Loch Leven 2001: Physical, Chemical and Algal aspects of water quality

Report No: F01LH03

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SCOTTISH NATURAL HERITAGE

COMMISSIONED REPORT

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LOCH LEVEN 2001:
PHYSICAL, CHEMICAL
AND ALGAL ASPECTS OF WATER QUALITY

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Contractor : Laurence Carvalho and Alex Kirika

BACKGROUND

Loch Leven is eutrophic and has suffered from periodic cyanobacterial blooms for many years. In terms of conservation interest, algal blooms reduce light penetration into the water, reducing macrophyte growth, with associated changes in macroinvertebrate, fish and bird communities. 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. The data are also evaluated in relation to changes in water quality following recent reductions in phosphorus loading to the loch. Evidence of ecological recovery is also discussed.

MAIN FINDINGS

- Phytoplankton crops in Loch Leven remained relatively low in 2001. This is illustrated by an annual mean chlorophyll$_a$ value of 24.5 µg l^{-1} and an annual mean total phosphorus (TP) concentration of 48 µg l^{-1}.
- These values exceed the statutory target values set by the Loch Leven Area management Group and endorsed in the Loch Leven Management Plan
- The annual mean chlorophyll$_a$ concentration was, however, the second lowest value recorded in the last 33 years of monitoring.
- The species composition of the algal community was also encouraging, with approximately 60 planktonic taxa being recorded.
- Four diatom taxa dominated the phytoplankton for most of the year
- Ten species of cyanobacteria were recorded during the year. Only *Anabaena* spp. were of any note, and even they only reached a peak of approximately 280 filaments ml^{-1} in August.
- The number of occasions warranting the display of notices warning of toxic algae was 7 out of a total of 25 samples analysed, and spanned the months from August to November.

Several features recorded in 2001 suggest ecological recovery is progressing: enhanced water clarity in summer, the absence of a late-summer peak in SRP, and one of the lowest annual mean chlorophyll$_a$ concentrations on record.

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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). These blooms have a direct impact on the various users of the loch, on the local economy, and occasionally pose a potential risk to human health. In terms of conservation interest, algal blooms also reduce light penetration into the water, reducing macrophyte growth, with associated changes in macroinvertebrate, fish and bird communities.

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 and chemical data from Loch Leven for the year 2001. 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 2001, water samples were collected at generally fortnightly intervals. This amounted to a total of 28 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 almost 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 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, pH, 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, determined by the Centre For Ecology and Hydrology Windermere Laboratory were used. 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 3.75 metres.

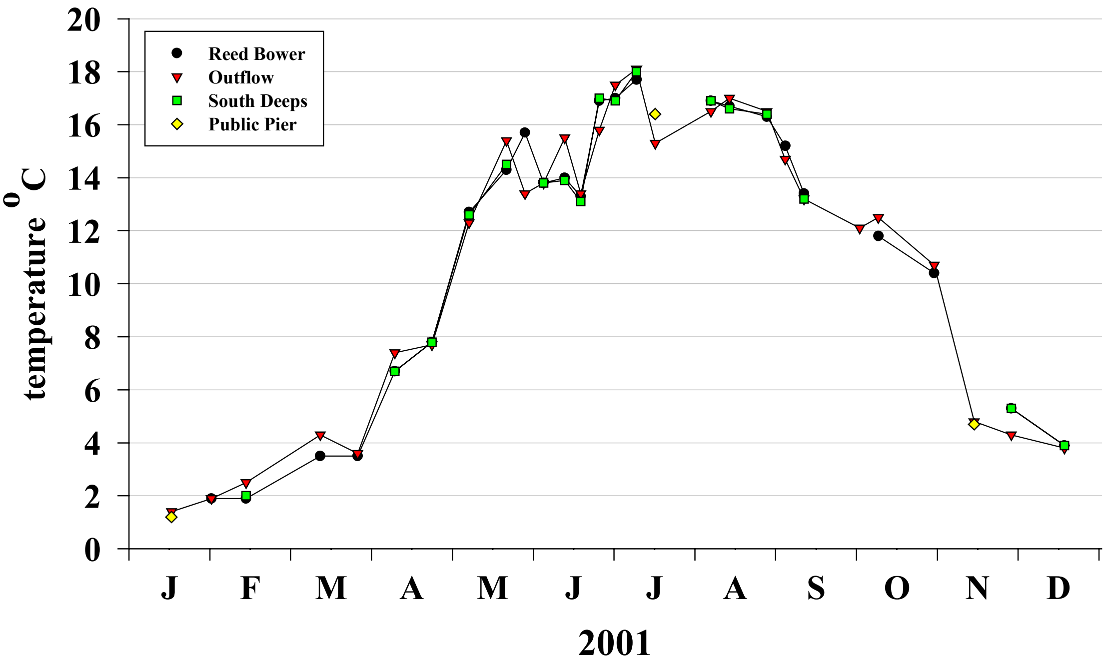
3 RESULTS

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 18.1°C being recorded at L on the 10 July 2001 (Figure 1). Intermittent rises and falls in temperature over the first three months were followed by a continuous rise of almost 10 ºC from early-April to mid-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°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 loch, as illustrated by the similarity in readings from the four sampling sites (Figure 1).

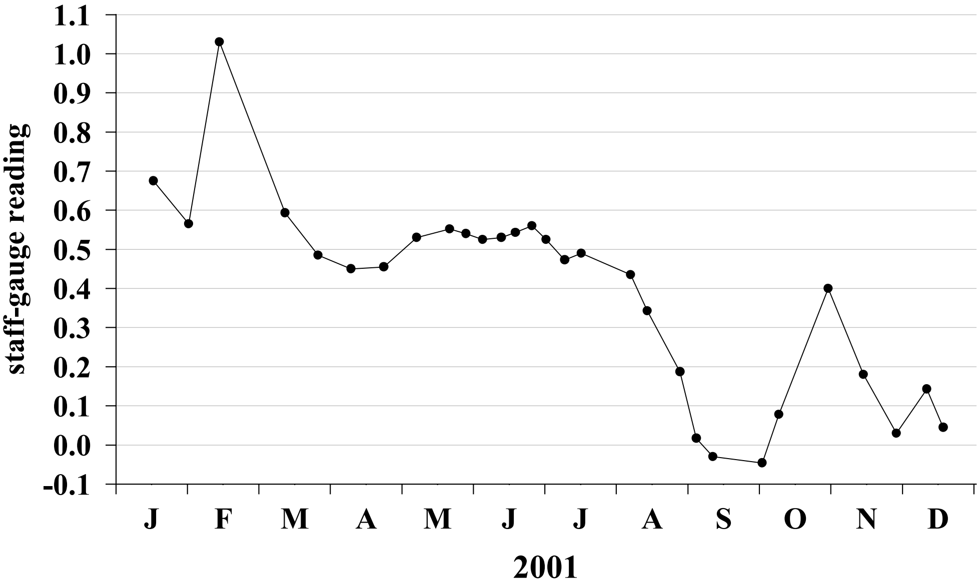
Figure 1 Spatial and temporal variation in surface water temperature



