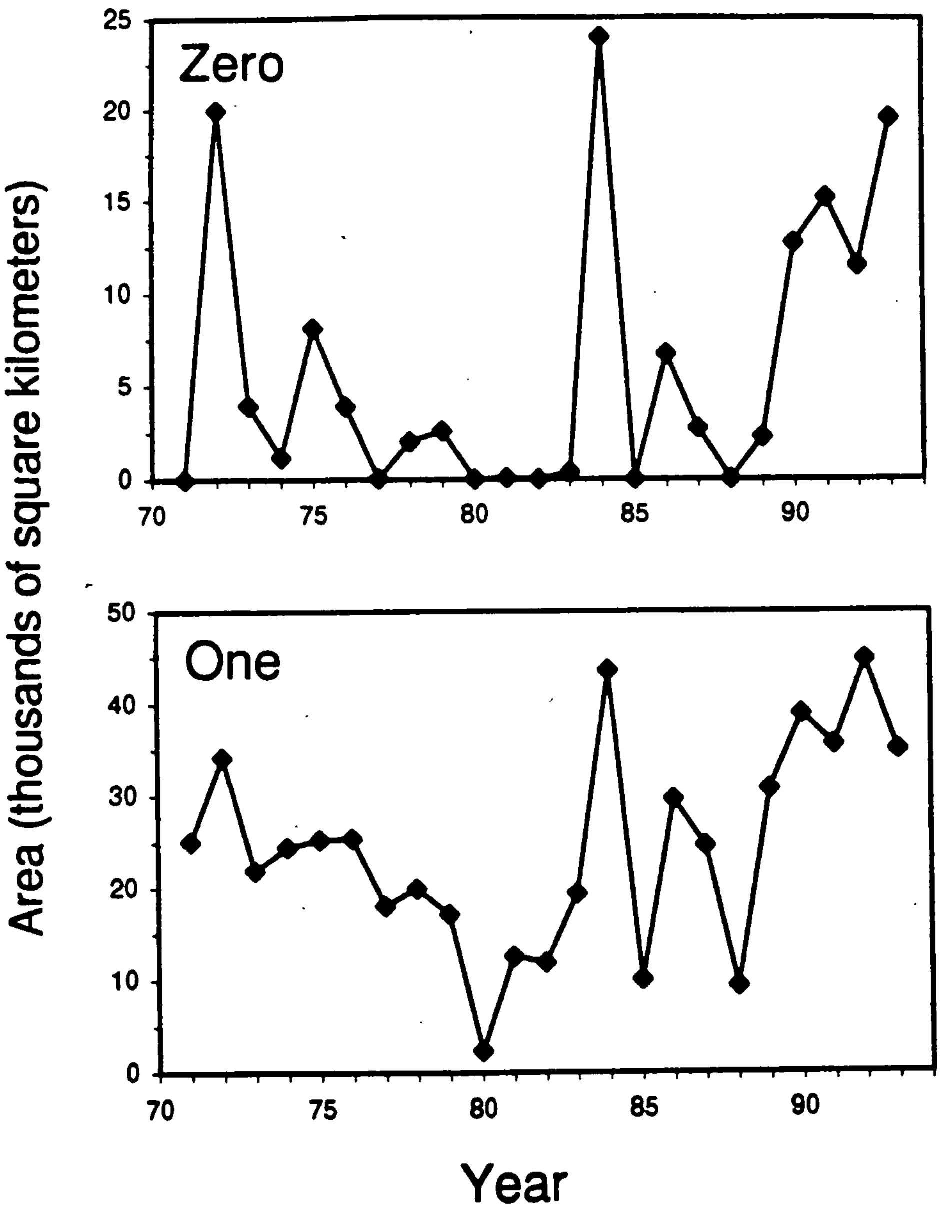

Figure 9. Area within the survey region (excluding strata 415, 425 and 439) with bottom temperature below 0° C or 1° C, 1971-1993.

