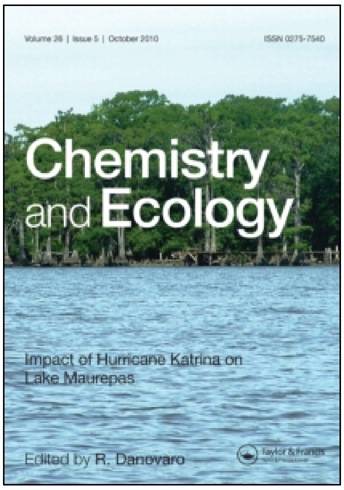

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PRE- AND POST-LIMING AQUATIC COMMUNITIES AND TROUT DIETS

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In the period following liming and before the introduction of brown trout to Loch Fleet, there was a reduction in the numbers of invertebrates, including the Chironomidae, Oligochaeta and Hydracarina in the loch, but an overall increase in invertebrates in the inlet and outlet streams. This was followed in the loch by a recovery in the numbers of certain groups (particularly the Trichoptera and Ephemeroptera) to pre-liming levels in spite of the introduction of the trout.

The diets of the trout comprised a wide variety of aquatic and terrestrial organisms ranging in size from Fprotozoans to newts and are dominated by chironomids. Opportunistic type of feeding as found in the present study appears to be typical of the brown trout and is reported for many water bodies by other workers.

Significant differences ($P > 0.05$ and $P > 0.001$) were found in the numbers and weights of certain food organisms in the stomachs of brown trout caught by different fishing methods in the summers of 1992 and 1993. Fish caught by gill net contained fewer planktonic crustaceans and chironomids, but greater numbers of trichopterans and terrestrial organisms, than in those caught by fly and spinner. The differences are probably related to differences in the depth at which the fish, caught by the various methods, were feeding.

KEY WORDS: Acid water, liming, aquatic invertebrates, trout diets

INTRODUCTION

The community structure and densities of aquatic invertebrates are used frequently as an indication of environmental changes and stresses. In the present context it was considered how the invertebrate communities of Loch Fleet might change after liming and after the introduction of trout. Recent studies have shown that these communities can be classified and used to predict stream acidity (Weatherley and Ormerod, 1987, Wade *et al.*, 1989).

The invertebrate studies have, in addition, provided information on which to base the fish stocking programme for the loch (Turnpenny, 1992).

The invertebrate community studies covered the period from 1984 to 1990 during which the invertebrates were subjected to three sets of conditions:

1) a pre-liming period from July 1984 to April 1986 when pH and calcium levels were low;

2) a post-liming period from summer 1986 to May 1987 before the introduction of brown trout;
3) a further post liming period combined with predation by brown trout, which extends from May 1987 to the present.

Brown trout were stocked in May 1987 (300 fish) and July 1988 (220 fish). Invertebrate sampling was continued during this period and until the summer of 1990. During the third period, samples of the gut contents of the brown trout were examined annually to see how these related to the invertebrate fauna of the loch. The first of these was taken in 1988 and the last in 1993.

INVERTEBRATES OF THE LOCH AND STREAMS

Methods

Samples of benthic invertebrates were taken in spring, summer and autumn from 1984 to 1990. The loch shore was sampled in nine bay areas using an open ended cylinder (0.16 m^2) which was adaptable for stone, sand and weed substrates (Figure 1). Two samples were taken in each bay area. Deeper water was sampled with a Petersen grab and an FBA airlift sampler fitted with a extension tube to operate at depths up to 4m (Drake *et al.*, 1983). The grab was used in 14 areas of the loch including two in the deepest part, while the airlift sampler was used down to about 4 m depth in 12 areas, as shown in Figure 1.

The inlet and outlet streams were sampled with a modified Surber Sampler fitted with a net with a 120 micron mesh and a quadrat covering 0.09 m^2 of stream bed. Three samples were taken from each stream on each sampling occasion.

