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ANALYSIS OF 1993 LOCH LEVEN CRUSTACEAN ZOOPLANKTON SAMPLES

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SUMMARY

Crustacean zooplankton samples collected from Loch Leven during 1993 were analysed. *Daphnia hyalina* and *Cyclops abyssorum* remained co-dominant. The relative and absolute abundance of *Daphnia* and *Cyclops* were similar to previous years though *Eudiaptomus gracilis* numbers were very low for the first 7 months of 1993. *Daphnia's* seasonal distribution was also comparable to earlier years, though *Cyclops* unusually had a larger autumnal peak in numbers (compared to the spring). It is thought that this maxima may be linked to a rise in *Eudiaptomus* numbers at the end of the year which in turn was probably a result of an increase in small centric diatoms. Overall the crustacean zooplankton community in Loch Leven remained indicative of eutrophic conditions.

During the summer, the *Daphnia* population all developed 'helmets', a phenomenon not reported in 1992. Possible explanations for this cyclomorphosis are discussed, but at present the adaptive significance for these morphological changes remains unclear though it may be an anti-predator mechanism, perhaps related to the introduction of rainbow trout.

CONTENTS

1. INTRODUCTION/BACKGROUND

In 1992/93 Scottish Natural Heritage (S. E. Region) funded the Institute of Freshwater Ecology to analyse Loch Leven zooplankton samples collected between 1978 and 1992 in order to evaluate whether or not there was evidence of qualitative or quantitative changes, particularly since 1989 when phosphorus (P) loading was reduced (Bailey-Watts *et al.*, 1993). May *et al.* (1993) concluded that the species composition, absolute and relative abundance of the crustacean zooplankton had changed little since 1970, when the 'cladoceran' *Daphnia hyalina* var. *lacustris* reappeared, indicating that Loch Leven was still eutrophic. However, there was evidence of changes in the rotifer community suggesting a possible improvement in water quality.

Interest had been focused on the zooplankton by earlier research at Loch Leven which showed that micro-crustacean grazing had had a considerable effect on the overall abundance and species composition of the phytoplankton (Bailey-Watts, 1978, 1986). This was manifested mainly in temporal changes in the size structure of the algal crops; inter-annual and seasonal increases in the relative abundance of large phytoplankton correlated well with *Daphnia* abundance. Also, Maitland *et al.* (1981) and Jones (1984) also considered crustacean zooplankton to be good indicators of environmental conditions, particularly the trophic status of lochs.

This report summarises the results of an analysis of crustacean zooplankton samples collected throughout 1993, with the aim of maintaining an up-to-date record with which to assess any changes in Loch Leven's trophic status. It also permits comparsions with data from earlier years, as well as on-going studies on phytoplankton, water quality and the feeding relationships between brown and rainbow trout. The latter area of work is discussed more fully by Gunn *et al.* (in prep.).

2. METHODS

2.1. Crustacean zooplankton

2.1.1. *Field Sampling*

Samples of crustacean zooplankton were taken at 10 sites, during 1993 (**Figure 1**). Sites 1, 2(Reed Bower) and 5 were sampled at weekly intervals from the end of January to the beginning of October and fortnightly thereafter. The other sites were sampled at fortnightly intervals throughout the year. All samples were collected and concentrated by vertical net haul (mesh size 118 μm) and fixed with 4% formaldehyde, except at site 5 where samples were taken with a bucket.

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). Normally three sub-samples were taken per sample. 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 microscope. The correct nomenclature for both *Cyclops stenuus/abyssorum* and *Daphnia hyalina* is discussed in more detail by Gunn *et al.* (in prep.). The counts of each major taxa were converted to numbers of individuals per litre by appropriate conversion factors. As analysing crustacean zooplankton samples

