Final Report for SEPA

Loch Leven 2007: trends in water quality and biological communities

Report to Scottish Environment Protection Agency

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Centre for Ecology & Hydrology (CEH)

SUMMARY

BACKGROUND

Loch Leven is eutrophic and has suffered from periodic cyanobacterial blooms for many years. These blooms have had a direct impact on the various users of the loch and on the local economy. 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. For these reasons the loch has been the focus for a series of restoration measures since the 1980s, specifically targeting reductions in the external nutrient load from a woollen mill and sewage works in the catchment.

This report is one of a series that describe and interpret physical, chemical and biological information from Loch Leven on a regular basis to measure the success of restoration and inform on-going management. Temporal and spatial variation in a number of key water quality parameters are presented and considered in relation to long-term trends and established restoration targets.

MAIN FINDINGS

The 2007 monitoring data show strong evidence of recovery in all three key water quality parameters in relation to previous years. Comparisons of the annual mean total phosphorus (TP) and chlorophyll concentrations with those recorded over the past forty years suggest that the recovery that appeared to be beginning to establish in 2000 and 2001 has returned and progressed. 2007 is the first year on record that TP concentrations have declined below the statutory target concentrations of 40 µg l^{-1} set by the Loch Leven Area Management Group (LLAMAG) in 1993. Although chlorophyll concentrations were still above the Loch Leven Area Management Group target, the annual mean of 24 µg l^{-1} recorded in 2007 was still the second lowest observed over the past 40 years.

In terms of the phytoplankton community, 2007 was fairly typical of recent years with diatoms dominating for much of the year. The slight differences were that diatoms remained common throughout summer, but had no autumn peak in October and the N-fixing cyanobacterium *Anabaena* was less abundant than *Microcystis* and *Woronichinia*. Cyanobacteria still remain a health hazard at Loch Leven. Both the magnitude and timing of cyanobacteria blooms in 2007 were broadly similar to patterns observed over the previous three years, indicating that warning signs need to be present from July to September, particularly during weather episodes that lead to the formation of surface scums.

2007 was an atypical year for the crustacean zooplankton community, both in terms of species composition and relative abundance of the principal taxa. Principally there were very low densities of *Cyclops* and much higher densities of the filter feeding herbivores *Eudiaptomus* and *Bosmina* compared with recent years. *Cyclops* species are typically omnivorous and may feed on small crustacea and rotifers, their low numbers may, therefore, have helped herbivorous zooplankton remain more abundant. There was also a large population peak of the main algal grazer *Daphnia* in early September, in addition to the

typical *Daphnia* peak in May.

Although an unusual year in many ways, what is not in doubt is that water quality in 2007 was much improved in comparison with the poor water quality of the early 1970s and early 1990s. There are a number of possible reasons for this:

1. Both nitrate and soluble reactive phosphorus availability were low throughout much of summer
2. Grazer densities remained relatively high through spring and summer
3. Macrophyte beds, which compete with phytoplankton for light and nutrients, were extensive

One reason why 2007 was so unusual may have been the weather, with a warm and dry spring and a very wet summer. Warmer spring temperatures have been shown to be associated with higher *Daphnia* densities in the loch and a strong spring clear water phase and it is thought that the increased coverage of macrophytes to deeper waters may be a response to improved water clarity during their early spring growth. The very wet and relatively cool summer may have had a number of effects. If external loading was the main driver of nutrient availability in the loch, the wet summer could have increased nutrient loadings to the loch and enhanced phytoplankton growth. This was not, however, apparent in the in-lake nutrient concentrations. It suggests that what may be more important is that the cooler summer reduced internal nutrient loading from sediments, a process that is known to be strongly temperature dependent in Loch Leven. Additionally the exceptional rainfall experienced during June and July may have enhanced the flushing of phytoplankton from the loch at a particularly critical time of year when their populations normally develop. The improvement in both TP and chlorophyll concentrations may, therefore, be a response to a number of factors all driven by the weather, both the warm spring and an exceptionally wet and cool summer. Another factor that may have been important in 2007 was the stopping of fish stocking. This may have been one reason for the unusual patterns observed in the zooplankton.

Water quality targets for Loch Leven are now being set under the EU Water Framework Directive (WFD). The WFD places an emphasis on the ecology of the lake (phytoplankton, macrophytes, benthic invertebrates and fish), rather than the chemistry. However, within the UK, standards for total phosphorus (TP) for water quality assessment are also being implemented. The new UK Environmental Standards for TP for Loch Leven are more stringent than those set by LLAMAG. The good/moderate (G/M) boundary TP target for a shallow, high alkalinity loch in Scotland, such as Loch Leven, is 32 µg l^{-1}., the moderate/poor (M/P) boundary is 46 µg l^{-1}. In general Loch Leven would classify as poor status, with 2007 the only year classifying as moderate status. New European standards for chlorophyll concentrations in lakes have been formally agreed by the European Commission as part of the Intercalibration process for the WFD. The G/M class boundary for chlorophyll for a shallow, high alkalinity lake, such as Loch Leven, has been agreed at 7.5 µg l^{-1}. Loch Leven is, however, near the depth boundary between lake types; a site-specific target is, therefore, considered most appropriate. Site-specific chlorophyll targets for Loch Leven would be 11 µg l^{-1} for the G/M boundary and 22 µg l^{-1} for the moderate/poor (M/P) boundary. In 2007, as in most years over the past decade, Loch Leven would, therefore, be classified as poor status on the basis of its chlorophyll concentrations. Although 2007, with an annual mean chlorophyll concentration of 24 µg l^{-1} is approaching the moderate status class.

The new WFD standards are not necessarily appropriate for management on an individual loch basis where a range of site-specific factors may affect targets. Site specific targets are, therefore, likely to be more appropriate for SEPA's management of Loch Leven, rather than the type-specific targets agreed at an European level.

There is clearly a need for continued lake and catchment management at Loch Leven to meet WFD targets for chlorophyll and enhance the ecological recovery. The large reductions in external phosphorus loadings appear now to be followed by reductions in internal loading and both N and P limitation of phytoplankton crops are important during the year. Catchment management should, therefore, continue to identify and reduce significant sources of both nitrogen and phosphorus. Analysis of nitrate concentrations in Loch Leven show a significant increasing trend, in particular since the mid 1990s, suggesting that management attention needs to be focused on this nutrient, as well as phosphorus.

Recent phosphorus loading figures from 2005 suggest little change in TP loadings since 1995, however, soluble reactive phosphorus (SRP) loads had declined. Compared to previous years, particulate phosphorus now contributes a greater proportion of the annual TP load to Loch Leven. This indicates that management of point sources in the catchment continues to reduce soluble P loadings, and that diffuse sources are now the dominant P source to the loch. Management initiatives to reduce diffuse P sources, primarily from agriculture and septic tanks, are critical to achieving further reductions of P loads.

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1 INTRODUCTION

Loch Leven is the largest loch in lowland Scotland. It is also one of the most important sites in the UK for waterfowl, with the largest population of breeding ducks and thousands of migratory ducks, geese and swans resident over winter (Scottish Natural Heritage, 2007). In recognition of its nature conservation importance both nationally and internationally, it is designated as a Site of Special Scientific Interest (SSSI), a National Nature Reserve (NNR), a Special Protected Area (SPA) and a RAMSAR wetland site of international importance. The loch is also an internationally-renowned brown trout fishery. Loch Leven has, however, suffered water quality problems, with dense cyanobacterial blooms occurring periodically in summer for many years. These have occurred, largely, as a result of large amounts of phosphorus entering the loch over many years, combined with a relatively low flushing rate and a favourable light-climate. These blooms have a direct impact on the various users of the loch, particularly anglers, and on the wider local economy. They also pose a potential risk to human and animal 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. Toxic cyanobacteria blooms can also impact directly on invertebrate (particularly filter feeding bivalves) and fish communities in the loch.

For these reasons the loch has been the focus for a series of restoration measures since the 1980s, specifically targeting reductions in the external phosphorus loads from a local woollen mill and several sewage works in the catchment (Bailey-Watts and Kirika 1999; Loch Leven Catchment Management Project 1999).

This report analyses monitoring data from 2007 and is one of a series that describe and interpret physical, chemical and biological information from Loch Leven on a regular basis to measure the success of restoration and inform on-going management. Temporal and spatial variation in a number of key water quality parameters are presented and considered in relation to long-term trends and established restoration targets.

2 METHODS

2.1 Sampling frequency and locations

Water samples were collected at approximately fortnightly intervals between 9th January and 12th December, 2007. Except during January, samples were taken at two sites, the first to the south of Reed Bower, and the second adjacent to the outflow of the loch. On the 9th and 23rd of January, samples were collected from the Reed Bower site only.

2.2 Water sampling and in situ measurements

Integrated (between water surface and 0.25 m above sediment surface) water samples were collected in duplicate at the Reed Bower site using a tube sampler. As a result of fluctuations in water level, sample depths varied from 3.0 to 3.5 metres. Surface water samples were collected in duplicate from the outflow using a bucket. Measurements of pH, conductivity, temperature and dissolved oxygen were recorded in the surface waters at each site using a Quanta probe (Hydrolab Water Quality Monitoring System, Hydrolab Corporation, Colorado, USA). Water clarity was measured using a Secchi disc where the Secchi depth is recorded as the depth in the water column at which the disk can no longer be seen. The lake water level (expressed as metres above sea level) was recorded at the harbour on each sample date.

Open water crustacean zooplankton samples were collected, and concentrated at the Reed Bower site, by drawing a plankton net (mesh size 120 μm, net mouth diameter 20 cm) slowly to the water's surface along a 4 m angled net tow. At the outflow site, 30-litre sub-surface samples collected with a bucket were concentrated by passing the sample through the plankton net. All samples were preserved in 4% formaldehyde solution.

2.3 Sample treatment and storage

On return to the laboratory, sub-samples of filtered (Whatman® GF/C within 6 hours of collection) or unfiltered water were taken from each duplicate site sample for soluble reactive phosphorus (SRP), total soluble phosphorus (TSP), nitrate (filtered and stored frozen), soluble reactive silicate (filtered and stored in fridge), total diatom silica (unfiltered and stored in fridge) and total phosphorus (TP; unfiltered and frozen) analyses. Two sub-samples of unfiltered water were taken for phytoplankton analysis and were stored in either 4% formaldehyde or Lugol's iodine solution. Samples for chlorophyll a analysis were prepared for each site by filtering 400 ml of lake water through a GF/C filter. The filter was stored (frozen) in a 15 ml centrifuge tube until analysis.

