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A critical assessment of the value of *Anisakis* sp. (Nematoda) as a biological tag in Atlantic salmon

by

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INTRODUCTION

Studies on the parasites of Atlantic salmon to determine which parasitic species might be useful to ascertain the continental origin of salmon caught on the high seas began in 1966. The first studies were made on parasites of fresh water origin and after about three years study it was concluded that these would be of little value to distinguish stocks on the high seas (Pippy, 1967, 1968). Thus, in 1968, emphasis was switched to parasites of marine origin. The most promising species were larvae of the nematode *Anisakis* sp. and the adult tapeworm, *Eubothrium crassum* (Pippy, 1969).

The efficiency of determining the abundance of *Anisakis* larvae in salmon was greatly increased in the fall of 1969 when ultraviolet light was used to aid in detecting the larvae (Pippy, 1970). Counts of larvae previous to that period were therefore not considered comparable to those made afterwards.

By 1970 the available data suggested *Anisakis* larvae were more abundant in European salmon than in those from North America. This suggestion agreed with that of Templeman (1967) who made an earlier comparison of the abundance of the larvae with the river ages of the fish. The difference was later confirmed in studies by Nyman and Pippy (1971, 1972). Such differences could only be used effectively as biological indicators if there were minimal annual variations in abundance of the larvae. If there were significant annual variations, they would have to be predictable to be useful. Pippy (1970) presented data suggesting that annual variations did exist but the validity of this was questionable because of the doubtful reliability of the data used (based on counts made without the aid of U.V. light). This report documents the procedure used in an assessment of the use of larval *Anisakis* sp. as a biological tag to separate stocks of Atlantic salmon on the high seas.

MATERIALS AND METHODS

A total of 4381 adult salmon from 14 sampling stations was examined for larval *Anisakis* sp. (Fig. 1 and Table 1). Salmon from North America and West Greenland were all taken from the sea whereas those from the United Kingdom were predominantly from fresh-water or estuarial habitats. In each case, only the viscera was included in the examination: heart, mesenteries, and the entire alimentary canal and associated organs. Viscera were collected in the field, frozen in polyethylene bags, and placed in frozen storage. Parasitological examinations were conducted within six months after collection.

Host ages were determined from the scales and expressed as the number of winters the salmon had spent at sea, e.g. Age I = 1 winter at sea, Age II = 2 winters at sea, etc.

Parasite counts were highly skewed to the left and the standard deviations approximated the mean (Table 2). This indicated a logarithmic transformation was required before statistical procedures applicable to normal distributions could be used. Barnes (1955) suggested the transformation $y = \log (x + 1)$ for such distributions. For convenience the one chosen in this study was: $y = 10 \log_e (x + 1)$. All analyses were conducted on transformed data (Table 3). Only samples containing 15 or more hosts were included in statistical analyses. Analysis of variance followed that described by Snedecor (1956). When analysis of variance suggested heterogeneity among the samples, a modified Duncan's multiple range test (Kramer, 1956) was used to compare the means and to group samples with similar means.

RESULTS

Abundance of *Anisakis* larvae in Atlantic salmon

The abundance of parasites in samples may be measured in two ways: the prevalence (Table 4) expressed as a percentage of the hosts infected, and the mean number of parasites per host (Tables 2 and 3). Zero counts are included in the calculation of the mean. Prevalence is of limited value as few standard statistical procedures are adaptable to this parameter. The relationship between the prevalence and the mean number of *Anisakis* larvae in the samples of salmon considered here was roughly linear. For example, the correlation coefficient of a regression of prevalence on the incidence of larvae among 1980 Age II salmon caught in Canadian waters during 1969, 1970 and 1971 (Fig. 2) was .89. The coefficient of variation ($r^2 = .80$) suggests that about 80% of the variation in the prevalence of the larvae can be explained in terms of the mean number of larvae in the samples. Apparently, about 20% of the variation was attributable to variables not considered in the analysis (for example, possible geographic or annual variations in the immunity of the salmon to infection by the larvae). Because of the above-mentioned relationship, and the facility with which standard statistical procedures could be applied to normal distributions more emphasis was placed on the mean number of larvae in the various samples than on their prevalence.

Abundance and host's sex

Abundance of *Anisakis* larvae was examined in 449 male and 1018 female salmon (total = 1467) from seven North American sampling stations from 1970 to 1971. In each case, regardless of the number of winters the salmon had spent at sea, there was no significant difference in the mean number of larvae per host (Table 5). This finding justified combination of data from male and female fish in all subsequent statistical analyses.

Abundance and host's age

The mean number of Anisakis larvae in salmon appeared to be related to the length of time the salmon spent at sea. However, this relationship was not consistent from sampling station to sampling station in the same year or from year to year at the same sampling station. For example: the mean number of larvae was similar in salmon of different ages collected at station 4 during 1969 but was different in salmon of different ages collected at stations 5, 6, 9 and 10 (Table 6, Treatments A, D, G, I and L). In 1970, the mean number of larvae in salmon of different ages was similar at stations 8 and 9 but significantly different at stations 4 and 5 (Treatments H, J, B and E). In 1971, it was similar at stations 4 and 9 but different at station 5 (Treatments C, K and F). There did not appear to be any particular pattern to these similarities and differences. Apparently, the factor or factors which contribute to the observed differences in the incidence of Anisakis larvae are not uniform throughout the various stocks of North American Atlantic salmon.

If Anisakis sp. larvae remain in the salmon for several years, one would expect an increase in the mean number of larvae with increasing age of its host. This was observed in salmon which left the river in 1968 and 1969. Thus, the mean number of larvae in Age I North American salmon caught in 1969 was 9.6 (transformed mean); in Age II salmon caught in 1970, 14.1; and in Age III salmon caught in 1971, 17.7 per host. Similarly, the mean in Age I salmon caught in 1970 (10.8) was lower than that in Age II salmon caught in 1971 (16.2). Analyses of variance and multiple range tests on these means suggested statistically significant differences with age in the mean number of larvae per host. However, for reasons which will be clarified in the following section, application of such statistical procedures to these samples is of doubtful validity and we may only conclude that the available data tend to support the suggestion that the larvae accumulate in salmon.