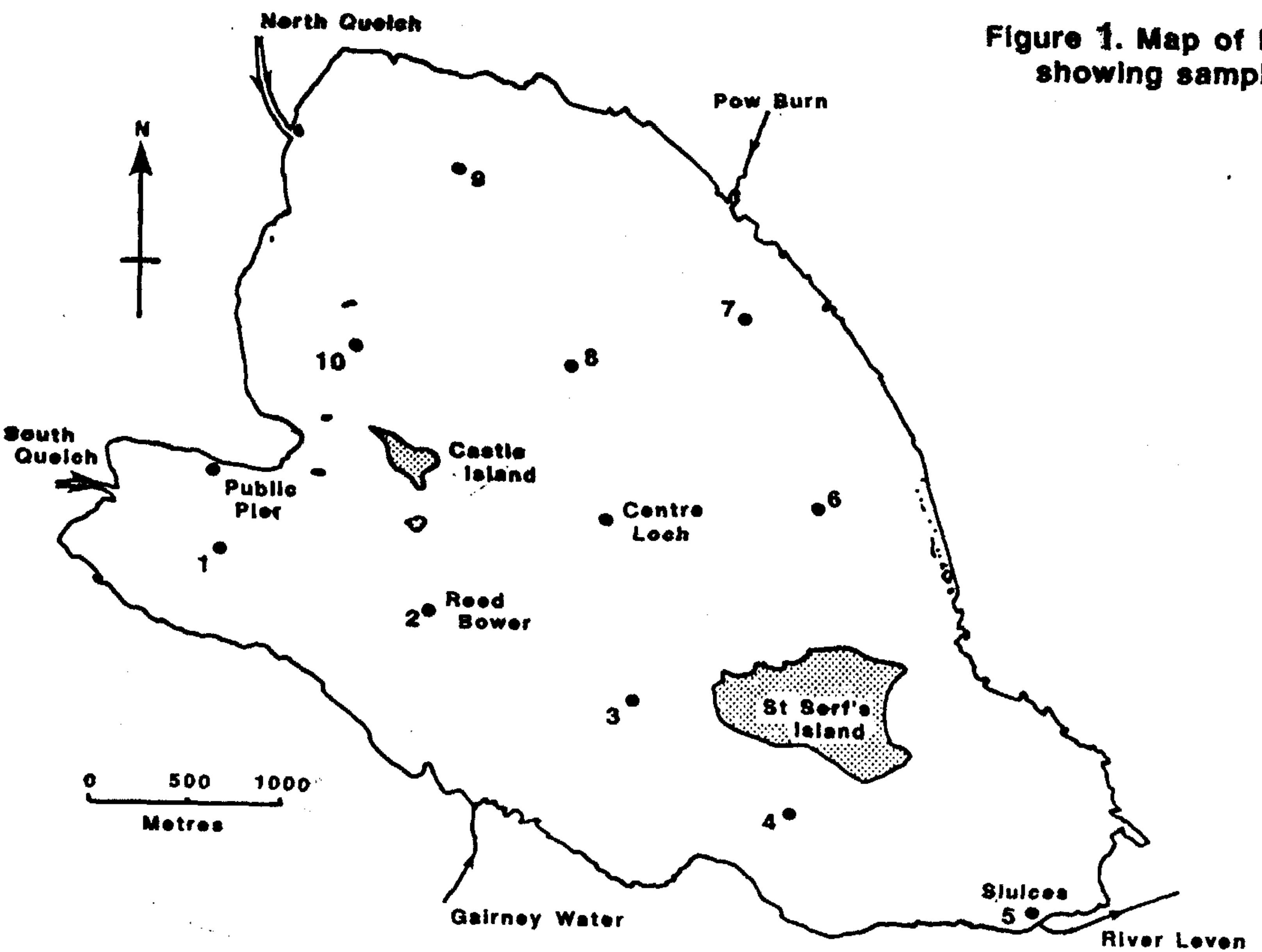


Figure 1. Map of Loch Leven showing sampling sites (•).

is very time consuming, it was not possible to count all of the samples collected in the time allocated. However, samples from five of the ten sample stations (i. e. 1, 2, 5, 8 and 9) were counted, ensuring a varied spatial and depth coverage.

3. RESULTS

3.1. Crustacean zooplankton species list

A complete species list of crustacean zooplankton found in Loch Leven in 1993 is shown in **Table 1.**

Table 1. Crustacean zooplankton species recorded from Loch Leven during 1993

Branchiopoda: Anomopoda

Daphnia hyalina Leydig

Alona affinis (Leydig)

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)

Occasional specimens of Chydoridae, *Alona affinis* and *Chydorus* sp., normally regarded as littoral species were found in the plankton.

3.2. Crustacean zooplankton abundance

The cyclopoid copepod *Cyclops abyssorum* and the 'cladoceran' *Daphnia hyalina* were co-dominant (**Figures 2 and 3**). Both *Cyclops* and *Daphnia* peaked in late May/early June (maximum densities for this period of 68 and 54.9 ind. l^{-1}, respectively), numbers dropping rapidly in the latter half of June. Very low numbers of *Cyclops* were recorded during the summer months before rising again in late September/October to very high levels (max. 81.7 ind. l^{-1}) in December. *Cyclops* nauplii exhibited a very similar pattern to the adult and copepodite stages, but their peak production occurred approximately six weeks earlier than these stages before declining in November/December (**Figure 4**). *Daphnia* exhibited a secondary peak in numbers during August (max. 18.9 ind.l^{-1}). During this period, the 'normal' rounded crest form of *Daphnia* was gradually replaced by a population with pronounced pointed crests. This 'helmeted' form predominated until the end of September when the rounded crest form of *Daphnia* reappeared in the samples. From this time onwards, *Daphnia* numbers returned to overwintering levels (site 8 was the exception with 25 ind. l^{-1} recorded in December). *Eudiaptomus gracilis* was only occasionally recorded in Loch Leven during the first 7 months of 1993 then numbers rose in August/September, fluctuating between 5 and 10 ind.l^{-1} (max. 21.8 ind. l^{-1} at site 8) in the period from

October to December (**Figure 5**). *Leptodora kindti* and *Bythotrephes longimanus* were minor constituents of the crustacean zooplankton, occurring in very low numbers in the summer period i.e. < 2 ind. l^{-1} (**Figure 6**). These two taxa were not recorded during the rest of the year.