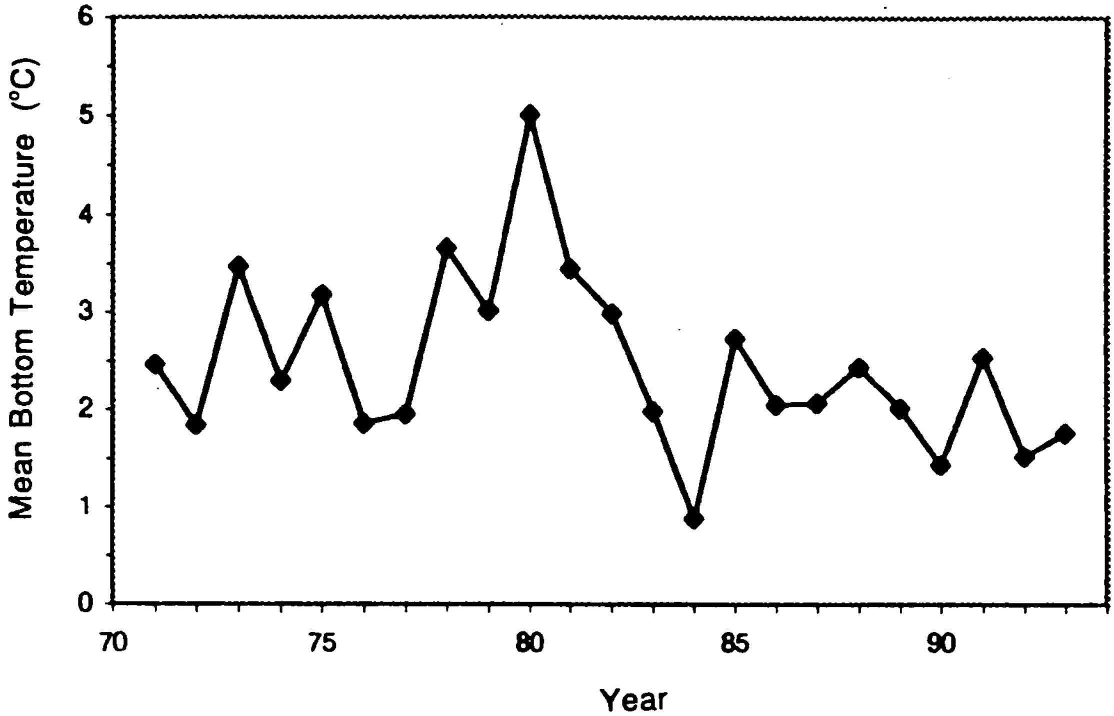

Figure 10. Stratified mean bottom temperatures in September groundfish abundance surveys of the southern Gulf of St. Lawrence, 1971-1993. Strata 415, 425, 426, 437, 438 and 439 are omitted due to missing values for depths over 155 m in 1984-1988.