A more accurate test of the above-mentioned hypothesis involves dealing only with fish of known history. For this analysis, tagged salmon were used. The transformed mean number of larvae in 71 salmon tagged as juveniles in the Miramichi River and caught as Age I salmon at Greenland in 1970 was 13.6. This value was significantly lower ($P < .01$) than the mean observed in 194 Age II salmon from the Miramichi area (station 8) the following year (16.6) (Table 6, Treatment M). Similar results were not observed in any of the other three tagging experiments (Treatments N, O and P). Thus, not all the data agree with the suggestion that Anisakis larvae accumulate in salmon. One way of interpreting these results is that there is an accumulation of larvae in all cases but, because of sampling errors and high standard errors, this accumulation is only sometimes detected. The presence of a statistically significant increase in one of four experiments suggests that this is in fact the case.

Geographic variations in abundance

For detailed analysis of geographic variations in the mean number of Anisakis larvae per fish, the data were stratified according to the number of winters the salmon had spent at sea (Table 7). Major areas (North America, United Kingdom, Greenland and the Labrador Sea) were dealt with separately.

(a) North America

Age I:- In 1969 the mean numbers of larvae in salmon from stations 5 and 10 were similar to one another but both were different from the means at station 4 (Table 7, Treatment A). In contrast, the following year (1970) the means at all three stations (4, 5, 8) were similar (Treatment B).

Age II:- In 1969 the mean number of larvae in salmon from North American sampling stations (4-11) was similar (Table 7, Treatment C). However, with 1970 and 1971 samples, considerable variations were observed (Treatments D and E). Multiple range tests on the means suggested that, in both years, they fell into three overlapping groups; there was no consistency in these groupings (compare range test results of Treatments D and E). A comparison of the differences in results for 1969, 1970 and 1971 suggests that variations in mean numbers of larvae per fish at the stations are random. However, insofar as many of the differences were statistically significant, they appear to be of some biological importance.

Age III:- There were no significant differences between the mean number of larvae per fish among samples in either of the years 1969, 1970 and 1971 (Treatments F, G and H). In this respect, Age III salmon differed from Age I and II salmon in that, in any given year, they seemed to be homogeneous with respect to the abundance of *Anisakis* larvae present.

(b) United Kingdom

Age II:- The mean numbers of *Anisakis* larvae per fish at stations 13 and 14 were similar but were significantly lower than the mean at station 12 (Table 7, Treatment I).

(c) Greenland

From a purely statistical point of view, the observed heterogeneity among samples precludes grouping of the data from many stations for purposes of comparison between widely separated geographic localities. The reason for this is that the mean number of larvae per host calculated from a combination of data from the various samples would depend upon the number of hosts examined from each of the sampling stations. For example, if many salmon were examined from an area which had high levels of infection and a few from an area with low levels, the observed mean in combined samples might be higher than the true mean for the combined populations. This problem becomes particularly acute when very few sampling stations are considered for comparison.

Bearing in mind the contents of the foregoing paragraph and the limitations on interpretation of results from analyses involving heterogeneous samples, analyses were performed to compare the mean number of *Anisakis* larvae in salmon from North America and the United Kingdom in 1970, with the mean number of larvae in salmon at Greenland the previous fall (1969). These analyses (Treatment J) suggested that the mean number of larvae in North American salmon (14.1) was lower than that in European salmon (20.2) and that the mean in salmon caught at Greenland was intermediate (16.1) between the two. This finding conforms with the view that salmon in Greenland originate in North American and European rivers. However, because of the high degree of local variations in abundance of the larvae it is not practical to use these data to estimate the proportion of North American salmon in the samples from Greenland.

(d) Labrador Sea

The mean number of larvae per Age I salmon in the Labrador Sea (station 2) in September of 1971 ($N = 39$, $\bar{x} = 12.6$, Table 3) was exactly the same as that for a sample taken off Greenland at about the same time ($N = 249$, $\bar{x} = 12.6$, Table 3) (Table 7, Treatment K). In contrast, the mean number of larvae per Age I salmon caught in Greenland in the fall of 1969 (16.1, Table 3) was higher than that of Age II salmon caught in the Labrador Sea in the spring of 1970 (10.6, Table 3) (Table 7, Treatment L). This observation was not repeated the following year when the mean in salmon in Greenland in 1970 (17.3, Table 3) was not significantly higher than that observed in salmon in the Labrador Sea the following spring (15.3, Table 3) (Table 7, Treatment M). One is inclined to favour interpretations that (1) the stock composition of salmon caught in the Labrador Sea in the fall is similar to that of salmon caught off Greenland the same fall, and (2) the stock composition of salmon caught in the Labrador Sea in the spring may or may not conform with that off West Greenland the previous fall. However, the relationship between the abundance of *Anisakis* in salmon off Greenland and its abundance in salmon in the Labrador Sea appears to be variable (compare Treatments L and M, Table 7) and definite interpretations based on the abundance of *Anisakis* sp. concerning the possible stock compositions are therefore not advisable.

Annual variations in abundance

If one assumes that the stock composition of Age I salmon off West Greenland is representative of all salmon of that age in the Atlantic region, a reasonable observation on annual variability of the abundance of *Anisakis* larvae is feasible. Analysis of variance on the mean number of larvae per salmon taken in Greenland during 1968-71 indicated there were significant differences ($P < .01$) between years. Subsequently, a multiple range test revealed that the abundance of larvae was fairly consistent in samples taken in 1968-69-70 and that it decreased in 1971 (Table 8, Treatment A).

In North America, Age III salmon were selected for comparison because in each year sampled these salmon appeared to represent a homogeneous group with respect to the abundance of larval *Anisakis*. Analysis of variance suggested there were significant differences ($P < .01$) between the samples taken in 1969, 1970 and 1971. A multiple range test further indicated that the salmon taken in 1969 and 1971 had similar numbers of larvae but the samples taken in 1970 had lower mean numbers of *Anisakis* larvae present (Table 8, Treatment B).

Similar studies were carried out on Ages I and II salmon and, again, different results were obtained (Table 8, Treatments C and D). Thus, among the Age I salmon, those collected in 1969 and 1970 had similar numbers of larvae while those collected in 1971 had more larvae than in the previous two years. Among the Age II salmon, the mean number of larvae per salmon was different in each of the years sampled. The results of analyses on Age I and II fish are presented here as a matter of interest only. Definite trends cannot be gained from these analyses because of heterogeneity among the Age I and II samples (see section on geographical variations).