3.1.2 *Water level*

Water-level fluctuated by over 1m (i.e. approximately 20% of the mean depth of the loch) during 2001 (Figure 2). The water level was maintained at a fairly constant level from May to July. There was a significant drop in August, despite steady levels of rain over the first few weeks. This highlights the control on water level exercised at the sluice gates by the paper mills, rather than natural, weather-influenced fluctuations (i.e. rainfall).

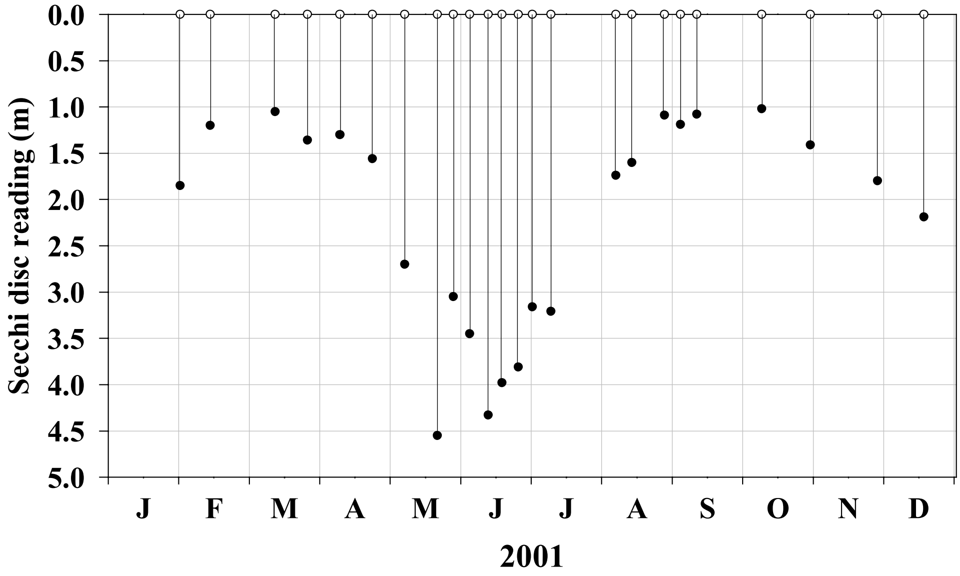
Figure 2 Water level fluctuation at the Harbour



3.1.3 *Water clarity*

The months of May, June and early July in 2001 were remarkable with regards to water clarity. Secchi disc readings over most of that period exceeded 3m (Figure 3) - a value approaching the mean depth of the system. As in the previous year, this represented a prolonged spell of 'clear' water during the period more normally associated with blue-green algal blooms The annual mean Secchi disc reading over the year was 2.24m with a maximum value of 4.55m at SD on 22nd of May.

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

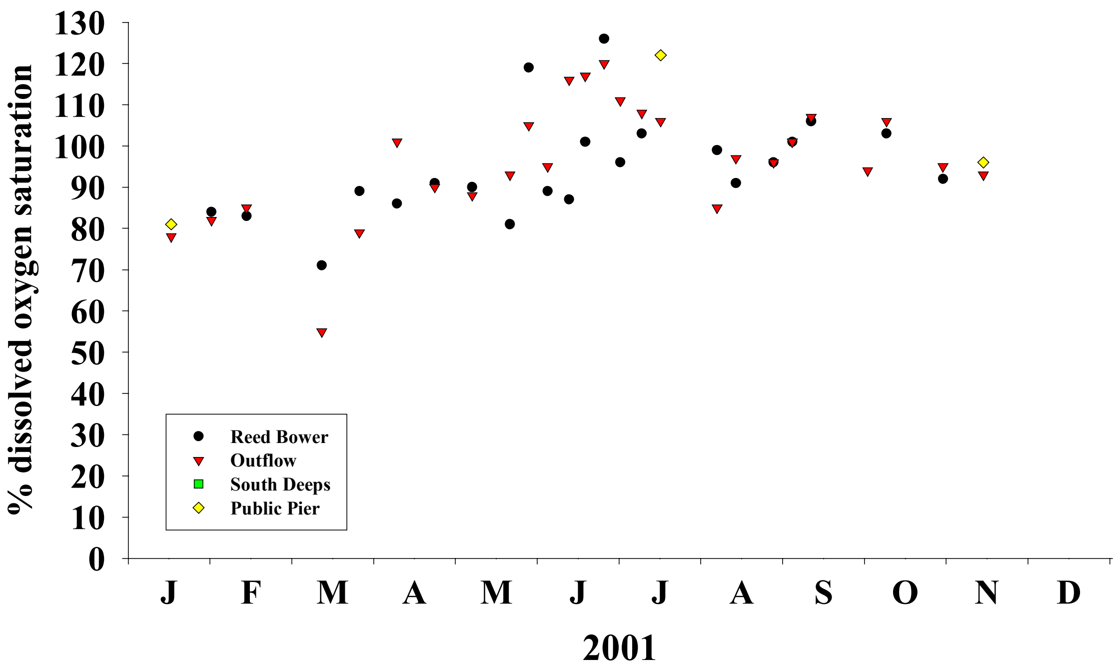


3.2 Chemical factors

3.2.1 *Dissolved oxygen*

Although only four values of less than 80% dissolved oxygen (DO) saturation were recorded during the first quarter of the year, the mean annual percentage DO saturation in the surface water at the Reed Bower sampling station was 94.7% (Figure 4). The loch water, therefore, appears to be generally well-supplied with oxygen. 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, particularly during the night.