RESULTS

Species present before liming

A total of 103 taxa were recorded in 1984–1985, prior to liming. A full species list is given in Milner and Aston (1987). The molluscs were restricted to one *Pisidium* species and the Mayfly nymphs to *Paraleptophelebia submarginata*, *Leptophlebia marginata*, and *L.vespertina*. Stonefly nymphs were represented by *Leuctra nigra.*, *L. hippopus*, *Amphinemura standfussi*, *Nemoura avicularis* and *N. cinerea* and the caddis fly larvae by *Chaetopteryx villosa*, *Plectrocnemia* spp., *Phryganea obsoleta*, *P. varia*, *Polycentropus flavomaculatus*, *Limnephilius rhombicus* and *L. griseus.*

Species present after liming and after fish stocking

The total number of species after liming was similar; no evident species losses were reported, but some species were reported in the catchment for the first time after liming. Species recorded for the first time after liming were as follows: Mayfly nymphs: *Baetis rhodani*, *Leptophlebia werneri* and *Ameletus* spp. Stonefly nymphs: *Amphinemura sulcicollis*, *Chloroperla torrentium*, *Isoperla* spp., *Protonemura* spp, and *Brachyptera risi.* Caddisflies: *Polycentropis kingi*, *Plectrocnemia geniculata*, *P. conspersa*, *Tinodes* spp. and

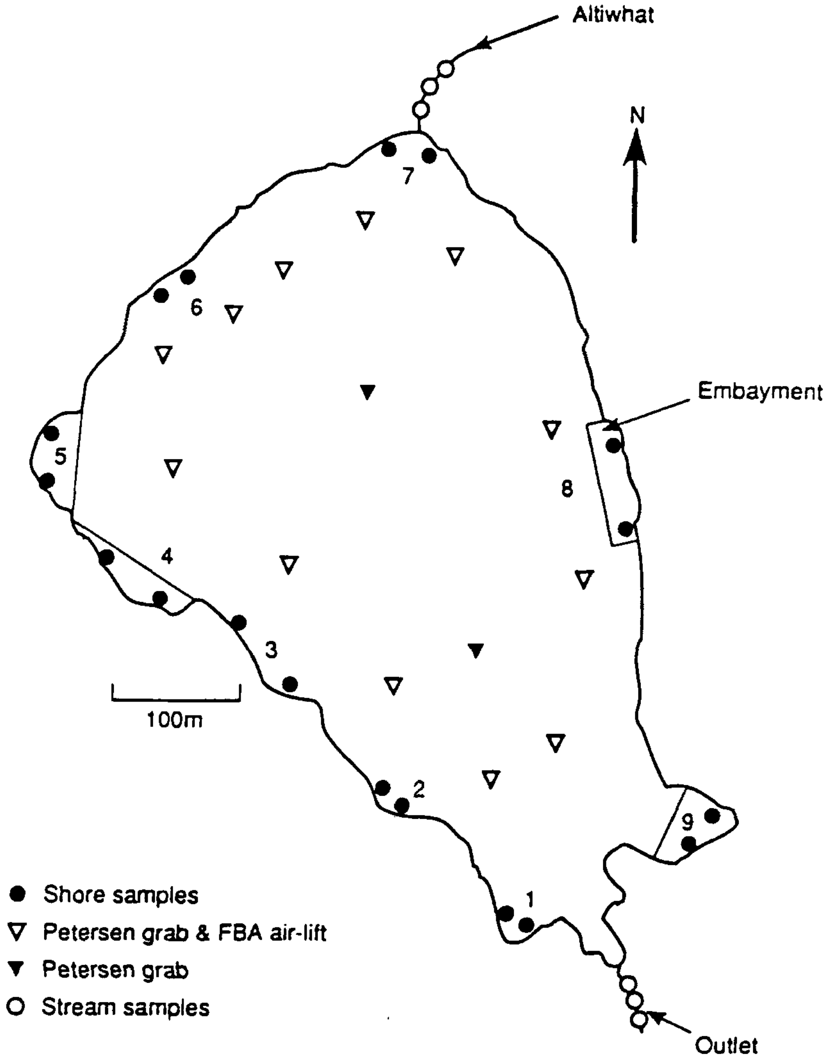

Figure 1 Invertebrate sampling points and methods used (numbers refer to bays).

Cyrnus flavidus. No Mayfly nymphs were found in the streams prior to liming. After liming, *Baetis rhodani* was found in the streams and *Leptophlebia werneri* in the loch.