Seasonal variations in abundance

The age composition of the salmon collected at station 5 during the fishing season from June 12 to July 27 varied with time (Table 9). During the period June 12-18, Age I salmon made up only 30.3% of the sample while Age II salmon constituted 63.6%. By the July 10-17 period, the ratio had reversed so that Age I salmon made up 77.5% of the sample and Age II, 22.5%. In addition to these changes, the abundance of *Anisakis* larvae dropped from about 6 per host (arithmetic mean) during the period June 12-18 to about 2 per host during July 18-25. Evaluation of the changes in the abundance of larvae and the possible relationship of these changes to changes in host age composition of the samples required stratification of the samples according to the age of the hosts.

Age I:- Analysis of variance indicated ($P > .05$) that the abundance of *Anisakis* larvae did not vary significantly among salmon collected during each of five sampling periods from June 12 to July 25 (Table 9). Also, a least squares regression line of the mean number of larvae on the time of collection yielded a correlation coefficient ($r = .08$) which was not significantly different from zero ($P > .05$).

Age II:- Analysis of variance yielded results similar to those obtained for Age I salmon. Also, the correlation coefficient of a least squares regression line was correspondingly low ($r = .09$).

Age III:- Analysis of variance indicated ($P > .05$) that the abundance of *Anisakis* larvae did not vary significantly among the three samples collected from June 12 to July 2. However, the correlation coefficient ($r = -.61$) of a least squares regression analysis was just significant at the 5% level of significance. The latter suggests that the mean number of larvae per Age III salmon decreased as the salmon fishing season progressed. It is likely that these apparently conflicting results of the two above analyses are related to the small sample sizes and the high standard errors in the sample distributions.

General:- If the abundance of larvae in any given age class of salmon at Bonavista is not related to the time in which the salmon were taken, then the observed decrease in abundance of larvae in Age I, II and III salmon combined must be attributable to a combination of the differences in the abundance of the larvae in the different age classes and the different age compositions of the various samples taken during the season.

Abundance of *Anisakis* sp. and *Eubothrium crassum*

The most obvious internal parasite in Atlantic salmon in North American waters is the large pseudophylidean cestode *Eubothrium crassum*. This cestode is usually found in the pyloric caecae and the pyloric region of the intestine. The mean volume of this cestode was 39 ml in 47 infected salmon and the greatest volume observed in a single salmon was 240 ml. In such cases, the pyloric caecae and intestine were noticeably distended by the cestode. The possibility that abundance of Anisakis larvae might be related to the prevalence of E. crassum in the salmon was investigated (Table 10).

The mean number of Anisakis larvae per salmon was significantly higher in salmon without E. crassum than in salmon with E. crassum in the two samples from the Saint John area of the Bay of Fundy (Table 10, Treatments K and L). In the remaining ten samples from North America there were no statistically significant differences in abundance of the larvae (Treatments A-J). However, despite the results of these tests, the observed mean number of larvae per salmon without E. crassum was higher than the mean per salmon with E. crassum in 9 of the remaining 10 North American samples. The consistency of a relatively high mean number of larvae in salmon without E. crassum and the results of Treatments K and L, in Table 10, suggests a relationship between the number of Anisakis larvae and the presence or absence of E. crassum.

Among samples of possibly mixed North American and European salmon (stations 1 and 2) the mean number of larvae per salmon without E. crassum was consistently significantly higher ($P < .05$) than the mean number in salmon with E. crassum (Table 10, Treatments M, N, O).

It is of interest to note that only 6 of 193 (3.1%) Age II salmon from the U.K. were infected with E. crassum (Pippy, 1972) while 491 of 1339 (36.7%) Age II salmon from North American waters had the cestode (from Table 10). If salmon from the U.K. have a greater abundance of Anisakis larvae than do salmon from North America (as suggested in the section on "Geographic variations in abundance"), then this difference may be, to some extent, related to differences in the prevalence of E. crassum in the two stocks.

DISCUSSION

Lear and May (1972) studied a marked decrease from north to south in the average river ages of Atlantic salmon from rivers of Newfoundland and Labrador. They concluded that the salmon fishery off Labrador (station 3) and the northeast coast of Newfoundland was based on salmon originating from rivers in these areas. They supported their conclusions with the results of tagging experiments by Blair (1957a, 1957b). The authors also noted that the fisheries south of Cape Freels on Newfoundland's east coast (stations 5 and 6) were likely a mixture of salmon originating in rivers in both Newfoundland and the Maritime Provinces. This conclusion was supported by the results of tagging experiments by Blair (1956). The river ages of salmon taken at Port aux Basques (station 7) suggested a mixture of Newfoundland and Maritime fish and this suggestion was supported by tagging studies they carried out in 1969 and by the results of a similar tagging program by Belding and Préfontaine (1938a).

Belding and Préfontaine (1939) tagged salmon in the Miramichi drift net fishing area (station 8) and concluded that salmon caught there were destined for the Miramichi River in New Brunswick and several river systems in Chaleur Bay. Other tagging experiments by Belding and Préfontaine (1938b) indicated that salmon tagged at various marine locations along the north shore of the Gulf of St. Lawrence were destined for a variety of different areas in the Gulf.

The high degree of mixing of different stocks of Atlantic salmon in the sea, as outlined above, represents one of the major obstacles in using the abundance of Anisakis larvae as a biological indicator in Atlantic salmon. The available data indicate that there are significant differences in the abundance of larvae in salmon originating in different river systems. These differences appear to be such that salmon returning to adjacent river systems may harbour similar, but not identical mean numbers of larvae. In this case no statistical difference would be expected between the means for adjacent populations. However, in widely separated populations, the means may (or may not) be significantly different. It is this geographical cline in the abundance of Anisakis larvae which presents the greatest difficulty in analysing the data with the intent of determining the stock compositions of given samples.

When this study was initiated it was hoped that the abundance of Anisakis larvae in salmon from both sides of the Atlantic would fall into discrete "blocks" and that these could be treated statistically to determine the percentage of North American and European salmon at Greenland. Most salmon which frequented Greenland in the fall return as Age II salmon the following year. Therefore, this age class may now be considered separately. In 1969 all samples of Age II North American salmon appeared to have a similar mean number of larvae present (Table 7, Treatment C). Also the highest mean number of larvae per sample in 1969, 15.0 (Table 3, station 9), was lower than the mean number of larvae in Greenland the previous fall (17.0). This suggested that (1) the mean number of larvae per salmon might be higher in European salmon than in those from North America, and (2) this difference in abundance might be used to determine continental stock proportions in Greenland. When the study was repeated in 1970 (Table 7, Treatments D and I), it was apparent that variations in the abundance of the larvae might be such that the mean calculated for combined samples from each area would be biased by the number of salmon collected from each sampling station. The study was therefore repeated in 1971 to assess the validity of the apparent variations in the 1970 data. Only specimens from North American waters were studied (Table 7, Treatment E). Analysis of the 1971 data strengthened earlier indications that there were significant variations in the abundance of larvae at different sampling stations. Furthermore, these variations appeared to be random and differed from year to year. Thus, it was not considered feasible to combine data collected from the various North American and European sampling stations. This precludes the possibility of using the abundance of Anisakis larvae to determine the proportion of North American and European salmon at Greenland.

