Loch Leven 2000: physical, chemical and algal aspects of water quality

Report No. F99LH08

Report to the Scottish Environment Protection Agency
and Scottish Natural Heritage

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COMMISSIONED REPORT

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BACKGROUND

Loch Leven is highly eutrophic and has suffered from periodic cyanobacterial blooms. These blooms have a direct impact on the various users of the loch and an indirect impact on the local economy. They also reduce light penetration into the water, reducing macrophyte growth, and may, on occasion, pose a potential risk to human health.

This report is one of a series of reports that describe and interpret physical, chemical and phytoplankton information from Loch Leven on an annual basis.

MAIN FINDINGS

In spite of significant reductions in phosphorus loadings since 1972, phytoplankton crops in Loch Leven remained high in 2000. This is illustrated by an annual mean chlorophyll$_a$ value of 33.1 µg l^{-1} and an annual mean total phosphorus (TP) concentration of 52.0 µg l^{-1}. These values exceed the statutory target values set by the Loch Leven Area management Group (LLAMAG) in 1993

75 planktonic species were recorded. Four diatoms dominated the phytoplankton for most of the year. These were *Aulacoseira italica*, *Asterionella formosa*, *Diatoma elongatum* and an assemblage of unicellular centric species comprising *Stephanodiscus* spp. and *Cyclotella* spp., but mainly consisting of *Stephanodiscus hantzschii*.

Approximately 10 species of cyanobacteria were recorded during the year. The number of occasions warranting the display of notices warning of toxic algae was 13 out of a total of 38 sampling visits.

The nutrient ratios (SiO_2:NO_3.N:SRP) and SiO_2 concentrations at the end of 2000 were 143:100:1 and 2.5 mg l^{-1}, respectively. These values suggest that green algae and/or cyanobacteria, rather than diatoms, will dominate the phytoplankton in spring 2001.

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1 INTRODUCTION

Loch Leven is the largest eutrophic freshwater body in Scotland. It has suffered from periodic cyanobacterial blooms for many years. These have occurred, largely, as a result of large amounts of phosphorus entering the loch, combined with a relatively low flushing rate and a favourable light-climate (Bailey-Watts and Kirika 1999). Such blooms have a direct impact on the various users of the loch and an indirect impact on the local economy. They also reduce light penetration into the water, reducing macrophyte growth, and occasionally pose a potential risk to human health. Recent management of Loch Leven has aimed at reducing the risk of these blooms occurring by reducing the loadings of phosphorus into the loch (Bailey-Watts and Kirika 1999; Loch Leven Catchment Management Project 1999).

Annual monitoring and evaluation of the status of the phytoplankton populations in Loch Leven is regarded as an important part of the assessment of water quality and ecological recovery. Frequent reporting on the status of the loch's phytoplankton populations is also invaluable in providing an early warning of the occurrence of severe cyanobacterial blooms that may be toxic to both people and animals.

This report describes and interprets phytoplankton as well as physical, chemical information from Loch Leven for the year 2000. Temporal and spatial variation in a number of key factors and interactions among them are discussed. The data are also evaluated in relation to changes in water quality following the recent reductions in phosphorus load to the loch. Evidence of ecological recovery is also discussed.

2 METHODS

During 2000, water samples were collected at weekly intervals from the beginning of March to early September, and fortnightly intervals during the other months. This amounted to a total of 38 sampling visits. Four sampling sites on the loch were used. The most representative sampling location was the 'Reed Bower' (RB) site which lies to the south of the island of that name, where the water depth is similar to that often cited as the mean depth of the loch i.e. 3.9m. However, at times of very rough weather, ice cover or other unfavourable conditions, a site at the Public Pier (PP) in the Kirkgate Park was used instead. On all sampling occasions the outflow site ('L') was sampled, this being accessible from the land or by boat. The South Deeps (SD) site, at approximately 25m depth, was visited occasionally.

For each sample site, and on each sampling occasion, the phytoplankton populations were assessed to determine their abundance and species composition. In addition, a number of physical and chemical variables (water temperature, level and clarity, dissolved oxygen, conductivity and pH) and nutrient concentrations (silica, nitrogen and phosphorus) were also measured. Field sampling and laboratory analyses followed the methods adopted over the last 30 years (Bailey-Watts and Kirika 2000), with the exception of those for inorganic nitrogen (N). In this report, total oxidised nitrogen (TON) values, supplied by the Scottish Environment Protection Agency (SEPA), were used. This is in contrast to previous reports that utilised the values for nitrate-nitrogen ($NO_3.N$) determined by the Centre For Ecology and Hydrology (formerly the Institute of Freshwater Ecology). It should also be noted that the 'whole water-column' samples, collected with an integrated tube sampler at the Reed Bower site, usually extended from the water surface to around 0.25 m above the sediment surface. As a result of fluctuations in water level brought about by the control of the outflow, sample depths varied from three to four metres.

3 RESULTS

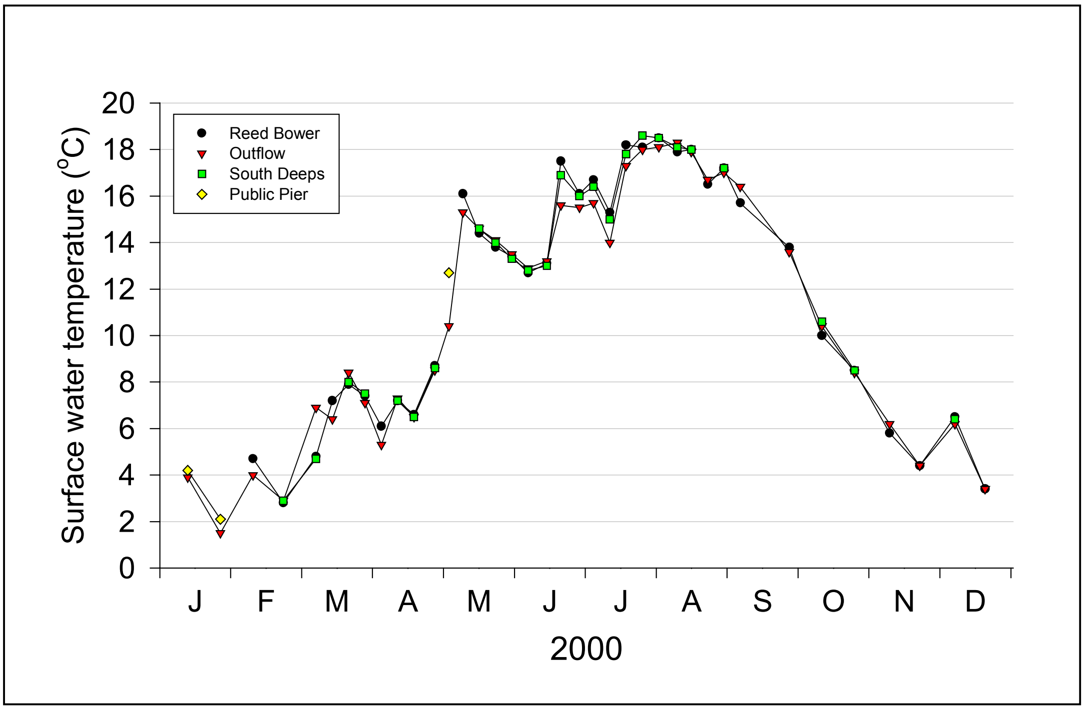
3.1 Physical factors

3.1.1 *Water temperature*

Variation in water temperature followed a generally simple pattern over the year with a maximum of 18.6^{o}C being recorded at SD on the 25 July 2000 (Figure 1). Intermittent rises and falls in temperature over the first three months were followed by a continuous rise of almost 10 degrees Celsius from mid April to early May. Unlike the previous year, the maximum temperature was achieved only after a couple of dips of almost four degrees each in May and late June to July. A fairly prolonged warm spell saw the surface temperature maintained at 18^{o}C or over for about a month from mid-July to mid-August. In contrast to the step-wise increases in temperature, the loch cooled at a more regular rate from the end of August to the end of the year, although the fortnightly sampling intervals during this period may mask a more complex picture. It is worth noting that the more-or-less uniform temperature over the whole lake, as illustrated by the similarity in readings from the four sampling sites (Figure 1).

From the temperature data described above, it is likely that releases of soluble reactive phosphorus (SRP), and possibly of silica too, would be observed during mid-July and late August. Information presented below (see Section 3.2.6) shows that these predictions were generally upheld, especially for SRP.

