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ANALYSIS OF 1998 ZOOPLANKTON SAMPLES - LOCH LEVEN

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SUMMARY

Zooplankton samples collected from Loch Leven during the period January to December 1998 were analysed. The results were compared with zooplankton data from earlier years and related to changes in phytoplankton abundance.

Eleven crustacean species were found, four more than in 1997. The majority of the 'new' species were benthic species occasionally collected in the plankton samples. For the first eight months of the year the crustacean zooplankton was dominated by the cladocran referred to the *Daphnia hyalina* species-complex and the cyclopoid copepod *Cyclops abyssorum*. As in earlier years the highest densities of *Daphnia* and *Cyclops* occurred in late spring and early summer, a period which coincided with a plentiful supply of small algal species. However, in late August *Daphnia* unexpectedly disappeared from the Loch Leven system leading *Cyclops* and a calanoid copepod *Eudiaptomus gracilis* to dominate the crustacean zooplankton for the rest of the year. The reason for the failure of the *Daphnia* population is currently unclear but possible links to food limitation and increased predation are discussed.

Sixteen species of rotifer were found, one less than in 1997. *Trichocerca pusilla*, which was previously considered a dominant species, was not recorded in any samples in 1998. The decline of this species was linked to a parallel decline in its preferred food, centric diatoms. As in previous years, the rotifer community was dominated by *Keratella cochlearis*, *Polyarthra dolichoptera*, *Synchaeta kitina*, *Keratella quadrata* and *Pompholyx sulcata*. Most species continued to show a marked seasonality of occurrence. In the short-term, rotifer abundance seemed to be inversely related to that of *Daphnia*. In the longer-term the rotifer community exhibited a slight increase in overall abundance in 1998, in contrast to the steady decline in rotifer numbers reported in recent years.

The species composition of the zooplankton community, as a whole, remains broadly characteristic of an eutrophic lake. Further evidence of the eutrophic nature of Loch Leven was provided by an analysis of the relative species composition of the long-term crustacean zooplankton data, which showed that *Cyclops* and *Daphnia* have remained dominant, relative to *Eudiaptomus*, for the last twenty years.

CONTENTS

1. INTRODUCTION

For many years the eutrophic Loch Leven has been troubled by algal blooms, largely as a result of large amounts of phosphorus (P) entering the loch, combined with a relatively low flushing rate and a favourable light climate (Bailey-Watts *et al.*, 1994). Recent management of the loch has had the aim of reducing the risk of these algal blooms as well as improving the local fishery. This policy has resulted in inputs of P to the loch being reduced from 20.5 tonnes y^{-1} in 1985 to 10.5 tonnes y^{-1} in 1995 (Bailey-Watts and Kirika, in press), and in the stocking of rainbow trout (Duncan, 1994).

The overall abundance and species composition of planktonic algae in Loch Leven is not only affected by the supply of nutrients (mainly P) but also by losses to the grazing activities of zooplankton, particularly the cladoceran *Daphnia* (Bailey-Watts, 1978; 1982; Bailey-Watts *et al.*, 1990; May and Jones, 1989). The Loch Leven zooplankton community, as in many lakes, is mainly composed of species of copepods, rotifers as well as cladocerans, constituting an important food source for the brown and rainbow trout fish populations (Thorpe, 1974; Duncan, 1994). Zooplankton are also considered to be useful indicators of trophic status (Gannon and Stemberger, 1978; Maitland *et al.*, 1981; Pejler, 1981; Jones, 1984; Bērziņš and Pejler, 1989; Pontin and Langley, 1993).

Routine monitoring of the zooplankton in Loch Leven began in the late 1960's (Johnson and Walker, 1974) as part of the International Biological Programme. However, sampling became more sporadic during the 1980's due to lack of suitable funding (May *et al.*, 1993). Regular sampling was not resumed until 1992, when public concern about the state of the loch was fuelled by the appearance of severe blue-green algal blooms during the summer months. Since then, the analysis of zooplankton samples collected at weekly or fortnightly intervals throughout the year has been funded on an annual basis by Scottish Natural Heritage. This has helped maintain the continuity of data needed to distinguish long-term changes in abundance and species composition from short-term temporal variation.

This report describes temporal variation in the species composition and abundance of the crustacean and rotifer zooplankton communities in Loch Leven during 1998. The results are compared with zooplankton data from earlier years and related to changes in phytoplankton abundance as well as the recent changes in the management of Loch Leven.

2. METHODS

2.1. Crustacean zooplankton

2.1.1. **Field sampling**

Samples of crustacean zooplankton were collected at the Sluices, South Deeps and Reed Bower sites though occasionally samples were also taken at the Public Pier during 1998 (**Figure 1**). These sites were sampled throughout the year at fortnightly intervals from January to the end of March, weekly throughout the spring and summer months and fortnightly again from the beginning of October.

All open water samples were collected and concentrated with a plankton net (mesh size 118 μm), which was drawn slowly to the water's surface from a depth of 4.5 m at the South Deeps and from a depth of 4 m at the Reed Bower site. At the Sluices, samples were normally taken with a bucket and, subsequently, concentrated by passing the sample through a plankton net (mesh size 118 μm). All of the samples were preserved with 4% formaldehyde.

2.1.2. **Laboratory analyses**

The samples were placed in a glass vessel and made up to a final volume of 250 ml with distilled water. Each sample was thoroughly mixed, to distribute the animals randomly, and then subsampled with a Stempel pipette (volume 5 ml). The animals present in each subsample were identified (Dussart and Defaye, 1995; Einsle, 1996; Flößner and Kraus, 1986; Harding and Smith, 1974; Scourfield and Harding, 1966;) and counted under a low power binocular microscope. In most cases, three subsamples were examined. The subsample counts were converted to numbers of individuals per litre using appropriate multiplication factors.

