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ANALYSIS OF 1994 LOCH LEVEN ZOOPLANKTON SAMPLES

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SUMMARY

Zooplankton samples were collected from Loch Leven throughout 1994. Analysis of these samples showed that several, marked changes had occurred within the crustacean zooplankton community during 1994, in comparison with earlier years. First, the abundance of *Daphnia* fell significantly. Secondly, the *Daphnia* population developed helmeted forms over the summer months. Thirdly, *Cyclops* increased in abundance and became the dominant crustacean zooplankton species at this site.

The changes in the *Daphnia* population were thought to have occurred in response to increased predation pressure from fish, following the introduction of rainbow trout into the loch in March 1993. This increase in predation pressure seemed to have been partly due to direct predation by the rainbow trout, and partly due to increased predation from the brown trout forced out into the deeper waters by the rainbow trout.

As *Daphnia* is the main grazer of phytoplankton in the loch, its decline in numbers will have caused a corresponding reduction in grazing pressure on the algae, especially the smaller species. This is thought to have been the main cause of the early summer bloom of *Oscillatoria subtilissima*, which is a very small blue-green alga. This algal bloom resulted in chlorophyll *a* concentrations of *ca.* 250 $\mu g\ l^{-1}$ and very turbid water conditions.

CONTENTS

1. INTRODUCTION

The high nutrient status of Loch Leven, particularly in terms of phosphorus (P), combined with a relatively low flushing rate and a favourable underwater light climate (Bailey-Watts *et al.*, 1994), has led to serious algal blooms over many years (Rosenberg, 1938; Brook, 1958; Bailey-Watts, 1978, 1988; Bailey-Watts and Kirika, 1994). However, in spite of the large reductions in inputs of phosphorus from point sources achieved by 1989 (Bailey-Watts *et al.*, 1991, 1993) and the ongoing work to improve phosphorus removal efficiency of local sewage treatment works (Fozzard, 1994), significant algal populations are still giving rise to turbid water conditions (Armstrong, *et al.*, 1994; Bailey-Watts, 1995).

The overall abundance and species composition of the phytoplankton in Loch Leven is affected by zooplankton grazing, particularly by *Daphnia hyalina* Leydig. This crustacean tends to feed on the smaller components of the phytoplankton community, causing temporal changes in the size structure of the algal crop (Bailey-Watts, 1978, 1982; Bailey-Watts *et al.*, 1990). In addition, when *Daphnia* are very abundant, the entire population can filter algae from a volume of water equivalent to that of the entire loch every 18 hours (May and Jones, 1989). This significantly reduces phytoplankton biomass, usually during late spring and early summer.

Zooplankton also have two other important roles in the loch. First, they contribute to the diet of several of the fish species found here, including trout (Thorpe, 1974; Duncan, 1993). Second, they can be useful indicators of environmental conditions, particularly trophic status (Maitland *et al.*, 1981; Pejler, 1981; Jones, 1984; Bērziņš and Pejler, 1989; Pontin and Langley, 1993).

Detailed routine monitoring of the zooplankton in Loch Leven began in the late 1960's as part of the U.K. contribution to the International Biological Programme (Johnson and Walker, 1974). Monitoring was maintained until the early 1980s when sampling became more sporadic (May *et al.*, 1993). However, following the publicity surrounding the severe blue-green algal blooms of *Anabaena* and *Microcystis* which occurred in 1992, Scottish Natural Heritage funded the resumption of a regular zooplankton monitoring programme and the analysis of samples which had been collected and stored, but not processed, between 1978 and 1991 (May *et al.*, 1993).

From their analysis of the crustacean zooplankton data, May *et al.* (1993) concluded that Loch Leven was still eutrophic, although there was also evidence of changes in the rotifer community during 1991/92 which suggested that the loch may be less eutrophic than it was. The authors found that the crustacean zooplankton community had changed little in terms of species composition and absolute/relative abundance since mid-1970, when *Daphnia* had reappeared in samples after having disappeared in 1966. This temporary loss has been attributed to poisoning by the insecticide dieldrin which was used as a moth-proofing agent during the late fifties/early sixties by a local woollen mill which discharged effluent into the loch (Morgan, 1970; Fozzard, 1994).

