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Water Mass Analysis and Groundfish Distributions on the Scotian Shelf, 1979-84

by

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ABSTRACT

Characteristic water masses on the Scotian Shelf during spring and during summer, 1979-84, were identified by their temperature and salinity properties using a technique from the literature. The seasonal research survey catches of four species of groundfish (cod, haddock, silver hake, and yellowtail flounder) were compared with these water masses to determine if a relationship existed, and if a small number of water masses could account for the largest catches. Results suggest that large catches occurred in only a few water masses, that these few water masses were species-specific, and that they were seasonally consistent for all but yellowtail flounder. The advantage of describing groundfish distributions using water mass analysis is that physical oceanographic processes causing changes in water masses may also cause changes in fish distributions

INTRODUCTION

Groundfishes on the Scotian Shelf occur within specific limits of temperature, salinity, and depth (Scott, 1982; Perry and Losier, in prep.). These limits are often species-specific, and enable groups of species to be identified which occur under similar habitat conditions. Knowledge of the environmental conditions at which species of groundfish occur may be used to predict geographic distributions and migration patterns, in particular under changing seasonal or interannual conditions. Such distribution studies often concentrate on a single environmental parameter such as temperature and disregard salinity, which may have a confounding effect in marine waters.

The combination of temperature and salinity has been used by McLellan (1954) and Houghton et al. (1978) to examine the distribution and mixing of water masses on the Scotian Shelf. They were able to identify the contributions of source waters to the Scotian Shelf and to model the changes in these waters across and along the shelf resulting from advection and mixing. Combination of this type of analysis with the ranges of temperature and salinity occupied by groundfish species on the Scotian Shelf may provide a mechanism by which oceanographic processes that predict changes in water mass characteristics and distribution could also be used to predict changes in the distributions of groundfishes.

In this paper we develop a method to examine whether seasonal (spring and summer) distributions on the Scotian Shelf of four representative groundfish species were related to specific water masses during the period 1979-84. We also examine whether interannual changes in these water mass distributions can be used to predict changes in groundfish distributions.

METHODS

Characteristic water masses on the Scotian Shelf were identified using all available hydrographic data from the Marine Environmental Data Service's (MEDS, Ottawa) bottle, CTD, and XBT data bases for March (spring) and July (summer), 1979-84. Data for all depths were plotted as temperature-salinity (TS) diagrams (Fig. 1). Following the technique of Miller (1950) and the examples of McLellan (1954) and Houghton et al. (1978), the temperature and salinity properties of the source water regions were determined and a grid constructed between these points. The areas in the interior of the grid were interpreted as the results of mixing among the various water masses, with the assumption that mixing was rapid relative to local and seasonal changes. The source regions used in this study were the same as defined by McLellan (1954) and Houghton et al. (1978):

Summer (Fig. 1b) -

A - surface water flowing from the Gulf of St. Lawrence through the western side of Cabot Strait;

B - surface water over the central slope;

C - slope water at intermediate depths (100-150 m);

D - subsurface water (>100 m) in Cabot Strait (north of 46°N latitude); and

E - deep slope water (200-300 m).

The source regions for the spring TS diagram (Fig. 1a) were the same as for summer, except that region B represented surface slope water from the southern Scotian Slope and the Northeast Channel, and region C represented temperature and salinity conditions of deep waters in LaHave and Emerald Basins. These latter were also the same temperature and salinity conditions of slope water at intermediate depths (region C in Fig. 1b), and likely represent water that had been advected from the slope region across the shelf and spilled into the Basins. The TS properties of each of these source regions and appropriate seasons were taken from the MEDS data when available (regions A and D), and from Drinkwater and Trites (1986) when not available in the data base within the defined latitude and longitude boundaries (regions B,C,E).

The grid was then divided into regions representing various proportions of mixing of the source water types (Fig. 2). Each region was labelled to represent the proportions of the constituent water types, e.g. A is water with >75% of source water A, Ab has 50-75% type A and 25-50% type B, etc. The proportions of source waters in the interior are more variable, but the dominant water types are indicated with capital letters.

Data on bottom temperature and salinity, and associated groundfish catches, were collected during regular Marine Fish Division groundfish research surveys. During the period 1979-84, these were conducted in spring (March) and summer (July) using the same stratified-random sampling design over the Scotian Shelf (Fig. 3), and the same sampling techniques. Details of the sampling design and protocol are available in Halliday and Koeller (1981). The characteristic water mass type at each station was then identified using the appropriate seasonal TS - water mass diagram (Fig. 2).

The groundfish species selected for this analysis were yellowtail flounder, cod, haddock, and silver hake. These represent species which occur in cool, intermediate, and warm waters (cod, haddock, and silver hake, respectively), and a species which remains on the offshore Banks throughout the year, with little change of distribution in response to wide seasonal changes in temperature (yellowtail founder) (Perry and Losier, in prep.). To determine if a relationship exists between the distribution of a species (as determined by catch data) and water mass type, the proportion of the total number of fish caught in each season over the period 1979-84 was identified for each water mass in a histogram. Catches >10% of the total 1979-84 catch for that season and species were considered strongly related to that water mass.