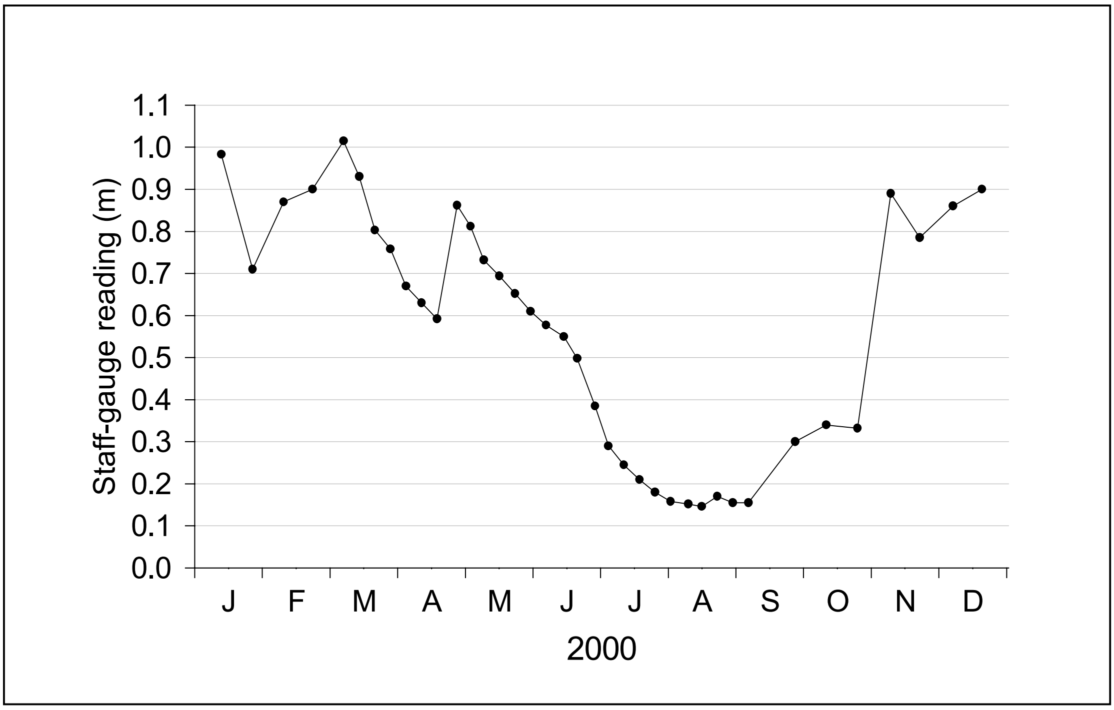
Figure 1 Spatial and temporal variation in surface water temperature



3.1.2 *Water level*

Water-level fluctuated by approximately 0.85 m (i.e. approximately 20% of the mean depth of the loch) during 2000 (Figure 2). A first group of four level changes ranged over 0.4 m between the beginning of the year and the end of April. This was followed by a gradual, and almost linear, fall in water level extending from mid May to the end of August. This was followed by a period of increasing water level so that, by the end of December, a value slightly higher than that recorded at the end of April had been restored. Most of this increase was achieved over a few days at the end of October. This highlights the amplification of any natural, weather-influenced effects (i.e. rainfall) by the control exercised over the outflow. Weekly or fortnightly excursions in water level of 10-20cm may not, in themselves, represent a major environmental change. However, the much greater shifts such as those outlined above, are likely to trigger major physical, chemical and biological (algal) changes in the loch.

Figure 2 Water level fluctuation at the Harbour



3.1.3 *Water clarity*

The months of May and June in 2000 were remarkable with regards to water clarity. Secchi disc readings over most of that period exceeded 3.5 m (Figure 3) - a value comparable to the mean depth of the system. This is the most consistent spell of 'clear' water for some considerable time. The annual mean Secchi disc reading over the year was 1.83m.

Casual observation also suggests that water clarity may have increased in the loch in recent years. During a sampling visit on 14 March 2000, a section of root was raised from the sediments by the boat anchor at the RB site potentially indicating that submerged macrophytes may have extended into previously 'uninhabited', deeper, waters. This is the first time, to the authors' knowledge, that rooted vegetation has been recorded at this site.

Figure 3 Water clarity (expressed as Secchi disc transparency) at the Reed Bower sampling site

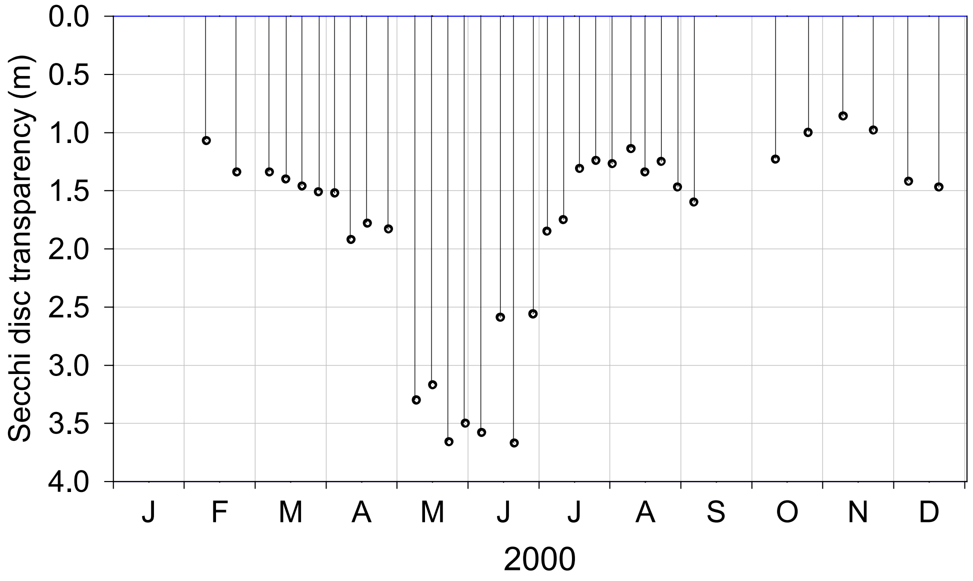
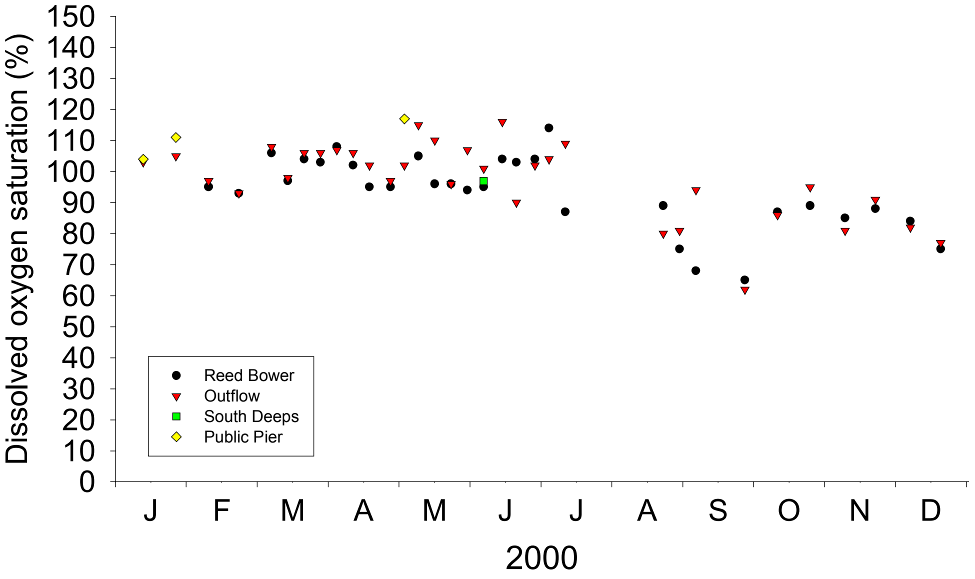


Figure 4 Dissolved oxygen concentrations at ambient water temperatures



3.2 **Chemical factors**

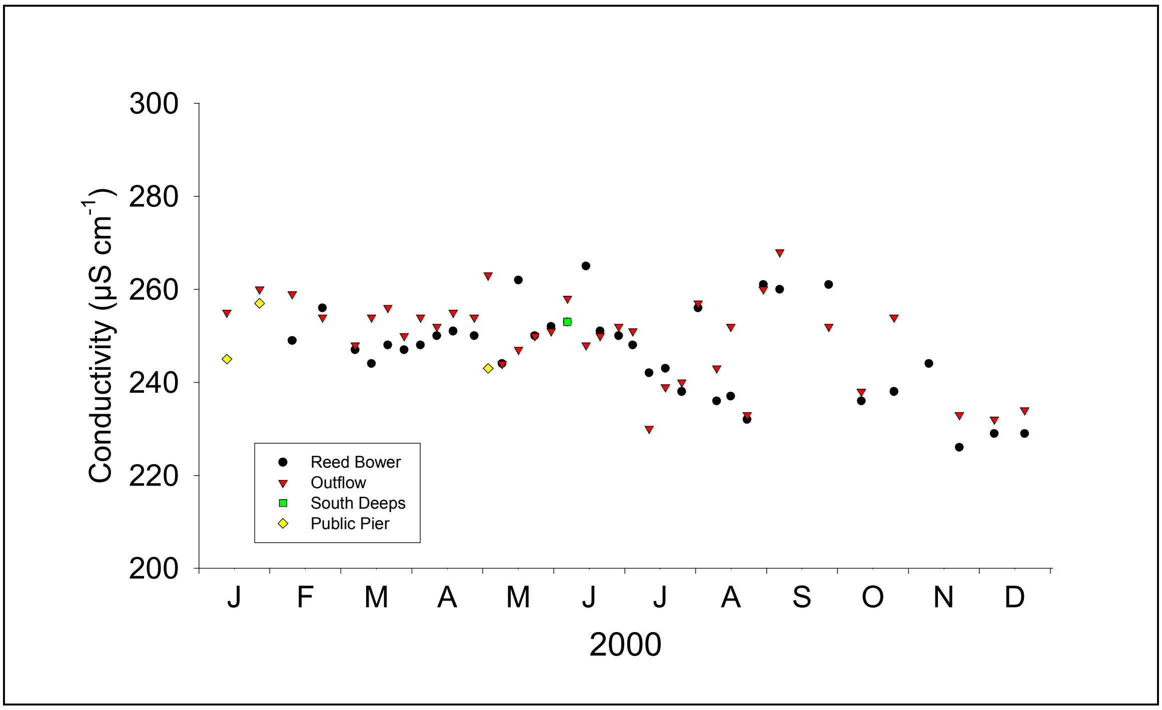
3.2.1 *Dissolved oxygen*

Although 10 values of less than 80% dissolved oxygen (DO) saturation were recorded during the last quarter of the year, the mean annual percentage DO saturation in the surface water at the Reed Bower sampling station was 93.4% (Figure 4). The loch is, therefore, generally well-supplied in this environmentally important element. However, no measurements of oxygen levels lower down in the water column were made during this study. Here, there could be potential decreases in DO concentrations during transient periods of thermal stratification.