In March 1993, 40,000 female rainbow trout (*Oncorhynchus mykiss* (Walbaum)), with a mean individual weight of 0.23 kg, were introduced in an effort to boost angling catches (Duncan, 1994; Montgomery, 1994). Initially, the crustacean zooplankton community seemed unaffected by this and continued to be dominated by *Daphnia* and *Cyclops abyssorum* Sars. However, after a few months, some changes began to occur. In contrast to previous years, *Cyclops* and *Eudiaptomus gracilis* Sars reached their highest population densities in December rather than in the summer. In addition, the *Daphnia* population developed pronounced pointed helmets during the summer months, a phenomenon which had not been recorded in 1992. The effect on the rotifer community is unknown, as rotifer samples were not examined during this initial period following the fish introduction.

Although, brown and rainbow trout are known to feed on zooplankton, it was unclear, from this very short period of post-stocking monitoring, whether these 'changes' within the zooplankton population were related to the introduction of the rainbow trout or, simply, natural variability. This report examines the population dynamics of the crustacean and rotifer zooplankton for an additional 12-month period, i.e.1994. In addition, long-term data are presented which show the likely effects of the decrease in P loading in 1989, and the stocking with rainbow trout in 1993, on the zooplankton community, underlining the importance of long-term monitoring programmes.

2. METHODS

2.1. Crustacean zooplankton

2.1.1. *Field Sampling*

Samples of crustacean zooplankton were taken at 6 sites during 1994 (**Figure 1**). The Sluice and Reed Bower sites were sampled throughout the year at fortnightly intervals from January to the beginning of March, then weekly throughout the summer and fortnightly again from mid-October, onwards. When bad weather prevented sampling at the Reed Bower sites, substitute samples were taken at the Public Pier. In addition to this regular sampling programme, samples were collected from the South Deeps from April onwards, and from the North Deeps from mid-July to mid-September. Also, samples were occasionally taken at Station 4. All samples were collected and concentrated by a 4.5m plankton net haul, except at the Sluices and the Public Pier. At these two sites samples were normally taken with a bucket and concentrated by filtration through a zooplankton net (mesh size 118 μm). All samples were preserved with 4% formaldehyde.

2.1.2. *Laboratory Analyses*

The preserved zooplankton samples were placed in a glass vessel and made up to a final volume of 250ml with distilled water. Each sample was thoroughly mixed to distribute the animals randomly and sub-sampled with a Stempel pipette (volume 5ml). On most occasions, three sub-samples were taken for counting. The animals in each sub-sample were identified to species level (Scourfield and Harding, 1966; Harding and Smith, 1974) and counted with a low power binocular microscope. The counts were converted to numbers of individuals per litre with appropriate factors, depending on the sampling method used and the number of subsamples examined. The nomenclature used in this study for both *Cyclops abyssorum* and *Daphnia hyalina* is discussed in more detail by Gunn *et al.*(in prep.).

2.2. Rotifer zooplankton

2.2.1. *Field Sampling*

Rotifer samples were collected at fortnightly intervals from January to March and from mid-October to December, and at weekly intervals over the summer months. In general samples were collected from the Reed Bower and Sluices sampling sites (**Figure 1**). However, during bad weather, samples were collected from the Public Pier instead of Reed Bower.

The open water samples at Reed Bower were taken with a section of Marley® plastic drainpipe, 2m in length and 5cm in internal diameter. Those collected from the Sluices and Public Pier sites were taken with a bucket, from just below the surface of the water. Each sample of water was mixed well and a 500-ml subsample was taken for counting. Procaine hydrochloride was added to each sample bottle to give a final concentration of approximately 0.04%. This relaxed the soft-bodied forms allowing easier identification of the specimens once preserved (May, 1985). After approximately 12 h, each subsample was preserved with 4% formaldehyde.

