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METAZOAN PARASITE ASSEMBLAGES OF EELS IN THE DUNKELIN CATCHMENT, WESTERN IRELAND

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A B S T R A C T. Samples of yellow eels (n=117 and 125) from two different sites in the alkaline lowland Dunkelin River system and of silver eels (n=32) migrating from a calcareous (maerl) lake, Lough Rea, in the same river basin have been examined for metazoan parasites. The diet of the eels was also investigated, as was the composition of the fish assemblages at the riverine sites. Fifteen species of parasites were recorded. Details of the infection parameters for each of these species are presented and discussed in relation to host sex and maturation, as well as to environmental and faunal differences between sampling sites. The composition and organisation of the parasite species assemblages, at both the infra-community and component community level, are compared with the results of some previous studies on eels in Ireland.

Key words: EEL, PARASITES, ASSEMBLAGES, INFECTION PARAMETERS.

INTRODUCTION

In recent years, there has been a marked increase of interest in the ecological parasitology of freshwater fishes and the eel has been the subject of a wide ranging study in Britain (Kennedy 1990) and of studies in Ireland (Conneely and McCarthy 1984, 1986). Likewise, there has been an increasing interest in the general ecology of eels in Ireland and the present study is part of a broad ecological study of this fish in a small alkaline river in western Ireland. Its objectives were to investigate the composition and structure of the eel parasite communities at three sampling sites and to identify contributory features of host biology and habitat.

STUDY AREA

The locations chosen for this investigation included two riverine sites, one on the alkaline Dunkelin river and one on the Rafford river as well as one calcareous lacustrine site - Lough Rea. The two riverine locations were third (Dunkelin) and fourth order (Rafford) stream sections at distances of approximately 13 and 16 km from the sea

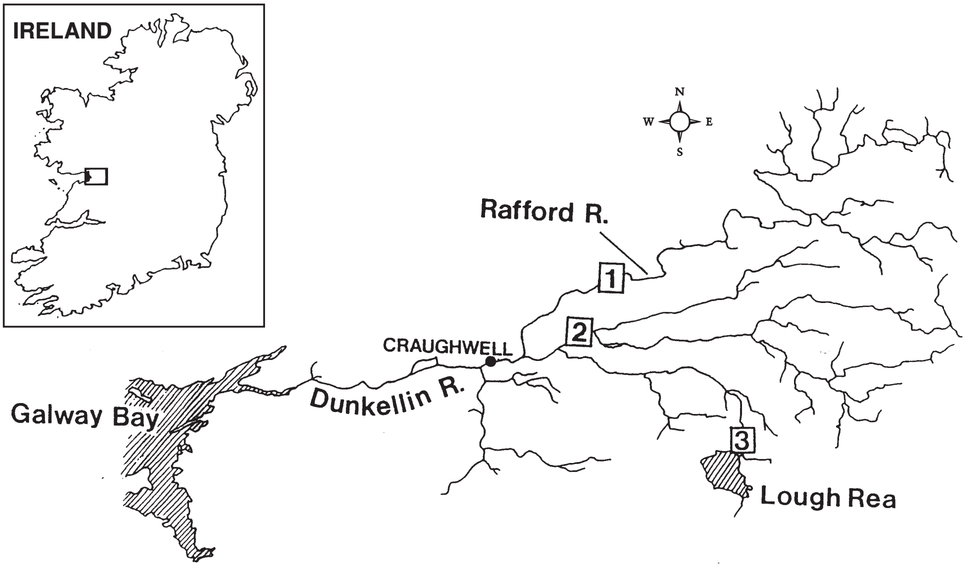

Figure 1. A map of the Dunkelin catchment area in western Ireland

(Fig. 1). Details of the study area have previously been outlined in Callaghan and McCarthy (1992).

MATERIALS AND METHODS

The eels at the two river sites were captured by electrofishing (Callaghan & McCarthy 1992). The silver eels from Lough Rea were captured in a commercial eel trap at the outlet from a weir in Lough Rea. The eels were deep frozen in the laboratory for subsequent examination. The length and weight of each eel was measured to the nearest mm and 0.01 g respectively. Sex was determined by a morphological examination of the gonads. Age determination of eels from the two riverine sites was carried out using the burning and cracking method as described by Christensen (1964) and modified by Moriarty (1973) and Hu and Todd (1981). The eels from Lough Rea were not aged.

Examination of the parasites from eels involved all the usual sites and organ systems (Conneely and McCarthy 1984). The eye lens and humor were treated as separate habitats. The intestinal tract was divided into eight equal sections and each section was also treated separately. The terms, prevalence, mean intensity and abundance used in the study follow the definitions of Margolis et al. (1982). The terms relating to parasite community structure - infracommunity, component community and compound community have been defined by Bush and Holmes (1986).

Non parametric tests available on the SPSS statistical package were used in the data analyses. The similarity of the parasite communities at the component community (all parasite species occurring in all eels at each site) and the infra-community (all the parasite species occurring in each eel) levels were examined using two different similarity indices: Jaccard's similarity index (qualitative) based on presence or absence data (Southwood 1978) and Percent Similarity Index (quantitative) based on proportions of each species (Hurlbert 1978). The Berger-Parker dominance index (Southwood 1978) measures the proportion of the total sample that is due to the dominant species. It can also serve as a measure of community diversity (Southwood, op. cit.).

RESULTS

A total of 274 eels (242 yellow, 32 silver) were examined (Table 1). There was a highly significant difference (Mann-Whitney U test p□0.005) between the three sites in respect of the size, length and weight of eels examined (Table 2). Therefore the data from each site have been analysed separately. Males, females and undifferentiated eels were examined from both riverine sites, while the eels examined for parasites from the lake included both male and female silver eels of which females formed the greater proportion (Table 3).

Fifteen parasite species were recovered, of which nine were generalists, three were specialists and two were accidental (Table 4). *Capillaria* sp. and *Phyllidostomum* sp. have not previously been reported from eels in Ireland.

Cumulative species richness-curves (Fig. 2) created from five randomizations of the data set, illustrate the sequential addition of species to the record list. An examination of approximately eighty eels resulted in the recovery of between 92 to 100% of the species recorded in the two riverine sites (11 of the 12 species in the Dunkelin (site 2) and 9 of the 9 species in the Rafford (site 1). Eleven helminth species were recorded at Lough Rea (site 3). However, it is apparent from Fig. 2 that the examination of more eels probably would have yielded further species to the parasite list from Lough Rea.

There was significant difference in the number of helminths species recorded per host between the different sites (Table 5). The greatest number of uninfected eels were

TABLE 1

The size and age of eels examined for parasites at each of the three sites

Site	No.	Mean length	S.E.	Range	Mean weight	S.E.	Range	Mean age	S.E.	Range
Dunkellin R.	117	29.04	0.93	10.3-59.4	49.98	5.39	0.96-300.51	8.81	0.39	3-21
Rafford R.	125	24.68	0.86	9.7-56.9	34.49	4.02	1.06-310.1	8.43	0.63	1-20
Lough Rea	32	447	1.107	35.09-54.6	163.87	13.3	69.19-348	-	-	-

TABLE 2

Mann Whitney U tests of the significant differences between the sites in respect of the weight, length and age of eels examined for parasites (** p □ 0.005, *** p □ 0.001)

Site	Weight		Length		Age	
	U value	Significance	U value	Significance	U value	Significance
1 and 2	5077	***	5762	**	4651	NS
2 and 1. Rea	325	***	296	***	-	-
1 and 1. Rea	177.5	***	189	***	-	-

TABLE 3

The sex ratios of the eels examined for parasites at each of the three sites

Site	N	% undiff	% male	% female
Dunkellin R.	117	36.9	41.4	21.6
Rafford R.	125	49.6	37.6	12.8
Lough Rea	32	-	37.5	62.5

found in the Rafford. In Lough Rea, all of the silver eels examined were parasitized by at least one species of helminths and up to six different parasite species were recorded from a single eel (Figure 3). The dominant species at both riverine sites was the generalist *Pomphorynchus laevis* while at Lough Rea *Sphaerostoma bramae* also a generalist species, was dominant (Table 6).