3.2.2 *Conductivity*

Figure 5 features the temperature-compensated conductivity values recorded at the four sampling sites. The data fall within a relatively small range of between 230 µS cm^{-1} to 260 µS cm^{-1} and, as such, are not unusual in the context of previous years' measurements. The values are, nevertheless, relatively high due to maritime influences on the loch. The fluctuation in values reflects changes in patterns of rainfall, wind direction and loch volume.

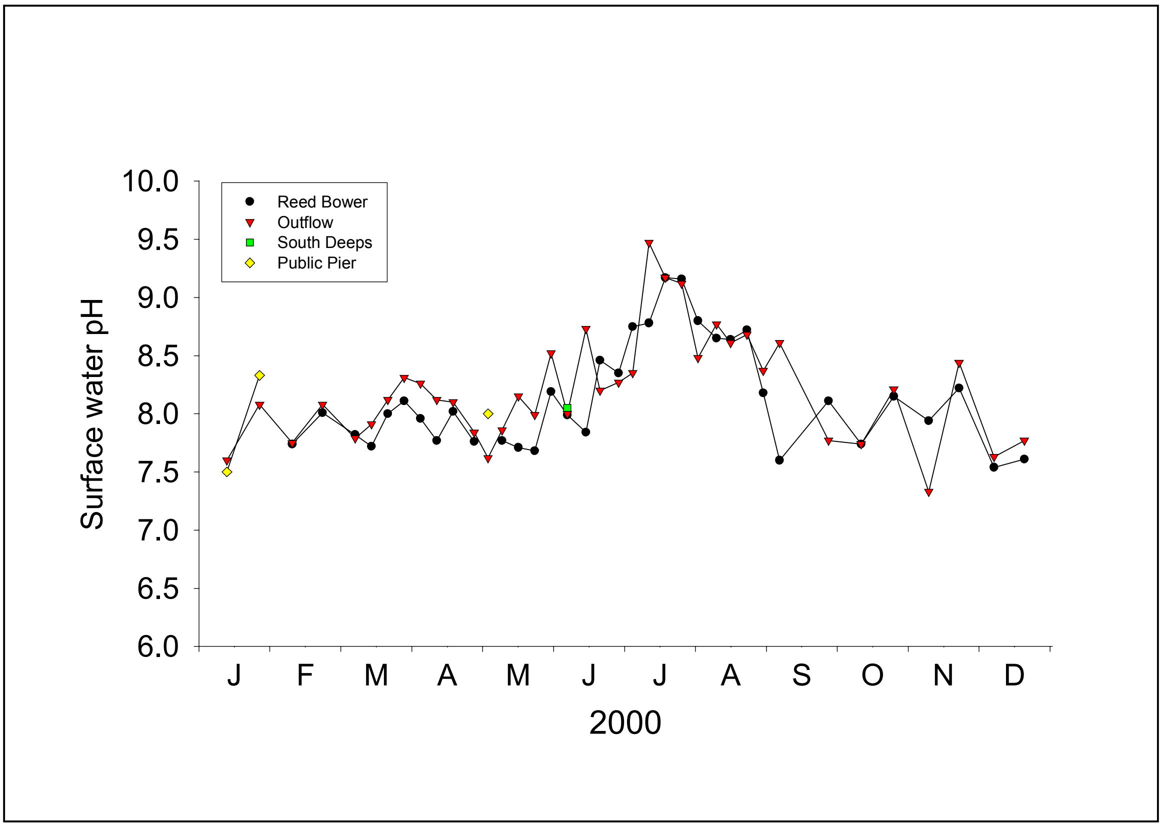
Figure 5 Electrical conductivity at ambient water temperature



3.2.3 *pH*

The range of pH values exhibited was fairly standard for the loch in recent times, generally falling between pH 7 and pH 8, with values as high as pH 9.5 - pH 10 during surface algal blooms in the summer. In 2000, the maximum and near-maximum values coincided with a substantial summer phytoplankton crop but not with the densest algal stand, which developed in the autumn.

Figure 6 Temporal and spatial variation in pH at ambient water temperature

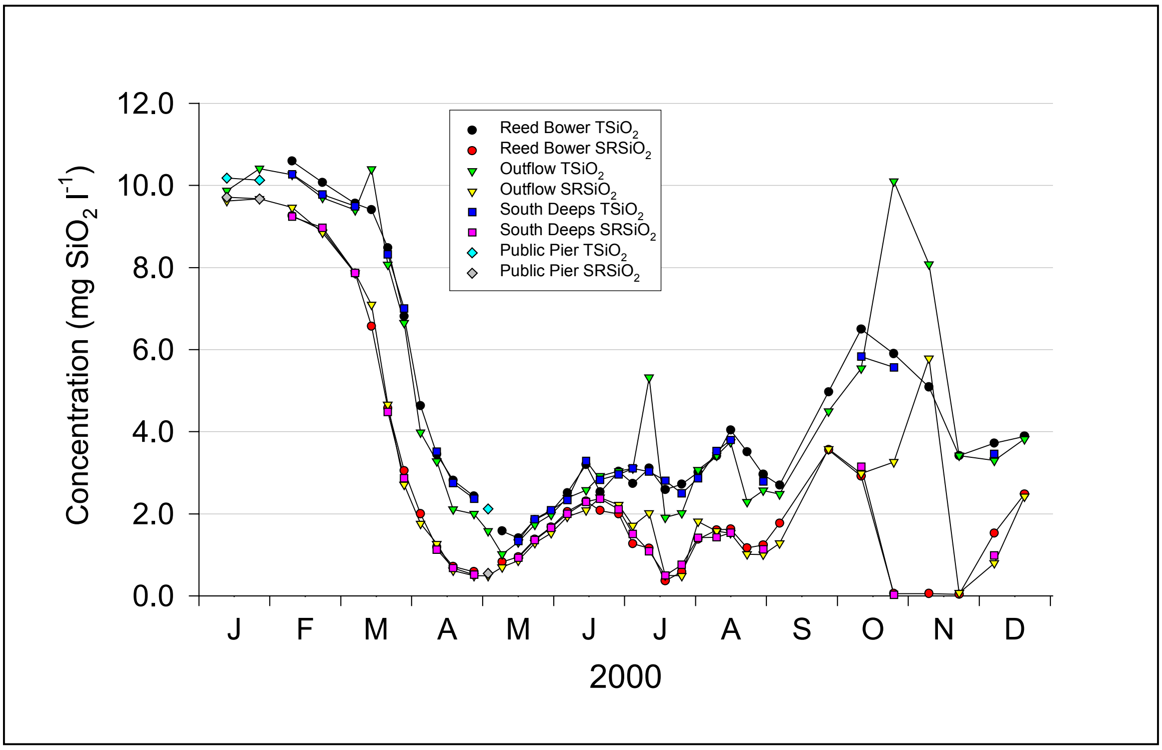


3.2.4 *Total silica and soluble reactive silica*

Silica, in the form of soluble reactive silica ($SRSiO_2$) is, at times, by far the most abundant of the three main nutrients whose availability effects temporal changes in the abundance and species composition of the phytoplankton. This section examines temporal and spatial variations in both $SRSiO_2$ and total silica ($TSiO_2$), which, in this context, is taken as $SRSiO_2$ plus opaline (non-crystalline) silica. The latter is mainly incorporated in diatoms, but also occurs in scale-bearing chrysoflagellates, for example. As with concentrations of nitrate-N and phosphate-P, $SRSiO_2$ values represent the instantaneously available nutrient resource that can be, potentially, taken up by the diatoms *etc*.

The dynamics of dissolved silica during 2000 (Figure 7) illustrate a number of features. The first is the wide range in silica concentrations recorded, from a high of around 10 mg l^{-1} to virtually zero. The second is the relative similarity in the spatial and temporal patterns of the total and dissolved silica concentrations over much of the year. Where differences occur, these indicate a substantial production of diatom biomass. An example of this can be seen at the end of March, when differences as high as 4-5 mg l^{-1} were recorded (Figure 7). Following the decline of the spring diatom crops (Figures 15 and 16) that had virtually exhausted the near 10 mg l^{-1} present at the start of the year, dissolved silica levels began to recover throughout May and into early June. The second half of the year was characterised by fluctuations in both $SRSiO_2$ and $TSiO_2$ concentrations, as successive diatom populations waxed and waned. Dissolved silica levels were reduced to values close to the limits of detection from late October to the middle of November as the result of a massive increase in a unicellular centric diatom population (Figure 20). The more exaggerated fluctuations in both the dissolved and total fractions recorded at the outflow (especially in early July, and in October and November) are attributable to re-suspension of benthic material by wave-induced disturbance in the shallow water at that site.