2.2.2. *Laboratory analyses*

The rotifer samples were concentrated by repeatedly settling the samples in glass measuring cylinders and siphoning off the overlying water. Note that plankton nets and sieves were not used as these can lead to significant under estimates of abundance (Bottrell *et al.*, 1976; Orcutt & Pace, 1984). The rotifers in each sample were identified according to Koste (1978) and counted with an inverted microscope. When rotifer numbers were high, the samples were randomly subsampled before counting.

3. RESULTS

3.1. Crustacean zooplankton

3.1.1. *Species list*

A complete species list of crustacean zooplankton found in Loch Leven in 1994 is shown in **Table 1**.

Table 1. Crustacean zooplankton species recorded from Loch Leven during 1994.

Branchiopoda: Anomopoda	
	Daphnia hyalina Leydig
Branchiopoda: Haplopoda	
	Leptodora kindti (Focke)
Branchiopoda: Onychopoda	
	Bythotrephes longimanus Leydig
Copepoda: Calanoida	
	Eudiaptomus gracilis Sars (formerly *Diaptomus gracilis* Sars)
Copepoda: Cyclopoida	
	Cyclops abyssorum Sars (formerly *Cyclops strenuus abyssorum* Sars)

All five of the species found had been recorded in Loch Leven in previous years (*cf* May *et al.*, 1993 and Gunn *et al.*, 1994).

3.1.2. *Abundance*

The cyclopoid copepod *Cyclops abyssorum* was the dominant planktonic crustacean in the loch in 1994. Early in the year, the numbers of nauplii, copepodites and overwintering adults were very low. Nauplii numbered less than 10 ind. l^{-1} until the beginning of April, and copepodite and adult densities were less than 15 ind. l^{-1} until early May (**Figure 2**). Nauplii numbers began to increase markedly in spring and densities of up to 100 ind. l^{-1} were recorded in May and June. They then declined steadily over the summer months, reaching very low densities by the end of August. The peak in nauplii abundance was followed by a corresponding increase in abundance of copepodites and adults, later in the year (**Figure 2**). *Cyclops* (copepodites + adults) achieved their first peak in abundance (54 ind. l^{-1}) in early May. After this, their numbers fluctuated around 30 ind. l^{-1} during June before dropping to a density of 20 ind. l^{-1} at the beginning of July. After this decline, however, the population quickly recovered and reached its annual maximum of 85 ind. l^{-1} in late July. *Cyclops* numbers fell steadily throughout August and September, reaching low levels of abundance (< 5 ind. l^{-1}) by late September. The numbers remained very low for the remainder of the year.

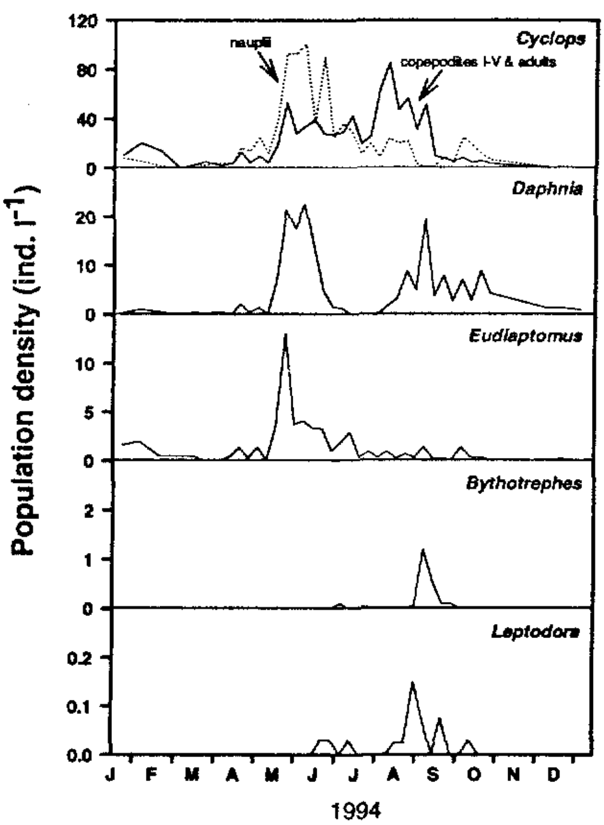

Figure 2. Mean population densities of crustacean zooplankton species in Loch Leven, 1994.

