CORE
Metadata, citation and similar papers at core.ac.uk
Provided by NERC Open Research Archive

Institute of Freshwater Ecology
Edinburgh Laboratory, Bush Estate, Penicuik,
Midlothian EH26 OQB, Scotland
Telephone 0131 445 4343; Fax 0131 445 3943

ANALYSIS OF 1995 ZOOPLANKTON SAMPLES - LOCH LEVEN NNR

Report to Scottish Natural Heritage - April 1996

Principal Investigators:

I D M Gunn BSc MSc CBiol MIBiol
L May BSc PhD CBiol MIBiol

Contract Completion Date: 30 April 1996
TFS Project No.: T11060u7
IFE Report No.: ED/T11060u7/1

The Institute of Freshwater Ecology contributed funds for this study

This is an unpublished report and should not be cited without permission, which should be sought through the Director of the Institute of Freshwater Ecology in the first instance: Windermere Laboratory, Far Sawrey, Ambleside, Cumbria LA22 OLP, UK. Tel.: 015394 42468; Fax.: 015394 46914.

The Institute of Freshwater Ecology is part of the Natural Environment Research Council's Centre of Ecology and Hydrology.

N:\WP\LEVEN\REPORT95.FIN

ANALYSIS OF 1995 ZOOPLANKTON SAMPLES - LOCH LEVEN NNR

SUMMARY

Zooplankton samples were collected from Loch Leven throughout 1995 as part of the routine monitoring programme.

The species composition of the crustacean zooplankton remained similar to earlier years, although a comparison of their population dynamics with earlier years revealed some unusual patterns of abundance. The most marked changes were (1) the relatively low densities recorded in all three major crustacea taxa, during the first seven months of the year and (2) the extraordinary rise in *Daphnia* numbers to a maximum population density of >100 ind l^{-1} in late August/early September. These changes appear, primarily to be related to the availability of suitably sized algae food. Trout gut content analysis and on-going research comparing the size structure of *Daphnia* individuals from pre- and post-rainbow trout introduction suggest that fish predation is not significantly affecting the structure and abundance of the crustacean community.

An increase in rotifer species diversity in Loch Leven was recorded in 1995 compared to 1994. *Keratella cochlearis* was the dominant rotifer species reaching a peak population density of >2000 ind l^{-1} in late August, although overall total rotifer abundance was relatively low compared to earlier years.

The zooplankton community indicates that Loch Leven is still eutrophic, although the overall decline in the abundance of both the crustacea and rotifers suggests that the loch is less productive than it was in the 1980s.

CONTENTS

1. INTRODUCTION

Loch Leven is a shallow eutrophic loch which has been troubled by algal blooms for many years. In the past, large amounts of phosphorus (P) entering the loch, combined with a relatively low flushing rate and favourable underwater light climate (Bailey-Watts *et al.*, 1994), have encouraged the growth of large amounts of algae (Rosenberg, 1938; Brook, 1958; Bailey-Watts, 1978, 1988; Bailey-Watts and Kirika, 1994). In more recent years, the input of phosphorus from point sources has been reduced considerably by eliminating P discharge from a relatively large industrial source nearby (Bailey-Watts *et al.*, 1991, 1993) and reducing the P load from local sewage treatment works effluent (Fozzard, 1994). In addition, local farmers are now being encouraged to reduce the P load to the loch from diffuse (land use) sources by reducing the application rate of P fertilisers and creating buffer strips between farmland and drainage channels. In spite of these efforts to reduce the P load, significant algal populations continue to give rise to turbid water conditions (Armstrong, *et al.*, 1994; Bailey-Watts and Kirika, 1995; Bailey-Watts *et al.*, 1996).

The overall abundance and species composition of the phytoplankton in Loch Leven is not only affected by the supply of nutrients, but also by losses to grazing zooplankton populations such as the cladoceran, *Daphnia*. *Daphnia* tend to feed on the smaller components of the phytoplankton community, causing changes in the size structure of the algal crop (Bailey-Watts, 1978, 1982; Bailey-Watts *et al.*, 1990). In addition, when these animals are very abundant, the entire population may filter algae from a volume of water equivalent to 133% of the entire loch every day (May and Jones, 1989). This can significantly reduce phytoplankton biomass in the summer months.

Zooplankton also have two other important roles in the loch. First, they form part of the diet of several fish species found here, including brown and rainbow trout (Thorpe, 1974; Duncan, 1994). Second, their species composition and abundance can be useful indicators of environmental conditions such as trophic status (Maitland *et al.*, 1981; Pejler, 1981; Jones, 1984; Bērziņš and Pejler, 1989; Pontin and Langley, 1993).

Although detailed routine monitoring of the zooplankton in Loch Leven began in the late 1960's (Johnson and Walker, 1974), sampling became more sporadic in the early 1980's (May *et al.*, 1993) due to lack of funding. A regular zooplankton monitoring programme, funded by Scottish

Natural Heritage, was resumed in 1992 when severe blue-green algal blooms of *Anabaena* and *Microcystis* in July aroused public concern about the state of the loch.