Figure 7 Spatial and temporal variation in concentrations of total silica ($TSiO_2$) and soluble reactive silica ($SRSiO_2$)

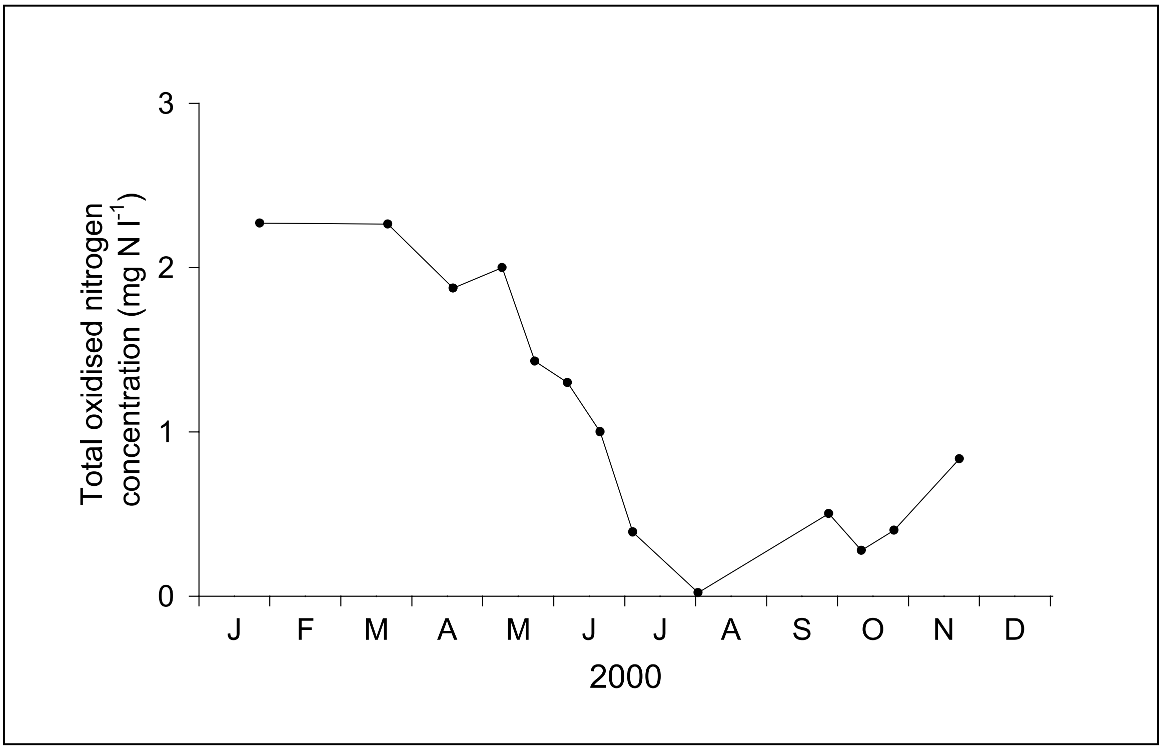


3.2.5 *Total oxidised nitrogen*

Patterns of change in the majority of the physical, chemical and algal factors considered in this report, can vary considerably from year to year. However, the seasonal pattern of change in NO_3.N/TON levels tends to be much the same each year - even if the concentration maxima and minima differ. For example, the annual minimum TON value of 0.02 mg N l^{-1} recorded on 3 August 2000 (Figure 8) compares very closely with the minimum value of 0.05 mg N l^{-1} recorded on 1 August 1999. There is, however, one major difference between these years. Whilst the first sample taken in 2000 yielded a concentration of approximately 2.5 mg N l^{-1}, the equivalent for 1999 was only 1.2 mg N l^{-1}.

As outlined by Bailey-Watts and Kirika (2000), the timing and magnitude of the annual summer draw-down in nitrate depends on the temperature at the sediment water interface. In Loch Leven, this is usually very similar to that of the surface water. Nitrate draw-down accelerates with rising temperatures due, primarily, to enhanced bacterial de-nitrification and consequent reducing (anoxic) conditions at the sediment surface. This results in a lack of nitrate in the water column which, together with reducing conditions, often triggers a release of soluble inorganic phosphorus from the sediments. Such conditions can then promote the production of N-fixing cyanobacteria such as *Anabaena* spp. Figures 1 and 8 show the periods when nitrate draw-down and rising temperatures co-incided.

Figure 8 Temporal variation in concentrations of total oxidised nitrogen at the Reed Bower sampling site



3.2.6 *Soluble reactive phosphorus*

Soluble reactive phosphorus (SRP) concentrations remained low (usually less than 5 µg l^{-1}) for the first seven months of 2000 (Figure 9). Much of this was due to the substantial biomass of planktonic diatoms recorded during this period. SRP concentrations increased at the beginning of August due to release from the sediments (Figure 9). This release, which occurred as soon as nitrate levels declined (and as predicted in Section 3.1.1) was both prolonged (*ca*. 4 weeks) and of substantial magnitude (*ca*. 25-30 µg P l^{-1}). Within four weeks, it had promoted an increase in algal biomass - mostly of centric diatoms - and, consequently, the open water concentrations of SRP fell to 5 µg P l^{-1} (Figure 9). The sudden increase in SRP concentration recorded at the outflow site, only, in early November was mirrored by a corresponding increase in $SRSiO_2$ (see Section 3.2.4). This suggested that the cause of this was wind-induced disturbance of the sediment.

3.2.7 *Total soluble phosphorus*

The trends in total soluble phosphorus (TSP) concentration shown in Figure 10, largely parallel those of the soluble reactive component. However, whereas SRP levels fluctuated between 2 µg P l^{-1} and 8 µg P l^{-1} over the first seven months of the year, TSP levels varied between 13 µg P l^{-1} and 35 µg P l^{-1}. Thus, there was considerably more soluble organic P than inorganic P in the water column over that period. Much the same situation prevailed over the remaining months, with SRP values ranging from 5 µg P l^{-1} to 39 µg P l^{-1} while TSP concentrations varied between 18 µg l^{-1} and 48 µg l^{-1}.

Figure 9 Spatial and temporal variations in concentrations of soluble reactive phosphorus

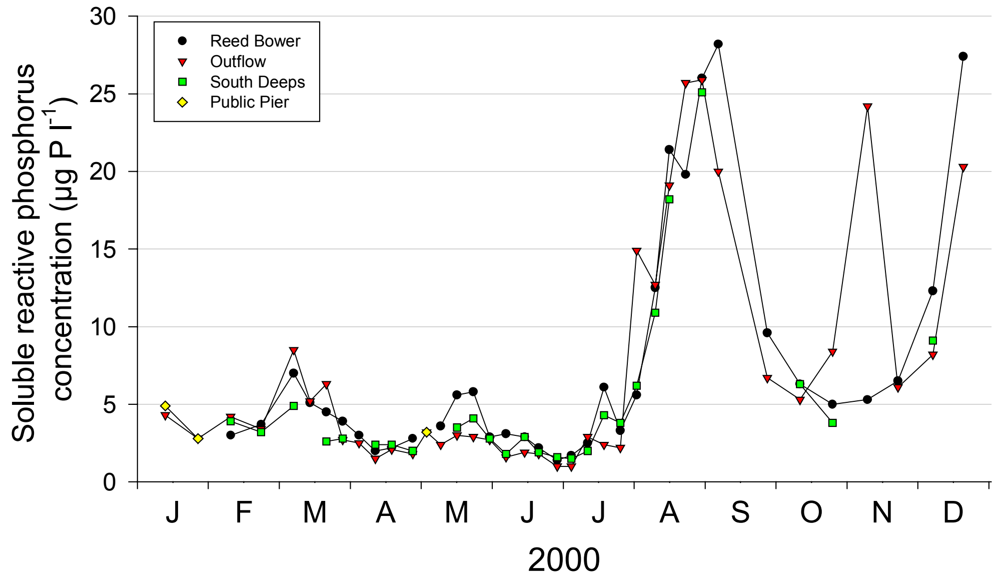
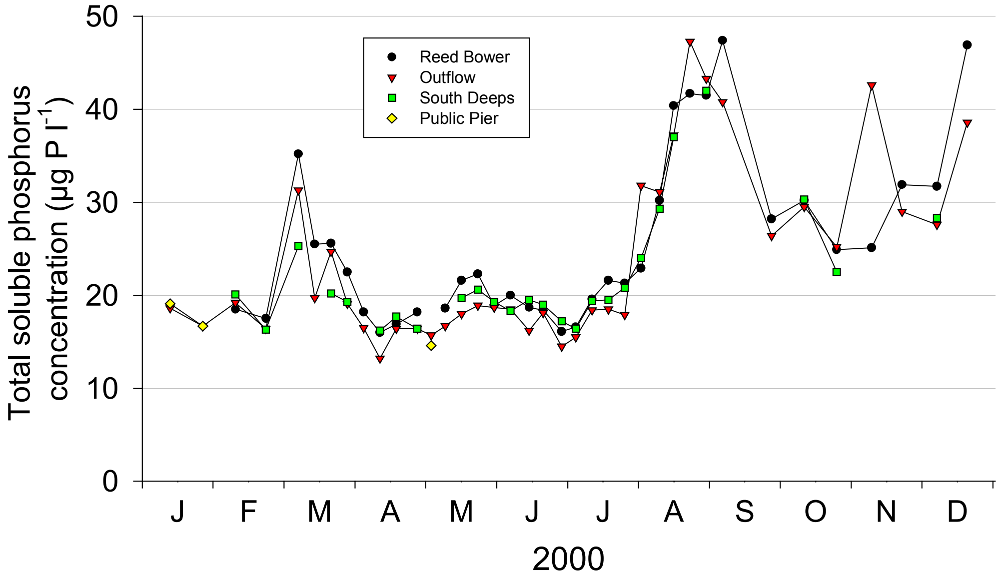


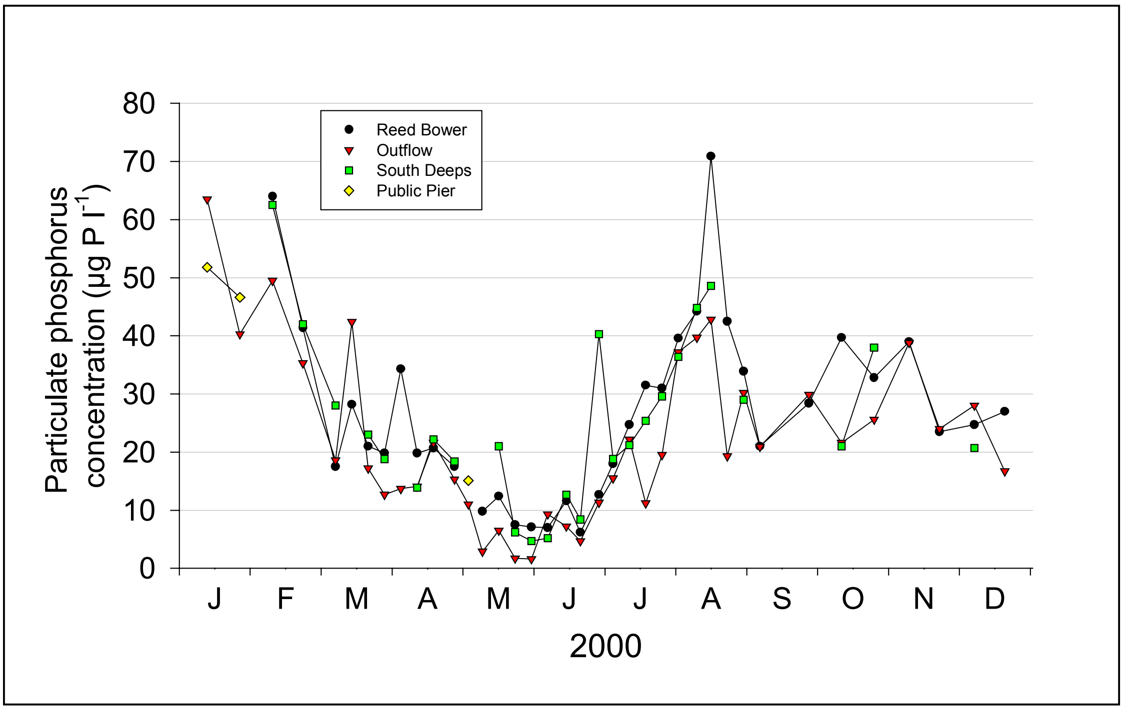
Figure 10 Temporal and spatial variation in concentrations of total soluble phosphorus



