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The incidence of *Anisakis* sp. larvae (Nematoda: Ascaridata) in the commercially exploited stocks of herring (*Clupea harengus* L., 1758) (Pisces: Clupeidae) in British and adjacent waters

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10 000 herrings from the commercial fisheries around the coasts of Great Britain and Ireland were examined for the nematode larva *Anisakis* sp. between October 1968 and October 1970. Heavy infestations were found in the North Sea stocks, moderate infestations west of Scotland and minimal infestations elsewhere; but nowhere was the parasite completely absent. Younger fish were often found to be more heavily infested than older fish and it is therefore suggested that the accumulation of larvae in the body cavity may be affected by annual fluctuations either in the population of an infested first intermediate host or in the extent to which the herrings are feeding on this host. A small but constant proportion of the parasites penetrate the musculature of the herring regardless of other factors such as the age or length of the host, or the number of other larvae present.

I. INTRODUCTION

Larval nematodes of the genus *Anisakis* Dujardin, 1845 are common parasites of many marine teleosts and their presence in a number of commercially important species has been recognized for some time. These larvae represent the dormant infective third stage awaiting ingestion by a suitable final host, normally a marine mammal. In British waters the herring is the most commonly infested fish host, at any rate amongst exploited species (Khalil, 1969), and here the larvae are generally encountered in the body cavity although a small proportion may be partially embedded in the body musculature. Usually between 15–30 mm long and whitish in appearance, they may be free in the body cavity or encysted in a tough membrane of host origin (Prusevich, 1964) and attached singly or in clumps to the mesenteries and body organs.

Particular concern at the presence of *Anisakis* larvae in herrings grew from the publication in Holland (Kuipers *et al.*, 1960; Thiel *et al.*, 1960) of the first documented case histories of patients suffering alimentary disorders following the accidental ingestion of live *Anisakis* larvae with raw or under-cooked herring. Thiel (1962) coined the name ' Anisakiasis ' for this particular pathological condition.

Dr L. F. Khalil, then of the N.E.R.C. Fisheries Helminthology Unit, carried out a survey of herrings for *Anisakis* infestations between 1966 and 1968. In all he examined 2326 adult herrings from the North Sea, Minches and Irish Sea. He also examined 3320 juvenile herrings from the North Sea. His results (Khalil, 1969) were certainly the most comprehensive on this parasite that had been produced, but the conclusions

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were in the nature of overall trends. Thus he showed that infestations varied with locality, increased with the length of the fish and appeared to be greater in fish caught closer to our Eastern coasts than out to sea.

As a logical development from Khalil's work, this survey was planned as a comprehensive assessment of the *Anisakis* infestation in each commercially exploited stock around our coasts in order to arrive at a more thorough understanding of this particular host-parasite relationship.

II. METHODS

1. ORGANIZATION OF SAMPLING

The majority of all adult herrings examined in this survey were processed at the Fisheries Helminthology Unit, St. Albans. This was made possible by the cooperation of various Ministry of Agriculture, Fisheries and Food and Department of Agriculture and Fisheries for Scotland personnel or, in some cases, by fish merchants themselves. Sampling of herrings from Galway Bay, the Irish Sea off Co. Waterford at Dunmore East and some of the Isle of Man stock was performed locally by Scientific Assistants sent from the Unit. Sampling of young herrings (I group) in the North Sea was carried out during M.A.F.F. cruises aboard the Research Vessel ' Ernest Holt ' while the vessel was taking part in the annual young herring surveys of the International Commission for the Exploration of the Sea.

2. METHODS OF SAMPLING

Records were kept of the length, weight and sex of every fish examined, the otoliths removed and the number of *Anisakis* larvae in the body cavity and musculature counted by naked-eye search. From July 1970 onwards this search was effected by a chemical digestion technique learnt from Dr P. van Banning in Ijmuiden, Holland. This involved scraping all the body cavity contents of each fish into individually numbered disposable beakers and covering with 150 ml of water to which was added $\frac{1}{4}$ teaspoon of citric acid powder and about the same quantity of pepsin. The beakers were incubated at 37° C for not more than 24 h after which the contents were sieved and the parasites removed and counted. *Anisakis* larvae are not harmed by this treatment but, on the contrary, they become more active and are easier to see.

3. AGEING THE FISH

The age of the fish was determined from examination of the otoliths and approximately 93 % of all the herrings were successfully aged by this method. The terminology used must be clarified. Fish are referred to as I group, II group etc. meaning that the otolith had 1 or 2 winter rings respectively, and so on. In this text, where it has been necessary to speak of years (e.g. where mean ages are calculated), a III group is taken to be a 3-year-old. In some publications a 3-year-old fish would mean one with only 2 winter rings in the otolith.

III. RESULTS

Over a period of 2 years from October 1968 to October 1970, the numbers of *Anisakis* found in approximately 10 000 herrings were recorded together with data on age, size and origin of each fish. The numbers of parasites/host varied from 0–278 with a preponderance of lower values, i.e. parasite counts displayed a highly skewed frequency distribution. In this situation the variance is dependent on the mean of each sample and routine statistical methods of analysis are not applicable. Following the suggestion of Southwood (1966) and the precedent of Bishop & Margolis (1955), the parasite counts were transformed by the use of the following equation:

$$y = 100 \log_{10} (x+1)$$

where y=the transformed value of x, the original observation. Henceforward all mean worm burdens are on the transformed scale unless otherwise indicated. Table I shows the effectiveness of this transformation in stabilizing the variance.

TABLE I. Effect of transformation: $y=100 \log_{10} (x+1)$.
Minch samples for 1968/69

		II	III	IV	V	VI
Raw data:	Mean	5·9	6·0	4·3	5·5	4·5
	s	22·69	53·72	26·94	36·90	29·41
Transformed:	Mean	72·12	63·01	55·73	64·81	58·00
	s	1329	2089	1355	1506	1484

In order to simplify the presentation of a large volume of data the essential details of the survey results are summarized in Fig. 1 and Tables II, III and IV. Figure 1 indicates the areas of sampling, while the three tables give the numbers examined, percentage infestations and mean worm burdens/age groups of herrings in each area covered by the survey.