2.4 Chemical analyses

2.4.1 *Phosphorus determinations*

Tubes of filtered water were defrosted, sub-sampled and analysed for SRP and TSP, and the set of defrosted 15 ml tubes of unfiltered water were analysed for TP. SRP concentrations were determined following the method of Murphy and Reilly (1962). The optical absorbance of the sample solutions was measured at a wavelength of 882 nm alongside the absorbance obtained for known standard solutions of SRP using a Philips PU8670 spectrophotometer fitted with a 40mm flow-cell.

TP was determined using a sulphuric acid-potassium persulphate digestion on unfiltered samples to convert all forms of phosphorus to SRP. This was then measured in a similar way to that described above. The method used was as described for TP by Wetzel and Likens (2000), with an added acidification step (0.1 ml of 30% H2SO4 was added to the samples before addition of persulfate). TSP was determined in the same way as TP using a filtered sample.

The concentration of total particulate phosphorus (TPP) was calculated as the difference between TP and TSP concentrations. Similarly, the concentration of soluble unreactive phosphorus (SUP) was calculated as the difference between TSP and SRP.

2.4.2 *Nitrogen determinations*

Filtered water samples were defrosted and analysed for nitrate (NO_3-N). Samples were analysed on a SEAL AQ2 analyser (SEAL Analytical Limited, Burgess Hill, West Sussex, UK). Nitrate was determined by the sulphanilamide/NEDD (N-1-naphthylethyene diamine dihydrochloride) reaction which produces a reddish-purple dye. This was measured spectrophotometrically at 546 nm.

2.4.3 *Silica determinations*

Filtered water samples were analysed for soluble reactive silicate ($SRSiO_2$) according to Golterman et al. (1978). The optical absorbance of the sample solutions at a wavelength of 810 nm was directly measured against that obtained for known standard solutions of SiO_2 using a Philips PU8670 spectrophotometer fitted with a 10mm flow-cell.

2.5 Biological determinations

2.5.1 *Chlorophyll$_a$*

Frozen filters were submersed in 90% methanol overnight in a dark fridge. The following day, the tubes were centrifuged for 10 minutes at 2500 r.p.m. Chlorophyll$_a$ was measured spectrophotometrically at 665 nm with a turbidity correction conducted at 750 nm. The concentration of chlorophyll a was determined using equation 1 (APHA, 1992).

$$[\text{chlorophyll}_a]\mu g.l^{-1} = (O.D._{665} - O.D._{750}) \times \{(13.9 \times v)/(V \times L)\} \quad \text{(eq. 1)}$$

where:

$O.D._{665}$ = optical density (absorbance) at 665nm, a distinctive peak for chlorophyll$_a$

$O.D._{750}$ = optical density at 750nm, a correction for any background turbidity

v = the volume of the extract in millilitres (e.g. 11.5ml)

V = the volume of water filtered in litres

L = the path-length of the cuvettes used in cm (e.g. 4cm)

13.9 = an absorbtion coefficient (a constant) for chlorophyll$_a$

2.5.2 *Phytoplankton*

Phytoplankton were sub-sampled from the integrated water sample taken from Reed Bower. Phytoplankton counting procedures followed UK standard guidance (Brierley & Carvalho, 2007) with taxonomy following John et al. (2003). Separate sub-samples were stored in formaldehyde and Lugol's iodine solution. Samples were concentrated by settling before enumeration.

2.5.3 *Crustacean Zooplankton*

Twenty-fours crustacean zooplankton samples were collected from the Reed Bower site. In the laboratory, each sample was placed in a glass vessel and made up to a final volume of 250 ml with distilled water. The sample was thoroughly mixed, to distribute the animals randomly, and then subsampled with a Stempel pipette (volume 5ml). The animals present in each subsample were identified (Dussart and Defaye 1995; Einsle 1996; Flößner and Kraus, 1986; Harding and Smith 1974; Scourfield and Harding 1966) and counted under a low power binocular microscope. In all cases, three sub-samples were examined. The level of identification of the preserved freshwater crustacean zooplankton taxa was taken to species level wherever possible. No specimen was identified beyond the level justified by its condition of preservation or stage of maturity as recommended in the appropriate key. The sub-sample counts were converted to numbers of individuals per litre using appropriate multiplication factors. The samples collected from the outflow site have not been examined.

3 RESULTS

3.1 Physical factors

3.1.1 *Water and air temperature*

Surface water temperature followed a typical seasonal pattern over the year, although temperatures peaked at only 17.0 °C in July 2007 (Figure 1), several degrees cooler than in recent years. The lowest recorded water temperature during 2007 was 2.5 °C, from the outflow site on 6th February. Air temperature data recorded at RAF Leuchars air base indicate that January to April 2007 were particularly warm months compared with the 30-year average, but June to August were fairly typical, although June air temperatures were cooler than recent years.

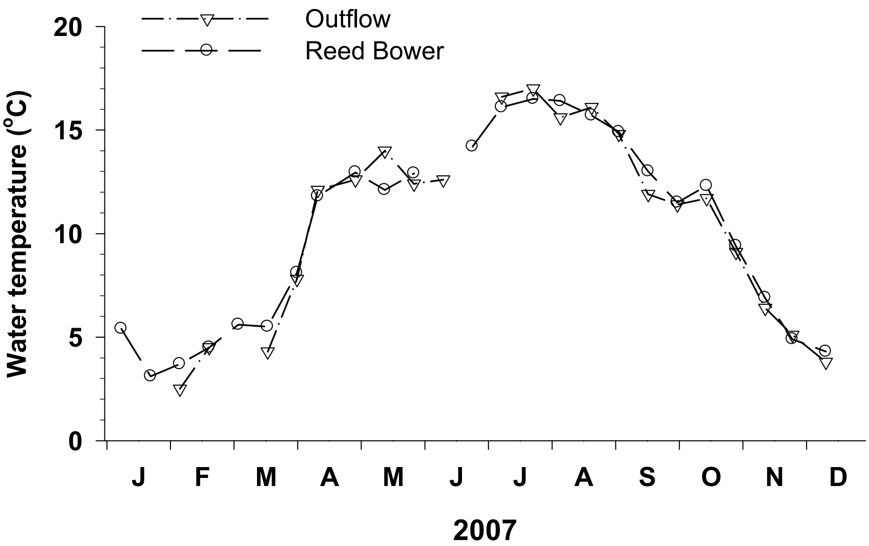


Figure 1 Spatial and temporal variation in surface water temperature

3.1.2 *Water level and rainfall*

Water level showed an atypical pattern in 2007, with water levels declining during spring, increasing again throughout summer and then declining in autumn (Figure 2). These patterns followed the exceptional rainfall patterns experienced in 2007, with March, April, September and October being much drier months than usual and June and July being exceptionally wet, with rivers along the east coast of Scotland all recording exceptionally high flows for June and July (Marsh and Hannaford, 2008). The lowest water level was recorded in November and the highest in January. A water level range of 1.13 m was recorded over the year.

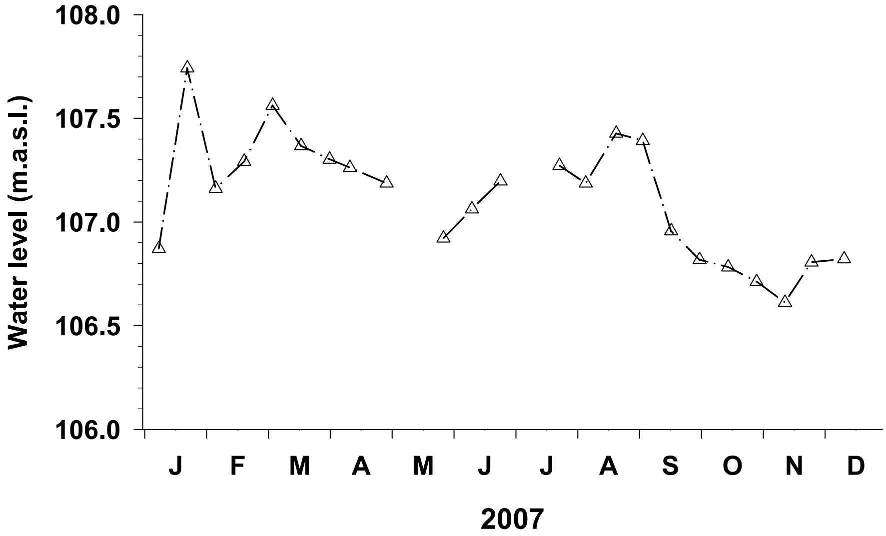


Figure 2 Water level fluctuation at the Harbour

3.1.3 *Water clarity*

Water clarity showed the characteristic trend observed in recent years at Loch Leven with a strong clear-water phase in May and June, followed by more turbid conditions throughout much of the rest of the year. The annual mean Secchi depth of 1.6 m (calculated as the average of 12 monthly averages) was relatively high in comparison to 1.4, 1.3 and 1.4 m in 2004, 2005 and 2006, respectively (Carvalho et al., 2007).

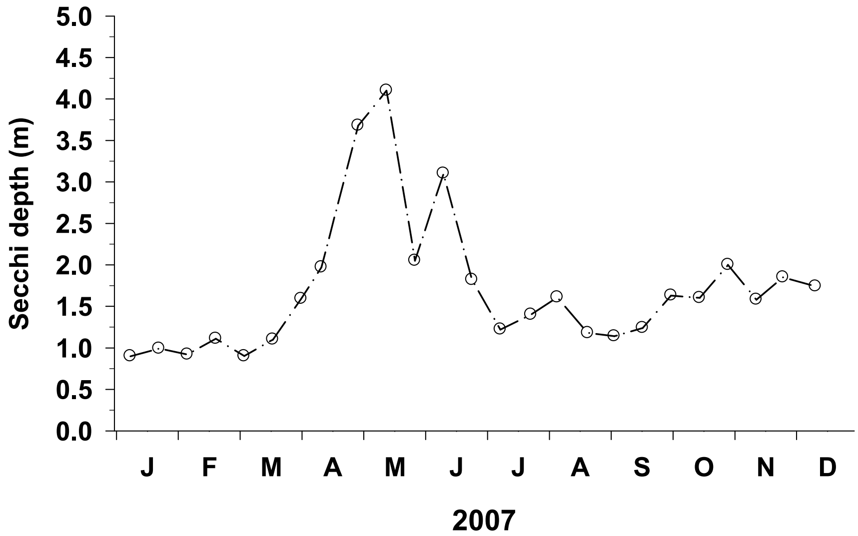


Figure 3 Water clarity (expressed as Secchi depth) at the Reed Bower sampling site

3.2 Chemical factors

3.2.1 *Dissolved oxygen*

Observations of dissolved oxygen saturation suggested that throughout 2007, as in previous years, the surface waters of the loch were well-supplied with oxygen, with mean readings around 90% saturation (Figure 4). Readings appear to have jumped lower than normal from August onwards; these values are atypical and may be erroneous and should be treated with caution.