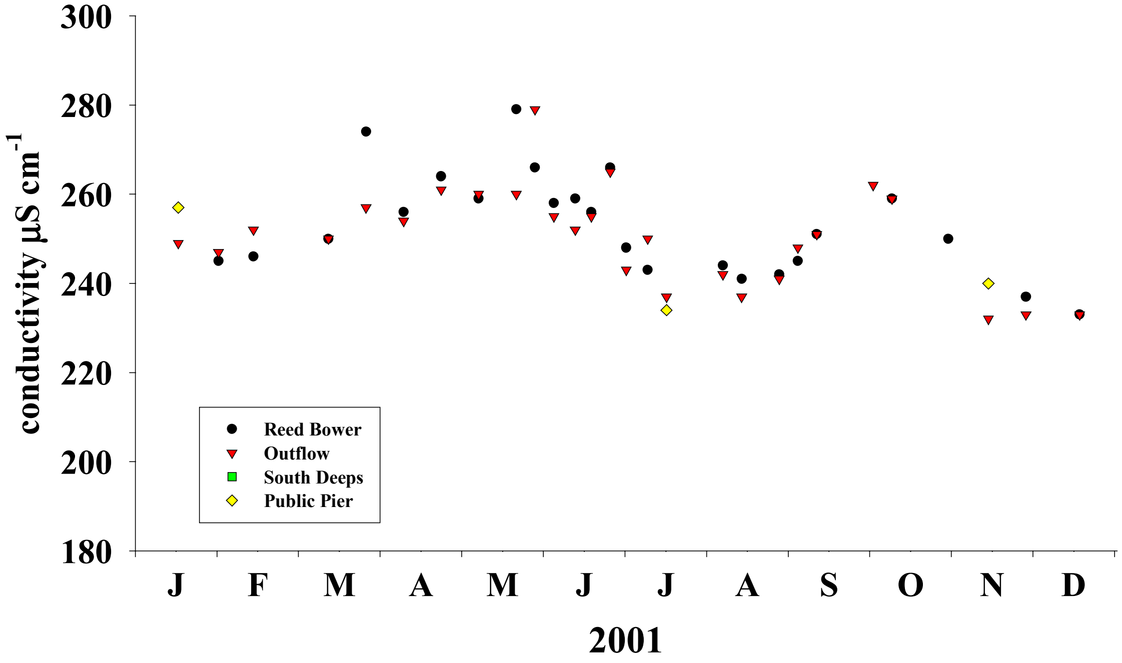
Figure 4 Dissolved oxygen concentrations at ambient water temperatures



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 232 µS cm^{-1} to 279 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 fluctuations in values are likely to reflect changes in patterns of rainfall, wind direction and loch volume.

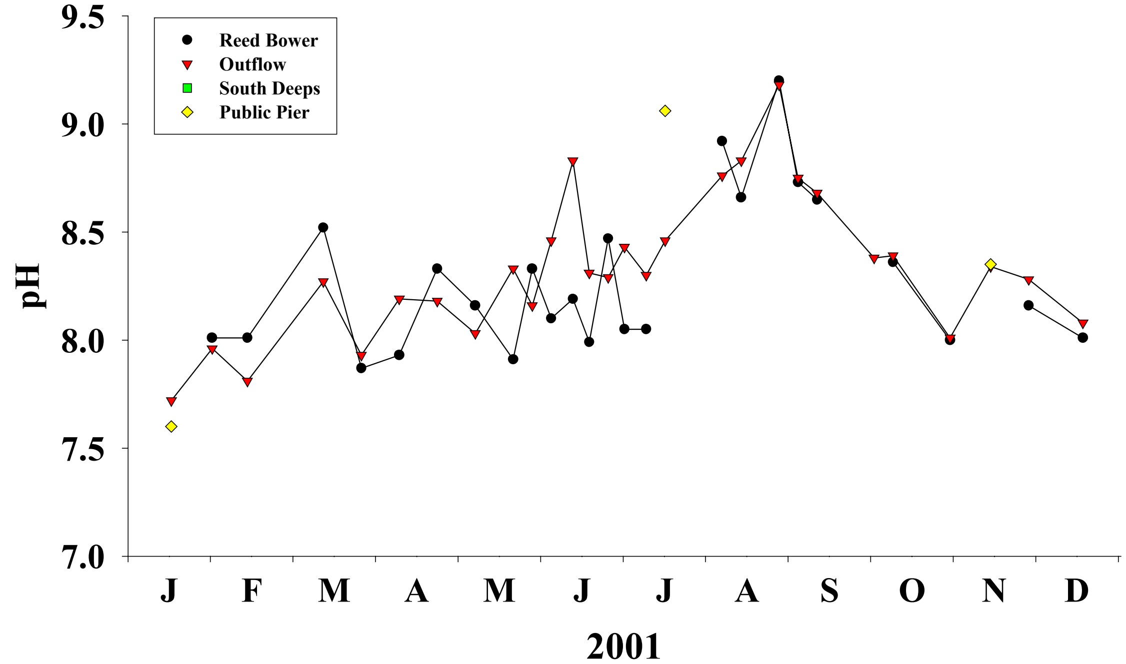
Figure 5 Electrical conductivity at ambient water temperature



3.2.3 *pH*

The range of pH values exhibited was fairly standard for the loch in recent times, generally falling between pH 7.5 and pH 8.5, with values as high as pH 9.2 during late summer