May *et al.* (1993) analysed zooplankton samples which had been collected between 1978 and 1991, but not processed, and concluded that Loch Leven was still eutrophic. Although some changes recorded in the rotifer community during 1991/92 were thought to suggest 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 the reappearance of *Daphnia* in mid-1970. This cladoceran had been lost from the plankton sometime between 1954 and 1966, possibly as a consequence of dieldrin poisoning. During the late fifties/early sixties, this chemical had been used as a moth-proofing agent 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 into the loch in an effort to boost angling catches (Duncan, 1994; Montgomery, 1994). A further 30,000 rainbow trout with a mean individual weight of *ca* 0.23kg (Wright, *pers comm.*) were added in 1994 and, again, in 1995. 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 were recorded. In contrast to previous years, *Cyclops* and *Eudiaptomus gracilis* Sars reached their highest population densities in December rather than in the summer (Gunn *et al.*, 1994). Further monitoring of the Loch Leven zooplankton was maintained throughout 1994 (Gunn and May, 1995). Analysis showed that several marked changes had occurred within the crustacean zooplankton community, namely, that *Daphnia* numbers had dropped significantly while *Cyclops* increased in abundance to become the dominant species. The rotifer community was dominated, as in previous years, by *Keratella cochlearis, Keratella quadrata, Polyarthra dolichoptera, Synchaeta kitina, Pompholyx sulcata* and *Trichocera pusilla* but with a continuing reduction in the population densities of all species, a continuing trend which had been recorded since 1990 (Gunn and May, 1995).

Although, brown and rainbow trout are known to feed on zooplankton, it was unclear whether these apparent changes within the zooplankton community were related to the introduction of the rainbow trout or were, simply, due to natural variability. This report examines the population dynamics of the crustacean and rotifer zooplankton communities for an additional 12-month period, i.e. 1995, and compares the species composition, seasonality and abundance of these animals during 1995 with records from previous years.

2. METHODS

2.1. Crustacean zooplankton

2.1.1. *Field Sampling*

Samples of crustacean zooplankton were taken at 5 sites during 1995 (**Figure 1**). The Sluice, South Deeps and Reed Bower sites were sampled throughout the year at fortnightly intervals from January to the middle of March, weekly throughout the summer months and fortnightly again from the beginning of November, onwards. When bad weather conditions prevented open water samples being taken, samples were collected from an alternative site at the Public Pier. In addition to this regular sampling programme, samples were collected occasionally from the North Deeps.

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. However, at the Sluices and the Public Pier, samples were normally taken with a bucket and, subsequently, concentrated by passing the sample through a zooplankton net (mesh size 118 μm). Occasionally, these samples were collected and concentrated by a 2-m plankton net haul. All of the 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 250 ml with distilled water. Each sample was thoroughly mixed to distribute the animals randomly, and then sub-sampled with a Stempel pipette (volume 5 ml). The animals present in each sub-sample were identified (Flossner and Kraus, 1986; Harding and Smith, 1974; Scourfield and Harding, 1966;) and counted with a low power binocular microscope. In most cases, three sub-samples were examined. The sub-sampled counts were converted to numbers of individuals per litre using appropriate multiplication factors.

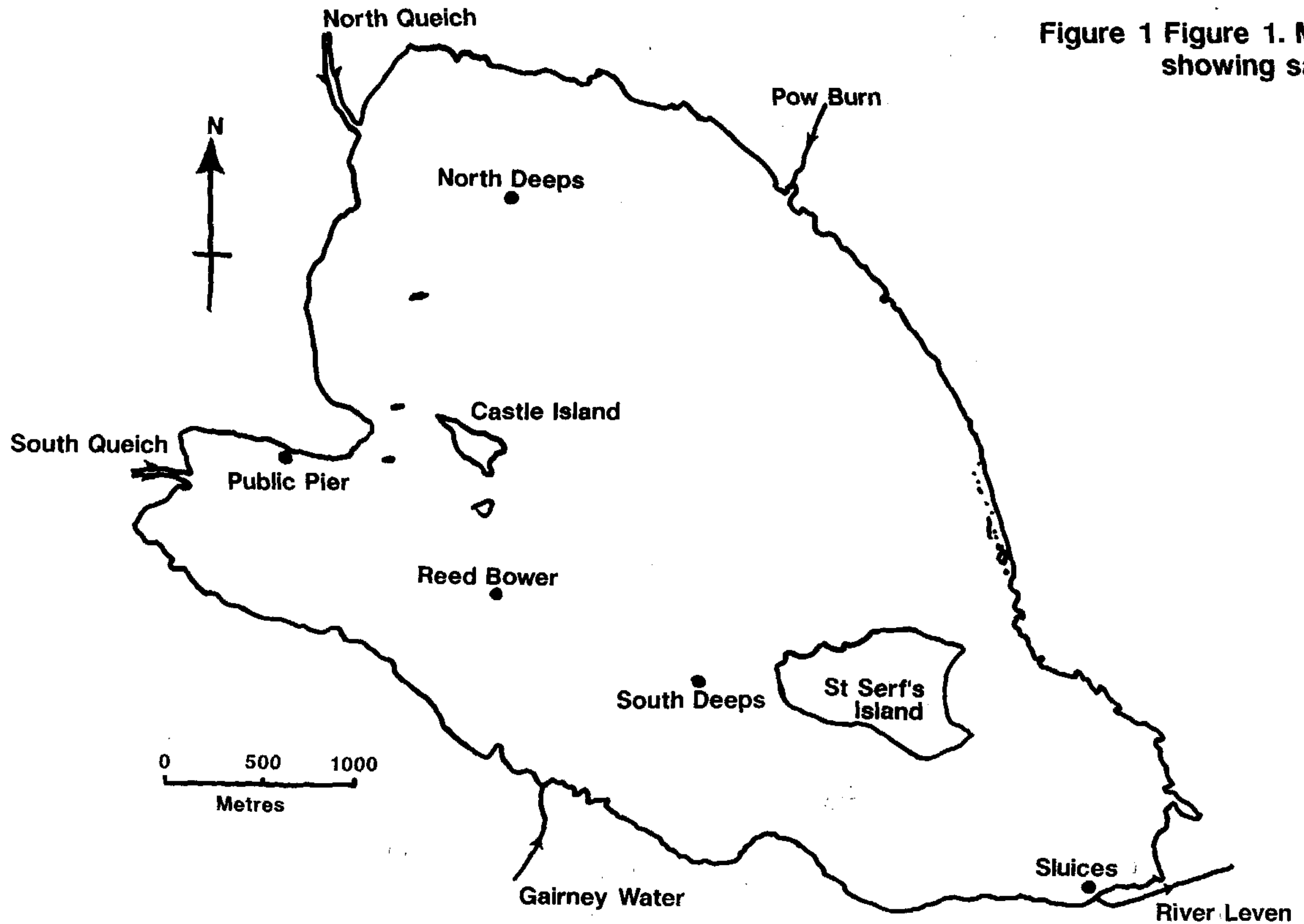

Figure 1 Figure 1. Map of Loch Leven showing sampling sites (•).

