Institute of Freshwater Ecology

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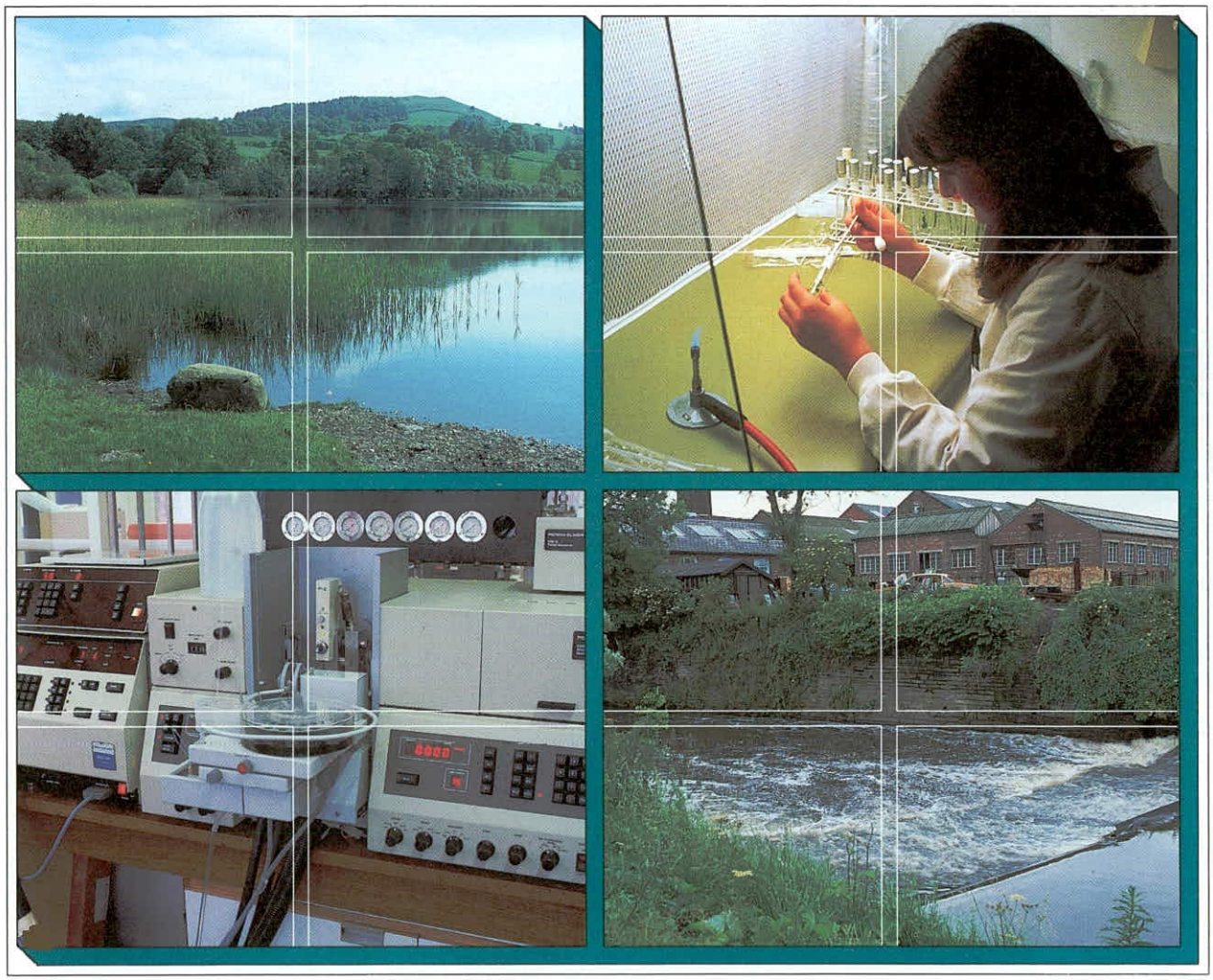
Project Manager: A E Bailey-Watts

Report to the Forth River Purification Board (February 1996)



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AN ANALYSIS OF PHYTOPLANKTON SAMPLES FROM LOCH KATRINE, SCOTLAND 1994-1995: A CONTRIBUTION TO THE ENVIRONMENTAL CHANGE NETWORK

Project Manager: A E Bailey-Watts

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Summary

The report presents the first series of data for the Environmental Change Programme (ECN), on the species composition and abundance of phytoplankton in oligotrophic Loch Katrine. The results are based on an examination of 6 samples collected from open water between June 1994 and December 1995.

Algal enumeration methods are described in some detail in order that the results can be compared with those generated by other ECN contributors.

Setting aside considerable difficulties encountered in identifying the algae, some 45 species distributed among the following algal groups were recorded: Chlorophyceae (*ca* 12 species), Bacillariophyceae (10), Chrysophyceae (*ca* 8), Cyanophyceae (*ca* 8), Cryptophyceae (1) and Desmidiaceae (4).

Many species were present at levels of <1 ml^{-1} although picoplanktonic forms occasionally numbered >5000 ml^{-1}.

Temporal variation in algal species and abundance is minor; lists of organisms published as long ago as 1912 include many of the types found during the present work.

Some of the Phytoplankton Quotients calculated from the present assemblages suggest eutrophic tendencies, but reasons are given for this apparent anomaly.

To improve on the current unsatisfactory situation regarding algal identification, it is suggested that live plankton (in addition to the preserved material) is submitted for analysis in the future.

The report also proposes that consensus views be established on aspects of the ECN philosophy; in particular, decisions have to be made on how much 'change' is to be regarded as significant.