2.2. Rotifer zooplankton

2.2.1. **Field sampling**

Rotifer samples were collected at fortnightly intervals from January to the end of March and from the beginning of October to December, and weekly during the spring and summer

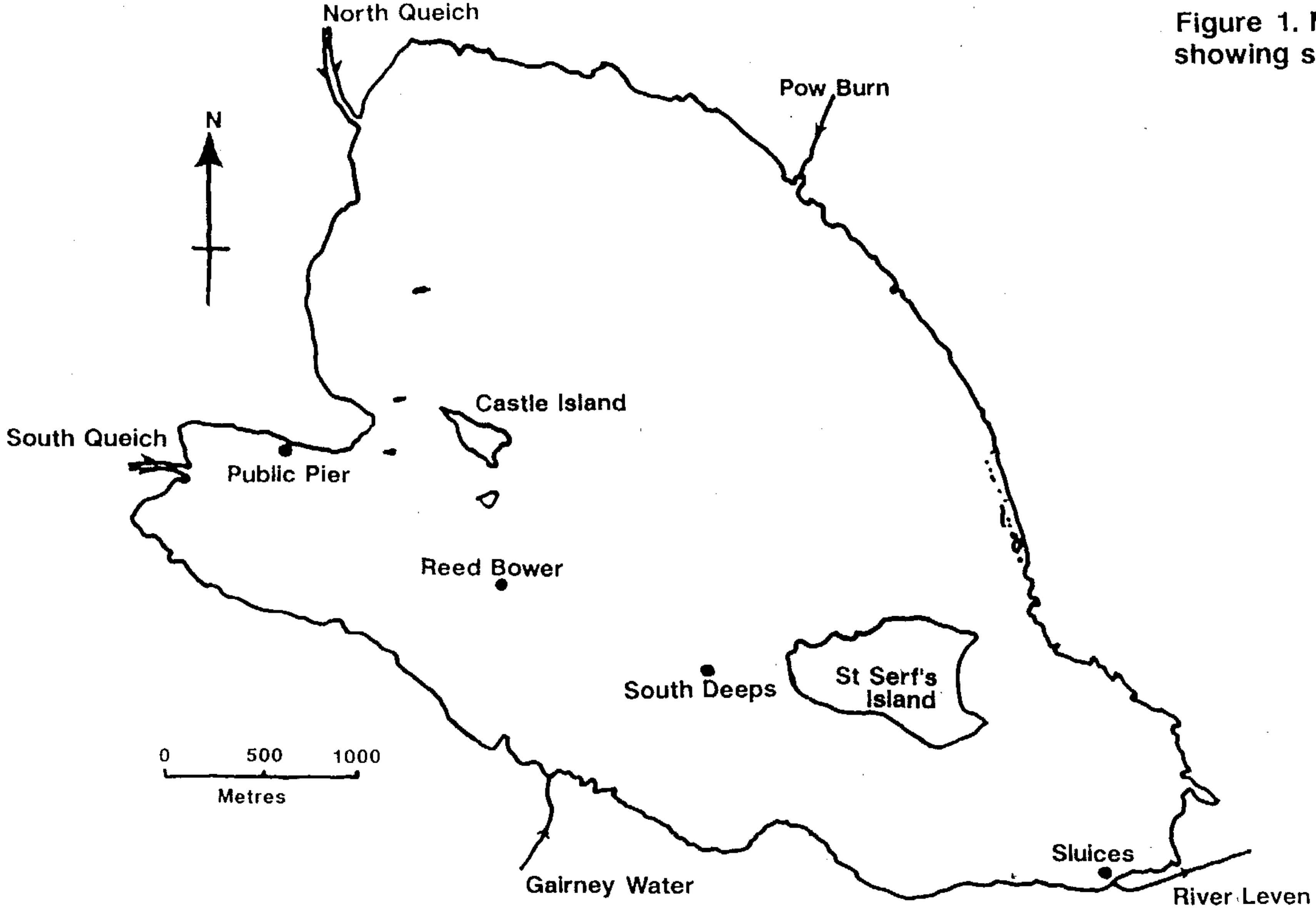

Figure 1. Map of Loch Leven showing sampling sites (•).

3. RESULTS

3.1. Crustacean zooplankton

3.1.1. **Species list**

Eleven crustacean species were found in Loch Leven during 1998 (**Table 1**), an increase from the seven species recorded in 1997. The cyclopoid copepod *Cyclops vicinus* was not recorded

Table 1. Crustacean zooplankton species recorded from Loch Leven during 1998.

Cladocera (Branchiopoda)	
Anompoda	
	Daphnia hyalina species-complex (formerly *D.hyalina* var *lacustris* Sars)
	Chydorus sphaericus (O. F. Müller)
	Alona quadrangularis (O. F. Müller)
	Eurycercus lamellatus (O. F. Müller)
Haplopoda	
	Leptodora kindti (Focke)
Onychopoda	
	Bythotrephes longimanus Leydig
Copepoda	
Calanoida	
	Eudiaptomus gracilis (Sars) (formerly *Diaptomus gracilis* Sars)
Cyclopoida	
	Cyclops abyssorum Sars (formerly *Cyclops strenuus abyssorum* Sars)
	Cyclops vicinus Uljanin
	Eucyclops agilis (Koch)
	Paracyclops fimbriatus (Fischer)

in 1997, although it was found in Loch Leven in 1996 (Gunn and May, 1997). The other 'new' species recorded in 1998, *Alona quadrangularis, Eucyclops agilis, Eurycercus lamellatus* and *Paracyclops fimbriatus* (as well as *Chydorus sphaericus*) are primarily benthic, only occasionally occurring in the plankton. Of the species found in 1997 only

Bosmina longirostris was not recorded in 1998.