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

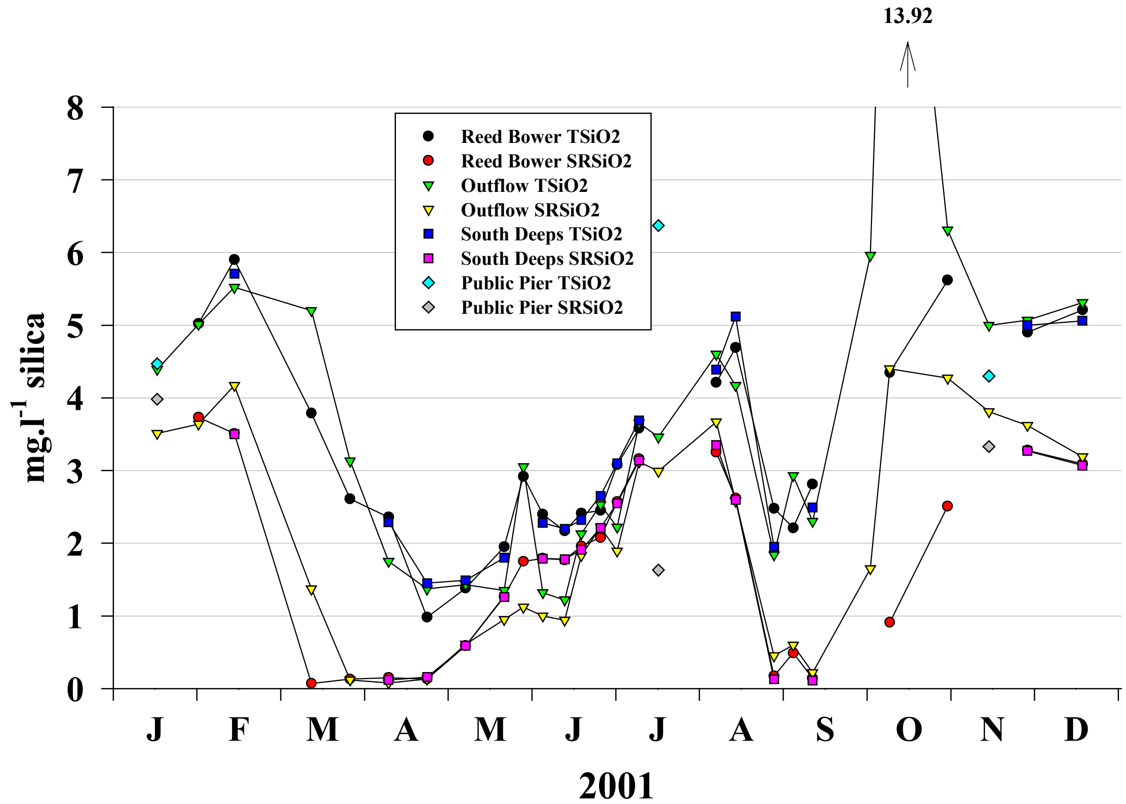


3.2.4 *Total silica and soluble reactive silica*

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 chrysophytes. As with concentrations of nitrate-N and phosphate-P, $SRSiO_2$ values represent the instantaneously available nutrient resource that can, potentially, be taken up by the diatoms.

The dynamics of dissolved silica during 2001 (Figure 7) illustrate a number of features. The first is the seasonal variation in silica concentrations recorded, with peaks between 3 and 4 mg l^{-1} in January and early August to virtually zero in March/April and late August/early September. Both declines associated with substantial growths of diatoms in spring and autumn (Figure 15). 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. This is evident in 2001 during both the spring and autumn periods. The more exaggerated increase in the total fraction recorded at the outflow in October is 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 ($SRSiO_2$)

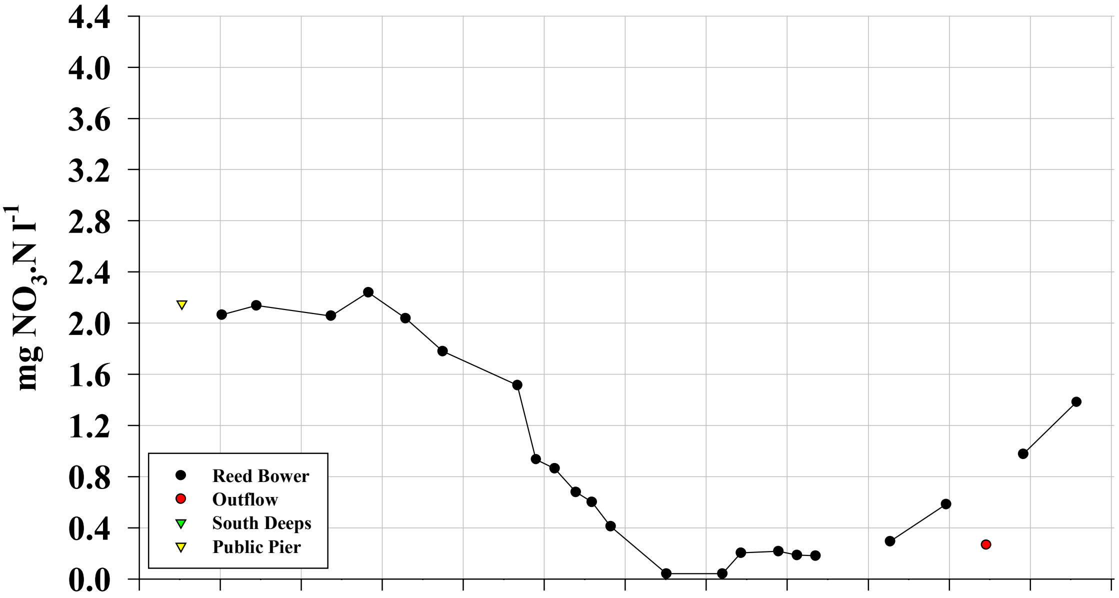


3.2.5 *Total oxidised nitrogen*

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 0.04 mg N l^{-1} recorded on 17 July 2001 (Figure 8) compares very closely with the minimum value of 0.02 mg N l^{-1} recorded on 3 August 2000. Indeed, the measured concentrations and overall trends were very similar.

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. A visual comparison of Figures 1 and 8 shows the periods when nitrate draw-down and rising temperatures were co-incident in Loch Leven in 2001.

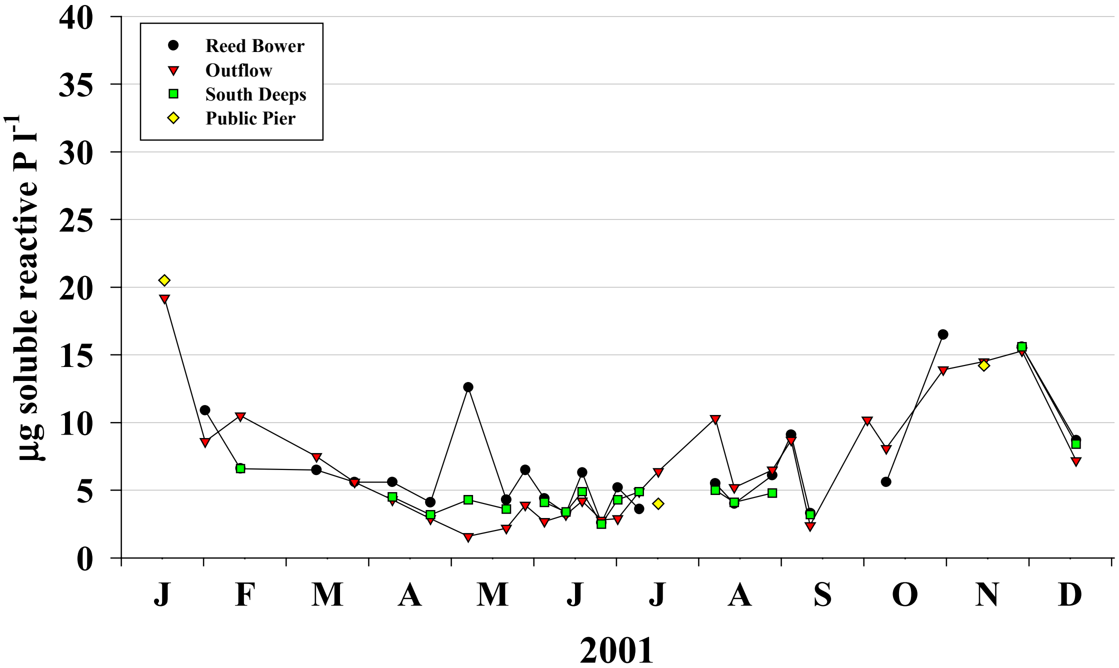
Figure 8 Temporal variation in concentrations of total oxidised nitrogen at the Reed Bower sampling site