The degree of similarity both in terms of the qualitative and the quantitative helminth community composition was high between the two riverine sites (Table 7) (0.75 Jaccard index and 71.88% percentage similarity). However between the riverine sites and Lough Rea similarity was lower, particularly in the case of the quantitative index

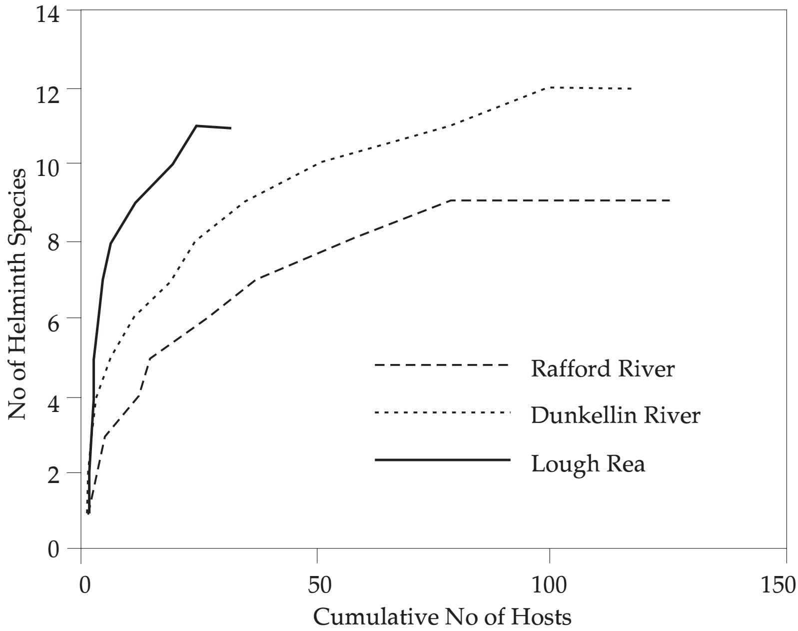

Figure 2. The cumulative species richness curves (based on five randomizations of the data set) indicating the sequential addition of species to the record lists for each of the three sites.

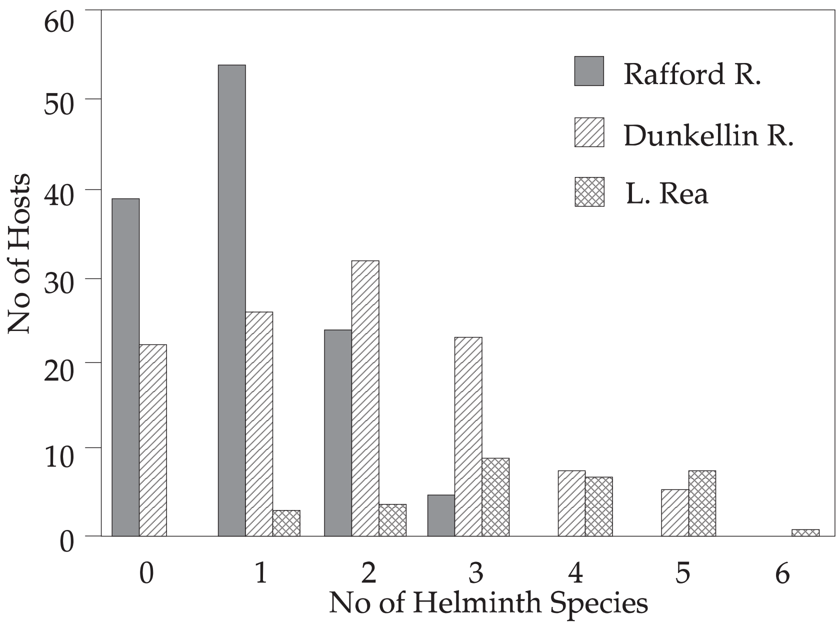

Figure 3. The number of helminth species per eel at each of the three sites investigated.

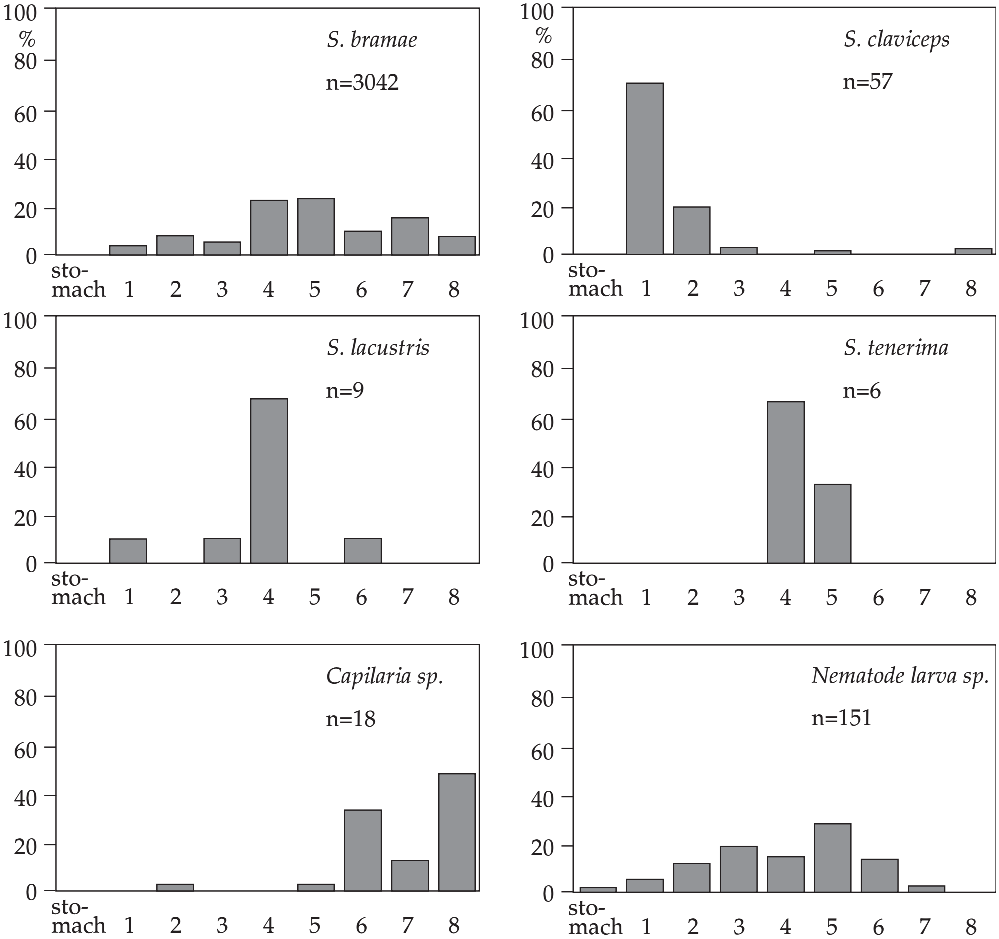

Figure 4. The percentage frequency of six eel parasite species in the stomachs and in each of the eight intestinal sections.

(% similarity), the degree of similarity between the Dunkelin helminth community and that of Lough Rea was only 26%. This is probably a result of the differences in the abundances of dominant species (*P. laevis* and *S. bramae*).

The parasite species may be ranked variously depending on which of their infection parameters (prevalence, mean intensity or abundance, is considered. The most prevalent parasites at the two riverine sites were *P. laevis* and *Diplostomum spathaceum* (Table 8). In contrast with the riverine sites, prevalences of parasite species were generally higher in the silver eels from Lough Rea. *D. spathaceum* was the most prevalent

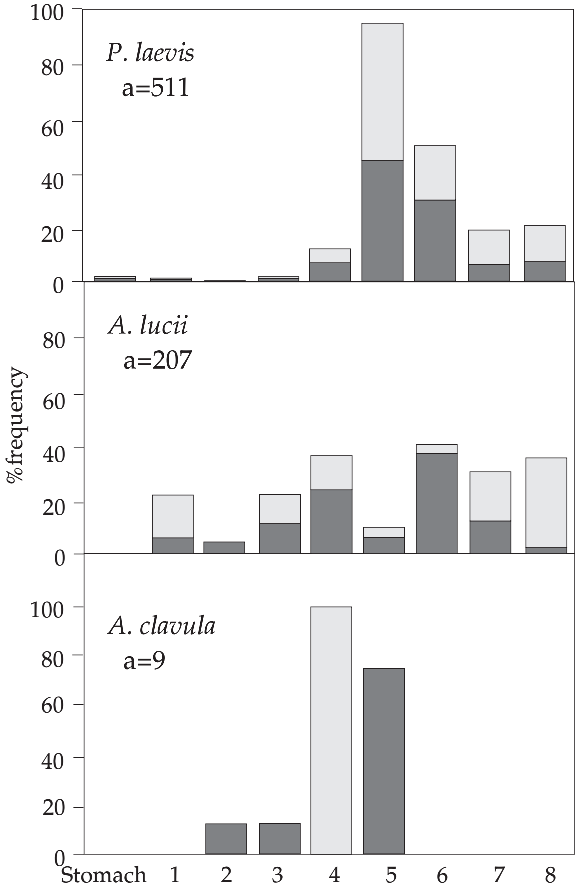

Figure 5. The percentage frequency of the male and female acanthocephalan species in the stomach and in each of the eight intestinal sections.

parasite species in Lough Rea. The prevalences of *S. bramae* and *Pseudodactylogyrus anguillae* were also high in the lake (Table 8).