4. DISCUSSION

Assessment of the Loch Leven crustacean zooplankton community indicates that, in 1993, it was similar to previous years in terms of composition of the main taxa, although these did exhibit some differences from the 'normal' seasonal abundance patterns (*cf.* May *et al.*, 1993). *Cyclops abyssorum* and *Daphnia hyalina* continued to co-dominate the crustacean zooplankton. Both species were abundant in May/early June with secondary peaks in the autumn and *Cyclops* numbers reaching an annual maximum in December. However, this secondary peak in *Cyclops* production was unusual both in magnitude (mean *ca.* 60 ind.l^{-1} compared to the usual 20 ind. l^{-1}) and in the fact that it exceeds the spring growth peak which is normally larger (*cf.* May *et al.*, 1993). The *Daphnia* seasonal trend was, however, comparable to earlier years. The *Eudiaptomus gracilis* population was at negligible levels until the autumn when numbers increased to densities of 5-10 ind.l^{-1}. This level of abundance was somewhat higher than recorded in 1992 and, in terms of absolute numbers, was more comparable to the period 1979-82. However, its seasonal distribution was quite different (*cf.* May *et al.*, 1993). What factors led to these atypically large increases in both *Cyclops* and *Eudiaptomus* numbers in the last few months is unclear, though perhaps it is related to the relatively high phytoplankton levels (chlorophyll$_a$ of 50-100 µg l^{-1}) prevalent at the time consisting of mainly small centric diatoms with a background of small flagellates and blue-greens (Bailey-Watts *et al.*, 1994). This phytoplankton assemblage is likely to favour the growth of

Eudiaptomus as it feeds preferentially on nannoplankton (i.e. < 15μm) and small net algae (Gliwicz, 1969). The *Cyclops* population is likely to have increased in response to the rise in *Eudiaptomus gracilis*, one of its major prey items (Fryer, 1957). The two large predatory 'cladocerans' *Bythotrephes longimanus* and *Leptodora kindti*, were only recorded occasionally. These animals reach a maximum of only a few indidviduals per litre in Loch Leven a situation common to other freshwaters. In general the maximum abundances reached by zooplankton species are inversely proportional to their size (Morgan, 1980). Maitland *et al.* (1981) and Jones (1984) concluded that it was possible to categorise Scottish lochs on the basis of their species diversity and absolute/relative abundance. They characterised eutrophic lochs as those having a relatively high crustacean zooplankton abundance coupled with a low species diversity dominated by *Cyclops/Daphnia*. The Loch Leven crustacean zooplankton community continues to fit into this classification and hence remains indicative of eutrophic conditions.

The transformation in head shape from the 'normal' rounded crest to a 'helmeted' form in open water *Daphnia* species, as exhibited by *D. hyalina*, is not an uncommon phenomenon during summer months (Fryer, 1991), though not noticed in Loch Leven in 1992. However, Johnson and Walker (1974) did report the presence of the 'summer helmeted form' of *Daphnia* in Loch Leven in 1970. The term cyclomorphosis is used to describe this seasonal polymorphism in planktonic animals such as *Daphnia*. The development of these 'helmets' are thought to be triggered by a number of environmental factors, particularly high temperature and water turbulence, being prevalent at the early stages of an individuals ontogeny (Hutchinson, 1967). It has also been suggested that chemical cues emitted by either predators or by injured or partially digested prey may also stimulate these morphological changes (Gliwicz, 1994). In postembryonic growth, influences such as temperature or food supply which change the rate of growth of a cladoceran carapace, may have a relatively greater effect on the head, thereby altering the relative growth (Hutchinson, 1967). The adaptive significance of these cephalic crests has not been resolved, but many authors (Brooks, 1965; Brooks, 1968; Havel, 1985; Hutchinson, 1967; Jacobs, 1966; Jacobs, 1980) consider that it may be an anti-predator device at a time (i.e. the summer) when zooplankton predation is at its greatest. Dodson (1988) suggested that helmets defend against tactile invertebrate predators such as *Leptodora* and cyclopoid copepods while reduction in the size of crustacean zooplankton is a more effective mechanism against visual predators like fish. Other authors (Brooks and Dodson, 1965; Hutchinson, 1967) have suggested that helmets help reduce visibilty to larger predators, for example fish. The development of the helmets may have successfully helped to reduce fish predation as there is no evidence of any significant change in the population dynamics of *Daphnia* since rainbow trout were introduced into Loch Leven in 1993. However, at present, the reasons why *Daphnia* developed these helmets in 1993 are unclear. Hopefully, current research into the feeding relationships of both brown and rainbow trout populations in Loch Leven will give an indication whether *Daphnia* is subject to fish predation.