Daphnia hyalina concentrations remained at < 10 ind. l^{-1} for most of the year, except for isolated peaks in abundance in May (23 ind. l^{-1}) and August (19 ind. l^{-1}) (**Figure 2**). However, an unusual (for Loch Leven) but marked change in body shape was noted during the summer period. By August, the 'normal' form of *Daphnia* with a rounded crest had been replaced by a population with more pointed helmets. These morphs of *Daphnia* predominated until November when the rounded crest form reappeared.

The remaining crustacean zooplankton species were present in very low numbers throughout the

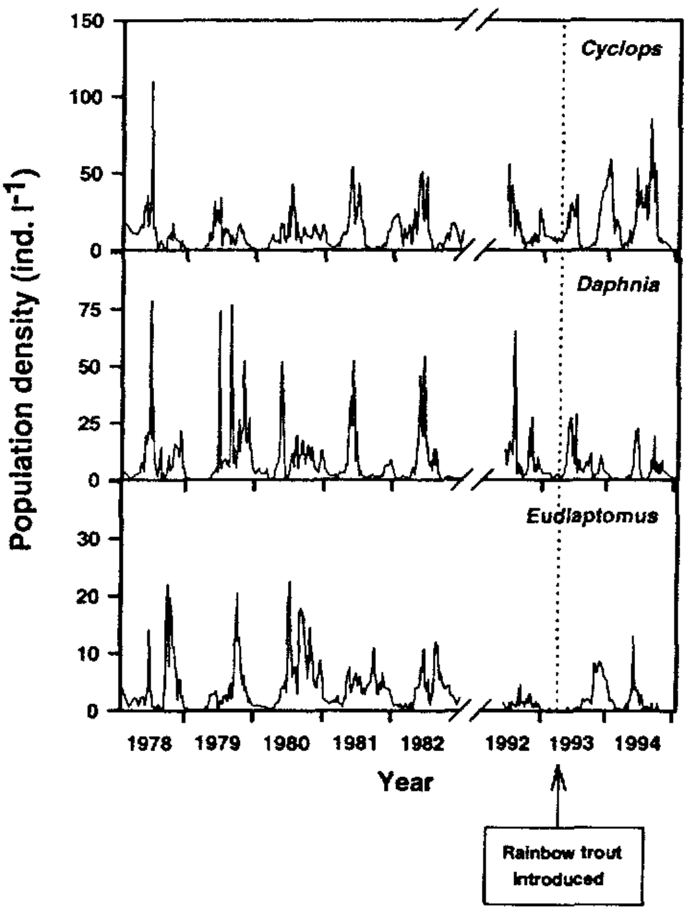

Figure 3. Long-term changes in abundance of *Cyclops*, *Daphnia* and *Eudiaptomus* in Loch Leven.

year. *Eudiaptomus gracilis* population densities fluctuated throughout the year, never exceeding 2 ind. l^{-1} except in May, when a population density of 13 ind. l^{-1} was recorded (**Figure 2**). *Leptodora kindti* (Focke) and *Bythotrephes longimanus* Leydig were minor constituents of the crustacean zooplankton, occurring in very low numbers (i.e. < 1 ind. l^{-1}) over the summer period, only (**Figure 2**).

The structure of the crustacean zooplankton community remained relatively unchanged until 1993/1994, after the introduction of rainbow trout (**Figure 3**). In previous years, *Daphnia* and *Cyclops* had co-dominated. However, by 1994, *Daphnia* numbers had begun to fall markedly and *Cyclops*, alone, began to dominate.