3.2.8 *Particulate phosphorus*

Variations in particulate phosphorus (PP) concentrations in 2000 are shown in Figure 11. The values recorded reflect the phosphorus content of all phosphorus-containing particles in the water-column, including detritus, re-suspended sediments, algae and zooplankton. The rich assemblages of phytoplankton characterising Loch Leven over much of the year account for much of this PP and, as a general rule, temporal patterns in PP concentrations follow those of chlorophyll$_a$ (compare Figures 11 and 13, particularly the period from March to the end of August). Exceptions to this 'rule' occur during windy weather as this disturbs the sediments and causes particles to become re-suspended in the water column.

Figure 11 Temporal and spatial variation in levels of particulate phosphorus



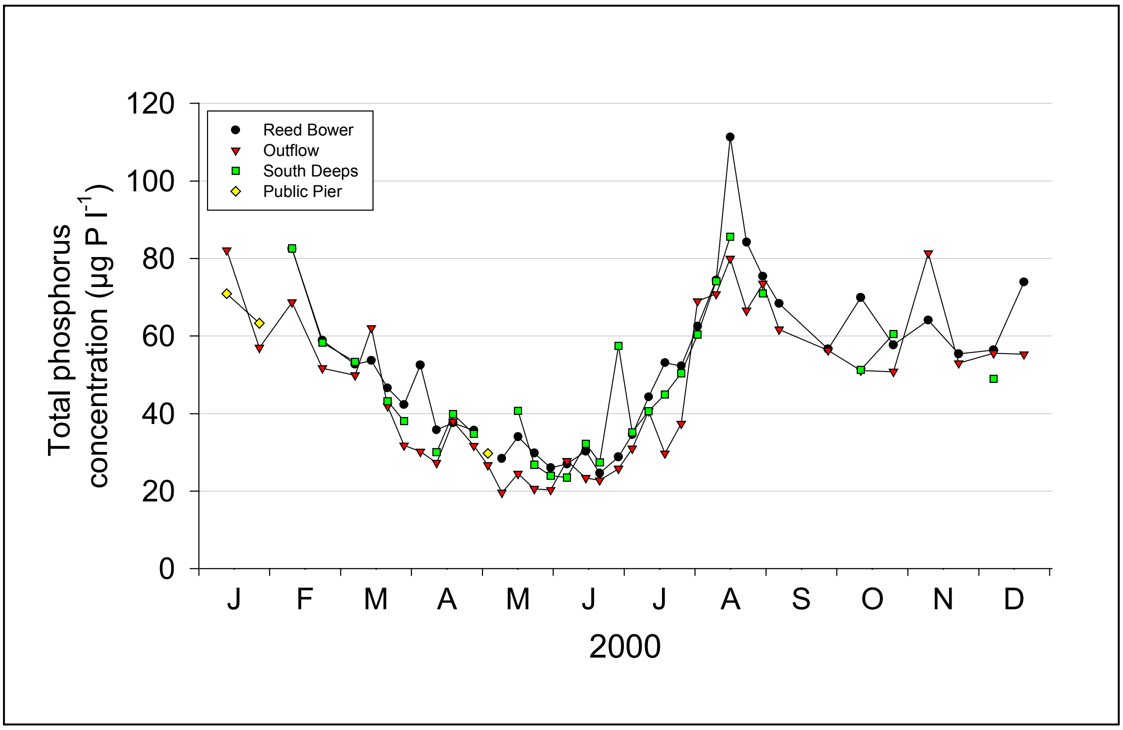
Inter-specific cellular pigment and phosphorus contents results in variable PP:pigment ratios. This was clearly illustrated in October and November 2000. An increase in chlorophyll$_a$ concentration, due largely to centric diatoms (Figures 13 and 20) was not matched by a corresponding increase in particulate P. This suggests that, for a period, the average cell P content decreased and was eventually exhausted; indeed the diatom population crashed soon afterwards. Ratios can, nevertheless, remain within a narrow band where there is available phosphorus and the phytoplankton is dense and dominated by a single species. Some examples of dense, mono-specific crops of algae are described later in this report.

3.2.9 *Total phosphorus*

Total phosphorus (TP) concentrations provide a simple index of lake trophic status. The data for 2000 (Figure 12) yield minimum, mean and maximum values of 24.6 µg P l^{-1}, 52.0 µg P l^{-1} and 111.3 µg P l^{-1}, respectively. The mean TP concentration recorded is higher than the target mean annual TP concentration of 40 µg P l^{-1} set by the Loch Leven Area management Group (LLAMAG) in 1993 (LLAMAG 1993) and endorsed in the Loch Leven Management Plan (Loch Leven

Catchment Management Project 1999). This suggests that the loch has yet to exhibit conclusive evidence of a reversal in the trend of eutrophication. However, the absence of any outflow (flushing) data makes it impossible to say whether the observed TP levels were due to continuing inputs from the catchment or whether they had occurred in response to increased P retention as a result of a particularly low flushing regime.

Figure 12 Temporal and spatial variation in concentrations of total phosphorus

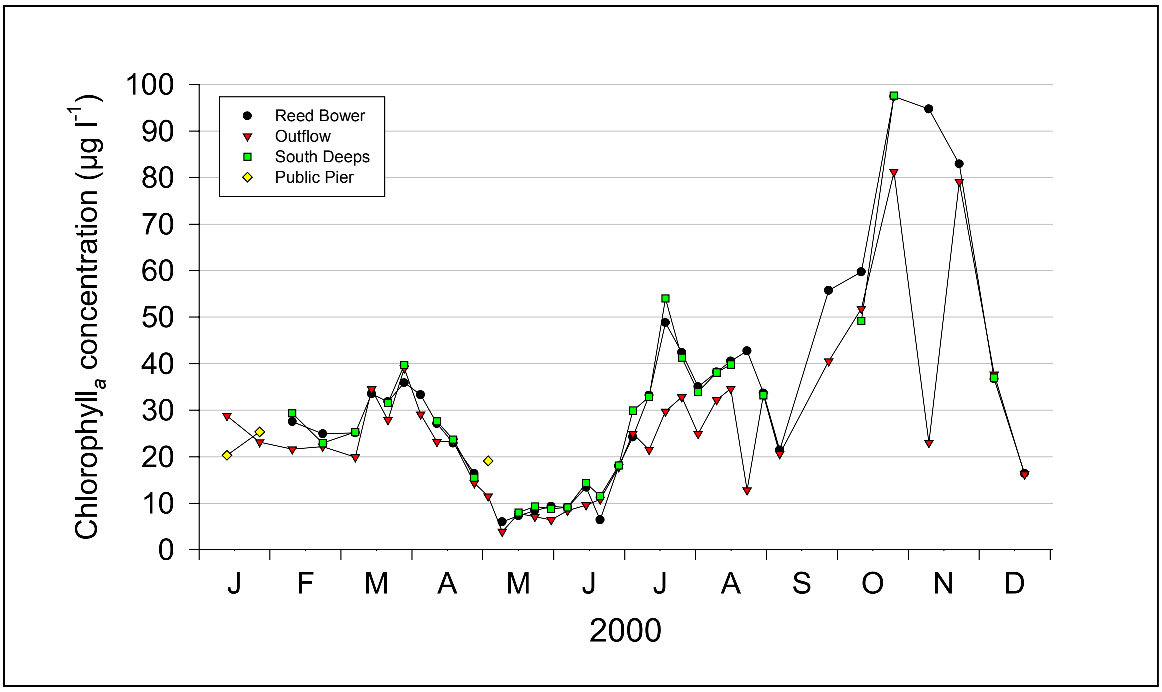


3.3 **Phytoplankton**

3.3.1 *Chlorophyll$_a$*

Although the long-term records were not examined in any detail, the pattern of changes in phytoplankton biomass (estimated as chlorophyll$_a$ concentration) observed in 2000 was somewhat rare. In most years, including 1999, the major phytoplankton pulse is observed in February or March as day length increases and when nutrient levels are generally high. The main algae involved are usually diatoms of one type or another. In 2000, however, the main crops of algal plankton developed in October, although still in the form of small centric diatoms (see below). The species dominating the crop in the early part of the year were filamentous algae – the cyanobacterium *Oscillatoria* in January and February (Figure 14), and the diatom *Aulacoseira* (Figure 15) providing the bulk of the relatively modest spring maximum of 40 µg l^{-1} of chlorophyll$_a$ in late March. Throughout April, the chlorophyll$_a$ levels declined, reaching an annual low of 6 µg l^{-1} by early May, with little change until the end of June. By mid-July, however, the concentration had reached the summer peak of 50 µg l^{-1}, with the phytoplankton assemblages now comprising non-filamentous forms such as *Asterionella*, *Gomphosphaeria*, and *Diatoma* (Figures 16, 17 and 18). In terms of biomass (as indicated by chlorophyll$_a$ concentrations), the period of greatest algal growth occurred from September through to November with the production of a large population of unicellular centric diatoms, more usually associated (as already mentioned) with the spring diatom crop. The chlorophyll$_a$ levels, having peaked at 97 µg l^{-1} in late October, then went into decline (as conjectured in Section 3.2.8) reaching 16 µg l^{-1} in the second half of December. The general pattern in 2000 was in sharp contrast to 1999 which saw an overall decrease in chlorophyll$_a$ concentrations from around 80 µg l^{-1} at the beginning of the year to the 20 to 30 µg l^{-1} that marked the start of 2000.