The relationships between the size of catches and water mass types were examined using contingency tables. For each season and species, the number of fish caught during each tow was expressed as a proportion of the total number caught for that season and year. These proportions were then divided into two classes, small catches (sets with ≤2.5% of the year's catch) and large catches (sets with >2.5% of the year's catch). For all species and both seasons over the period 1979-84, between 75-90% of the sets in each year caught only small numbers of fish ($\leq$2.5% of the total for each season and year). Therefore, relatively few sets (7-25%) in any year represented large catches. The dependence of size of catch on water mass type was tested using the SPSS Crosstabs procedure (Nie et al., 1975), after excluding water masses with incidental catches of fish (<0.1% of the total 1979-84 seasonal catch). Statistical significance of dependence was tested using the Wilks' likelihood ratio χ^2_W (Legendre and Legendre, 1983; also known as the G statistic, Sokal and Rohlf, 1981), and the strength of the relationship was determined using the asymmetric uncertainty coefficient. This latter statistic represents the proportion by which "uncertainty" in the size of catch is reduced by knowledge of the water mass type (Nie et al., 1975).

RESULTS

The distribution of temperature and salinity on the Scotian Shelf during March and July, 1979-84, available in the MEDS data bases, and the constructed grid of the characteristic water masses, are shown in Fig. 1. The strong seasonal cooling of Cabot Strait surface water (source region A) is clearly identified by comparing Figs. 1a and 1b, while the temperature and salinity characteristics of source regions C, D, and E remained similar. The points that fall outside the grid represent nearshore waters or unusual combinations of temperature and salinity, such as the cluster to the left of souce region A in summer from St. Margarets Bay. The identification of the characteristic water masses enclosed by these grids is shown in Fig. 2.

The relationships of catches with each water mass are shown in Fig. 4 for summer, and Fig. 5 for spring, over the period 1979-84. Several points are evident:

(1) While the four species selected for analysis were caught to some extent in most water masses, they were concentrated within a smaller number of specific water masses, each defined as representing >10% of the total seasonal catch. The largest numbers of cod occurred in water masses D, cD, and acD in summer (Fig. 4a), characteristic of cool waters, while silver hake occurred predominantly in the warm water masses C and Cd in summer (Fig. 4c).

(2) The water masses in which fish concentrated were generally adjacent to each other on the TS diagram, representing different degrees of mixing of similar source water regions.

(3) These principal water masses, and the proportions of the catches they represent, are different between the four fish species. Cod occurred in water masses dominated by Cabot Strait intermediate water (source region D), haddock occurred in a mixture of Cabot Strait and Slope intermediate waters (source regions D and C), and silver hake in intermediate depth Slope water (region C). The dominant water mass distribution of yellowtail flounder was the same as cod during summer, but during spring yellowtail occurred in cooler and fresher water masses than did cod.

(4) The water masses with the greatest proportions of total catches were the same between spring and summer for cod and silver hake, were similar for haddock, but differed for yellowtail flounder.

The contingency table analysis indicates there was a significant relationship between the size of catch (separated into large or small catches) and water mass type for two species during spring and all four species during summer (Table 1). This implies that small catches occurred in almost any water mass, but large catches occurred in a small number of particular water masses. The proportion of the "uncertainty" in catch size which can be reduced by knowledge of the water mass type is indicated in Table 1 by the asymmetric uncertainty coefficient.

DISCUSSION

This analysis indicates there are relationships between groundfish distributions on the Scotian Shelf and temperature and salinity redefined as water mass types. These relationships are species-specific, and seasonally consistent for typically cool or warm water species such as cod or silver hake. The seasonal relationship with the same water mass is somewhat less consistent for species such as haddock and yellowtail flounder. Scott (1982) and Perry and Losier (in prep.) found haddock were distributed at intermediate temperatures, warmer than cod but cooler than silver hake, in part reflecting the distribution of haddock which is centered on the warmer southern half of the Scotian Shelf. This is clear from the water masses in which the largest catches of haddock occurred, and also accounts for the seasonal differences in principal water masses. Perry and Losier (in prep.) defined yellowtail flounder as a eurythermal species, which appears to remain on the shallow banks throughout the year. As a consequence, this species is exposed to a wide seasonal range of temperatures. This accounts for the large proportions of yellowtail flounder which occurred in the water mass dominated by cold and fresh Cabot Strait surface water (Abd) in spring, but shifted to the Cabot Strait intermediate water (D) in summer. This latter water mass is typical of the shallow banks of the Scotian Shelf in summer.

The lack of a significant statistical relationship between catch size and water mass type during spring for haddock and silver hake (Table 1), despite the clear relationships identified in Fig. 5, may be due to the large numbers of these species that were caught. Both these species in spring had the largest total seasonal catches of all the species and season combinations exmained in this study (Table 1). It may be that when very large numbers of a species are present, they disperse over a broader area and into more water masses than when abundances are relatively modest and catches more concentrated.