3.2. Rotifer zooplankton

3.2.1. *Species List*

A species list of the rotifers found in Loch Leven during 1994 is shown in **Table 2**. Many of these

Table 2. A list of rotifers species collected from Loch Leven during 1994. Eutrophic indicator species are indicated with an asterisk.

		Ploima
Brachionidae		
		Keratella cochlearis (Gosse)
	*	*Keratella tecta* (Gosse)
	*	*Keratella quadrata* (Müller)
		Notholca squamula (Müller)
Trichocercidae		
	*	*Trichocerca pusilla* (Lauterborn)
Asplanchnidae		
		Asplanchna priodonta Gosse
Synchaetidae		
		Polyarthra dolichoptera Idelson
		Synchaeta kitina Rousselet
		Flosculariacea
Testudinellidae		
	*	*Pompholyx sulcata* Hudson
	*	*Filinia longiseta* (Ehr.)
Conochilidae		
		Conochilus unicornis Rousselet

species are considered to be indicators of eutrophic conditions, although their overall reduction in abundance (see below) may indicate that the loch is now less eutrophic than it was.

The species diversity is more restricted than in earlier years. Only 11 species were recorded in 1994 compared to 15-24 species in previous years, although most of the 'missing' species had formerly been considered rare or occasional. Their apparent disappearance suggests that their already very sparse populations had fallen below detectable densities. It is unlikely that these species have disappeared completely.

3.2.2. *Abundance*

The dominant species in 1994, as in previous years, were *Keratella cochlearis, Keratella quadrata, Polyarthra dolichoptera, Synchaeta kitina, Pompholyx sulcata* and *Trichocera pusilla.* Although their levels of abundance were generally low (**Figure 4**), they continued to show the same seasonality of occurrence as had been recorded in previous years (May, 1983; May *et al.,* 1993). *K. cochlearis* and *K. quadrata* were perennial species, although they were more abundant in summer than in winter. *K. cochlearis* reached maximum population densities of 744 ind. l^{1} in mid-May and *K. quadrata* a maximum of 186 ind. l^{-1} at the beginning of June. *P. dolichoptera* and *S. kitina* were most abundant in the spring, reaching maximum population densities of 490 ind. l^{1} and 820 ind. l^{1}, respectively, at the beginning of May. Both of these species disappeared during the summer months, and then re-

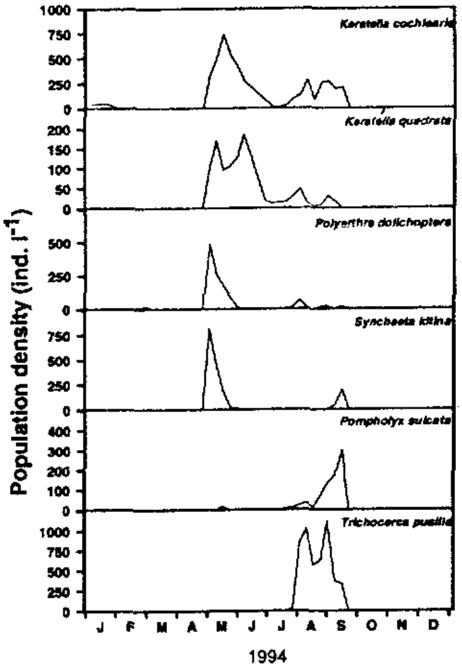

Figure 4. Abundance of the six dominant rotifer species in Loch Leven, 1994.

appeared in low numbers in the autumn. In contrast, *P. sulcata* and *T. pusilla* were found only during the summer (i.e. July-September). *P. sulcata* reached a population maximum of 304 ind. l^{-1} in mid-September, while *T. pusilla* showed a peak in abundance of 1026 ind. l^{-1} in early August and a population maximum of 1122 ind. l^{-1} at the end of August.