An analysis of phytoplankton samples from Loch Katrine 1994-95, Scotland: a contribution to the Environmental Change Network

Contents

1. Introduction

This report concerns the nature and abundance of the phytoplankton of the large (1240 km^2 surface area, and 61m mean depth) oligotrophic Loch Katrine (NGR NN 450097). It deals first, with the methods used to estimate the population densities of the organisms; the procedures are described in some detail in order that the results can be compared with those of other contributors to the Environmental Change Network (E.C.N.). The main results follow with information on qualitative and quantitative characteristics of the algae and briefly, variation in these features on the basis of samples collected on 6 occasions between June 1994 and December 1995. The findings are discussed with reference to previously published information on the planktonic algae of Loch Katrine and how the assemblages reflect the basic nature of this waterbody. In the light of the present findings, the report concludes with some suggestions for enhancing the value of the E.C.N. phytoplankton programme.

2. Materials and methods

Samples were collected in open water by staff of the Forth River Purification Board, using a weighted plastic tube (Lund, 1949) to secure a sample integrated over the uppermost 15m of the water column. Table 1 shows the information that accompanied the 100-fold concentrated, Lugols Iodine-fixed samples submitted to the author for microscopic analysis. Time has not allowed comparison of the algal data with corresponding information on other aspects of water quality (determined by the Forth River Purification Board). Nevertheless, the opportunity to 'predict' some aspects of the of the situation as regards the ecology of the phytoplankton is taken on the basis of the quantitative and qualitative features of the algae.

Table 1: Sampling dates and locations

Sampling date	Location/Grid Reference
6 June 1994	No details supplied
4 August 1994	No details supplied
6 March 1995	West Ellens Isle: 7111. NN4878 0825
19 June 1995	" " 7111.NN4882 0825
12 September 1995	L1201
4 December 1995	L1201 NN4882 0825

After thoroughly shaking the sample, approximately 1 ml was withdrawn into a Pasteur pipette. A Lund nanoplankton counting chamber (Lund, 1959, 1962; Bailey-Watts & Lund, 1973; Youngman, 1971) was then filled quickly but smoothly from the pipette. The volume of the chamber used throughout this study has been measured as 0.452 ml.The procedure results in what is to all intents and purposes a random distribution of the phytoplankters (see also Jones 1979); as far as this author is aware this is in contrast to the patchy - or more significantly, unknown - distribution of particles that results during the filling of all other counting chambers, even the haemocytometer unless it is filled in the manner recommended by Lund, Kipling and Le Cren (1958). As a consequence, the time and effort invested in order to obtain statistically acceptable population estimates, is dictated by the operator; with counting procedures employing other chambers, the sample dictates how many cells or colonies need to be enumerated.

In order to keep 'searching' time at the microscope to a minimum - especially where small species requiring high power magnification are present - the organisms are concentrated (i.e. brought closer together) by sedimentation overnight in tall glass cylinders, or by the swifter method of centrifugation. Counting time varies considerably depending on the 'mix' and size distribution of the species present, and on the relative importance of algae and other particles in the water. As a general rule, however, a count taking for example, an hour or so by the Lund method could take many hours with the inverted microscope and other chamber procedures. This author took some 1½ hours over each of the Katrine samples, even though the present analysis was limited primarily to (i) numerically dominant species, and (ii) sparse forms as long as they were particularly striking. The main reasons for taking this length of time are as follows:

- organic and mineral detritus often dominates over algae; further concentration of the material would not have eased observation and counting.
- many of the species recorded are small i.e. <5 μm and even down to 1 μm.
- the majority of the species were present in low numbers, such that relatively few 'views' and/or life-stages of them were presented to aid classification; in the case of small forms in particular, it was thus often impossible to provide a definitive identification beyond the level of Genus, even Family and Order (see Discussion).
- the samples were examined using a variety of occular-objective combinations that resulted in the following routine range magnifications: 40x, 100x, 250x and 500, with the additional option of increasing each of these 2.5-fold, i.e. extending the range to 1250x.

As far as possible, the relatively sparse organisms were also logged - not least since they may herald the development of a more substantial population. It should be borne in mind too, that rare species may well be the more informative indicators of water quality (and lake type as regards availability of plant surfaces and other shallow substrates); desmids, which rarely (but see e.g. Brook 1994, and Bailey-Watts 1994) attain massive population densities, are a very good case in point (Brook 1959, 1964, 1965; Nygaard, 1949). It is probably fair to say that the enumeration of relatively rare, small species has not received adequate attention - due to the considerable increase in time needed.

The procedure followed for enumerating the different organisms is extremely flexible. The magnification at which a particular organism is enumerated is varied according to mainly, its size and how easily it can be distinguished from other species and particles present. In addition, with the lower power magnifications at least, the operator can decide whether counts based on transects or random quadrats (each defined by a Miller square placed in the microscope eyepiece) are the more convenient and efficient option; quadrat counts are invariably used where high-power magnifications are involved. The factors used for converting counts to population densities (numbers per millilitre in this author's case) vary according to the following:

- the viewing magnification, which determines the area and thus volume of sample represented by each quadrat or transect.
- the degree to which the organisms have been concentrated (100-fold in this case), as the effective volume of original sample viewed is then (100-fold) greater than the actual volume surveyed.
- the number of quadrats or transects sampled as these determine the total/effective volume of water in which each species has been enumerated.

Robson and Bailey-Watts (1987) developed a computer-based programme with the facility for inputting date and location of sample, and allowing a reasonably free-format entry of the factors for converting counts to numbers, as well as the counts and codes for each species. An associated programme re-formats the above inputs and calculates the actual population densities of each organism (i.e. count (N) times coversion factor (K). The main results for the present study are shown in this form in Appendix III. Appendix I is the continually evolving list of the codes and full names of algae recorded in Scotland by this author over some 30 years; however, this is far from complete, in not featuring for example, the extra species recorded during two substantial programmes (Bailey-Watts and Kirika 1991; and Bailey-Watts *et al* 1992).