The relative abundance of the various invertebrate groups in the main inflow stream, the loch (shore and benthos), and in the outlet stream, is illustrated in Figure 2.

Changes in population densities

The densities of invertebrates (all species combined) per unit area (m^2) before and after liming and before and after the introduction of trout are summarised in Figure 3. It will be noted that there was a significant reduction in invertebrate numbers in the loch, but not in the tributary streams, after liming and before fish stocking. The reductions were

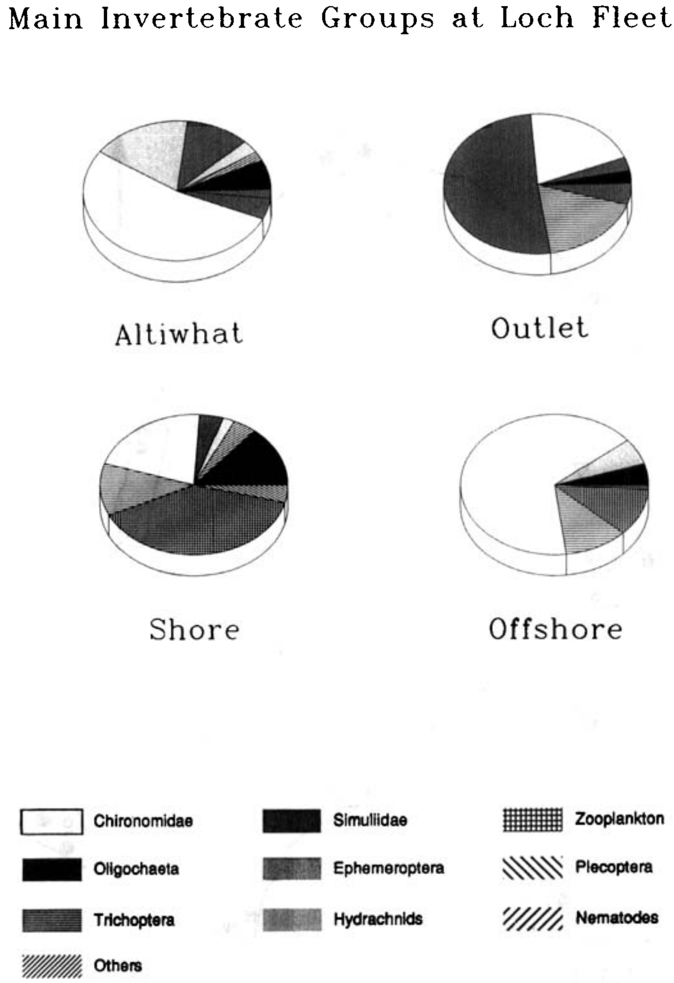

Figure 2 Releative occurrence of invertebrate groups found in summer 1988 (post-liming, post fish re-introduction) in the main inflow stream (Altiwhat), the loch (shore and benthos) and in the loch outlet stream

mainly in the Chironomidae, the Oligochaeta and the Hydracarina ($P < 0.01$). This was followed by a later recovery in numbers in deeper water mainly due to increases in the Ephemeroptera ($P < 0.05$), Chironomidae and Trichoptera ($P < 0.01$).

In contrast, in the inlet stream (Altiwhat) the numbers of Chironomidae and Ephemeroptera increased soon after liming. The numbers of Ephemeroptera continued to rise after the re-introduction of brown trout but there was a significant reduction in the numbers of Coleoptera and Trichoptera, probably due to fish predation. In the outlet stream, however, the numbers of Trichoptera and Simulidae increased after the introduction of trout and after liming. Here it seems likely that the increased numbers were related to higher productivity in the loch which increased the supply of suspended food.