Total rotifer abundance tended to be low throughout 1994, reaching a maximum, in mid-May, of only 1,750 ind. l^{-1}. This represented a continuation of the general decline in total rotifer

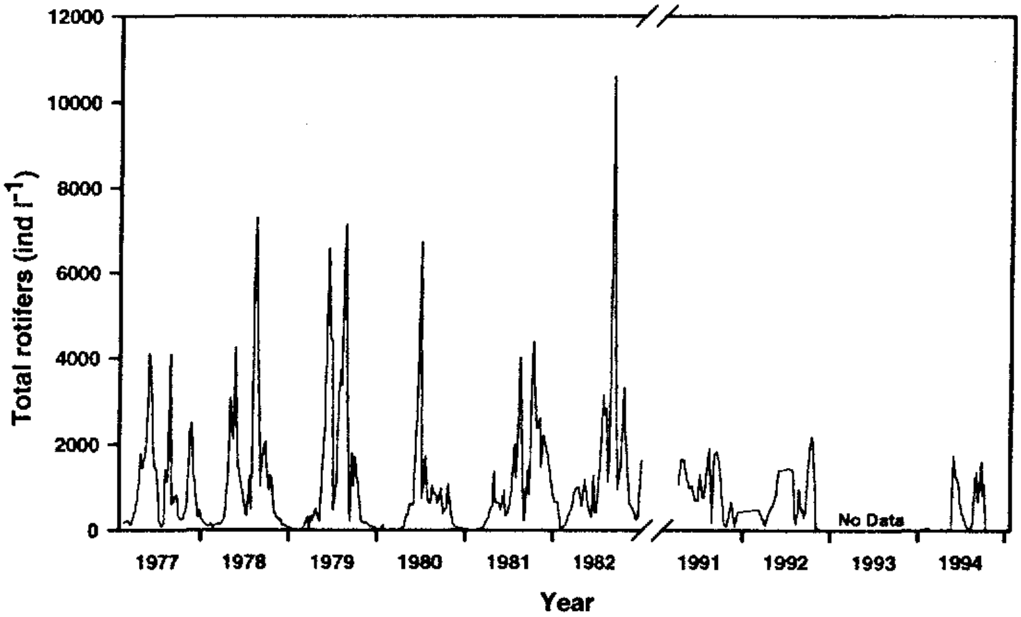

Figure 5. Long-term changes in total rotifer abundance in Loch Leven, 1977-1994.

numbers which had been recorded since 1990 (**Figure 5**). The decline was not due to any particular rotifer but, rather, an overall reduction in the population densities of all species.

4. DISCUSSION

The results of the 1994 monitoring programme identified several changes within the crustacean zooplankton community at Loch Leven in comparison with data from earlier years. These changes were most noticeable in the *Daphnia* population, which showed a marked decrease in abundance and the appearance of helmeted forms. In addition, an overall increase in *Cyclops* abundance was recorded.

The structure of a zooplankton community is generally thought to be determined by two major factors, predation (from fish and invertebrates) and food availability (Harper, 1986). It, therefore, follows that, if that structure changes, corresponding changes have probably occurred in one, or possibly both, of these controlling factors. The data from Loch Leven suggest that the changes recorded here have probably occurred as a result of increased predation pressure, rather than decreased food availability. A decrease in *Daphnia* numbers, alone, could have occurred as a result of either less food or greater predation pressure, but the almost simultaneous development of helmeted forms within the *Daphnia* population over the summer months tends to suggest that increased predation pressure was the more likely cause of their decline. This is because helmeted forms are thought to develop as a defense mechanism against visual predators (Brooks and Dodson, 1965; Hutchinson, 1967).

This increase in predation pressure is likely to have occurred as a result of the introduction of rainbow trout in March, 1993. Gut content analyses carried out soon after the fish were introduced showed that both the resident brown trout population and the rainbow trout were feeding on the zooplankton, including *Daphnia* (Duncan, 1994). Clearly, predation from the rainbow trout would have increased the overall level of predation on the zooplankton, but there was also some evidence that predation on zooplankton by the brown trout may have increased, too. A spatial survey showed that the rainbow trout were more commonly found in the shallower waters, while the brown trout were more abundant at the deeper sites (Duncan, 1994). If this is the case, then the brown trout may have been forced into deeper water by competition from the rainbow trout, where they would probably feed more heavily on the zooplankton than they had before. In addition, George and Reynolds (pers. comm.) found, in experimental enclosures in Blelham tarn, that predation from brown trout could induce helmeted forms of *Daphnia* to appear if the fish were forced to feed on zooplankton.