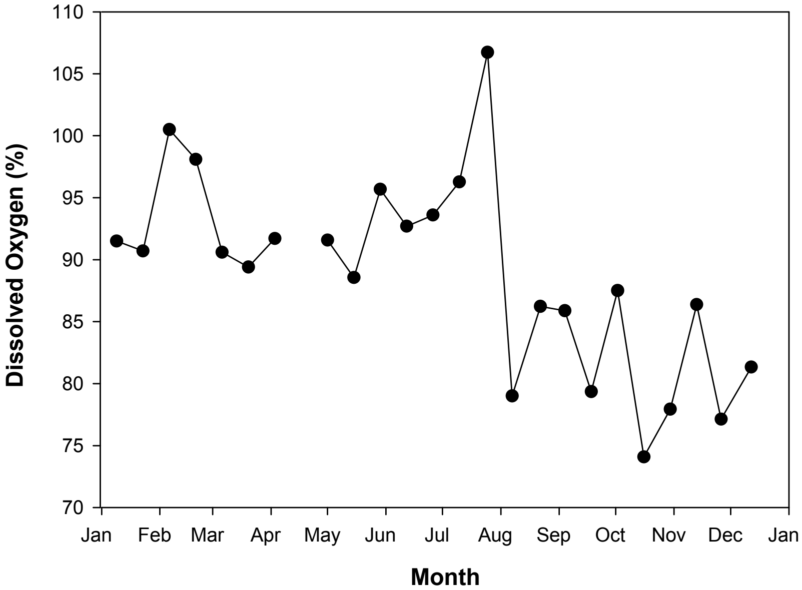


Figure 4 Dissolved oxygen saturation at the surface at Reed Bower

3.2.2 *Conductivity*

A seasonal pattern in conductivity was observed with peaks in spring and late autumn and minima in mid-summer. The values ranged between 199 μS cm^{-1} and 233 μS cm^{-1} and were typical for the loch.

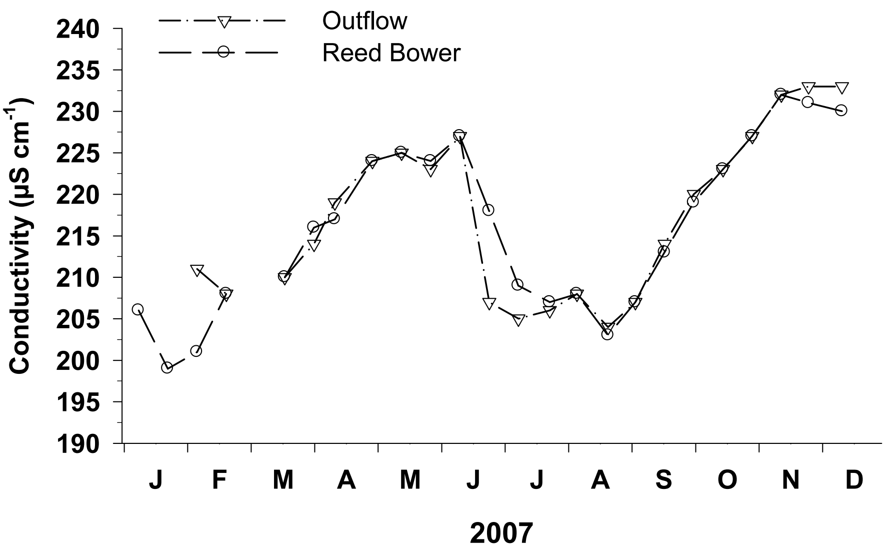


Figure 5 Electrical conductivity at ambient water temperature

3.2.3 *pH*

The range of pH values observed was fairly characteristic for the loch, ranging from just under pH 7.7 to pH 9.6. Peak values were recorded in summer and autumn and minima during the clear water phase in late spring (Figure 6). No data are available after 30[th] October 2007 due to a fault with the probe.

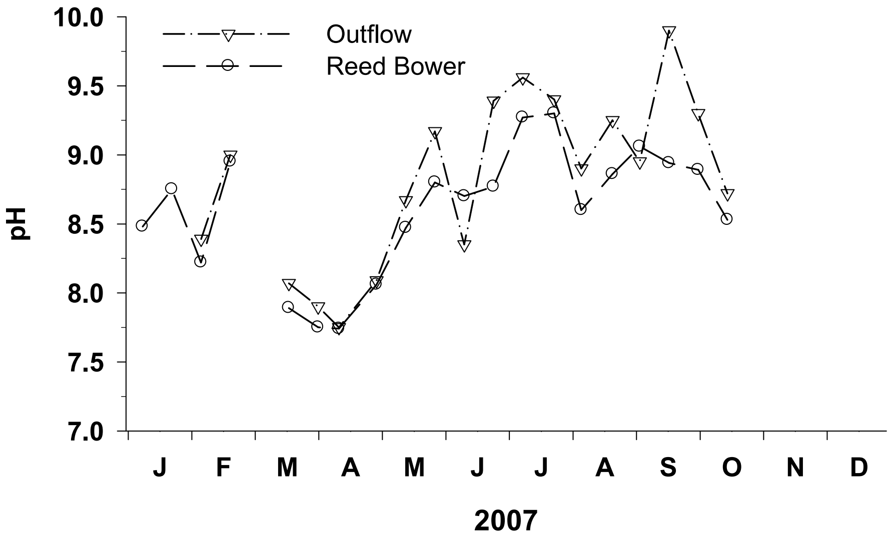


Figure 6 Temporal and spatial variation in pH at ambient water temperature

3.2.4 *Soluble reactive silica*

Silica, in the form of soluble reactive silica ($SRSiO_2$), is still generally the most abundant of the three main nutrients whose availability affects the abundance and species composition of the phytoplankton. Figure 7 shows the temporal and spatial variations in $SRSiO_2$ concentrations, which represent the instantaneously available nutrient resource that can, potentially, be taken up by diatoms.

$SRSiO_2$ concentration started the year relatively high, declining very rapidly over January to near undetectable levels in February, March and April. A slight increase was observed in late April and early May before another decline and concentrations didn't start increasing until late August. These changes are largely associated with diatom growth in spring and early summer, losses from the water column, and re-mineralisation of organic matter in the sediments leading to replenishment of Silica in the water column. Silica limitation is likely an important driver of the diatom phytoplankton community structure in spring, with other nutrients limiting production in summer and winter.

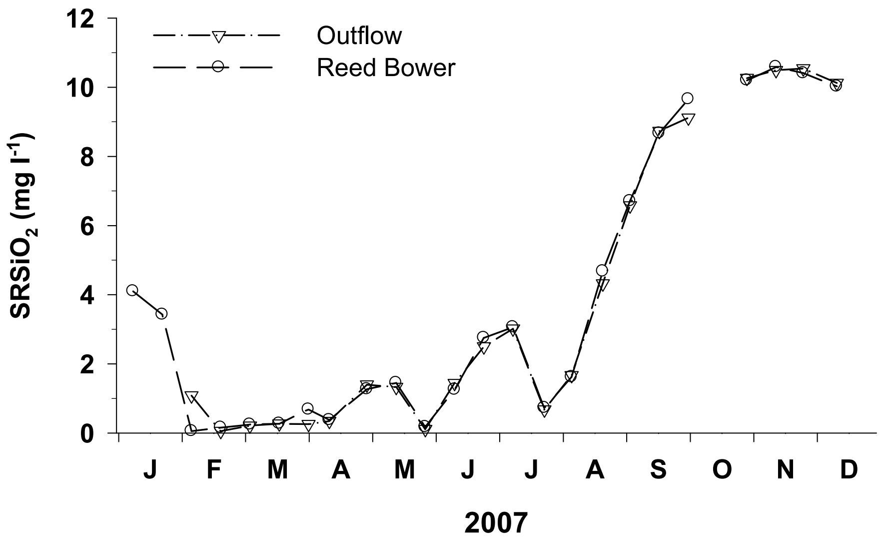


Figure 7 Spatial and temporal variation in concentrations of soluble reactive silica ($SRSiO_2$)

3.2.5 *Nitrate-nitrogen (NO_3-N)*

Nitrate concentrations showed a typical seasonal pattern with concentrations declining from a January peak to levels near detection limit by July. Concentrations remained low until October then continued to rise through November and December.

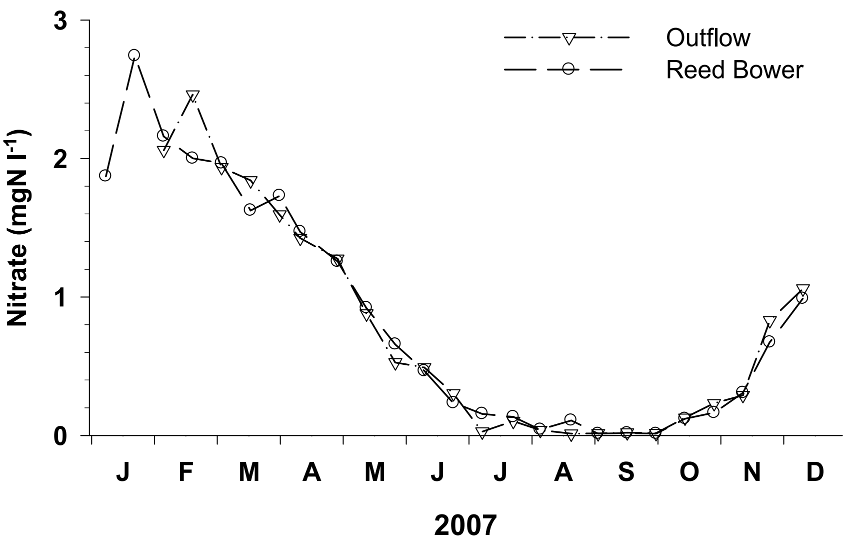


Figure 8 Spatial and temporal variation in concentrations of Nitrate-nitrogen

3.2.6 *Soluble reactive phosphorus*

Soluble reactive phosphorus (SRP) concentrations were very low (<10 µg l^{-1}) throughout the year, only increasing in late November (Figure 9). The characteristic sharp increase during August and September observed over the last 15-20 years was much reduced indicating a reduction in internal loading. The SRP concentrations indicate that both internal and external sources of P remain much lower than in previous decades and that P-limitation of phytoplankton crops may be important throughout the spring, summer and autumn.

