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The Relation of Cod Distributions with Environmental Conditions on the eastern Scotian Shelf, 1970-84

by

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Introduction

Atlantic cod (Gadus morhua) are widely distributed throughout the waters of the Scotian Shelf and Bay of Fundy (Leim and Scott, 1966). This implies there is a wide range of environmental conditions within which cod will occur and be available to fishing gear. Scott (1982) analysed the distribution of cod on the Scotian Shelf relative to bottom temperature and salinity in summer over the period 1970 to 1979. He found that cod did occur over a wide range of conditions, although the "preferred" ranges (occurrences of cod greater than 10% of the total) were narrower (3-7°C for temperature and 32-34 ppt salinity). However, Kohler (1968) suggested that, on the basis of distribution and migration patterns, cod in NAFO Subarea 4 may be divided into four major groups, two of which are the Bay of Fundy - southwest Scotian Shelf, and the eastern Scotian Shelf. Scott (1982) also recognized the differences between these groups, and noted an increase in the preferred temperature ranges from northeast (3-4°C, mean 3.2°C) to southwest (7-8°C, mean 7.8°C). On the scale of NAFO Subdivisions, he found differences for cod between Subdivision 4Vs and 4W in depth and temperature, but not salinity. The mean temperature of occurrence was 3.4°C in 4Vs, and 4.9°C in 4W, while salinity in both was 32.7 ppt.

The waters of the Scotian Shelf have a complicated vertical structure (Hachey, 1942) consisting of three characteristic water masses. Bottom temperatures depend largely on the depth of the bottom relative to these three water masses (McLellan, 1954), and it is assumed the distribution of cod is restricted within appropriate temperature and salinity ranges with

deeper occurrences limited by warm water and shallow occurrences limited by cold water (Scott, 1976).

In this paper we examine the distribution of cod relative to temperature and salinity in summer from 1970-84 on the eastern Scotian Shelf. We identify the locations of major aggregations of cod in each of NAFO Subdivisions 4Vs and 4W, and compare their characteristic temperatures and salinities to define the "preferred" physical environment in each region. We then examine cod distributions on the scale of a single bank, the Sable Island-Middle-Western Bank complex, to determine the ability of temperature and salinity to regulate the expansion and contraction of cod distributions. Such expansions and contractions of appropriate range can have implications for the management aspect of survey results.

Methods

Data on the distribution of cod, and bottom temperatures and salinities were obtained from standard otter trawl groundfish surveys conducted by the Marine Fish Division (Bedford Institute of Oceanography, Dartmouth, N. S.) during summer of 1970 to 1984. Sampling followed a depth-stratified random survey, as described by Halliday and Koeller (1981); depth strata are shown in Fig. 1A. Geographical features to which these strata correspond are shown in Fig. 1B.

To examine shifts of fish distribution between areas and years, it was first necessary to remove the effects of interannual changes of cod abundance. This was done by normalizing the cod catch per tow data by the mean catch per tow of cod in Subdivisions 4VsW for that year's summer survey. Thus, a normalized cod density value of unity indicates the catch of cod at that location was average for that year's survey.

Results

The distributions of fully recruited cod (ages 5 to 12), as normalized catch per tow, are presented in Fig. 2 for three time periods: 1970-74, 1975-79, 1980-84. The highest relative density consistently occurred north of Banquereau Bank (Strata 43, 44, 45), and on the western edge of the Sable Island-Middle-Western Bank complex. Relatively few large catches of cod occurred in Emerald and LaHave Basins (comprising the Scotian Gulf), and on

top of Banquereau and the eastern part of Sable Island Banks.

Also shown in Fig. 2 are composite contours of bottom temperature, measured simultaneously with the trawl survey. Clearly defined features are the warm waters of the Scotian Gulf, the cooler waters on top of the Sable Island Bank complex, the cool waters of Banquereau Bank, and the cold waters of the mixed depth region north of Banquereau. Such features are consistent with known oceanographic processes, with the Scotian Gulf influenced by slope water, Sable Island Bank influenced by seasonal warming of the upper layer, and Banquereau Bank and waters to the north residing within the cold intermediate layer of Labrador Shelf origin (McLellan, 1954). This difference in bottom temperature between waters north of Banquereau Bank (Strata 43, 44, 45) and the Sable Island Bank complex (Strata 55, 56, 58, 64) is significant and consistent over time (Fig. 3). The similar pattern of annual variation presented by the time series in Fig. 3 further suggests both areas responded to similar external forcings, for example, annual variations in the supply of Labrador Shelf water. The difference of mean bottom salinity over time between the two areas is less marked than for temperature, with the area north of Banquereau somewhat saltier and less variable than on the Sable Island Bank area, undoubtably due to the contribution of deep water to the former.

