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The interrelationships between herring stocks in the Canadian Atlantic fisheries as revealed by multivariate analyses of their meristic characters

by

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Introduction

The problem of herring stock identification is one of the important research problems in management of herring fisheries. In the past, the herring fisheries in the northwest Atlantic, with the exception of those in the Bay of Fundy and the Gulf of Maine, were based upon adult fish, caught with fixed gear near the spawning grounds. Fish caught in this manner, during their spawning migration, constituted homogeneous spawning populations and for fisheries management purposes could be treated as discrete stocks. However, with the advent of purse-seine fisheries in the mid 1960's, fish began to be caught offshore, away from the spawning grounds during the feeding stage of their life cycle and the winter migration. During feeding and the winter migration, fish originating in different spawning areas gather together on common feeding grounds and overwintering areas. Thus, management of the fisheries has become much more complicated and the question came to be raised as to whether it was possible that the same herring stocks were now being fished in different locations at different stages of their life cycle.

Several investigations have been carried out to determine the migration routes of herring and the relationships between different herring stocks. Winters (1971), Stobo et al. (1975), and Stobo (1978) have conducted tagging studies to learn about migration patterns and mixing of discrete spawning stocks. Other researchers have attempted to identify the origins of herring stocks on the basis of their meristic characteristics. Messieh and Tibbo (1971), Parsons (1973), Hodder and Parsons (1971) and Messieh (1974) have done univariate analyses comparing meristic characters of different stocks. Parsons (1972) and Messieh (1975) have also used meristic measurements to develop multivariate discriminant functions for distinguishing between herring stocks. These studies have established that spring and autumn spawning herring can be distinguished between on the basis of their meristic characteristics.

The present study was undertaken to see if meristic characteristics could also be used to distinguish between herring collected in different geographical areas and to determine if interrelationships exist between herring from different areas.

Materials and Methods

Thirty-two herring samples consisting of a total of 1843 fish were collected during 1973 from various areas in the northwest Atlantic (Fig. 1). These samples were of many different types - spawning fish, young fish, spring spawners, autumn spawners and samples of an unknown nature. The locations sampled, the months the samples were collected, and the number of fish used in the analyses are given in Table 1. Meristic counts were made on each fish on its vertebral numbers (V), pectoral fin-rays (P), dorsal fin-rays (D), gill rakers on the lower arch (G), anal fin-rays (A) and posterior keeled scales (K). The techniques used to examine and count these meristic characters have been described in detail by Messieh (1974, 1975). Only fish having no missing observations on all six meristic characters were considered in the analyses that followed.

Initially, it was decided that discriminant analyses should be done to determine if herring coming from different geographical areas could be distinguished between on the basis of their meristic measurements. Six groups of samples, representative of different geographical areas, were selected as test groups for setting up a discriminant function to classify the remaining samples. Four of the six test groups consisted of autumn-spawning herring. These were the GULF A group, composed of two samples from areas (432) and (436) in the southern Gulf of St.Lawrence, the SYDN A group from the Sydney area (470), the CHED A group from area (451) in Chedabucto Bay, and the SWNS A group from areas (463) and (466) off southwestern Nova Scotia. The remaining two test groups consisted of the spring spawning herring groups: GULF S from area (433) in the southern Gulf of St.Lawrence and CHED S from area (451)in Chedabucto Bay. Subsequently, the Sydney group was discarded as a representative group because it showed little cohesion.

Two discriminant analysis programs from the Biomedical Package, Dixon (1973) were used to examine the interrelationships between the six test groups described above. The first program BMD04M (Discriminant Analysis for Two Groups) was used to compare all possible pairs among the six test groups to see if these groups could be distinguished between on an individual basis. Each of these 15 pairwise discriminant analyses included a multivariate test of the hypothesis that the two groups being compared, had the same mean meristic measurements and the classification of each fish in the two groups being compared into one or other of the groups.

