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Variances of Vertebral Sample Frequencies in Atlantic Cod (*Gadus morhua*) of the Newfoundland and Adjacent Areas, 1947–71

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Abstract

Variances of frequencies of vertebral numbers from samples of cod (*Gadus morhua*) from the Northwest Atlantic showed significant differences between many cod populations of this area. Cod produced in areas with limited and low temperature range during egg and early larval development – such as in West Greenland, offshore Canadian areas from Funk Island Bank northward on offshore banks and coastally in northern Labrador, on Flemish Cap, the southern Scotian Shelf, and Georges Bank – tend to have low variances, whereas the frequencies of cod vertebral numbers from the Grand Bank, St. Pierre Bank, Newfoundland coastal areas, and most other areas with later spawning and higher temperature range and higher temperatures during egg development typically have higher variances. Where two groups of cod with differing patterns of vertebral numbers intermingle, variances tend to be high. Chi-square calculations were used to show differences between groups of variances in many areas occupied by different or mixed stocks.

Key words: Cod, biological characteristics, complexes, Newfoundland area, stock

Introduction

Vertebral numbers were used to define areas of separation and intermingling for stocks and stock complexes of cod (*Gadus morhua*) of the Newfoundland and adjacent areas (Templeman, 1981; 1989). The time and length of the spawning period and the related temperatures, largely controlling the speed of egg and early larval development and, thus, the numbers of vertebrae, affect the range of vertebral numbers and, thus, the variances of the samples. The variances show even greater relative differences than vertebral means, indicate areas of separation and intermingling of stocks and stock complexes, and sometimes show differences between stocks which are not readily separated by vertebral means.

The purpose of this paper is to present and compare variances of cod vertebral number frequencies in the Northwest Atlantic and to demonstrate how and why variances and groups of variances differ in relation to major stocks of cod and to their intermingling as previously outlined in vertebral number, spawning, and migratory comparisons. For convenience in presentation in Fig. 3 and 5, variances are multiplied by 100 and called variance indices (VI).

Materials and Methods

The variances of cod vertebral frequencies used in this paper are for the same samples and locations shown in the figures of Templeman (1981) for cod vertebral means. Figure 1 shows the various NAFO Subareas and Divisions and various locations from which samples shown in Fig. 2–5 were taken. The urostylar half-vertebra is included as a vertebra in these frequencies which were collected during 1947–71. Attempts were made to collect 120 specimens for each vertebral sample so that at least 100 would remain after discarding vertebral columns because of breakages and vertebral fusions. This was not always possible when catches were small. The methods of collecting and preparation of vertebral columns and of counting vertebrae are outlined in Templeman (1981).

Results

General patterns of differences in variances

In the Newfoundland area (Fig. 3 and 5), the lowest variances are on Flemish Cap; and the next lowest are on the offshore part of the Northeast Newfoundland and Labrador shelves from Funk Island, Belle Isle, and Hamilton banks northward to Ungava Bay and coastally from northward of the

[1] This paper was submitted by Dr Wilfred Templeman on 4 April 1990, the day before he passed away at the age of 82. We have published the original, unrevised paper as a tribute to one of the most outstanding marine scientists.