3.2.7 *Total soluble phosphorus*

The trends in total soluble phosphorus (TSP) concentration (Figure 10) are similar to those observed in SRP. However, whereas SRP levels ranged between 2 µg P l^{-1} and 17 µg P l^{-1} over the year with an annual mean of 6 µg P l^{-1} (the average of 12 monthly averages), TSP levels were a little higher, ranging between 6 µg P l^{-1} and 18 µg P l^{-1}, with an annual mean of 12.5 µg P l^{-1}. There was, therefore, more soluble un-reactive P than reactive P in the water column for much of the year.

3.2.8 *Total phosphorus*

Total phosphorus concentrations showed a much greater seasonality (Figure 11) than those of TSP and SRP. This seasonality is in agreement with past years where TP is lowest during late spring / early summer during the clear-water phase, and highest in late summer-autumn as a result of the largest phytoplankton crops and breakdown and release of phosphorus from the sediments. Thus, although the internal loading event appears to have reduced (i.e. SRP peak absent) it is still sufficient to increase planktonic biomass during this period, suggesting that P is being rapidly taken up by the phytoplankton during summer. The TP concentrations then declined during October and November before increasing again in winter. TP ranged from 12 µg l^{-1} to 58 µg l^{-1}.

One outlier point was recorded at Reed Bower in March due to one of the two replicate samples from this site having a high concentration. Considering the TP concentration recorded in the other replicate, the TP concentrations at the outflow and the chlorophyll concentrations for the same date, this appears to be either due to analytical error, contamination or a particle in the sample. This value did not significantly affect the annual mean and so the decision was made not to exclude it in this analysis.

The annual mean TP concentration for 2007 was 32.5 µg l^{-1}. This is well below the target annual mean TP concentration of 40 µg P l^{-1} set by the Loch Leven Area Management Advisory Group (LLAMAG, 1993) and is considerably lower than the annual mean values recorded in 2004, 2005 and 2006 (Carvalho et al., 2007).

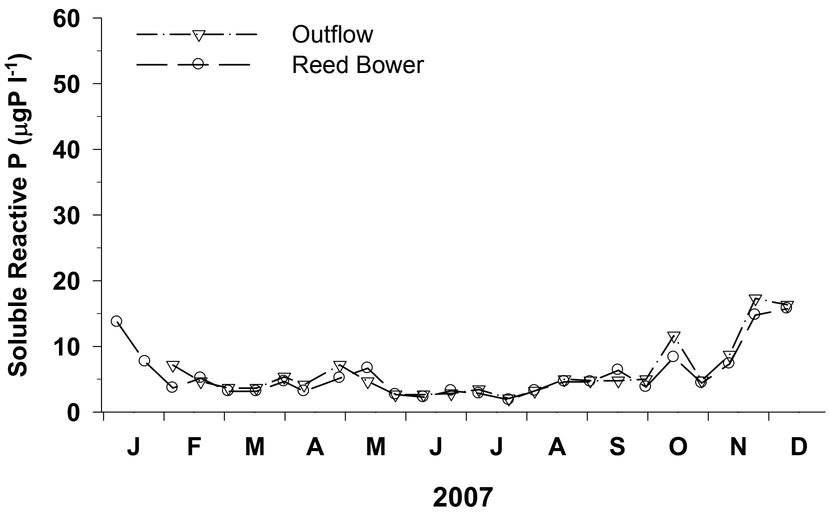


Figure 9 Spatial and temporal variations in concentrations of soluble reactive phosphorus

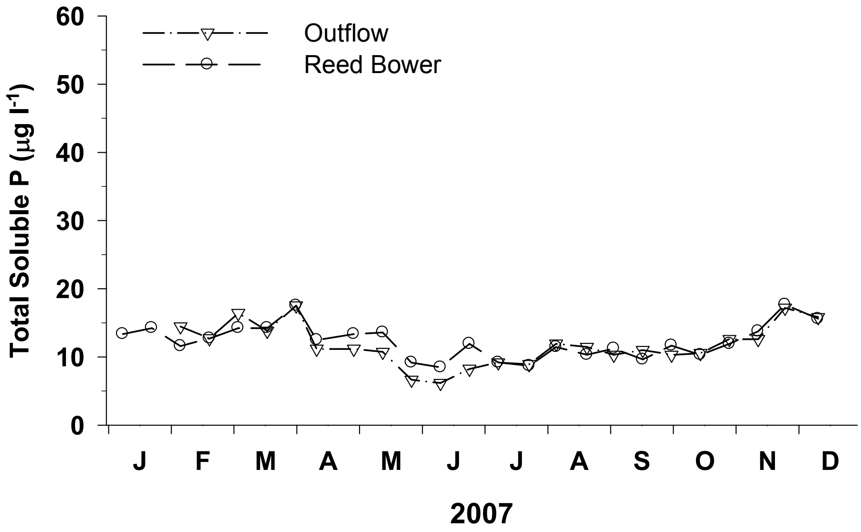


Figure 10 Spatial and temporal variation in concentrations of total soluble phosphorus

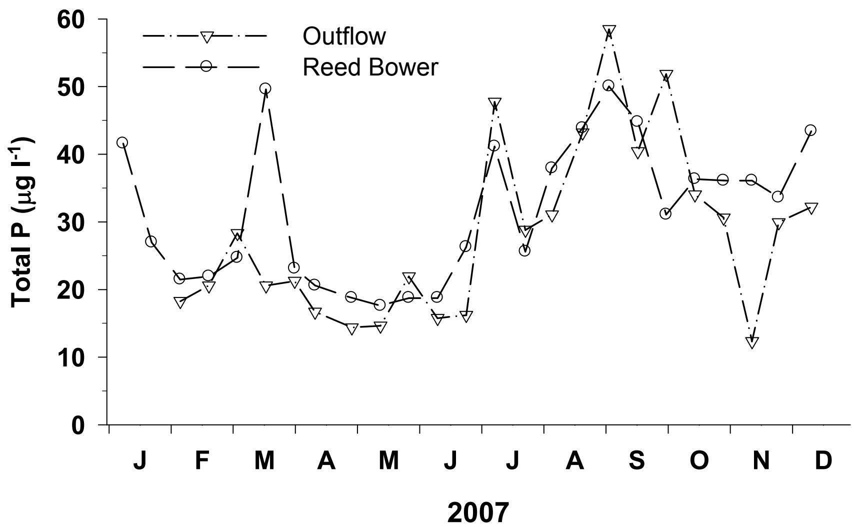


Figure 11 Spatial and temporal variation in concentrations of total phosphorus

3.3 Phytoplankton

3.3.1 *Chlorophyll$_a$*

Chlorophyll$_a$ concentrations showed a small peak in early February, then declined to relatively low concentrations for Loch Leven, generally not exceeding 10 µg l^{-1} from early April to mid-June. Higher concentrations, generally greater than 20 µg l^{-1}, were observed from late June to the end of the year with several small peaks throughout summer and autumn (Figure 12). Concentrations were generally more varied for the outflow than for the Reed Bower site, with the very high peak at the outflow in July probably representing a wind-blown accumulation. Concentrations at Reed Bower ranged through the year from 5 µg l^{-1} in early May to 46 µg l^{-1} in July.

The annual mean chlorophyll$_a$ concentration for the Reed Bower site was 24 µg l^{-1}. This value is low for the loch and much lower than annual mean concentrations recorded in 2004, 2005 and 2006 of 48, 35 and 37 µg l^{-1}, respectively. The 2007 mean was, however, still higher than the target mean annual chlorophyll$_a$ concentration of 15 µg l^{-1} set by the Loch Leven Area Management Advisory Group (LLAMAG 1993) and endorsed in the Loch Leven Catchment Management Plan (Loch Leven Catchment Management Project 1999).

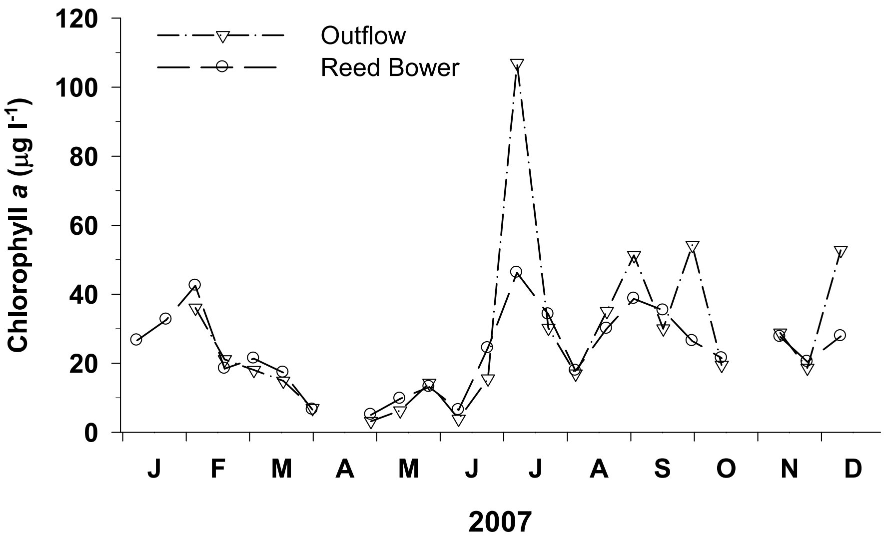


Figure 12 Temporal and spatial variation in chlorophyll$_a$ concentration

3.3.2 *Phytoplankton composition*

The phytoplankton community of Loch Leven was dominated by diatoms for much of 2007 (Figure 13). The 'spring' diatom bloom occurred early, in February, as in 2006. By May, diatoms had declined and were replaced by small flagellates and green algae. Very low concentrations of phytoplankton were present in June, but by July diatoms had increased again and cyanobacteria were present in large numbers. Diatoms remained an important component throughout summer alongside cyanobacteria with the latter dominating in August and September. Unusually, no typical October diatom peak was observed, with their increase in 2007 delayed until November and December.