The second discriminant analysis program BMD07M (Stepwise Discriminant Analysis) was used to set up a discriminant function which would distinguish between all six test groups. The meristic variables were entered into the discriminant function in a stepwise manner according to their relative ability to discriminate between the six test groups. The discriminant function developed using all the meristic variables was then used to classify each fish in the six test groups and the remaining samples as belonging to one of the six groups. The output also included a plot of the meristic data on each fish as transformed by the first two canonical discriminant functions, which was meant to give an optimal two-dimensional picture of the separation between groups.

Two clustering procedures (cluster analysis and principal component analysis) were used to group the herring samples without setting up the predetermined test groups required in a discriminant analysis. These procedures permitted comparison of each sample with every other sample in order to determine which samples were most alike on the basis of their meristic measurements. It is important to note that both clustering procedures were based on sample means rather than individual observations. As a result, variation within samples was not taken into account in the cluster analyses.

The principal component analysis based on the sample means was run on the Biomedical program BMD01M, which performed a principal component analysis based on the correlation matrix of the mean meristic counts for the 32 samples collected and then transformed the sample means by the first two principal components so that they could be plotted by hand.

The cluster analysis based on the sample means was run on the 1975 version of the Biomedical programme BMDP2M (Cluster Analysis on Cases) using the Euclidean distance to measure the similarity between samples and the group centroid method of amalgamation, Everitt (1974).

Results

The meristic characteristics measured do not appear to be correlated with the length of the fish. The only apparent relationship was that young fish under 16 cm. in length had slightly lower gill raker counts than larger fish (Table 3). Such small fish, however, comprised less than one per cent of the total number.

The mean values of all meristic characters for representative groups from the six major fisheries are listed in Table 2. With only one exception, the mean meristic measurements of the autumn spawning groups were higher than those of the spring spawning groups. In the Sydney autumn spawning group, the mean anal fin-count was 17.696 as compared to 17.714 in the spring spawning Chedabucto Bay group.

The pairwise tests of equality of the representative group means, computed in the pairwise discriminant analyses, are given in Table 4. The F values were significant in 10 out of the 15 cases at the .05 probability level and 9 out of 15 at the .01 level. The means which were not significantly different were those of pairs of autumn spawning groups.

The results of the stepwise discriminant analysis are presented in Tables 5 and 6. Table 5 is a summary table showing the relative ability of the meristic variables to discriminate between the six test groups. The variables best at distinguishing between the test groups were, in descending order: gill raker counts (G), pectoral fin counts (P) and vertebral counts (V). Table 6 lists the classification results for the six test groups. It is interesting to note that the classification function developed for discriminating between the six test groups is good at distinguishing between spring and autumn spawning herring but not at recognizing herring from different fishing areas within these spawning groups. Only 20% of the Sydney group were correctly classified. Hence it was decided to eliminate this group from further analyses and reduce the number of representative groups to five.

Classification functions derived from the meristic counts on these five groups are given in Table 7. The classification results obtained by applying these functions to the data from which they were derived are in Table 8. Again, the percentage correctly classified is extremely poor. 66.7% of the GULF S and 62.9% of the CHED S spring spawning groups were correctly classified, while only 38.5% of the GULF A, 28.6% of the CHED A and 54.8% of the SWNS A autumn spawning groups were correctly classified. However, 85% of the autumn spawning fish were classified as autumn spawning fish and 89% of spring spawning fish were classified as spring spawning. The results of the analysis classifying remaining samples using the classification function developed from the five test groups are given in Table 9, but these results should only be viewed in terms of classification into spring or autumn spawning groups.

The sample means of the five representative groups and all the remaining samples are plotted as canonical variates in Fig. 2. This graph also should be viewed only in terms of separation into spring and autumn spawning groups.