To demonstrate one aspect of the utility of this water mass approach in studying fish distributions, Fig. 6 indicates the summer (July) mean bottom temperatures as measured over the Scotian Shelf on the standard stratified-random groundfish surveys from 1979-1984. Considerable interannual variability in seasonal-mean bottom temperature is apparent. Fig. 7 plots the summer distributions on the northern Scotian Shelf of the characteristic water masses for the two extreme years as indicated in Fig. 6, relatively warm 1980 and relatively cool 1982, and the correspoding catches of cod. Cold water of type D was the dominant water mass on the offshore banks during 1982, compared with the warmer temperatures of water masses cD and acD in 1980. The distribution of large catches of cod also differed between these two years, being closer to the edge of the continental shelf and the warmer Slope water in 1982 (the cold year) than in the warmer year of 1980. Further studies are currently underway to elucidate the role of water mass types in fish distributions for the study of seasonal and interannual variability. Another significant advantage of using this type of water mass analysis is its use by physical oceanographers for the study of advection and mixing over the Scotian Shelf. Oceanographic mechanisms which alter the distribution and/or characteristics of these water masses may also be used to predict the distributions of groundfishes.

REFERENCES

Drinkwater, K. F., and R. W. Trites. 1986. Monthly means of temperature and salinity in the Scotian Shelf region. Can. Tech. Rep. Fish. Aquat. Sci. 1539.

Halliday, R. G., and P. A. Koeller. 1981. A history of Canadian groundfish trawling surveys and data usage in ICNAF Divisions 4TVWX. Bottom trawl surveys. Can. Spec. Publ. Fish. Aquat. Sci. 58: 27-41.

Houghton, R. W., P. C. Smith, and R. O. Fournier. 1978. A simple model for cross-shelf mixing on the Scotian Shelf. J. Fish. Res. Board Can. 35: 414-421.

Legendre, L., and P. Legendre. 1983. Numerical Ecology. Elsevier Scientific Publishing Co., New York. 420 p.

McLellan, H. J. 1954. Temperature-salinity relations and mixing on the Scotian Shelf. J. Fish. Res. Board Can. 11: 419-430.

Miller, A. R. 1950. A study of mixing processes over the edge of the continental shelf. J. Mar. Res. 9: 145-160.

Nie, N. H., C. H. Hull, J. G. Jenkins, K. Steinbrenner, and D. H. Bent. 1975. SPSS: Statistical Package of the Social Sciences, 2nd Ed. McGraw-Hill, N.Y.

Perry, R. I., and R. J. Losier. Seasonal temperature, salinity, and depth distributions of groundfishes on the Scotian Shelf, NW Atlantic, 1979-84. In preparation.

Scott, J. S. 1982. Depth, temperature and salinity preferences of common fishes of the Scotian Shelf. J. Northw. Atl. Fish. Sci. 3: 29-39.

Sokal, R. R., and F. J. Rohlf. 1981. Biometry. 2nd Ed. W. H. Freeman and Co., San Francisco. 859 p.

Table 1. Results of the contingency table analysis of catch size (large defined as sets with >2.5% of that year's total seasonal catch; small <2.5%) as the dependent variable versus water mass type as the independent variable for the two seasons and four species, 1979-84. Significant values of X^2_W indicate a dependence of catch size on water mass type.

Season	Species	% of sets with large catches	X^2_W	df	Asymmetric uncertainty coefficient
Spring	Cod	8.3	38.36*	22	.116
	Haddock	11.5	28.56	21	.098
	Silver hake	24.4	14.45	18	.119
	Yellowtail flounder	20.6	37.77**	18	.121
Summer	Cod	7.4	37.06**	15	.111
	Haddock	9.9	39.04**	17	.102
	Silver hake	15.6	41.29**	15	.126
	Yellowtail flounder	25.8	44.48**	10	.136