3. Results

3.1 Qualitative features of the algal assemblage

Bearing in mind the uncertainties in identifying many of the organisms observed, some 45 species have been encountered during the enumeration procedures, and Appendix II groups these according to major algal Class. Very few other algae were noticed 'on the way' i.e. seen outside the sampling quadrats/transects. The loch appears to be dominated by Chlorophycean green algae (approximately 12 spp.) and diatoms (10). The green algae include unicellular and colonial Chlorococcales. However, some of the former (e.g. *Ankistrodesmus* and *Monoraphidium*) have been assigned to *Koliella* which is similar to these other species in its often very slender spindle form, but belongs to one of the filamentous group of chlorophycean algae (Ulotrichales) although it consists of only 1- or 2-cell filaments. However, in the absence of specimens in stages of division it is difficult to distinguish between any of these algae. Chrysophytes and Cyanobacteria including the 'infamous' *Anabaena flos-aquae*, also feature, with *ca* 8 species each. The rest of the algae recorded comprise four desmids and probably what amounts to only one type of cryptomonad. Undoubtedly, a concentrate of material taken by fine (*ca* 20-µm) mesh tow-net would reveal many more species - although such a method of collection is unlikely to preserve the numerical proportions of the species (see Discussion).

There is a host of other silica-utilising algae (Chrysophyceae) of which, so far, very few have been identified in this study to Genus let alone species. As a consequence, in Appendix III, 'X' indicates unknown identity; for example, MAXX is an unidentified *Aulacoseira* (formerly *Melosira*, Haworth 1988), while XXXX refers to a form yet to be identified to any level.

The time taken to assess each sample is more or less the same, but differences in species composition and detrital content mean that the numbers of species recorded on each occasion are not strictly comparable. Nevertheless, the present data suggest that species numbers are reasonably low with between 12 and 18 algae in 5 of the samples, and only 6 in the sample of March 1995.

3.2 Quantitative features of the algal assemblage

Appendix III lists the counts and estimated population densities of the phytoplankton types on each of the 6 sampling occasions. Two counts are listed for some species. These result from situations where an organism has been counted initially at what later seemed to be an inappropriately low magnification. Generally, the population density derived from the larger of the two counts is the more reliable. Good examples where two counts have been made, concern *Rhizosolenia* and *Koliella*. *Rhizosolenia longiseta* is very delicate diatom, often >100 µm in

length, but often narrow e.g. *ca* 5 µm. As a consequence it is commonly only noticed if phase contrast illumination is used, although careful observation can reveal the (normally extremely small) central protoplast even under bright-field. *Koliella* is very narrow even at the widest part of the cell/cells i.e. *ca* 2-3 µm. It was often the most abundant of the eukaryotic forms in each of the samples.

Many of the algae recorded were present in extremely low concentrations, i.e. <1 per 10 ml of water in some instances, and rarely more than 10 ml^{-1}. Prominent because of their large size amongst these, are cyanobacteria including the *Anabaena* referred to above, and species and varieties of desmids including *Staurodesmus* and *Cosmarium*. However, the filamentous centric diatom *Aulocoseira* and colonial pennate diatoms such as *Tabellaria fenestrata*, *T. flocculosa* and *Asterionella formosa*, and a mixture of what are probably *Synedra* species, also rarely achieved population densities of more than 10 ml^{-1}.

Organisms often attaining numerical densities of between 10 and 100 individuals ml^{-1} include the *Rhizosolenia* mentioned above, but otherwise generally much smaller organisms such as *Rhodomonas*, *Koliella* and a few chrysomonads.

In contrast to the appreciable range of forms present at low densities, a few mainly small, species including the colonial blue-green *Aphanocapsa* and *Merismopedia* (both prokaryotes) exceeded 500 ml^{-1}. Unicellular forms of 1-2 µm tentatively classified as pico-cyanobacteria (also prokaryotes) have attained a value of more than 5000 ml^{-1}.

Excluding the populations of picoplankton, this loch appears to have manifested the higher biomass levels in August 1994 and June and September 1995. Minimum biomass appears to be more definitely focussed on March 1995. The effects, however, of sampling frequency on the interpretation of these and other results are considerable (see below).

4. Discussion

4.1 Algal quality

The number of species recorded throughout this study is very moderate (45), as are the 6-18 species recoded on each sampling occasion. Comparable attention to that paid here, to samples from rich waters such as Loch Leven and Loch Eye commonly yielded 20 to 30 species. The mixture of species is interesting in that it includes features more traditionally associated with richer waters, whereas the densities of algae and information on the nutrient status of the loch (e.g. Bailey-Watts, Kirika and Howell 1988) confirm its oligotrophic nature. Consider, as proposed by Nygaard (e.g. 1949), how the 'species' recorded are distributed between the major algal Classes: 8 'Myxophyceae' (Cyanophyceae); 10 Bacillariophyceae (with pennate forms dominating over centric species); 12 chlorococcalean Chlorophyceae; 4 Desmidiaceae and zero Euglenineae. Nygaard used 5 different ratios (quotients, which increase with trophic status) between these groups to classify waters. The quotients obtained from the tentative list of algae in Appendix II are as follows:

- 1.0 for the Myxophycean Quotient (i.e. Myxophyceae/Desmidiaceae)
- 3.0 for the Chlorophycean Quotient (i.e. Chlorococcales/Desmidiaceae)
- *ca* 1.0 for the Diatom (Bacillariophyceae) Quotient (i.e. Centrales/Pennales)

- 6.0 for the Compound Quotient (i.e. [Myxophyceae + Chlorococcales + Centrales + Euglenineae]/Desmidiaceae

Nygaard (1949) and Brook (e.g. 1965) consider the Compound Quotient to be the most reliable of these. Even taking into account the shortcomings already outlined regarding species identification, the value of 6 suggests 'a high degree of contamination' (Nygaard 1949). This apparent anomaly can be explained, however. Firstly, the original quotients were based on material collected with tow-nets. This would result in a more efficient trapping of large species than small forms - and thus a bias towards oligotrophic indicators, particularly desmids. Secondly, the earlier work would not have paid so much attention to small cyanobacteria - which feature very prominantly in the present samples and, as such, raise the quotients in which they feature. Thirdly, it cannot be assumed that all cyanobacteria indicate eutrophic conditions; indeed, visible blooms of these organisms are probably as common (though not as dense) in nutrient-poor systems as they are in eutrophic waters.

