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Use of scale characters and a discriminant function for identifying continental origin of Atlantic salmon[1]

by

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Introduction

The total catch of Atlantic salmon at West Greenland increased from 60 metric tons in 1960 to an average of 2269 tons during 1969-72 with a peak total catch of 2689 tons in 1971. This increased catch has resulted mainly from the extension of the drift net fishery into offshore waters hitherto not fished for salmon.

The concern in salmon producing countries over the increased salmon catches at West Greenland generated discussions at meetings of the International Commission for the Northwest Atlantic Fisheries (ICNAF) and the International Council for the Exploration of the Sea (ICES). These discussions led to the formation in 1966 of the ICES/ICNAF Joint Working Party on North Atlantic Salmon. One of the main problems facing the Working Party was to determine the proportions of salmon being fished at West Greenland that originate in the various salmon producing areas of the North Atlantic particularly North America and Europe.

It has been well documented that the West Greenland fishery exploits salmon from all the salmon producing areas of both North America and Europe (Parrish, 1973; May, 1973; Tetreault and Carter, 1972; Turner, 1972; and Peet and Pratt, 1972; Meister, MS, 1972).

Scale characteristics have been used to identify continental origins of chum salmon (Tanaka, Shepard and Bilton, 1969) and sockeye salmon (Anas and Murai, 1969) in the Pacific Ocean. Discriminant functions were used to facilitate discrimination between salmon originating from Asia and North America. Parsons (1972) also showed that a discriminant function can be used to classify spring- and autumn-spawning Atlantic herring.

This paper applies the technique of discriminant function analysis to scale characteristics of Atlantic salmon in an attempt to classify by continent of origin salmon exploited by the West Greenland fishery and also those wintering in the Labrador Sea (Fig. 1).

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Methods and Materials

Source of data

On the basis of a previous study (Lear, MS, 1972), it was demonstrated that there were five characters which could be useful in discriminating between salmon of European and North American origin. These are:

1. Largest anterior radius of second river zone (WR_2).
2. Number of circuli in second river zone (CR_2).
3. Largest anterior radius of first sea zone (WS_1).
4. Number of circuli in first sea zone (CS_1).
5. River age (RA).

Scales of adult salmon which were tagged as smolts in North America and Europe (Fig. 2) and recaptured at West Greenland during 1968-70 were collected and examined. These scales form the basic standards upon which the discriminant function was constructed. The function was applied to scale data collected during the research cruises of the A. T. Cameron at West Greenland and Labrador Sea during the autumn of 1969-71, by the Adolf Jensen, Scotia, A. T. Cameron and Cryos, during the International Joint Tagging Experiment at West Greenland during August-October 1972, and of the A. T. Cameron in the Labrador Sea during the springs of 1970-72. Results from the discriminant function analysis have also been compared with those obtained from the tagging-recapture data and from electrophoretic studies as well as with scales collected from the commercial fisheries in eastern Newfoundland.

Scales were taken from the left side of the fish about 3-6 scale rows above the lateral line and on a line extending from the posterior edge of the dorsal fin to the anterior edge of the anal fin. They were washed and impressions of them were made on plastic slides. These impressions were projected onto the ground glass screen of a microprojector at a magnification of 30X. The scale was then measured by means of the micrometer stage in absolute measurements to the nearest hundredth of a millimetre. The width of the annulus was obtained by measuring the distance from the beginning of the summer zone to the end of the winter zone along the longest anterior axis of the scale. The problem of counting broken or branched circuli was solved by counting only those circuli which continued intact within an angle of 10° on each side of a line drawn through the longest axis of the scale (Fig. 3).

The techniques and computer programs used to construct the discriminant functions were adapted from Cooley and Lohnes (1966).

Construction of the discriminant function

1. Examination of discriminating power of individual characters

For a preliminary examination of the data, the total sample of salmon of known European origin in which data were available for all five characters was utilized together with a randomly chosen (by computer generated random numbers) sample of 80 fish of known North American origin (tagged as smolts in North American rivers).