3.1.2. **Abundance**

The population dynamics of the main crustacean zooplankton species are shown in **Figure 2**. The three principal species, as in earlier years, were the cyclopoid copepod *Cyclops abyssorum*, the calanoid copepod *Eudiaptomus gracilis*, and the cladoceran referred to the *Daphnia hyalina* species-complex (*cf.* May *et al.*, 1993; Gunn *et al.*, 1994; Gunn and May, 1995; 1996; 1997; 1998). In the first eight months of 1998 *Daphnia* and *Cyclops abyssorum* co-dominated with *Eudiaptomus gracilis* found in smaller numbers. However, in August the *Daphnia* population crashed. For the remaining months of 1998 the crustacean zooplankton community was dominated by *Cyclops abysorrum* and *Eudiaptomus*. The copepod *Cyclops vicinus* and the large predatory cladocerans, *Leptodora kindti* and *Bythotrephes longimanus*, were relatively rare and seasonal in occurrence.

The features of the population dynamics of each of the main crustacean zooplankton species are summarised as follows:

(a) Population densities of *Daphnia* were very low (<3 ind.l^{-1}) during the first four months of 1998. This was followed by a rapid increase in numbers during May, which enabled the population to reach an annual maximum of 39.6 ind. l^{-1} in early June. Numbers declined to relatively low densities of less than 4 ind.l^{-1} during July, before increasing again to a secondary peak in numbers of 25.4 ind. l^{-1} in early August. The *Daphnia* population then declined rapidly. From the end of August to the end of the year not one *Daphnia* was recorded in Loch Leven. For approximately the first eight months of 1998 the population dynamics of *Daphnia* were of a similar pattern to earlier years with an annual peak in numbers occurring in the early summer followed by a later secondary peak in biomass. However, the ensuing complete absence of *Daphnia* from Loch Leven is unparalleled in Loch Leven since the late 1960's. Normally, during the latter part of the year, *Daphnia* populations would decline to relatively low over-wintering levels of about 2 ind.l^{-1}.

(b) The concentrations of the nauplii, copepodites and adults of *Cyclops abysorrum* were very low until the end of February when they began to increase, reaching a maximum of 57.6 ind.l^{-1} in late April. The *Cyclops* population generally maintained concentrations greater than 15 ind.l^{-1} until the end of July when numbers declined. However, numbers rose again towards the end of the year reaching 39.1 ind.l^{-1} in October. The population densities and the seasonal patterns of occurrence of *Cyclops* recorded in Loch Leven during 1998 were similar to previous years, including 1997.