2.2. Rotifer zooplankton

2.2.1. *Field Sampling*

Rotifer samples were collected at fortnightly intervals from January to mid-March and from November to December, and weekly during the summer months. On most occasions, samples were collected from both the Reed Bower and Sluices sampling sites (**Figure 1**). However, during bad weather, samples were collected from the Public Pier instead of the open water site at Reed Bower.

The Reed Bower samples were taken with a section of Marley® plastic drainpipe, 2 m in length and 5 cm in internal diameter, while those from the Sluices and Public Pier sites were taken from just below the surface of the water, with a bucket. Each sample of water was mixed well and a 500-ml subsample was taken for counting. Sufficient procaine hydrochloride was then added to each sample bottle to give a final concentration of approximately 0.04%. This relaxed the soft-bodied forms allowing preserved specimens to be identified more easily during the counting process (May, 1985). Each subsample was preserved with 4% formaldehyde approximately 12 h after collection.

2.2.2. *Laboratory analyses*

The rotifer samples were concentrated by allowing the samples to settle in glass measuring cylinders and siphoning off the overlying water. In contrast to many other studies, plankton nets and sieves were not used to concentrate rotifer samples 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 at x20 magnification. When rotifer numbers were high, the samples were randomly subsampled before counting. Several subsamples were examined in turn until either the entire sample had been enumerated or until at least 200 individuals had been counted.

3. RESULTS

3.1. Crustacean zooplankton

3.1.1. *Species list*

The species of Crustacean zooplankton found in Loch Leven during 1995 are shown in **Table 1**.

Table 1. Crustacean zooplankton species recorded from Loch Leven during 1995.

Branchiopoda: Anomopoda

Daphnia galeata Sars/*D. hyalina* Leydig*

Alonella sp.

Chydorus sp.

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)

* see below

Apart from very occasional specimens of *Alonella* sp. and *Chydorus* sp., (taxa which are generally regarded as being littoral rather than planktonic), the species diversity of the crustacean zooplankton in the loch during 1995 was similar to earlier years (*cf.* May *et al.*, 1993; Gunn *et al.*, 1994; Gunn and May, 1995). However, the present study has given some consideration to the correct identification of the *Daphnia* species which is found here. Previous investigators identified this cladoceran as *D. hyalina* var *lacustris* Sars (e.g. Johnson and Walker, 1974) or *D. hyalina*

Leydig (e.g. Gunn and May, 1995), basing their determinations, primarily, on the key of Scourfield and Harding (1966). However, there remains some uncertainty about these identifications because of the wide range of morphological variation and the existence of transitional characters which exist between different forms of *Daphnia*; this is especially true of the *Daphnia hyalina-galeata* group whose morphology is known to vary with age, season and habitat. Flossner and Krause (1986) re-examined this species complex and concluded that the form previously known as *Daphnia hyalina* var. *lacustris* should probably be placed in the species *D. galeata.* This suggests that *Daphnia* individuals from Loch Leven should be identified as *D.galeata* rather than *D. hyalina.* In contrast, however, recent genetic analyses of individuals collected from the loch have indicated that *D. hyalina* is present, although *D. hyalina* x *galeata* hybrids were not ruled out, as some individuals seemed to have intermediate morphological traits (Schwenk, *pers comm.*).

3.1.2. *Abundance*

The abundances of the main crustacean zooplankton species in the loch during 1995 are shown in **(Figure 2)**. As in previous years, the crustacean zooplankton community was dominated by the cladoceran *Daphnia*, the cyclopoid copepod *Cyclops abyssorum*, and the calanoid copepod *Eudiaptomus gracilis*, while the large predatory cladocerans, *Leptodora kindti* and *Bythotrephes longimanus*, were relatively rare **(Figure 2)**.

The main features of their population dynamics are as follows:

(a) *Daphnia* concentrations were unusually low during early 1995, with population densities remaining below 10 ind.l^{-1} until mid-August. This was followed by a rapid increase in numbers which continued until early September, when a maximum population density of 113 ind. l^{-1} was recorded. By October, *Daphnia* numbers had again fallen to very low densities of less than 3 ind.l^{-1}. These very low levels of abundance were maintained over the winter months **(Figure 2)**.