The time series of mean annual catches of cod north of Banquereau Bank, and on the Sable Island Bank complex, are shown in Fig. 4A for mean normalized densities, and in Fig. 4B for mean abundance data (unstratified). The normalized cod densities indicated better than average catches of cod in waters north of Banquereau Bank throughout most of the period 1970 to 1984, with the exception of the late 1970's. This is substantiated by the mean abundance data (Fig. 4B). This area had consistently greater densities and higher abundances of cod than the Sable Island Bank area, except for the late 1970's. The abrupt increase in cod abundance in 1979 and through the 1980's in both areas warrants further investigation, particularily as it coincides with a relatively warm period which began about 1977 (Fig. 3).

It is concluded, therefore, that for the waters of the eastern Scotian Shelf, the preferred area for cod in summer from 1970 to 1984 has been to the north of Banquereau Bank. This area has sustained relatively high densities within a small geographic area, and has shown indications of higher abundances and greater densities in the 1980's. Cod occurred in this area despite low temperatures; the grand mean of the weighted (by normalized

cod density) mean temperature of occurrence for each year was 2.3°C, and salinity 31.1 ppt, while the grand means for the Sable Island Bank area were 5.3°C and 32.5 ppt. These grand mean temperatures are similar to, but slightly wider than, the mean temperatures calculated for Subdivisions 4Vs and 4W by Scott (1982), suggesting the waters north of Banquereau Bank and on Sable Island Bank represent the extremes of their respective NAFO Subdivisions.

Figure 4A indicated higher than average cod densities during the late 1970's on the Sable Island Bank complex, and Fig. 2 also suggested higher concentrations of cod along the Western Bank edge during the period 1975-79. Considering the preferred distribution of cod in warmer temperatures in Subdivision 4W, we asked whether this distribution would be restricted or expanded by less favourable temperatures in deep water and on top of the Bank.

The area of the Sable Island-Middle-Western Bank complex defined as having higher than average densities of cod is shown in Fig. 1B. Cod were relatively abundant in this area in all three time periods, but were most dense during 1975-79 (Fig. 2). This increase in density was not due to one dominant year, but was composed of relatively high densities in all years of this time period. The area of the Scotian Gulf to the west (Strata 62, 63, 65) and the remainder of Sable Island Bank to the east (parts of Strata 55, 56, 58) had lower densities of cod, particularily in the Scotian Gulf. When the mean normalized cod densities for each of these three adjacent areas are presented as time series, the higher densities on the edge of the Bank during 1975-79 become clear (Fig. 5A). What also becomes clear are the similar densities between the edge of the Bank and top of the Bank during 1980-84, particularily the higher densities on top of the Bank in 1982. The pattern of mean cod abundance in each of these areas was similar to that for density, being high on the edge of the Bank from 1976-1981 (Fig. 5B). The peak abundance on the top of the Bank in 1979 was due to two large catches on the southeastern edges of Sable Island Bank. However, note the apparent switch of cod abundance from the edge of the Bank to the top of the Bank during the 1980's, suggesting a spreading out or widening of the cod distribution over the whole of the Bank. Cod were rarely caught from the Scotian Gulf.

These changes in distribution of cod can be explained by the time series of mean bottom temperatues within the three areas (Fig. 6). The