Figure 13 Temporal and spatial variation in chlorophyll$_a$ concentration (used as an index of total phytoplankton biomass)

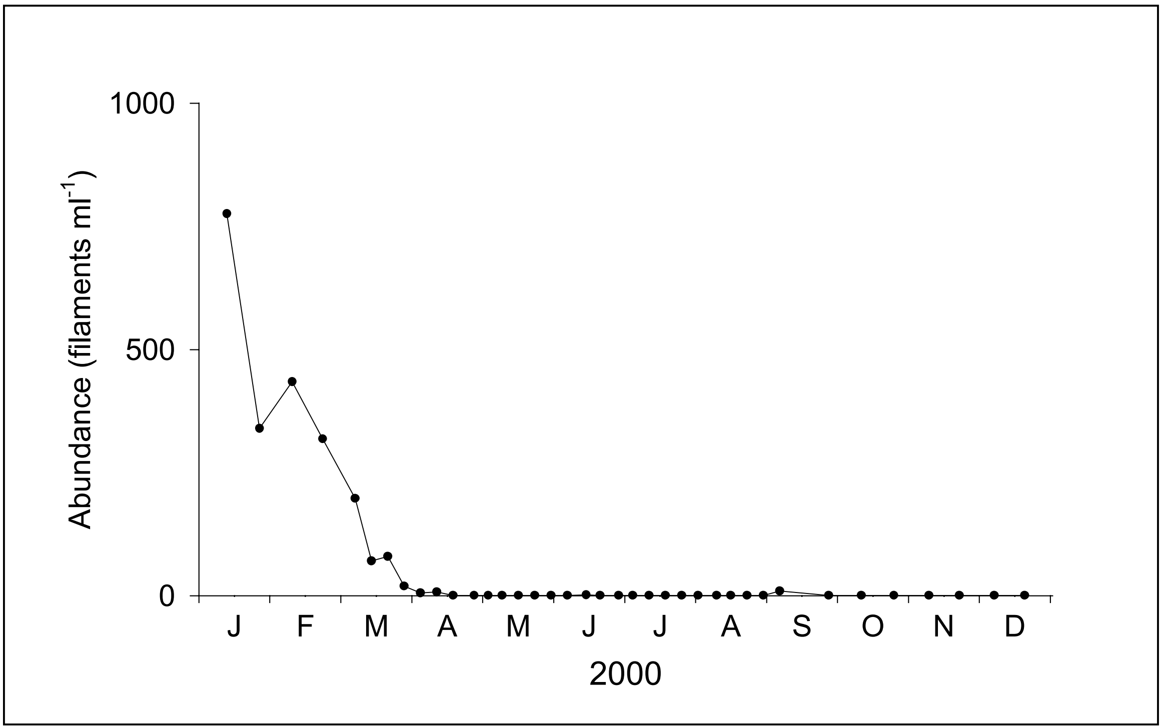


In summary, the chlorophyll$_a$ concentrations ranged from 6.0 µg l^{-1} to 97.4 µg l^{-1} with a mean value of 33.1 µg l^{-1}. The target value of 15 µg l^{-1} set by SEPA was therefore exceeded by 120%. At first glance, this seems dispiriting, but the situation could have been far worse. Diatoms dominated the phytoplankton assemblages more or less throughout 2000 (see also below). This was even the case during the warmest period at the end of July. We suggest that the poor performance of bloom-forming cyanobacteria this year was due largely to a combination of (i) ample silica availability and (ii) wind-induced mixing (see e.g. Figures 1 and 13). These factors also enhanced the lake-wide distribution and biomass accumulation of at least two relatively dense diatom populations (see Figures 16 and 18).

3.3.2 *Algal species*

Some 75 species of phytoplankton were recorded in Loch Leven during the analysis of 38 samples collected from Loch Leven during 2000 (see also Bailey-Watts 2001a). Small green algae of the order Chlorococcales were the most numerous of these. This reflects the continuing eutrophic nature of the loch. The majority of the algal biomass (recorded as chlorophyll$_a$ concentration), and the densest algal populations, through the year, were accounted for by eight phytoplankton species or groups of species (see Figures 14-21). Their 'succession', the periods over which they occurred and their maximum population densities are described below.

Figure 14 Population dynamics of <u>Oscillatoria agardhii</u> var. <u>isothrix</u>



Throughout January, February and March there was a declining population of the large blue-green alga *Oscillatoria agardhii* var. *isothrix* Gomont which had achieved its maximum concentrations of 2000 filaments ml^{-1} in late September 1999, and had already fallen to 770 filaments ml^{-1} by early 2000 (Figure 14).

The diatom *Aulacoseira italica* (Ehrenberg) Simonsen was recorded throughout the year, peaking at the end of March with a population density of 1300 filaments ml^{-1} (Figure 15).

Asterionella formosa Hassall also occurred throughout the year with a minor peak in abundance of *ca.* 2500 cells ml^{-1} in late April, and a population maximum of 5900 cells ml^{-1} in mid-July (Figure 16).

