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Use of Meristic Characters and a Discriminant Function for Classifying Spring- and Autumn-spawning Atlantic Herring

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Introduction

The herring concentrations which overwinter in the fjords of southwestern Newfoundland from late November to April and support an intensive winter purse seine fishery consist of two spawning groups, autumn spawners comprising two-thirds of the population, spring spawners the remainder (Hodder, 1970; Hodder and Parsons, MS, 1970; 1971). Studies on this herring stock complex have revealed significant meristic differences between spring- and autumn-spawning herring (Parsons and Hodder, 1971a). Mean numbers of gill rakers and of pectoral, anal and dorsal fin rays are all higher for autumn spawners than for spring spawners, with gill raker and pectoral fin ray numbers exhibiting the greatest degree of difference between spawning groups.

Several Canadian investigators who have studied the vertebral counts of herring in the western North Atlantic have found no significant difference between the mean vertebral numbers of spring and autumn spawners (Jean, 1956; Day, 1957; Tibbo, 1957; Parsons and Hodder, 1971a). From similarities in mean vertebral numbers and head length of spring- and autumn-spawning herring at Grande Rivière, Quebec, Jean (1956) concluded that each spawning population was a mixture of fish hatched in the spring and fish hatched in the fall. However, the distinct differences in mean numbers of fin rays and gill rakers found by Parsons and Hodder (1971a) indicate that spring- and autumn-spawning herring belong to relatively distinct breeding populations.

To further evaluate the use of meristic characters as indices for racial separation, it is necessary to consider several characters simultaneously. Fisher (1936) derived the linear discriminant function, a multivariate statistical technique for classifying individuals to one of two populations. This technique has been widely used in recent years for discriminating between racial groups (Hill, 1959; Fukuhara et al., 1962; Kilambi, MS, 1965; Anas and Murai, 1969). Basically this method involves reducing a set of counts or measurements from an individual to a single value by which the individual can be classified as being from one group or the other. Detailed discussions of the statistical techniques employed in the construction of a discriminant function are given by Fisher (1936), Mahalanobis (1936), Rao (1952), Fukuhara et al. (1962) and Andersen (1966).

This paper applies the technique of discriminant function analysis to herring meristic data for spring and autumn spawners and assesses the usefulness of such data for classifying individual herring to their respective spawning groups.

Materials and methods

The samples used in this study were taken at random from the landings of purse seiners which obtained their catches along southwestern Newfoundland and in the vicinity of the Bird Rocks, just north of the Magdalen Islands (Table 1).

Stage of maturity was determined by gross examination of gonads using the various stages of gonadal development as adopted by ICNAF in 1964 (ICNAF, 1964). Immature specimens have not been included in the data analyses. Since there was little change in gonadal development during the period under consideration (November-April), each of the adults could be assigned to one of two categories on the basis of gonadal development. Those with well-developed gonads (Stage IV) were designated as spring spawners and those showing little if any gonad development (Stage VIII) were classed as autumn spawners.

Meristic counts were determined as described by Parsons and Hodder (1971a). Three meristic characters were used in the discriminant function analyses - pectoral and anal fin rays and gill rakers on the lower branch (hypobranchial and ceratobranchial) of the first left gill arch. The few damaged specimens for which meristic data were incomplete were not included in these analyses. Discriminant analyses were made with the Multiple Discrimant Analysis Program (DISCR) for the IBM 1130 computer (Pienaar and Thomson, MS, 1967) as modified by E. J. Sandeman of the St. John's Biological Station.

Results

Analyses of variance showed no significant ($P > 0.05$) meristic variation between samples within each major period and area for either spring or autumn spawners. Arithmetic regression coefficients of meristic number on total length did not differ significantly ($P > 0.05$) from the null hypothesis; hence, length was not considered to a source of variation.

A linear discriminant function was computed for 131 spring spawners and 343 autumn spawners from southwestern Newfoundland taken during late November-early December 1969. Means and differences between means of the two spawning groups are given in Table 2. The discriminant function for these data is

$$Y = 0.9157X_1 + 0.3420X_2 + 0.2110X_3$$

In this equation X_1, X_2 and X_3 represent the numbers of pectoral and anal fin rays and gill rakers respectively.