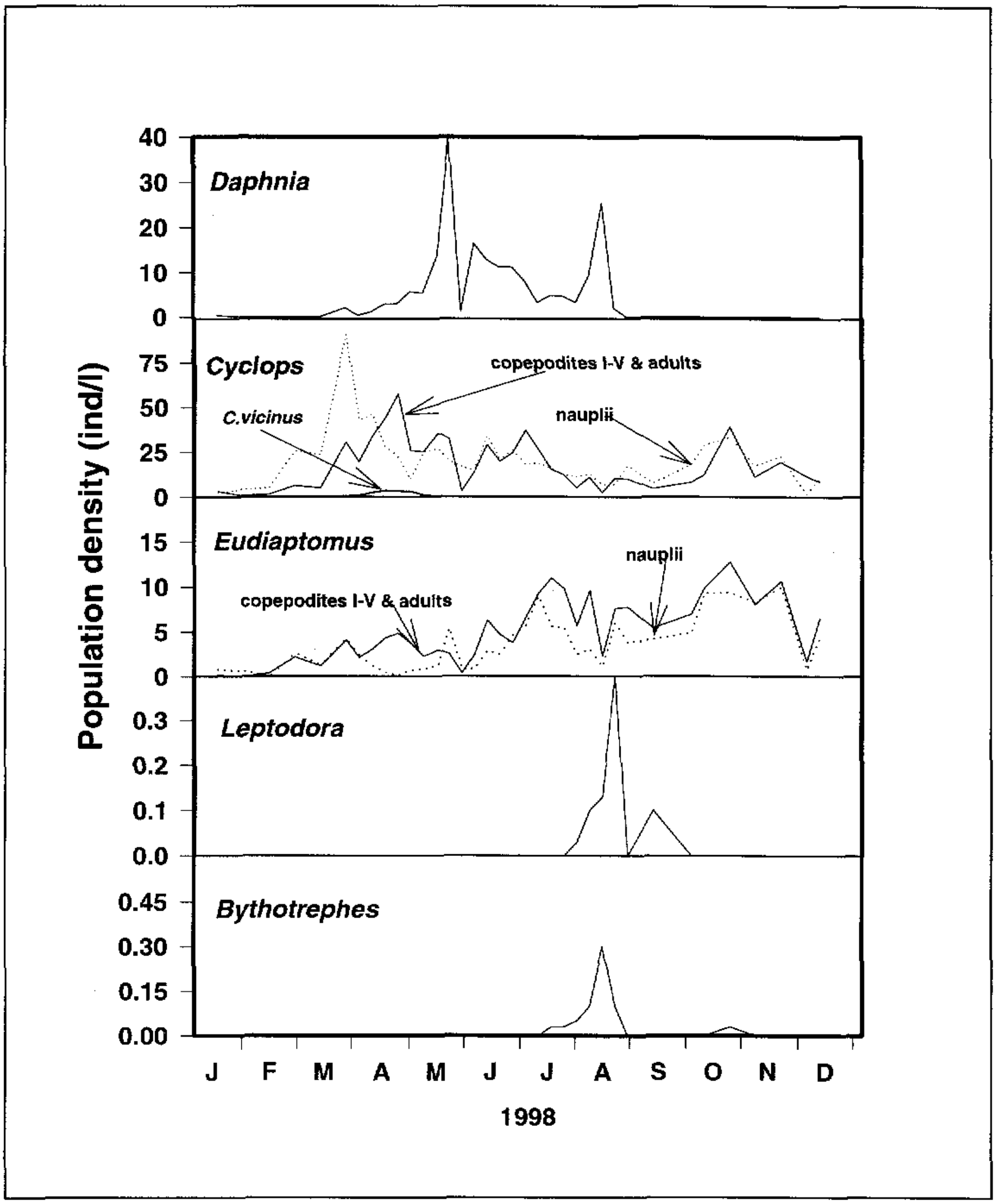

Figure 2. Mean population densities of crustacean zooplankton in Loch Leven, 1998

(c) *Eudiaptomus* densities remained at levels of less than 5 ind.l^{-1} until June. After this period numbers generally remained above this level for the rest of 1998, reaching a population

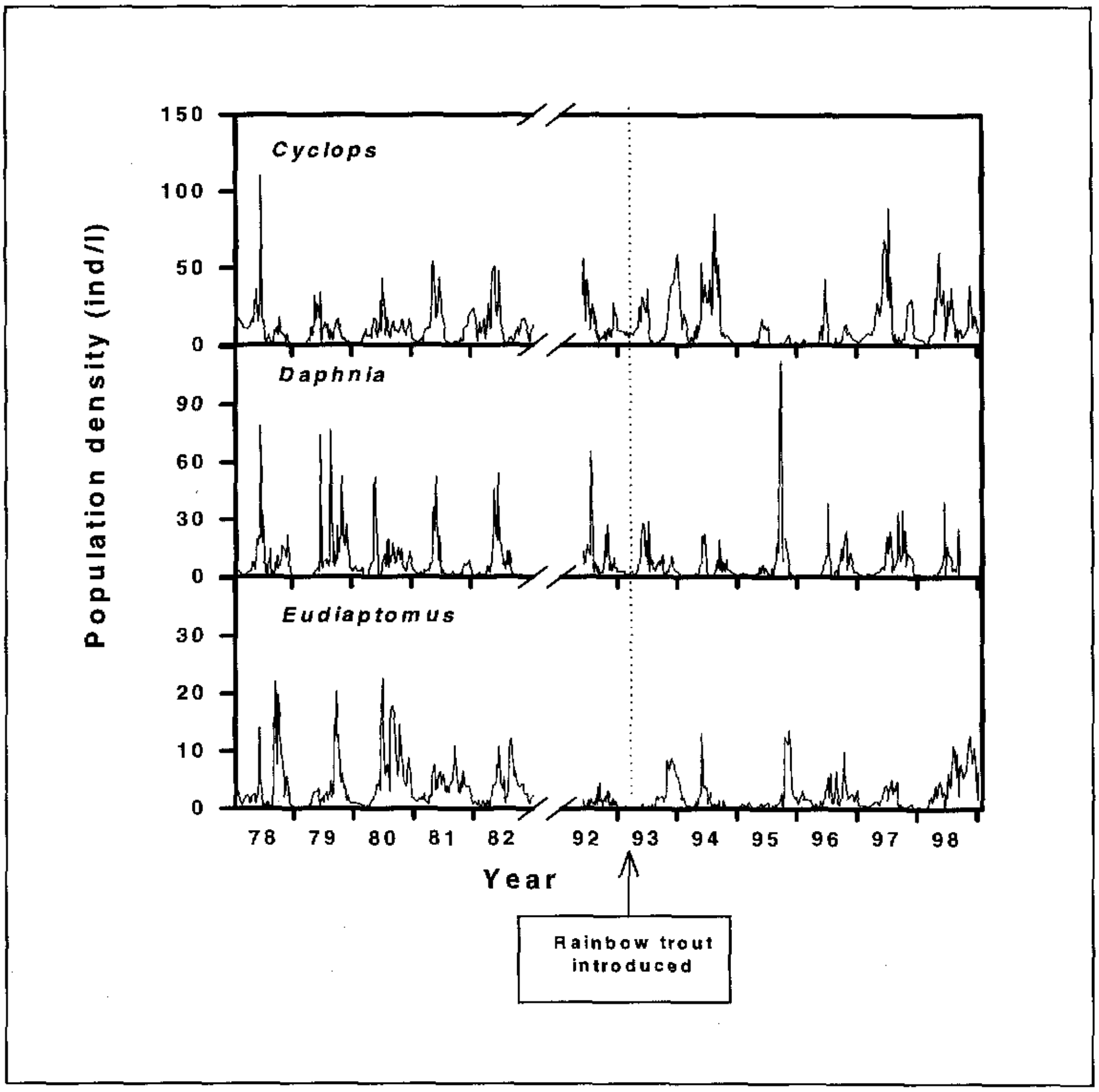

Figure 3. Long-term changes in abundance of *Cyclops*, *Daphnia*, and *Eudiaptomus* In Loch Leven, 1978-98

maximum of 12.7 ind.l^{-1} in mid October. This latter population pattern is in contrast to 1997 when *Eudiaptomus* numbers remained at a level of <1 ind.l^{-1} after the beginning of August.