Figure 15 Population dynamics of <u>Aulacoseira italica</u>

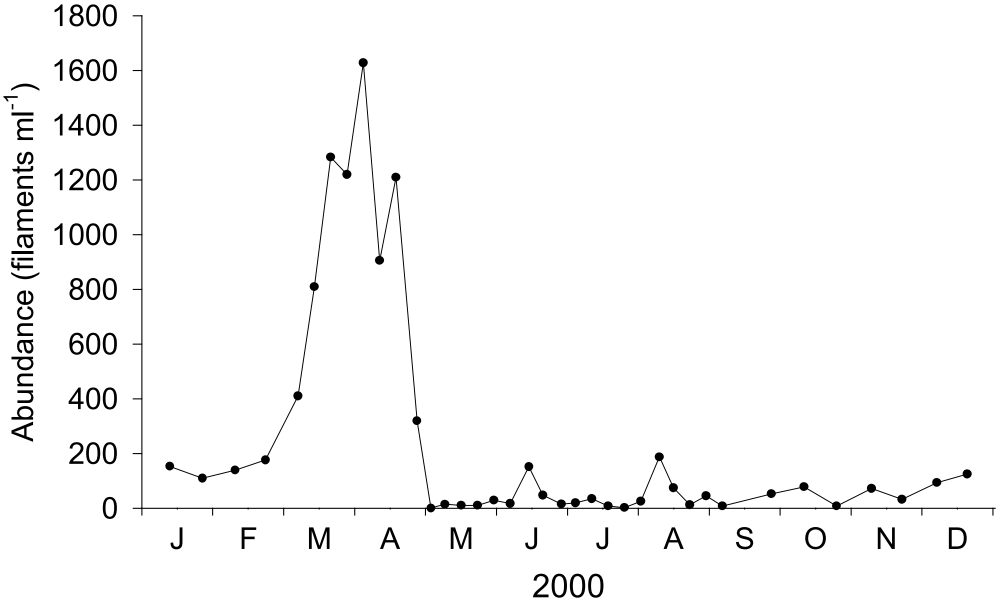


Figure 16 Population dynamics of <u>Asterionella formosa</u>

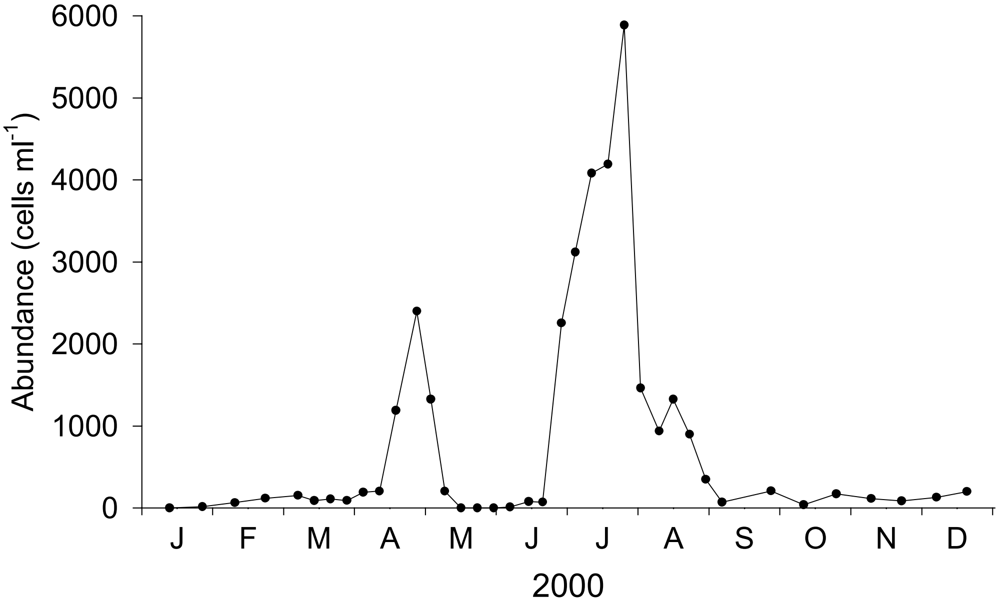


Figure 17 Population dynamics of Gomphosphaeria lacustris

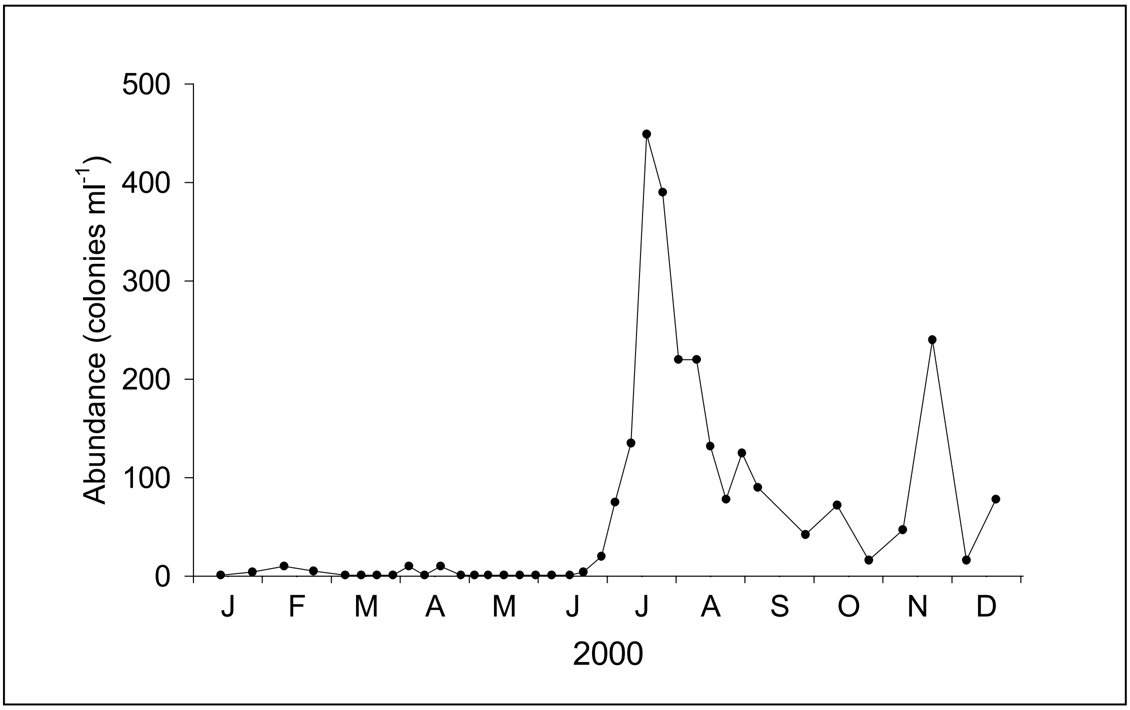


Figure 18 Population dynamics of Diatoma elongatum

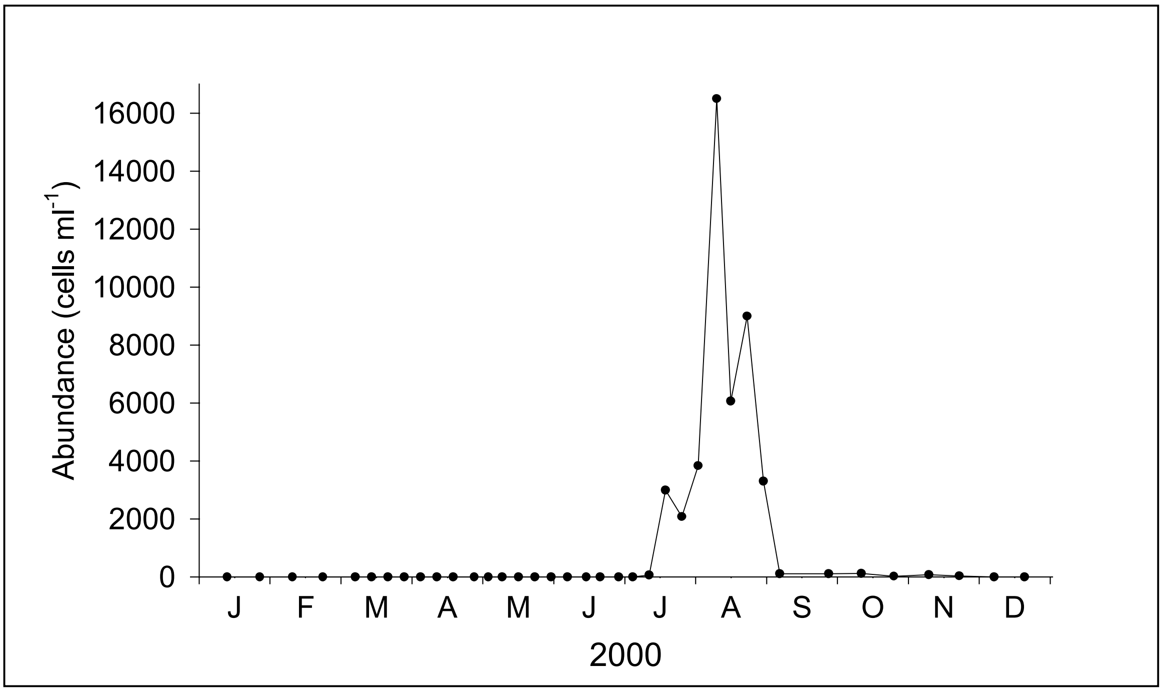
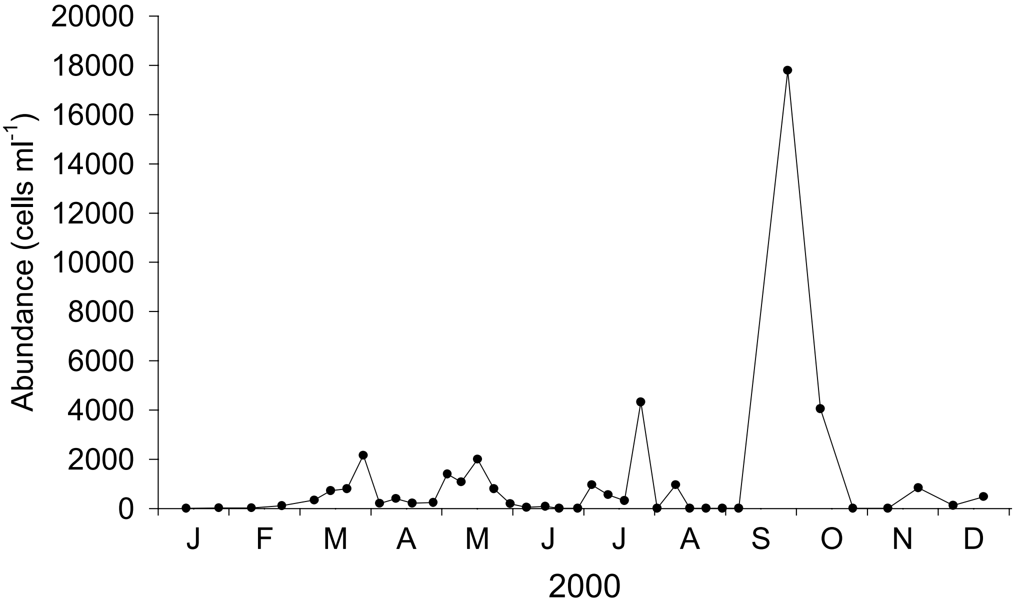


Figure 19 Population dynamics of Rhodomonas minuta var nannoplanctica



The cyanobacterium *Gomphosphaeria* nr. *lacustris* Chodat was recorded throughout the year, but most noticeably from mid-July to the end of September. It achieved an annual maximum of 450 colonies ml^{-1} in mid-June, and a second peak of abundance of 250 colonies ml^{-1} in mid-November (Figure 17). This species was the only cyanobacterium to achieve significant growth in 2000.

The colonial diatom *Diatoma elongatum* (Lyngbe) Agardh remained at very low levels for most of the year, apart from the period from July to early September. The population reached a maximum of 16500 cells ml^{-1} in early August (Figure 18).

Rhodomonas minuta var. *nannoplanctica* Skuja was present throughout the year, reaching a major peak in abundance of 17800 cells ml^{-1} in late September (Figure 19)

An assemblage of centric diatoms, comprised mainly of *Stephanodiscus hantzschii*, was also present throughout the year. A major stand of these organisms numbering 10500 cells ml^{-1} was recorded at the end of October (Figure 20).

In addition to these graphs, Figure 21 shows the dynamics of a group of *Cryptomonas* species that varied in abundance throughout the year.