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Table 1. Number of Atlantic salmon examined from each of 14 sampling stations during 1968-71. Station numbers are those of Fig. 1. Fisheries areas are those given in May and Lear's (1971) Appendix 3.

Station No.	Place name	Position	Fisheries areas	Collection period	1968	1969	1970	1971	Total
1	West Greenland			Sept-Oct	181	397	380	251	1209
2	Labrador Sea			Spring & Fall	-	-	25	127	152
North America									
3	Pack's Hr.	53-51-45N 56-58 W	O	July	-	13	82	8	103
4	St. Anthony	51-21-30N 55-33-30W	A	June-July	-	50	103	105	258
5	Bonavista	48-39-10N 53-07 W	C	June	-	125	97	170	392
6	St. John's	47-33-50N 52-40-45W	F	May-June	-	99	-	-	99
7	Port aux Basques	47-35 N 59-07-40W	J & K	May-June	-	86	90	-	176
8	Loggieville	47-04-18N 65-22-54W	70, 73, 75	June-July	-	106	293	200	599
9	Carleton	48-05 N 66-15 W	13, 14, 15	June-July	-	159	252	392	803
10	Bay of Fundy (east)		35, 40	July	-	113	-	-	113
11	Saint John	45-10 N 67-05 W	48, 49	June-July	-	71	143	46	260
United Kingdom									
12	Scotland (N. Esk R.)	56-37-24N 02-27-36W		April-July	-	-	112	-	112
13	Ireland			March-April	-	-	55	-	55
14	England (R. Axe)	50-36-24N 01-56-24W		April-May	-	-	50	-	50
					181	1219	1682	1299	4381

Table 2. Number (N), arithmetic mean number ($\bar{x}$) and standard deviation (S) of larval *Anisakis* sp. found in Atlantic salmon at 14 sampling stations (see Table 1) from 1968-71 arranged according to host's sea age.

Area	Station No.	Year	I			II			III			IV			V		
			N	$\bar{x}$	S	N	$\bar{x}$	S	N	$\bar{x}$	S	N	$\bar{x}$	S	N	$\bar{x}$	S
West Greenland	1	1968	155	5.77	4.49	10	9.00	6.00	-	-	-	-	-	-	-	-	-
Canadian (by tagging)	1	1968	8	4.50	4.60	6	4.00	3.41	2	3.00	1.41	-	-	-	-	-	-
Canada	All	1969	126	2.48	3.04	531	3.77	3.71	152	6.90	7.68	11	5.00	4.00	2	2.50	0.71
	3	1969	5	8.20	5.98	8	3.00	2.65	-	-	-	-	-	-	-	-	-
	4	1969	19	3.95	2.74	28	3.00	2.38	2	2.50	0.50	1	2.00	0	-	-	-
	5	1969	40	1.65	1.17	61	3.12	2.75	23	5.13	3.25	1	6.00	0	-	-	-
	6	1969	11	5.64	4.58	72	3.33	4.01	16	12.69	20.36	-	-	-	-	-	-
	7	1969	1	0	0	71	2.99	3.02	13	5.85	4.07	1	1.00	0	-	-	-
	8	1969	-	-	-	95	4.19	3.89	11	5.91	4.72	-	-	-	-	-	-
	9	1969	-	-	-	70	4.57	3.58	81	7.84	9.72	6	6.50	4.92	2	2.50	0.71
	10	1969	49	1.39	1.65	57	3.63	4.15	6	4.67	3.20	1	5.00	0	-	-	-
	11	1969	1	0	0	69	4.12	4.95	-	-	-	1	2.00	0	-	-	-
West Greenland	1	1969	205	6.17	6.57	15	6.00	8.18	-	-	-	-	-	-	-	-	-
European (by tagging)	1	1969	20	7.20	8.09	4	9.75	4.79	-	-	-	-	-	-	-	-	-
Canadian (by tagging)	1	1969	147	4.35	3.64	5	6.00	3.08	-	-	-	1	6.00	0	-	-	-
Labrador Sea (Spring)	2	1970	-	-	-	23	3.70	5.89	2	2.50	3.54	-	-	-	-	-	-
Canada	All	1970	135	2.56	2.14	803	4.07	3.19	112	5.21	5.47	9	6.67	4.24	-	-	-
	3	1970	8	1.50	1.19	72	4.06	2.93	2	22.00	25.46	-	-	-	-	-	-
	4	1970	42	2.29	2.33	61	4.39	3.99	-	-	-	-	-	-	-	-	-
	5	1970	44	2.71	2.27	46	5.09	3.64	7	2.86	2.34	-	-	-	-	-	-
	7	1970	-	-	-	87	3.94	3.29	3	3.00	1.73	-	-	-	-	-	-
	8	1970	35	3.03	1.99	238	4.09	3.33	19	4.90	3.91	1	10.00	0	-	-	-
	9	1970	-	-	-	175	4.55	3.09	71	5.56	4.80	5	2.13	0.41	-	-	-
	11	1970	6	2.17	1.17	124	2.92	2.50	10	2.20	1.75	3	3.33	4.04	-	-	-
British Isles	All	1970	6	4.16	2.14	193	9.27	11.83	17	2.59	2.09	1	1.00	0	-	-	-
	12	1970	4	4.50	2.65	107	14.20	13.02	-	-	-	-	-	-	-	-	-
	13	1970	2	3.50	0.71	41	6.12	8.86	11	2.73	2.37	1	1.00	0	-	-	-
	14	1970	-	-	-	45	6.00	7.57	6	2.33	1.63	-	-	-	-	-	-
West Greenland	1	1970	162	6.34	5.50	9	9.89	7.04	1	4.00	0	1	14.00	0	-	-	-
North American (by tagging)	1	1970	139	4.17	3.07	12	8.17	4.71	-	-	-	-	-	-	-	-	-
European (by tagging)	1	1970	54	5.28	5.99	1	7.00	0	1	12.00	0	-	-	-	-	-	-
Labrador Sea (Spring)	2	1971	5	3.60	2.41	75	4.81	3.89	5	7.20	5.76	-	-	-	-	-	-
Canada	All	1971	41	4.41	3.25	658	5.13	3.89	194	6.79	6.61	19	6.95	3.86	9	5.11	3.98
	3	1971	4	5.75	4.35	4	3.50	1.29	-	-	-	-	-	-	-	-	-
	4	1971	26	4.65	3.31	77	4.13	3.47	2	9.00	1.41	-	-	-	-	-	-
	5	1971	11	3.36	2.66	133	5.18	4.63	26	8.46	6.68	-	-	-	-	-	-
	8	1971	-	-	-	194	5.30	3.61	5	5.40	4.39	1	9.00	0	-	-	-
	9	1971	-	-	-	204	5.46	3.67	161	6.53	6.71	18	6.83	3.94	9	5.11	3.98
	11	1971	-	-	-	46	4.61	4.45	-	-	-	-	-	-	-	-	-
Labrador Sea (Autumn)	2	1971	39	3.23	2.39	2	2.50	.71	1	14.00	0	-	-	-	-	-	-
West Greenland	1	1971	249	3.73	3.81	2	2.50	.71	-	-	-	-	-	-	-	-	-