* Significant at $\alpha = .05$
** Significant at $\alpha = .01$

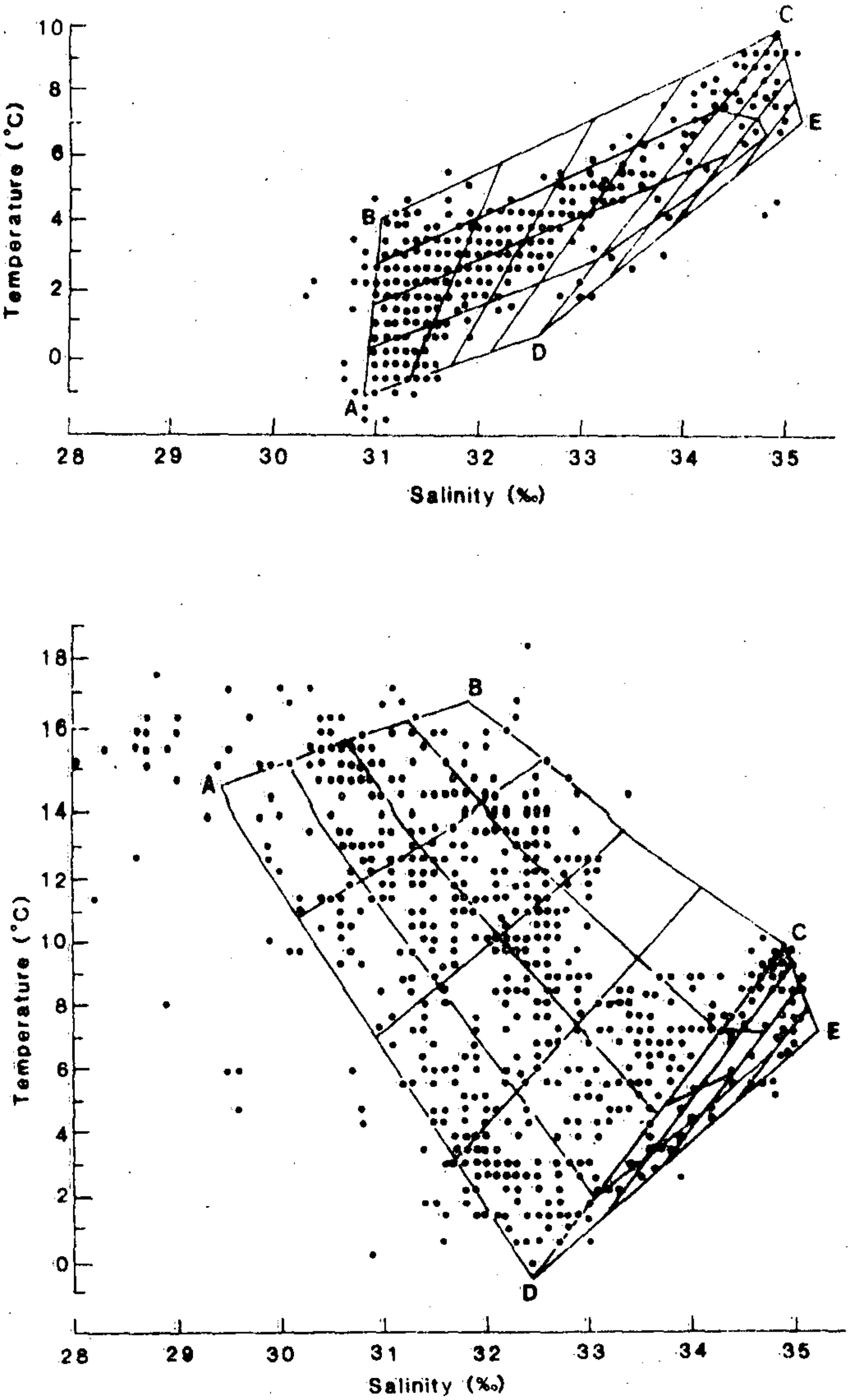

Fig. 1. Temperature-salinity diagrams of data for the Scotian Shelf contained in MEDS (Ottawa) data bases. Each dot represents one or more samples. Letters and grid lines represent source water regions and water masses as defined in the text. (A) Spring (Feb., Mar, Apr., 1979-84), (B) summer (June, July, Aug., 1979-84).