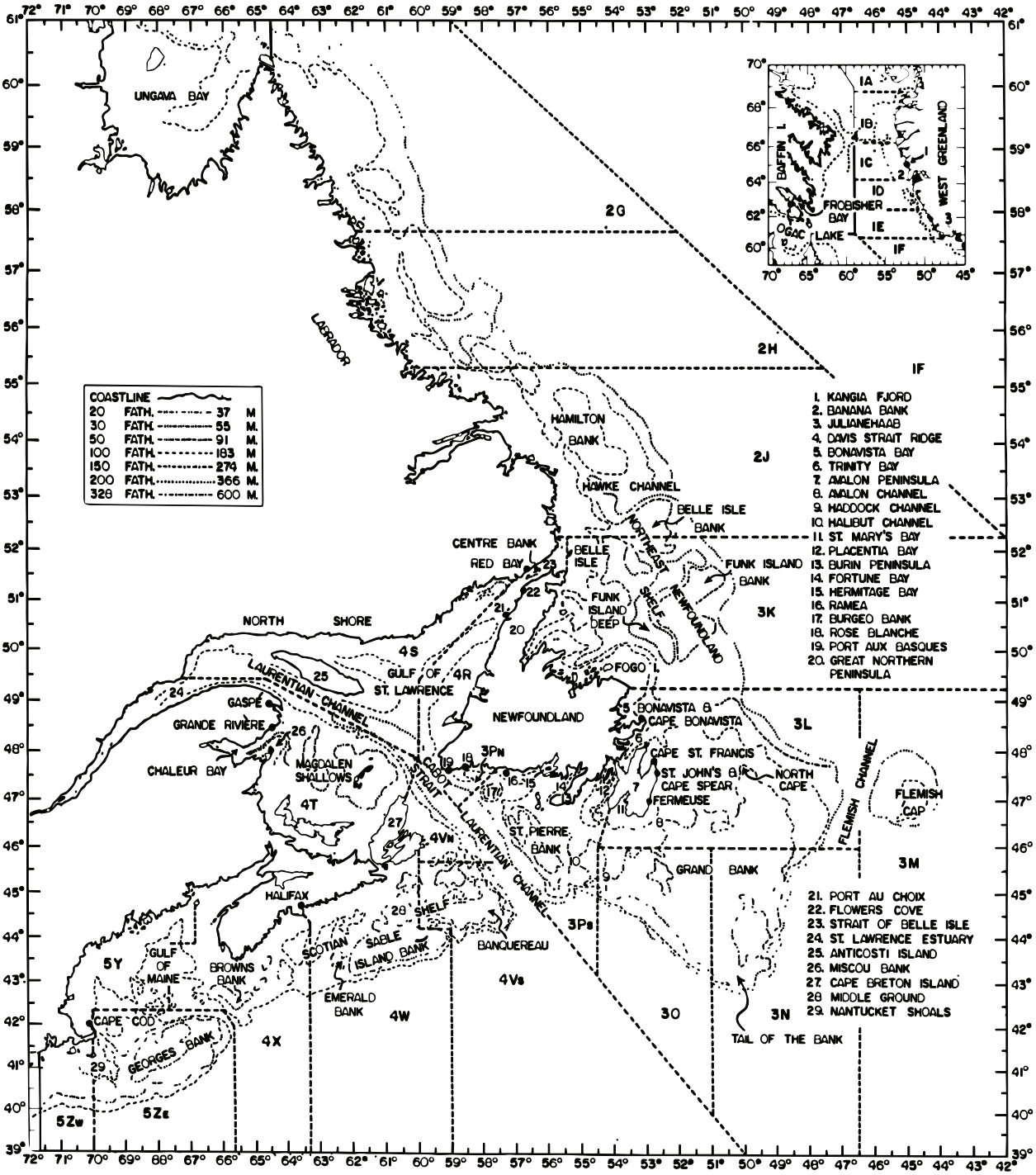

Fig. 1. Place names from the sample area, and NAFO Divisions and Subareas (from Templeman, 1981).

northern border of the entrance of Hamilton Inlet along the Labrador coast. Variance values are higher coastally off southeastern Labrador; around the island of Newfoundland; in the northern part of the Gulf of St. Lawrence; and on the Grand Bank, St. Pierre and adjacent banks. Variances are lower in the southern than in the northern Gulf of St. Lawrence and on Banquereau than on St. Pierre Bank, declining to still lower values along the more southern part of the Scotian Shelf and on Georges Bank.