(b) Numbers of *Cyclops* nauplii, copepodites and adults were very low until the beginning of April when they began to increase, reaching a maximum of 17 ind.l^{-1} in mid May. Population

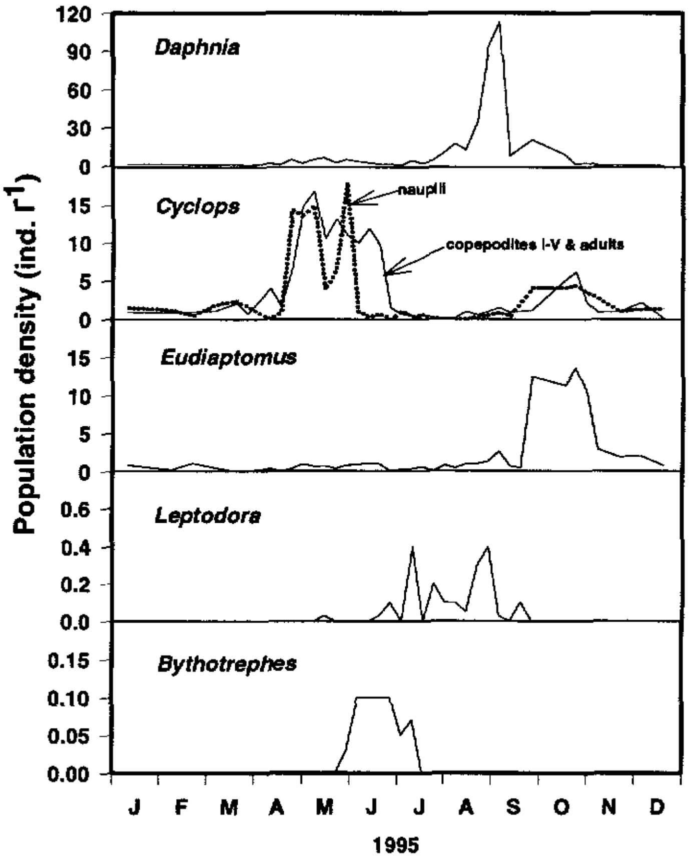

Figure 2. Mean population densities of crustacean zooplankton species in Loch Leven, 1995.

densities then fluctuated around 10 ind.l^{-1} until late June, before declining rapidly during the first half of July. The *Cyclops* population then remained at very low levels of abundance (i.e. < 2 ind.l^{-1}) for the remainder of the year, apart from a small peak in abundance in October, when the mean density reached 6 ind.l^{-1} **(Figure 2).**

(c) *Eudiaptomus* numbers were very low (<2 ind.l^{-1}) from January until mid September. The population density then increased rapidly, achieving a population maximum of 14 ind.l^{-1} in late October. This was followed by a sharp decline in numbers which reduced the population to its former baseline level by the end of October (**Figure 2**).

(d) *Leptodora kindti* and *Bythotrephes longimanus* occurred in extremely low numbers (<0.5 ind.l^{-1}) over the summer period (**Figure 2**). *Leptodora* was most abundant between mid

June and late September, while *Bythotrephes* was recorded only from the end of May until mid July.

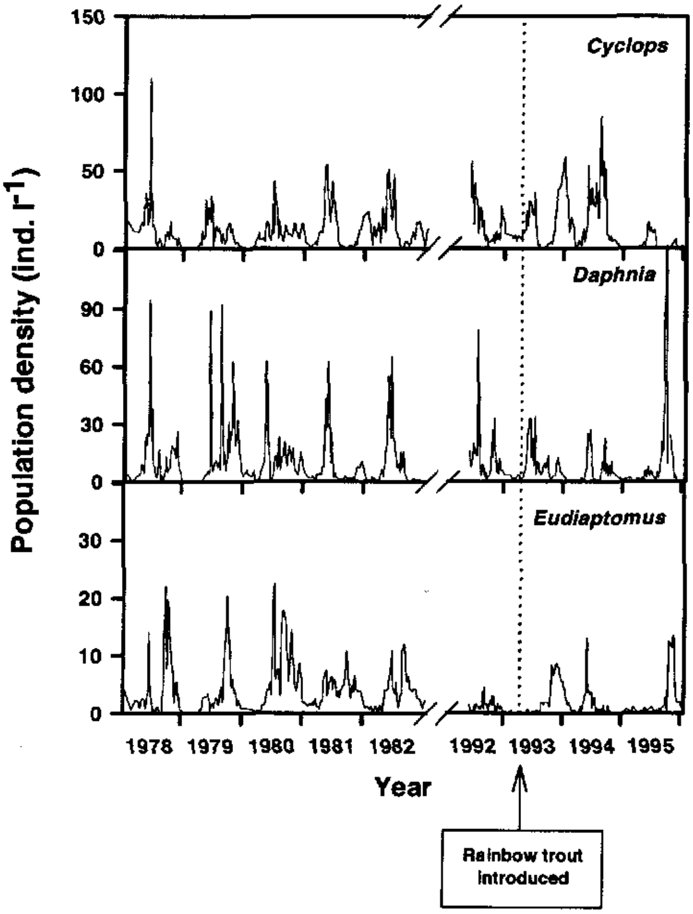

Figure 3. Long-term changes in abundance of *Cyclops*, *Daphnia* and *Eudiaptomus* in Loch Leven, 1978-1995.

Comparisons of the population dynamics of *Cyclops*, *Daphnia* and *Eudiaptomus* during 1995, with the long-term patterns of abundance, reveal a remarkable contrast, both in terms of their relative and absolute abundance and in their seasonality of occurrence (**Figure 3**). The most striking changes occurred during the first 8 months of the year when relatively low densities were recorded in all three of the major Crustacean taxa. During this period, *Cyclops* reached a population maximum of only 17 ind. l^{-1} (*cf.* 85 ind. l^{-1} in 1994), *Daphnia* numbers remained below 10 ind. l^{-1} (*cf.* 23 ind. l^{-1} in 1994) and *Eudiaptomus* densities did not exceed 2 ind. l^{-1} (*cf.* 13 ind.

N:\WP\LEVEN\REPORT95.FIN

l^{-1} in 1994). This is in marked contrast to the situation in 1994, and most other years, when these species were most abundant during late spring and early summer.

3.2. Rotifer zooplankton

3.2.1. *Species List*

Table 2 shows the rotifer species found in Loch Leven during 1995.

Table 2. A list of rotifers species collected from Loch Leven during 1995.