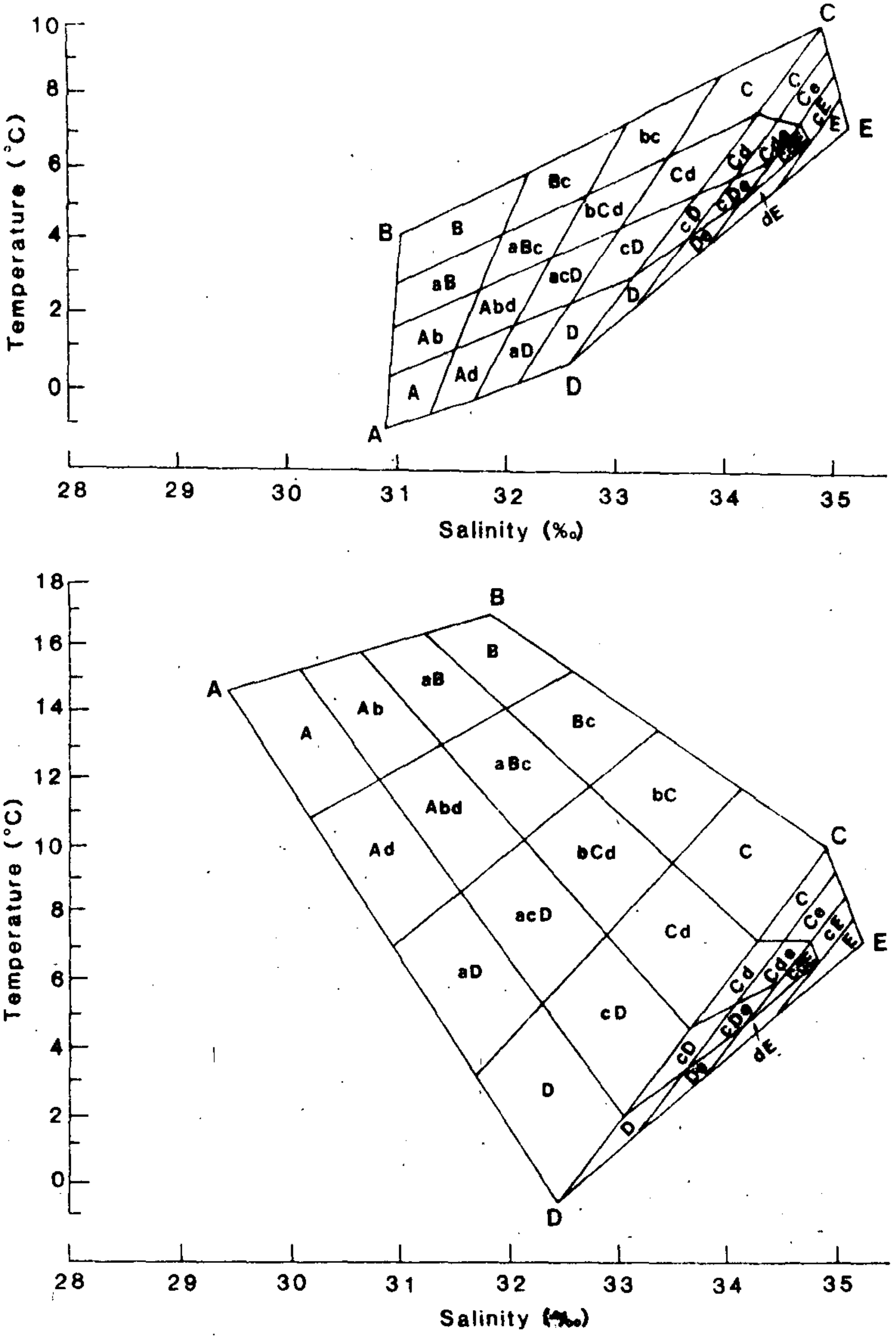

Fig. 2. Temperature-salinity diagrams as for Fig. 1, but with data points removed and the cells labelled as to their characteristic water mass (see text for details). (A) Spring, 1979-84; (B) Summer, 1979-84.

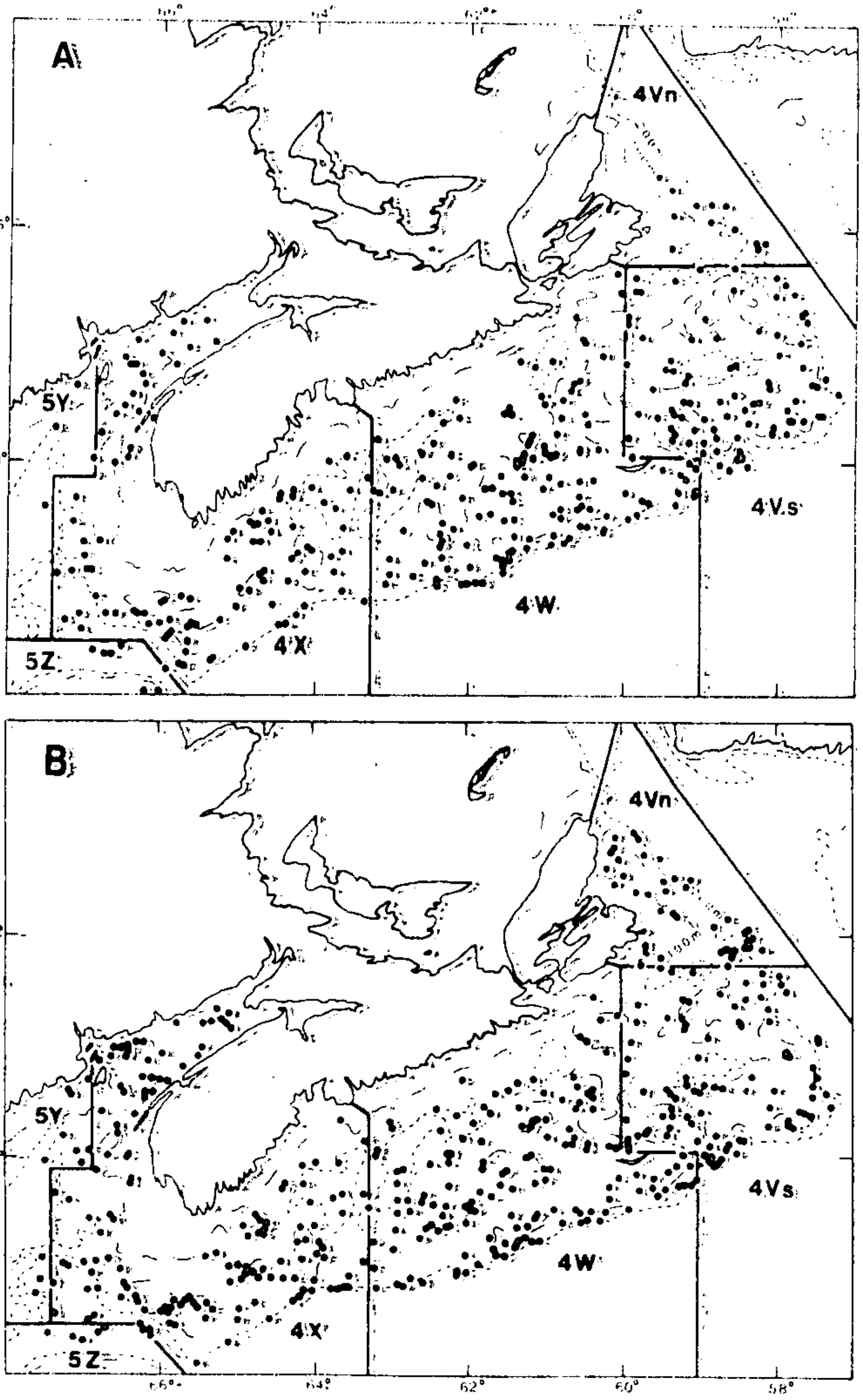

Fig. 3. Locations of stations sampled during spring (A) and summer (B) standard groundfish surveys of the Scotian Shelf, 1979-1981.