Daphnia is a filter-feeder and has been shown to be the main grazer of phytoplankton, particularly the smaller species, in Loch Leven (Bailey-Watts, 1978, 1982, 1986; Bailey-Watts and Kirika, 1981). For this reason, any decline in the *Daphnia* population would be expected to result in a corresponding reduction in grazing pressure, especially on the populations of smaller algae, allowing the smaller forms to proliferate. This is certainly what seems to have happened in the loch in 1994. The very small blue-green alga *Oscillatoria subtilissima* Kutz (individual filament diameter *ca* 1.5μm) became unusually abundant in July, 1994, causing very high chlorophyll$_a$ levels (*ca* 250μg l^{-1}) and turbid water conditions (Bailey-Watts and Kirika, 1995). It is of interest that this is the first significant bloom of *Oscillatoria* to have occured in Loch Leven since 1968-1971, when the crustacean zooplankton was dominated by *Cyclops* (Bindloss, 1974; Holden and Caines, 1974; Johnson and Walker, 1974) and *Daphnia* was either absent or scarce, exerting little or no grazing pressure on the small species of algae.

Bailey-Watts *et al.* (1993) and May *et al.* (1993), while considering the possible ecological effects of the proposed introduction of rainbow trout into Loch Leven, concluded that more information was needed on the interactions between trout and zooplankton populations before it would be possible to reliably predict the effect that this introduction would have on the zooplankton community. However, these authors did suggest that, if fish predation on *Daphnia* increased, then *Daphnia* numbers would fall and this would lead to a decrease in grazing pressure and an increase in algal biomass. As *Daphnia* tend to consume the smaller components of the phytoplankton, a reduction in *Daphnia* numbers would also be expected to cause a shift in the algal size distribution, away from large bloom forming blue-green algae towards much smaller species. The observed changes in Loch Leven in 1994 certainly seem to support these hypotheses.

There is little published information on the interrelationships between co-existing populations of brown and rainbow trout. However, Lucas (1993), from his study of the diets of brown and rainbow trout in a small put-and-take fishery, found that each species tended to utilize different food resources. In his lake, the rainbow trout fed, primarily, on Cladocera and chironomid pupae in the open water, while the brown trout fed on the benthos and sticklebacks. Both species of trout are thought to be generalist predators, capable of changing their feeding habitats according to prey availability so, both species may exploit similar food resources under certain conditions (Lucas, 1993). Gut content analyses of the brown and rainbow trout in Loch Leven during 1993 indicated that zooplankton (including *Daphnia*) formed a major component of the diet of both fish species, although the rainbow trout seemed to be feeding less on zooplankton than the brown trout (Duncan, 1994).

Unfortunately, there is no published information on changes in the diet/feeding grounds of brown trout after the introduction of rainbow trout with which these results can be compared. It would be helpful to have more information on the current dietary inter-relationships of these two fish species in the loch before coming to any more definite conclusions. For example, results of the sampling programme carried out during 1994 to evaluate the abundance, distribution and diet of both the brown and rainbow trout (Wright, 1994), in conjunction with the data available from the surveillance of the plankton and the survey of the invertebrate benthos (Gunn and Kirika, 1994), would be valuable in assessing the current food preferences of the trout and whether there is any inter- and intra-specific competition for limited food resources. Also, it may be necessary to identify and quantify grazing interactions (e.g. between zooplankton and phytoplankton) and predator-prey relationships (e.g. between fish and zooplankton) by experimental studies under controlled environmental conditions (May *et al.*, 1993) in order to interpret the field data, fully. However, these initial findings do raise issues of concern regarding the future management of Loch Leven, particularly in relation to any further stocking of rainbow trout and the current measures being employed to reduce the likelihood of algal blooms.

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