The overall results of the principal component analysis and the cluster analysis are very similar. In each case, there appears to be a tightly knit autumn spawning group, all very much alike, and a loosely knit spring spawning group, with the two samples from the American Bank (438) being outliers. The results of the principal component analysis are presented in Fig. 3, a plot of the sample means as transformed by the first two principal components. However, since the first two principal components accounted for only about 70% of the total variation, and since the meristic sample means were not highly correlated, the relationships between individual samples can better be determined by examining the dendrogram or tree diagram produced by the cluster analysis based upon the meristic means of the 32 samples. (Fig. 4) When the cluster analysis was repeated omitting 11 samples of young fish and fish of unknown origin, there were still essentially two groups but no outliers (Fig. 5). A pairwise discriminant analyses (Table 10), based on these two groups of sample means, resulted in every sample being assigned to its correct group.

Discussion

The discriminant function developed for distinguishing between the five test groups on the basis of their meristic characteristics was successful at classifying the test groups into spring and autumn spawning herring but was not good at distinguishing between test groups from different geographic areas, within these spawning groups. This was particularly clear in the case of autumn spawning herring in which more than half of the fish were assigned to the wrong group.

These poor classification results may have been due to the inadequacy of either the meristic variables or the test groups chosen to set up the discriminant function. It may not be possible to identify geographical subgroups of spring and autumn spawning herring on the basis of their meristic counts. Another possibility is that the five test groups being collected as they were, from purse-seine catches taken offshore, away from the spawning grounds, were not pure stocks.

In future studies of this type, it is essential to ensure that the samples chosen as test groups for setting up a discriminant function be selected from discrete spawning stocks.

When the classification results from the discriminant analyses proved to be disappointing, it was decided that cluster analyses based on the sample means of the meristic variables should be performed in order to learn more about the relationships between the samples. The two clustering procedures permitted comparison of each sample with every other sample, without setting up predetermined test groups. Cluster analyses based upon the sample means can be used to roughly identify the interrelationships between herring samples from different regions and also to identify representation samples to be chosen as test groups for discriminant analyses based on individual observations. Cluster analyses of this type are also useful for identifying outliers such as the two samples from area (438) near the American Bank, which were quite different from the others because of their large vertebral counts.

The two samples taken in area (438) near the American Bank, which were quite distinct from the other samples, were made up of young fish caught in October or November. These fish may have come from a distinct herring population which was not present in the other areas sampled. One possible explanation is that these fish may have come from a separate stock spawning along the Gaspé coast and were on their winter migration to the south. Recent tagging studies by Coté (personal communication), in which fish tagged in the Gaspé area have been recovered in the Bay of Chaleur, do not preclude this possibility.

Caution must be taken in interpreting the results of the cluster analyses since similarity of meristic characters does not necessarily imply that intermingling has occurred between the herring populations in question. Some of the similarities shown in the dendrograms have in fact been substantiated by tagging results. For example, Stobo et al. (1975) and Stobo (1978) have shown that the herring populations off southwestern Nova Scotia, in Chedabucto Bay and possibly in the Sydney area were interrelated. Winters and Beckett (1978) have established an interrelationship between the herring populations in the Gulf of St.Lawrence. Some of other similarities shown in the dendrograms seem unlikely and remain to be substantiated by further sampling and tagging experiments.

It should be emphasized here that fishing areas where the meristic characteristics of the herring have been shown to be similar are the areas which require further investigation, preferably investigations based on the study of a set of independent characters. Such studies should be supplemented by tagging experiments. Tagging of discrete unit stocks on their spawning grounds should provide information about migration routes and mixing patterns of the herring.

Currently, intensive sampling programs are being carried out to resolve the problem of herring "mixing" in the Gulf of St.Lawrence and along the Nova Scotia coast. The techniques described above should provide information on the seasonal and geographic variations in the population structure.

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Table 1. List of herring samples used in the present analysis, showing number of fish, sampling klocation and month. All samples were collected in 1973.