4.2 Algal abundance

In contrast to the quality of the algal assemblage, the population densities recorded place this loch firmly in the oligotrophic category. It is likely that chlorophyll concentrations corresponding to these samples are <5 $\mu g\ l^{-1}$. As far as this author is aware, however, there are few other data with which to compare the Katrine 'picoplankton' concentrations. Even in the unlikely event that the present population estimates of picoplankton and small-celled colonies of blue-green algae (i.e.>5000 ml^{-1}) represent only 70% of the true concentration (the others having been overlooked), these crops equate to approximately 0.001% of the density of similarly small blue-green algae in Loch Leven, for example (Bailey-Watts, Bindloss and Belcher 1968; Bailey-Watts and Komarek 1987).

4.3 Change in phytoplankton species and abundance

The combination of the large size and oligotrophic nature of this waterbody would suggest that massive and rapid changes in the nature of the plankton are unlikely (see e.g. Bailey-Watts and Duncan 1981; Bailey-Watts *et al* 1992a, b, and 1993; Gibson, Bailey-Watts and Foy, in press). It is thus all the more noteworthy that a number of the species recorded in the 1994-1995 samples also feature in the lists derived by West and West (1912), Bailey-Watts, Kirika and Howell (1988) and Bailey-Watts *et al* (1992). To emphasise the difficulties in identifying some of the organisms, however, the 1992 publication features *Monoraphidium*, while the present study prefers *Koliella*; similarly, *Staurodesmus subulatus* in the 1992 work is considered here to be *S. triangularis* var *parallelus*.

The 1994-1995 data have not yet been explored to ascertain the detailed 'succession' of species and the timing of the various maxima and minima. However, with one or two exceptions, the differences between the nature of the phytoplankton recorded in June 1994 and June 1995, are no greater than those between either of these months and the other sampling occasions.

4.4 A personal comment on the E.C.N. programme in the light of the present findings

The study has obviously yielded new information on the loch. It has possibly also examined the phytoplankton and interpreted the results more than hitherto. However, the identification of the organisms is far from satisfactory. Yet, one of the major requirements of the E.C.N. programme

is the accurate - or at least consistent - identification of the organisms, and a reasonable assessment of the population densities.This author thus recommends that the following points are stressed in future editions of the protocol for phytoplankton counts.

Particularly during the early stages of study on a particular waterbody, a fine-net concentrate of phytoplankton should be provided for live examination of the organisms; while Lugol's Iodine-fixed material has proved adequate in many aspects of phytoplankton assessment, this author's experience suggests that all algae are to varying extents subject to changes in the following features that are often of crucial taxonomic significance:

- alteration in colour
- distortion of chloroplast shape
- changes in overall shape - particularly in the case of 'metabolic' forms such as cryptomonads, euglenoids and many naked flagellates
- masking of certain organelles and intracellular contents; e.g. collapse of gas-vacuoles
- loss of flagella

Plainly too, preserved specimens cannot demonstrate the way in which a species, flagellum or haptonema moves.

Also in the early stages of the programme, regardless of pre-conceptions about (the lack of) variability, sampling frequency should be increased. Perhaps some thought should also be given to assessing spatial variation in such a large water body.

More discussion is necessary to establish consensus views (possibly site-specific) on the following, since they are likely to have a bearing on temporal and spatial frequency of sampling:

- what is meant by 'change' in the context of E.C.N. - what type of changes are to be considered, and to what degree is a change to be considered 'permissible'?
- is it possible that by the time a change viewed as undesirable (due to enhanced burdens of e.g. nutrients, acid ions, heavy metals) is detected, the focus has to shift from prevention to restoration? See e.g. Bailey-Watts, May and Lyle 1992; Bailey-Watts *et al* 1994, and in press).
- are the statutes/directives that initiated the E.C.N. activities, powerful enough to protect at least what are the more unique and special freshwater sites, in the face of 'economic' considerations?

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Appendix I: Codes used by the author for the computer logging of genera, species, varieties and forms of (primarily) algae.

ACTINASTRUM AM; A. hantzschii AMHI
ACTINOPHRYS ACT
AKANTHOCHLORIS AK
AMOEBOFLAGELLATE AMFL
ANABAENA AA; A.flos-aquae *forma* flos-aquae AAFA; A. flos-aquae *forma* treleasii AATI; A. solitaria AASO; A .spiroides AASP; A. affinis AAAF; A. circinalis AACS
ANKISTRODESMUS AS; A.falcatus ASFS; A. closterioides ASCS; since change to MONORAPHIDIUM, MO applies e. g. M. contortum MOC; M. griffithii MOG; M. minutum MOMM. See also QUADRIGULA.
ANKYRA AY; usually A. spatulifera AYS or A. lanceolata AYL
APHANIZOMENON AZ
APHANOCAPSA AN
APHANOTHECE AP usually A. clathrata, therefore APCA; APCC (cells); also A. alascense APAE
ASTERIONELLA formosa AB (COLONIES) & ABC (CELLS)
ASTEROCAELUM algophilum ACA (Protozoa)