Capillaria sp. and *Pomphorhynchus laevis* exhibited preferences for the posterior sections of the intestine (Figure 4 and 5). Others such as *Acanthocephalus clavula* and *Bothriocephalus claviceps* were found in the anterior sections. *Sphaerostoma bramae*, nematode larva sp. and *Acanthocephalus lucii* were distributed along the length of the intestine rather than being concentrated in a particular area. *Cammallanus lacustris* and *Paraquimperia tenerrima* appeared to favour the mid sections of the intestine (Figure 4). The acanthocephalan species *A. clavula* and *P. laevis* appear to occupy distinctly different regions within the intestine (Figure 5).

TABLE 4

The helminth species recovered from eels in the Dunkellin catchment together with their locations in the hosts in which they were recorded and their basic life history characteristics

	Location in Dunkellin eels	Status	Intermediate hosts	Preferred definitive host
Pseudodactylogyrus anguillae	gills	S	none	eel
Diplostomum gasterostei	eye	G	various fish species	piscivorous birds
Diplostomum spathecum	eye lens	G	various fish species	piscivorous birds
Phyllodistomum sp.	kidney	A	invertebrates	various species of fish
Sphaerostoma bramae	intestine	G	invertebrates	various species of fish
Bothriocephalus claviceps	intestine	S	copepod	eel
Camallanus lacustris	intestine	G	copepod	perch
Paraquimperia tenerrima	intenstine	S	U	eel
Capillaria sp.	intestine	A		various species of fish
Nematode larva sp.	intestine	U	U	
Acanthocephalus clavula	intestine	G	A.meridianus	eel
Acanthocephalus lucii	intestine	G	A.aquaticus	perch
Pomphorynchus laevis	intestine	G	G.duebeni	various species of fish
Acanthocephalus anguillae	intestine	G	A.aquaticus	various species of fish
Piscicola geometra	gill chamber	G	none	various species of fish

TABLE 5

Mann-Whitney U tests of the significant differences between the sites in respect of the number of helminth species recorded per host (*** p □ 0.001)

Site	U value	Significance
Rafford R. and Dunkellin R.	4633.5	***
Dunkellin R. and L. Rea	781.5	***
Rafford R. and L. Rea	317	***

Pomphorhynchus laevis was the dominant helminth species in the majority of infracommunities at the Dunkelin and Rafford sites (Table 9). This was followed by *Diptostomum spathaceum* and *S. bramae. Diplostomum spathaceum* was the dominant species in the majority of Lough Rea eels, and was followed by *S. bramae*, *Pseudodactylogyrus anguillae* and *A. lucii* (Table 9). The mean dominance indices for the infra communities at all three sites was high and ranged from 0.73 to 0.85 (Table 9, Figure 6). These high values are as a result of the large number of infra communities which have a dominance index of one and are a reflection of the number of eels which were parasitized by one species only (Figure 3 and Figure 6), particularly at the riverine sites. When only the

TABLE 6

A summary of the eel parasite component community characteristics

	Rafford (Site 1)	Dunkellin (Site 2)	Lough Rea (Site 3)
No. of eels examined	125	117	32
No. infected	86	95	32
Total no. metazoans	9	12	11
Mean no. helminths per infected host	1.5	2.32	3.5
Total no. individuals	376	808	3846
Berger Parker dominance index	0.26	0.51	0.74
Dominant species	*P. laevis*	*P. laevis*	*S. bramae*
Status	generalist	generalist	generalist
Total no. intestinal helminths	7	9	8
Mean no. intestinal helminths per host	1.32	1.78	2.29
No. eels infected	71	90	28
Total no. of individuals	293	646	3062
Intestinal dominance index	0.33	0.63	0.93
Dominant intestinal species	*P. laevis*	*P. laevis*	*S. bramae*
Status	generalist	generalist	generalist

TABLE 7

The similarity values between the component helminth comunities in eels of the Dunkellin catchment. Values above the diagonal represent qualitative similarities (Jaccard), those below represent quantitative similarities (% similarity)

Site	Dunkellin R.	Rafford R.	Lough Rea
Dunkellin R.		0.75	0.54
Rafford R.	71.88		0.53
Lough Rea	26.39	42.65	

TABLE 8

The basic infection parameters of each of the parasite species at the three sites investigated.
* Dispersion Index

Rafford River (Site 1)								
Parasite Species	No infec-ted	Preva-lence	Mean intensity ±SE	Max	Total no of parasi-tes	Mean Abun-dance	Variance	ID*
P. anguillae	0	-	-	-	-	-	-	-
D. gasterostei	3	2.40	2.33±0.04	5	7	0.06	0.21	3.83
D. spathaceum	32	25.60	2.38±0.14	14	76	0.61	2.61	4.29
Phyllodistomum sp.	0	-	-	-	-	-	-	-

S. bramae	20	16.0	4.65±0.32	33	93	0.74	13.00	17.47
B. claviceps	2	1.60	2.50±0.03	4	5	0.04	0.14	3.39
C. lacustris	0	-	-	-	-	-	-	-
P. tenerrima	2	1.6	1.00±0.01	1	2	0.02	0.02	0.99
Capilaria sp.	4	3.2	1.00±0.02	1	4	0.03	0.03	0.98
Nematode larva sp.	8	6.4	5.50±0.27	34	44	0.35	9.38	26.63
A. clavula	0	-	-	-	-	-	-	-
A. lucii	9	7.20	5.22±0.28	35	47	0.38	9.95	26.45
P. laevis	49	39.20	2.00±0.11	4	98	0.78	1.38	1.76
A. anguillae	0	-	-	-	-	-	-	-
P. geometra	0	-	-	-	-	-	-	-
Dunkellin River (Site 2)								
Parasite Species	No infected	Prevalence	Mean intensity ±SE	Max	Total no of parasites	Mean Abundance	Variance	ID*
P. anguillae	0	-	-	-	-	-	-	-
D. gasterostei	8	6.84	2.38±0.06	4	19	0.16	0.48	2.97
D. spathaceum	52	44.44	2.71±0.24	23	141	1.21	6.80	5.64
Phyllodistomum sp.	2	1.71	1.00±0.01	1	2	0.02	0.02	0.99
S. bramae	22	18.80	4.00±0.24	24	88	0.75	6.98	9.28
B. claviceps	5	4.27	1.00±0.02	1	5	0.04	0.04	0.97
C. lacustris	0	-	-	-	-	-	-	-
P. tenerrima	3	2.56	1.00±0.01	1	3	0.03	0.03	0.98
Capilaria sp.	9	7.69	1.44±0.04	3	13	0.11	0.19	1.67
Nematode larva sp.	37	31.62	2.89±0.19	10	107	0.91	4.08	4.46
A. clavula	1	0.85	5.00±0.04	5	5	0.04	0.21	5.00
A. lucii	8	6.84	1.88±0.06	7	15	0.13	0.49	3.84
P. laevis	74	63.25	5.53±0.47	26	409	3.50	26.36	7.54
A. anguillae	1	0.85	1.00±0.01	1	1	0.01	0.01	1.00
P. geometra	0	-	-	-	-	-	-	-
Lough Rea (Site 3)								
Parasite Species	No infected	Prevalence	Mean intensity ±SE	Max	Total no of parasites	Mean Abundance	Variance	ID*
P. anguillae	18	56.25	16.17±2.77	61	291	9.09	245.64	27.01

D. gasterostei	0	-	-	-	-	-	-	-
D. spathaceum	29	90.63	16.93±1.86	36	491	15.34	110.17	7.18
Phyllodistomum sp.	0	-	-	-	-	-	-	-
S. bramae	21	65.63	135.76±46.33	1273	2851	89.09	68691.31	771.00
B. claviceps	13	40.63	3.62±0.47	10	47	1.47	6.97	4.74
C. lacustris	6	18.75	1.50±0.12	3	9	0.28	0.47	1.66
P. tenerrima	1	3.13	1.00±0.03	1	1	0.03	0.03	1.00
Capilaria sp.	1	3.13	1.00±0.03	1	1	0.03	0.03	1.00
Nematode larva sp.	0	-	-	-	-	-	-	-
A. clavula	4	12.50	1.00±0.06	1	4	0.13	0.11	0.90
A. lucii	14	43.75	10.36±1.84	51	145	4.53	108.26	23.89
P. laevis	4	12.50	1.00±0.06	1	4	0.13	0.11	0.90
A. anguillae	0	-	-	-	-	-	-	-
P. geometra	1	3.13	2.00±0.06	2	2	0.06	0.13	2.00

TABLE 9

The dominant species (Berger Parker) and the percentage number of infracommunities in which they were dominant at each of the three sites