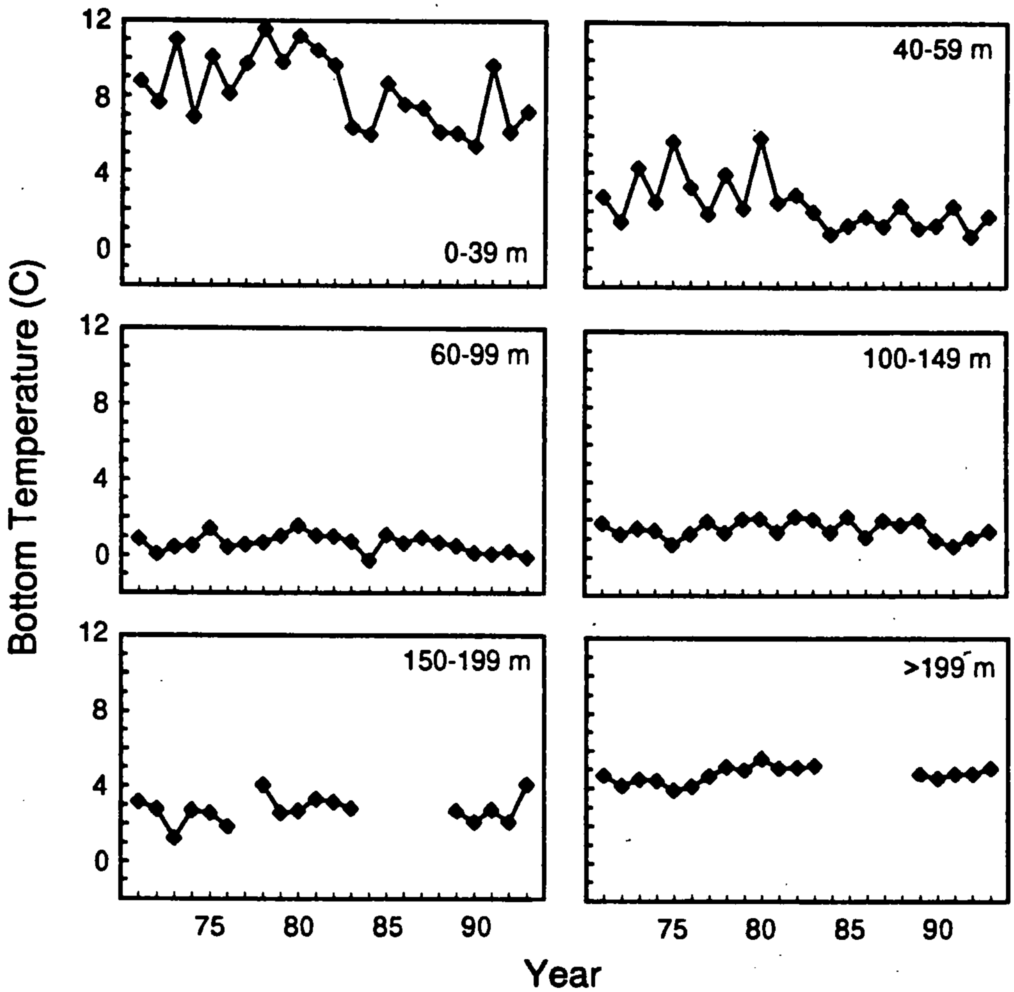

Figure 11. Annual mean bottom temperatures by depth zone in the southern Gulf of St. Lawrence, September, 1971-1993.