Table 3. Number (N), transformed mean number ($\bar{x}$) and standard deviation (S) of larval *Anisakis* sp. found in Atlantic salmon at 14 sampling stations (see Table 1) from 1968-71 arranged according to host's sea age. Transformation is based on the equation $y = 10 \log_e(x + 1)$, where x is the original observation on the number of larvae in a given fish and y is the transformed value.

Area	Station No.	Year	I			II			III			IV			V		
			N	$\bar{x}$	S	N	$\bar{x}$	S	N	$\bar{x}$	S	N	$\bar{x}$	S	N	$\bar{x}$	S
West Greenland	1	1968	155	17.02	7.19	10	20.44	8.20	-	-	-	-	-	-	-	-	-
Canadian (by tagging)	1	1968	8	14.09	8.11	6	13.45	8.66	2	13.50	3.62	-	-	-	-	-	-
Canada	All	1969	126	9.61	7.31	531	12.91	7.26	152	18.16	7.00	11	1.61	6.05	2	12.38	2.04
	3	1969	5	19.40	8.94	8	11.16	8.30	-	-	-	-	-	-	-	-	-
	4	1969	19	14.35	6.02	28	11.77	6.87	2	12.38	2.04	1	-	-	-	-	-
	5	1969	40	86.29	4.95	61	11.82	7.07	23	16.48	6.37	1	-	-	-	-	-
	6	1969	11	15.57	9.49	72	13.15	7.49	16	19.69	7.29	-	-	-	-	-	-
	7	1969	1	-	-	71	11.39	6.92	13	16.49	8.57	1	-	-	-	-	-
	8	1969	-	-	-	95	14.07	7.11	11	17.27	6.57	-	-	-	-	-	-
	9	1969	-	-	-	70	15.04	6.72	81	19.07	6.96	6	18.43	6.03	2	12.38	2.04
	10	1969	49	6.65	6.27	57	12.13	8.14	6	15.62	6.47	1	-	-	-	-	-
	11	1969	1	-	-	69	12.76	8.33	-	-	-	1	-	-	-	-	-
West Greenland	1	1969	205	16.11	8.63	15	16.07	7.63	-	-	-	-	-	-	-	-	-
European (by tagging)	1	1969	20	16.83	9.36	4	22.83	5.10	-	-	-	-	-	-	-	-	-
Canadian (by tagging)	1	1969	147	14.39	7.30	5	18.69	4.15	-	-	-	-	-	-	-	-	-
Labrador Sea (Spring)	2	1970	-	-	-	23	10.64	9.49	2	8.96	12.70	-	-	-	-	-	-
Canada	All	1970	135	10.81	6.33	803	14.14	6.58	112	15.28	7.76	9	18.47	7.21	-	-	-
	3	1970	8	7.92	5.55	72	14.38	6.48	2	26.59	14.89	-	-	-	-	-	-
	4	1970	42	9.49	7.08	61	14.34	7.24	-	-	-	-	-	-	-	-	-
	5	1970	44	11.56	6.26	46	16.15	6.53	7	11.77	6.57	-	-	-	-	-	-
	7	1970	-	-	-	87	13.43	7.54	3	13.04	5.29	-	-	-	-	-	-
	8	1970	35	12.48	5.76	238	14.25	6.59	19	14.89	8.52	1	-	-	-	-	-
	9	1970	-	-	-	175	15.39	6.17	71	16.30	7.35	5	21.25	4.10	-	-	-
	11	1970	6	10.97	3.67	124	11.75	6.27	10	9.95	6.42	3	11.95	8.68	-	-	-
British Isles	All	1970	6	15.74	3.83	193	20.20	9.56	17	10.96	6.57	1	-	-	-	-	-
	12	1970	4	16.14	4.80	108	23.91	8.56	-	-	-	-	-	-	-	-	-
	13	1970	2	14.98	1.58	41	15.22	8.89	11	11.10	7.01	1	-	-	-	-	-
	14	1970	-	-	-	44	15.78	8.57	6	10.63	6.22	-	-	-	-	-	-
West Greenland	1	1970	162	17.28	7.52	9	21.72	7.18	1	-	-	1	-	-	-	-	-
North American (by tagging)	1	1970	139	14.68	6.05	12	21.15	4.35	-	-	-	-	-	-	-	-	-
European (by tagging)	1	1970	54	15.38	7.50	1	-	-	1	-	-	-	-	-	-	-	-
Labrador Sea (Spring)	2	1971	5	14.06	5.48	75	15.33	6.99	5	19.06	6.94	-	-	-	-	-	-
Canada	All	1971	41	15.01	6.40	658	16.18	6.37	194	17.71	7.44	19	19.26	5.95	9	16.06	6.90
	3	1971	4	17.62	6.08	4	14.62	2.98	-	-	-	-	-	-	-	-	-
	4	1971	26	15.58	6.18	77	13.97	7.19	2	22.94	1.40	-	-	-	-	-	-
	5	1971	11	12.73	6.94	133	16.16	6.33	26	20.17	6.90	-	-	-	-	-	-
	8	1971	-	-	-	194	16.62	6.22	5	16.34	7.64	1	-	-	-	-	-
	9	1971	-	-	-	204	16.99	5.91	161	17.29	7.54	18	19.06	6.05	9	16.06	6.90
	11	1971	-	-	-	46	14.66	7.27	-	-	-	-	-	-	-	-	-
Labrador Sea (Autumn)	2	1971	39	12.62	6.37	2	12.38	2.04	1	-	-	-	-	-	-	-	-
West Greenland	1	1971	249	12.64	7.61	2	12.38	2.04	-	-	-	-	-	-	-	-	-

Table 4. Prevalence of infection with Anisakis sp. in five age groups of Atlantic salmon from fourteen different sampling stations in the north Atlantic (1968-71). Prevalence in percent; Number examined in brackets; N.A. = North American; Eur. = European.