5. ACKNOWLEDGEMENTS

We thank Charlotte Bryant for sampling during 1993. We are also grateful to Scottish Natural Heritage (especially Alan Lauder) and the Loch Leven Estates (especially Willie Wilson) for their help in sample collection.

6. REFERENCES

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. (1986). "Seasonal variation in size spectra of phytoplankton assemblages in Loch Leven, Scotland", Hydrobiologia, 138, 25-42.

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., Gunn, I. D. M., Bryant, C. M. and Wiltshire, N. J. (1994). "The environment of fish: physics, phosphorus, phytoplankton and fleas", in press.

Brooks, J. L. (1965). "Predation and relative helmet size in cyclomorphic *Daphnia*", Proceedings of the National Academy of Sciences, U.S.A., 53, 119-126.

Brooks, J. L. (1968). "Symposium: The effect of body size . The effects of prey size selection by lake planktivores", Systematic Zoology, 17, 273-291.

Brooks, J. L. and Dodson, S. I. (1965). "Predation, body size and composition of plankton", Science, 150, 28-35.

Dodson, S. I. (1988). "Cyclomorphosis in *Daphnia galeata mendotae* Birge and *D. retrocurva* Forbes as a predator-induced response", Freshwater Biology, 19, 109-114.

Fryer, G. (1957). "The food of some freshwater cyclopoid copepods and its ecological significance", Journal of Animal Ecology, 26, 263-268.

Fryer, G. (1991). "Functional morphology and the adaptive radiation of the Daphniidae (Branchiopoda: Anomopoda).", Philosophical Transactions of the Royal Society of London B, 331, (1259), 1-99.

Gliwicz, Z. M. (1969). "Studies on the feeding of pelagic zooplankton in lakes with varying trophy", Ekologia Polska, 17A, 663-708.

Gliwicz, Z. M. (1994). "Relative significance of direct and indirect effects of predation by planktivorous fish on zooplankton", Hydrobiologia, 272, (1-3), 201-210.

Gunn, I. D. M., Bailey-Watts, A. E. and May, L. (in prep.). "The crustacean zooplankton of Loch Leven, with reference to phosphorus loading reduction and introduction of rainbow trout (*Oncorhynchus mykiss* Walbaum)", Harding, J. P. and Smith, W. A. (1974). A key to the British freshwater cyclopid and calanoid copepods, Scientific Publications of the Freshwater Biological Association, No. 18, (2nd Edition).

Havel, J. E. (1985). "Cyclomorphosis of *Daphnia pulex* spined morphs", Limnology and Oceanography, 30, 853-861.

Hutchinson, G. E. (1967). A Treatise on Limnology, Volume II. Introduction to Lake Biology and the Limnoplankton, Wiley, New York.

Jacobs, J. (1966). "Predation and rate of evolution in cyclomorphic *Daphnia*", Verhandlungen, Internationale Vereinigung für Theoretische und Angewandte Limnologie, 16, 1645-1652.

Jacobs, J. (1980). "Environmental control of cladoceran cyclomorphosis via target-specific growth factors in the animal", in Evolution and Ecology of Zooplankton Communities (Ed. W. C. Kerfoot), The University of New England , Hanover (N. H.).

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", Monographiae Biologicae, 44, 135-154.