Ploima	
Brachionidae	
	Keratella cochlearis (Gosse)
	Keratella tecta (Gosse)
	Keratella quadrata (Müller)
	Notholca squamula (Müller)
Lecanidae	
	Lecane lunaris (Ehr.)
Trichocercidae	
	Trichocerca pusilla (Lauterborn)
	Trichocerca sp. Lamarck
Asplanchnidae	
	Asplanchna priodonta Gosse
Synchaetidae	
	Polyarthra dolichoptera Idelson
	Polyarthra major Burkhardt
	Synchaeta kitina Rousselet
	Synchaeta oblonga Ehrb.
	Synchaeta grandis Zacharias
Flosculariacea	
Testudinellidae	
	Pompholyx sulcata Hudson
	Filinia longiseta (Ehr.)
Conochilidae	
	Conochilus unicornis Rousselet
Collothecidae	
	Collotheca mutabilis (Hudson)

Seventeen rotifer species were found in Loch Leven during 1995. Although this amounted to an increase in species diversity in comparison with 1994 (11 species), all of the species found in 1995 had been found in the loch between 1977 and 1994 and no new species were recorded. The 6 species which were found in 1995, but were not found in 1994, were occasional species

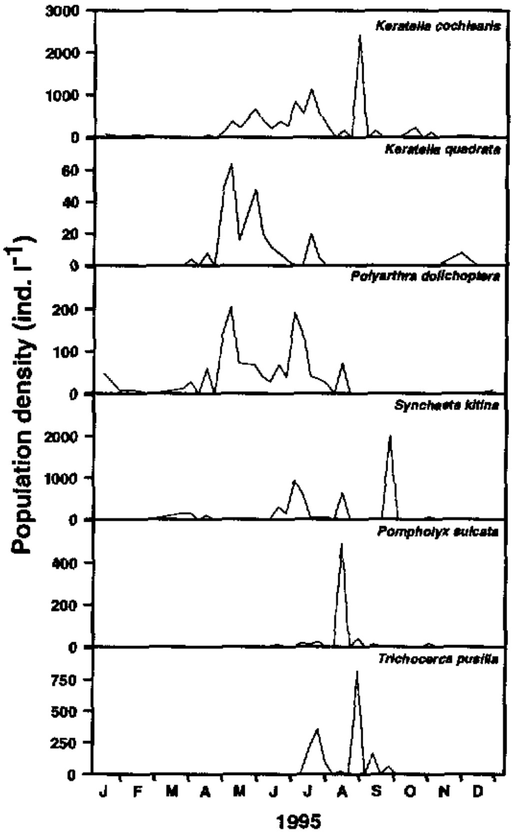

Figure 4. Abundance of the 6 dominant rotifer species in Loch Leven, 1995.

which occurred in very low numbers, apart from a large rotifer from the species *Trichocerca* (*Trichocerca* sp.) which was relatively abundant (up to 324 ind. l^{-1}) for a short period in July.

3.2.2. *Abundance*

The population dynamics of the 6 most important rotifer species during 1995 are shown in **Figure 4**. *Keratella cochlearis* occurred throughout the year, reaching population densities of 500 to 1000 ind. l^{-1} between May and July, and a maximum population density of 2420 ind. l^{-1} in late August. This species was dominant in most samples throughout the year. *Synchaeta*

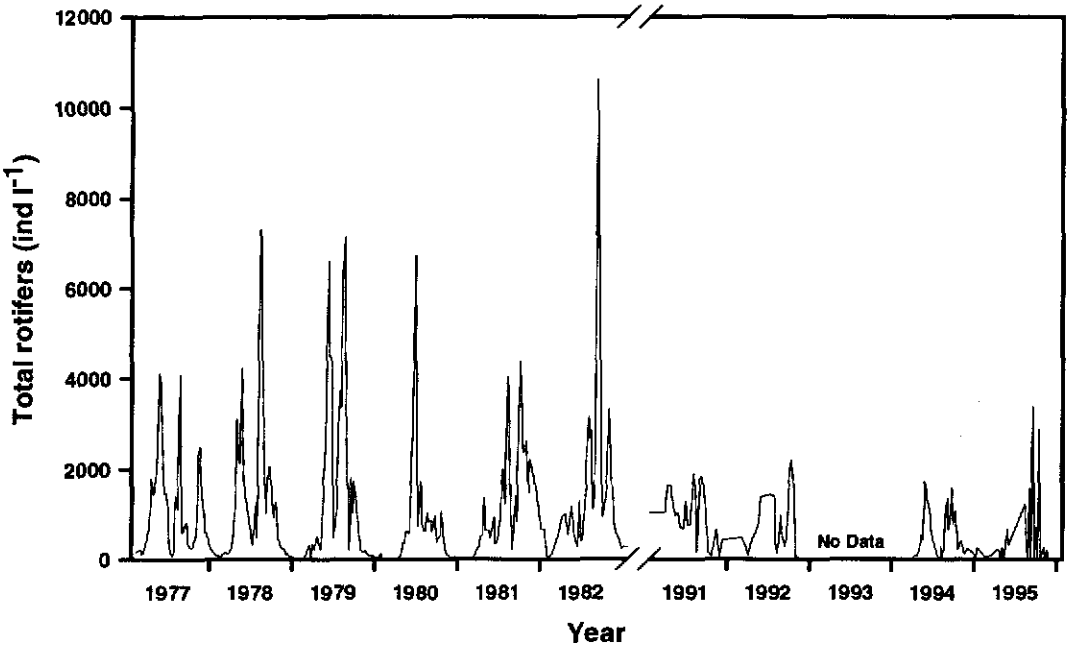

Figure 5. Long-term changes in total rotifer abundance in Loch Leven, 1977-1995.

kitina was the next most abundant species. It occurred sporadically throughout the year, reaching significant peaks of abundance at the end of June (943 ind. l^{-1}) and in mid August (636 ind. l^{-1}), and its maximum abundance (2010 ind. l^{-1}) at the end of September. *Keratella quadrata* and *Polyarthra dolichoptera* were most commonly found in late spring and early summer, reaching maximum abundances of 64 ind. l^{-1} and 204 ind. l^{-1}, respectively, in early May. *Pompholyx sulcata* and *Trichocerca pusilla* appeared only during the summer months, June to September, reaching maximum population densities of 492 ind. l^{-1} and 820 ind. l^{-1}, respectively, in August. In general, the seasonal pattern of occurrence of these species was similar to that found in previous years.