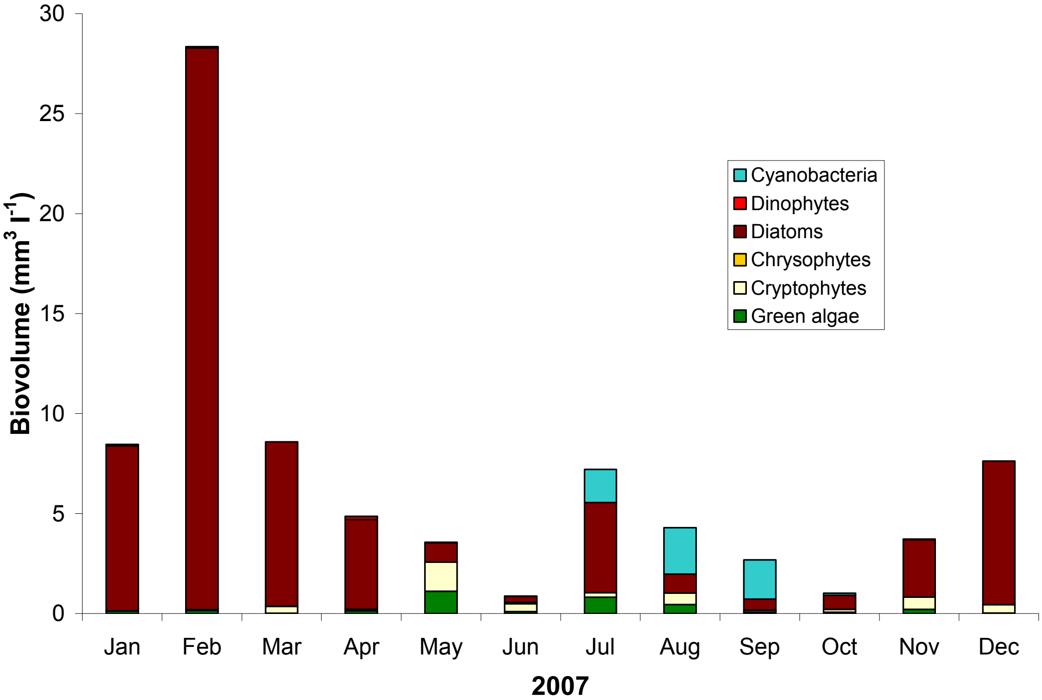


Figure 13 Temporal variation in phytoplankton classes at Reed Bower

In terms of World Health Organisation (WHO) guidance levels (Scottish Executive Health Department, 2007), cyanobacteria were above the 20,000 cells per ml "relatively low probability of health risk" threshold for recreational waters during July, August and September (Figure 14). Cell concentrations never reached the "moderate risk" guidance level of 100,000 cells per ml. Potentially toxic species, such as *Microcystis*, were key components of the phytoplankton community from July to September and water samples taken for analysis in August contained Microcystin toxin concentrations above WHO thresholds (Codd, *pers. comm.*). Surface scums or aggregations were also observed on the loch during August (Figure 15). These have a high probability of adverse human and animal health effects if exposure is high (whole body contact with scum or ingestion) (Scottish Executive Health Department, 2007). At such times, water sports, such as canoeing, should be strongly discouraged.

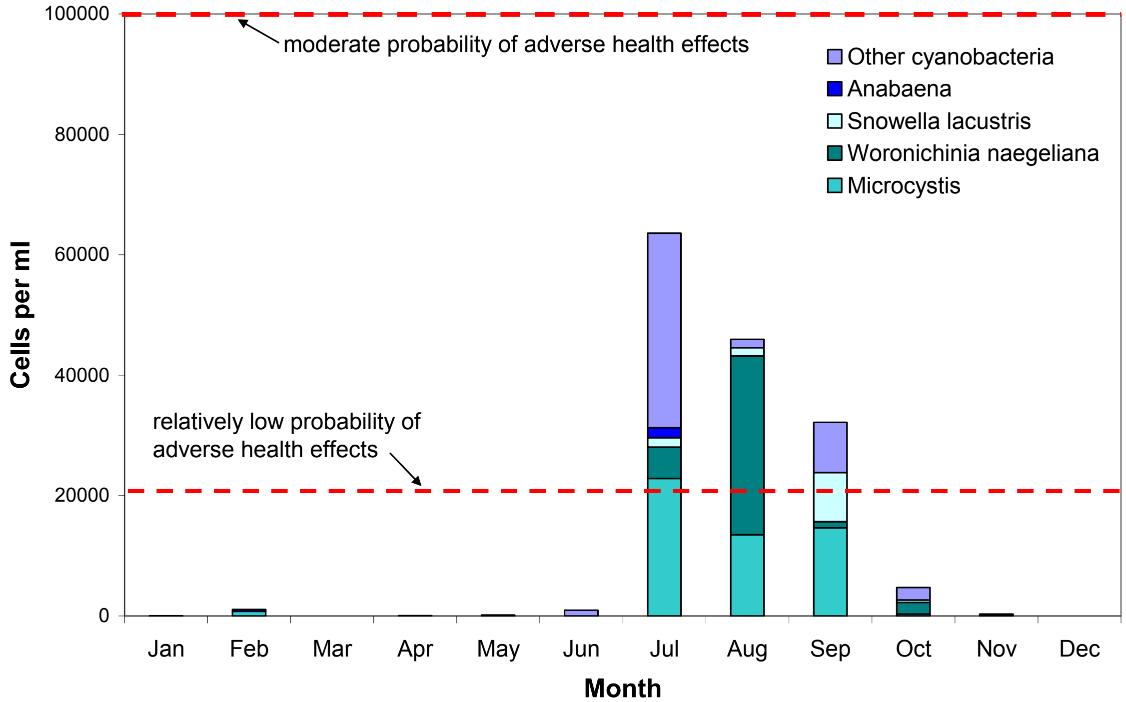


Figure 14 Temporal variation in cyanobacteria cell numbers in relation to health guidance levels (Scottish Executive Health Department, 2007)

Figure 15 Cyanobacteria scums, Loch Leven, August 2007

3.4 Crustacean Zooplankton

3.4.1 *Species List*

Nine crustacean zooplankton species were recorded from the Reed Bower samples during 2007 (Table 1).

Table 1 Crustacean zooplankton species recorded in Loch Leven during 2007

Cladocera (Branchiopoda)

Anompoda
Bosmina longirostris (O.F. Müller)
Daphnia hyalina species-complex (formerly *D. hyalina var.lacustris* Sars)
Chydorus sphaericus (O.F. Müller)
Alona sp.
Halopoda
Leptodora kindti (Focke)
Onychopoda
Bythotrphes longimanus Leydig

Copepoda

Calanoida
Eudiaptomus gracilis (Sars) (formerly *Diaptomus gracilis* Sars)
Cyclopoida
Cyclops abyssorum Sars (formerly *Cyclops strenuous abyssorum* Sars)
Cyclops vicinus Uljanin

3.4.2 *Abundance*

Temporal variation in the main crustacean zooplankton species in 2007, as indicated by their monthly mean densities, are shown in Figure 16. The principal taxa were the calanoid copepod *Eudiaptomus gracilis*, the cladoceran referred to as the *Daphnia hyalina* species-complex (cf. May et al. 1993: Gunn et al. 1994), the cyclopoid copepod taxa *Cyclops* and *Bosmina longirostris*. The relative abundance of *Bosmina* is particularly noteworthy as only a few specimens have been recorded in the Loch Leven plankton in recent years.

The general seasonal features of the population dynamics of each of the main crustacean zooplankton taxa over the period 2007 can be summarised as follows:

(a) Population densities of *Daphnia* were very low (<3 ind. l^{-1}) during the first three months of the year, followed by a rapid increase in numbers to a peak in May (maximum of 34 ind.l^{-1} in mid May 2007). As is typical at Loch Leven, *Daphnia* numbers then declined to relatively low densities in June and July. More unusually, the population increased again during August to a maximum peak of 56.8 ind.l^{-1} in early September. Thereafter, *Daphnia* numbers declined rapidly back to typical over-wintering levels of less than 1 ind.l^{-1}.

(b) In 2007, unlike earlier years, the *Cyclops* population was dominated by *Cyclops vicinus* in the early part of the year rather than *Cyclops abyssorum*, which was only recorded in the plankton in the latter half of the year. The concentrations of the nauplii, copepodites and adults of *Cyclops* were low (<5 ind. l^{-1}) in the first three months of the year before increasing to a maximum of around 27.3 ind. l^{-1} in mid-April before declining rapidly to very low mean population densities (<2 ind. l^{-1}) over the summer months (May to August). Thereafter, *Cyclops* numbers recovered a little but remained consistently low (generally <5 ind. l^{-1}).

(c) *Eudiaptomus* population densities were low in the first three months of the year (<4 ind.l^{-1}) before increasing to an unusually high peak in numbers in mid-May (maximum of 59.3 ind. l^{-1}). Although numbers declined thereafter, they remained relatively high throughout the summer months before returning to over-wintering levels in October.

(d) *Bosmina longirostris* numbers were very low in the first three months of 2007 before increasing to a maximum of 32.1 ind. l^{-1} in mid-May. No *Bosmina* were recorded during the summer months but they were recorded again in very low numbers (<1 ind.l-1) from mid-October onwards.

(e) As is usual, the predatory cladocerans *Leptodora kindti* and *Bythotrophes longimanus* occurred in extremely low numbers (<0.4 ind.l^{-1}) over the summer months during 2007.

(f) The Chydoridae species*, Chydorus sphaericus* and *Alona* sp., were occasionally recorded in 2007.