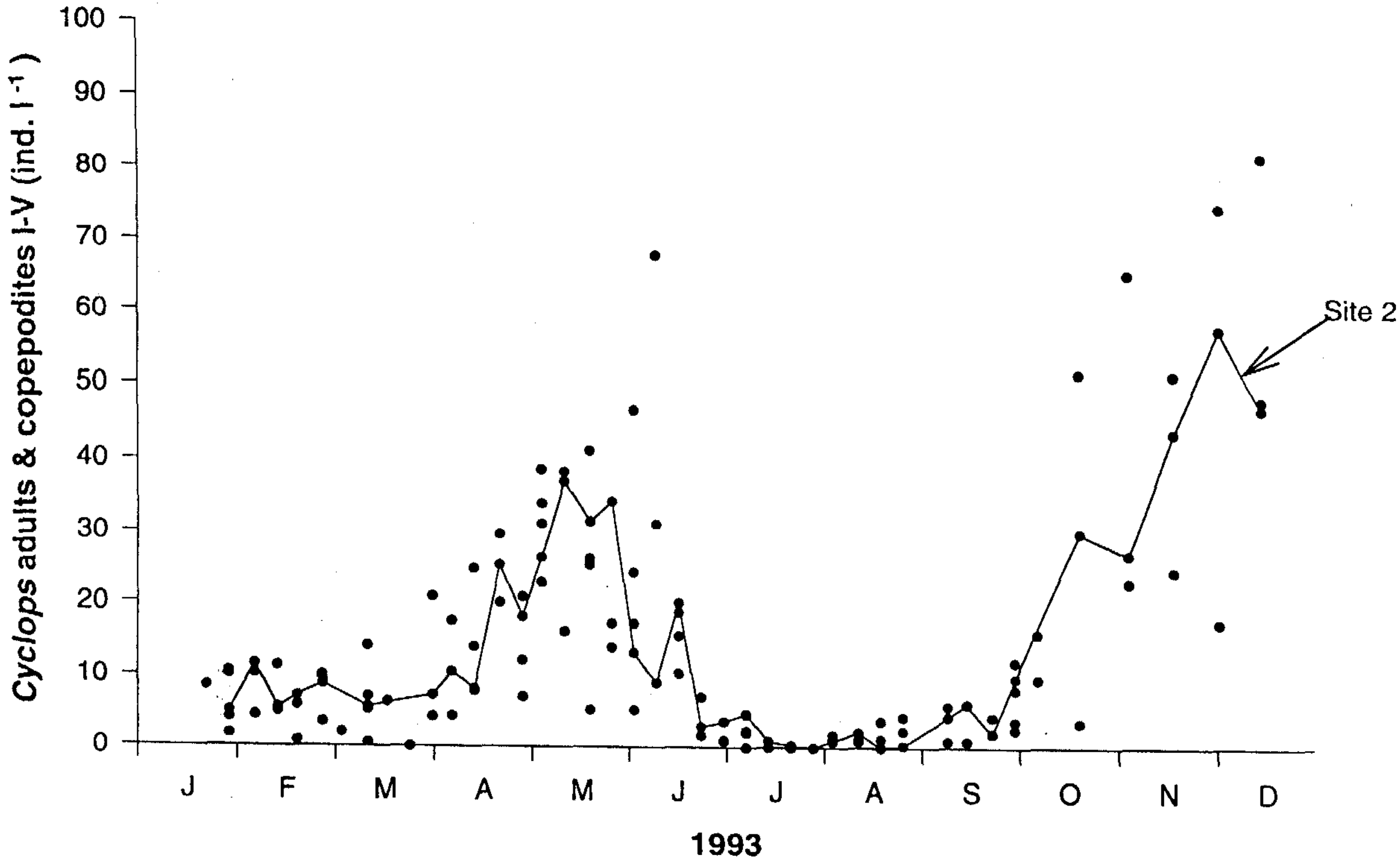
May, L., Gunn, I. D. M. and Bailey-Watts, A. E. (1993). Zooplankton of Loch Leven, Kinross-shire, Scotland (Report to Scottish Natural Heritage). Institute of Freshwater Ecology. Edinburgh.

Morgan, N. C. (1980). "Secondary production", in The functioning of freshwater ecosystems (Eds E. D. Le Cren and R. H. Lowe-McConnell). Cambridge University Press, Cambridge.

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.