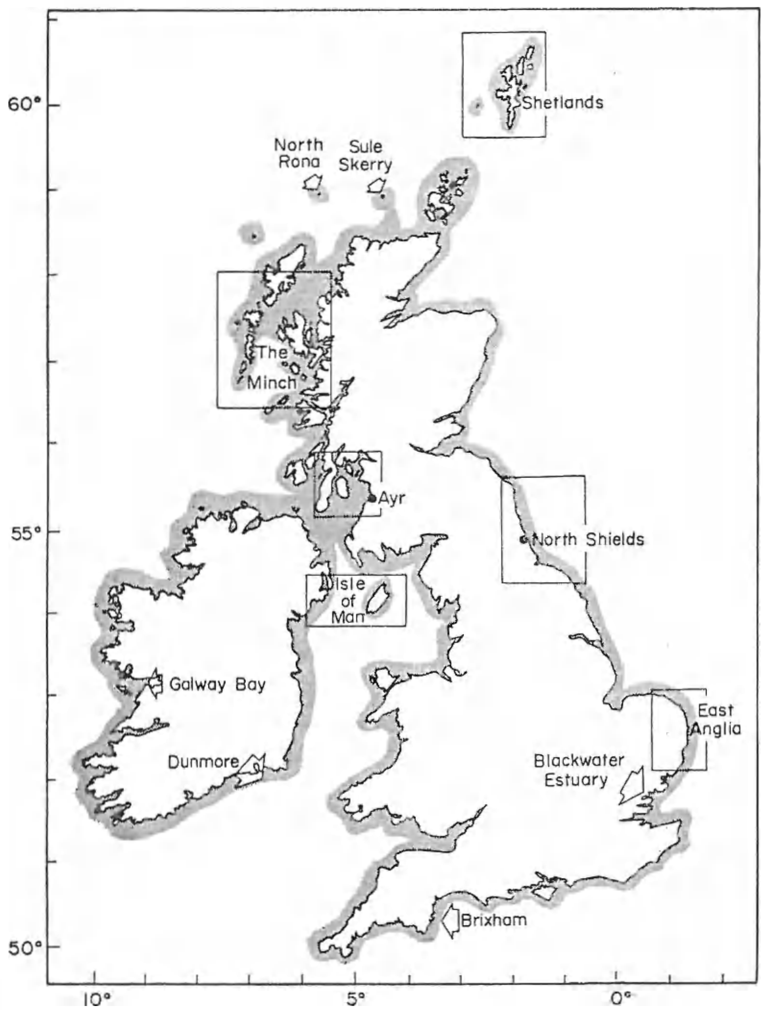

FIG. 1. Herring survey, 1968–70: areas of sampling.

TABLE II. Age composition of herring samples

Area	I	II	III	IV	V	VI	VII	VIII	IX	X	XII	Total
Shetland 1969			1	290	60	21	6					378
Shetland 1970	12	141	83	15	7	5						263
North Shields 1969	23	609	148	194	33							1007
North Shields 1970	14	657	128	5								804
East Anglia Autumn	43	210	113	72	21	1	1					461
East Anglia Spring	2	126	80	54	50	12	4	2	1	1	1	333
Blackwater 1968/69	1	41	60	75	8							185
Blackwater 1970	25	93	198	233	167	44	24	11	4	4		803
Minch 1968/69	1	22	51	232	148	64	31	1				550
Minch 1969/70		8	10	222	248	97	33	2	2	1		623
Ayr 1969				31	44	8	6					89
Ayr 1970	233	314	238	101	50	13	6	3				958
Isle of Man 1969	1	141	46	30	10	8						236
Dunmore East 1970		15	25	71	148	41	40	32	32	4		408
Galway Bay 1970	8	75	58	16	17							174
Brixham 1969/70	41	92	44	108	164	84	39	16				588
I.C.E.S. Survey 1969	662	86	2									750
I.C.E.S. Survey 1970	328	90	5	2	1							426
Total	1394	2720	1290	1751	1176	398	190	67	39	10	1	9036

TABLE III. Percentage of infected herrings in each age group for all areas in the survey

Area	I	II	III	IV	V	VI	VII	VIII	IX
Shetland 1969				94·1	96·7	95·2			
Shetland 1970		93·6	100	100					
North Shields 1969	87	91·5	87·8	72·7	69·7				
North Shields 1970		83	85						
East Anglia Autumn	46·5	77·6	85·8	88·9	81				
East Anglia Spring		80·2	93·8	96·3	100				
Blackwater 1968/69		12·2	10	12					
Blackwater 1969/70	16	26·9	14·7	9	15	6·8	8·3		
Minch 1968/69		95	78·4	56	87·8	84·4	80·7		
Minch 1969/70				82·6	69·4	68	66·7		
Ayr 1969				0	6·8				
Ayr 1970	13·3	7·6	11·8	14·9	10				
Isle of Man 1969		9·2	10·9	16·7	20				
Dunmore East 1970		13·3	24	14	25·5	47·5	40	65·6	68·8
Galway Bay 1970		24	34·5	62·5	70·6				
Brixham 1969/70	4·9	8·7	11·4	12	6·7	8·3	20·5	25	

TABLE IV. Transformed mean worm burdens of herrings in each age group for all areas in the survey

Area	I	II	III	IV	V	VI	VII	VIII	IX
Shetland 1969				75·93	86·45	93·49			
Shetland 1970		83·78	113·07	122·81					
North Shields 1969	54·33	81·71	65·54	45·07	52·43				
North Shields 1970		67·40	74·31						
East Anglia Autumn	31·55	64·84	91·02	93·06	68·97				
East Anglia Spring		74·57	113·37	126·55	135·34				
Blackwater 1968/69		6·90	6·74	9·19					
Blackwater 1969/70	10·11	24·03	7·97	6·20	10·82	2·05	2·51		
Minch 1968/69		72·12	63·01	55·73	64·81	58·00	50·13		
Minch 1969/70				61·92	49·76	51·68	45·46		
Ayr 1969				0	3·42				
Ayr 1970	4·36	2·89	5·08	6·24	8·55				
Isle of Man 1969		4·07	6·11	18·82					
Dunmore East 1970		5·19	12·13	8·47	17·10	36·49	34·07	49·47	73·91
Galway Bay 1970		12·13	16·18	35·55	44·47				
Brixham 1969/70	1·47	5·59	5·41	5·91	3·32	3·14	13·31	10·51	

1. INFESTATION WITH *ANISAKIS* IN RELATION TO SEX OF THE FISH

There was no reason to expect that either sex would be more prone to infestation with *Anisakis* than the other, but a test was made initially as a precaution. The mean worm burden of males and females was calculated separately for V group herrings from Dunmore, IV and V group herrings from the 1969/70 Minch samples and II and III group herrings from two 1970 Shetland samples. These were chosen for their low, intermediate and high degrees of infestation respectively. Table V shows that in no case did the difference between the means for each sex exceed twice the standard error. In all subsquent analysis it was deemed safe to ignore the sex of the fish.