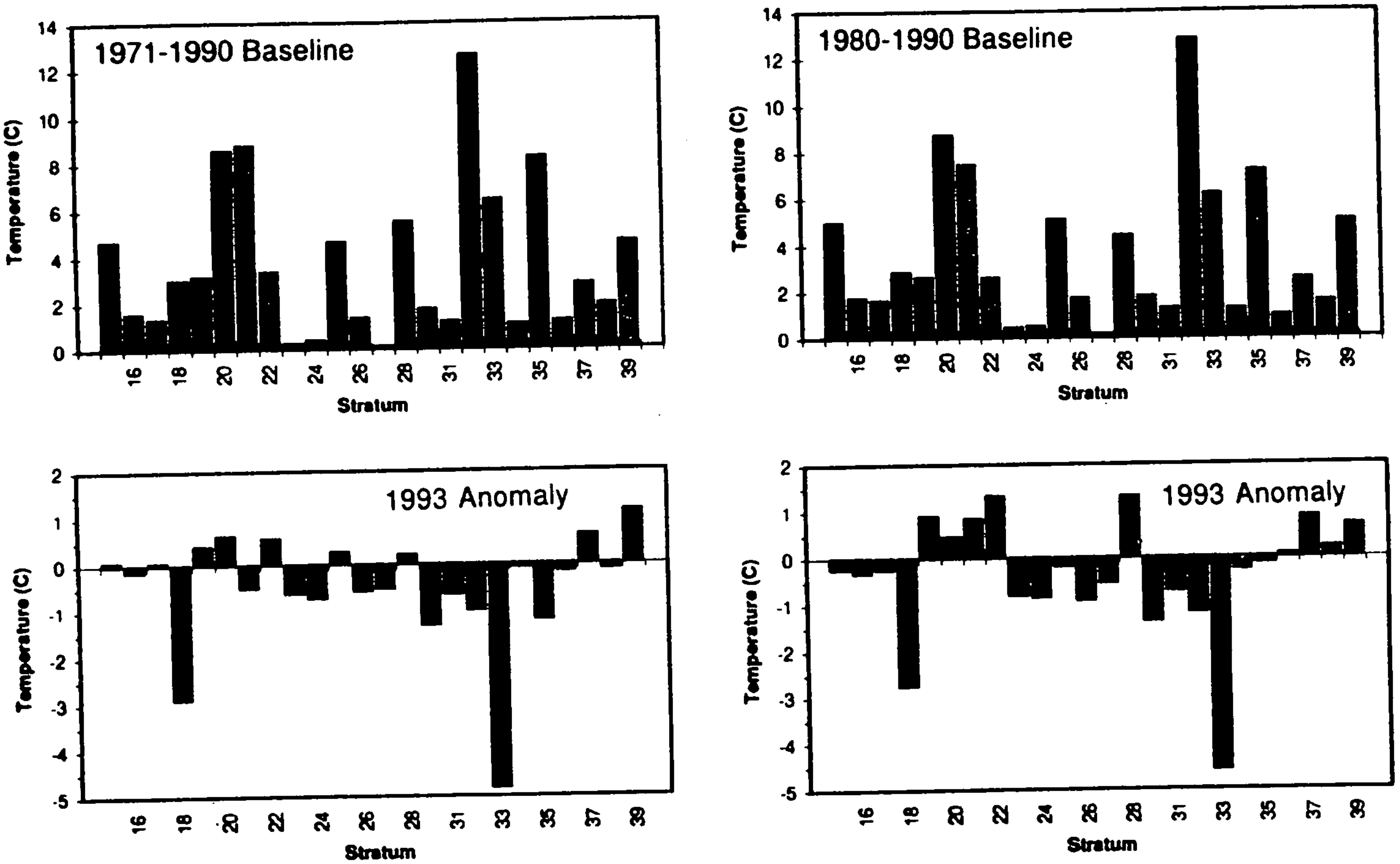

Figure 12. Bottom temperatures in 1971-1990 and 1980-1990 baselines and 1993 anomalies from the baselines by stratum.