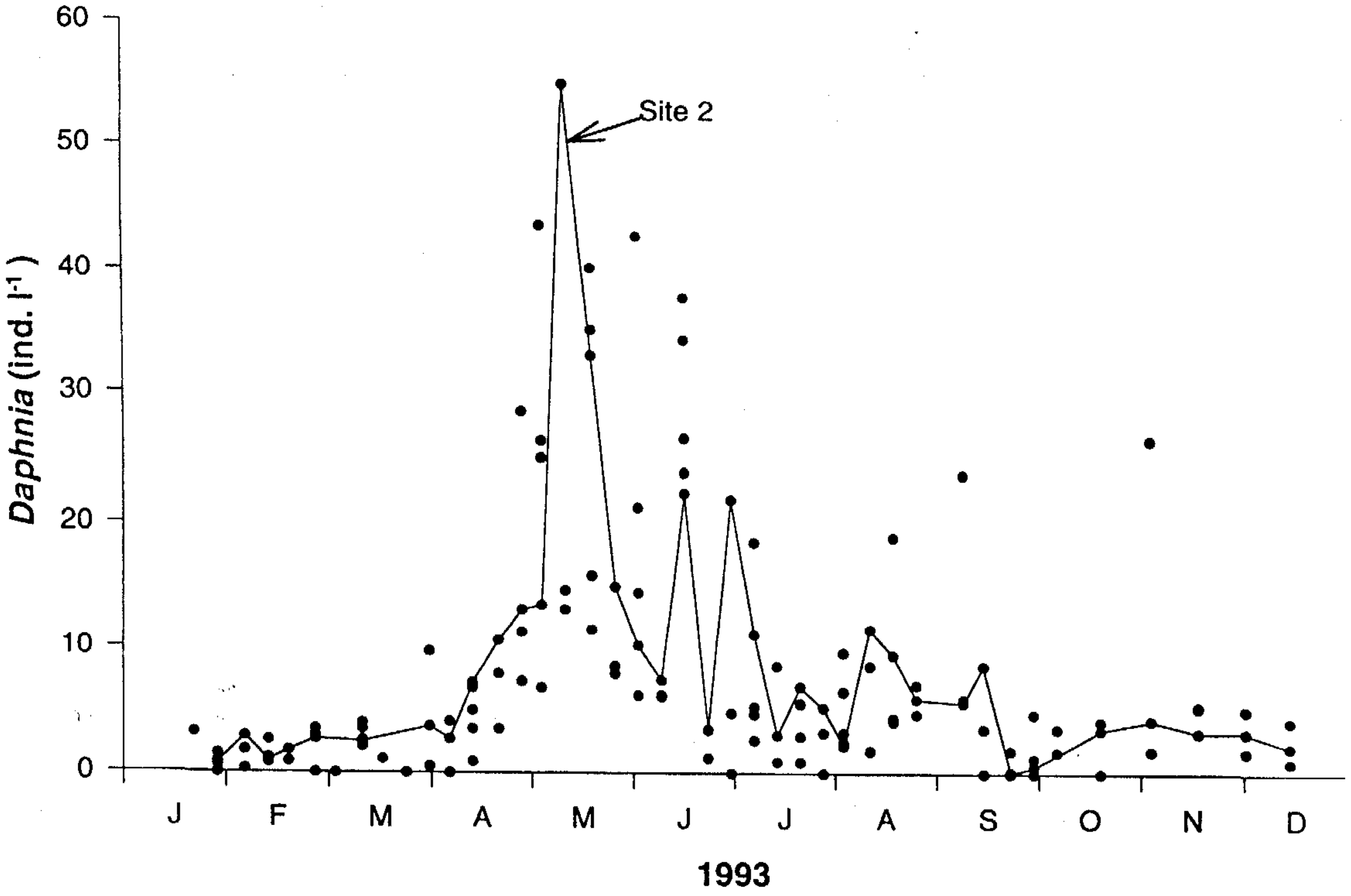
FIGURES

Figure 2. Total abundance of *Cyclops abyssorum* (adults +copepodites I-V) in Loch Leven, 1993.



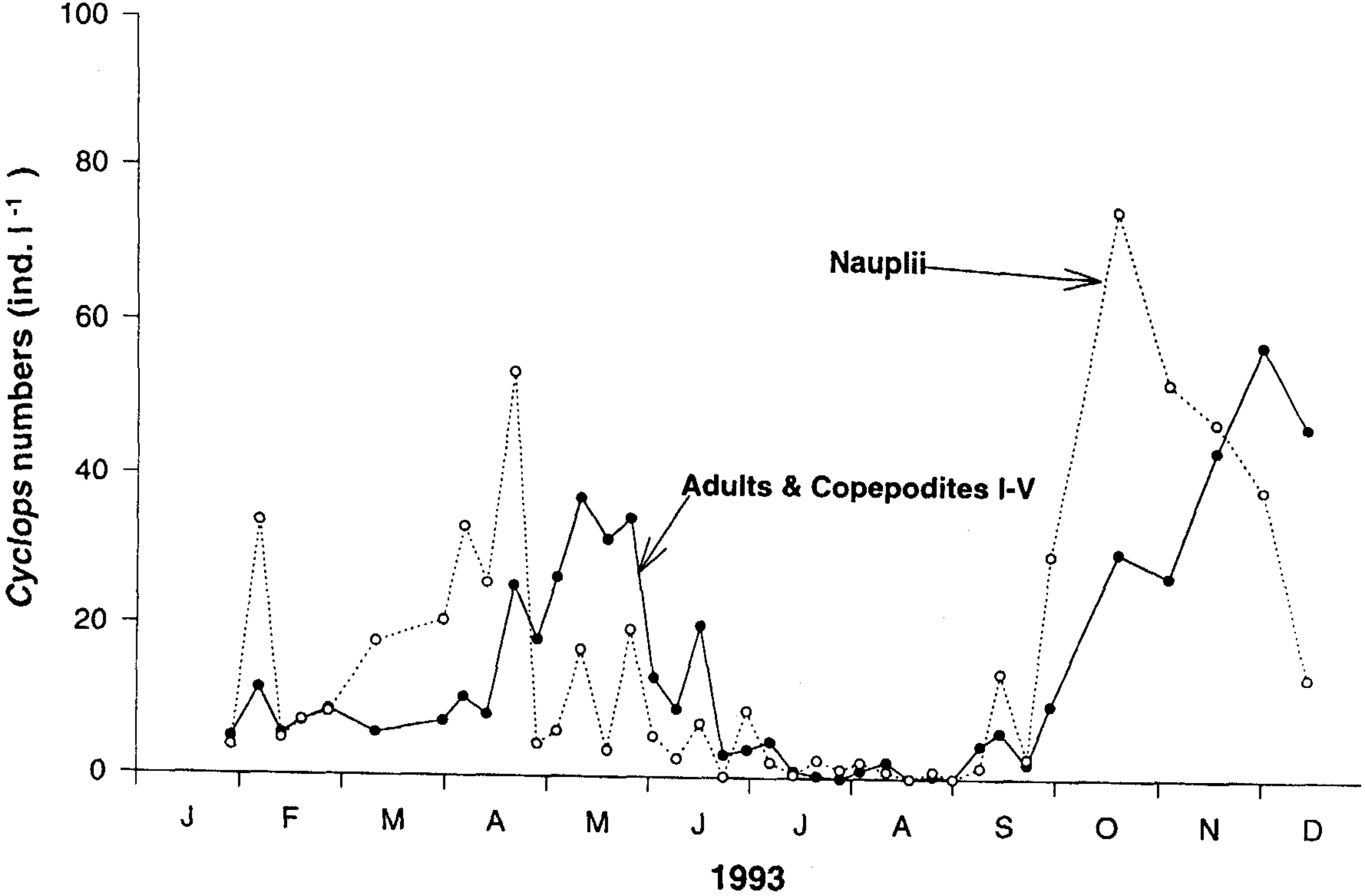
Cyclops adults & copepodites I-V (ind. l -1)
100
90
80
70
60
50
40
30
20
10
0
J
F
M
A
M
J
J
A
S
O
N
D
1993
Site 2