For each of the five characters, means and standard deviations for the fish of European and North American origin were computed. While the means for each character from fish of European origin were demonstrated to be significantly different from those of North American origin by means of t tests, the overlap between the two samples for each character intuitively did not encourage the use of single characters for discrimination between fish of different origin. This was confirmed for all characters other than the number of circuli in the zone laid down in the first sea year, when, under the assumption that each character was normally distributed within the samples from each area of origin, the points of intersection of the two samples were computed for each character and these values used as the decision criteria for allocation. The theoretical misclassification percentages obtained under these decision criteria are shown in Table 1, and it is evident that with the exception of the character - No. of circuli in the 1st. sea year, the misclassification percentage was too large to be useful in discriminating between the salmon of different origin.

2. A discriminant function utilizing all five characters

A discriminant function analysis was conducted utilizing all five characters on the two samples discussed above. It was found that the following discriminant function:

$$Y = 0.209\ WR_2 - 0.948\ CR_2 + 0.074\ WS_1 - 0.198\ CS_1 - 0.115\ RA$$

accounted for all the variance. However, although a theoretical efficiency of classification of 75.8% could be achieved using this function, it was apparent from the scaled vectors that the characters which contributed mostly to the separation along the discriminant function were those of CS_1 and CR_2 with RA appearing a rather poor third.

3. A discriminant function utilizing CS_1 and CR_2

Following the indications of the above analysis, a discriminant function analysis was now conducted using the best two characters indicated above, i.e. CS_1 and CR_2. Once again, it was found that the total variance could be accounted for by the one discriminant function, viz:

$$Y = 0.374\ CR_2 + 0.928\ CS_1$$

With the probability of misclassification reduced to 6.4% and the theoretical efficiency therefore 93.6%, it is clear that a considerable improvement in efficiency of classification could be achieved by the use of a discriminant function based on these two characters.

Unfortunately, however, while the use of the number of circuli in the 2nd. river zone is evidently a very useful character for achieving discrimination in the samples examined, both of which were derived from the tagging of naturally reared smolts in their native rivers, this character is not suitable for use in a discrimination involving hatchery reared smolts. The hatchery reared smolts show abnormal growth which is reflected in a very much greater number of circuli in the 2nd. river zone than would be expected to occur in natural smolts with origins in either Europe or North America (Lear, 1972).

Thus, while these two characters could yield excellent discrimination between naturally reared fish of different origin, the presence of hatchery reared salmon in the samples caused us to reject this function.

4. A discriminant function using WS_1 and CS_1

Because of the abnormal growth characteristics during the fresh water period of hatchery reared smolts, it seemed desirable to utilize only those characters determined in the 1st. sea year.

Thus a discriminant function was constructed using both the width of the 1st. sea zone and the number of circuli in this zone. The discriminant function, $Y = -0.8507\ WS_1 + 0.5257\ CS_1$, accounted for 100% of the variance. This function, however, showed a probability of misclassification of 14.4%. The theoretical efficiency of 85.6% indicates that this function is considerably less efficient than those discussed previously.

5. Other discriminant functions examined

An attempt to improve the efficiency of discrimination by incorporating river age as well as characters pertaining to the scale growth in the first sea year proved abhortive in as much as the discriminant function based on these characters attained a theoretical efficiency of only 83.8%.

Results

A linear discriminant function was computed for 80 salmon of North American origin and 80 of European origin on the basis of WS_1 and CS_1 for the reasons outlined above. 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 from West Greenland during autumn 1969-72, Labrador Sea during autumn 1969-72, Labrador Sea and Northeast Newfoundland Shelf during spring 1970-72 and Bonavista during spring 1970-72. Also fish for which continental origin had been previously determined by tagging and electrophoresis were classified by the discriminant function.

The proportions of North American salmon present at West Greenland, as determined by the function, are as follows: 46% during 1969, 34% during 1970, 32% during 1971 and 35% during 1972. The proportions estimated from the research vessels sampled during 1972 varied between 32% and 4% (Table 2). In the Labrador Sea during autumn values for 1970-71 range from 50% to 29% but during 1972 the proportions of North American fish account for 74% according to the scale characters. In the Labrador Sea during spring the proportions of North American fish are extremely high, ranging from 72% to 89%.