Sampling station	Year	Sea-winters				
		1	2	3	4	5
Greenland						
1 (random)	1968	92.90(155)	100.00(10)	-	-	-
1 N.A. Tagged	1968	100.00(8)	100.00(6)	100.00(2)	-	-
Canada (Total)	1969	75.40(126)	86.81(531)	96.05(152)	100.00(11)	100.00(2)
3	1969	100.00(5)	75.00(8)	-	-	-
4	1969	94.73(19)	85.71(28)	100.00(2)	100.00(1)	-
5	1969	82.50(40)	83.61(61)	95.65(23)	100.00(1)	-
6	1969	81.82(11)	88.89(72)	93.75(16)	-	-
7	1969	0 (1)	85.91(71)	92.31(13)	100.00(1)	-
8	1969	-	89.47(95)	100.00(11)	-	-
9	1969	-	95.71(70)	95.76(81)	100.00(6)	100.00(2)
10	1969	61.22(49)	78.95(57)	100.00(6)	100.00(1)	-
11	1969	0 (1)	84.06(69)	-	100.00(1)	-
Greenland						
1 (random)	1969	91.22(205)	100.00(15)	-	-	-
1 N.A. Tagged	1969	90.48(147)	100.00(5)	-	100.00(1)	-
1 Eur. Tagged	1969	90.00(20)	100.00(4)	-	-	-
2 (Spring)	1970	-	69.57(23)	50.00(2)	-	-
Canada (Total)	1970	83.70(135)	91.66(803)	91.07(112)	100.00(9)	-
3	1970	75.00(8)	91.67(72)	100.00(2)	-	-
4	1970	73.81(42)	91.80(61)	-	-	-
5	1970	86.36(44)	95.65(46)	85.71(7)	-	-
7	1970	-	87.35(87)	100.00(3)	-	-
8	1970	91.43(35)	91.60(238)	84.21(19)	100.00(1)	-
9	1970	-	94.86(175)	94.37(71)	100.00(5)	-
11	1970	100.00(6)	88.71(124)	80.00(10)	100.00(3)	-
United Kingdom	1970	100.00(6)	95.86(193)	82.35(17)	100.00(1)	-
12	1970	100.00(4)	97.20(107)	-	-	-
13	1970	100.00(2)	92.68(41)	81.82(11)	100.00(1)	-
14	1970	-	95.56(45)	83.33(6)	-	-
Greenland						
1 (random)	1970	96.30(162)	100.00(9)	100.00(1)	100.00(1)	-
1 N.A. Tagged	1970	95.68(139)	100.00(12)	-	-	-
1 Eur. Tagged	1970	96.30(54)	100.00(1)	100.00(1)	-	-
England	1970	95.83(24)	100.00(1)	-	-	-
Scotland	1970	94.44(18)	-	100.00(1)	-	-
France	1970	100.00(4)	-	-	-	-
Norway	1970	100.00(4)	-	-	-	-
Ireland	1970	100.00(2)	-	-	-	-
Sweden	1970	100.00(1)	-	-	-	-
2 (Spring)	1971	100.00(5)	94.67(75)	100.00(5)	-	-
Canada (Total)	1971	95.12(41)	95.90(658)	96.39(194)	100.00(19)	100.00(9)
3	1971	100.00(4)	100.00(4)	-	-	-
4	1971	96.15(26)	89.61(77)	100.00(2)	-	-
5	1971	100.00(11)	96.24(133)	100.00(26)	-	-
8	1971	-	96.39(194)	100.00(5)	100.00(1)	-
9	1971	-	98.04(204)	95.65(161)	100.00(18)	100.00(9)
11	1971	-	93.48(46)	-	-	-
2 (Fall)	1971	89.74(39)	100.00(2)	100.00(1)	-	-
1 (ATC 190)	1971	85.94(249)	100.00(2)	-	-	-

Table 5. Results of Student's t tests on the mean number of *Anisakis* larvae in male and female Atlantic salmon in ten different samples. * indicates mean of original data.

Year	Sampling station	Host age	Sex	N	$\bar{x}$*	$\bar{x}$	S	t	P
1970	3	II	M	25	4.12	14.64	6.10	.28	.7 < P < .8
			F	47	4.02	14.18	6.70		
	4	I	M	24	2.33	9.74	7.10	.25	.8 < P < .9
			F	18	2.22	9.16	7.28		
	5	II	M	20	5.45	16.71	6.93	.50	.5 < P < .6
			F	26	4.81	15.71	6.31		
	7	II	M	23	3.78	13.22	7.10	-.21	.8 < P < .9
			F	63	4.05	13.61	7.77		
	8	II	M	40	4.03	13.92	6.98	-.34	.7 < P < .8
			F	198	4.11	14.31	6.49		
	9	II	M	81	4.70	15.70	6.38	.40	.6 < P < .7
			F	91	4.50	15.32	5.94		
	11	II	M	17	2.65	10.64	7.11	-.78	.4 < P < .5
			F	104	2.97	11.94	6.16		
1971	5	II	M	34	4.74	15.97	5.75	.20	.8 < P < .9
			F	99	5.33	16.23	6.59		
	8	II	M	24	6.04	17.40	7.36	.66	.5 < P < .6
			F	168	5.20	16.50	6.09		
	9	II	M	137	5.64	17.53	5.32	1.87	.05 < P < .1
			F	67	5.09	15.89	6.86		
		III	M	24	8.42	19.87	7.81	1.81	.05 < P < .1
			F	137	6.20	16.84	7.45		

Table 6. Results of analyses of variance and multiple range tests on variations of the mean number of <u>Anisakis</u> sp. larvae in salmon which have spent different numbers of years at sea.