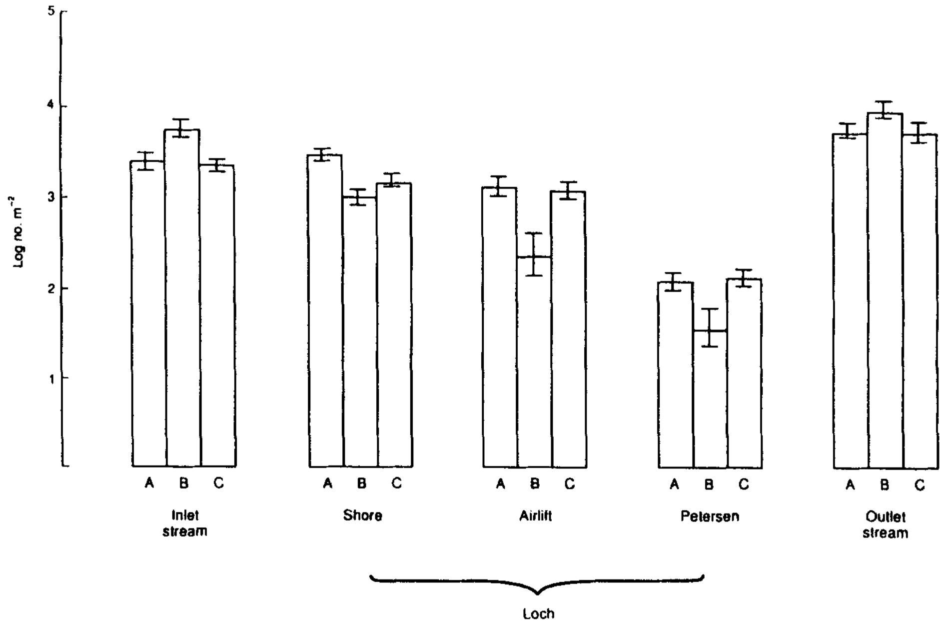

Figure 3 Numbers (means and standard errors) of invertebrates (all groups combined) in the Altiwhat (inlet stream), the loch and the loch outlet stream. A: pre-liming, B: post-liming before fish stocking, C: post-liming after fish restocking.

The percentage composition of the main groups of aquatic invertebrate communities remained relatively consistent through the changes in water quality that followed liming, and the re-introduction of trout, with Chironomidae, Ephemeroptera and Oligochaeta, Trichoptera and Crustacea (planktonic) present. In the loch, chironomids dominated the benthos but most other major groups were found; inshore sites show greater diversity, with zooplankton, trichopterans and chironomids as major components. The contribution of the Hydracarina fell after liming and fish introduction. The inlet stream was dominated by chironomids, while simulids were the major component in the outlet stream. This fauna is characteristic of other oligotrophic lakes in the region (Morrison and Collen, 1993), or of acid upland lakes in Norway (Raddum, 1980).

DISCUSSION

It has been noted that while there was an initial decrease in the numbers of invertebrates in the loch after liming, the numbers in the inlet and outlet streams increased (Figure 3). Whether these changes were within the normal year to year variation or whether they were related to the increased pH and/or related chemical parameters is not entirely clear from the results of this study. An initial decrease in numbers of invertebrates after lake liming has also been recorded by Scheider and Dillon (1976), Broberg (1978), and Raddum *et al.* (1984). However, in these cases the lime was added directly to the lakes and not to the surrounding catchment, giving a much more rapid change in water chemistry than the chemical changes recorded in Loch Fleet.

Where the numbers were higher after the introduction of fish than before liming (Crustacea, Ephemeroptera and Trichoptera in the loch, Trichoptera in the outlet stream and Ephemeroptera in the inlet stream), it is reasonable to conclude that the increases were probably brought about by the direct or indirect effects of liming, since they occurred in spite of predation by the trout.

An increase in Ephemeroptera has also been reported in other limed waters (Eriksson *et al.*, 1983; Hasselrot *et al.*, 1984). Weatherley and Ormerod (1987) also report higher numbers of Ephemeroptera and some species of Trichoptera in circumneutral (unlimed) streams than in more acid streams. In Loch Dee streams, diversity varied little between streams, although in the circumneutral Black Laggan (pH $\sim$ 7, Ca $\sim 3\,mg\,l^{-1}$) (a tributary of the White Laggan (pH < 6, Ca $\sim 1.6\,mg\,l^{-1}$) numbers and abundance was greater, and the fauna includes molluscs (*Ancylus and Limnaea* sp.),; *Baetis rhodani* was often abundant there, but less frequent in the W. Laggan and Green Burn: (pH $\sim$6.5, Ca $\sim 1\,mg\,l^{-1}$). The most acid tributary, Dargall Lane (pH $\sim$ 5, Ca $\sim 1.2\,mg\,l^{-1}$) has fewer invertebrate taxa (Lees and Farley, 1993; Morrison and Collen, 1993); *B. rhodani* has been found only once.