BITRICHIA BI; B. longispina? BILA; B. phaseolus BIPS
BOTRYOCOCCUS BS; probably only 1 species - braunii - so BSBI

CENTRITRACTUS CB
CERATIUM CE; C. hirundinella CEHA
CHARACIUM CHA
CHLAMYDOCAPSA CIA
CHLAMYDOMONAS GF/GFL
CHILOMONAS CHL
CHLORELLA UG; 'groups of UG' UGC
CHLOROCOCCALES CC
CHLOROGONIUM CNM
CHODATELLA CA; C. ciliata CACA; C. genevensis CAGS C. longiseta CALA;
CHROMULINA YGF
CHROOCOCCUS CHC; C. limnetica CHCL
CHROOMONAS RS - so C. rubra RSRA
CHRYSOCHROMULINA CYS
CHRYSOCOCCUS CCCS
CHRYSOIKOS CYK
N.B. these last 2, both CY...
CLOSTERIOPSIS CF; C. acicularis CFAS
CLOSTERIUM CM; C. strigosum CMSG; C. limneticum CMLM; C. acutum *var* acutum CMAA; C. acutum *var* variabile CMAV; C. aciculare CMAC; C. kutzingii CMKI; C. setaceum CMST; C.parvulum CMPV C. turpinii CMTI
COELASTRUM CL; C. microporum CLMM
COLLODICTYON CN
COELOSPHAERIUM CQ; C. kutzingianum CQKM
COENOCHLORIS as C. pyrenoidosa CPA; C. ovalis CPO
COENOCOCCUS CW
COLONIAL CHRYSOPHYCEAE YGC (e. g. CHRYSOSACCUS?)
CORONASTRUM CR
COSMARIUM CO; C. botrytis COB; C. depressum *var* planktonicum CODP; C. orbicilare CORB; C. subundulatum COSM
CRUCIGENIA (and ?TETRACHLORELLA) CU; C. rectangularis CURS; C. quadrata CUQA; C. irregularis CUIS; C. tetrapedia CUTA
CRUCIGENIELLA CVXX
CRYPTOMONAS CS; C. erosa CSEA; C. marssonii CSMI; C. ovata CSOA; C. reflexa CSRA; C. phaseolus CSPS; C. curvata CSCA
CYATHOMONAS CJ; C.truncata CJTA
CYCLOTELLA CT; C. glomerata CTG; C. comta CTCA; C. pseudostelligera CTPS; C. spp. with different nos. of processes (5,7 and 9 etc.) observed in SEM and LM studies, CT5S, CT7S and CT9S etc.; these codes will

be modified if, and as, identifications are improved.
CYLINDROSPERMUM CYL
CYMATOPLEURA CMT
CYMBELLA CY

DACTYLOCOCCOPSIS DC
DESMATRACTUM DE; D. bipyramidatum DEBM
DIATOMA DA (COLONIES) & DAC (CELLS); normally D. elongatum DAEM
DICHOTOMOCOCCUS DS; D. curvatum DSCM
DICTYOSPHAERIUM DM; normally D. pulchellum DMPM
DIDYMOCYSTIS DI; D. planctonica DIPA AND D. inconspicua DIIA
DINOBRYON DY; D. divergens DYDV

ELAKATOTHRIX EX; E. gelatinosa EXGA
EUASTRUM EM; E. ansatum EMAM; E. bidentatum EMBM; E. denticulatum EMDM
EUCAPSIS ES
EUDORINA EA
EUGLENA EU

'FILAMENTOUS GREENS' FILG
FRAGILARIA FA; F. crotonensis FACS (colonies) FACC (cells); F.intermedia FAIA; F. brevistriata FABV; F. capucina FACA
FRANCEIA FR

GLENODINIOPSIS GN; G. steinii GNSI
GLOEOTHECE GC
GLOEOTILA GT; G. pelagica GTPA
GLOEOTRICHIA GL; G. echinulata GLEA
GOLENKINIA GO
GOMPHONEMA GO; G. acuminatum GOAM
GOMPHOSPHAERIA GA; G. compacta GACA; unicells GAUN
G.lacustris GALS
GONIUM GM
GYMNODINIUM GY; G. helveticum *var* achroum GYHA
GYROMITUS GS
GYROSIGMA GR

HALTERIA HALT (Protozoa, probably more likely to be STROMBIDIUM - 'STRO')
HETEROMASTIX HX
HOFMANIA HF
HORMIDIUM HM

N.B.! 'K' is not accepted as an initial letter of a species code, by the FTN programmes used for sorting and re-formatting the 'ALGA','PASS' and 'DIM' files, as it is used in connection with the factors used for converting cell counts and measurements to population densities and dimensions; the initial 'K' of each of the following organisms is thus replaced by 'Y' in these data files.

KEPHYRION KN/YN
KIRCHNERIELLA KA/YA; Y. contorta KACA; Y. lunaris KALS
KOLIELLA KO/YO; K. longiseta YOLA; K. spiculiformis YOSS

MALLOMONAS MS
MARSONIELLA ML
MELOSIRA MA; M. granulata MAG; M.g.angustissima MANG;
M. italica MAIT; M. ambigua MAA; where left as 'MA' in earlier years, assign now to 'MAG'
MERISMOPEDIA MR; M. tenuissima MRTA
MICRACTINIUM MM; M.pusillum MMPM;
MICROCYSTIS MIC (colonies), UB (cells) the latter with AA, GA unicells
MICROGLENA? MB
MONODUS MD
MONORAPHIDIUM MO - see Ankistrodesmus - M. contortum MOC; M. griffithii MOG; M. minutum MOMM;

M. convolutum MOVM; M. arcuatum MOAM
MONOSIGA MN
MOUGEOTIA MG

NANNOKLOSTER NN
NAVICULA NV
NEPHROCHLAMYS NS; N. subsolitaria NSSA
NEPHROCYTIUM NM
NEPHRODIELLA NA
NITZSCHIA NZ; N. closterium NZCM

OCHROMONAS OS
OOCYSTIS OO; O. lacustris OOL; O.parva OOPA;
OSCILLATORIA OA; O. limnetica OALA; O. agardhii OAAG; O. koeltzii OAKI; O. redekei OARI; O. rubescens OARS; O. geminata OAGA; O. bourrellyi OABI; O. mougeotii OAMI; N.B.: many Oscillatoria species have been trnasferred to new genera such as Limnothrix and Planktothrix, but the Oscillatoria codes have been retained here.