	Rafford River (Site 1)	Dunkellin River (Site 2)	Lough Rea (Site 3)
Number of eels	86	95	32
Dominant Species (and % of infracommunities in which each species was dominant)	*P. laevis* (48.8) *D. spathaceum* (19.8) *S bramae* (15.1) *A. lucii* (5.8) Nematode larva (3.5) *D. gasterostei* (2.3) *B. claviceps* (1.2) *Capillaria* sp. (1.2)	*P. laevis* (56.8) *D. spathaceum* (13.7) *S. bramae* (10.5) *Nematode larva* (5.3) *A. lucii* (2.1) *D. gasterostei* (1.1) *A. clavula* (1.1) *Capillaria* sp. (1.1)	*D. spathaceum* (40.6) *S. bramae* (28.1) *P. anguillae* (18.8) *A. lucii* (12.5)
Dominance index (all helminths)			
Median Interquartile range	1 0.33	0.75 0.44	0.76 0.33
Dominance index (intestinal helminths)			
Median Interquartile range	1 0	0.89 0.33	0.95 0.30

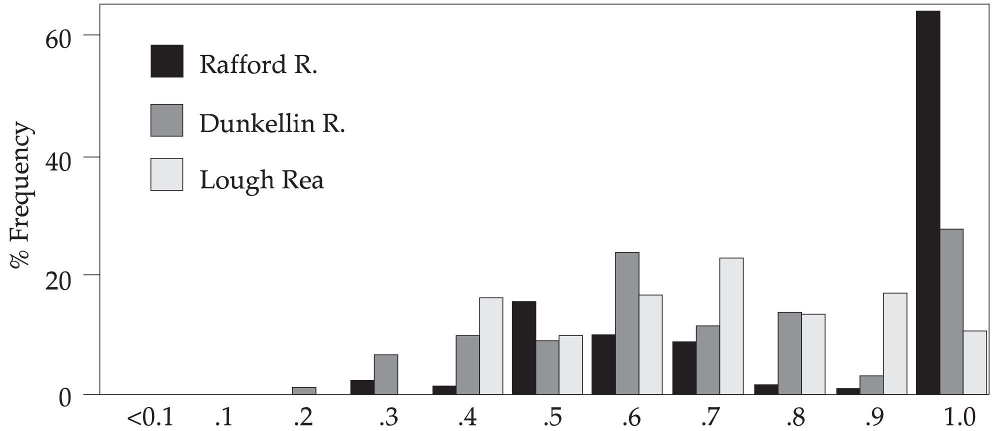

Figure 6. Berger-Parker dominance indices for all helminth infracommunities at each site.

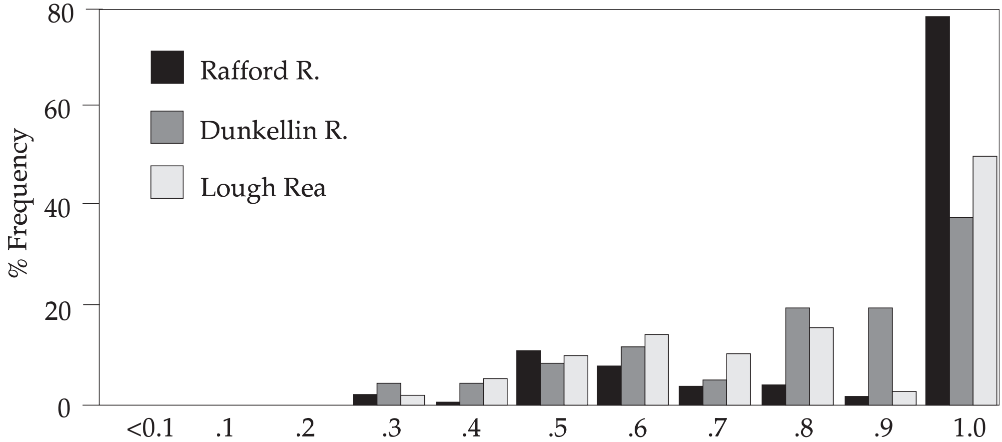

Figure 7. Berger-Parker dominance indices for the intestinal helminth infracommunities in eels at each site.

intestinal helminths are considered, the mean dominance indices increase further (0.83 to 0.91) (Figure 7). The largest increase being recorded in the lake as *D. spathaceum* and *P. anguillae* are excluded. *Sphaerostoma bramae* (15 eels) and *A. lucii* (8 eels) both generalist species, are then the most important species at the infra community level (Table 9). The lower dominance indices at the Dunkelin and Lough Rea sites indicated that these sites had greater community diversity while at the Rafford where the majority of dominance indices were equal to 1 (i.e. only 1 species was present) community diversity was low (Figure 6). In relation to the intestinal infra communities however helminth community diversity was lowest in the silver eels from Lough Rea (Figure 7).

The degree of similarity (both Jaccard and percent similarity) between helminth communities in individual eels was low. The mean degree of similarity between the infra communities at all three sites (Table 10) was not greater than 39% whilst the infra communities in the Rafford were the least similar.

THE ABUNDANCE OF PARASITE SPECIES IN RELATION TO HOST SIZE

Analyses were only carried out with species which occurred in at least three eels at each particular site. The total parasite abundance at each site was highly significantly correlated with both the length and weight of eels ($p < 0.05$) (Table 11). Only two species, *Diplostomum spathaceum* and *Acanthocephalus lucii*, were significantly correlated with eel size at all three locations. *Pomphorhynchus laevis* was significantly correlated with eel size at the Dunkelin but not at the Rafford.

HOST AGE

A similar pattern as that observed in relation to eel size was also observed for eel length. *Acanthocephalus lucii* and *Diplostomum spathaceum* were again the only helminth species which were significantly correlated with the age of the hosts at all three sites. The majority of species which were significantly correlated with eel size were also significantly correlated with eel age. The total parasite abundance at both riverine sites were strongly associated with eel age ($p < 0.05$, Table 11).

HOST SEX

There was a significant difference in the total parasite abundance at each site between the undifferentiated and differentiated eels (Mann-Whitney U test $p < 0.05$) with higher abundances of parasites being recorded in differentiated eels. In contrast no significant difference was found between males and females in respect of total parasite abundance at any of the three sites (Mann-Whitney U test $p<0.05$).

In undifferentiated eels (examined from the riverine sites only) and in male eels, *Pomphorhynchus laevis* was the most prevalent and abundant helminth species in both the Dunkelin and Rafford sites (Table 14, 15 and 16). In female eels, *Diplostomum spathaceum* was the most prevalent species at all three sites. It was also the most prevalent

TABLE 10

The degree of similarity between the parasite infracommunities in eels at each of the three sites

Site	Dunkellin R.	Rafford R.	Lough Rea
Jaccard's Index	0.35±0.004	0.27±0.006	0.39±0.009
% Similarity	39.04±0.004	28.58±0.006	36.05±0.012

TABLE 11

Spearman rank correlation coefficients describing the relationship between parasite abundance and the length, weight and age of eels at the Rafford River (Site 1)

Species	Weight	Length	Age
S. bramae	0.018 0.423 NS	0.035 0.349 NS	0.040 0.330 NS
Nematode larva sp.	0.172 0.028*	0.176 0.026*	0.192 0.016*
Capillaria sp.	0.076 0.201 NS	0.066 0.235 NS	0.024 0.397 NS
P. laevis	0.120 0.092 NS	0.129 0.077 NS	0.046 0.305 NS
A. lucii	0.168 0.031*	0.167 0.032*	0.162 0.036*
D. spathaceum	0.281 0.001***	0.288 0.001***	0.315 0.000***
D. gasterostei	0.224 0.006*	0.236 0.004**	0.160 0.037*
Total parasite Abundance	0.271 0.001***	0.274 0.001***	0.268 0.001***

parasite species in the male silver eels at Lough Rea. *Acanthocephalus clavula* was recovered only from female eels. *Paraquimperia tenerrima* adults were found only in sexually differentiated eels (Table 14, 15 and 16).