TABLE V. Comparison of infestation between the sexes

Age and origin	Mean worm burden ♂	Mean worm burden ♀	Difference	S.E. of difference	No. of fish
V Dunmore	15·07	19·94	4·87	5·91	148
IV Minch	58·64	61·32	2·68	5·78	222
V Minch	46·59	51·17	4·58	5·11	258
II Shetland	83·32	90·23	6·91	9·84	67
III Shetland	100·08	119·81	19·73	10·09	73

2. ANALYSIS OF RESULTS BY AREAS

The infestation of a host population can be measured in two ways. The incidence, expressed as a percentage of hosts infested in a sample, is perhaps the less valuable parameter. Statistical methods are more applicable to, and tell us more about, the intensity of infestation, measured as the mean number of parasites/host in a sample. It is usual to include zero counts in calculating this mean. The incidence and intensity of infestation of the different age groups of herrings sampled have already been given in Tables III and IV, but it remains to examine, area by area, the results of more detailed statistical analysis within and between samples. In the calculation of mean worm burdens, samples or sub-samples of less than 15 fish have been ignored, or else attention is drawn to them.

(a) *The North Sea*

(i) Shetland. Herring samples were obtained through Aberdeen from the landings made during the late spring and summer months at Fraserburgh. Most of the samples came from within 60 miles of the Shetlands, often from close in-shore, but in 1970 two samples originated from near the islands of North Rona and Sule Skerry. All the fish had a high level of infestation. In 1969 the mean worm burden increased in the 3 successive age groups examined. But even higher worm burdens were recorded for the younger age groups that made up the 1970 samples. Amongst IV group fish, which predominated in the 1969 samples, the mean worm burden varied significantly from sample to sample (Table VI). This was not the case for the II group fish which were the majority group in 1970 samples.

(ii) North Shields. This is the largest herring fishery and consequently much attention was paid to it. The samples, obtained between June and September, were mostly caught either near the Farne Islands or from an area 10–30 miles north-east of the Tyne. In 1969 the II group fish had the highest mean worm burden, the means falling

TABLE VI. Analyses of variance on the mean worm burdens of IV group herring from 1969 and II group herring from 1970 Shetland samples

Age	Sum of squares		D.F.	Mean square	*F*-value
IV	Between	62 087	7	8870	7·9982*
	Within	312 757	282	1109	
	Total	374 844	289		
II	Between	5512	3	1837	1·3302
	Within	189 237	137	1381	
	Total	194 749	140		

* Significant at $P=0\cdot005$.

off for III and IV group fish. On the other hand, the mean worm burden/fish of each cm length group showed a rise interrupted only at 23 cm (Fig. 2). The explanation points an interesting moral. An age-length analysis of the fish in these samples showed that II group fish predominated in every cm length group except 23 and 24 cm. Had length been regarded as broadly indicative of age and worm burden related only to length, it is apparent that a false conclusion might have been drawn. For this reason emphasis has been laid on age rather than length in assessing and comparing the infestations recorded in this survey.

In both years the mean worm burden of II group fish for each sample varied, showing a tendency to rise during the season (Fig. 3). For the 1969 figures, these mean worm burdens were significantly correlated with the mean length of each sample ($r=0\cdot74$), but this was not the case in 1970 ($r=0\cdot35$). In 1970 sampling began earlier and compared with 1969 the II group fish would appear to have a lower mean worm burden—67·4 in 1970, 81·71 in 1969; but this is only because of the inclusion in 1970 figures of II group fish sampled in June with lowest worm burdens of the season. If

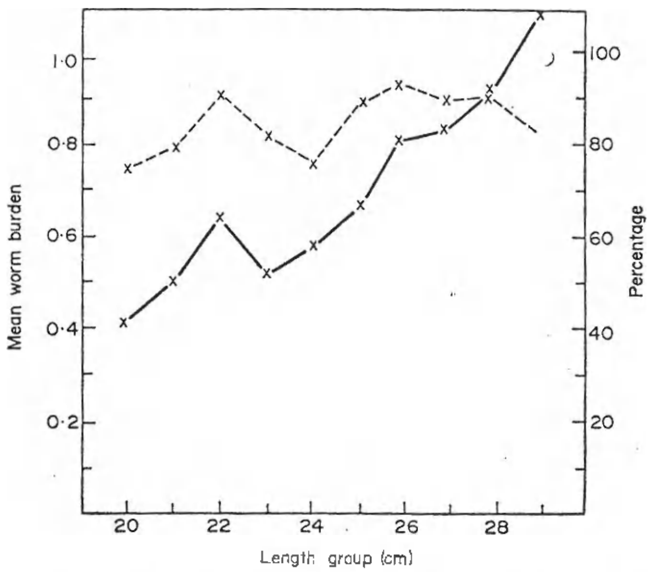

FIG. 2. Mean worm burdens (————) and percentage infestations. (– – – – – –) per cm length groups of North Shields herrings in 1969.