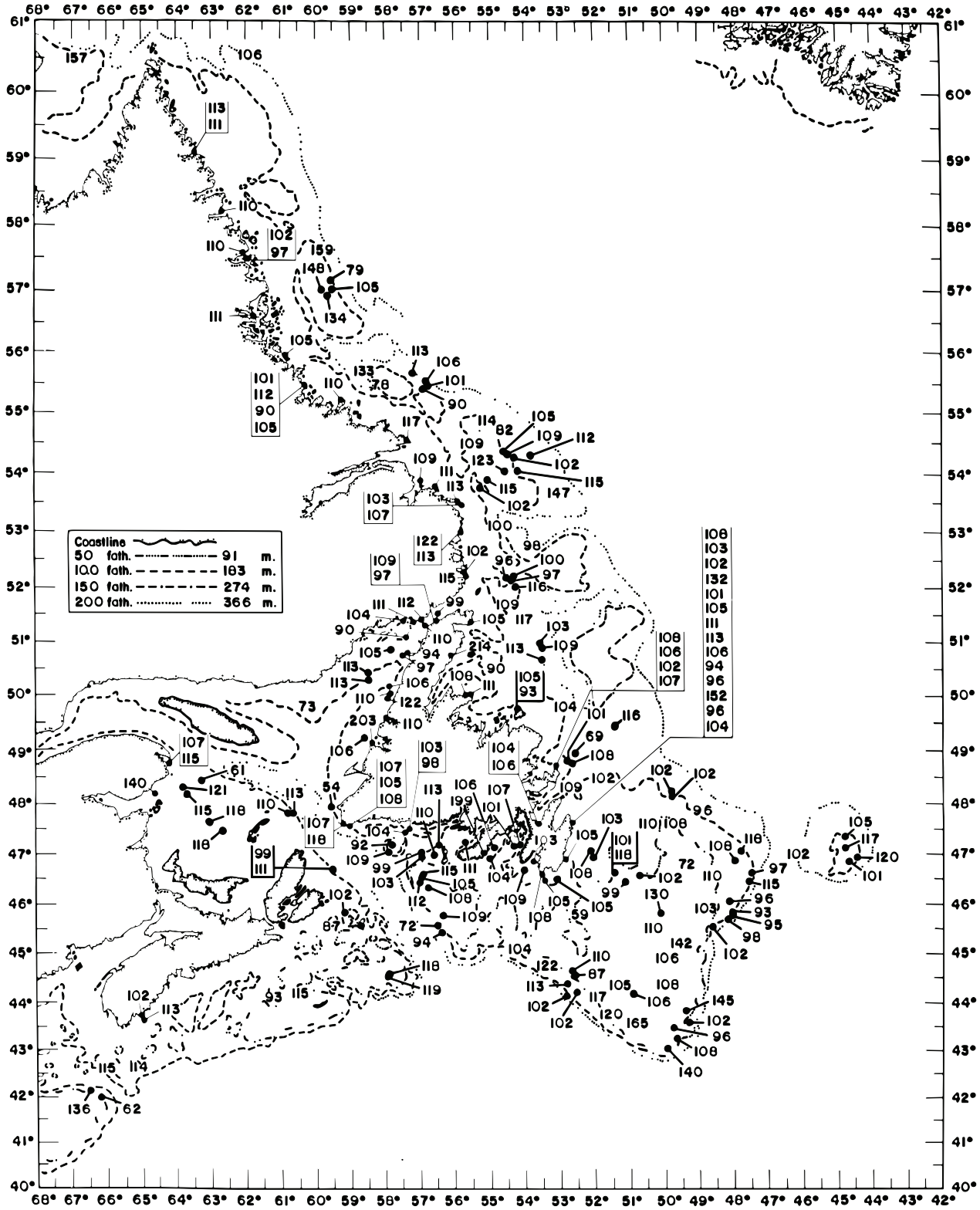

Fig. 2. Numbers of cod vertebral columns included in vertebral counts for the period 1947–60, whose frequency variance indices are shown in Fig. 3 (encircled numbers in Fig. 2–5 are those of samples with less than 70 vertebral columns).