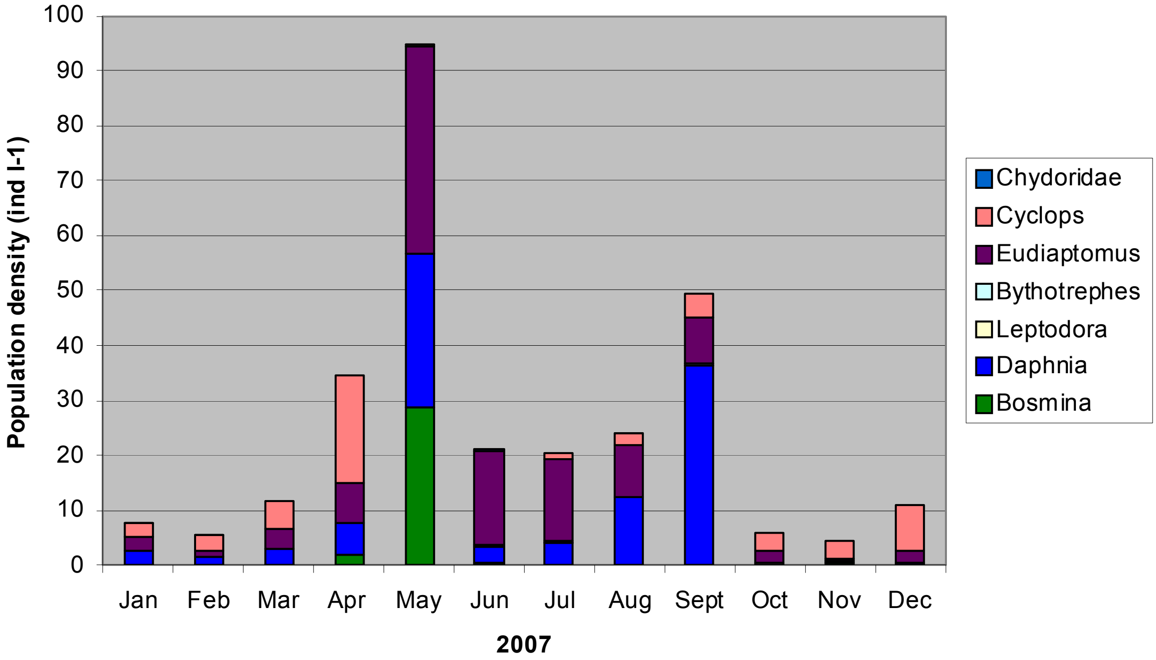


Figure 16 Temporal variation in crustacean zooplankton, Loch Leven, 2007.

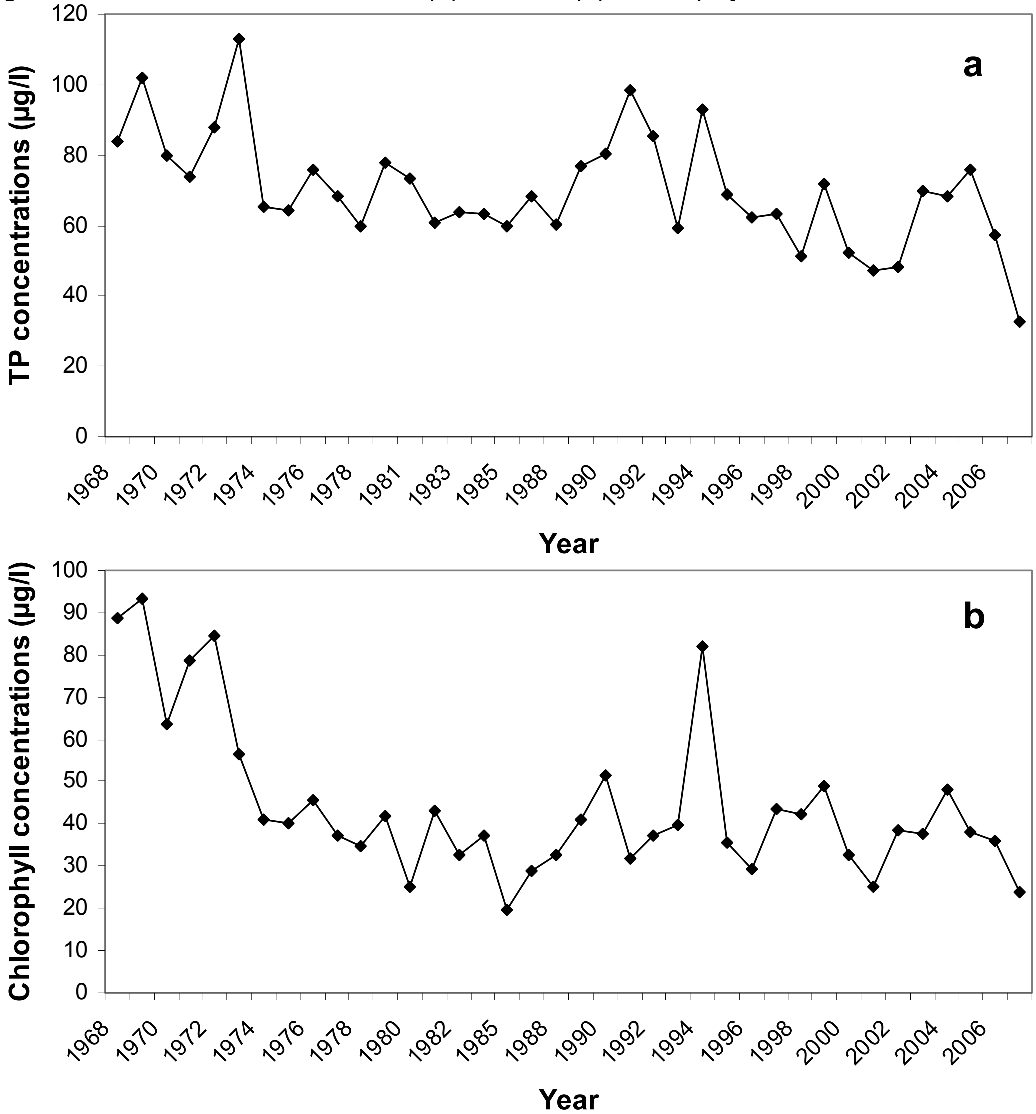
4 DISCUSSION

4.1 Recent Trends in Water Quality and Plankton Dynamics

Evidence of recovery from eutrophication in all three water quality parameters was stronger in 2007 than in previous recent years. Comparison of the annual mean TP and chlorophyll concentrations with those recorded over the past forty years suggest that the recovery trend that was apparent up to 2001 (Carvalho et al., 2003; Ferguson et al., 2008), and which then appeared to stall in recent years (Carvalho et al., 2007), has now returned and is progressing well (Figure 17a).

In 2007, the annual mean TP concentration was 32.5 µg l^{-1}. This is the first year on record that the annual mean TP concentration was below the statutory target concentration of 40 µg l^{-1} set by the Loch Leven Area Management Group (LLAMAG, 1993). Phosphorus concentrations, both bio-available forms (SRP) and total phosphorus, showed a large improvement compared with previous years. Chlorophyll concentrations were still above the Loch Leven Area Management Group target of 15 µg l^{-1}, but the annual mean value of 24 µg l^{-1} recorded in 2007 was still the second lowest observed over the past 40 years (Figure 17b).

Figure 17 Trends in annual mean (a) TP and (b) chlorophyll$_a$ concentrations at Loch Leven



In terms of the phytoplankton community, 2007 was fairly typical of recent years with diatoms dominating for much of the year. The slight differences were that diatoms remained common throughout summer, but had no October peak and the cyanobacterium *Anabaena* was less abundant than *Microcystis* and *Woronichinia*. The lack of an October diatom peak is not explained by growth-limitation by silica, concentrations of which were increasing by August.

Cyanobacteria still remain a health hazard at Loch Leven. Both the magnitude and timing of cyanobacteria blooms in 2007 were broadly similar to patterns observed over the previous three years, indicating that warning signs need to be present from July to September, particularly during weather episodes that lead to surface scums forming.

Comparing the 2007 results for the Loch Leven crustacean zooplankton community with previous years' data indicates that it was a very unusual year both in terms of species composition and relative abundance of the principal taxa. The main features of interest were as follows:

(i) Increases in the spring densities in *Daphina,* the main phytoplankton grazer in Loch Leven, have recently been linked to improvements in water clarity and reductions in spring chlorophyll concentrations (Ferguson et al., 2007). In the first half of 2007, population dynamics of *Daphnia* were broadly similar in terms of absolute concentrations and seasonality of occurrence to the pattern exhibited in recent years (Figure 18). More unusually the annual maximum population peak occurred in early September, although this was similar in terms of absolute numbers to the population peak recorded in August 2005.

(ii) *Cyclops*, which normally co-dominate the Loch Leven crustacean zooplankton community, were found in very low numbers in 2007 compared to earlier years (Figure 19). No adults of *Cyclops abyssorrum,* which has been the main species recorded in Loch Leven since regular monitoring began in the late 1960s, were recorded in the early part of the year although it reappeared in the plankton in the autumn. In the spring samples, only copepodites and adults of *Cyclops vicinus* were recorded. *Cyclops* species are typically omnnivorous and may feed on small crustacea and rotifers (Fryer, 1993). They have been observed to feed on young *Eudiaptomus* and *Daphnia* in Loch Leven (Johnson and Walker, 1974), therefore, their low numbers may have helped herbivorous zooplankton remain more abundant. However, Rutkowski (1980) studied the diet of *Cyclops abyssorum* in Loch Leven over 1 year and found it to predominantly feed on the filamentous diatom *Aulacoseira*. The cause of the low *Cyclops* densities in 2007 is unclear.

(iii) In the relative absence of *Cyclops*, the herbivorous *Eudiaptomus gracilis* unusually became the dominant copepod species in Loch Leven in 2007 reaching a mean density in May of 37.7 ind. l^{-1}. This population was much higher compared to what had been recorded in earlier years (Figure 20) probably as a result of less predation pressure being exerted by *Cyclops*. In the last few months of the year the *Eudiaptomus* population returned to more 'normal' low over-wintering numbers with the recovery of *Cyclops* in the plankton.

(iv) The phytoplankton grazer *Bosmina longirostris* is a swimming species characteristic of large eutrophic water bodies (Fryer, 1993). The appearance of *Bosmina* in large numbers in May in Loch Leven was very surprising as only a few individual specimens have been recorded in the plankton in recent years (May et al., 1993; Gunn and May, 1998).