Total rotifer abundance was, again, relatively low throughout 1995 (**Figure 5**), although short-lived peaks in abundance were recorded during late summer (ie 3380 ind. l^{-1} in August and 2890 ind. l^{-1} in September). These were significantly higher than those recorded in 1991, 1992 and 1994 which were each around 2000 ind. l^{-1}, but markedly lower than the maxima recorded in earlier years (1977-1982), i.e. before the reduction in P load. It still seems likely that the overall reduction in abundance of these animals since 1989 reflects the recent reduction in P load, suggesting that the loch is becoming less productive.

4. DISCUSSION

The results of the 1995 monitoring programme identified several changes within the Loch Leven crustacean zooplankton community, compared with 1994 and earlier years. The most marked were the relatively low abundance of *Daphnia* during most of the year, coupled with an extraordinary population increase at the end of August/early September, and the relative decline of the *Cyclops* population. While the species composition of the zooplankton remains stable, indicating that Loch Leven is still eutrophic, the overall decline in abundance of both crustacean and rotifer zooplankton may indicate that the loch is now less productive than it was in earlier years.

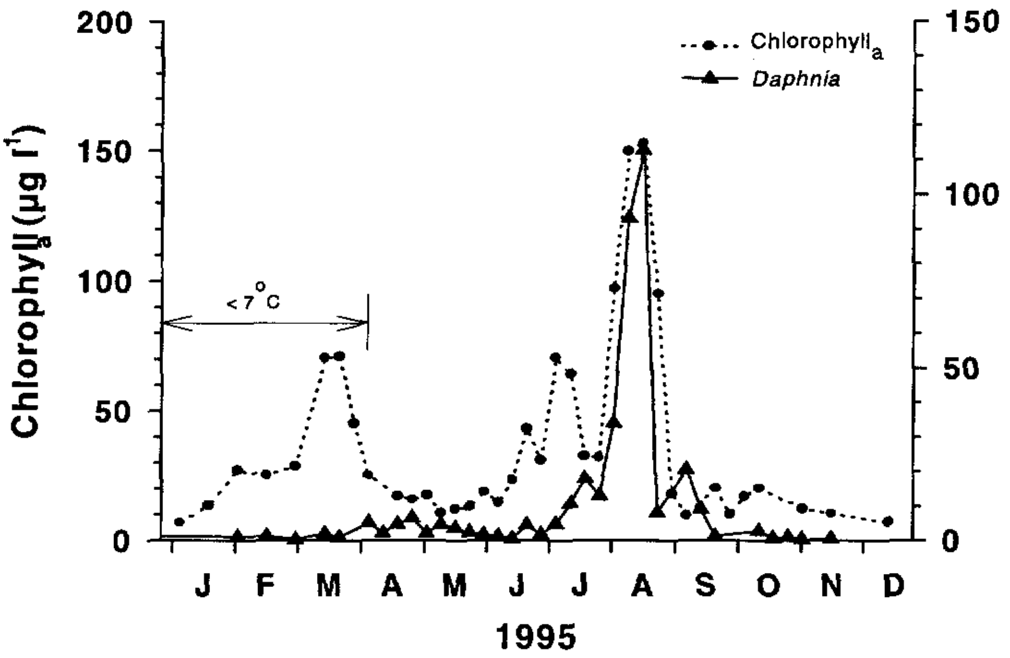

Figure 6. Chlorophyll$_a$ concentration and *Daphnia* abundance in Loch Leven, 1995, showing the period in spring when water temperature is below 7°C.

The structure of crustacean zooplankton communities is generally determined by food availability and predation (Harper, 1986). Any changes in that structure, such as those recorded in Loch Leven during 1995, probably reflect changes in one, or possibly both, of these controlling factors. The food supply, in the form of algae, fluctuated considerably throughout the year (**Figure 6**). During the first three months, phytoplankton were relatively abundant. The phytoplankton community was dominated by diatoms, especially *Aulacoseira subartica*, which reached its maximum abundance in March, coinciding with a chlorophyll$_a$ level of *ca* 70 μg l^{-1} (Bailey-Watts *et al.*, 1996). However, the *Daphnia* were unable to respond to this potential food supply as their reproductive rates were suppressed by low water temperatures of less than 7^{0}C (George, *pers comm.*) (**Figure 6**). During the late spring and early summer, zooplankton numbers remained low because, although the water temperature had increased, phytoplankton levels had fallen to very low levels and food was scarce (Bailey-Watts *et al.*, 1996). By early September, however, the *Daphnia* population had attained record levels of abundance. This period was noteworthy for the very high densities of the large blue-green alga *Anabaena spiroides* (Bailey-Watts *et al.*, 1996) which probably occurred as a result of size-selective feeding behaviour of the *Daphnia* population. This cladoceran grazes, preferentially, on small phytoplankton species in Loch Leven; thus, when its numbers are high, large algae tend to dominate the phytoplankton community (Bailey-Watts, 1978, 1986).