The increase in the numbers of certain invertebrate species after liming may be caused by increased calcium, increased pH or reduced aluminium or a combination of these three factors. In the case of *Baetis rhodani*, for example, there is evidence to suggest that calcium is more important than high pH, since this species has been recorded at pH values as low as 4.2 when calcium concentrations were equal to or greater than $3\,mg\,l^{-1}$ (Aston *et al.*, 1985). Note that *Leptophlebia werneri*, one of the Mayfly species recorded in the loch after liming, is also normally found in waters containing relatively high calcium levels (Elliott, 1988). Most species found before liming were still present post liming and it is likely that many so-called "acidophilous" species are simply acid tolerant and able to exploit the cool and nutrient poor conditions (Foster, 1991 and this issue)

THE DIETS OF BROWN TROUT IN LOCH FLEET

Following the stocking of Loch Fleet with brown trout in May 1987 (300 fish) and in July 1988 (220 fish) (Turnpenny, 1992), studies on the diets of the re-established trout population have been carried out each year from 1988 to 1993 (Milner, 1989 and 1991; Milner and Dalziel, 1990; Aston, 1992 and 1993).

METHODS

The trout population was sampled each year by a variety of methods including fly fishing, spinning and gill netting. The fish (length range 130–260 mm) were anaesthetised with MS222 and their gut contents removed using a flushing method described in Meehan and Miller (1978).

During the five year study, the stomach contents of a total of 282 fish were analysed. The largest sample, made up of 105 sets of stomach contents, was taken in June 1993 and, unless stated otherwise, the following account applies to this large sample. Prey items were identified to the lowest practical taxon and counted for each sample. In view of the fragmented nature of many of the food organisms, estimates of the weights of the stomach contents were made by reconstruction from the wet weights of whole organisms. The majority of the weight measurements for these were taken from measurements of whole specimens from samples obtained in the summers of 1991 and 1992 (Aston, 1993).

For statistical analyses, various taxa were combined within appropriate orders or families. A category "other aquatic organisms" was used to include relatively small numbers of Foraminifera, *Pisidium* sp., Hydracarina, Coleoptera, Plecotoptera, Corixidae, *Sialis lutaria* and Amphibia. A further category, "other terrestrial invertebrates", includes Gastropoda, Araneida, Thysanoptera, Coleoptera and unidentified insects. The presence of oligochaetes in the gut was monitored by careful searching for chaetae.

In a preliminary assessment of the data sets for numbers and reconstructed weights of the organisms in each sampling method, the variances for the majority of taxa were greater than the mean. Log $(n + 1)$ transformations were therefore carried out on the counts (Sokal and Rohlf, 1981) and on the reconstructed weights. One-way analyses of variance were carried out on the transformed data sets for the numbers and weights of organisms in each group followed by Student '**t**' tests. Geometric averages of the numbers and weights of the various food organisms per stomach were taken as the antilog of the mean of the transformed data, minus one.

RESULTS

Variety of food items

A list of the various taxa found in the diets of the trout sampled from 1988 to 1993 is given in Table I. It will be seen that the list contains at least 53 taxa made up of 32 aquatic and 21 terrestrial taxa. Allowing for the fact that a number of food items in the samples were not identifiable to species because they were partly digested, it seems likely that the number of species consumed by the trout was considerably larger than the number of taxa recorded. No evidence of oligochaetes (i. e. the presence of chaetae) was found in any of the samples.

Percentages of stomachs containing various food items

In Figure 4 are shown the percentages of fish stomachs containing various food items in 105 samples taken in summer 1993. It will be seen that the majority of trout had consumed chironomids. Other food items were present in a smaller number of stomachs and varied according to the method by which the fish were caught. It will also be seen from Figure 4 that in general, fish caught by gill-netting were more likely to contain any given food item, than fish caught by spinning or fly fishing (chi squared test: $P < 0.001$).