Scotian Gulf was consistently warmest, and at the very high end of the range of temperatures in which cod may be found on the Scotian Shelf (Scott, 1982). Mean temperatures on the edge and top of the Bank were similar from 1970-74, when cod densities and abundance were similar, and also during the 1980-84 period. It was the 1975-79 period, however, when the edge of the shelf was cooler than either adjacent areas, which corresponded to the period of highest cod densities. We suggest cod preferred the cooler temperatures along the edge of the Bank, and were "squeezed" into a relatively narrow band by the warmer waters of the Scotian Gulf, and on top of the Bank. This preference for cooler water is apparent by comparing the weighted (by normalized cod density) mean temperatures of cod occurrence for each year for each area; occurrence on the edge of the Bank (Area 1) was consistently in cooler water from 1974 to 1980 (Table 1). The fact that the marked cooling on the whole of the Bank in 1982 corresponded with a spread of cod across the Bank, lends support to this arguement. A scatterplot of normalized cod density against temperature during 1975-79 for the three areas shows clearly the correspondence of higher-than-average cod catches with colder temperatures on the edge of the Bank than on the top of the Bank or in the Scotian Gulf (Fig. 7). The variation of mean salinity between these three areas follows the same pattern as for temperature.

The strong warming of bottom temperatures in all three areas in 1983 is likely related to the anomalously warm sea surface temperatures observed throughout the Scotian Shelf in that year and may be related to large-scale atmospheric events (Trites and Drinkwater, 1985). It is too early yet to determine its effect on the distribution of cod in the region.

Discussion

The analysis of cod distributions between Subdivisions 4Vs and 4W suggests that cod preferred colder water in the area north of Banquereau Bank than on the Sable Island Banks. This agrees with the conclusions of Scott (1982), although the temperature preferences appear to be more extreme. However, the range of bottom temperatures between the two areas was quite different, and the preference of cod for warmer temperatures on Sable Island Bank was very likely due to the warmer ambient conditions available. This is confirmed by the distribution of cod on the Sable Island Bank complex between the deep water, the edge, and the top of the Bank. Cod

occurred in the coolest water available in this region, and became "squeezed" along the western edge of the Bank during 1975-79 when temperatures warmed up on the top of the Bank. Thus, it appears cod selected colder water on the central Scotian Shelf if it was available. A similar example of cod vertical distributions being restricted into a cold water layer has been described for the Gulf of St. Lawrence by Yves (1964). Such a restriction in the distribution of cod due to temperature provides another potential source of error when expanding catch per tow data into the areal abundance of cod within a stratum, by violating the assumption of a homogeneous distribution.

It must be noted, however, that the distribution of a fish is not determined solely by temperature and salinity. Biological conditions such as prey distribution and availability, spawning requirements (although not for cod in this region during summer), etc. may override the usual temperature preferences. It is entirely conceivable for cod to cross a thermocline or temperature front for short periods of time while foraging, if the energy return is sufficient.

Acknowledgements

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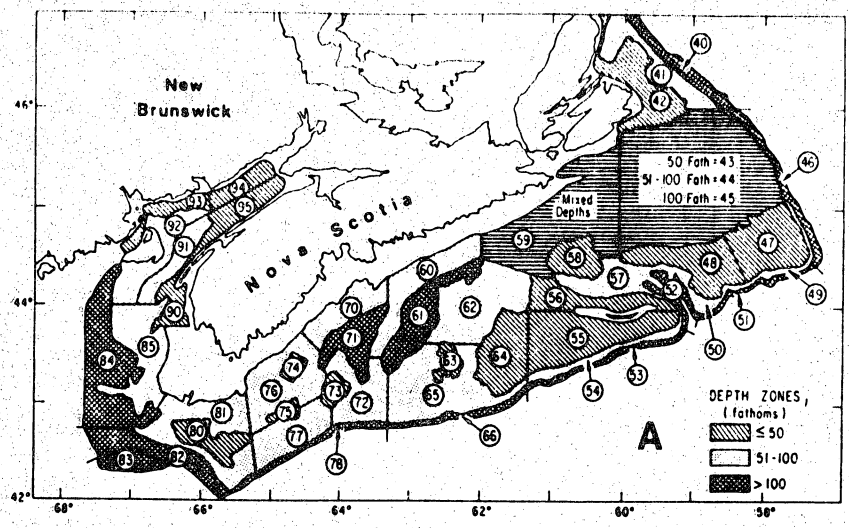
Table 1. Weighted mean temperature of occurrence (°C) of cod in each of the three areas of the central Scotian Shelf: 1 - western edge of Sable Island Bank (see Fig. 1B); Area 2 - Scotian Gulf (Strata 62, 63, 65); Area 3 - remainder of Sable Island Bank not included in Area 1 (Strata 55, 56, 58, 64). Weighted mean temperatures were calculated as: (normalized cod density for set i/sum of normalized cod density for that survey) * Temperature of occurrence.