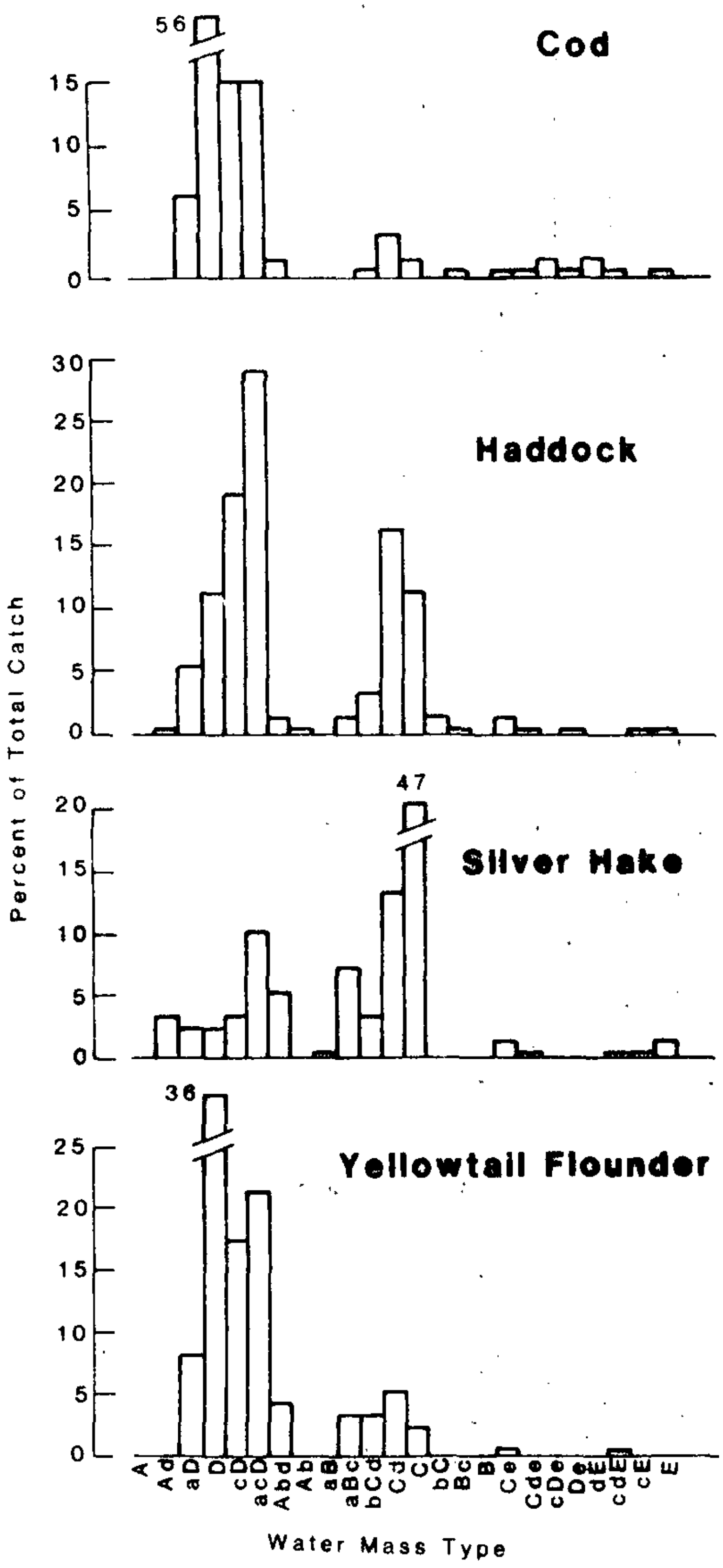

Fig. 4. Histograms representing the percentage of the total 1979-84 summer catch of each species that occurred in each water mass type. Water mass identifications are as represented in Fig. 2b. Total numbers of each species caught were: cod (44394), haddock (60185), silver hake (48211) and yellowtail flounder (18515).