PANDORINA PD
PAULSCHULZIA PZ
PEDIASTRUM PM; P. boryanum PMBM; P. duplex PMDX; P. tetras PMTS
PENNATE DIATOM PENN
PERIDINIUM PE
PHACUS PH
PINNULARIA PI
PLANCTOMYCES FUNG
PLANCTONEMA PL
PLANKTOSPHAERIA SIX
POLYBLEPHARIS POLY
POLYTOMA (4-flagella) PY
PRASINOPHYTA PA
PROTOMONODALES PT
PROTOZOAN near type found first in L. Leven February 1969 - PROT
PSEUDANABAENA PUAA
PSEUDOSPHAEROCYSTIS PS; P. lacustris PSLS
PSEUDOSTAURASTRUM PR
PSEUDOTETRAEDRON PN

QUADRIGULA QAXX; Q. closterioides QACS (= Ankistrodesmus closterioides acc. to some authors)

RADIOCOCCUS RD
RAPHIDONEMA RA; R. longiseta RALA
RHABDODERMA RB; R. linearis RBLS
RHIZOSOLENIA RZ
RHODOMONAS RS; R. minuta RSM; R. minuta v. nanoplanctica RSMN
RHOICOSPHENIA RH

[**Rotifers**: Filinia ROFA; Kellicottia RORA; Keratella ROYA; Polyarthra ROPA; Trichocerca ROTA]

SCENEDESMUS SS; S. quadricauda SSQA; S. acuminatus SSAS; 2-cell SSII; S. ecornis SSEC; S. abundans SSAB; S. alternans SSNS; S.'brasiliensis' SSBS; S. acutus SSAS; S.dimorphus SSDS; S. tenuispina SSTA; S. pannonicus SSPS; S. serratus SSSS; S. subspicatus SSSU; S.verrucosus SSVS
SCHRODERIA SD; S. setigera SDSA
SELENASTRUM SL
SPHAEROCYSTIS SI; S. schroeteri SISI
SPONDYLOSIUM SP; S. planum SPPM
SPIROGYRA SG
STAURASTRUM SM; 'armless' form SM2; S. chaetoceras SMCS; S. cingulum SMCM; S. grande SMGE; S. inflex SMIX; S. longipes SMLS; S.longispinum SMLG; S. lunatum SMLM; S. megacanthus SMMG; S. muticum SMMM; S. pingue SMPG (SMPE sometimes); S. planktonicum SMPM; S. polymorphum SMPL better SMPO; S.polytrichum SMPY; S.pseudopelagicum SMPL; S.punctulatum SMPU

STAURODESMUS SB; S. megacanthus SBMS; S. convergens SBCV; S. dejectum SBDJ; S.subulatus SBSS; S. aversus SBAV; S. triangularis *var* parallelus SBTP; S. indentatus SBIS
STEINIELLA SN (cells SNC)
STEPHANOCODON SF
STEPHANODISCUS ST; a variety of species and/or types has been distinguished from LM and SEM studies (see e.g. Bailey-Watts 1986). Otherwise such forms are coded as CDL.
STICHOCOCCUS SH; S. bacillaris SHBS
SURIRELLA SR
SYNCRYPTA SYC
SYNECHOCOCCUS SCS for the form that was abundant in Loch Leven 1968 to 1971; in 1990 a ms. by Bailey-Watts and Komarek was submitted to Algological Studies, proposing S. capitatus *nov. spec.* SCCS). For a different form - prominent in Loch Leven autumn 1969 - the code SCSN is used; S.minutus SCMS
SYNEDRA SA; S. ulna SAUA; S. acus SAAS (sometimes, e. g. late 1980s on, SY... by mistake).
SYNURA SYU

TABELLARIA TA; T. fenestrata TAFA; T. flocculosa TAFC
TETRACHLORELLA TC; T. alternans TCAS
TETRAEDRON TE; T. caudatum TECM; T. minimum TEMM; T. platyisthmum TEPM
TETRAMORUS TT (?including EUTETRAMORUS)
TETRASPORA TG or TB
TETRASTRUM TM; T. staurogenaeiforme TMSE; T. glabrum TMGM
TINTINNOPSIS TN (Protozoa)
TRACHELOMONAS TL
TRACHYDISCUS TS
TREUBARIA TR

ULOTHRIX UX
UNICELLULAR CENTRALES CD; live CDL; dead CDD; and where parasitised, CDLP and CDDP

NON-FLAGELLATE UNICELLULAR CHRYSOPHYTE YGU

VOLVOCALES VO
VOLVOX VX
VORTICELLA VA

WESTELLA WA

XANTHIDIUM XM; X. antilopeum XMAM; X. cristatum XMCM

ZOOSPORES ZSP - GFZ for green flagellate zoospores

Appendix II. Algae recorded in samples taken on 6 occasions between June 1994 and December 1995 from the surface waters (0- to 15-m column) of Loch Katrine. Species grouped by algal Class.