CORE AND SATELLITE SPECIES

There were significant correlations between the prevalences of species and their mean abundance and/or the mean intensity. Two species were identified as core species - *Pomphorhynchus laevis* and *Diplostomum spathaceum* (Figure 10), a further three species could be identified as secondary or intermediate species (*Sphaerostoma bramae,*

TABLE 12

Spearman rank correlation coefficients describing the relationship between parasite abundance and the length, weight and age of eels at the Dunkellin River (Site 2)

Species	Weight	Length	Age
S. bramae	0.031 0.369 NS	0.046 0.316 NS	0.114 0.116 NS
Nematode larva sp.	0.356 0.000***	0.346 0.000***	0.276 0.002**
Capillaria sp.	0.119 0.101 NS	0.110 0.127 NS	0.109 0.126 NS
P. tenerrima	0.099 0.143 NS	0.100 0.149 NS	0.178 0.031 NS
B. claviceps	0.199 0.016*	0.215 0.012*	0.151 0.056 NS
P. laevis	0.229 0.008*	0.272 0.002**	0.210 0.013*
A. lucii	0.403 0.000***	0.413 0.000***	0.406 0.000***
D. spathaceum	0.355 0.000***	0.385 0.000***	0.347 0.000***
D. gasterostei	0.146 0.059 NS	0.139 0.074 NS	0.106 0.134 NS

TABLE 13

Spearman rank correlation coefficients describing the relationship between parasite abundance and the length, weight and age of eels at Lough Rea (site 3)

Species	Weight	Length
S. Bramae	0.007 0.485 NS	-0.055 0.382 NS
B. claviceps	-0.289 0.054 NS	-0.316 0.039*
C. lacustris	0.057 0.379 NS	0.051 0.391 NS
P. laevis	-0.215 0.119 NS	-0.220 0.113 NS
A. lucii	-0.502 0.002**	-0.486 0.002**
A. clavula	0.041 0.412 NS	0.036 0.423 NS
D. spathaceum	0.362 0.021*	0.323 0.036*
P. anguillae	0.109 0.277 NS	0.046 0.401 NS
Total parasite Abundance	0.063 0.365 NS	-0.001 0.498 NS

TABLE 14

The prevalence, mean intensity and abundance of each of the parasite species in undifferentiated, male and female eels at the Lough Rea (site 3)

Parasite Species	Males (N=12)				Females (N=20)			
	prevalence	n	mean intensity	mean abundance	prevalence	n	mean intensity	mean abundance
P. anguillae	58.33	7	22.29	13.00	55.00	11	12.27	6.75
D. gasterostei	-	0	-	-	-	0	-	-
D. spathaceum	91.67	11	12.45	11.42	90.00	18	19.67	17.70
Phyllodistomum sp.	-	0	-	-	-	0	-	-
S. bramae	75.00	9	26.33	19.75	60.00	12	217.83	130.70
B. claviceps	50.00	6	4.50	2.25	35.00	7	2.86	1.00
C. lacustris	8.33	1	2.00	0.17	25.00	5	1.40	0.35
P. tenerrima	-	0	-	-	5.00	1	1.00	0.05
Capillaria sp.	-	0	-	-	5.00	1	1.00	0.05
nematode larva sp.	-	0	-	-	-	0	-	-
A. clavula	-	0	-	-	20.00	4	1.00	0.20
A. lucii	66.67	8	8.00	5.33	30.00	6	13.50	4.05
P. laevis	16.67	2	1.00	0.17	10.00	2	1.00	0.10
A. anguillae	-	0	-	-	-	0	-	-
P. geometra	-	0	-	-	5.00	1	2.00	0.10

TABLE 15

The prevalence, mean intensity and abundance of each of the parasite species in undifferentiated, male and female eels at the Dunkellin site (site 2)

Parasite Species	Undifferentiated eels (N=62)				Males (N=47)				Females (N=16)			
	Prevalence	n	Mean intensity	Mean abundance	Prevalence	n	Mean intensity	Mean abundance	Prevalence	n	Mean intensity	Mean abundance
P. anguillae	0	-	-	-	0	-	-	-	0	-	-	
D. gasterostei	2.44	1	4.00	0.10	10.87	5	2.40	0.26	8.33	2	1.50	0.13
D. spathaceum	24.39	10	1.60	0.39	58.70	27	2.11	1.24	62.50	15	4.53	2.83
Phyllodistomum sp.	2.44	1	1.00	0.02	2.17	1	1.00	0.02	-	0	-	-
S. bramae	14.63	6	2.50	0.37	21.74	10	3.30	0.72	25.00	6	6.67	1.67
B. claviceps	2.44	1	1.00	0.02	2.17	1	1.00	0.02	12.50	3	1.00	0.13
C. lacustris	-	0	-	-	-	0	-	-	-	0	-	-
P. tenerrima	-	0	-	-	2.17	1	1.00	0.02	8.33	2	1.00	0.08
Capillaria sp.	9.76	4	1.50	0.15	10.87	5	1.40	0.15	-	0	-	-
Nematode larva sp.	12.20	5	1.40	0.17	52.17	24	2.50	1.30	33.33	8	5.00	1.67
A. clavula	-	0	-	-	-	0	-	-	4.17	1	5.00	0.21
A. lucii	-	0	-	-	-	0	-	-	33.33	8	1.88	0.63
P. laevis	56.10	23	3.52	1.98	78.26	36	5.75	4.50	62.50	15	8.07	5.04
A. anguillae	-	0	-	-	2.17	1	1.00	0.02	-	0	-	-
P. geometra	-	0	-	-	-	0	-	-	-	0	-	-

TABLE 16

The prevalence, mean intensity and abundance of each of the parasite species in undifferentiated, male and female eels at the Rafford site (site 1)

Parasite Species	Undifferentiated eels (N=43)				Males (N=49)				Females (N=25)			
	Preva-lence	n	Mean inten-sity	Mean abun-dance	Preva-lence	n	Mean inten-sity	Mean abun-dance	Preva-lence	n	Mean inten-sity	Mean abun-dance
P. anguillae	-	-	-	-	-	-	-	-	-	-	-	-
D. gasterostei	-	-	-	-	4.26	2	3.00	0.13	6.25	1	1.00	0.06
D. spathaceum	14.52	9	2.00	0.29	27.66	13	1.92	0.53	62.50	10	3.30	2.06
Phyllodistomum sp.	-	-	-	-	-	-	-	-	-	-	-	-
S. bramae	14.52	9	1.78	0.26	19.15	9	5.22	1.00	12.50	2	15.00	1.88
B. claviceps	1.61	1	4.00	0.06	2.13	1	1.00	0.02	-	-	-	-
C. lacustris	-	-	-	-	-	-	-	-	-	-	-	-
P. tenerrima	-	-	-	-	2.13	1	1.00	0.02	6.25	1	1.00	0.06
Capillaria sp.	3.23	2	1.00	0.03	2.13	1	2.00	0.04	-	-	-	-
Nematode larva sp.	1.61	1	1.00	0.02	10.64	5	8.20	0.87	12.50	2	1.00	0.13
A. clavula	-	-	-	-	-	-	-	-	-	-	-	-
A. lucii	4.84	3	2.00	0.10	2.13	1	2.00	0.04	25.00	4	9.75	2.44
P. laevis	38,71	24	1.54	0.60	42.55	20	2.60	1.11	31.25	5	1.80	0.56
A. anguillae	-	-	-	-	-	-	-	-	-	-	-	-
P. geometra	-	-	-	-	-	-	-	-	-	-	-	-

nematode larva sp., *Acanthocephalus lucii*), while the larger number of remaining rarer species correspond to satellite species. Both of the core species are generalists, one of which is autogenic (matures in fish) and the other allogenic (matures in a vertebrate other than fish). In contrast the satellite group of species contained the specialist eel helminths, *Paraquimperia tenerrima*, *Bothriocephalus claviceps* and *Pseudodactylogyrus anguillae*.

EEL DIET AND PARASITE COMPOSITION

The acanthocephalan species utilize *Asellus aquaticus*, *Asellus meridianus* and *Gammarus duebeni* as their intermediate hosts. The principle food item in the diet of Dunkelin eels was found to be *G. duebeni*, the intermediate host for *Pomphorhynchus laevis* in Ireland. The cystacanths of *P. laevis* were frequently found in *G. duebeni* in the stomachs of eels. *A. aquaticus* and *A. meridianus* formed a lesser proportion of the diet at both river sites (Figure 11). However *A. aquaticus* was numerically more important in the diet than *A. meridianus*. Correspondingly, the acanthocephalans *A. lucii* and *Acan-*