Predation, may also have affected the growth of the *Daphnia* population. Invertebrate predation is unlikely to be an important loss factor, as the *Daphnia* in Loch Leven are relatively large bodied and only the juveniles are likely to be susceptible (Gulati, *pers comm.*). However, Bailey-Watts *et al.* (1993) and May *et al.* (1993) suggested that if fish predation increased, following the introduction of rainbow trout, then *Daphnia* numbers would fall and this, in turn, would lead to a decrease in grazing pressure and an increase in algal biomass. The observed changes in the *Daphnia* and algal populations in 1994 (Bailey-Watts and Kirika, 1995; Gunn and May, 1995), following the introduction of rainbow trout in March 1993, appeared to support for this hypothesis. However, dietary analysis of both brown and rainbow trout during 1993 and 1994 indicated that the main diet of these fish was benthic invertebrates (Duncan, 1994; Duncan, *pers comm.*), which are in plentiful supply in Loch Leven (Gunn and Kirika, 1994), rather than zooplankton. Although growth rates of both the brown and rainbow trout are very high (Duncan, 1994), the stock of fish in the loch seem to be sufficiently low for both species to exploit similar food resources, i.e. the benthos, with a minimum of competition. Where zooplankton does form a significant dietary component of any particular

5. ACKNOWLEDGEMENTS

We thank Angela Smith (Forth River Purification Board) for sampling during 1995. We are also grateful to Scottish Natural Heritage and the Loch Leven Estates for their help in sample collection.

6. REFERENCES

Armstrong, J. A., Fozzard, I. R. and Sargent, R. J. (1994). Development and collapse of an *Oscillatoria* bloom in Loch Leven during July 1994. *Freshwater Forum*, 4, 203-210.

Bailey-Watts, A. E. (1978). A nine-year study of the phytoplankton of the eutrophic and non-stratifying Loch Leven (Kinross, Scotland). *Journal of Ecology*, 6, 741-771.

Bailey-Watts, A. E. (1982). The composition and abundance of phytoplankton in Loch Leven 1977-1979 and a comparison with the succession in earlier years. *Internationale Revue der gesamten Hydrobiologie*, 67, 1-25.

Bailey-Watts, A. E. (1986). Seasonal variation in size spectra of phytoplankton assemblages in Loch Leven, Scotland. *Hydrobiologia*, 138, 25-42.

Bailey-Watts, A. E. (1988). "Studies on the control of the early spring diatom maximum in Loch Leven 1981", in *Algae and the Aquatic Environment* (ed. F. E. Round), pp. 53-87, Biopress, Bristol.

Bailey-Watts, A. E., Gunn, I. D. M. and Kirika, A. (1993). *Loch Leven: past and current water quality and options for change* (Report to the Forth River Purification Board). Institute of Freshwater Ecology. Edinburgh.

Bailey-Watts, A. E., Kirika, A., May, L. and Jones, D. H. (1990). Changes in phytoplankton over various timescales in a shallow, eutrophic loch: the Loch Leven experience with special reference to the influence of flushing rate. *Freshwater Biology*, 23, 85-111.

Bailey-Watts, A. E., Kirika, A., Gunn, I. D. M., Bryant, C. L. and Wiltshire, N. J. (1994). "The environment of fish: physics, phosphorus, phytoplankton and fleas", in *The Loch Leven Trout Fishery - its future* (eds. P. Hutchinson and A. F. Walker), pp. 7-15, Institute of Fisheries Management, Pitlochry.

Bailey-Watts, A. E. and Kirika, A. (1994). *Loch Leven NNR: Water quality 1992-1993 with special reference to nutrients and phytoplankton, and an assessment of phosphorus levels in the loch sediments* (Report to Scottish Natural Heritage). Institute of Freshwater ecology. Edinburgh.

Bailey-Watts, A. E. and Kirika, A. (1995). *Phytoplankton dynamics and the major ecological determinants in Loch Leven NNR during 1994* (Report to Forth River Purification Board and Scottish Natural Heritage). Institute of Freshwater Ecology. Edinburgh.

Bailey-Watts, A. E., May, L. and Kirika, A. (1991). *Nutrients, phytoplankton and water clarity in Loch Leven following phosphorus loading reduction.* (Report to the Scottish Development Department). Institute of Freshwater Ecology. Edinburgh.

Bailey-Watts, A. E., Wiltshire, N. J. and Kirika, A. (1996). *The ecology of the phytoplankton of Loch Leven during 1995.* (Report to the Scottish Development Department). Institute of Freshwater Ecology. Edinburgh.

Berzins, B. and Pejler, B. (1989). Rotifer occurrence and trophic degree, *Hydrobiologia*, 182, 171-180.

Bottrell, H., Duncan, A., Gliwicz, Z. M., Grygierek, E., Herzig, A., Hillbricht-Ilkowska, A., Kurosawa, H., Larsson, P. and Weglenska, T. (1976). A review of some problems in zooplankton production studies. *Norwegian Journal of Zoology*, 24, 419-456.

Brook, A. J. (1958). Changes in the phytoplankton of some Scottish hill-lochs resulting from their artificial enrichment. *Verhandlungen, Internationale Vereinigung für Theoretische und Angewandte Limnologie,* 13, 298-305.

Duncan, W. (1994). "The fish community in Loch Leven", in *The Loch Leven Trout Fishery - its future* (eds. P. Hutchinson and A. F. Walker), pp. 29-38, Institute of Fisheries Management, Pitlochry.

Flossner, D. and Krause, K. (1986). On the taxonomy of the *Daphnia hyalina-galeata* complex (Crustacea: Cladocera). *Hydrobiologia*, 137, 97-115.