The estimated mean values of the coefficients of the discriminant function for the spring spawners ($\bar{Y}_s$) and the autumn spawners ($\bar{Y}_a$) were determined by substituting $\bar{X}_i$, the mean numbers of each of the three meristic characters for each spawning group, into the function. The values of $\bar{Y}_s$ and $\bar{Y}_a$ were 31.792 and 33.588 respectively. Therefore, in discriminating between the two spawning groups, those fish with a value of Y less than 32.690 are classified as spring spawners and those with values of Y more than 32.690 are classified as autumn spawners. An analysis of variance revealed that differences between the two spawning groups were significant at less than the .001 level ($F_{3,470}$ = 129.34).

The variance of Y is D^2 and is given by

$$D^2 = l_1 d_1 + l_2 d_2 + l_3 d_3$$

where l_1, l_2 and l_3 are the coefficients of the discriminant function and d_1, d_2 and d_3 are the differences between the estimated population means of the three characters (Table 2). The probability of correctly assigning an individual fish to its respective spawning group is equal to the probability that a normal deviate with mean zero and standard deviation of 1 will be less than or equal to ½D (Rao, 1952). Since D^2 in this instance is 1.796, the probability of misclassification is approximately 25.2 percent. This error of classification would be the proportion of spring spawners having Y values less than 32.690 and the proportion of autumn spawners having Y values more than 32.690.

This discriminant function was then used to classify individual fish in the original samples from which the function was derived and also to classify individuals in January 1969 and April 1970 samples from southwestern Newfoundland and November 1969 samples from the Magdalen Islands area. The resulting frequencies and percentages of Y values above and below the critical value 32.690 (Y_o) are shown in Table 3. The percentages of misclassification of autumn spawners in the January 1969 and April 1970 samples from southwestern Newfoundland and the November 1969 samples from Magdalen Islands were in close agreement with the percentage of misclassification of the southwestern Newfoundland autumn spawners used in the construction of the discriminant function. Percentages of misclassification of spring spawners in the January 1969 and April 1970 southwestern Newfoundland samples were very similar to that resulting from classification of the southwestern Newfoundland spring spawners upon which the function was based. The percentage of misclassification for Magdalen Islands spring spawners (9.3 percent) was even less than for those from southwestern Newfoundland.

The actual errors of misclassification for both spawning groups were in all instances less than the 25.2-percent average error of misclassification inherent to the function. Percentages of correct classification ranged from 80.6 to 86.2 percent for autumn spawners and from 79.4 to 90.7 percent for spring spawners.

Discussion

Meristic characters exhibit plasticity under the influence of environmental factors, especially temperature, during the incubation period and early larval life (Schmidt, 1921; Vladykov, 1934; Tåning, 1944; Lindsey, 1954; Barlow, 1961). Hempel and Blaxter (1961) demonstrated that the myotome count of Atlantic herring is determined before hatching and that vertebral number is modified by incubation temperature. However, Barlow (1961) cites several studies which have shown a genetic as well as a phenotypic basis for meristic characters in various fish species. Differences in the mean numbers of fin rays of spring- and autumn-spawning Atlantic herring appear to be related to water temperatures during early development and to differences in developmental rates of spring- and autumn-hatched larvae (Parsons and Hodder, 1971a). Autumn-hatched larvae develop during a period of declining water temperatures in the autumn; spring-hatched larvae develop during a period of increasing water temperatures. Thus temperatures at the time of fin ray fixation, which apparently occurs during the larval stage (Lebour, 1921; Tåning, 1944; Blaxter, 1962), are higher for spring-hatched than for autumn-hatched larvae. Autumn-hatched larvae have a longer period of development than spring-hatched larvae (Jean, 1956) and, hence, would be expected to have higher mean fin ray numbers than spring-hatched larvae.

Blaxter (1958) presented evidence which suggests that the difference in spawning season between the two groups is genetical and is based on different responses to the environment. In an earlier paper Blaxter (1956) reported that under experimental conditions spring-spawned eggs were markedly inviable at autumn spawning temperatures. He concluded that in typical spring- and autumn-spawning herring groups reproductive isolation exists, although a slight amount of interchange probably occurs, and suggested that spring- and autumn-spawning herring may be referred to as different sibling species, using the main criterion of difference in breeding season.