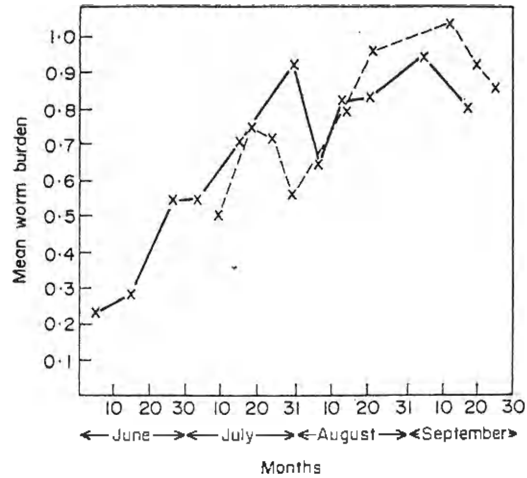

FIG. 3. Mean worm burdens of II group herrings from North Shields in 1969 (------) and 1970 (————), showing the tendency for these to rise during the season.

only the July to September samples are compared for the two years the mean worm burdens for this age group are about the same—79·49 in 1970, 81·71 in 1969. Thus while II group fish had higher mean worm burdens than III group fish in 1969, the reversal of this situation in 1970 was due mainly to an increased level in 3-year-olds—i.e. the same year class as 1969 II group.

(iii) East Anglia. It is well known that the once great East Anglian herring fishery has declined drastically over recent years and sampling of this area was patchy. Herrings were sampled either in the autumn or the spring/early summer, all the catches coming from just off the coast between Cromer and Lowestoft. On average the autumn fish proved to be rather smaller—22–29 cm as compared with 25–30 cm—and younger —3·0 years as against 3·4 years—than the spring/early summer fish. Infestations with *Anisakis* were very high. The mean worm burden of the autumn fish was lower than that of the others, whether expressed per age group (see Table IV) or per cm length group (Fig. 4).

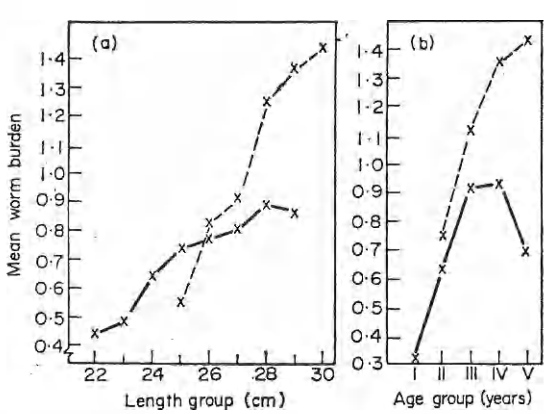

FIG. 4. East Anglian herring: variation in mean worm burden/cm length group (a) and per age group (b). ————, Spring caught herrings; ------, autumn caught herrings.

(iv) Blackwater Estuary. These herrings were obtained during the period December to April from the Estuary of the Blackwater out as far as Eagle Bank off Clacton, Essex. The stock is believed to be a local one and was characterized by a heavy infestation with the larval cysts of a tetrarhynch cestode. On the other hand, infestation with *Anisakis* was generally lower than in the North Sea stocks so far considered. Of 114 herrings infested with *Anisakis*, 82 had 5 or fewer larvae, mostly only one, but the remaining 32 had counts ranging right up to a record 278. It would seem that these figures, coupled with an inverse relationship between *Anisakis* count and cestode cyst count, can best be explained by assuming that those fish with a high *Anisakis* count are strays from the open North Sea, not belonging to the local Blackwater stock. Their low cestode cyst count would also be consistent with a short term association with the Estuary stock. It may also be significant that most of them were II group—the dominant age group in East Anglian samples.

(b) *West of Scotland*

(i) Minches. An extensive winter fishery exists in this area and over 1000 fish were sampled from landings at Oban during the two winters of the survey period. The location of samples is shown in Fig. 5. In the 1968/69 season 6 samples (M1 to M6) were taken and the mean worm burden was found to fall rather than to rise with successive age groups, although there was a rise from IV to V group fish. The mean worm burdens of each age group in the 1969/70 samples (M7 to M15) showed the same pattern for the same year classes—there was an overall fall, but with a rise from V to VI group. In 1968/69, the mean worm burdens of any given age group did not vary significantly amongst the samples, but the means for whole samples did produce a significant *F*-value in an analysis of variance (Table VII). Surprisingly, these means did not correspond to the age composition of the samples. Thus when an ' expected ' mean worm burden was calculated for each sample using the age composition and the mean worm burdens of age groups, they agreed with observed means for samples M1, 2, 4 and 5, but departed significantly for M3 and 6. Figure 6 shows how an aggregation in sample M3 of the lower mean worm burdens and in sample M6 of the higher means has produced this situation. The pattern was repeated in 1969/70 when M8 had a significantly low mean worm burden and M13 a significantly high one.

(ii) Ayr (Clyde Estuary). Few herring were obtained from this summer fishery in 1969 in contrast to a long series of samples that were secured in 1970. The samples were taken in the area between the Cumbraes and the southern tip of Arran including the channels to the north and west of the latter island. Levels of infestation with *Anisakis* were low and no statistical significance could be attached to the slight variation in mean worm burdens of successive age groups. An analysis of variance on the sample means gave a significant *F*-value (Table VIII) which could not be correlated in any obvious way with either age composition or locality.

(c) *Irish herring fisheries*

(i) Isle of Man. Four samples were obtained in June and September of 1969 from Manx boats fishing just off the coast of Co. Down and from both west and east sides of the Island. The numbers of *Anisakis* were mostly low and present in only a few fish. Because three fish had conspicuously high larval counts, no meaningful analysis of the data was possible. In terms of real counts, out of 240 herrings examined, 28 were infested and of these 7 had 4, 6, 8, 9, 27, 33 and 40 larvae respectively, all remaining counts being 3 or less.