F = ratio of mean square of sample means to mean square of individuals, ** = P < .01
a = salmon tagged in the Miramichi River and caught in Greenland
b = " " " " North Esk River " " " "
c = " " " " Axe River " " " "
Bracketed figures represent number of fish in sample.

Treatment	Year	Sampling station	Ages	F_{df}	P	Multiple range test (for different ages)
A	1969	4	I,II	$1.75_{1,45}$		-
B	1970	4	I,II	$11.29_{1,101}$	**	-
C	1971	4	I,II	$1.04_{1,101}$		-
D	1969	5	I,II,III	$11.11_{2,121}$	**	<u>I</u> <u>II</u> <u>III</u>
E	1970	5	I,II	$13.18_{1,88}$	**	-
F	1971	5	II,III	$8.37_{1,157}$	**	-
G	1969	6	II,III	$10.03_{1,86}$	**	-
H	1970	8	I,II,III	$1.23_{2,289}$		-
I	1969	9	II,III	$12.97_{1,149}$	**	-
J	1970	9	II,III	$.99_{1,244}$		-
K	1971	9	II,III,IV	$.81_{2,380}$		-
L	1969	10	I,II	$14.64_{1,104}$	**	-
M	1970 1971	1[a] 8	I (71) II (194)	$78.66_{1,791}$	**	-
N	1969 1970	1[a] 8	I (93) II (238)	$.85_{1,329}$		-
O	1969 1970	1[b] 12	I (5) II (108)	$.86_{1,111}$		-
P	1969 1970	1[c] 14	I (9) II (44)	$2.25_{1,51}$		-

Table 7. Results of analyses of variance and multiple range tests on variations of the mean number of *Anisakis* sp. larvae in salmon of different ages at different sampling stations during different years.

F = ratio of mean square of sample means to mean square of individuals, ** = $P < .01$

Treatment	Year	Sampling stations	Age	F_{df}	P	Multiple range test (for different stations)
A	1969	4,5,10	I	$12.18_{2,105}$	**	10 5 4
B	1970	4,5,8	I	$2.12_{2,118}$		-
C	1969	4-11	II	$1.99_{7,515}$		-
D	1970	3-5,7-9,11	II	$4.68_{6,796}$	**	11 7 8 4 3 9 5
E	1971	4,5,8,9,11	II	$4.03_{4,649}$	**	4 11 5 8 9
F	1969	5,6,9	III	$1.54_{2,117}$		-
G	1970	8,9	III	$.53_{1,88}$		-
H	1971	5,9	III	$3.31_{1,185}$		-
I	1970	12-14	II	$22.60_{2,190}$	**	13 14 12
J	1969 1970 1970	(a) 1 (b)3-5,7-9,11 (c) 12-14	I II II	$50.84_{2,1198}$	**	b a c
K	1971 1971	1 (Sept) 2 (Sept)	I I	$0_{1,286}$		-
L	1969 1970	1 2	I II	$8.07_{1,226}$	**	-
M	1970 1971	1 2	I II	$3.42_{1,235}$		-

Table 8. Annual variations in the mean number of *Anisakis* sp. larvae per salmon. Results of analyses of variance and multiple range tests. N = number in sample, $\bar{x}$ = transformed mean, F = ratio of mean square of sample means to mean square of individuals, ** = P < .01

Treatment	Year	Sampling stations	Age	N	$\bar{x}$	F_{df}	P	Multiple range test
A	1968	1	I	155	16.6	$14.88_{3,767}$	**	12.6 16.1 16.6 17.2
	1969	1	I	205	16.1			
	1970	1	I	162	17.2			
	1971	1	I	249	12.6			
B	1969	4-10	III	152	18.2	$5.47_{2,455}$	**	15.3 17.7 18.2
	1970	3,5,7-9,11	III	112	15.3			
	1971	4,5,8,9	III	194	17.7			
C	1969	3-7,10,11	I	126	9.6	$9.84_{2,299}$	**	9.6 10.8 15.0
	1970	3-5,8,11	I	135	10.8			
	1971	3-5	I	41	15.0			
D	1969	3-11	II	531	12.9	$35.60_{2,1989}$	**	12.9 14.1 16.2
	1970	3-5,7-9,11	II	803	14.1			
	1971	3-5,8,9,11	II	658	16.2			

Table 9. Abundance of *Anisakis* sp. larvae in Age I, II and III salmon collected at Bonavista (station 5) from June 12 to July 25, 1972. N = number of hosts examined, $\bar{x}^*$ = arithmetic mean number of larvae per host, $\bar{x}$ = transformed mean, F = F ratio from analysis of variance.

	I			II			III			I + II + III		
	N (%)	$\bar{x}^*$	$\bar{x}$	N (%)	$\bar{x}^*$	$\bar{x}$	N (%)	$\bar{x}^*$	$\bar{x}$	N (%)	$\bar{x}^*$	$\bar{x}$
June 12-18	10 (30.3)	2.40	11.11	21 (63.6)	7.62	18.15	2 (6.1)	6.00	19.39	33 (100)	5.94	16.09
June 19-25	- -	-	-	24 (85.7)	5.63	16.79	4 (14.3)	3.75	14.54	28 (100)	5.36	16.47
June 26-July 2	14 (35.9)	2.00	10.02	20 (51.3)	5.80	17.74	5 (12.8)	2.00	9.70	39 (100)	3.95	13.94
July 3-9	28 (70.0)	2.75	11.57	12 (30.0)	5.58	16.04	- -	-	-	40 (100)	3.60	12.91
July 10-17	31 (77.5)	2.00	9.15	9 (22.5)	5.00	15.86	- -	-	-	40 (100)	2.68	10.66
July 18-25	10 (100)	2.30	10.25	- -	-	-	- -	-	-	10 (100)	2.30	10.25
June 12-July 25	93 (48.9)	2.30	10.34	86 (45.3)	6.08	17.14	11 (5.8)	3.36	13.22	190 (100)	4.08	13.59
F_{df}			$.68_{4,88}$			$.28_{4,81}$			$2.4_{2,8}$			
P			> .05			> .05			> .05			

Table 10. Comparisons of the abundance of *Anisakis* sp. larvae in salmon infected with *Eubothrium crassum* with those not infected with E. crassum. N = number of hosts examined, $\bar{x}^a$ = arithmetic mean number of larvae per host, $\bar{x}$ = transformed mean, S = standard deviation of transformed data.