(d) *Cyclops vicinus* occurred in low numbers during the spring (maximum of 3.6 ind. l^{-1}).

(e) *Leptodora* and *Bythotrephes* occurred in extremely low numbers (<0.4 ind.l^{-1}) over the summer period.

Comparing the 1998 results with previous year's data (**Figure 3**) indicates that the relative abundance, absolute concentrations and seasonality of occurrence was broadly similar for *Cyclops*, *Daphnia* and *Eudiaptomus*. However, in the last four months of 1998 there were some noticeable differences. The most marked being the complete disappearance of *Daphnia* coupled with a marked increase in the population densities of *Eudiaptomus.*

3.2. Rotifer zooplankton

3.2.1. *Species list*

Sixteen rotifer species were found in Loch Leven during 1998 (**Table 2**). This is one

Table 2. A list of rotifer species collected from Loch Leven during 1998.

	Ploima
Brachionidae	
	Keratella cochlearis (Gosse)
	Keratella tecta (Gosse)
	Keratella quadrata (Müller)
	Notholca squamula (Müller)
	Kellicottia longispina (Kellicott)
Colurellidae	
	Colurella adriatica Ehr.
Lecanidae	
	Lecane lunaris (Ehr.)
Trichocercidae	
	Trichocerca sp. Lamarck
Asplanchnidae	
	Asplanchna priodonta Gosse
Synchaetidae	
	Polyarthra dolichoptera Idelson
	Polyarthra major Burkhardt
	Synchaeta kitina Rousselet
	Flosculariacea
Testudinellidae	
	Pompholyx sulcata Hudson
	Filinia longiseta (Ehr.)
Conochilidae	
	Conochilus unicornis Rousselet
Collothecidae	
	Collotheca mutabilis (Hudson)

fewer species than was recorded in 1997, because *Trichocerca pusilla* was not found in 1998.

3.2.2. *Abundance*

The population dynamics of the five dominant rotifer species during 1998 are shown in **Figure 4**. *Keratella cochlearis* was present throughout most of the year, dominating the spring and autumn samples and reaching a maximum population density of 2830 ind. l^{-1} in early May. The next most abundant species was *Polyarthra dolichoptera*. This species occurred throughout spring and early summer, but was most abundant during the spring (March to April) and reached a maximum abundance of more than 800 ind. l^{-1} in late March.

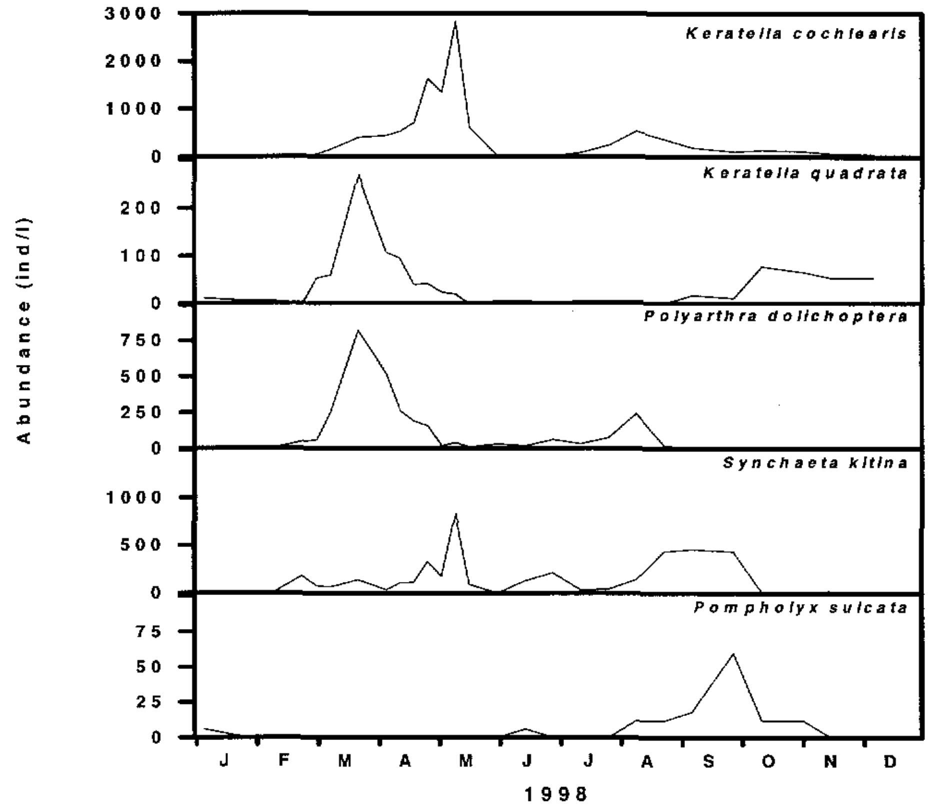

Figure 4. Abundance of the five dominant rotifer species in Loch Leven, 1998.

In terms of mean annual abundance, the next most important species was *Synchaeta kitina*. Though a perennial species, *S. kitina* was recorded in higher numbers in late spring (April/May) and late summer (August/September) than at other times of year. It reached its maximum abundance (830 ind. l^{-1}) in mid May.