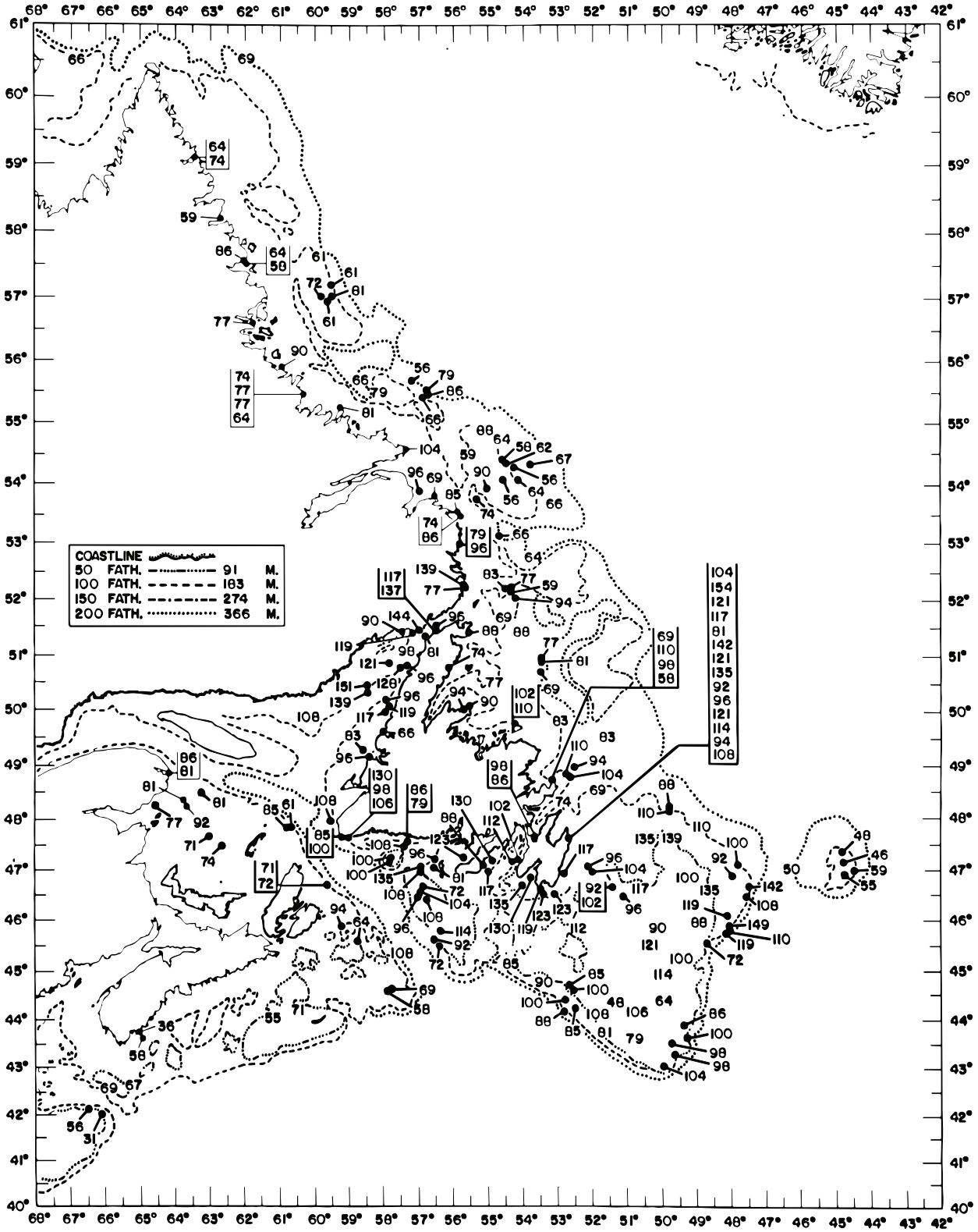

Fig. 3. Variance indices (variance 100) for the cod vertebral samples of Fig. 2, 1947–60 (and for the vertebral means of fig. 3 of Templeman, 1981).