Figure 20 The population dynamics of unicellular centric diatoms – mainly Stephanodiscus hantzschii

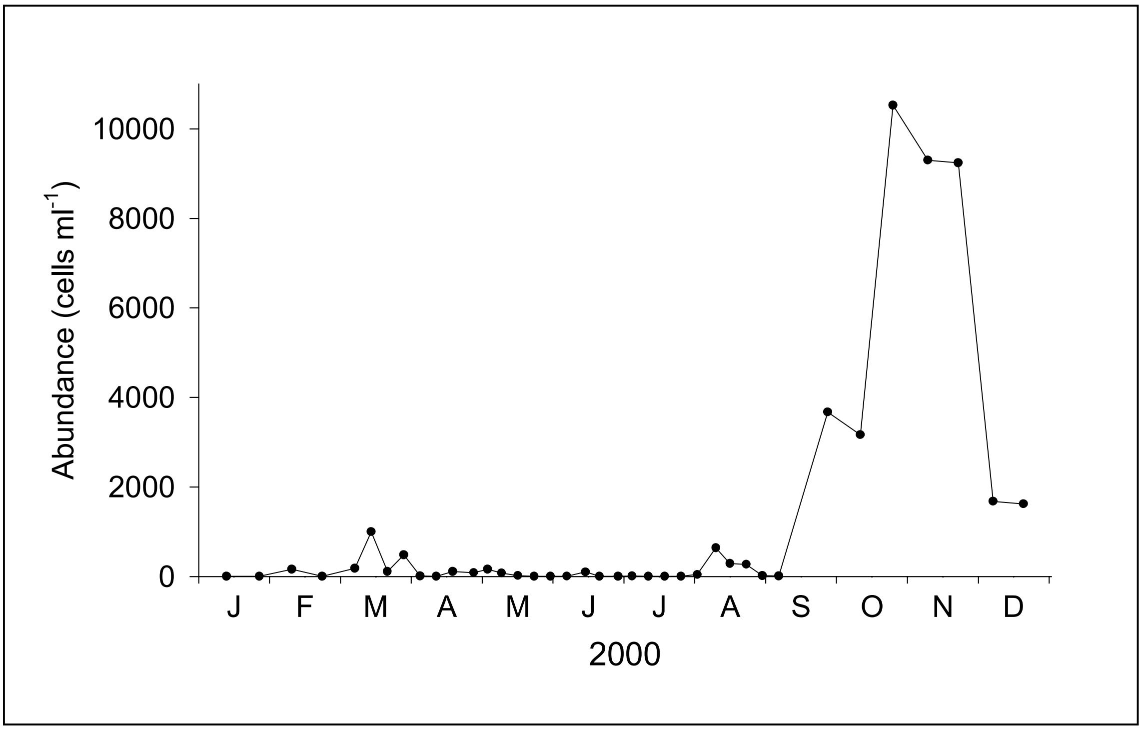
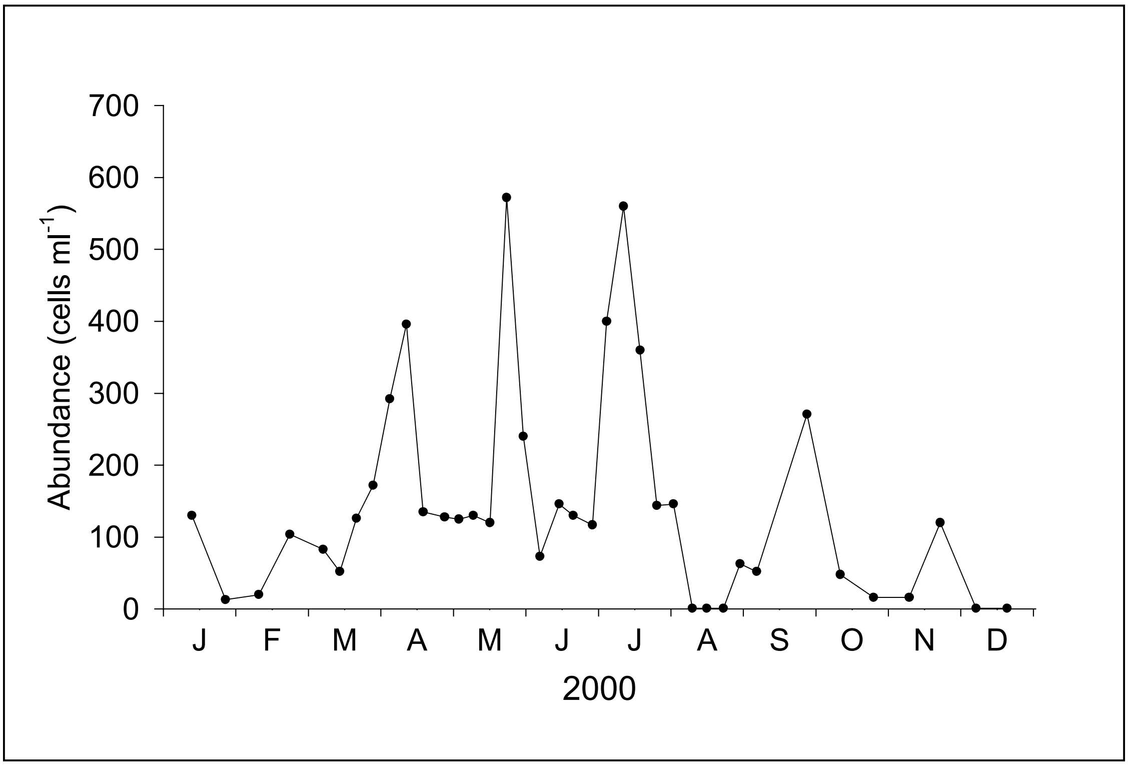


Figure 21 The dynamics of the assemblage of Cryptomonas species



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5 DISCUSSION

Many of the interactions between physical and chemical factors and the dynamics of the main phytoplankton species during 2000 conform to our increasing understanding of the way Loch Leven functions. Major examples are:

- the decline in diatom population densities as soon as silica concentrations approach the level of analytical detection
- warming of the water (and thus of the sediment surface) which enhances the draw-down of nitrate; this, in turn, triggers the release of phosphorus and silica from the sediments.

Table 1 Values for a range of physical and chemical variables recorded in Loch Leven: first and last sampling dates in 2000 compared

Factor	Value @ 12.1.2000	Value @ 19.12.2000
Water temperature (^oC)	4.2	3.4
Staff-gauge reading (m)	0.983	0.900
Water transparency (m) (first reading on 9.2.2000)	1.07	1.47
pH	7.50	7.61
Conductivity ($\mu S\ cm^{-1}$)	245	229
Nitrate-N ($mg\ l^{-1}$)	2.25	2.00 (estimated)
Soluble reactive P ($\mu g\ l^{-1}$)	4.9	27.4
Total soluble P ($\mu g\ l^{-1}$)	19.1	46.9
Total P ($\mu g\ l^{-1}$)	70.9	73.9
Soluble reactive SiO_2 ($mg\ l^{-1}$)	9.71	2.48

Potentially toxic, nitrogen-fixing, *Anabaena* spp. (*flos-aquae, spiroides* and *solitaria*) were recorded from mid-July until at least early September, but neither the individual species nor the group as a whole were sufficiently abundant to be of concern. Although other cyanobacteria, such as *Microcystis aeruginosa* and the very small-celled *Aphanothece/Aphanocapsa,* were also recorded over the same period, the entire summer assemblage of cyanobacteria was generally very small - with the exception of *Gomphosphaeria lacustris* (Figure 17). In spite of this, the 'precautionary principle' was adopted and warnings of toxic algae were posted on 13 occasions over the year. The first seven of these related to declining *Oscillatoria* populations during the early part of the year. The remaining six occasions coincided with generally sparse algal concentrations over the majority of the loch, but high local concentrations of cyanobacterial scums occurred in numerous small bays along the shoreline.

Bailey-Watts and Kirika (2000) explored the possibility of predicting some major features of the early 2000 phytoplankton community by referring to the start-of-year SiO_2:NO_3N:SRP weight ratios and the actual concentrations of the main limiting nutrient, i.e. SRP. On the 5 January 1999, the ratio of SiO_2:NO_3N:SRP was recorded as 195:100:1, with a reasonably high open water SRP concentration of 12 µg l^{-1}. This indicated an extreme surplus of SiO_2 over NO_3N and, especially, over SRP. These values suggested a relatively moderate algal biomass in early 2000. Figure 13 supports this expectation. The nutrient status at the end of 1999 also indicated that diatoms would feature prominently in the early months of 2000. The sequence of four major diatom populations in 2000 described above is ample evidence of this.

Table 2 Chlorophyll$_a$ concentrations and population densities of the 7 most prominent phytoplankton species recorded in Loch Leven: first and last sampling dates in 2000 compared.

Chlorophyll$_a$ concentration (µg l^{-1}):	20.3	16.4
Species	Population density @ 12.1.2000	Population density @ 19.12.2000
Aulacoseira italica (centric diatom)	155 filaments ml^{-1}	125 filaments ml^{-1}
Other centric diatoms	'nil'	1600 cells ml^{-1}
Diatoma elongatum (pennate diatom)	'nil'	100 cells ml^{-1}
Asterionella formosa (pennate diatom)	<10 cells ml^{-1}	<10 cells ml^{-1}
Rhodomonas minuta (cryptoflagellate)	<10 cells ml^{-1}	480 cells ml^{-1}
Gomphosphaeria nr. *lacustris* (colonial cyanobacterium)	<10 colonies ml^{-1}	80 colonies ml^{-1}
Oscillatoria agardhii var. *isothrix* (filamentous cyanobacterium)	800 filaments ml^{-1}	'nil'

In Loch Leven, at least, diatoms thrive on SiO_2:NO_3N:SRP weight ratios of approximately 50:10:1 (Bailey-Watts, 1988). At the end of 2000, this nutrient ratio was approximately 143:100:1 which is very different from the 'ideal' nutrient ratio for diatoms, especially in relation to the low ratio of silica to nitrate. The year 2000 ends with and, thus, the year 2001 starts with, a SiO_2 concentration of approximately 2.5 mg l^{-1}. This is less than half of the concentration recorded at the same time in 2000. This suggests that diatoms may well be out-competed by non-silicious algae such as cyanobacteria and green algae during 2001.

As outlined by Bailey-Watts and Kirika (2000), the loch responds rapidly to weather-driven processes such as water mixing, flushing-rate and changing water-level. Table 1 illustrates the consequential, and often marked, inter-annual changes in the 'behaviour' of the loch by comparing the first and last sampling dates in 2000 for a selection of physical and chemical factors.

In comparison with the situation at the start of the year, the water quality at the end of the year displayed:
- a considerably greater soluble reactive phosphorus concentration
- a considerably greater total soluble P concentration
- considerably less soluble reactive silica
- similar nitrate-N concentration

Such a disparity is likely to effect equally erratic shifts in the algal 'succession', as is displayed in Table 2.

Bailey-Watts and Kirika (2000) highlighted that, traditionally, the loch has been managed for water quantity rather than water quality. The authors are now embarking on an analysis of flushing-rate and water-level/water-volume regimes to explore whether water quality would improve under natural outflow regimes dictated by the weather, rather than those orchestrated by sluice-gate operators.

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