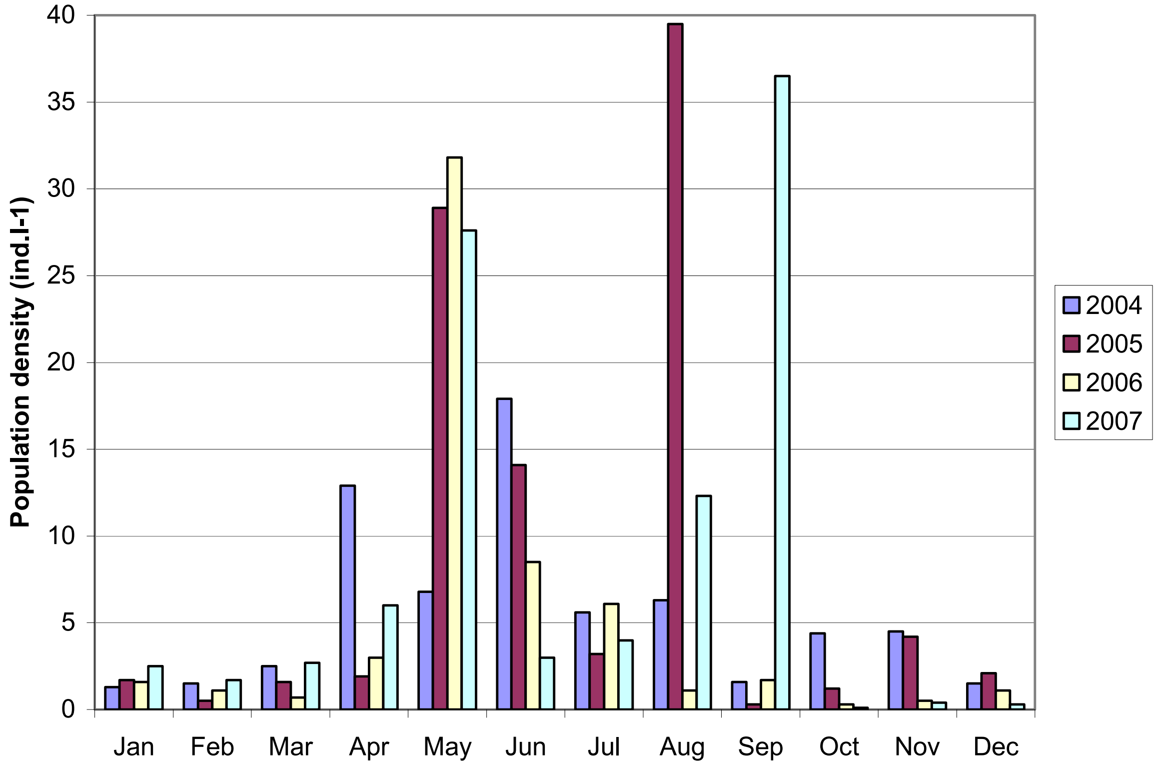


Figure 18 Mean densities of Daphnia, Loch Leven 2004-2007

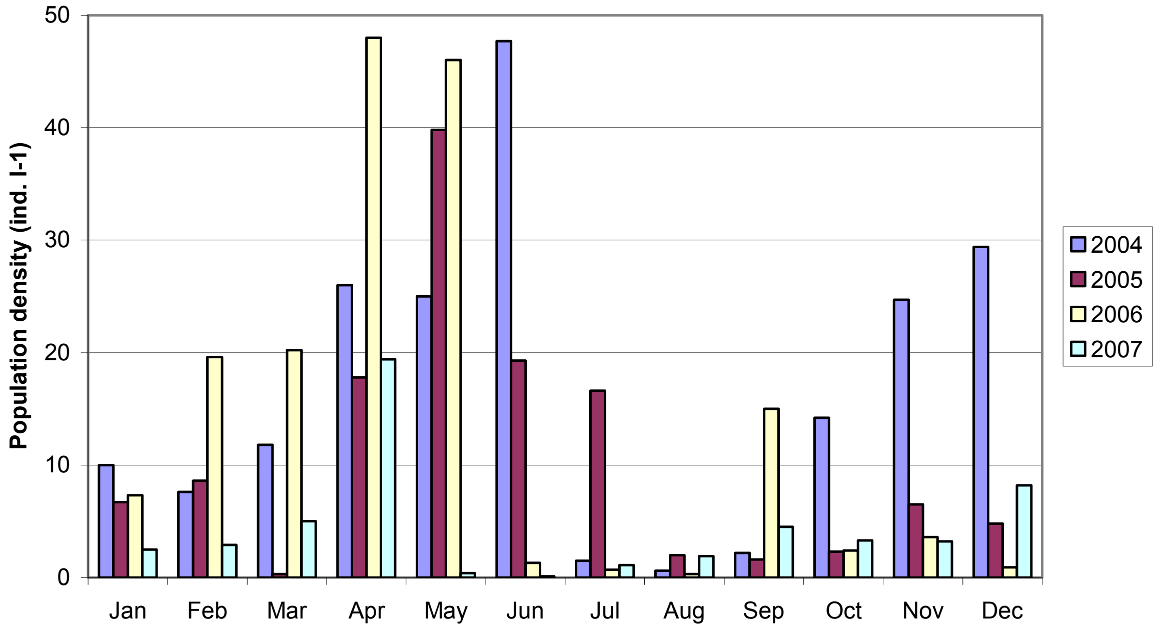


Figure 19 Mean densities of Cyclops, Loch Leven 2004-2007

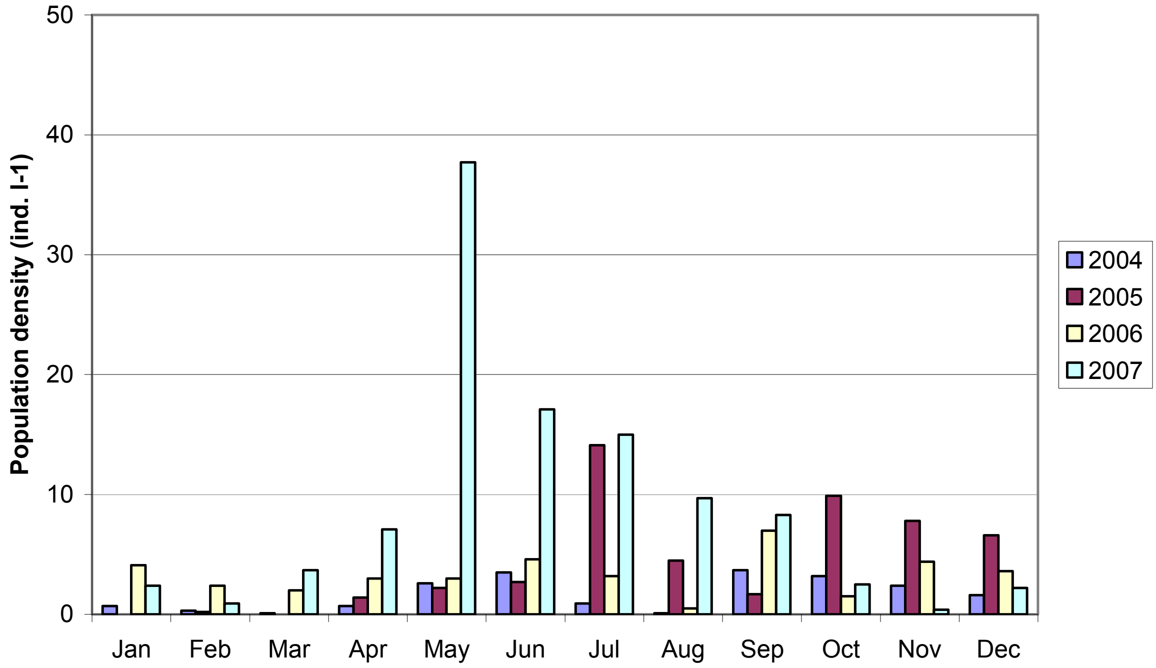


Figure 20 Mean densities of Eudiaptomus, Loch Leven 2004-2007

Although an unusual year in many ways, what is not in doubt is that 2007 was a much improved water quality year for Loch Leven compared with the poor water quality observed in the early 1970s and early 1990s. There are a number of possible reasons for this:

- Both nitrate and soluble reactive phosphorus availability were low throughout much of summer despite the high rainfall
- Grazer densities remained relatively high, particularly of the filter-feeding herbivores, *Daphnia* (May, August and September), *Bosmina* (May) and *Eudiaptomus* (May to September)
- Macrophyte beds (which compete with phytoplankton for light and nutrients) have become much more extensive with a maximum growing depth of 5 m observed off St Serf's Island in 2006. This coupled with the low wind mixed depth may also have reduced wind-induced sediment disturbance and associated nutrient release.

2007 was an unusual weather year in which a warm, dry and calm (Figure 21a) spring and a cooler and exceptionally wet summer were observed. Warmer spring temperatures have been associated with higher *Daphnia* densities in the loch and a strong spring clear water phase (Ferguson et al., 2007; 2008) and it is thought that the increased coverage of macrophytes to deeper waters may be a response to improved water clarity during their early spring growth. Additionally, the calm conditions (compared to 30 year mean values (1979-2007)) observed in spring resulted in a shallower wind mixed depth and more favourable conditions for macrophyte growth (Figure 21b). The exceptionally wet and cooler summer may have had a number of effects. If external loading was the main driver of nutrient availability in the loch, the wet summer would be expected to increase nutrient loadings to the loch and enhance phytoplankton growth. This was not, however, apparent in the in-lake nutrient concentrations. This suggests that what may be more important is that the cooler summer reduced internal nutrient loading from sediments, a process that is enhanced under high temperature conditions (Spears et al., 2007b; Spears et al., 2008). Additionally the exceptional rainfall experienced during June and July may have enhanced the flushing of phytoplankton from the loch at a particularly critical time of year when their populations normally develop. Further work is required to assess long-term trends in seasonality of nutrient discharge from the loch (as outlined in Spears et al., 2007a) and to assess controlled flow regulation as an effective management strategy in Loch Leven. The improvement in both TP and chlorophyll concentrations may, therefore, be a response to a number of factors all driven by the weather, both the warm spring and an exceptionally wet and cool summer. Another factor that may have been important in 2007 was the stopping of fish stocking. This may have been one reason for the unusual patterns observed in the zooplankton.