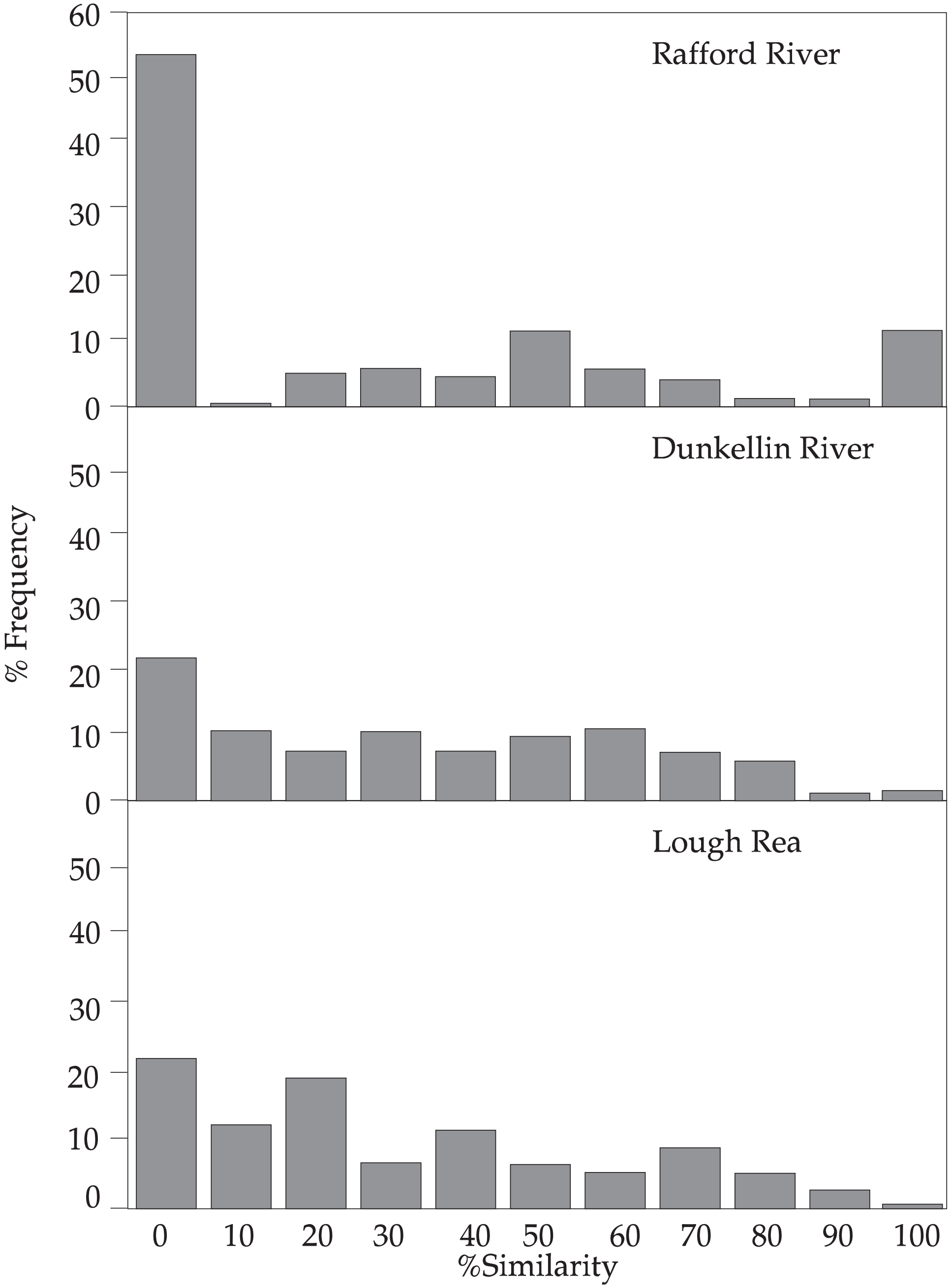

Figure 8. The within population similarity values (% similarity: quantitative) at each of the three sites investigated for parasites.

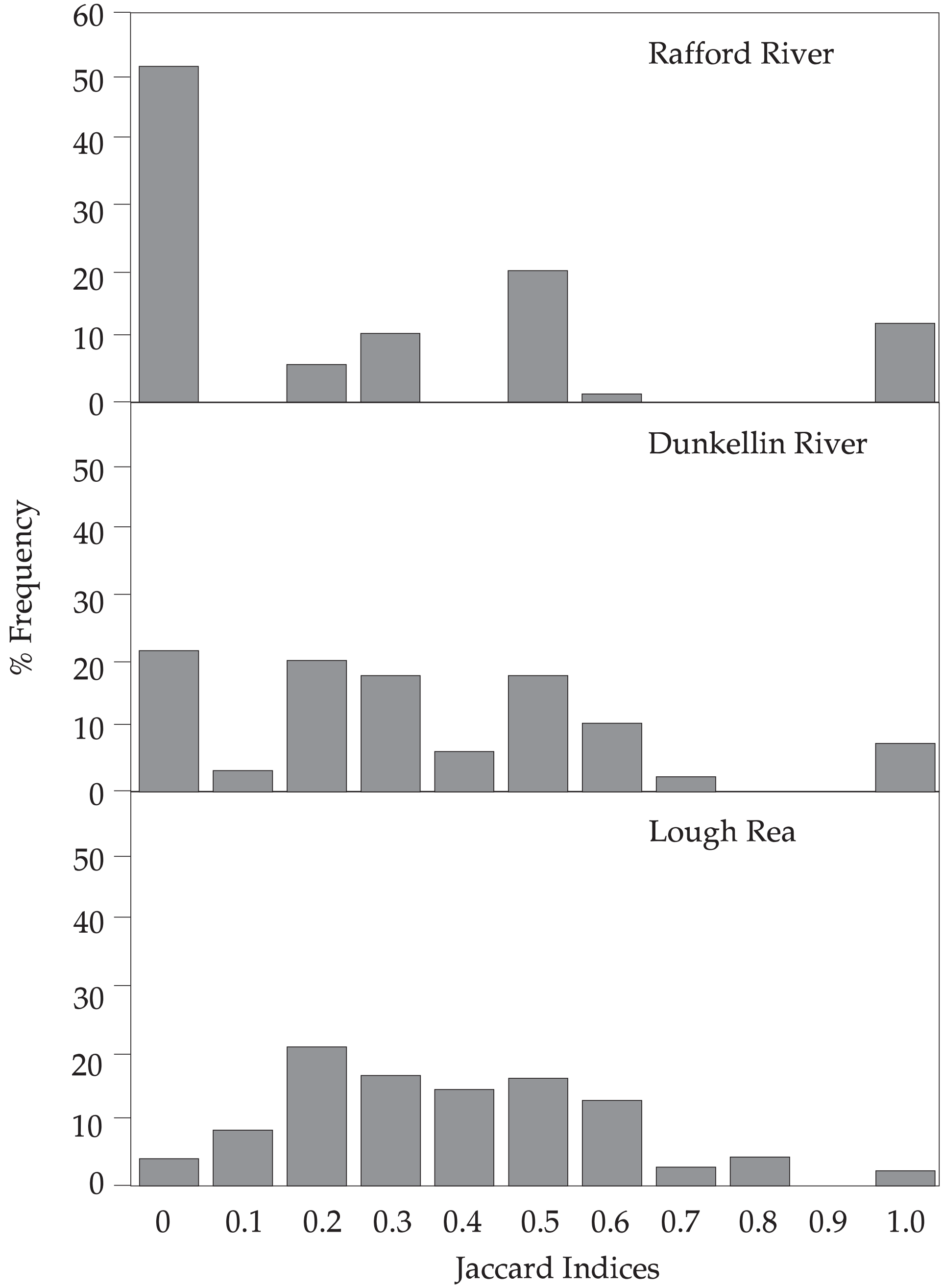

Figure 9. The within population similarity values (Jaccard index: qualitative) at each of the three sites investigated for parasites.

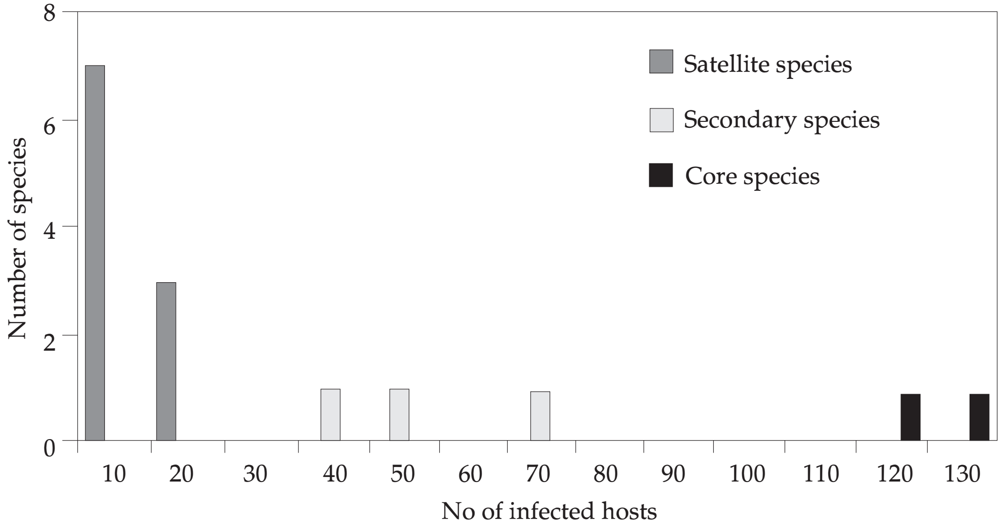

Figure 10. Frequencies of helminth species in the total sample (n = 274).