Year	Area 1	Area 2	Area 3
1970	5.1	5.2	6.3
1971	4.6	7.7	4.4
1972	4.6	6.0	5.8
1973	7.1	11.0	5.5
1974	6.3	8.1	8.3
1975	3.7	5.6	3.9
1976	4.4	6.7	5.6
1977	3.6	9.9	6.3
1978	4.0	6.9	4.5
1979	6.1	9.6	6.8
1980	5.1	7.5	5.1
1981	4.9	5.8	8.6
1982	3.5	5.2	2.8
1983	3.2	6.9	7.1
1984	5.6	7.2	7.8



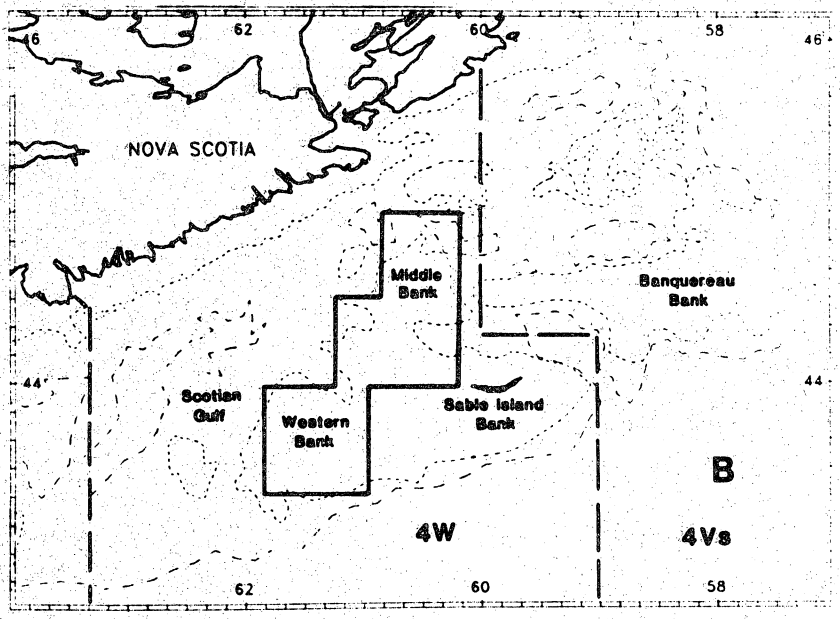


Fig. 1A. Stratification scheme for the depth-stratified random groundfish survey, 1970-84.

Fig. 1B. Area map and place names referred to in the text. Heavy dashed boundaries refer to NAFO Divisions 4Vs and 4W; Heavy lined area identifies the high density cod region on the edge of the Sable Island-Middle-Western Bank complex. Contour lines are in 50 fathom intervals.