The empirical efficiency of the function is demonstrated by the high frequency of correct classifications obtained when the discriminant function was applied to fish of known origin (Table 3). The percentage of North American fish correctly classified from West Greenland samples varied from 82% to 100%, while the percentage of Europeans correctly classified varied from 79% to 100%. In the Labrador Sea during autumn the percentage of North American fish correctly classified varied from 64% to 100% and in the Labrador Sea during spring it varied from 81% to 89%. At Bonavista 86-95% of the fish were classified correctly to continent of origin.

Since the scale character CS_1 used on its own exhibited a theoretical misclassification probability of 12.5%, the proportions of North American and European salmon were estimated using the same samples. The proportions obtained by this method are almost identical to those obtained by the discriminant function (Table 4), and the proportions correctly classified are equal to and in some cases greater than those obtained by using the discriminant function (Table 4).

Discussion

The North American:European proportion of salmon at West Greenland during 1969 was 46:54, i.e. approximately 50:50. This is in agreement with results obtained from tagging during 1969 by the Canadian research vessel <u>A. T. Cameron</u> at West Greenland. Of 13 tags recaptured in home waters, 54% were from North America and 46% from Europe. Nyman and Pippy (1972) determined that the proportion of North American salmon at West Greenland during 1969 was 43% based on serum transferrin polymorphisms.

During 1970, based on data collected by the <u>A. T. Cameron</u>, our estimate of 34% North American compares not too unfavourably with Payne (MS, 1973) who estimated 23% North American based on samples collected on the Danish commercial drifter <u>Polarlaks</u>. During 1971 our estimate is 32% North American as opposed to 53% by Payne (MS, 1973). This discrepancy is possibly due to sampling error since no blood samples were collected from approximately 80 fish, taken in the northern area, for which we had scale samples and of which 82% were estimated to be of European origin.

During 1972, the variability between proportions of North American fish taken by the four research vessels is minimal and the overall proportion at West Greenland is estimated at 35%. Payne (MS, 1973) obtained an estimate of 20%, while estimates from tagging recaptures indicate a North American proportion of 25%.

During autumn 1969-71, the proportions in the Labrador Sea were approximately the same as at West Greenland. During 1972, however, the North American proportion in the Labrador Sea was of the order of 75%, suggesting that in this year the North American component was not subject to such intense fishing exploitation at West Greenland as in previous years, thus resulting in increased survival to home waters fisheries.

During spring 1970-72, the North American fish form the predominant component of the stocks wintering in the Labrador Sea with estimates ranging from 72% to 89%.

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Table 1. Summary analysis of discriminating power of individual characters from samples of known origin.

Character	North American Mean	North American SD	European Mean	European SD	t	Significance	Decision criterion	% Misclassification
WR_2	.3256	.1390	.4812	.1743	5.90	**	.43	29.9
CR_2	12.950	3.897	17.104	4.530	5.90	**	15.50	29.7
WS_1	1.9255	.2188	2.2709	.2391	9.07	**	2.10	22.3
CS_1	31.3875	3.4107	40.0149	4.1688	13.56	**	35.60	12.5
RA	3.000	.7291	2.3731	.5459	5.95	**	2.81	31.2