Sample No.	Location*	Month	Number of fish	Sample No.	Location*	Month	Number of fish
1	414	May	79	17	451	Nov.	84
2	431	May	37	18	461	July	16
3	431	May	45	19	463	June	52
4	431	May	79	20	463	June	6
5	432	Sept.	89	21	463	Sept.	38
6	433	June	78	22	465	Oct.	48
7	433	Sept.	85	23	466	June	72
8	436	May	86	24	466	Sept.	68
9	436	Sept.	85	25	467	June	76
10	438	Nov.	29	26	467	Aug.	90
11	438	Oct.	18	27	467	Aug.	68
12	451	Feb.	47	28	470	Dec.	32
13	451	Feb.	37	29	470	Aug.	69
14	451	May	35	30	511	Aug.	86
15	451	Aug.	39	31	512	May	67
16	451	Sept.	33	32	523	Sept.	70

* For sampling location, see Figure 1

Table 2. Variable means of six groups* of herring sampled from spring (S) and autumn (A) fisheries.

	Group means					
Variable	GULF(A)	SYDN(A)	CHED(A)	SWNS(A)	GULF(S)	CHED(S)
V	55.552	55.522	55.357	55.484	55.205	55.029
P	18.420	18.449	18.429	18.452	17.512	17.829
D	19.598	19.565	19.524	19.500	19.244	19.229
G	48.305	49.130	48.881	49.387	45.718	46.371
A	17.810	17.696	18.012	17.831	17.115	17.714
K	13.195	13.319	13.190	13.290	13.077	12.571

*For variable and group codes see text.

Table 3. Mean number of gill rakers ($\overline{X}$) by fish length of herring samples collected from four locations. Number of fish (N) are shown.

Sampling location*	433		451		465		467	
Fish length (cm)	N	$\overline{X}$	N	$\overline{X}$	N	$\overline{X}$	N	$\overline{X}$
15							6	47.0
16	1	44.0					12	48.2
17	14	45.5	4	48.8			12	48.5
18	54	45.4	10	48.1			15	48.3
19	27	45.9	13	47.5			6	48.0
20	4	47.0	11	47.6			8	48.3
21			17	48.1			13	48.8
22			11	48.9			16	48.8
23			19	48.3			7	49.4
24			6	49.0			2	49.5
25			5	48.4	10	49.1		
26	6	45.2			8	48.6		
27	16	45.5			5	49.8		
28	10	45.9			5	50.2		
29	19	45.8	1	50.0	7	48.9		
30	30	45.8			4	47.8		
31	15	45.7	1	47.0	4	49.0		
32	4	45.8	1	50.0	2	49.5		
33					1	50.0		
34					6	51.2		
35					1	50.0		
36								
37					1	49.0		
Total	200		99		54			

*For sampling location, see Fig. 1.

Table 4. Results of discriminant function analysis - two groups - showing values of Mahalanobis D^2 and F-values between groups of herring in each pair of comparisons.

	GULF (A)	SYDN (A)	CHED (A)	SWNS (A)	GULF (S)	CHED (S)
GULF (A)	-	.275 F(6,236)=2.221	.219 F(6,251)=2.028	.493 F(6,291)=5.853	4.519 F(6,245)=29.752	3.336 F(6,202)=15.808
SYDN (A)	-	-	.372 F(6,146)=2.273	.061 F(6,186)=.436	6.278 F(6,140)=36.987	4.301 F(6,97)=15.828
CHED (A)	-	-	-	.233 F(6,201)=1.899	5.694 F(6,155)=37.184	3.997 F(6,112)=15.755
SWNS (A)	-	-	-	-	8.324 F(6,195)=64.770	5.764 F(6,152)=25.410
GULF (A)	-	-	-	-	-	1.053 F(6,106)=4.050
CHED (S)	-	-	-	-	-	-

Table 5. Results of classification by stepwise discriminant analysis of herring populations based on six representative fisheries and six variables.