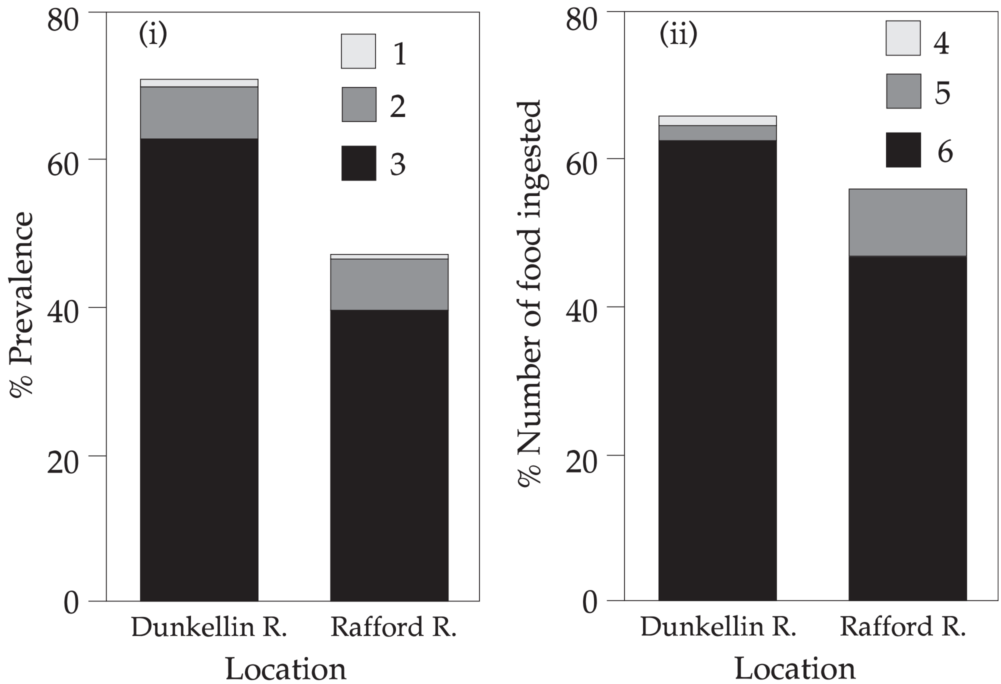

Figure 11.(i) The percentage prevalence of the three acanthocephalan species at the two riverine sites.
(ii) The percentage composition of their intermediate hosts in the eel diet at both riverine.

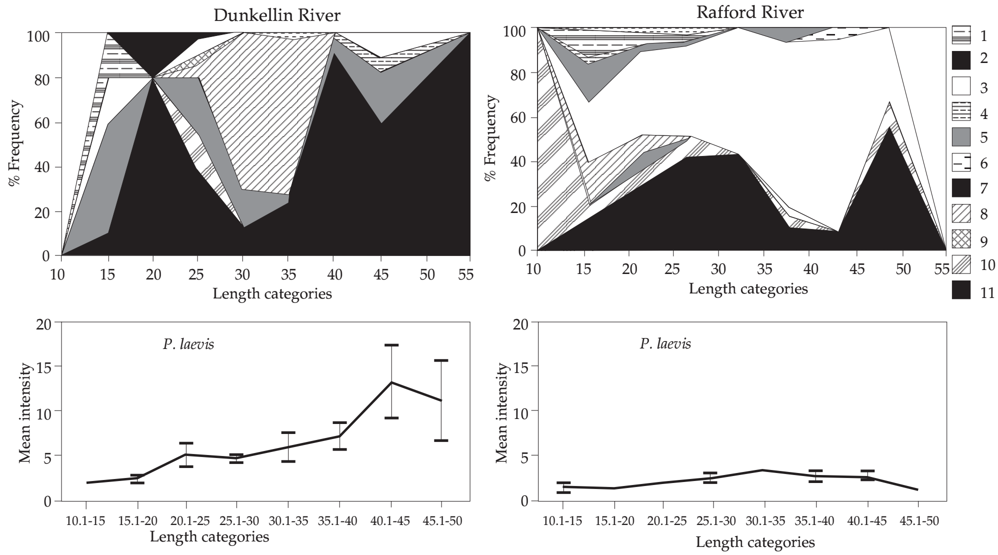

Figure 12. The variation of the mean intensity of infection of *P. laevis* with eel length and the variation in the dietary composition with eel length at both the Rafford (site 1) and Dunkelin (site 2) rivers. 1 - others, 2 - Terrestrial insects, 3 - *Diptera* larvae, 4 - *Oligochaeta*, 5 - *Coleoptera*, 6 - *Gastropoda*, 7 - fish, 8 - *Trichoptera*, 9 - *Simulium*, 10 - *Ephemeroptera*, 11 - *Asellus*, 12 - *Gammarus duebeni*

thocephalus clavula were not as prevalent as *P. laevis* while *A. lucii* was more prevalent than *A. clavula* (Figure 11). As the eels increased in size there was an increase in the consumption of *G. duebeni*, particularly at the Dunkelin site and correspondingly the mean intensity of infection of *P. laevis* also increased with increasing eel length (Figure 12).

DISCUSSION

The Dunkelin catchment is a small river system in which eels are abundant and have a wide distribution (Callaghan and McCarthy 1992). Fifteen metazoan parasites were recorded from the 274 eels examined (Table 4). The number of species in each of the three component communities varied from nine to twelve (Table 6), or if only the intestinal helminths are considered the number of helminths varied from seven to nine (Table 6). This is in the higher range of species recorded for eels from a single locality when compared with Britain (Kennedy 1990), and similar to the number of helminth species recorded by Conneely and McCarthy (1986) for another west of Ireland catchment. However, investigations of the parasite fauna of eels in other European localities have recorded a greater number of metazoan species in a single locality (Markowski 1933, Englebrecht 1958, Seyda 1973, Moravec 1985, Koie 1988). In comparison with these investigations some of the studies on the parasite fauna of eel in Britain (Williams and Bolton 1985, Kennedy et al. 1986, Chubb 1963) have yielded only between three and six species in any one locality.

In an extensive study on the intestinal helminths of eel in Britain and Ireland, Kennedy (1990) found that over 74% of the component communities were composed of less than three species. The maximum number recorded in any locality was nine. He found no apparent regional or habitat pattern, and similar to the results of this study there did not appear to be any relationship between sample size and the total number of helminths recorded in the component community. Gregory (1990) found a strong correlation between species richness and sampling effort and found that the number of parasite species correlated positively with the number of citations and the number of hosts examined. In view of this, and in order to assess the minimum sample size necessary, cumulative species richness curves which were based on randomizations of the data set (Figure 2) revealed that a sufficient number of hosts appeared to have been examined at the two riverine sites, while at Lough Rea it is probable that additional helminth species would have been recovered had more eels been examined. With the exception of one sample of 55 eels, the number of eels examined by Kennedy (1990) ranged from 8 to 35 and the majority of component communities (intestinal) were found to be very species poor, composing of three species or less. In a further study carried out by Kennedy et al. (1992) larger sample sizes (64 to 233 eels) resulted in a larger number of helminth species, i.e. six to ten (five to eight intestinal), being recorded in any one locality.

HABITAT

The parasite species which occurred in the lake generally had higher prevalences than species which parasitized the riverine eels. This is possibly a reflection of the size of eels examined from the lake which were large mature individuals (Table 1) and therefore prevalences would be expected to be higher compared with the smaller and mostly yellow eels which were examined from the riverine sites (Table 1). When individual parasite species common to both habitats are compared, differences in infection parameters between the lake and riverine sites are also probably in some instances due to the habitat preferences of the intermediate hosts or the feeding habits of the eels concerned, as well as other factors which operate at the community compound level, such as the ichthyofaunal differences between the three sites or as in the case of the *Diplostomum* sp. the presence at Lough Rea of fish eating birds.

SIZE, AGE AND SEX OF HOST

Dogiel (1961) first noted that there appeared to be a general tendency for infection parameters of fish parasites to vary according to the size and age of the host. The results of this study generally agree with this conclusion. Increasing abundance of helminth species with increasing size of host is a common phenomenon and can be accounted for by changes in host habitat, feeding habits, extended exposure to infections, large available microhabitats for parasites and changes in physiological conditions with maturity (Polyanski 1958, Hooper 1983). The total parasite abundance (total number of individuals per fish) was highly significantly correlated with eel size and age at both riverine sites (sites 1 and 2) but not in Lough Rea (site 3) eels. This may be due to the narrower size range examined in Lough Rea (Table 1) and therefore a relationship between parasite abundance and eel size would be less likely to be detected.