The remaining species were more seasonal in occurrence. *Keratella quadrata* tended to occur in spring, reaching a maximum abundance of 270 ind. l^{-1} in late March. In contrast, *Pompholyx sulcata* was present only during the summer and autumn, i.e. June to October, reaching maximum population densities of 60 ind. l^{-1} in late September. In general, the seasonal pattern of occurrence of these species was similar to that found in previous years, but the maximum abundance tended to be lower.

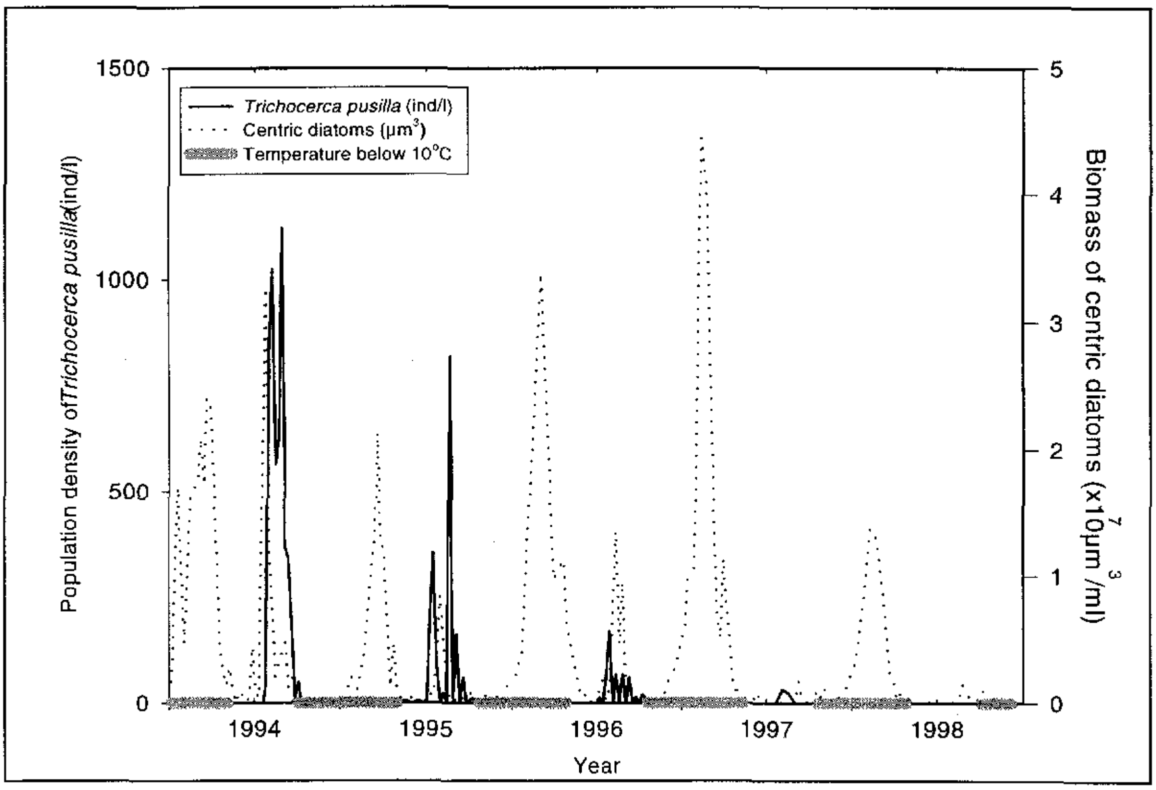

Figure 5. The relationship between *Trichocerca pusilla* and centric diatom abundances, 1994-1998, during periods when the water temperature was above 10°C.

It is notable, however, that *Trichocerca pusilla* was not recorded in any samples during 1998. In the 1980s, this species had been dominant in the summer and early autumn, reaching densities of up to 2860 ind. l^{-1} in 1979. However, it steadily declined in abundance during the 1990s, culminating in its apparent complete disappearance in 1998 (**Figure 5**). The most likely explanation for this seems to be that, during periods when the water temperature was suitable for this summer species to survive (i.e. above 10°C), its abundance was determined by the availability of its preferred food, centric diatoms. In Loch Leven, this group of algae is represented predominantly by a filamentous form, *Aulacoseira* (formerly *Melosira*) spp., and a range of smaller unicellular species (e.g. *Stephanodiscus* spp.) **Figure 5** shows that, within its preferred temperature range, *T. pusilla* was only abundant when the summer biomass of centric diatoms was high (i.e. 1994 – 1996). When centric diatoms were scarce in summer, i.e. in 1997 and 1998, *T. pusilla* numbers were correspondingly low.