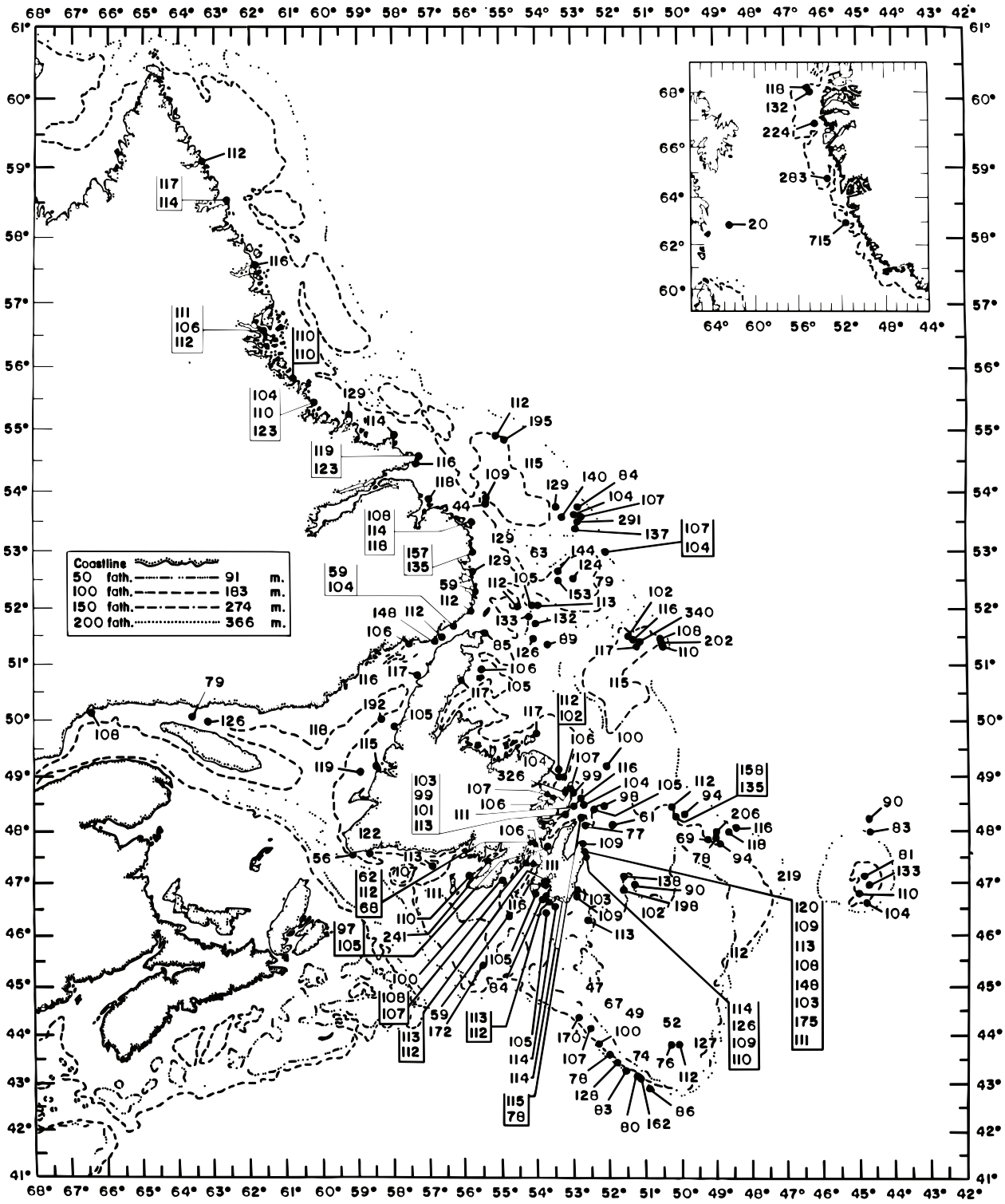

Fig. 4. Numbers of cod vertebral columns included in vertebral counts for the period 1961–71, whose frequency variance indices are shown in Fig. 5 (the Baffin Island sample in Fig. 4 and 5 was taken in 1959 but for convenience was included with the 1961–71 data).

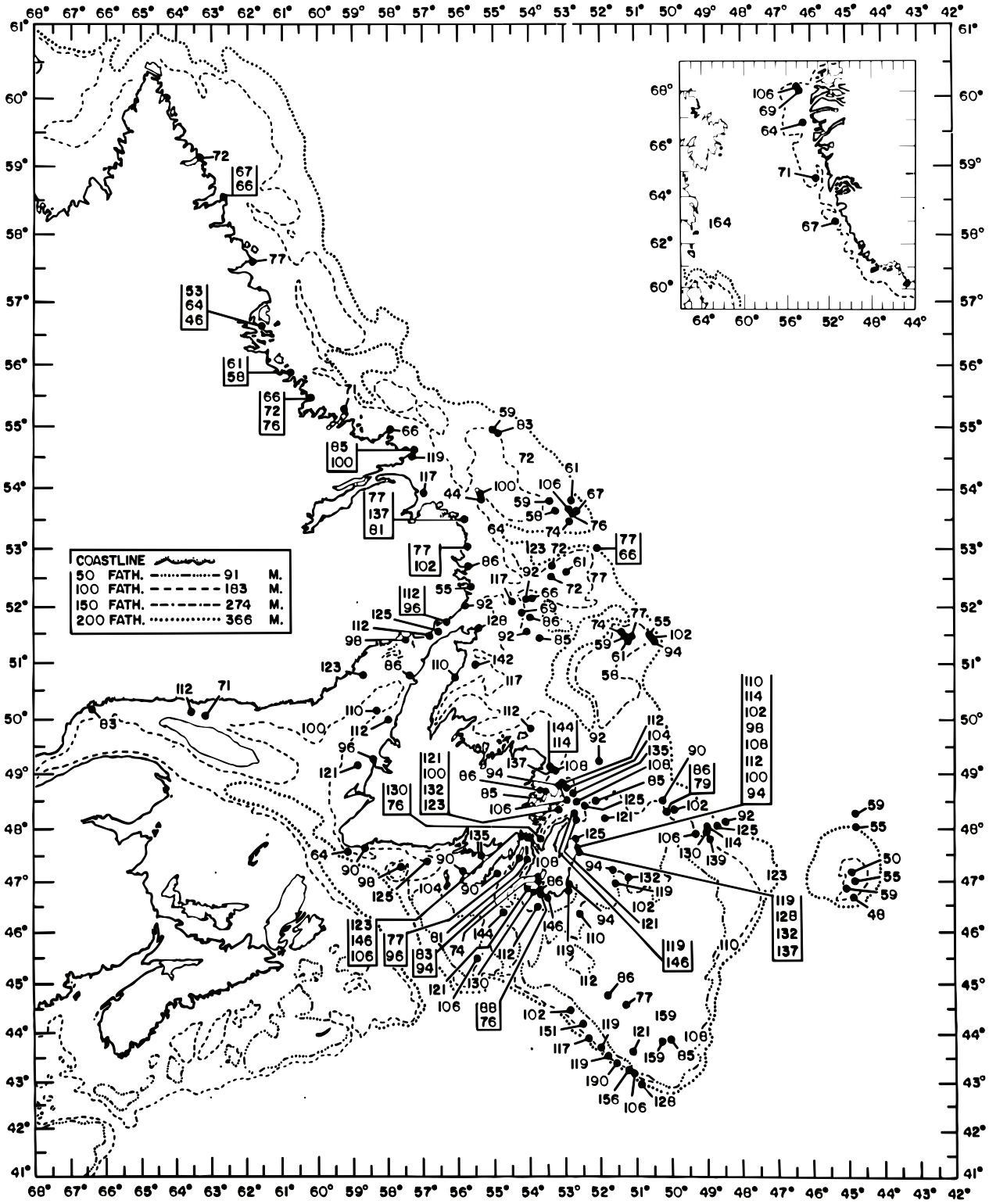

Fig. 5. Variance indices for the cod vertebral samples of Fig. 4, 1961–71 (and for the vertebral means of fig. 5 of Templeman, 1981).