FOOD

Diet in fish is a well known determinant of the gut parasite composition (Polyanski 1958, Kennedy 1975, Hooper 1983). The increased prevalence of the acanthocephalan species *Pomphorhynchus laevis* with increasing lengths appears to be directly related to the increase in the consumption of *G. duebeni*, its intermediate host (Figure 12). The differences in parasite abundances between the sexes (Tables 14, 15 and 16) are probably related to size and age differences between the undifferentiated, male and female eels as well as to habitat and feeding differences. Thus female silver eels, which have usually spent more time in fresh water and may have a more diverse diet than yellow eels, would be likely to encounter more parasites. Two of the parasite species recorded in this study, *Pseudodactylogyrus anguillae* and *Piscicola geometra*, have direct life cycles and require no intermediate hosts (Table 4). The remaining species all have indirect life cycles with at least one intermediate host, although paratenic hosts may be involved in some cases. The prevalence and intensity of infections of parasite species acquired by the ingestion of food will reflect feeding specializations and the habitat use of the host. An omnivorous diet of invertebrates and fish is considered to account for much of the variation in total helminth richness and intestinal helminth richness per host. The broad diet of eels means that they have the potential to ingest a wide range of intermediate hosts and consequently of larval helminth species. The parasitic fauna of eels has led some authors to suggest that they may regularly feed on plankton (Kennedy et al. 1992), although evidence from feeding studies does not uphold this view and ingested invertebrate prey is mainly composed of benthos dwelling organisms (Moriarty 1978, Tesch 1977).

The intermediate hosts of the four acanthocephalan species recorded in the Dunkellin River are *Gammarus duebeni (Pomphorhynchus laevis)*, *Asellus aquaticus (Acanthocephalus lucii* and *Acanthocephalus anguillea)* and *Asellus meridianus (Acanthocephalus clavula)* (Table 4). All three of these crustacean species were ingested by the Dunkelin eels (Fig. 11 and 12). However, of the three prey species *Gammarus duebeni* was by far the most important food item in the diet (Fig. 11). The *Asellus* spp. were not as important but of the two species, *A. aquaticus* was ingested more frequently than *A. meridianus*. The intensities of infection and the prevalences of the acanthocephalan species in the Dunkelin eels reflect the dietary habits of their hosts. *Pomphorhynchus laevis* was found to be the dominant parasite species (Table 6) and *G. duebeni*, its intermediate host, was the most important food item (Figs 11 and 12). It appears that the diet of eels is a most important factor in determining parasite composition and infection parameters, as it explains much of the variation between different sizes, sex and habitat differences in this study.

PARASITE COMMUNITIES

Generally the gut communities of parasites of freshwater fish differ from the helminth communities of birds in that they are less predictable and less diverse (Kennedy et al. 1986). Helminth communities in the same species of fish can often show low degrees of similarity in composition dominance and numbers between localities (Esch et al. 1988, Kennedy 1990). Eels harbour a variable number of helminth species (Markowski 1933, Englebrecht 1958, Chubb 1963, Seyda 1973, Moravec 1985, Wiliams and Bolton 1985, Conneely and McCarthy 1986, Kennedy et al. 1986, Koie 1988, Kennedy 1990). Many species of parasites are specific to a particular group of fish species (specialists) while other parasite species exibit wide host specificity (generalists). A third group of species of parasites are accidental and eels may acquire these parasites from another species of fish (Nie and Kennedy 1991, 1992). The eels in this catchment harboured three specialist species - *B. claviceps*, *Pseudodactylogyrus anguillae* and *Paraquimpera tenerrima*. Two species encountered in this survey are considered to be accidental - *Phyllidostomum* sp. and *Capillaria* sp. The remainder of the species recorded were generalists with the ability to develop in a number of different host species. Virtually all eel communities including those of the Dunkelin catchment are composed of a mixture of eel specialists, generalists and accidentals. Esch et al. (1988) found that eel helminth communities were less predictable than those of trout and cyprinids. Eel infra and component communities are generally characterized by having low species diversity (Kennedy 1990) as well as being dominated by a single species which can be a generalist or a specialist, although most often a generalist, in particular a species of acanthocephalan (Kennedy 1990). The results in this study are similar to these findings. A generalist, the acanthocephalan *Pomphorhynchus laevis* is the dominant species in the majority of infracommunities at both riverine sites. In the lake *Diplostomum spathaceum*, also a generalist, dominated the majority of infracommunities. In contrast with the rivers, *Pomphorhynchus laevis* did not dominate any of the lake infracommunities. Most of the infracommunities in the Rafford River, and over 25% in the Dunkellin River, consisted of a single species and therefore the dominance index was equal to one (Figure 6). In Lough Rea relatively few eels were parasitized by a single species and the number of infracommunities with a dominance index of one was low. The Lough Rea eels examined were larger (Table 1) and probably older than the eels of the riverine sites. There was a significant difference (Mann Whitney U test $p < 0.05$) in the size of eels between all three locations, with the Rafford having the smallest eels. This probably accounts for some of the observed differences between the sites in respect of the parasite infracommunity richness. Nevertheless, eels from the two riverine sites have spent relatively the same amount of time in freshwater (mean age is approx 8 years), and there was no significant difference in age between the sites. However if eels from the Rafford are smaller at the same age than those at the Dunkelin, then growth rate is probably less in the Rafford eels, which may possibly be linked to the quantity and/or quality of prey ingested affecting the type and abundance of intestinal helminths present.

Esch et al. (1988) found that the mean percentage similarity in parasite communities between individual eels varies greatly from locality to locality. The mean similarity, both mean percent and Jaccard's index was low particularly in the case of the Rafford eels.

COMPONENT COMMUNITY

At both the Dunkelin River (site 2) and Lough Rea (site 3), the helminth component community was clearly dominated by a single species, *Pomphorhynchus laevis* at the river site and *Sphaerostoma bramae* in the lake community. This appears to be a feature of most eel helminth infracommunities which are characterized by low diversity and dominance by a single species (Kennedy 1990). In contrast, the dominance index for the component community of the Rafford eels is low, indicating that *Pomphorhynchus laevis* is not as important at this site as it was at the other riverine site. *Sphaerostoma bramae* is almost as equally abundant and *Diplostomum spathaceum* is also important. The degree of similarity between component communities of the riverine sites was high (Table 7 and 8). Qualitatively the degree of similarity (Jaccard) between the riverine sites and Lough Rea component communities was relatively high (0.5). However, quantitatively the similarity between the lake and the river component communities was less than 50%, indicating the variable abundances of some of the parasite species such as *Sphaerostoma bramae*, *Diplostomum spathaceum*, *Pomphorhynchus laevis* between the riverine and lake sites.

CORE AND SATELLITE SPECIES

In parasitology the core and satellite species hypothesis (Hanski 1982) has been used to describe interactive communities of parasites within a host species (Holmes and Price 1986). Core species are those species which are regionally common, locally abundant and relatively well spaced out in niche space. Satellite species are infrequent and few (Hanski 1982). *Pomphorhynchus laevis* and *Diplostomum spatheceum* were found to be the core species in eels in this study. A further three taxa could be described as secondary or intermediate species - *Sphaerostoma bramae*, nematoda larva and *Acanthocephalus lucii*, while the remaining species which were infrequently recorded and were not abundant can therefore be described as satellite species. Eel helminth communities are considered to be less predictable than those of some other fish species (Esch et al. 1988). The fact that there are only two core species would also suggest this in the case of the Dunkelin eels. Life cycle strategies are considered to be one of the most important factors for the status of a species as a core or satellite species (Esch et al. 1988). In this regard, *Diplostomum spatheceum* which is an allogenic species, has greater dispersal ability than autogenic species (Esch et al. 1988). *Pomphorhynchus lae-*

vis, also a generalist, has become established as a core species as a result of utilising *Gammarus duebeni* as its intermediate host. Since *Gammarus duebeni* is the main food item of eels in the catchment, *Pomphorhynchus laevis* was common and abundant in eels in the river system.

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STRESZCZENIE

ZAINFEKOWANIE WĘGORZA ZE ZLEWNI RZEKI DUNKELIN, ZACHODNIA IRLANDIA, PASOŻYTAMI Z GRUPY *METAZOA*

Próby węgorza żerującego (n=117 i 125) pobrane z dwóch stanowisk położonych w alkalicznej zlewni rzeki Dunkelin oraz jedną próbę węgorza strebrzystego (n=32) spływającego z silnie alkalicznego jeziora Rea, położonego w tej samej zlewni, przebadano pod względem stopnia zainfekowania pasożytami z grupy *Metazoa*. Zbadano także pokarm węgorza oraz skład gatunkowy pogłowia ryb na stanowiskach rzecznych. Stwierdzono, że na badanych rybach występowało 15 gatunków pasożytów. Przedstawiono szczegółowe dane dotyczące zakresu zainfekowania ryb przez poszczególne gatunki pasożytów oraz uwzględniając płeć węgorza i dojrzałość płciową. Dyskusję przeprowadzono na tle danych o warunkach środowiska i różnicach faunistycznych między stanowiskami poboru prób. Omówiono skład i strukturę zbiorowisk pasożytów i zależności wewnątrz i między zbiorowiskami oraz porównano je z wynikami badań wcześniejszych.