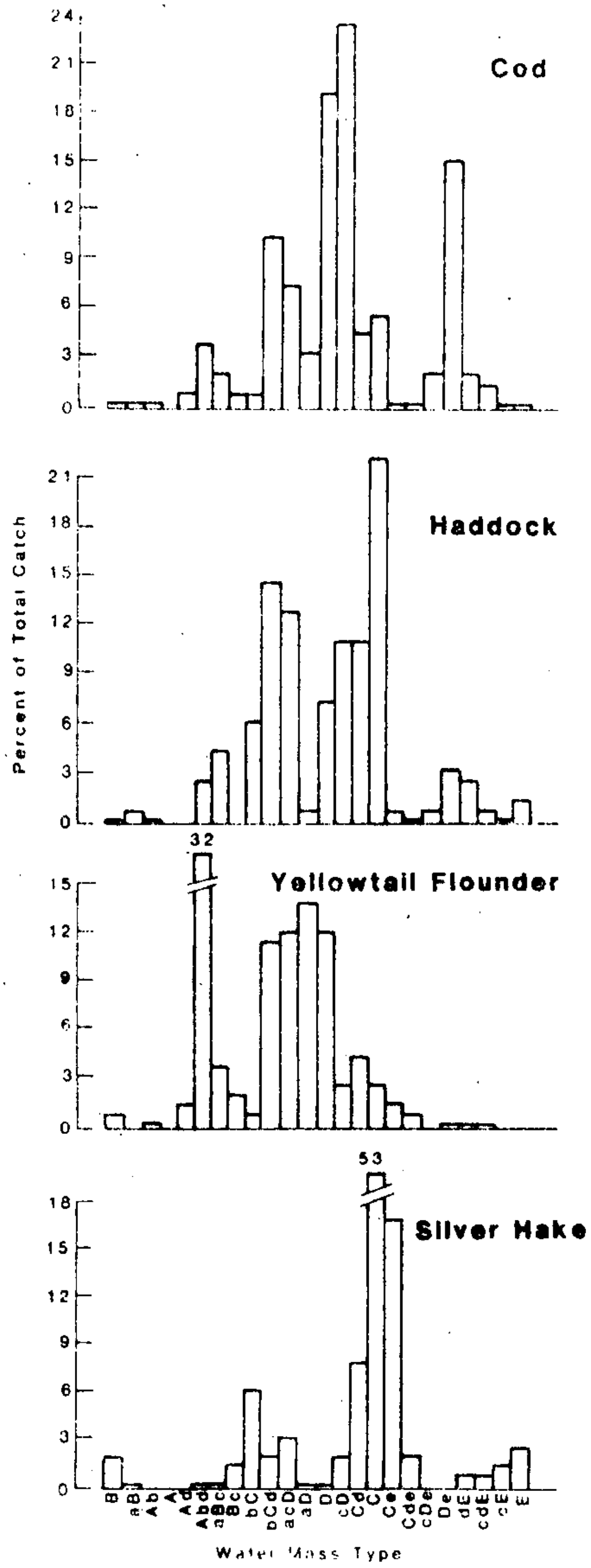

Fig. 5. Histograms representing the percentage of the total 1979-84 spring catch of each species that occurred in each water mass type. Water mass identifications are as represented in Fig. 2a. Total numbers of each species caught were: cod (25924), haddock (86158), yellowtail flounder (9367), and silver hake (66495).