Table 2. Results of discriminant function applied to data, based on WS_1, CS_1

Area	Ship		Date	No. examined	% NA	% E
West Greenland	A. T. Cameron		1969	212	46	54
West Greenland	A. T. Cameron		1970	128	34	66
West Greenland	A. T. Cameron		1971	246	32	68
West Greenland	A. T. Cameron		1972	398	32	68
West Greenland	Adolf Jensen		1972	687	36	64
West Greenland	Scotia		1972	287	40	60
West Greenland	Cryos		1972	140	32	68
West Greenland	All Ships		1972	1512	35	65
Labrador Sea	A. T. Cameron	A	1969	8	50	50
Labrador Sea	A. T. Cameron	A	1970	31	32	68
Labrador Sea	A. T. Cameron	A	1971	41	29	71
Labrador Sea	A. T. Cameron	A	1972	62	76	24
Labrador Sea	Cryos	A	1972	89	72	28
Labrador Sea	A. T. Cameron and Cryos	A	1972	151	74	26
Labrador Sea	A. T. Cameron	S	1970	18	83	17
Labrador Sea	A. T. Cameron	S	1971	80	89	11
Labrador Sea	A. T. Cameron	S	1972	25	72	28

A = Autumn
S = Spring

Table 3. Test of the discriminant function, based on WS_1 and CS_1 characters from fish of known origin.

Area	Type	Origin	Date	No. examined	% Classified correctly
West Greenland	Tagged	North America*	1968–70	80	91
West Greenland	Tagged	Europe*	1968–70	80	91
West Greenland	Tagged	North America	1968–70	239	90
West Greenland	Electrophoresis	North America	1971	39	82
West Greenland	Electrophoresis	North America	1972	22	91
West Greenland	Electrophoresis	Europe	1972	4	100
West Greenland	Tagged	North America	1972	3	100
West Greenland	Tagged	Europe	1972	14	79
Labrador Sea	Electrophoresis	North America	A 1971	11	64
Labrador Sea	Electrophoresis	North America	A 1972	10	100
Labrador Sea	Tagged	North America	A 1972	1	100
Labrador Sea	Tagged	Europe	A 1972	1	0
Labrador Sea	Electrophoresis	North America	S 1971	45	89
Labrador Sea	Electrophoresis	North America	S 1972	16	81
Bonavista, Nfld.	Commercial Sample	North America	S 1970	183	95
Bonavista, Nfld.	Commercial Sample	North America	S 1971	80	95
Bonavista, Nfld.	Commercial Sample	North America	S 1972	80	86

* Continental Standard.

A = Autumn
S = Spring

Table 4. Proportions of North American and European salmon at West Greenland based on CS_1 character.

Area	Ship		Date	No. examined	% NA	% E
West Greenland	A. T. Cameron		1969	212	46	54
West Greenland	A. T. Cameron		1970	128	32	68
West Greenland	A. T. Cameron		1971	246	32	68
West Greenland	A. T. Cameron		1972	398	32	68
West Greenland	Adolf Jensen		1972	687	37	63
West Greenland	Scotia		1972	287	40	60
West Greenland	Cryos		1972	140	32	68
West Greenland	All Ships		1972	1512	36	64
Labrador Sea	A. T. Cameron	A	1969	8	50	50
Labrador Sea	A. T. Cameron	A	1970	31	32	68
Labrador Sea	A. T. Cameron	A	1971	41	32	68
Labrador Sea	A. T. Cameron	A	1972	62	77	23
Labrador Sea	Cryos	A	1972	89	73	27
Labrador Sea	Cryos and A. T. Cameron	A	1972	151	75	25
Labrador Sea	A. T. Cameron	S	1970	18	83	17
Labrador Sea	A. T. Cameron	S	1971	80	90	10
Labrador Sea	A. T. Cameron	S	1972	25	76	24

A = Autumn
S = Spring

Table 5. Empirical test of proportions of North American and European salmon, based on CS_1 character from fish of known origin.

Area	Type	Origin	Date	No. examined	% Classified correctly
West Greenland	Tagged	North America*	1968-70	80	91
West Greenland	Tagged	Europe*	1968-70	80	90
West Greenland	Tagged	North America	1968-70	239	91
West Greenland	Electrophoresis	North America	1971	39	85
West Greenland	Electrophoresis	North America	1972	22	95
West Greenland	Electrophoresis	Europe	1972	4	100
West Greenland	Tagged	North America	1972	3	100
West Greenland	Tagged	Europe	1972	14	79
Labrador Sea	Electrophoresis	North America	A 1971	11	64
Labrador Sea	Electrophoresis	North America	A 1972	10	100
Labrador Sea	Tagged	North America	A 1972	1	100
Labrador Sea	Tagged	Europe	A 1972	1	0
Labrador Sea	Electrophoresis	North America	S 1971	45	84
Labrador Sea	Electrophoresis	North America	S 1972	16	81
Bonavista, Nfld.	Commercial Sample	North America	S 1970	183	96
Bonavista, Nfld.	Commercial Sample	North America	S 1971	80	95
Bonavista, Nfld.	Commercial Sample	North America	S 1972	80	89