The most northerly western sample off Baffin Island had a very high variance (VI 164) but only 20 fish (Fig. 4 and 5).

There are area patterns showing considerable changes in variance within short distances: the low variances of Flemish Cap and the high variances of the northeastern Grand Bank, the low variances of Funk Island Bank and the higher variances of the northern Grand Bank, the lower variances in coastal Labrador north of the northern entrance to Hamilton Inlet and the higher coastal variances in coastal Labrador southward of this point, the lower variances of Hamilton and Belle Isle Banks and the considerably higher variances in the Strait of Belle Isle and the northern Gulf of St. Lawrence, the high variances of the northern Gulf of St. Lawrence, and the lower variances of the southern Gulf.

Some differences are apparent between the variance values for 1947–60 (Fig. 3) and those for 1961–71 (Fig. 5): higher variances on the coastal shelves off northeastern Newfoundland and in the Bonavista area in 1961–71; much higher variances on the southwestern Grand Bank in 1961–71 than in 1947–60.

In many areas, there are occasional higher or lower variances than those typical of the area; but some of these values could be chance occurrences and others due to schools or mixtures of schools from different stocks.

Statistical comparisons

Individual samples. For the variances of Fig. 3 and 5, almost all the sample numbers were between 70 and 120 or more and only 20 of the 416 samples contained fewer than 70 vertebral columns (Fig. 2 and 4). These low number samples were omitted in the statistical calculations for Table 1. The usual differences in numbers in the vertebral frequencies from which the variances were calculated have negligible effects on the variance. In a sample of 70 vertebral columns from the southern Grand Bank, for example, with vertebral numbers and (frequencies): 52(7), 53(17), 54(21), 55(20), 56(5), the variance of the sample was 1.23. If the sample is doubled to 140, the variance is 1.22; and with the sample quadrupled to 280, the variance is 1.22. The differences are negligible for the sample numbers used in these figures apart from variations from normal in the frequency spread.

It is possible, therefore, for studies of differences in groups of variances, to use direct comparisons of variance values as in the chi-square comparisons below. Because, where stocks with lower and higher vertebral numbers intermingle – as on the northern slope of the Grand Bank (Templeman, 1979; 1981) – the resulting variances tend to be high, variances are not usually useful for separating stocks within these areas.

Comparisons of groups of variances. Because with the sample numbers used – apart from chance variations in the vertebral frequency pattern – the variances are negligibly affected by changes in sample numbers, their relative variance values in different areas (as represented by variance indices) may be compared by using 2×2 chi-square contingency tables as in Table 1. It is apparent from this table: that the variances for the cod stocks offshore from Funk Island Bank northward offshore along the Labrador Shelf and coastally off northern Labrador were highly significantly lower than those of the Grand Bank cod (Table 1A); that the variances of the coastal cod of northern Labrador were highly significantly lower than those of the southern Labrador coasts (Table 1C); that the variances of the offshore Hamilton Bank, Belle Isle Bank, Funk Island Bank, and vicinity were significantly lower than those of the adjacent coastal regions of southern Labrador and northeastern Newfoundland (Table 1D); that the variances from Flemish Cap were highly significantly lower than those from the adjacent northeastern Grand Bank (Table 1E); that the variances from the Gulf of St. Lawrence, south of the Laurentian Channel, were highly significantly lower than those from the northern Gulf, north of the Laurentian Channel (Table 1F); and that the variances from the southern part of the Scotian Shelf and Georges Bank were significantly lower than those from the northern part of the Scotian Shelf and the southern Gulf of St. Lawrence (Table 1G). However, the variances form the offshore Labrador Banks north of Hamilton Bank were not significantly different from those of the adjacent Labrador coastal areas (Table 1B). Items B, F and G of Table 1 were checked by Fisher's Exact Test (Zar, 1974); and the results were similar to those of Table 1 – i.e. the groups of B were not significantly different at the $P \leq 0.05$ level and those of F and G were significantly different.

Discussion

Higher variances come from a greater spread in vertebral frequencies. These may be provided within a stock from an extended spawning season or from spawning later in the year with upper layer temperatures increasing more rapidly, by differences in vertebral numbers between year-classes from yearly differences in time of spawning and/or in upper layer temperatures and by intermingling of stocks with differing vertebral number frequencies.

TABLE 1. Chi-square comparisons of variance indices of vertebral number frequencies of cod from the Northwest Atlantic. (Chi-square comparisons of data in 2 × 2 contingency tables with Yates correction for continuity. Samples with less than 70 vertebral columns (encircled in Fig. 2–5) omitted.)