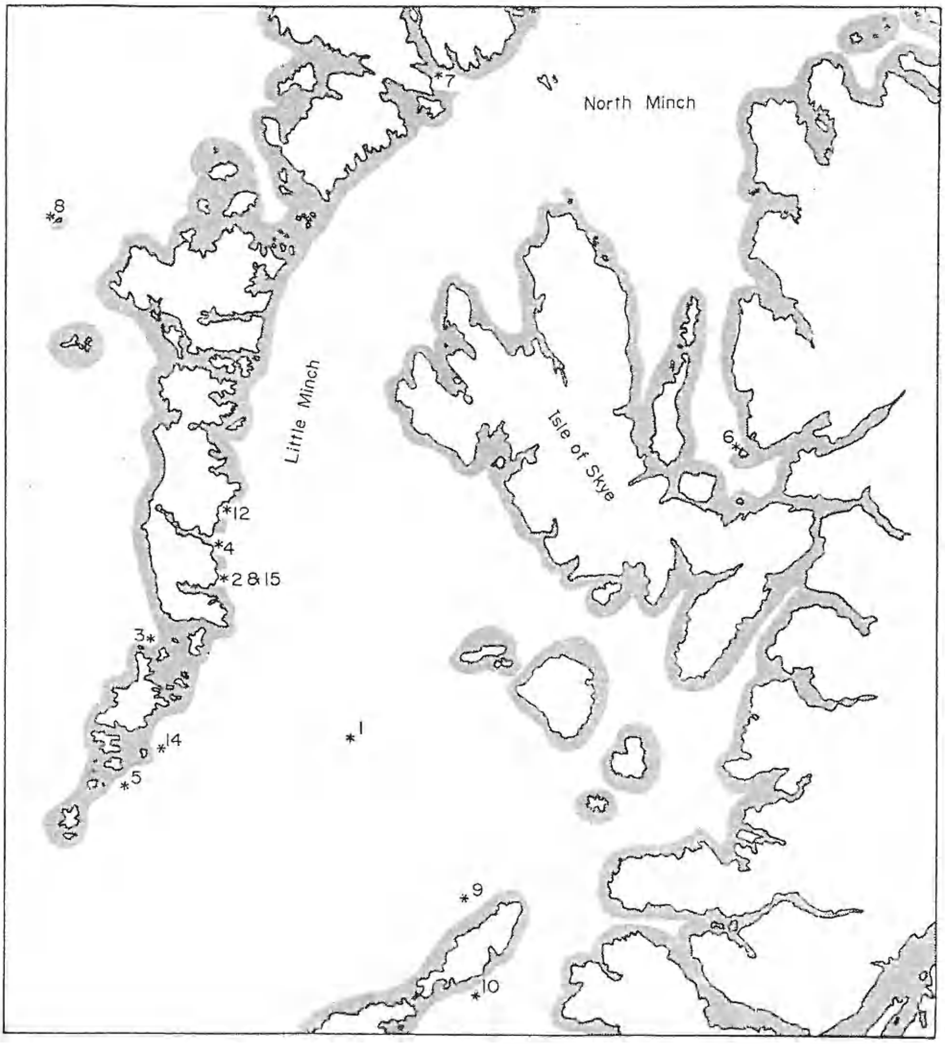

FIG. 5. Distribution of Minch samples. Numbers 1–6 caught between November '68 and March '69; numbers 7–15 caught between October '69 and February '70. Location of samples 11 and 13 not known.

(ii) Dunmore East. Sampled only on one occasion, in January 1970 off Co. Waterford, Eire, the herrings were of a wide range of ages with a peak in the V group. About 34% were infested and a definite and significant rise in the mean worm burden was found with successive age groups. Although the numbers of larvae were generally low in fish up to V group, VI group and over had quite substantial numbers—in real terms over 20 and up to 64/fish.

(iii) Galway Bay. Also sampled on one occasion only, in October 1970, these herrings had a level of infestation intermediate between the previous 2 stocks. The mean worm burden varied for each age group giving a significant F-value in an analysis of variance ($F=9{\cdot}0125$ for 3 and 162 degrees of freedom) but the accumulation effect is only noticeable in the III and IV groups.

TABLE VII. Analysis of variance on the mean worm burdens of each age group in the 1968/69 Minch samples

Age	Sum of squares		D.F.	Mean square	F-value
III	Between	1670	3	557	0·2478
	Within	101 163	45	2248	
	Total	102 833	48		
IV	Between	15 529	5	3106	2·2821
	Within	298 779	226	1322	
	Total	314 308	231		
V	Between	10 396	5	2079	1·3888
	Within	212 574	142	1497	
	Total	222 970	147		
VI†	Between	10 543	3	3514	2·6421
	Within	75 794	57	1330	
	Total	86 337	60		
Total	Between	28 418	5	5684	3·8958*
	Within	706 115	484	1459	
	Total	734 533	489		

* Significant at $P=0{\cdot}005$.
† Some samples with less than 15 fish.

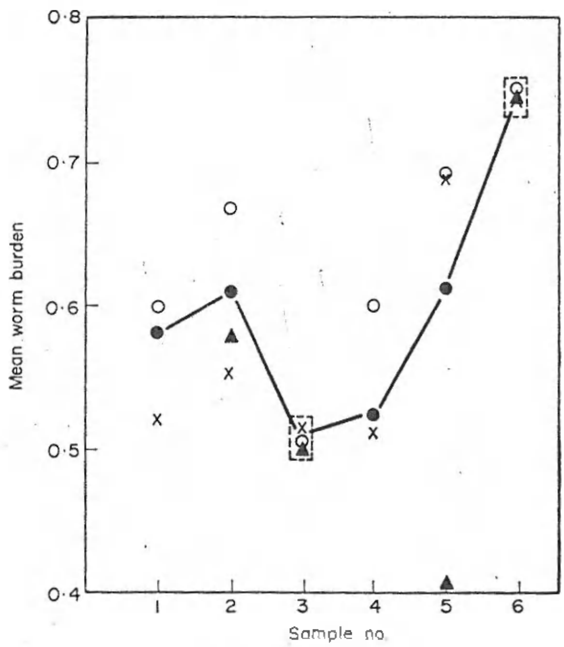

FIG. 6. Aggregation of high and low mean worm burdens of some age groups in Minch samples 1–6 (1968–69). ×, IV group means; ○, V group means; ▲, VI group means; ●, sample means.

(d) *The English Channel*

(i) Brixham. The fishery at Brixham is barely viable and this was reflected in the sporadic nature of the sampling. All the samples came from just off the coast of Devon between Berry Head and Dartmouth, between October 1969 and September 1970. In the first place the age composition proved remarkable. Frequency distribution

TABLE VIII. Analysis of variance on the mean worm burdens of each age group and on whole samples for Ayr herrings, 1970

Age	Sum of squares		D.F.	Mean square	*F*-value
I	Between	210	4	53	0·3926
	Within	29 440	218	135	
	Total	29 650	222		
II	Between	2103	13	162	1·3846
	Within	35 233	300	117	
	Total	37 336	313		
III	Between	5031	11	457	1·5651
	Within	63 055	216	292	
	Total	68 086	227		
IV	Between	826	6	138	0·4000
	Within	25 863	75	345	
	Total	26 689	81		
Total	Between	4949	13	381	2·0053*
	Within	175 201	911	190	
	Total	180 150	924		

* Significant at $P=0·025$.

graphs of each age group against length showed that for the IV, V and VI group fish the curves had more than one peak. Moreover for each of these 3 age groups the first peak in the curve was entirely accounted for by the fish from the October 1969 sample (Fig. 7). Although caught in the same area, it seems possible that the IV to VI group fish in that sample came from a different stock.