* Continental Standard

A = Autumn
S = Spring

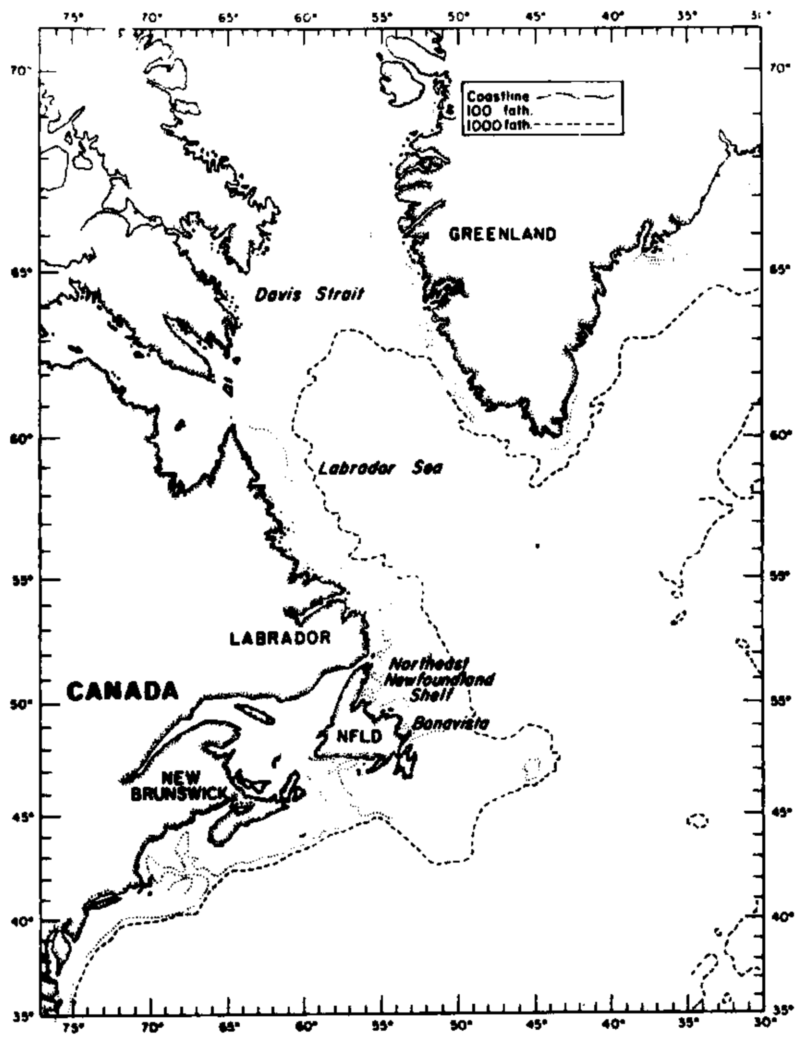

Fig. 1. Area map of the Northwest Atlantic showing place names mentioned in the text.