	Number of cases classified to:					
Group	GULF(A)	SYDN(A)	CHED(A)	SWNS(A)	GULF(S)	CHED(S)
GULF(A)	60	22	26	28	14	24
SYDN(A)	16	12	6	25	6	4
CHED(A)	21	4	23	24	5	7
SWNS(A)	18	19	31	48	3	5
GULF(S)	6	0	1	1	51	19
CHED(S)	3	1	1	0	9	21

Table 6. Results of stepwise discriminant function analysis showing the relative significance of variables used.

Variable entered	F-value to enter or remove	Number of variables included	U-statistic
G	66.475	1	.627
P	10.486	2	.573
V	5.608	3	.545
K	3.468	4	.529
A	2.924	5	.515
D	2.186	6	.505

Table 7. Classification functions for five representative herring groups.

Variable	GULF A	CHED A	SWNS A	GULF S	CHED S
V	112.80	112.44	112.78	112.04	111.73
P	29.01	28.99	29.00	27.66	28.12
D	30.99	30.82	30.68	30.17	30.23
G	22.16	22.37	22.58	21.17	21.39
A	2.87	3.01	2.88	2.55	2.94
K	12.47	12.48	12.64	12.39	11.55
Constant	-4348.39	-4337.82	-4364.12	-4213.52	-4211.62

Table 8. Results of classification by stepwise discriminant analysis of herring populations based on five representative fisheries and six variables.

	Number of cases classified to:				
Group	GULF(A)	CHED(A)	SWNS(A)	GULF(S)	CHED(S)
GULFA	67	24	46	14	23
CHEDA	24	20	29	5	6
SWNSA	18	29	68	3	6
GULFS	5	1	1	52	19
CHEDS	3	1	1	8	22

Table 9. Percent classification to groups by stepwise discriminant analysis of herring samples from different locations*.

Location	Month	GULF A	CHED A	SWNS A	GULF S	CHED S
414	May	16.5	3.8	19.0	46.8	13.9
431	May	21.6	2.7	0	59.5	16.2
431	May	35.6	15.6	28.9	8.9	11.1
431	May	27.9	11.4	22.8	19.0	19.0
433	Sept.	8.2	2.4	1.2	60.0	28.2
436	May	25.6	1.2	4.7	47.7	20.9
438	Oct.	38.9	5.6	27.8	11.1	16.7
438	Nov.	34.5	0	10.3	20.7	34.5
451	Feb.	29.8	23.4	27.7	8.5	10.6
451	Feb.	21.6	21.6	18.9	8.1	29.7
451	Aug.	18.2	0	9.1	30.3	42.4
451	Sept.	12.8	10.3	2.6	38.5	35.9
461	July	25.0	6.3	50.0	12.5	6.3
463	June	16.7	33.3	50.0	0	0
463	Sept.	13.2	34.2	50.0	2.6	0
465	Oct.	22.9	27.1	43.8	6.3	0
466	Sept.	19.1	23.5	33.8	4.4	19.1
467	June	18.4	22.4	35.5	10.5	13.2
467	Aug.	25.6	16.7	47.8	3.3	6.7
467	Aug.	26.5	17.7	32.4	2.9	20.6
470	Aug.	27.5	8.7	47.8	8.7	7.3
470	Dec.	15.6	25.0	31.3	12.5	15.6
511	Aug.	26.7	17.4	43.0	3.5	9.3
512	May	22.4	20.9	37.3	4.5	14.9
523	Sept.	17.1	25.7	47.1	1.4	8.6

*For sampling locations, see Fig. 1

Table 10. Results of pairwise discriminant function analysis of two groups of herring. The two groups, presumably spring and autumn spawners were revealed by cluster analysis of the combined samples.