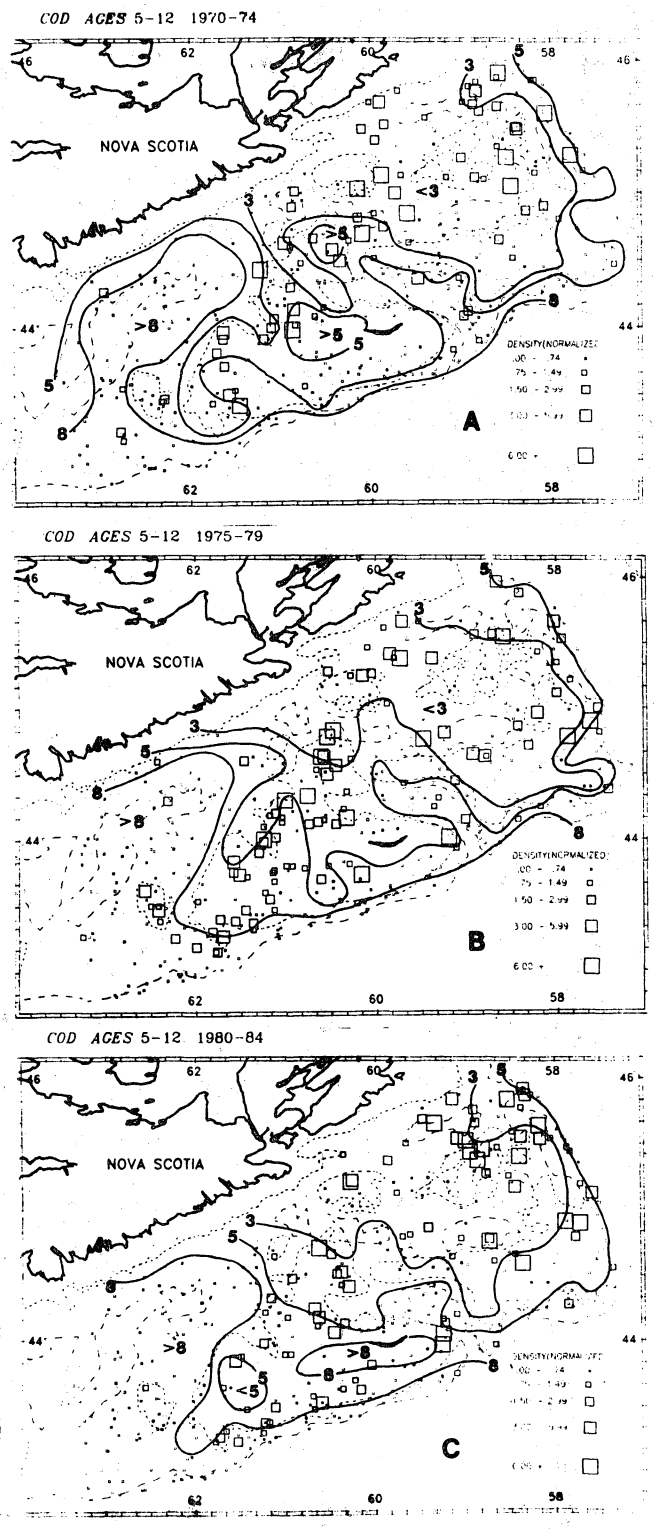


Fig. 2. Normalized densities of cod ages 5 to 12 for each location sampled on the groundfish survey; bottom temperature contours are in °C.
A. 1970-74, B. 1975-79, B. 1980-84.

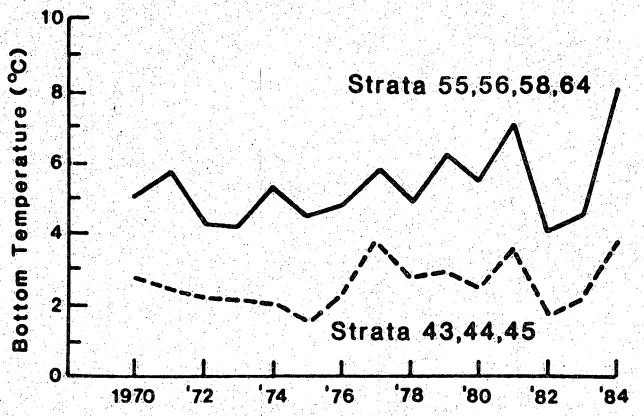


Fig. 3. Time series of bottom temperatures measured on the groundfish surveys. Points are means for each summer survey, calculated for waters north of Banquereau Bank (Strata 43, 44 45) and the Sable Island Bank complex (Strata 55, 56, 58, 64).

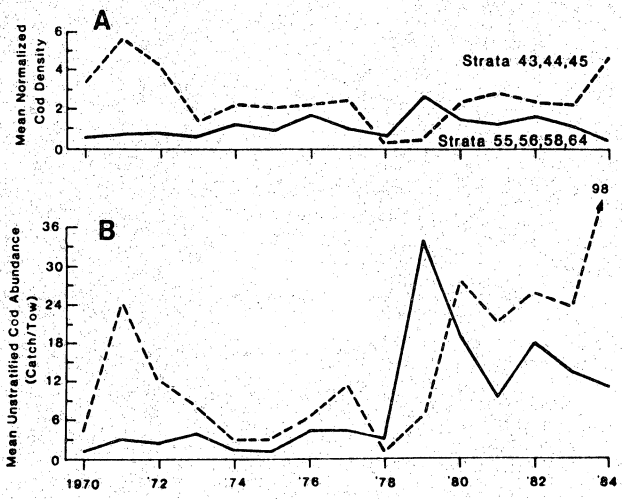


Fig. 4. Time series of cod for Strata 43, 44, 45 and Strata 55, 56, 58, 64. A. Yearly means of normalized cod densities; B. Yearly means of cod abundance (catch/tow).