3.2.6 *Soluble reactive phosphorus*

Soluble reactive phosphorus (SRP) concentrations started the year at a relatively high level, having increased to over 20µg P l^{-1} in December 2001 (Figure 9). Decreasing to around 5µg P l^{-1} by early April, it then rarely exceeded 10µg P l^{-1} until the end of October. Unlike the previous year there appeared to be no major release from the sediments in late summer, or if there was, it was immediately taken up by a fairly substantial crop of diatoms, appearing as particulate rather than dissolved P.
Minimum value 3µg P l^{-1} maximum 17µg P l^{-1} mean 7µg P l^{-1} (at RB).

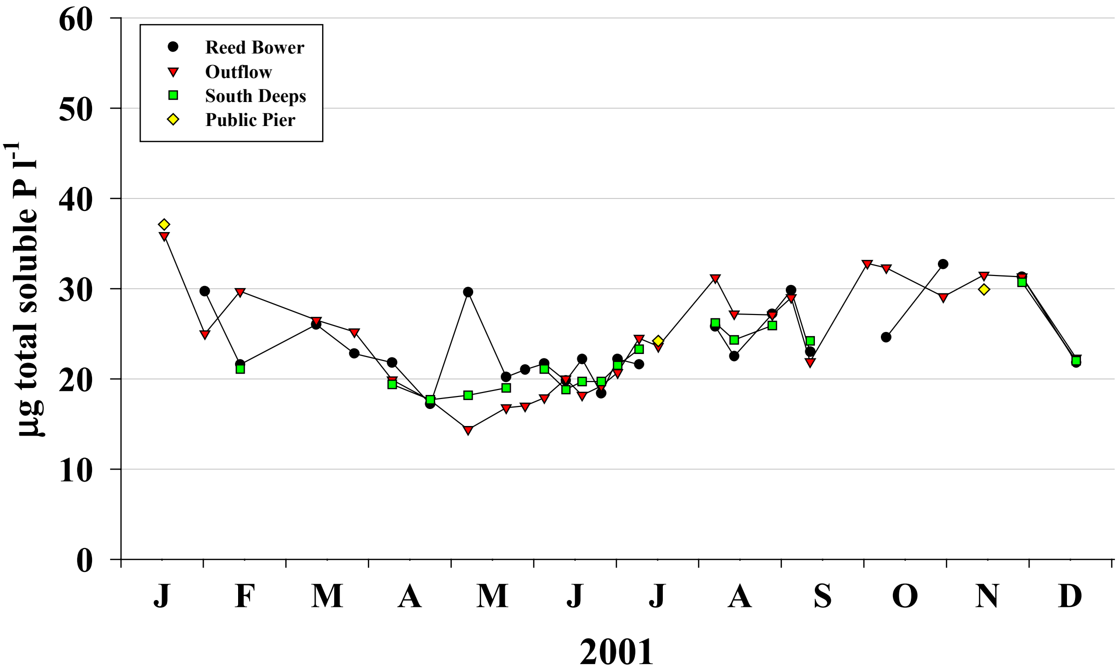
Figure 9 Spatial and temporal variations in concentrations of soluble reactive phosphorus



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 3µg P l^{-1} and 17µg P l^{-1} over the year, TSP levels varied between 17µg P l^{-1} and 33µg P l^{-1}, with a mean of 24µg P l^{-1}. There was, therefore, considerably more soluble organic P than inorganic P in the water column.

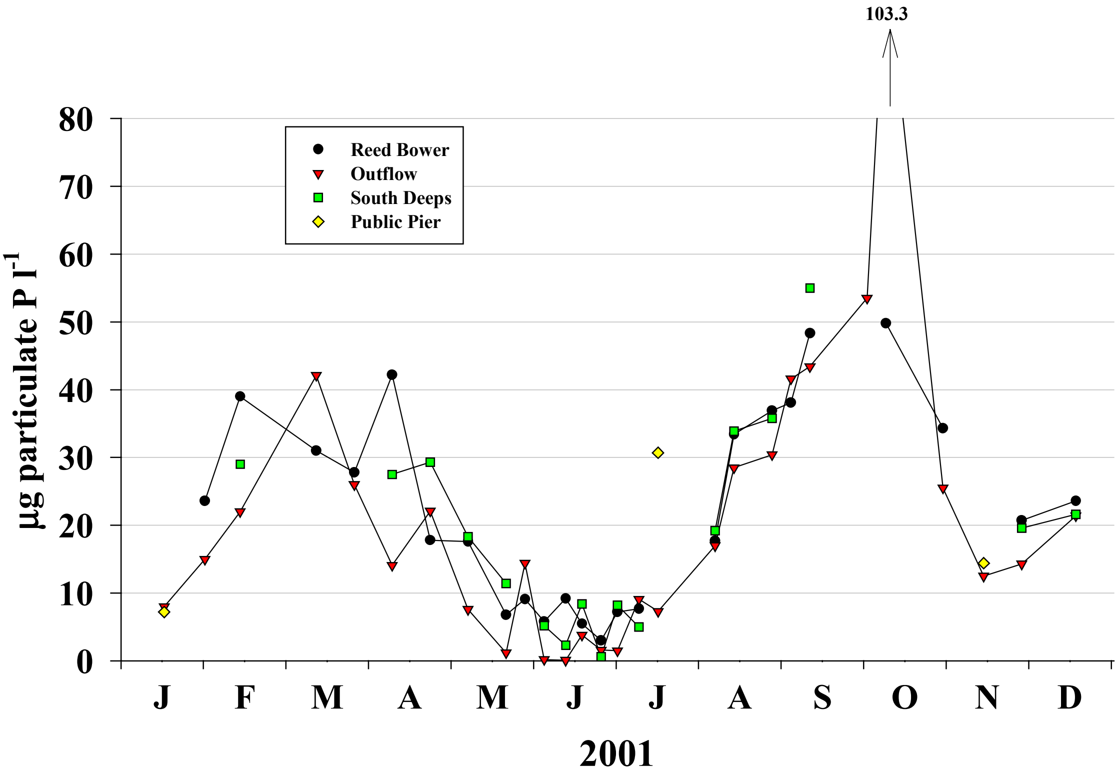
Figure 10 Temporal and spatial variation in concentrations of total soluble phosphorus