	Group 1			Group 2		
Rank	Sampling location	Number of fish	Z Value	Sampling location	Number of fish	Z Value
1	433	100	-105.791			
2	431	96	-105.804			
3	436	100	-105.951			
4	451	52	-106.443			
5	451	100	-106.551			
6	414	100	-106.645			
7	451	57	-106.924			
8				470	41	-108.508
9				431	100	-108.831
10				465	100	-108.947
11				436	100	-109.024
12				466	100	-109.135
13				523	100	-109.144
14				431	88	-109.248
15				451	100	-109.310
16				466	100	-109.384
17				470	84	-109.531
18				463	64	-109.548
19				432	100	-109.579
20				463	36	-109.604
21				463	41	-109.906

Mean Z ± SD = -106.301 ± .451 (Group 1)
= -109.264 ± .366 (Group 2)

Mahalanobis D^2 = 56.299
F = 32.265

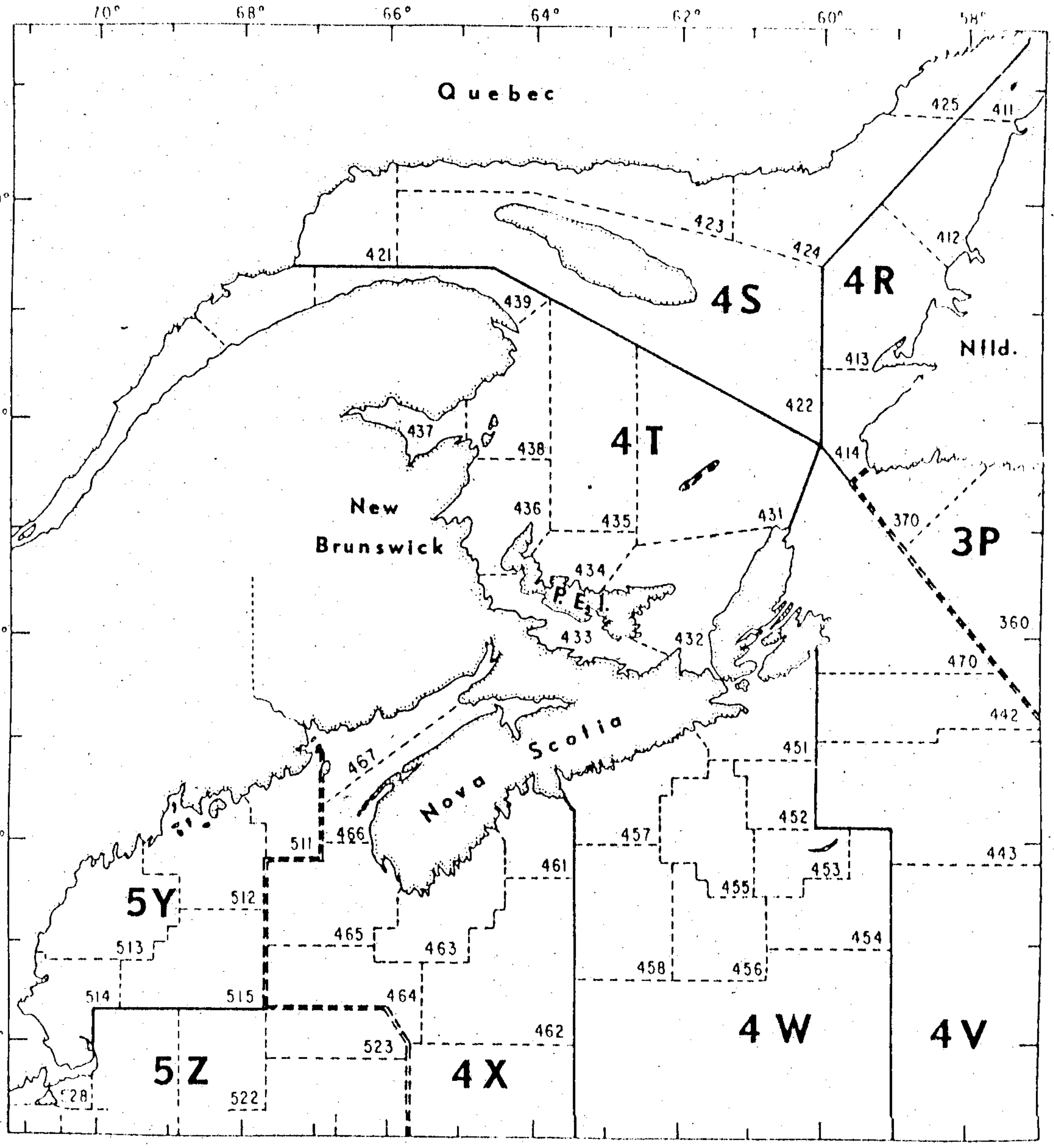

Fig. 1. Map of the Northwest Atlantic waters showing ICNAF Divisions and herring sampling locations.