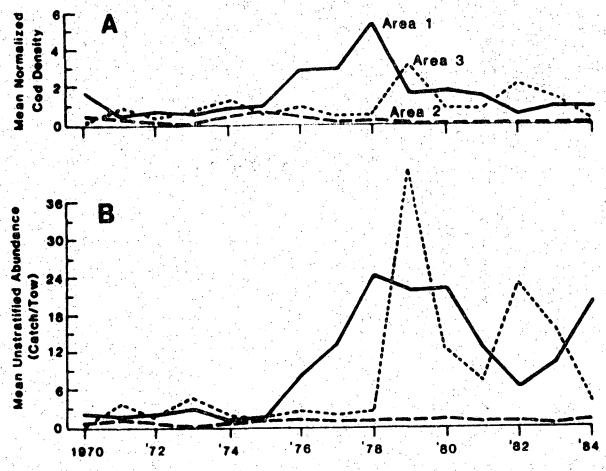


Fig. 5. Time series of cod data for the Sable Island Bank complex: Area 1 - western edge of the Bank (outlined on Fig. 1B); Area 2 - Scotian Gulf; Area 3 - remainder of the Sable Island Bank not included in Area 1. A. Mean normalized cod density. B. Mean cod abundance.

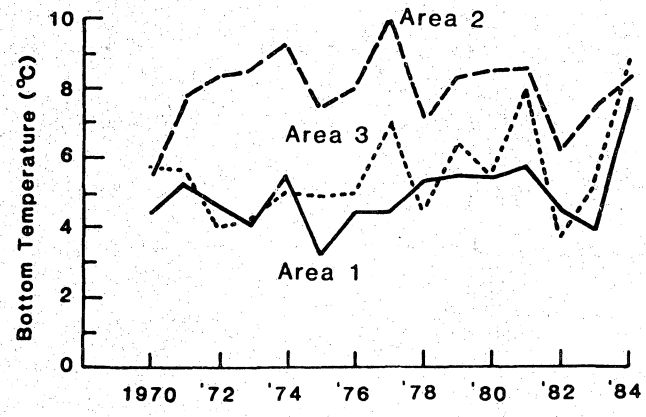


Fig. 6. Mean bottom temperature time series in Areas 1-3 (see legend to Fig. 5).

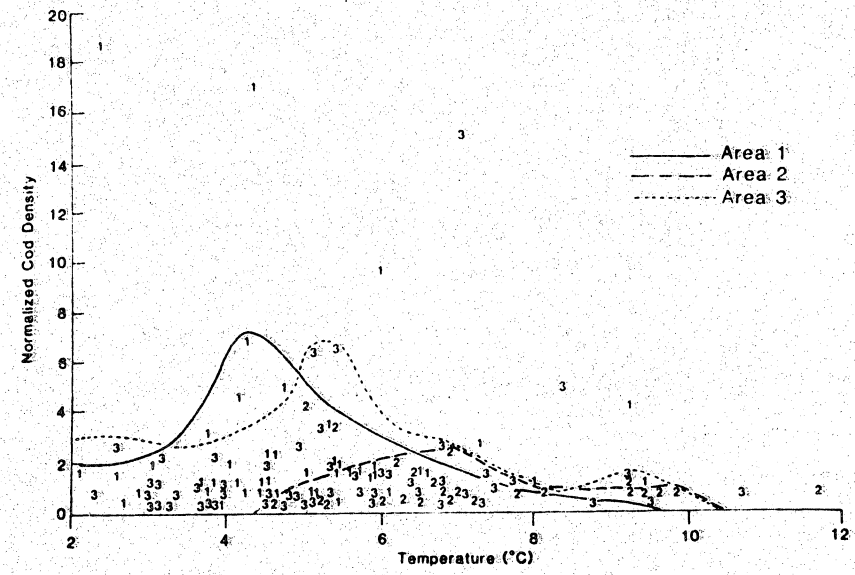


Fig. 7. Scatterplot of normalized cod density against bottom temperature for Areas 1-3 in the central Scotian Shelf, 1975-79. Numbers represent the appropriate Areas; envelopes enclose the densest aggregations of points separately for each area, i.e. outliers have not been included in the envelopes, but are identified by their Area number.