In the following list, 'unidentified species' are those seen in very few numbers (just one specimen in many cases). The main algal grouping (Classes) is that of Bourrelly (1966, 1968, 1970), although retaining some features proposed by Christensen (1962). The following texts have also been consulted with the view to assigning organisms to species although as indicated in the main text, the majority of the names suggested must be viewed as tentative at this stage: Anagnostidis (1961), Anagnostidis and Komarek (1988), Ettl (1978), (Hindak (1978), Hustedt (1930), Korshikov (1953), Krammer and Lange-Bertolot (1991), Lind and Brook (1980) and Starmach (1966). Additional papers are cited below, with the view to reflecting as many as possible of the latest (continuing) taxonomic debates on certain species. For example, some of the organisms listed have been transferred to new, or other existing, taxa; an example is the *Aulacoseira* which for many decades was termed *Melosira* (Haworth 1988).

Cyanobacteria (blue-green 'algae')

Anabaena flos-aquae (mainly forma *flos-aquae* Ralfs *ex* Born *et* Flah). (AAFA).
Aphanothece (I am not completely convinced this is the form commonly assigned to *A. clathrata* W. *et* G.S. West (APCA); a possibility is *A. alascense*; also, some colonies could be of a small-celled *Microcystis* (MIC).
Cylindrospermum catenatum Ralfs *ex* Born *et* Flah). (CYL). So far, this is the nearest organism to which I can assign some small but otherwise characteristic fragments in these samples.
Dactylococcopsis sp. (DCXX).
Merismopedia species - near *M. tenuissima* Lemm. (MRTA).
Microcystis aeruginosa Kutz. *emend* Elenkin (MIC), but see *Aphanothece* above.
Unidentified *Oscillatoria* species *circa* 1.5 µm diameter (OAXX).
Unidentified picocyanobacterium *circa* 0.5 µm diameter (PICO).

Bacillariophyceae (diatoms):

Asterionella formosa Hassall (ABC).
Aulacoseira ambigua (Berk.) Lom-Legu. (MAXX).
Aulacoseira subarctica (O. Mull.) Haworth (MAIT).
unicellular Centrales (CDL or, if parasitised CDLP); the assemblage has yet to be checked for species composition.
Rhizosolenia longiseta Zacharias (RZLA).
Synedra sp., or single cell of *Fragilaria* sp. (SYFR).
Synedra acus Kutz. (SAAS).
Tabellaria fenestrata (Lyngb.) Kutz. (TAFA).
Tabellaria flocculosta ((Roth.) Kutz. (TAFC).
unidentified *Synedra* species

Euchlorophyceae ('green' algae)

Actinastrum (probably not *hantzschii*) Lagerh. (AMXX).
Botryococcus braunii Kutz. (BSBI).
Closteriopsis acicularis (G.M. Smith.) Belcher (CFAS/CFXX)
Crucigenia (near *C. tetrapedia* (Kirchn.) W. et G.S. West (CUTA).

Elakatothrix sp. (Probably not *E. gelatinosa* Wille). (EXXX).
Monoraphidium contortum (Thur.) Kom.-Legn. (MOCM).
Koliella spiculiformis (Visch.) Hind (YOSS). [So few features to focus upon in these samples; the organism may well be one of a number of other spindle-shaped 'green' algae, including the following that are also cited: *Ankistrodesmus closterioides* (Bohl.) Kors. (ASCS); *A. pfitzeri* (Schroed.) G. S. West (ASPZ; as well as those that are not listed such as *Monoraphidium griffithii* (Berk.) Kom-Legu.)].
Oocystis A.Br. (OOXX). [Not *Oocystis lacustris* Chod.]
2-cell *Scenedesmus* near *S. dimorphus* (Turp.) Kutz. (SSII)
Unidentified unicellular green algae (chlorelloid?). (UG).
Sphaerocystis schroeteri Chod. (G.M.Smith). (SISI).

Chrysophyceae ('yellow-green' algae)

Bitrichia sp. near *B. phaseolus* (Fott) Fott. (BIPS).
Chrysococcus sp. (CCCS).
Chrysolykos planctonicus Mack (CYK).
Dinobryon sp. (DYXX).
Species of *Chromulina* Cienk. (YGFS for ≤5 μm: YGFL for > 5 μm).
Species of *Mallomonas* Perty (MSXX).
Species of *Ochromonas* Wyss (OSXX).
Colonial chrysophyte species - not *Dinobryon* - (YGC).

Cryptophyceae

Mainly an assemblage of *Cryptomonas* (CSXX) with forms resembling *C. curvata* Ehrenb., *C. erosa* Ehrenb. and *C. ovata* Ehrenb., and of *Rhodomonas* Karsten including forms still known as *Rhodomonas lacustris* var *nanoplanktica* Skuja (see Lund 1962b) and *R. pusilla* Bachm.

Zygophyceae ('desmids')- see Lind and Brook (1980), and Ruzicka (1977)

Euastrum denticulatum (Kirch.) Gay (EMDM).
Staurodesmus triangularis (Lagerheim.) Teiling var *parallelus* (Smith) Thom. (SBTP).
Staurastrum chaetoceras (Schroed.) G. M. Smith. (SMCS).
Staurastrum cingulum (W. and G. S. West) G. M. Smith. (SMCM).

Appendix III: Species abundances: output from computerised handling of species and count data (see Robson and Bailey-Watts 1987).

Note: (i) 'KAT' denotes data for Loch Katrine.

(ii) day number assumes day 1 is 1.1.1968 (when routine algal work on Loch Leven commenced).

(iii) 'K' is the factor for converting the number of individuals counted (N) to abundances in numbers per millilitre.

Section 2 of the report gives information on how the conversion factors are derived and the organisms are counted.