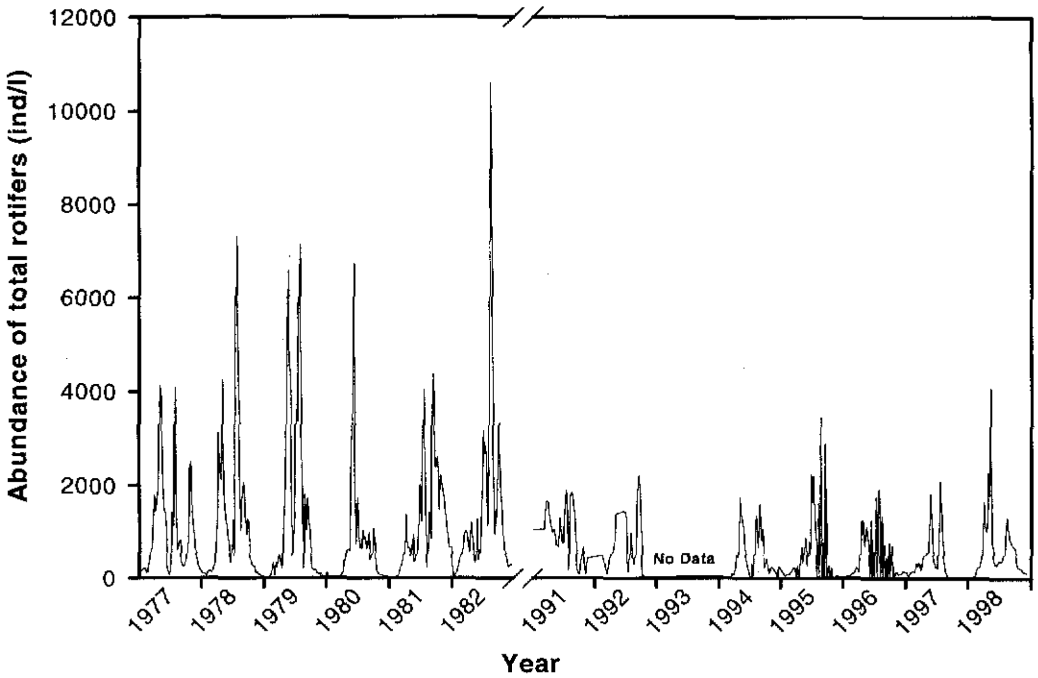

Figure 6. Long-term changes in total rotifer abundance in Loch Leven, 1977-1998.

Total rotifer abundance was, again, relatively low during 1998 compared to the period 1977-1982 (**Figure 6**). However, the maximum abundance recorded in mid-May (4080 ind. l^{-1}) was greater than the annual maxima which had been recorded in recent years and was close to many of those recorded between 1977 and 1982.

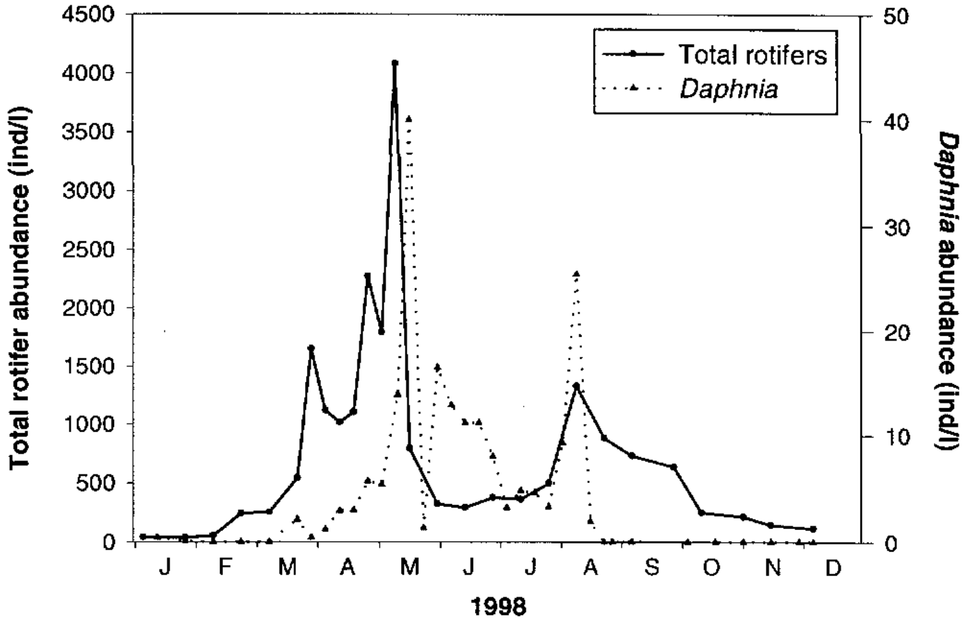

Figure 7. Abundances of *Daphnia* and total rotifer populations in Loch Leven, 1997.

As in previous years, short-term variations in total rotifer abundance appeared to be inversely related to *Daphnia* numbers (**Figure 7**). Rotifer abundance increased rapidly in early spring, reaching a maximum of 4080 ind. l^{-1} in late May. Their numbers then declined rapidly in early May, as *Daphnia* became more abundant. Rotifer densities remained relatively low from the end of May until the *Daphnia* population declined towards the end of June. This was followed by a rapid increase in rotifer numbers, which reached their second population peak (1300 ind. l^{-1}) in early August. However, almost immediately, *Daphnia* numbers increased again and rotifer numbers began to fall. Although, the *Daphnia* disappeared abruptly in mid August, rotifer numbers continued to decline over the remainder of the year.

4. DISCUSSION

More crustacean zooplankton species were recorded in Loch Leven in 1998 than in 1997. However, this increase in species diversity is unlikely to reflect a significant change in water quality. This is because one of the additional species, *Cyclops vicinus,* is typical of large, lowland, eutrophic lakes (Fryer, 1993; Einsle, 1996) and the other 'new' species (*Alona quadrangularis, Eurycercus lamellatus, Eucyclops agilis,* and *Paracyclops fimbriatius*) are benthic species that occasionally migrate into the plankton.