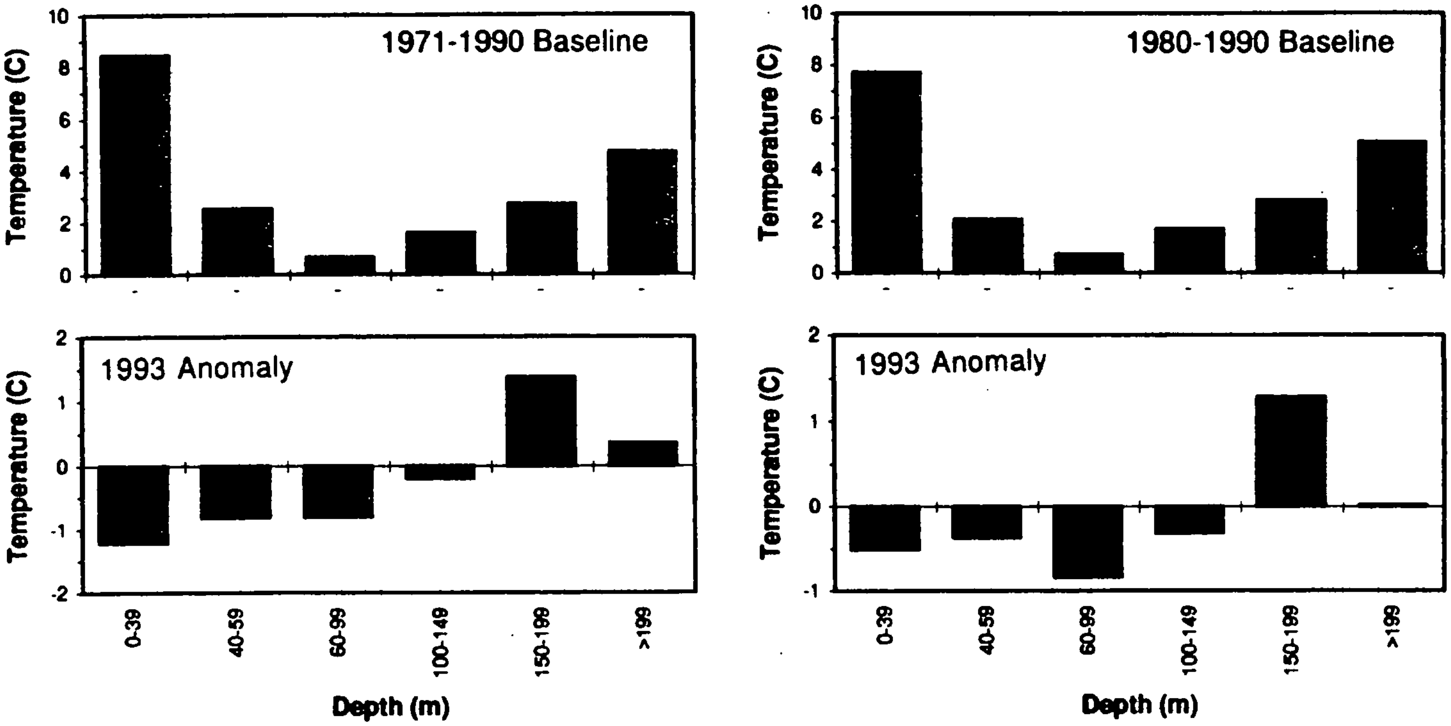

Figure 13. Bottom temperatures in the 1971-1990 and 1980-1990 baselines and 1993 anomalies from the baselines by depth zones.

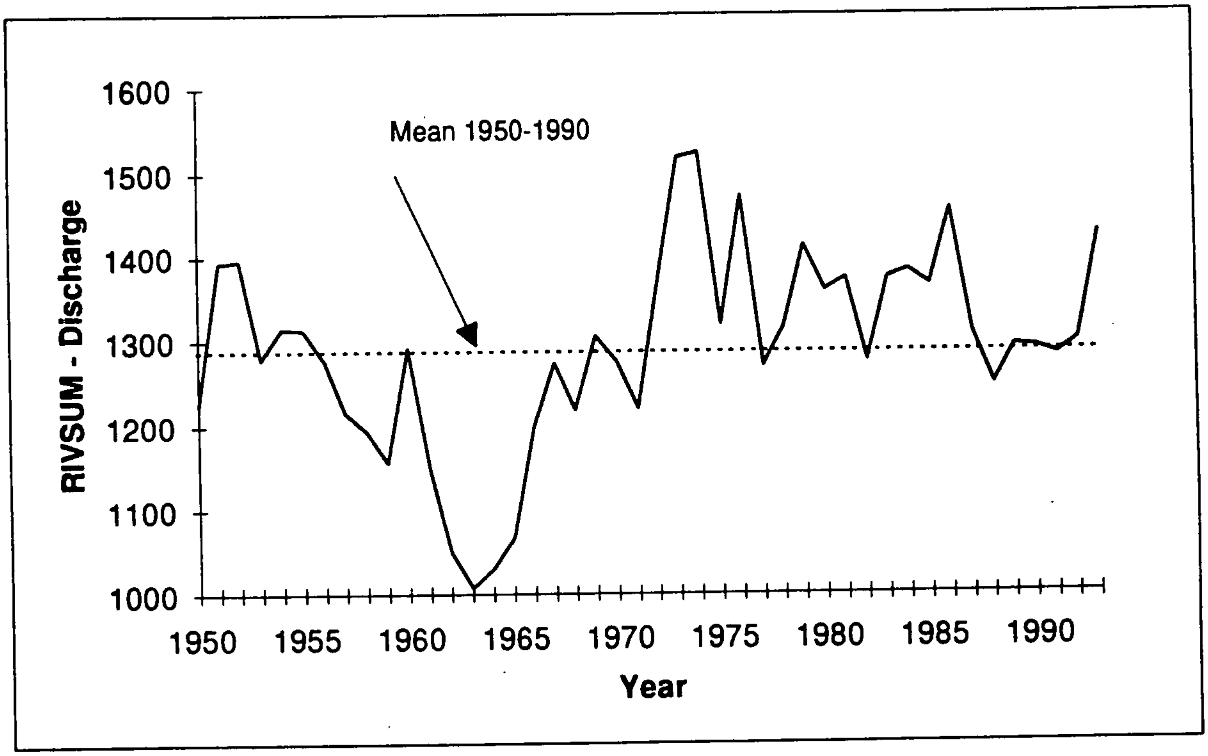

Figure 14 Index of the discharge from the St. Lawrence River (RIVSUM). Discharge values are in hundreds of m^3/s.