The Brixham herrings had an extremely low incidence of *Anisakis* infestation and were also infested with cestode cysts similar to those noticed in the Blackwater Estuary herrings. In common with that stock and with the Isle of Man herrings, the numbers of *Anisakis* larvae were low with a number of notable exceptions. Also the IV to VI group herrings of October 1969 had noticeably fewer infested with *Anisakis* than the same age groups in the remaining samples; 3 fish out of 164 in the October sample were infested with only 1 or 2 larvae each, while 28 out of 184 fish in the remaining samples had larval counts ranging from 1 up to 26. These infested fish were randomly spread through the 1970 samples.

(e) *North Sea young herrings*

Young herrings. I group herrings under 20 cm length, were sampled from a variety of areas in the North Sea. The opportunity for this sampling came only through the M.A.F.F.'s contribution to the annual young herring survey of the I.C.E.S. This imposed an arbitrary pattern on the areas of sampling over which the author had no control. All the fish were classified as 'autumn spawners' by Lowestoft fisheries biologists. On the 1969 survey the numbers of *Anisakis* larvae were recorded for whole samples at some stations, not for the individual fish. In order to make the 2 years' samples comparable, the number of larvae/100 I group fish was calculated (untransformed) and Fig. 8 shows these numbers for each station on the 2 years' cruises. Since most of the samples were of less than 100 fish the numbers are mostly extrapolations. For 1969 the figures were nearly all low, indicating a real count of less than 1 larva/fish on average. The single exception was the station close to the British

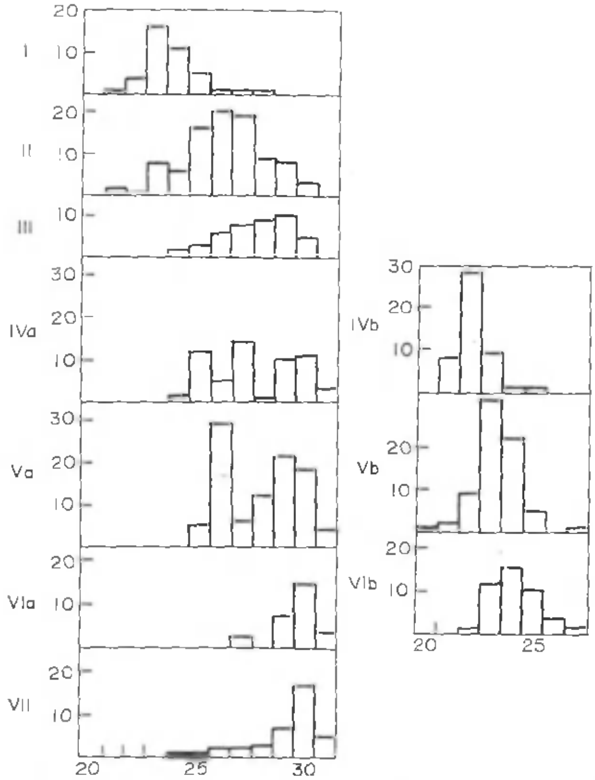

FIG. 7. Frequency distributions of centimetre length groups within each age group for Brixham herrings. Histograms at left, herrings from samples BX 2 to 6; histograms at right, herrings from sample BX 1 only.

coast—statistical square 6E. In 1970 the majority of figures were high, and most of these were close to the British coast. But 2 high figures occurred far out in the open sea at squares 13H and 13J.

3. THE OCCURRENCE OF *ANISAKIS* LARVAE IN THE MUSCULATURE OF THE HERRING.

As has been noted, the normal situation of the *Anisakis* larva in the body of the herring is as an encysted larva attached to the mesenteries and body organs. A few may be found excysted and with the head end buried in the musculature of the belly wall. Oishi *et al.* (1969) in recording the numbers of *Anisakis* larvae from the body cavity of *Pneumatophorus japonicus* noted an increase in the percentage of larvae occurring in the muscles as the fish length increased from 29–34 cm, although there was a fall-off in fish over this length.

In the present survey the numbers of larvae found penetrating the musculature were recorded and when correlated with the length of the fish gave an approximately normal curve closely reflecting that of the sampling distribution (Fig. 9). The percentage of larvae occurring in the muscles remains practically constant in all length groups, at about 0·77% or 1 in every 130 larvae. Examination of the data confirmed that the same result held when the numbers were plotted against age groups. This result shows that the tendency for each *Anisakis* larva to penetrate the herring's musculature is