Item	Row	Areas compared	Sizes variance indices compared: Column Period	Sizes variance indices compared: Column a & b	No. variance indices compared Row 1 a & c Row 2 b & d: Column c & d	No. variance indices compared Row 1 a & c Row 2 b & d: Column a & b	c & d	Chi-N	P square	(DF = 1)
A	1	Offshore Funk I. Bank to most northern Labrador Banks and Ungava Bay and coastal Labrador N of N entrance to Hamilton Inlet at about 54°40'N	1947–71	<80 a	>80 c	75	23	172	79.73	<0.001
	2	Grand Bank		b	d	5	69			
B	1	Offshore Labrador banks from N of Hamilton Bank to Ungava Bay	1947–60	<70 a	>70 c	8	5	26	0.62	>0.05
	2	Coastal Labrador N of northern entrance to Hamilton Inlet at about 54°40'N		b	d	5	8			
C	1	Coastal Labrador N of N point of entrance to Hamilton Inlet	1947–71	<80 a	>80 c	24	3	48	23.84	<0.001
	2	Coastal Labrador, N point entrance Hamilton Inlet to N entrance Strait of Belle Isle		b	d	6	15			
D	1	Offshore Hamilton Bank, Belle Isle Bank, Funk I. Bank and vicinity	1947–71	<80 a	>80 c	40	18	92	16.19	<0.001
	2	Coast and coastal shelf, N entrance Hamilton Inlet to and including Notre Dame Bay		b	d	8	26			
E	1	Flemish Cap	1947–71	<60 a	>60 c	11	0	36	31.44	<0.01
	2	NE Grand Bank N from 45°N and E from 50°W		b	d	0	25			
F	1	S Gulf of St. Lawrence, S of Laurentian Channel	1947–60	<90 a	≥90 c	8	1	29	11.43	<0.001
	2	N Gulf, N of Laurentian Channel to and including Strait of Belle Isle		b	d	3	17			
G	1	S Scotian Shelf from Sable I. Bank southwards and Georges Bank	1947–60	<70 a	>70 c	6	1	23	5.04	<0.05
	2	S Gulf of St. Lawrence and N Scotian Shelf including Banquereau		b	d	4	12			

The low Flemish Cap variances are due to an unusual scarcity of both high and low vertebral numbers and the resulting concentration of the frequencies in few vertebral numbers. This, in turn, is a result of the spawning, mainly in March, in an area where the upper water layers at that time are relatively stable, with usually a lack of considerable temperature difference in the upper 100-m layer in the early part of the year. The cod populations of the Flemish Cap and of the northeastern Grand Bank are clearly different, as defined by variances; whereas, they are not distinct in vertebral numbers including all year-classes (Templeman, 1976; 1979; 1981). However, Lear *et al*. (MS 1979) reported that the variance of the vertebral frequency for each of the cod year-classes of 1956–59 on Flemish Cap was significantly lower than that of the corresponding year-class on the adjacent slope of the northeastern Grand Bank.

The next lowest variances in the Newfoundland area were in Ungava Bay and off Labrador and southward offshore to Funk Island and for 1947–60 off the eastern coast of the Great Northern Peninsula. This includes most of the area where the Labrador/East Newfoundland stock complex is not intermingled greatly with other stocks. The main spawning is in the Labrador to Funk Island Bank area in March and April. At this time, the presence of ice ensures that upper layer temperatures in this area are stable, usually at or below 0°C, with little increase in temperature above 0°C at the surface before the end of May; and even then and into June and later, most of the upper 100 m remains at or below 0°C (Templeman, 1979; 1981). The spawning of most of the cod early in the year, and the lack of any considerable increase in temperature for several months after the major spawning, reduces the spread in the vertebral frequencies and, hence, ensures low variances.

The higher coastal and coastal shelf variances and the lower vertebral numbers off the northeast coast of Newfoundland in 1961–71 than in 1947–60 may have been mainly produced by the greatly increasing fishery on the spawning cod off Labrador from 1960 onward, reducing the numbers of high-vertebral-count cod produced from spawning in the earlier part of the year, which formed the majority of cod in the earlier period and, thus, increasing the relative numbers of cod of lower vertebral count from spawning on coastal shelves and in coastal bays later in the year or from migration of cod from areas of lower vertebral count. In the second period also, owing to the increasing use of large-meshed synthetic gillnets (usually used in deeper water than the traps and handlines and most of the bottom longlines providing the inshore samples of the early period), more large cod with lower vertebral numbers were sampled (Templeman, 1989). These may have come from the Gulf, or from Grand Bank or other southern areas with low vertebral numbers. The new mixture could have produced the lower vertebral numbers as well as the higher variances.