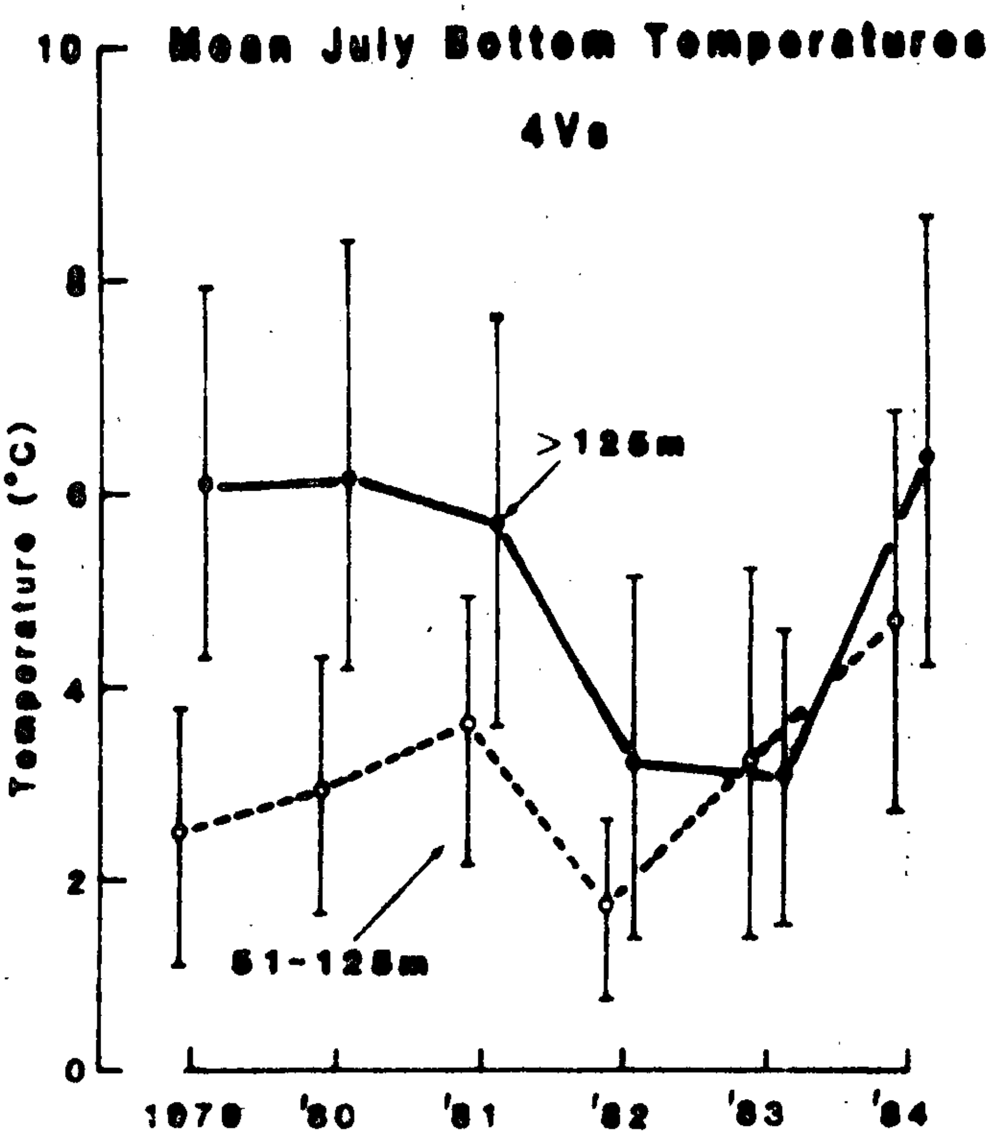

Fig. 6. Mean (±1 standard error) bottom temperatures from data collected during groundfish surveys during summer (July), 1979-84, on the northern Scotian Shelf (NAFO Division 4Vs). The two depth ranges approximate the cold intermediate water layer (51-125 m) and the warm bottom layer (>125 m).

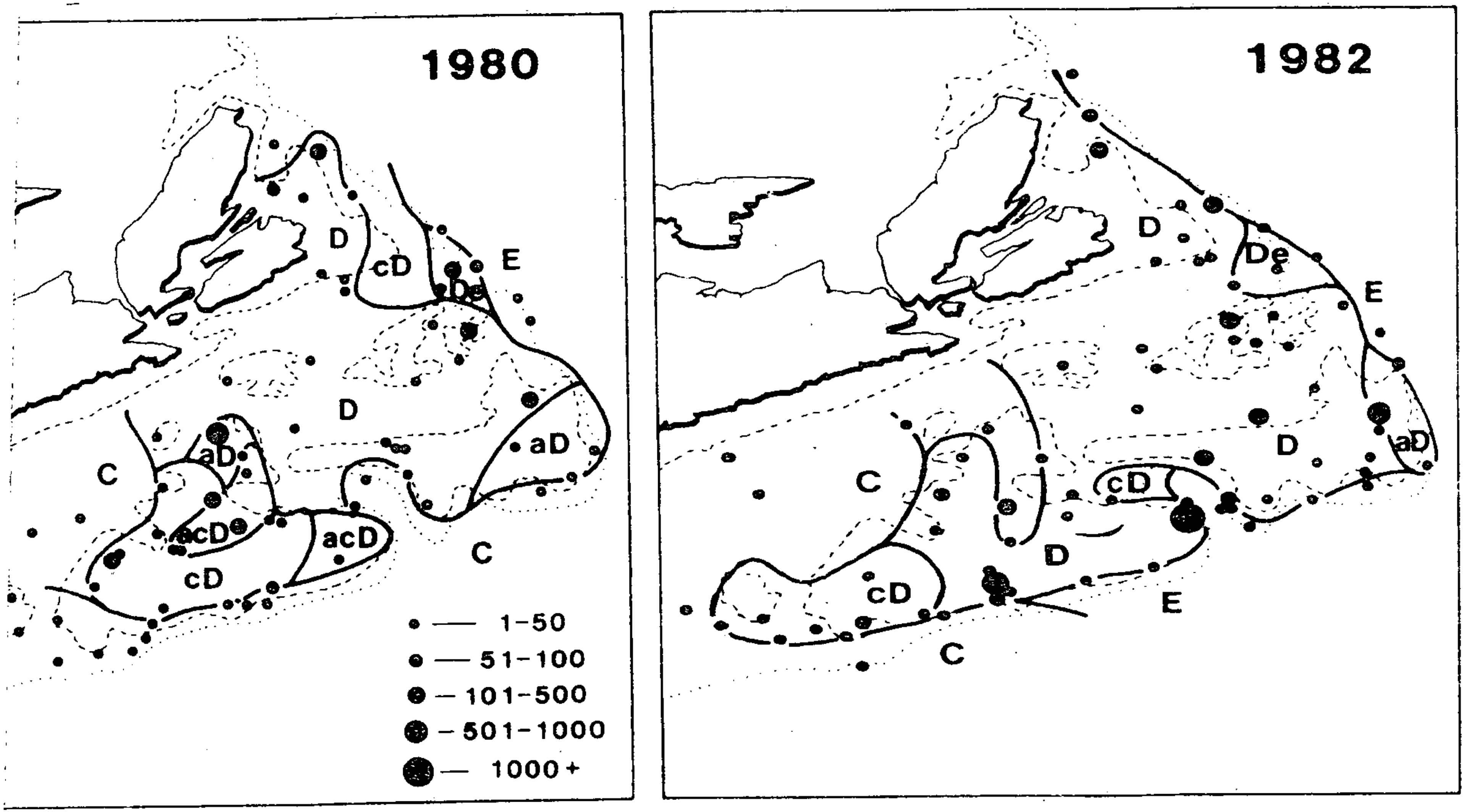

Fig. 7. Summer 1980 (A) and 1982 (B) catches of cod on the northern Scotian Shelf superimposed on the characteristic bottom water mass types. Water mass designations as in Fig. 2.