The species composition of the crustacean zooplankton community, as a whole, is still broadly characteristic of a eutrophic waterbody (May *et al*., 1993; Gunn *et al*., 1994; Gunn and May, 1995; 1996; 1997; 1998). However, a more detailed analysis of the species composition was also undertaken during this study. This involved using the ratio of calanoid copepods to cyclopoid copepods to assess the trophic status of Loch Leven. This method is based on the observation that calanoid copepods appear to dominate oligotrophic waters while cyclopoid copepods and cladocerans are relatively more abundant in eutrophic lakes (Gannon and Stemberger, 1978; Jones, 1984). High ratios indicate oligotrophic lakes, i.e. dominated by *Eudiaptomus*, while low values indicate eutrophic systems, i.e. dominated by *Cyclops* and *Daphnia*. The results of this analysis for the long-term crustacean zooplankton data for Loch Leven are shown in **Table 3.** They suggest that *Cyclops* and *Daphnia* have continued to dominate the crustacean zooplankton community over the last twenty years. There is no evidence of a trend towards the proportion of *Eudiaptomus* increasing relative to *Cyclops* and *Daphnia.* In fact the ratios tend to suggest that Loch Leven was more eutrophic in the early 1990's compared to the late 1970's and early 1980's. However, there was a marked increase in the population density of *Eudiaptomus* over the last four months of 1998, coinciding with the temporary disappearance of *Daphnia* from the system. This was in contrast to the first eight months of the year when the population dynamics of the crustacean zooplankton were similar to those observed in earlier years, with the highest densities of *Cyclops* and *Daphnia* occurring in late spring and early summer. When the *Daphnia* disappeared unexpectedly in late August, the two copepods, *Cyclops* and *Eudiaptomus,* dominated the crustacean zooplankton. The reason for the failure of the *Daphnia* population is unclear. It may be linked to food limitation, increased predation or, possibly, a pollution incident. This required further investigation.

Table 3. Annual mean abundance and abundance ratio of *Eudiaptomus*, *Cyclops* and *Daphnia* in Loch Leven, 1978-82 & 1992-98.

Year	Annual mean abundance (ind. l^{-1})			Annual abundance ratio
	Eudiaptomus	*Cyclops*	*Daphnia*	***Eudiaptomus*:*Cyclops*+*Daphnia***
1978	4.7	13.3	10.8	1: 6.1
1979	3.5	8.9	13.1	1: 7.3
1980	6.0	11.1	9.7	1: 4.6
1981	4.0	13.1	7.3	1: 6.1
1982	4.0	14.3	8.7	1: 6.8
1992	1.4	15.9	10.9	1: 20
1993	1.6	14.8	7.4	1: 14.7
1994	1.4	22.1	4.8	1: 19.7
1995	2.0	3.9	9.3	1: 7.7
1996	2.7	5.5	7.0	1: 5.7
1997	1.8	19.1	10.7	1: 17.5
1998	5.3	18.8	5.4	1: 5.6

In previous years, changes in the *Daphnia* population had often been linked to the changing pattern of phytoplankton abundance. So, food limitation seemed the most likely cause of the apparent disappearance of *Daphnia* in the autumn of 1998. During the year, the relatively high mean chlorophyll$_a$ values (*ca.* 40μg l^{-1}) and the phytoplankton species composition suggested that Loch Leven was still a very productive environment (Bailey-Watts *pers comm.*). In general, the phytoplankton was dominated by centric diatoms during the first half of the year, followed by a 'summer' assemblage of blue-green algae. This was superseded by a diverse crop of mainly green algae in late September/October and diatoms dominated again by the end of the year. The spring peaks in *Daphnia* abundance tended to coincide with times when these filter-feeding grazers could exploit the large number of smaller algal species which were abundant in the water column. Later in summer, when the larger (and inedible) blue-green algal species predominated, *Daphnia* numbers fell due to food limitation. However, *Daphnia* numbers failed to recover in the autumn despite the increased availability of smaller algal species as food. This suggests that food limitation was not responsible for the sudden and prolonged disappearance of *Daphnia* during the autumn.

In Loch Leven, fish are the most likely predators of *Daphnia*, which are relatively poor swimmers and have a poorly developed escape response. Stocking with rainbow trout began in 1993 and, initially, this seemed to have a marked impact on the *Daphnia*, *Cyclops* and *Eudiaptomus* populations. However, since then, their population dynamics have returned to the general patterns of abundance recorded prior to 1993. This implied that the introduction of rainbow trout had had no lasting effects on the zooplankton (Gunn and May, 1996; Gunn and May, 1997), at least until the end of 1997. However, it is possible that the almost unprecedented decline in the *Daphnia* population towards the end of 1998 may have been due to increased fish predation resulting from changes in the fish-stocking regime. Detailed analyses of the fish stocking procedures for 1998, and some detailed fish gut content analyses, are needed to investigate this further. Also, the examination of adult *Daphnia* collected just prior to their disappearance may also give some indication of whether the *Daphnia* population was limited by food availability or predation. A food-limited population has very low egg numbers per adult whereas a well-fed population, which is limited by predation, would have a high egg per female value.

The rotifer community showed little change from previous years, apart from a slight increase in overall abundance and the apparent disappearance of one species, *Trichocerca pusilla*. Although this species is generally thought to be a eutrophic indicator species (Bērziņš and Pejler, 1989), it is too early to say whether its disappearance is indicative of a general improvement in lake water quality or just part of the long-term variation within the system. In general, its decline seemed to be linked to a similar decline in its preferred food, centric diatoms. The reason for the success or failure of these centric diatoms during the summer months is unclear and requires further investigation. However, it is also interesting to note that in the summer of 1994, when *Daphnia* numbers were low, the centric diatom community was composed, predominantly, of small unicellular forms. In contrast, in the summers of 1995 to 1998, when *Daphnia* numbers were greater, large filamentous forms prevailed. *T. pusilla* seemed able to feed opportunistically on whatever form of centric diatom was present.

5. ACKNOWLEDGEMENTS

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