There were sharp increases in the variance for most samples along the east coast of Newfoundland from Fogo Island southwards around the Avalon Peninsula and on northern Grand Bank. Migration studies (Templeman, 1979) showed that gradually decreasing proportions of cod from north to south, in the coastal region from Fogo Island to and around the Avalon Peninsula, migrated to reside, in winter/spring, off Labrador and on the Northeast Newfoundland Shelf. These studies also showed that fish from these coastal areas migrated in gradually increasing proportions from north to south to spend the winter/spring on the northern and northwestern Grand Bank. Both migrations were presumably for spawning. Similarly, some cod from the northern slope of Grand Bank migrated northward for spawning and others with low vertebral numbers spawned on northern Grand Bank. Vertebral numbers throughout the above area similarly showed a mixture of northern high-vertebral-count and southern low-vertebral-count cod (Templeman, 1981). The higher variances in the area were, thus, partly due to the presence of cod of the northern stock complex with a large proportion of cod with a high vertebral count and more southern stocks with a large proportion of cod with a lower vertebral count. Similar high variances were common for cod of the southern Grand Bank stock on the southern part of and over Grand Bank. From cod of this stock, spawning mainly in April-June, eggs develop not only under rapidly increasing temperatures but also in a wide range of temperatures in the same month. Thus, there are wider ranges of temperature effects and considerably higher temperature conditions than during the developmental period of the Labrador/East Newfoundland stock complex so that, usually, a wider range of vertebral numbers is produced giving high variances. A similar argument is applicable to St. Pierre Bank variances which were somewhat similar to those of the southern Grand Bank.

During 1961–71, some samples with higher variances and some with higher percentages of high vertebral numbers than during 1947–60 were present on the southwestern slope of the Grand Bank. As an example, three of these samples taken in May 1965 in the same general area of the southern Grand Bank with standard deviation indices of 156, 159 and 190 (Fig. 5) were examined by length range, with results as in Table 2. The high variances were due to the wide range of the vertebral frequency and the resulting high variances in the

TABLE 2. Statistical and other parameters by length range of fish for three cod vertebral samples taken 12–15 May 1965 on southern Grand Bank, with variance indices: 156, 159 and 190 (Fig. 5).

Fish length range (cm)	Mean vertebral number	Variance	S.E.	No. of fish	Percentage 50–52 vertebrae	Percentage 57–59 vertebrae	Range of vertebral numbers
11–30	54.38	2.19	0.21	50	8	4	51–57
31–50	54.30	1.88	0.14	92	8	3	51–58
51–70	54.07	1.14	0.21	27	4	4	52–57
71–90	53.53	1.46	0.21	34	18	0	51–56
91–120	53.36	0.69	0.14	36	11	0	52–55
11–120	54.04	1.77	0.09	239	9	3	51–58

smaller fish, especially at 11–50 cm, including some fish within the normal southern Grand Bank range and others with higher than usual percentages of high vertebral numbers for this area. This situation presumably resulted from lower than usual temperatures during egg and possibly early larval development. The larger cod had the usual southern Grand Bank vertebral characteristics, with low vertebral averages, zero percentages of high vertebral numbers, and low variances. The vertebral mean, the variance, and the percentages of high vertebral numbers were higher or lower depending on the predominance of smaller or larger fish in the sample.

The generally higher variances in the Gulf of St. Lawrence north of the Laurentian Channel than those off Labrador can be partly ascribed to a later and more extended spawning season (Templeman, 1979; 1981), and those in and near the Strait of Belle Isle to some intermingling between the Labrador/East Newfoundland and the Northern Gulf stocks (Templeman, 1979). This is indicated also by the presence of samples with low, and of others with high, vertebral numbers in and near the Strait of Belle Isle (Templeman, 1981), whose intermingling provides high variances. The Southern Gulf stock south of the Laurentian Channel typically had lower variances than the Northern Gulf stock and only a little higher than those off Labrador. The explanation for the rather low variances of the Southern Gulf stock is not completely available. It may be that spawning is concentrated in a shorter time and smaller area than in the northern Gulf but this is not known.

The generally low variances on the Scotian Shelf and on Georges Bank may be ascribed to spawning occurring early in the year with a slower rate of temperature increase and a lesser temperature range and lower temperatures during egg development than would occur if spawning were later in the year. Peak spawning in the area occurs later in the year from south to north, approximately from late February on Georges Bank, to late March on Brown's Bank, in April on Sable Island Bank and in May on Banquereau, which tends to balance the rate of temperature increase. (See Templeman, 1981, for related detailed discussion and references.) The occasionally higher variances on Banquereau may be partly due to the intermingling of Banquereau cod with those of the southern Gulf and of cod and cod larvae from St. Pierre Bank and vicinity.

The high variance of the Baffin Island sample (VI 164; Fig. 5) and the related possession of a typical percentage of high vertebral numbers and a higher than expected percentage of low vertebral numbers, similar to those of West Greenland, offer the possibility that some of the Baffin Island cod have their origin off West Greenland or from Ogac Lake in Frobisher Bay (Templeman, 1981).

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