060694 KAT	DAY NUMBER :	9649	
K=0.11			
SBTP	1.00	N * K =	0.1100
K=0.522			
CSXX	2.00	N * K =	1.0440
MAXX	3.00	N * K =	1.5660
ABC	4.00	N * K =	2.0880
TAFA	3.00	N * K =	1.5660
SYFR	1.00	N * K =	0.5220
YOSS	12.00	N * K =	6.2640
K=1			
YOSS	9.00	N * K =	9.0000
MSXX	1.00	N * K =	1.0000
TAFA	4.00	N * K =	4.0000
MAXX	1.00	N * K =	1.0000
SAXX	2.00	N * K =	2.0000
SBTP	1.00	N * K =	1.0000
AB	1.00	N * K =	1.0000
ABC	2.00	N * K =	2.0000
TAFC	1.00	N * K =	1.0000
K=5.4			
CUTA	1.00	N * K =	5.4000
RSMN	3.00	N * K =	16.2000
RZLA	6.00	N * K =	32.4000
SSII	1.00	N * K =	5.4000

040894 KAT	DAY NUMBER :	9708	
K=0.055			
TAFA	44.00	N * K =	2.4200
SBTP	6.00	N * K =	0.3300
MIC	1.00	N * K =	0.0550
SAAS	2.00	N * K =	0.1100
CFXX	1.00	N * K =	0.0550
BSBI	1.00	N * K =	0.0550
TAFC	2.00	N * K =	0.1100
K=0.522			
YOSS	73.00	N * K =	38.1060
TAFA	4.00	N * K =	2.0880
MRTA	1.00	N * K =	0.5220
APCA	14.00	N * K =	7.3080
SISI	1.00	N * K =	0.5220
AMXX	2.00	N * K =	1.0440
CSXX	1.00	N * K =	0.5220
K=5.4			
APXX	30.00	N * K =	162.0000
YOSS	3.00	N * K =	16.2000
MRTA	18.00	N * K =	97.2000
CDL	1.00	N * K =	5.4000
CDLP	3.00	N * K =	16.2000
SSII	3.00	N * K =	16.2000
XXXX	5.00	N * K =	27.0000
YOSS	14.00	N * K =	75.6000
OAXX	1.00	N * K =	5.4000

K=30

YGF	4.00	N * K =	120.0000
YGC	1.00	N * K =	30.0000
PICO	190.00	N * K =	5700.0000

060395 KAT DAY NUMBER : 9922

K=0.0733

AB	7.00	N * K =	0.5131
ABC	12.00	N * K =	0.8796
YOSS	41.00	N * K =	3.0053
SBTP	1.00	N * K =	0.0733

K=5.4

MSXX	1.00	N * K =	5.4000
RSMN	3.00	N * K =	16.2000

K=16

YGF	16.00	N * K =	256.0000

190695 KAT DAY NUMBER : 10027

K=0.1375

AB	11.00	N * K =	1.5125
ABC	26.00	N * K =	3.5750
MAXX	1.00	N * K =	0.1375
TAFA	39.00	N * K =	5.3625
TAFC	3.00	N * K =	0.4125
DYXX	1.00	N * K =	0.1375
BSBI	2.00	N * K =	0.2750

K=0.4483

YOSS	152.00	N * K =	68.1416
RSMN	36.00	N * K =	16.1388
MSXX	4.00	N * K =	1.7932
CSXX	5.00	N * K =	2.2415
EMDM	1.00	N * K =	0.4483

K=3.333

APCA	144.00	N * K =	479.9520
YGF	6.00	N * K =	19.9980
RZLA	4.00	N * K =	13.3320
XXXX	1.00	N * K =	3.3330

K=16

UG	10.00	N * K =	160.0000
RZLA	10.00	N * K =	160.0000
YGF	3.00	N * K =	48.0000
CYK	1.00	N * K =	16.0000
YGF	10.00	N * K =	160.0000

120995 KAT DAY NUMBER : 10112

K=0.07

CFXX	5.00	N * K =	0.3500

K=0.03

AAFA	3.00	N * K =	0.0900
BSBI	3.00	N * K =	0.0900
SBTP	2.00	N * K =	0.0600

K=0.667

YOSS	111.00	N * K =	74.0370
RSMN	48.00	N * K =	32.0160
SISI	1.00	N * K =	0.6670
MOCM	2.00	N * K =	1.3340
MSXX	3.00	N * K =	2.0010
SBTP	1.00	N * K =	0.6670
SMCS	1.00	N * K =	0.6670
SMCM	1.00	N * K =	0.6670

K=5.4

EXXX	1.00	N * K =	5.4000
MRTA	64.00	N * K =	345.6000

K=6.94

CYL	6.00	N * K =	41.6400
APCA	90.00	N * K =	624.6000

K=30

XAAA	6.00	N * K =	180.0000
YGF	4.00	N * K =	120.0000
OOXX	5.00	N * K =	150.0000
BIPS	4.00	N * K =	120.0000

041295 KAT DAY NUMBER : 10195

K=0.11			
BSBI	1.00	N * K =	0.1100
MAXX	2.00	N * K =	0.2200
AB	1.00	N * K =	0.1100
ABC	7.00	N * K =	0.7700
K=0.5216			
YOSS	48.00	N * K =	25.0368
CSXX	6.00	N * K =	3.1296
RSMN	3.00	N * K =	1.5648
K=4			
RZLA	6.00	N * K =	24.0000
RSMN	2.00	N * K =	8.0000
K=20			
UGXX	44.00	N * K =	880.0000
YGLF	5.00	N * K =	100.0000
SSII	41.00	N * K =	820.0000
YGFS	6.00	N * K =	120.0000
XBBB	6.00	N * K =	120.0000
CDLX	7.00	N * K =	140.0000