3.2.8 *Particulate phosphorus*

Variations in particulate phosphorus (PP) concentrations in 2001 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 occur during windy weather as this disturbs the sediments and causes particles to become re-suspended in the water column. Minimum value 3µg P l^{-1} maximum 50µg P l^{-1} mean 23µg P l^{-1} (at RB, but with a 'peak' of 103µg P l^{-1} caused by resuspended sediment in October at L)

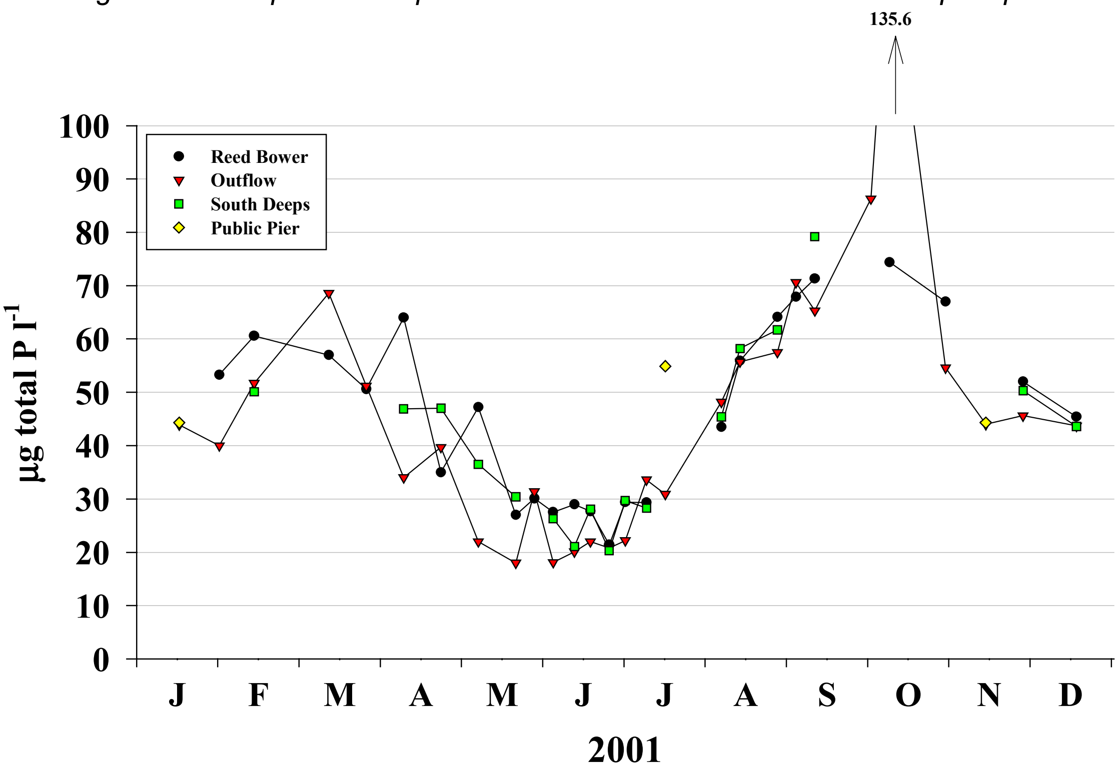
Figure 11 Temporal and spatial variation in levels of particulate phosphorus



3.2.9 *Total phosphorus*

Total phosphorus (TP) concentrations provide a simple index of loch trophic status. The data for 2001 (Figure 12) yield minimum, mean and maximum values at RB of 21µg P l^{-1}, 47µg P l^{-1} and 74µg 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 still has a little way to go in terms of recovery from eutrophication. The absence of any outflow (flushing) data, however, makes it impossible to say whether the observed TP levels were due to continuing inputs from the catchment or whether they 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