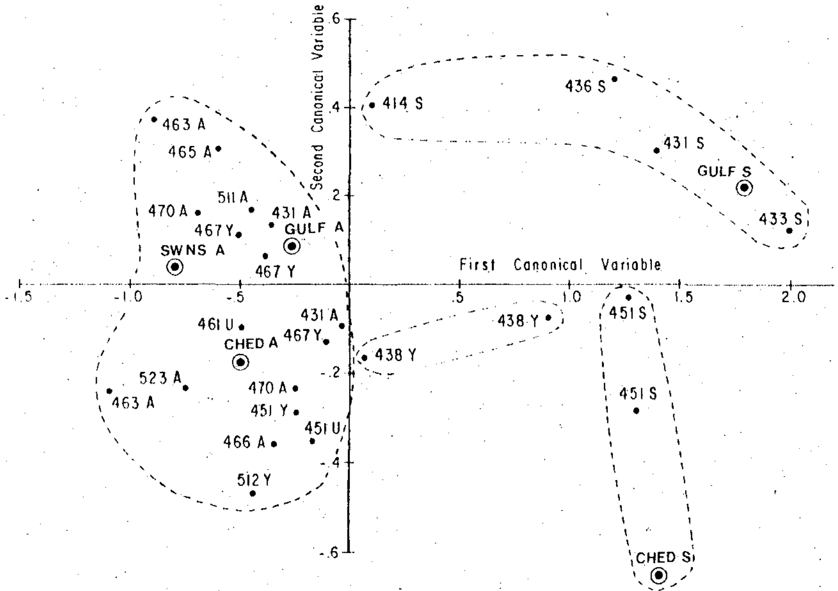

Fig. 2. Canonical variate chart showing the interrelations of herring stocks in different areas, as shown by six meristic characters assessed along two canonical variates.

CHED S = Spring spawning group, Chedabucto Bay.
GULF S = Spring spawning group, Gulf of St. Lawrence.
CHED A = Autumn spawning group, Chedabucto Bay.
GULF A = Autumn spawning group, Gulf of St. Lawrence.
SWNS A = Autumn spawning group, S.W. Nova Scotia.

For sampling locations, see Figure 1.

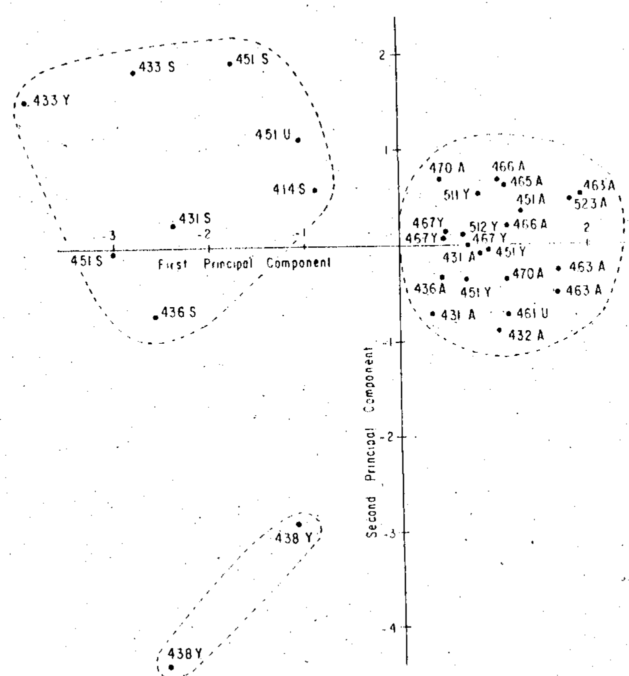

Fig. 3. Principal component chart showing the interrelations of herring stocks in different areas, as shown by six meristic characters assessed along two principal components.