Figure 3. Total abundance of *Daphnia hyalina* in Loch Leven, 1993.



60
50
40
30
20
10
0
Daphnia (ind. l-1)
Site 2
J
F
M
A
M
J
J
A
S
O
N
D
1993

Figure 4. Total abundance of *Cyclops abyssorum* at site 2 (Reed Bower), in Loch Leven, 1993.



Cyclops numbers (ind. l -1)
100
80
60
40
20
0
J
F
M
A
M
J
J
A
S
O
N
D
1993
Nauplii
Adults & Copepodites I-V

Figure 5. Total abundance of *Eudiaptomus gracilis* (adults + copepodites I-V) Loch Leven, 1993.

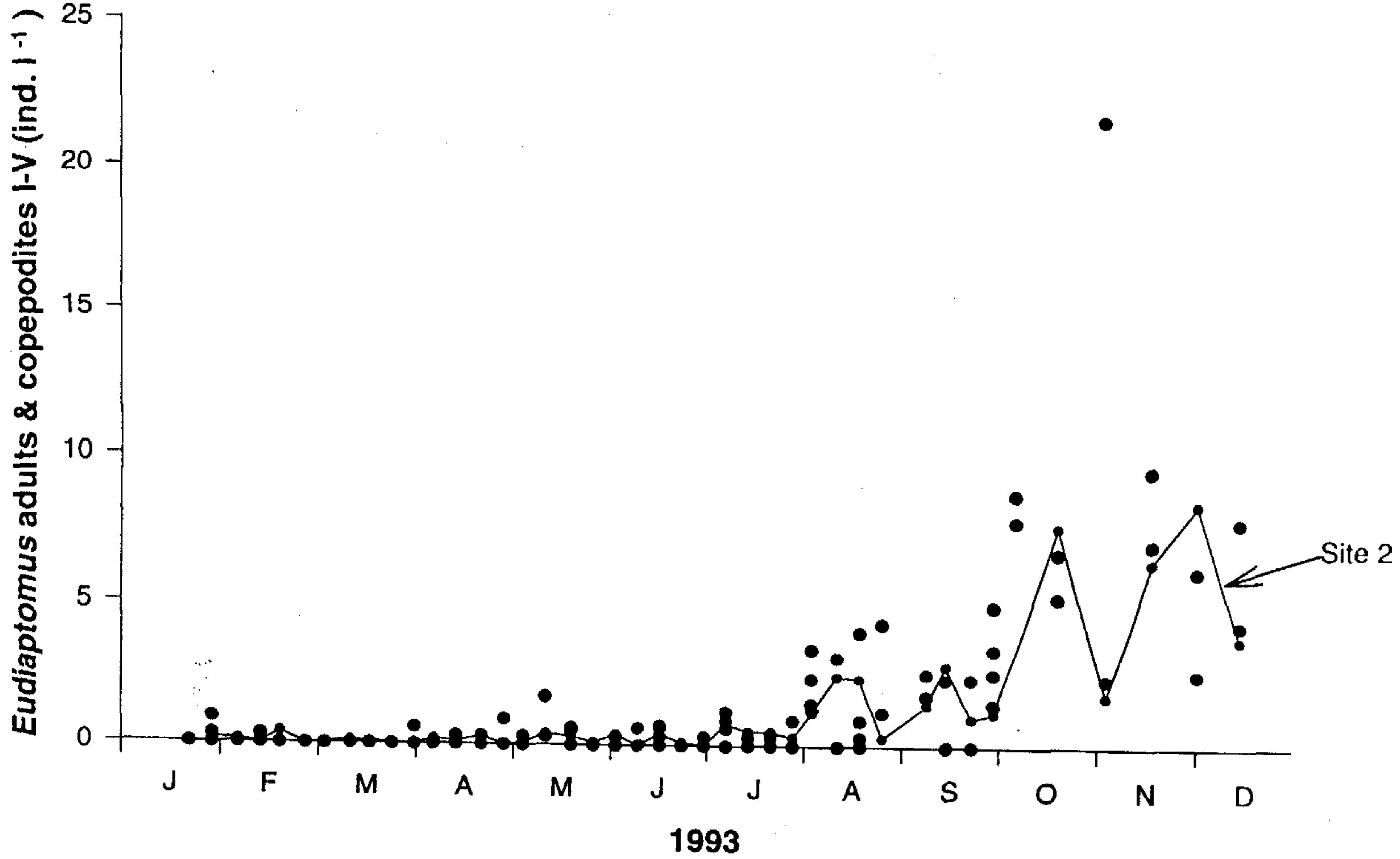
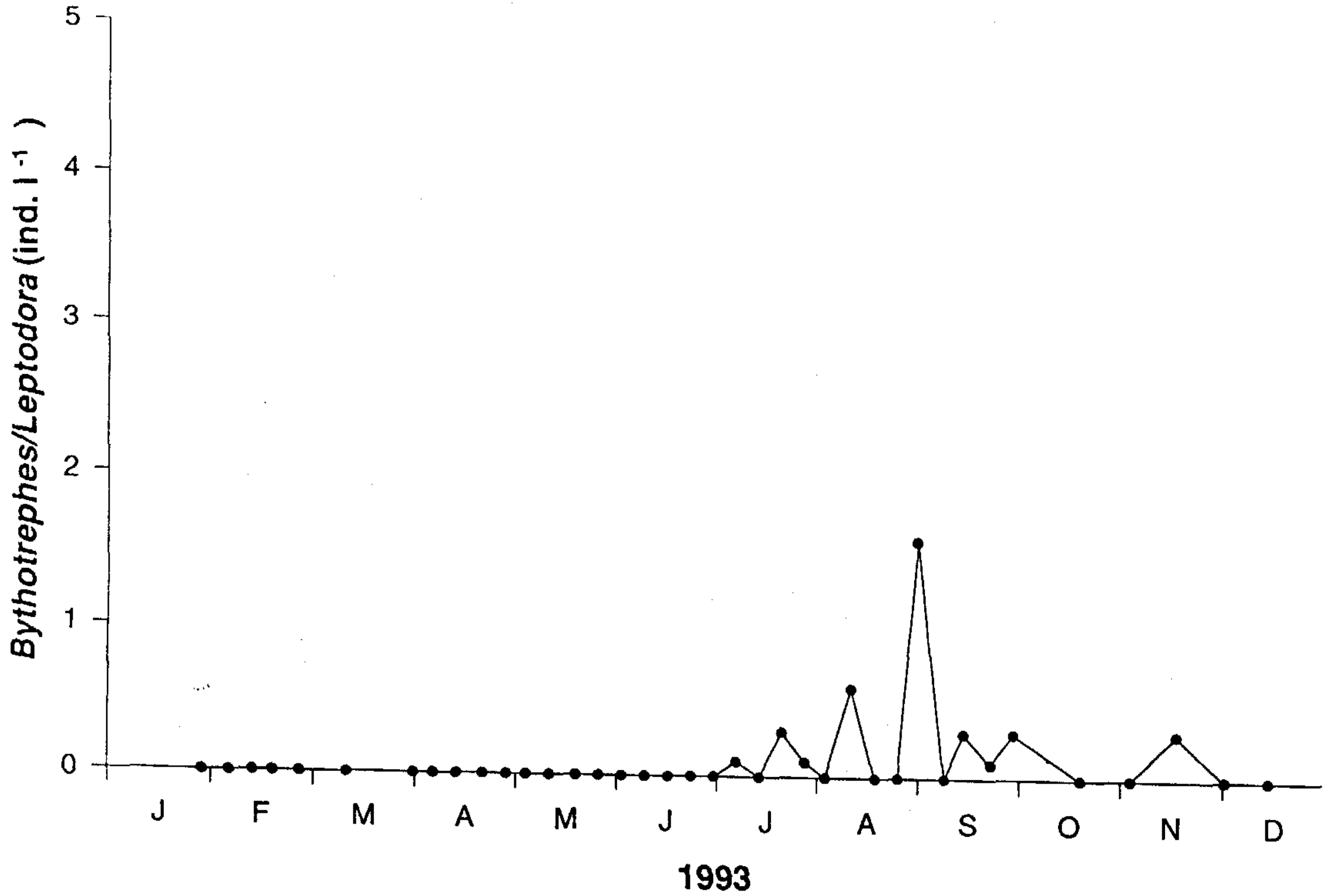

Eudiaptomus adults & copepodites I-V (ind. l -1)
25
20
15
10
5
0
J
F
M
A
M
J
J
A
S
O
N
D
1993
Site 2

Figure 6. Total abundance of *Bythotrephes longimanus* and *Leptodora kindti*, in Loch Leven, 1993.



Bythotrephes/Leptodora (ind. l -1)
0
1
2
3
4
5
J
F
M
A
M
J
J
A
S
O
N
D
1993

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