Treatment	Sampling station	Year	Host age	*E. crassum*	N	$\bar{x}^a$	$\bar{x}$	S	t	P
North America										
A	4	1970	II	with	45	4.56	14.49	7.58	.21	.8 < P < .9
				without	16	3.94	14.03	6.48		
B	4	1971	II	with	58	3.83	13.44	7.02	1.11	.3 < P < .4
				without	19	5.05	15.58	7.69		
C	5	1971	II	with	47	4.13	14.59	6.11	2.13	.025 < P < .05
				without	86	5.76	17.03	6.36		
D	7	1970	II	with	50	3.50	12.59	7.24	1.19	.2 < P < .3
				without	37	4.54	14.55	7.89		
E	8	1970	II	with	45	3.62	13.62	6.05	.70	.4 < P < .5
				without	193	4.20	14.39	6.73		
F	8	1971	II	with	69	4.99	15.79	6.74	1.37	.1 < P < .2
				without	125	5.48	17.08	5.94		
G	9	1970	II	with	44	3.80	14.01	5.86	1.71	.05 < P < .1
				without	131	4.80	15.85	6.22		
H	9	1971	II	with	51	5.08	16.27	6.33	1.00	.3 < P < .4
				without	153	5.58	17.23	5.75		
I	9	1970	III	with	55	5.02	15.71	6.92	1.15	.05 < P < .1
				without	16	7.44	18.15	8.60		
J	9	1971	III	with	83	5.72	16.19	7.58	1.92	.05 < P < .1
				without	78	7.40	18.47	7.39		
K	11	1970	II	with	62	2.69	10.54	7.00	2.16	.02 < P < .05
				without	62	3.15	12.95	5.21		
L	11	1971	II	with	20	3.95	14.48	5.98	4.19	P < .01
				without	26	5.12	14.80	8.25		
Labrador Sea										
M	2	1970	I	with	20	4.15	12.70	8.59	2.95	P < .01
				without	142	6.65	17.88	7.10		
Greenland										
N	1	1969	I	with	36	4.25	13.30	7.65	2.15	.02 < P < .05
				without	169	6.57	16.67	8.69		
O	1	1970	I	with	20	4.15	12.70	8.59	2.95	P < .01
				without	142	6.65	17.88	7.10		

D 6

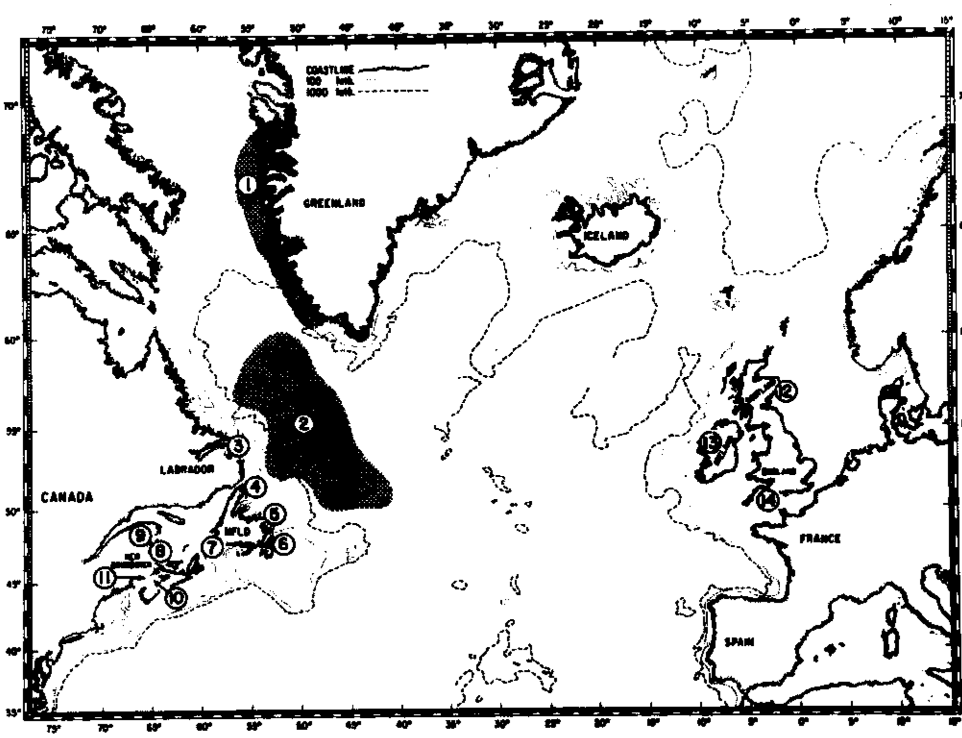

Fig. 1. Distribution of sampling stations for Atlantic salmon in the North Atlantic. See Table 1 for details on locations and numbers of fish examined from each station.

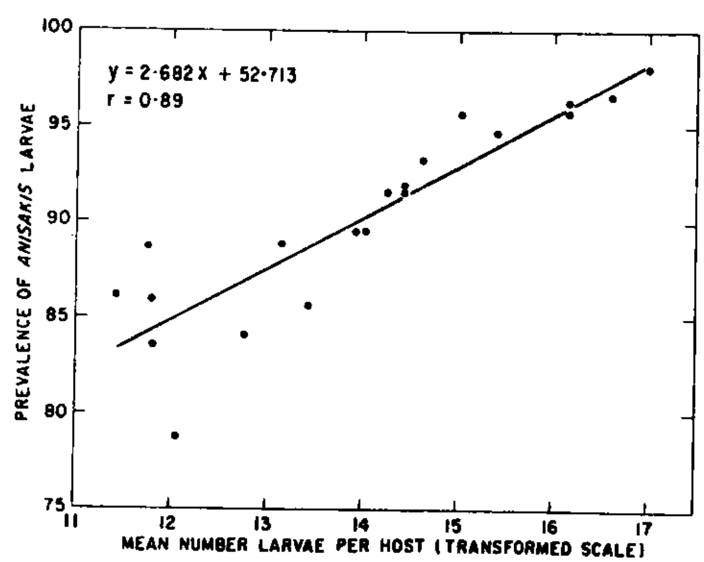

Fig. 2. Relationship of the prevalence of infection (% hosts infected) to the mean number of <u>Anisakis</u> larvae per salmon.