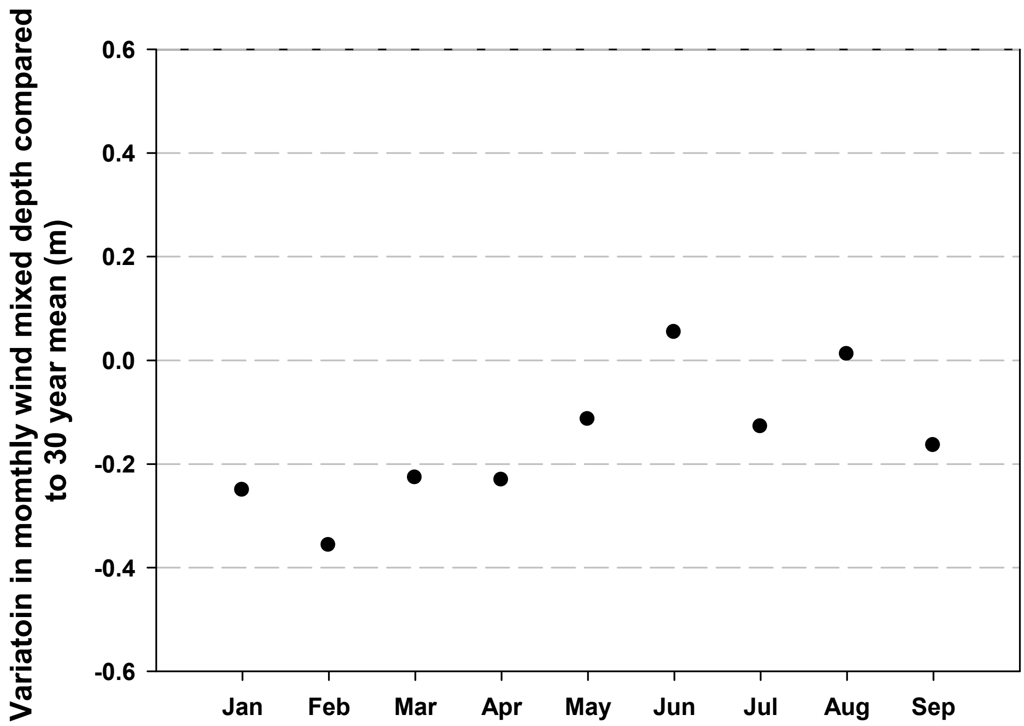


Figure 21. Variations in the monthly wind mixed depths in 2007 at the Reed Bower site from the 30 year monthly means (1979-2007). Wind mixed depths were estimated using the methods of Smith and Sinclair (1972). Comparisons between January and September are shown only due to a lack of data availability for 2007 at the time of writing this report.

4.2 Water Framework Directive Standards

Water quality targets for Loch Leven are now being set under the EU Water Framework Directive (WFD) (European Commission, 2000). The WFD places an emphasis on the ecology of the lake (phytoplankton, macrophytes, benthic invertebrates and fish), rather than the chemistry. However, within the UK, TP standards for water quality assessment are also being implemented (UKTAG, 2008). The new UK Environmental Standards for TP for Loch Leven are more stringent than those set by LLAMAG (1993). The good/moderate (G/M) boundary TP target for a shallow, high alkalinity loch in Scotland, such as Loch Leven, is

32 µg l^{-1}, the moderate/poor (M/P) boundary is 46 µg l^{-1} (Carvalho et al., 2006). In general Loch Leven would classify as poor status, with 2007 the only year classifying as moderate status. These are targets informally agreed for Northern Europe (by the Northern Geographical Intercalibration Group). Central European targets for this lake type, being applied in more southern and eastern parts of the UK, are similar to the LLAMAG (1993) targets with a G/M boundary TP target of 36 µg l^{-1} and a M/P boundary of 71 µg l^{-1} (UK TAG, 2008). Using these Central European standards, Loch Leven would often classify as moderate status, with 2007 classifying as good status.

New European standards for chlorophyll concentrations in lakes have been formally agreed by the European Commission as part of the Intercalibration process for the Water Framework Directive. The good/moderate status class boundary for chlorophyll for a high alkalinity, shallow lake, such as Loch Leven, has been agreed at 7.5 µg l^{-1}. The same target for a very shallow, high alkalinity lake (<3 m mean depth) is 16.5 µg l^{-1}. Loch Leven is near the depth boundary between lake types; a site-specific target is, therefore, considered most appropriate by the UK. Using site-specific predictive models developed as part of the UK Phytoplankton Classification Tool (Carvalho et al., 2006), Loch Leven would have a G/M chlorophyll target of 11 µg l^{-1} and a moderate/poor (M/P) target of 22 µg l^{-1}. In 2007, as in most years over the past decade, Loch Leven would, therefore, be classified as poor status on the basis of its chlorophyll concentrations. Although 2007, with an annual mean chlorophyll concentration of 24 µg l^{-1} is approaching the moderate status class.

Evidence from palaeolimnological data suggests that a reference TP baseline for Loch Leven should be about 45 µg l^{-1} (Bennion et al., 2001), suggesting the type-specific standards for TP are too stringent for this site. The European chlorophyll G/M standard also appears unachievable at this site. This highlights the fact that the new standards are all derived from large populations of European lakes to get a general picture of the state of the European environment. They are not necessarily appropriate at an individual lake basis where a range of site-specific factors may affect targets. Water colour, flushing rates, macrophyte coverage, zooplankton grazer populations and fish stocking are all individual lake factors that are likely to shape an achievable target. For example, with its large fetch, Loch Leven may be functionally more similar to a very shallow loch (< 3m mean depth) with wind-mixing regularly disturbing sediments, reducing water clarity and bringing both nutrients and benthic algae into the water column. Site specific targets based on palaeolimnological or historical data and predictive models are, therefore, likely to be more appropriate for SEPA's management purposes than the type-specific targets agreed at a European level. The latter should be viewed as more general targets for giving SEPA a view of the state of Scotland's environment, with sites over- and under-protected by type-specific standards generally balancing each other out.

4.3 Lake and Catchment Management Implications

There is clearly a need for continued lake and catchment management at Loch Leven to try to meet WFD targets for chlorophyll and to sustain and enhance the ecological recovery. The large reductions in external phosphorus loadings appear now to be followed by reductions in internal loading. Both N and P limitation of phytoplankton crops are important during the year and, therefore, catchment management should continue to identify and reduce significant sources of both nitrogen and phosphorus. Indeed, analysis of annual mean nitrate concentrations in Loch Leven since 1970 show a significant increasing trend, in particular since the mid 1990s (Ferguson et al., 2008), highlighting the fact that more management attention needs to be focused on this nutrient, as well as phosphorus.

Recent phosphorus loading figures from 2005 suggest little change in loadings since 1995. In 2005, phosphorus loads to Loch Leven were estimated to be 7.69 t TP, 2.68 t SRP and

4.11 t PP (Figure 22). There has been little change in TP loadings over the past decade; TP loads reduced by just 0.48 t between 1995 and 2005. However, SRP loads continue to decline, with a reduction of 2.27 t between 1995 and 2005. In 1995, SRP and PP loads contributed 62% and 37% of the annual TP load, whilst in 2005 SRP and PP loads contributed 37% and 56% (Figure 23). Compared to previous years, PP now contributes a greater proportion of the annual TP load to Loch Leven. This indicates that management of point sources in the catchment continues to reduce soluble P loadings, and that diffuse sources are now the dominant P source to the loch. Management initiatives to reduce diffuse P sources, primarily from agriculture and septic tanks, are critical to achieving further reductions of P loads.

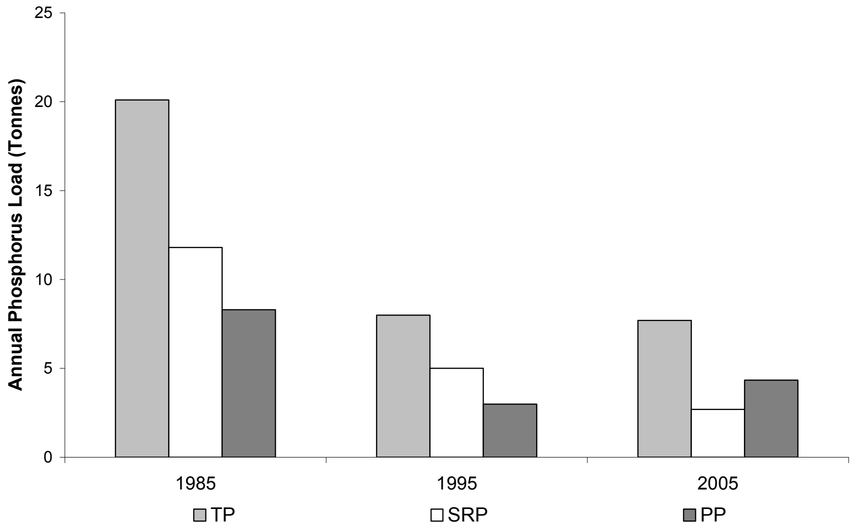


Figure 22. Variations in phosphorus loads to Loch Leven during 1985, 1995 and 2005. (Source: Lindsey Defew)

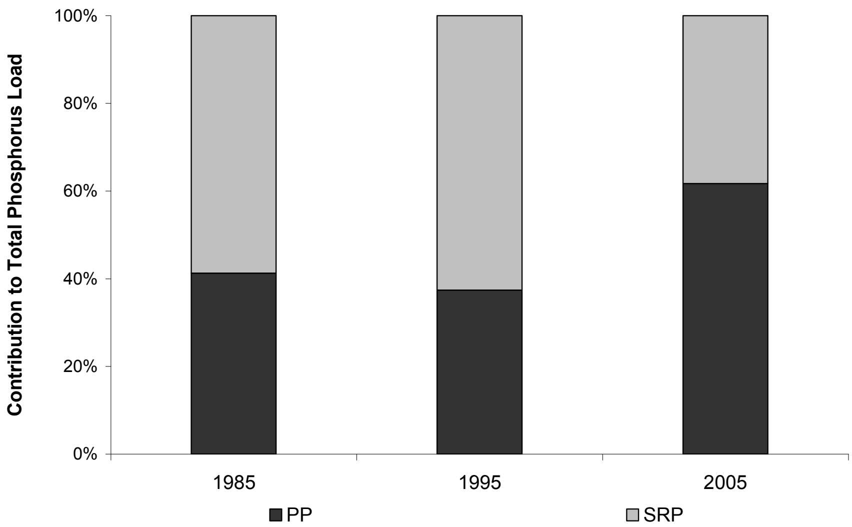


Figure 23. The contributions of soluble and particulate phosphorus to the annual total phosphorus load in 1985, 1995 and 2005. (Source: Lindsey Defew)

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