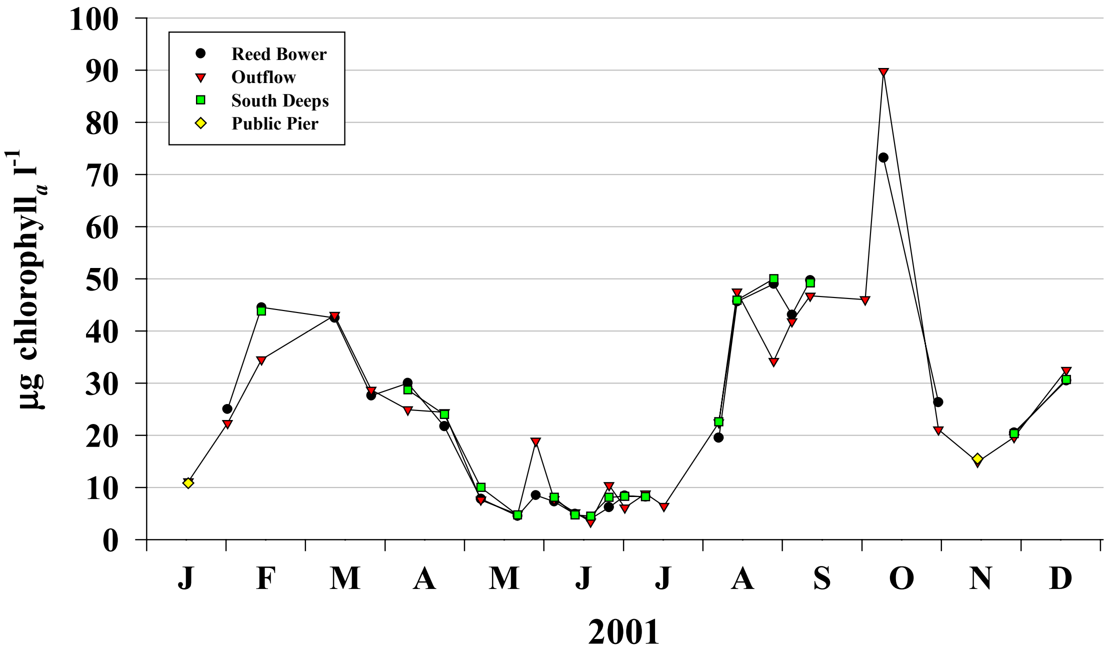


3.3 Phytoplankton

3.3.1 *Chlorophyll$_a$*

The pattern of changes in phytoplankton biomass (estimated as chlorophyll$_a$ concentration) observed in 2001 was somewhat rare for this site, but fairly typical for a mesotrophic shallow loch (Reynolds, 1984). In most years the major phytoplankton pulse is observed in February or March, as day length increases and when nutrient levels are generally high, with the main algae involved being centric diatoms. In 2001, however, there were two 'pulses' of growth, the usual spring diatom bloom, followed by a period of low growth during the summer, with a second 'pulse' from August to October, again dominated by diatoms. The spring maximum in February was a relatively modest 45 µg l^{-1} of chlorophyll$_a$. Throughout April, the chlorophyll$_a$ levels declined, reaching an annual low of 4 µg l^{-1} by mid June, with little change until the end of July. By late August, however, the concentration had peaked again at around 50 µg l^{-1}, with the exception of a turbulence-induced 'peak' of over 70 µg l^{-1} in October. The annual mean concentration (at RB) was 25 µg l^{-1}, the second lowest value recorded in the last 33 years of monitoring (20 µg l^{-1} was recorded in 1985). Despite this, it still far exceeded the target value of 15 µg l^{-1} set by SEPA.

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



3.3.2 *Algal species*

Some 62 species of phytoplankton were recorded in Loch Leven during the analysis of 25 samples collected from Loch Leven during 2001. In terms of cell/colony/filament densities, the phytoplankton was dominated by diatoms (Bacillariophyta), peaking in spring and autumn (Figure 14). Small Cryptophyta and Chlorophyta were abundant throughout the year. The former dominated in May, June and July when other algal groups declined, resulting in particularly good water-clarity conditions throughout this period. Ten species of blue-green algae (cyanobacteria) were recorded during the year, but they never dominated the phytoplankton assemblage. Only *Anabaena* spp. were of any note, and even they reached a peak of only approximately 280 filaments ml^{-1} in August. The number of occasions warranting the display of notices warning of toxic algae was 7 out of a total of 25 samples analysed, spanning the months from August to November.

In terms of biovolume, which takes into account cell, filament or colony size, a slightly different pattern emerges, which is more in agreement with $chlorophyll_a$ concentrations (Figure 15). Diatoms still dominate the phytoplankton, but the autumn peak can be seen to be greater than the spring peak. Because of their large biovolume per individual filament compared with Chlorophyta and Cryptophyta cells, cyanobacteria are seen to be much more significant during the late summer/autumn period. There is a discrepancy between peak biovolume recorded in September compared with a peak $chlorophyll_a$ concentration in early-October, the reasons for this are not clear.

Figure 14 Temporal variation in phytoplankton groups (numbers per ml)