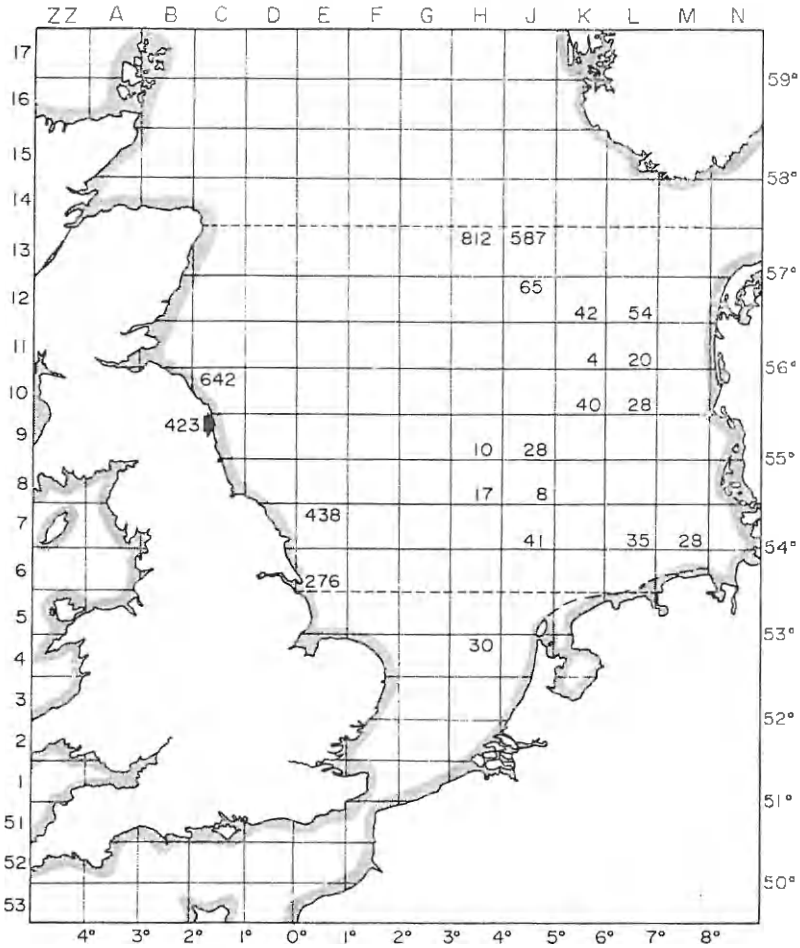

FIG. 8. Numbers of *Anisakis* (untransformed) per hundred I group herrings at stations on I.C.E.S. Young Herring Surveys in February 1969 (figures in lower half of squares) and February 1970 (figures in upper half of squares).

constant and independent of any other factors such as the age or length of the host, numbers of other larvae in the same host or the length of time already spent in the host.

IV. DISCUSSION

The herrings examined in this survey were not assigned either individually or collectively to particular spawning stocks. This cannot be done for individuals in the case of herrings, and to do it collectively requires the cataloguing of much additional data on meristic characters, an increase in the work of sampling that was not considered feasible in this survey.

The existence of different spawning stocks must be borne in mind in the interpretation of the survey results. Whilst most herring fisheries are pre-spawning, spawning or spent fisheries, the North Shields summer fishery largely exploits feeding herring, pre-recruits to the Downs (southern North Sea) stock, on their way south to the

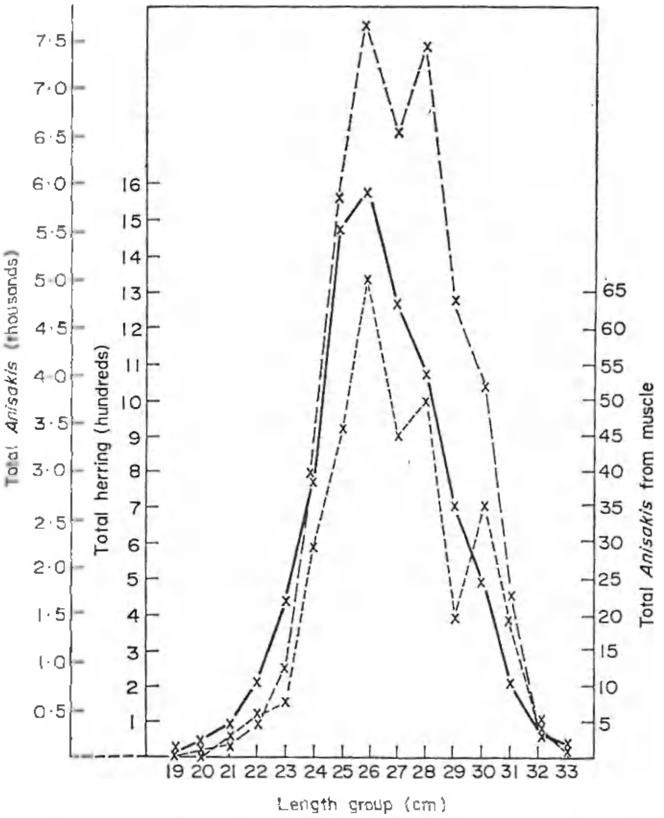

FIG. 9. Relationship between numbers of *Anisakis* larvae in the muscle and the total number of larvae recorded from all the herrings examined in each cm length group. — — —, Total *Anisakis* in thousands; ————, total herring in hundreds; – – – –, total *Anisakis* from muscle.

spawning grounds. In fact all three North Sea herring stocks have their feeding grounds in the western part of the middle and northern North Sea (Harden-Jones, 1968). Less is known about the other stocks. The Minch herrings are a mixture of spring and summer spawners (Baxter, 1958). The Clyde and Blackwater Estuary herrings may be regarded as isolated stocks confined to these particular areas, although this does not preclude the presence of non-local strays. The herrings sampled from the English Channel, the Irish Sea and Galway Bay are also each rather localized populations, but to what extent they involve mixed stocks is not clear.

1. INCREASE OF INFESTATION WITH LENGTH AND AGE

It was a major conclusion of Khalil's (1969) survey that infestations increased with the length, and age of the fish. But length is only strictly related to age within a given spawning stock and the experience of this survey was that the same set of data can give two different impressions if mean worm burdens are related first to length and then to age. It is most probable that this arises from the mixture of different stocks in the same samples. A rising trend of mean worm burdens relating uniformly to both length and age was found only for the Galway and Dunmore samples where mixtures of stocks were probably not involved and where sampling was restricted. Higher rates of infestation occurring in the younger age groups were recorded for Minch, Shetland

and North Shields samples where such mixing may occur and where sampling error was minimal.

2. VARIATIONS OF INFESTATION WITH LOCALITY

While it is clear enough that Khalil's conclusion on this point has been amply reinforced by the present survey data, it is of interest to consider the matter further at the level of variations within a locality. The IV group fish in the 8 samples from around the Shetlands in 1969 had significantly different mean worm burdens not obviously correlated with the precise location or with the time of sampling. One can only fall back on the mixture of stocks explanation, noting that in addition to all 3 North Sea stocks this area at this time could contain Norwegian spring-spawning herring.

The mean worm burden of Clyde samples in 1970 apparently varied significantly while showing no correlation with the age composition or location of samples. But presumably if the level of infestation is low enough, the chances of each herring encountering a single *Anisakis* larva in its food are such that, even with sample sizes of 100 fish, mean worm burdens cannot be judged significantly different from one another at conventionally accepted probability levels. Much more rigorous standards must be applied and the significance rejected.