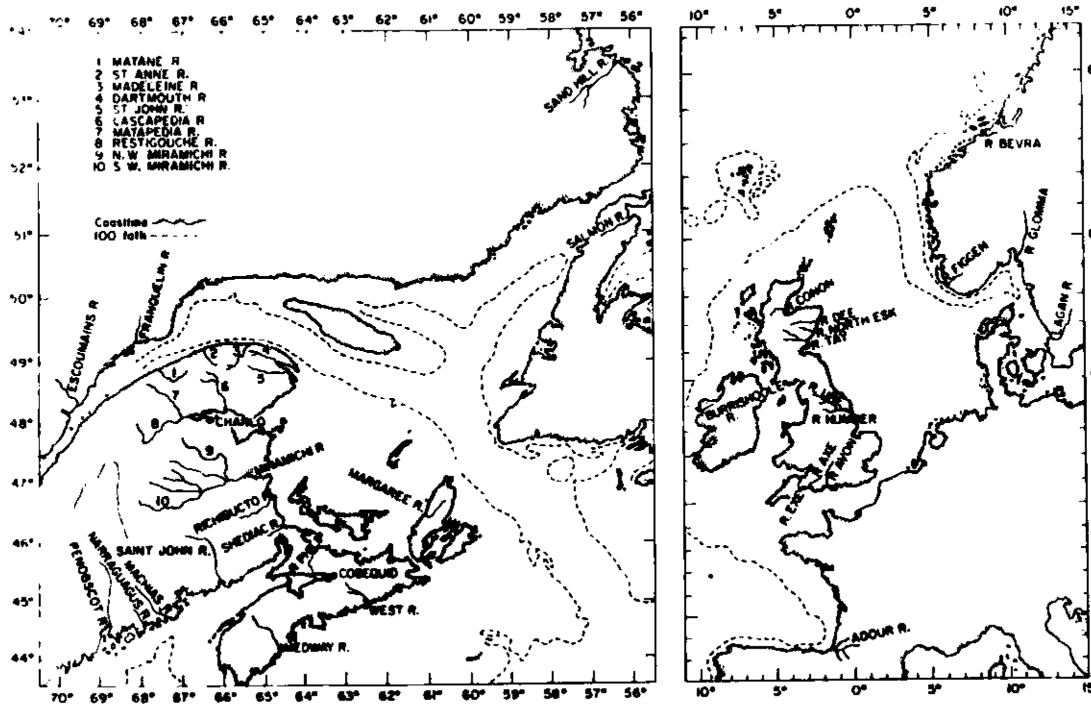

Fig. 2. Atlantic salmon rivers of North America and Europe from which smolts were tagged and recaptured as adults in West Greenland and which form the basis of the discriminant function.

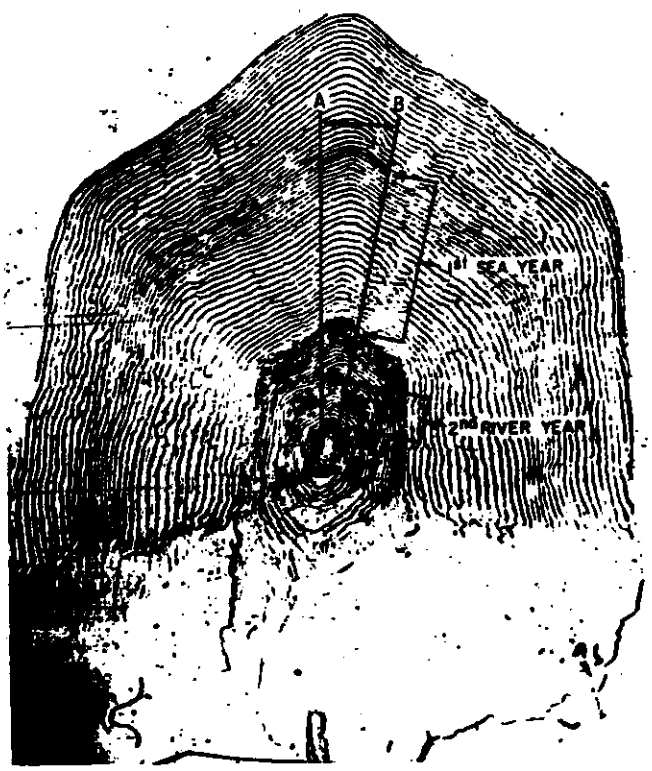

Fig. 3. Scale of Atlantic salmon with an age of 3 river and 1+ sea years showing the selected radius and the area (AB) inside which the circuli were counted.