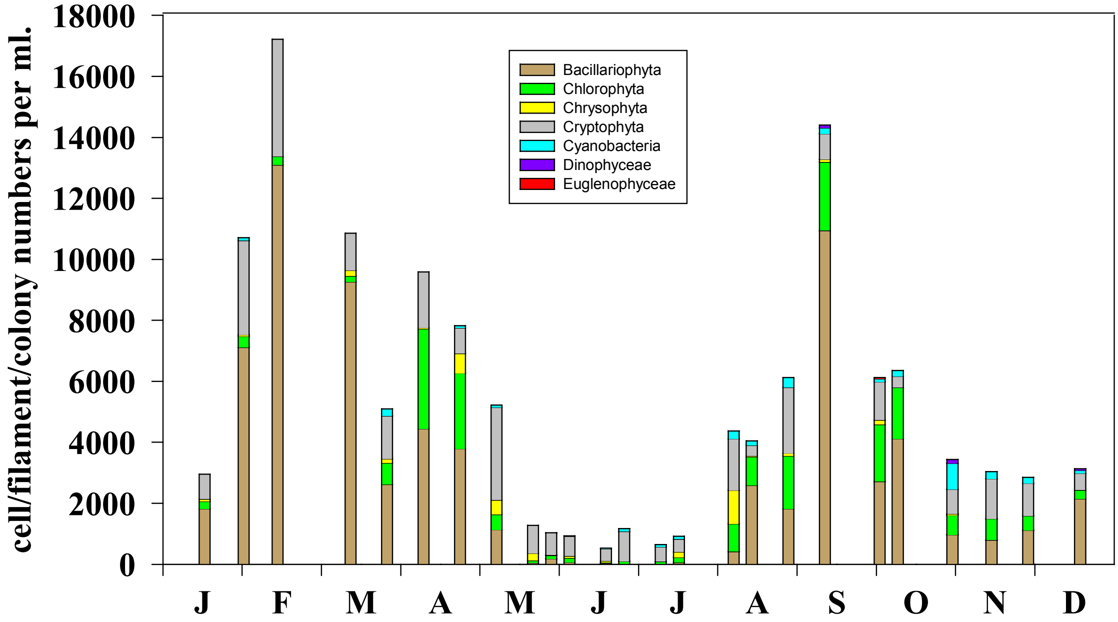
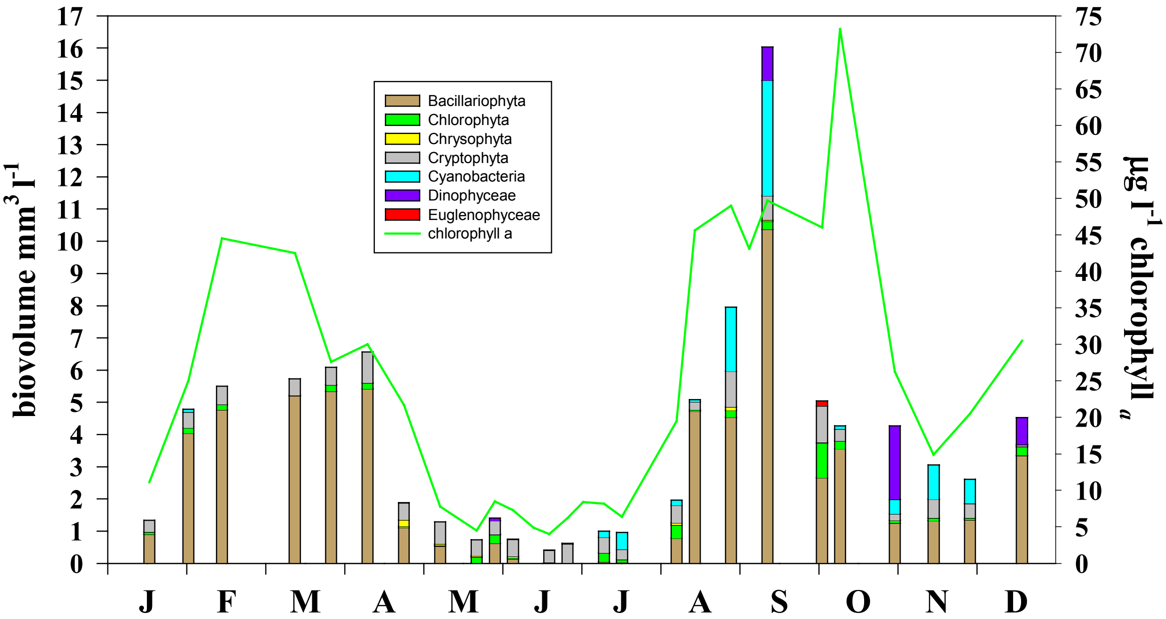
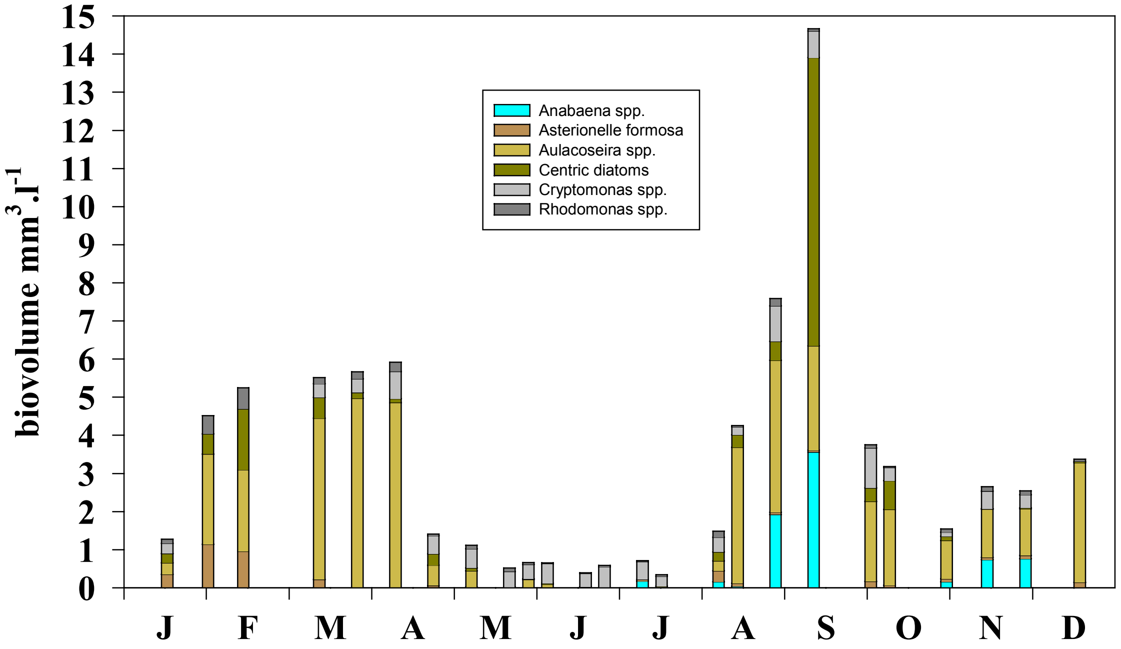


Figure 15 Temporal variation in phytoplankton biomass (biovolume and chlorophyll$_a$)



The majority of the algal biomass, and the densest algal populations, through the year, were accounted for by six phytoplankton species or groups of species (Figure 16).

Figure 16 Temporal variation in dominant phytoplankton taxa (biovolume)



The diatom genus *Aulacoseira* was the most dominant taxon throughout most of the year, reaching peak biovolume at the end of March (Figure 16). Like all the diatom species, it declined in abundance through April and was absent though mid-summer due to silica depletion.

An assemblage of centric diatoms, comprising mainly *Stephanodiscus* and *Cyclotella* species, was also present during spring and autumn. A major stand of these organisms was recorded in September.

Asterionella formosa Hassall was the third diatom attaining significant biomass in 2001, with a peak in abundance at the end of January, but also present later in the year in autumn.

Several species of the cyanobacterium genus *Anabaena* were recorded in the second half of the year, but most noticeably during August, September and November. They achieved an annual maximum of approximately 280 filaments ml^{-1} in late-August, and a second peak of abundance of approximately 190 colonies ml^{-1} in November. This genus was the only cyanobacterial group to achieve significant growth in 2001.

The Cryptophytes *Rhodomonas minuta* and a group of *Cryptomonas* species were present throughout the year, reaching high densities in terms of cell numbers per ml, but not in terms of biovolume. They did, however, dominate during the summer clear-water phase.

4 DISCUSSION

There are several features recorded in 2001 that suggest ecological recovery is progressing:

- Enhanced water clarity in May, June and July that should result in abundant growth of submerged macrophytes extended to deeper waters.
- The absence of a late-summer peak in SRP, which suggests reduced rates of internal release from the sediments.
- An annual mean chlorophyll$_a$ concentration of 25 µg l^{-1} (at RB), the second lowest value recorded in the last 33 years of monitoring.
- A seasonal pattern of phytoplankton abundance typical of a mesotrophic lake, with dominance by diatoms, rather than cyanobacteria.

The targets for mean annual TP and chlorophyll$_a$ concentrations 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) have yet to be reached, which suggests that the loch still has a little way to go in terms of recovery from eutrophication. Although palaeoecological evidence (Bennion *et al.*, 2001) suggests that these targets may be set too low and may be unachievable within an agricultural landscape.

Potentially toxic, nitrogen-fixing, *Anabaena* spp. (*flos-aquae, spiroides* and *solitaria*) were recorded from mid-July onwards, but neither the individual species nor the group as a whole reached high densities, although they were sufficiently abundant to exceed threshold guidelines for recreational waters (Scottish Executive Health Department, 2002).

A greater understanding of the extent of ecological recovery will be possible by putting the 2001 data in context through the 2002 review commissioned by SNH of all historical survey and monitoring data available for the site.

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