For the Minch samples there was some correlation between the varying sample means and the exact location of the sample. The evidence suggested a higher mean worm burden in samples caught close to the mainland (M6, ?M13), and lower ones in the most westerly (off-shore) samples (M3, M8). This may reflect a division of the stocks (spring and summer spawners) or it may tell us something about the distribution of the first intermediate host in these waters.

3. INCIDENCE OF INFESTATION IN RELATION TO THE NORTH SEA COAST

Khalil (1969) considered that infestations were greater closer to our eastern coasts than off-shore in the North Sea. Given that his fish were not aged and adding the complications arising with mixed stocks, this result must be treated with caution. In the present survey only I group and a few II group herrings were sampled from off-shore locations in the North Sea and these leave a highly ambiguous situation with regard to the point: in February 1969 high *Anisakis* infestations were recorded in I group herrings from the only coastal location, while low levels were registered off-shore, but in the following year high levels occurred both in-shore and off-shore.

4. THE FIRST INTERMEDIATE HOST OF *ANISAKIS*: FACTS AND DEDUCTIONS

At present no published records of naturally occurring infested first intermediate hosts of *Anisakis* exist for this area of the world. Van Banning (personal communication, 1970) has found a single infested euphausid, *Meganyctiphanes norvegica*, from the North Sea and J. W. Smith (personal communication, 1971) has also found some infested euphausids. The Japanese reported a few euphausid infestations from the northern Pacific (Oshima *et al.*, 1969). It is generally assumed that the first intermediate host is a planktonic crustacean but, despite several diligent searches, records of natural infestations are few and far between. In this situation the following theory from Zijlstra (personal communication, 1970) bears careful consideration.

It is often assumed that the lack of marked host specificity shown by *Anisakis* in relation to its teleost and mammalian hosts extends to its likely choice of first intermediaries. But it would not be incompatible with the infestations encountered in teleosts for the parasite to be quite specific to its first intermediate host. Zijlstra further conjectures that *Anisakis* is indigenous to more northerly waters than ours but has extended its range, perhaps only in recent years, as a result of a corresponding extension in the range of the first intermediate host. Since the Dutch workers also believe that levels of infestation in the herrings in the North Sea have been falling over the last decade, this situation may now be reversing itself.

This is an attractive theory. Of the 3 species of *Anisakis* (Davey, 1971) it is most likely that the larva in herrings is that of *Anisakis simplex* and the majority of (final) host records of this species are from cetaceans of polar waters (both hemispheres). It has been noted that all 3 North Sea stocks of herring feed in the north-western part of that Sea. If they are receiving the infestation from a crustacean which is at the limits of its geographical range, then annual fluctuations in the populations of this crustacean such as are common to most planktonic organisms, are bound to affect the level of infestation to which the herrings are exposed each year. Herrings feed selectively (Hardy, 1924) so if, say, the numbers of *Calanus* (a favourite food item) were low in a given year, greater than usual numbers of the infested crustacean host might be taken. With such factors operating the accumulation of *Anisakis* larvae with increasing age would be exceedingly complex.

5. ANNUAL TRENDS IN *ANISAKIS* INFESTATIONS

It was mentioned above that Dutch workers believe *Anisakis* infections in North Sea herring to be on the decline. Khalil (1969) believed that where he had comparable samples the trend was upwards in the period 1966–68, except in the Blackwater Estuary herring. A 2 year survey period is not sufficiently long for the elucidation of such trends, especially considering the views formulated above concerning the fluctuations in levels of infestation likely to be encountered by the teleost hosts. What is apparent is that there were no dramatic changes in any of the stocks sampled over the whole survey period. The II group fish that predominate in the Shields fishery had roughly the same mean worm burden in 1970 as in 1969; and in the Minches the situation also seemed to remain comparatively static over the 2 seasons of sampling. It is unfortunate that none of the present survey data are strictly comparable with those of Khalil.

V. CONCLUSIONS

No area surveyed was found to be completely free of *Anisakis* infestation. Levels were highest in the North Sea where mean (transformed) worm burdens exceeded 100 in all 3 fisheries (Shetlands, North Shields and East Anglia), with 90–100 % infestation rates. In real terms this means that for the heaviest infested samples almost every fish had more than 10 worms, with counts often in excess of 50. At the other extreme Ayr (Clyde) herrings had mean worm burdens as low as 6 with as few as 2 % infested. Real counts were of 1 or 2 larvae only. Minch herrings held the intermediate values with mean worm burdens between 34 and 74 for around 80 % of fish infested. Here larval counts were generally less than 10, with an exceptional record of 54. In all the remaining areas (Galway Bay, Dunmore, Isle of Man, Brixham and the Blackwater Estuary) worm burdens were below 25 and rates of infestation generally below 30 %. The larval counts tended to be more variable in these areas, counts exceeding 10 being not uncommon. In some cases these may have been due to the presence of non-local strays in the area, such as East Anglian herrings entering the Blackwater Estuary.

The percentage of fish infested was generally well correlated with the mean worm burden. The phenomenon of accumulation of larvae with host age is apparently modified by several factors. In extremely low infestations, e.g. Ayr herrings, accumulation was virtually undetectable as might be expected. It was plainly shown by the Dunmore and Galway Bay herrings but was ambiguous in the Minch and North Sea herrings, the trend often being reversed. Two main explanations were forwarded for this. In the first instance stocks were not separated in the samples and mixtures of stocks in the same samples could modify the accumulation graph. Secondly, the level of infestation to which the herrings are exposed each year may fluctuate in accordance with the distribution and infestation of an as yet unidentified first intermediate host. The selective feeding behaviour of the herring could further modify the accumulation of larvae.

In the Minch there was some evidence that higher infections were associated with proximity to the mainland coast. A similar effect in the North Sea, observed by Khalil (1969), could not be confirmed.

The tendency of each *Anisakis* larva to bore into the musculature of the herring was shown to be constant in that approximately one in every 130 larvae was found in this circumstance regardless of the age or length of the host, the number of other larvae present in the same host, or the length of time spent in the host. Over the period of the survey it could not be said that the fish of any area showed a dramatic rise or fall in infestation rates. The Blackwater Estuary herring had between 6 and 26% infection rates which are generally higher than the 7–8% recorded by Khalil for the fish of this area.

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