Table I Taxa present in the diet of brown trout, Loch Fleet in samples taken 1988–1993.

AQUATIC ORGANISMS		
Protozoa:	Foraminifera:	Unidentified
Crustacea:	Cyclopoida:	Unidentified
	Cladocera:	*Eurycercus lamellatus*
		Chydoridae: Unidentified
		Polyphemus pediculus
		Holopedium gibberum
		Bosmina coregoni
		Bythotrephes longimanus
Ephemeroptera:		*Leptophlebia vespertina*
		Brachyptera risi
Plecoptera:		*Protonemura* sp.
		Amphinemura sulcicollis
		Chloroperla torrentium
Corixidae:		Unidentified
Neuroptera:		*Sialis lutaria*
Trichoptera: Polycentropidae:		*Polycentropus kingi*
		P. flavomaculatus
		Plectrocnemia conspersa
		Cyrnus flavidus
		Tinodes sp.
	Psycomyidae:	Unidentified
	Phryganeidae:	Unidentified
Diptera	Chironomidae:	Unidentified
	Culicidae:	Unidentified
	Dixidae:	Unidentified
Coleoptera:		*Potamonectes depressus*
		Helophorus sp.
		Hydroporus palustris
		Hygrotus quinquelineatus
Hydracarina:		Unidentified
Mollusca:		*Pisidium* sp.
Amphibia:		*Triturus* sp.
TERRESTRIAL ORGANISMS		
Heteroptera:	Delphacidae:	Unidentified
	Cerccopidae:	Unidentified
	Pemphigidae:	Unidentified
Homoptera:	Aphidae:	*Adelgida abietis*
		Unidentified
Thysanoptera:		Unidentified
Neuroptera:		*Hemerobius* sp.
Diptera:	Tipulidae:	Unidentified
Bibionidae:		Unidentified
	Mycetophilidae:	*Sciara* sp.
	Psycodidae:	*Psycoda* sp.
Hymenoptera:	Ichneumonidae:	Unidentified
	Braconidae:	Unidentified
	Proctotrupoidea:	Unidentified
	Formicoidea:	*Formica rufa*
	Apoidae:	*Bombus* sp.
	Symphyta:	*Diprion pini*
Coleoptera:	Staphylinidae:	Unidentified
	Curculionidae:	Unidentified
Arachnida:	Araneida:	Unidentified
Gastropoda:		Unidentified

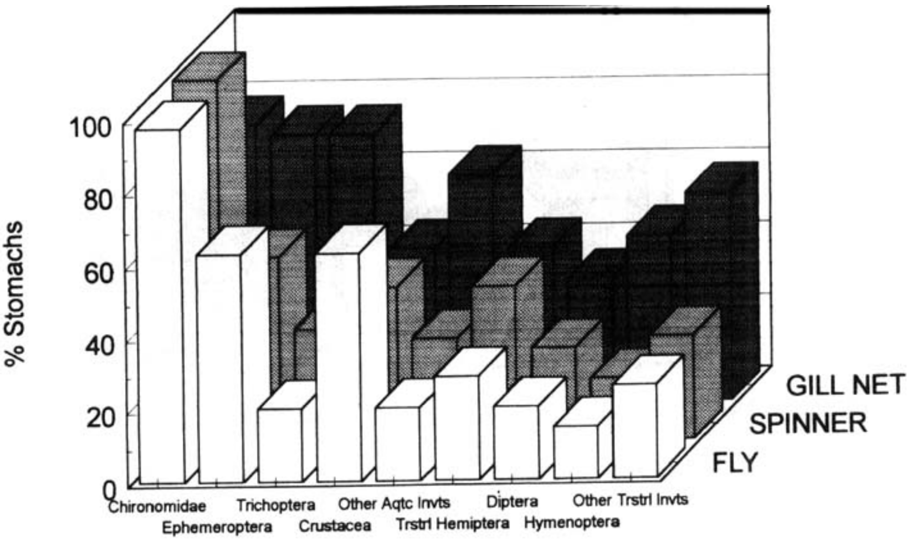

Figure 4 Percentages of stomachs containing various food items in trout caught by different fishing methods.