The results of the preliminary discriminant function analyses reported here support the conclusion of Parsons and Hodder (1971a) that the spring- and autumn-spawning components of the herring stock complex which migrates eastward from the southern Gulf of St. Lawrence in the autumn to overwintering areas along southwestern Newfoundland and westward again into the Gulf in the spring (Hodder and Parsons, MS, 1970; 1971; Hodder and Winters, MS, 1970; Winters, 1970; Parsons and Hodder, 1971b) are not members of a homogeneous group but constitute distinct breeding populations which developed at different times of the year under different environmental conditions. From 79 to 91 percent of individual spring and autumn spawners can be correctly classified to their respective spawning groups by the use of a linear discriminant function based on three meristic characters. This clearly demonstrates that the vast majority of autumn spawners are the progeny of herring which spawned in the autumn and spring spawners of herring which spawned in the spring. The amount of interchange between the two spawning groups is probably slight.

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Table 1. Date and locality of capture and maturity condition of herring samples used in this study.

Sample No.	Date of capture	Locality	Maturity condition: Imm.	Maturity condition: Spring spawn.	Maturity condition: Autumn spawn.	Maturity condition: Total
	1969					
1	22 Nov.	Burgeo, Southwest Nfld.	-	10	40	50
2	25 Nov.	" " " "	1	11	38	50
3	25 Nov.	White Bear Bay, Southwest Nfld.	-	13	37	50
4	29 Nov.	Cape LaHune, " " "	-	9	41	50
5	30 Nov.	Bay de Vieux, " " "	1	14	35	50
6	1 Dec.	White Bear Bay, " " "	-	14	36	50
7	1 Dec.	Burgeo, " " "	-	25	25	50
8	4 Dec.	La Poile Bay, " " "	1	10	39	50
9	5 Dec.	White Bear Bay, " " "	1	22	27	50
10	12 Dec.	Burgeo, " " "	-	11	39	50
			4	139	357	500
11	1 Nov.	Magdalen Islands	-	11	39	50
12	2 Nov.	"	4	10	36	50
13	2 Nov.	"	6	11	33	50
14	8 Nov.	"	5	14	31	50
15	9 Nov.	"	-	14	36	50
16	17 Nov.	"	1	6	43	50
17	17 Nov.	"	3	14	33	50
18	17 Nov.	"	-	10	40	50
19	17 Nov.	"	1	10	39	50
20	17 Nov.	"	-	12	38	50
			20	112	368	500
21	21 Jan.	La Poile Bay, Southwest Nfld.	-	16	34	50
22	28 Jan.	" " " "	-	26	24	50
			-	42	58	100
	1970					
23	1 Apr.	Grand Bay, Southwest Nfld.	-	16	34	50
24	1 Apr.	Pigeon Island, " "	-	19	31	50
			-	35	65	100

Table 2. Means and differences between means for autumn and spring spawners from southwestern Newfoundland (November-December 1969).

Character	Mean for autumn spawners	Mean for spring spawners	Difference
Pectoral fin rays (X_1)	18.571	17.183	1.388
Anal fin rays (X_2)	18.149	17.595	0.554
Gill rakers (X_3)	49.163	47.573	1.590

Table 3. Frequency and percentage of the values (Y) of the discriminant function above and below the critical value 32.690 (Y_o) for autumn and spring spawners from southwestern Newfoundland and Magdalen Islands.

Locality and time of capture	Spawning[1] group	Classification matrix				
		Frequency			Percent	
		$Y > Y_o$[2]	$Y < Y_o$[3]	Total	$Y > Y_o$[2]	$Y < Y_o$[3]
Southwestern Nfld. (Nov.-Dec. 1969)[4]	Autumn	287	56	343	83.7	16.3
	Spring	18	113	131	13.7	86.3
Southwestern Nfld. (Jan. 1969)	Autumn	47	11	58	81.0	19.0
	Spring	8	34	42	19.0	81.0
Southwestern Nfld. (Apr. 1970)	Autumn	56	9	65	86.2	13.8
	Spring	7	27	34	20.6	79.4
Magdalen Islands (Nov. 1969)	Autumn	290	70	360	80.6	19.4
	Spring	10	98	108	9.3	90.7

[1]Based on gonad maturity
[2]Classified as autumn spawners
[3]Classified as spring spawners
[4]Source data for discriminant function