S = spring spawning A = Autumn spawning
Y = Young or immature U = Unidentified or mixed

For sampling locations, see Figure 1.

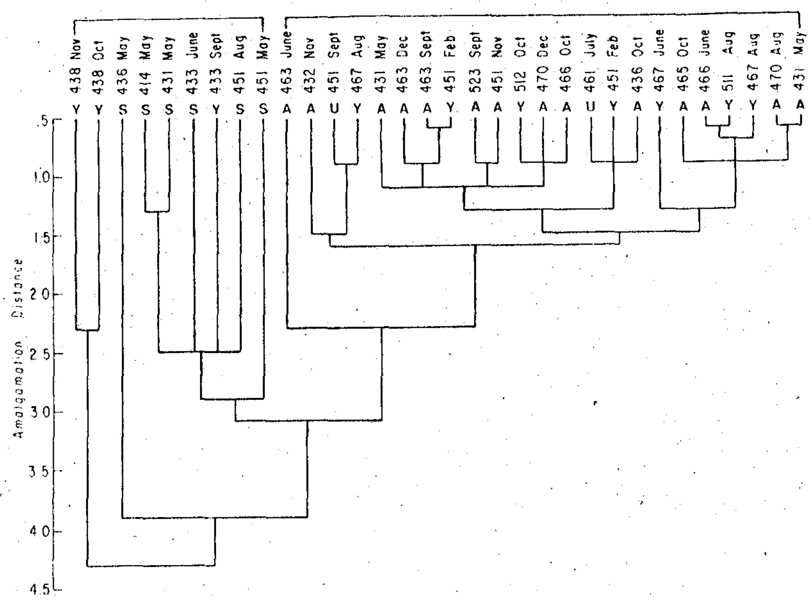

Fig. 4. Dendrogram based on the cluster analysis showing amalgamation distances between herring samples from different areas.

For sampling locations, see Figure 1.

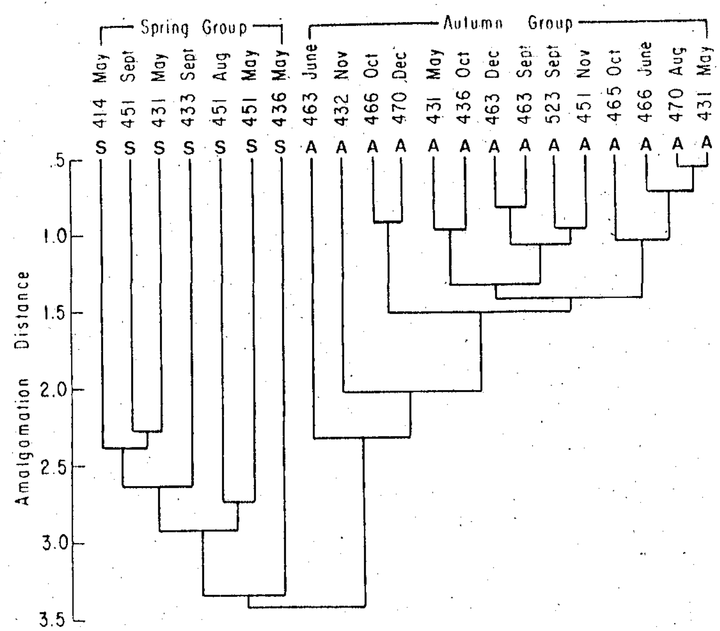

Fig. 5. Dendrogram based on the cluster analysis showing amalgamation distances between herring samples from spring and autumn spawning groups. Samples of young fish and unidentified spawning origin are excluded.

For sampling locations, see Figure 1.