Numbers of food organisms per stomach

Figure 5 shows the geometric means for the numbers of food organisms from various invertebrate groups in the stomachs of fish caught by fly, spinner and gill-net in summer 1993. The most abundant food organisms in the fly and spinner samples were chironomid pupae, many of which were ready for, or in the process of emerging as adult flies. In the gill-net samples chironomid pupae were also most abundant, along with trichopterans.

It will be seen that these data reflect the percentage occurrence data in Figure 4 and that differences between the mean number of food items for different fish sampling methods are again quite evident. In an analysis of variance of the numbers present in each group, significant differences are seen between the geometric means for different fish-sampling methods for crustaceans, trichopterans, chironomids, 'other aquatic organisms', hymenopterans, and 'other terrestrial invertebrates' (chi squared test: $P < 0.001$).

The geometric mean for planktonic crustaceans in the sample of fish caught by fly was found to be significantly higher than in fish caught by spinner while the means for trichopterans, hymenopterans and 'other terrestrial invertebrates' were significantly lower (Figure 5). In other respects, the fly and spinner samples were more alike than either the fly and gill net samples or the spinner and gill net samples.

Weights of food organisms per stomach

The reconstructed weights (geometric means + 1) for various groups of invertebrates in the stomachs of trout from fly, spinner and gill net samples are shown in Figure 6. The

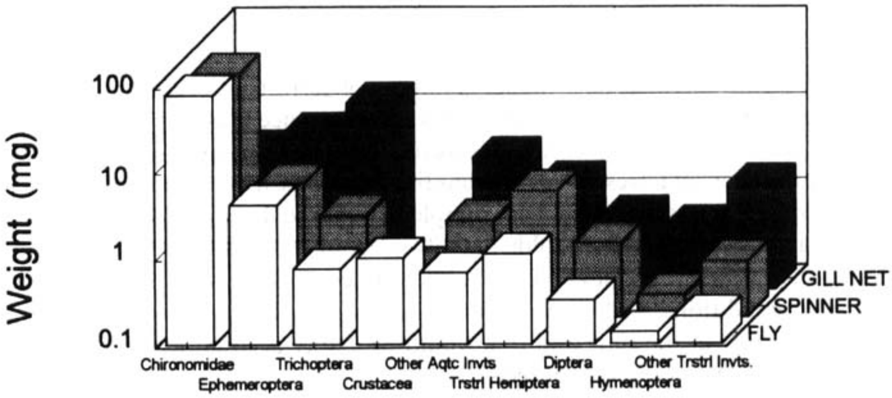

Figure 5 Numbers (geometric means) of food organisms in the stomachs of trout caught by fly, spinner and gill nets (log scale).

total weights (geometric means) of food items were 121 mg, 137 mg and 76 mg for fish caught by fly, spinner and gill net respectively. Statistical comparisons of the geometric mean weights of most groups again indicate significant differences for different sampling methods (chi squared test: $P<0.001$).

DISCUSSION

It is quite clear from the results of this study that the brown trout in Loch Fleet are opportunistic feeders, able to adapt to whatever food is available. This has also been reported in many other water bodies (eg Cada *et al.*, 1987; Frost and Brown, 1967; Papageorgiou *et al.*, 1984; Maitland and Campbell, 1992; Swift, 1970). In the present study it is well illustrated by the wide variety of terrestrial as well as aquatic invertebrates in the diet, which range from very small foraminiferans to newts (Table I). Many of the food organisms present in the diets of the brown trout of Loch Fleet are likely to be available seasonally for a relatively short time yet they have clearly been able to exploit these temporary sources of food.

Chironomids were the main food source for trout caught by all sampling methods in 1993 (Figures 4 and 5) and in all other years in which samples were taken (Milner, 1989 and 1991; Milner and Dalziel, 1990; Aston, 1992 and 1993). This observation is reflected in the earlier study of the aquatic invertebrates of the loch (Battarbee *et al.*, 1992), in which chironomids were found in greater numbers than any other macroinvertebrate. In terms of weight (Figure 6), the next most important food organisms in the 1993 sample of trout were ephemeropterans followed by hemipterans (mainly aphids) and trichopterans. Trichopterans are one of the few groups present in the diets which appear to have increased in population density in the loch since liming. From the results of the present study, however, it would appear that they make up only a relatively small proportion of the diet, so that the effects of liming on the amount of food available to the trout in the loch appears to be small. On the other hand seasonal sampling of diets might reveal that trichopterans are a more important component of