Fozzard. I. R. (1994). "Controlling water quality", in *The Loch Leven Trout Fishery - its future*. (Eds P. Hutchinson and A. F. Walker), pp. 16-25, Institute of Fisheries Management, Pitlochry.

Gunn, I. D. M. and Kirika, A. (1994). *Benthic Invertebrate Survey - Loch Leven NNR (1994)* (Report to Scottish Natural Heritage). Institute of Freshwater Ecology. Edinburgh.

Gunn, I. D. M., May, L. and Bailey-Watts, A. E. (1994). *Analysis of 1993 Loch Leven Crustacean Zooplankton Samples* (Report to Scottish Natural Heritage). Institute of Freshwater Ecology. Edinburgh.

Gunn, I. D. M. and May, L. (1995). *Analysis of 1994 Loch Leven Zooplankton Samples.* (Report to Scottish Natural Heritage). Institute of Freshwater Ecology. Edinburgh.

Koste, W. (1978). Rotatoria: Die Rädertiere Mitteleuropas. Gebrüder Borntraeger, Berlin, Stuttgart.

Harding, J. P. and Smith, W. A. (1974). A key to the British freshwater cyclopoid and calanoid copepods. Scientific Publications of the Freshwater Biological Association, No. 18.

Harper, D. M. (1986). The effects of artificial enrichment upon the planktonic and benthic communities in a mesotrophic to hypertrophic loch series in lowland Scotland. *Hydrobiologia*, 137, 9-19.

Johnson, D. and Walker, A. F. (1974). The zooplankton of Loch Leven, Kinross. *Proceedings of the Royal Society of Edinburgh, B*, 74, 285-294.

Jones, D. H. (1984). Open-water zooplankton from five Tayside lochs. *The Scottish Naturalist,* 65-91.

Maitland, P. S., Smith, B. D. And Dennis, G. M. (1981). The ecology of Scotland's largest lochs: Lomond, Awe, Ness, Morar and Shiel. 6. The crustacean zooplankton. *Monograhiae Biologicae*, 44, 135-154.

May, L. (1985). The use of procaine hydrochloride in the preparation of rotifer samples for counting. *Verhandlungen, Internationale Vereinigung für Theoretische und Angwandte Limnologie*, 22, 2987-2990.

May, L., Gunn, I. D. M. and Bailey-Watts, A. E. (1993). *Zooplankton of Loch Leven, Kinross-shire, Scotland* (Report to Scottish Natural Heritage,). Institute of Freshwater Ecology. Edinburgh.

May, L. and Jones, D. H. (1989). Does interference competition from *Daphnia* affect *Keratella cochlearis* populations in Loch Leven?. *Journal of Plankton Research,* 11, 445-461.

Montgomery, D. (1994). "Management of the Loch Leven Trout Fishery", in *The Loch Leven Trout Fishery* - its future (eds P. Hutchinson and A. F. Walker), pp. 26-28, Institute of Fisheries Management, Pitlochry.

Morgan, N. C. (1970). Changes in the fauna and flora of a nutrient enriched lake. *Hydrobiologia*, 35, 545-553.

Orcutt, J. D. and Pace, M. L. (1984). Seasonal dynamics of rotifer and crustacean zooplankton in a eutrophic, monomictic lake with a note on rotifer sampling techniques. *Hydrobiologia*, 119, 73-80.

Pejler, B. (1981) "On the use of zooplankters as environmental indicators", in *Some Approaches to Saprobiological Problems* (ed. M. Sudzuki) pp. 9-12, Sanseido Co. Ltd., Tokyo.

Pontin, R.M. and Langley, J.M. (1993) The use of rotifer communities to provide a preliminary national classification of small waterbodies in England. *Hydrobiologia*, 255/256, 411-419.

Rosenberg, M. (1938). Algae and Trout. A biological aspect of the poor trout season in 1937, *Salmon and Trout Magazine*, 89, 313-322.

Scourfield, D. J. and Harding, J. P. (1966). *A key to the British species of freshwater Cladocera.* Scientific Publications of the Freshwater Biological Association, No. 5.

Thorpe, J. E. (1974). Trout and Perch populations at Loch Leven, Kinross. *Proceedings of the Royal Society of Edinburgh, B*, 74, 295-313.

DISTRIBUTION SHEET

To be completed by all Project Leaders completing commissioned research project reports. Please bind a copy of this distribution sheet as the final page in all internal (IFE) copies of the report.

1	Title: Analysis of 1995 Zooplankton Samples - Loch Leven NNR Authors: Gunn, I. D. M. and May, L. Report ref: ED/T11060u7 Master copy held by: IDMG Report access code (assign a suitable code from list below): N		
2	DISTRIBUTION LIST [A)-H) standard, I) other]	No.copies	Date
A)	Contract customer: Scottish Natural Heritage	3	"
B)	Director - Prof A.D. Pickering	1	"
C)	Asst Director - Prof J. Hilton (title page and abstract only)	1	"
D)	River Laboratory Library	1	"
E)	Windermere Library	1	"
F)	Diana Morton (title page only + no.pages for adding to publication list)	1	"
G)	Project leader: IDMG	1	"
H)	Other (list below and indicate no.copies in RH column)		
1	L. May	1	"
2	A. E. Bailey-Watts	1	"
3			
4			
5			
6			
7			
8			
9			
10			
	Total number of copies made		

REPORT ACCESS CODES

S — **In strict confidence - restricted access** - Access to named customer(s) - (could be named restricted access individuals), IFE Directorate, Project Leader and all authors.

C — **In confidence - restricted access** - Access to customer, IFE Directorate, Project Leader, all authors, and IFE staff with permission of Project Leader.

N — **`Normal' access** - Access to customer and all IFE staff. Access to visitors and general public with permission of Project Leader.

G — **General access** - General access to anyone as required.