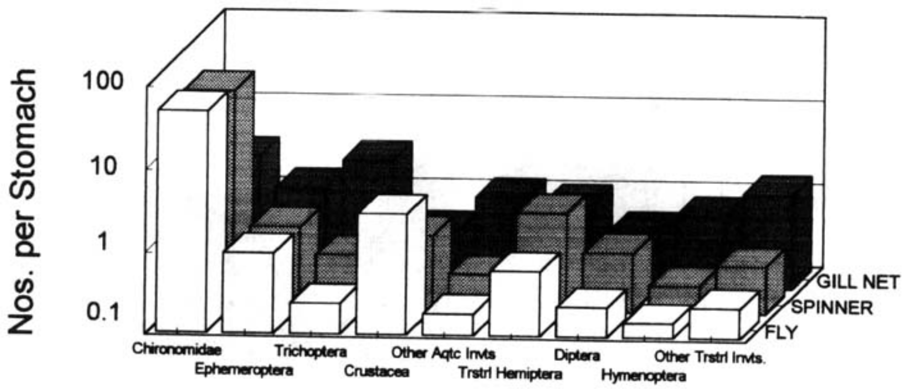

Figure 6 Weights (geometric means) of food organisms in the stomachs of trout caught by fly, spinner and gill nets (log scale).

the diet at other times than is immediately apparent from the results of the present (summer) study.

In view of the substantial differences in the stomach contents of trout by fly, spinning and gill netting in the 1993 samples (Figs. 4, 5 ,6), it is pertinent to ask whether they were the result of fish sampling methods or some other factors. In a similar study of trout diets carried out in the first week of June 1992 (Aston, 1992), where differences were also recorded between the stomach contents of fish caught by gill net and fly (Aston, 1993), this question was then unresolved but two hypotheses were proposed. The first was that the differences were related to the horizontal distribution of invertebrate food organisms. In the 1992 study, the gill nets were set near the western edge of the loch, which is known to support more benthic organisms than the southern end of the loch, where most of the fly fishing took place. The second hypothesis was that the differences were related to the vertical distribution of invertebrate food organisms: the trout caught by fly were feeding near the surface, where planktonic crustaceans are normally most abundant, while those caught by gill-netting were feeding nearer the bottom where trichopteran larvae were more abundant. From this hypothesis we might expect the diets of trout caught by spinner in the present study to be somewhere intermediate between those caught by fly and gill netting.

The two hypotheses can be tested from the results of the 1993 study. As the gill nets were set in areas near the shore, some of which overlapped with areas used for fly fishing, to satisfy the first hypothesis we would expect the gill net and fly-caught samples to contain similar numbers of trichopterans and other benthic organisms. In fact, as in the 1992 study, there were higher numbers of trichopterans and lower numbers of planktonic crustaceans in the diet of the gill netted trout than in the trout caught by fly. This hypothesis must therefore be rejected.

If the second hypothesis holds we might expect higher numbers of planktonic crustaceans in the fly-caught samples than in the spinner and the gill-net samples. It will be seen from Figure 5 that this is so ($P < 0.001$). We might also expect higher numbers of trichopterans and other benthic invertebrates in the gill net sample than in the fly-caught samples and the spinner samples and again this is supported by data presented in Figure 5 ($P<0.001$).

In addition, we might expect higher numbers of terrestrial organisms in the fly-caught sample than in the gill net and spinner samples since these are likely to be held by surface tension at the water surface. However, it will be seen from Figure 5 that there were larger numbers of terrestrial organisms (i.e. dipterans, hymenopterans and "other terrestrial invertebrates") in the gill net sample than in the fly-caught sample. Here the vertical-distribution hypothesis holds only if the trout eat these terrestrial organisms predominantly if and when they sink below the surface. Sinking is probably accelerated in turbulent conditions, with wave action. During sampling, the water surface was 'choppy' for much of the time and this would probably account for the presence of terrestrial organisms in the deeper-feeding fish.

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