Summary of Lakes Tour 2021/22 survey

Introduction

The English Lake District is England's largest national park and was designated as a UNESCO World Heritage Site in 2017. The Lake District is particularly unusual in having a wide range of lake types in a small geographic area. The underlying geology of the region is in part responsible for this variation.

Lakes, such as Wastwater, which are naturally less 'productive' – ie they support lower amounts of algal growth – and have low background concentrations of nutrients tend to occur on the harder volcanic rocks. More naturally nutrient-rich, 'productive' lakes such as Esthwaite Water are situated on softer rocks. This diversity in lake types supports a wide diversity of plant and animal life in the lakes.

Imposed over this natural nutrient gradient due to the underlying geology, human activities on the land draining into these lakes (their catchments) also varies in intensity, with more farming activity, settlements and tourist attractions tending to be focused along the more fertile valley floors.

These activities also contribute to the productivity of the lakes, through the input of nutrients such as phosphorus and nitrogen. Excessive supplies of these nutrients are known to have negative effects on water quality and biodiversity.

Similar to much of the natural environment, human pressures on the Lake District have grown over time, and these have impacted on the water quality of the lakes. Inputs of sewage from tourist activities and the local population, combined with changes in the intensity of agriculture, industrial pollutants, climate change and introduction of invasive non-native species all place multiple ecological pressures on the lakes.

The Lake District has a long history of environmental monitoring dating back to the 1920s. The current form of the 'Lakes Tour survey' – of which this report presents the findings – covers 20 major lakes and tarns, and started in 1984. The survey has been repeated on a roughly five-yearly interval since then. The latest survey, carried out in 2021-22, was led by the newly independent charitable research institute, the UK Centre of Ecology & Hydrology (UKCEH).

Sampling for the Lakes Tour survey is done on a seasonal basis to provide a snapshot of change over the year. Because the survey has been carried out in approximately the same way since it began in 1984, the Lakes Tour dataset also enables comparison over the past 30 years, to provide a robust and fairly comprehensive picture of how lakes have responded to long-term environmental pressures. The survey can also be used to identify patterns of water quality changes across the region and show where further investigations of changes at individual lakes are needed.

Methodology

The Lakes Tour 2021/22 survey was carried out in April, July, October /November 2021 and January/February 2022. Twenty lake basins were surveyed, including the two basins of Windermere (north and south). The location and catchments of the lakes included in the survey are shown in Figure 1 on the following page.

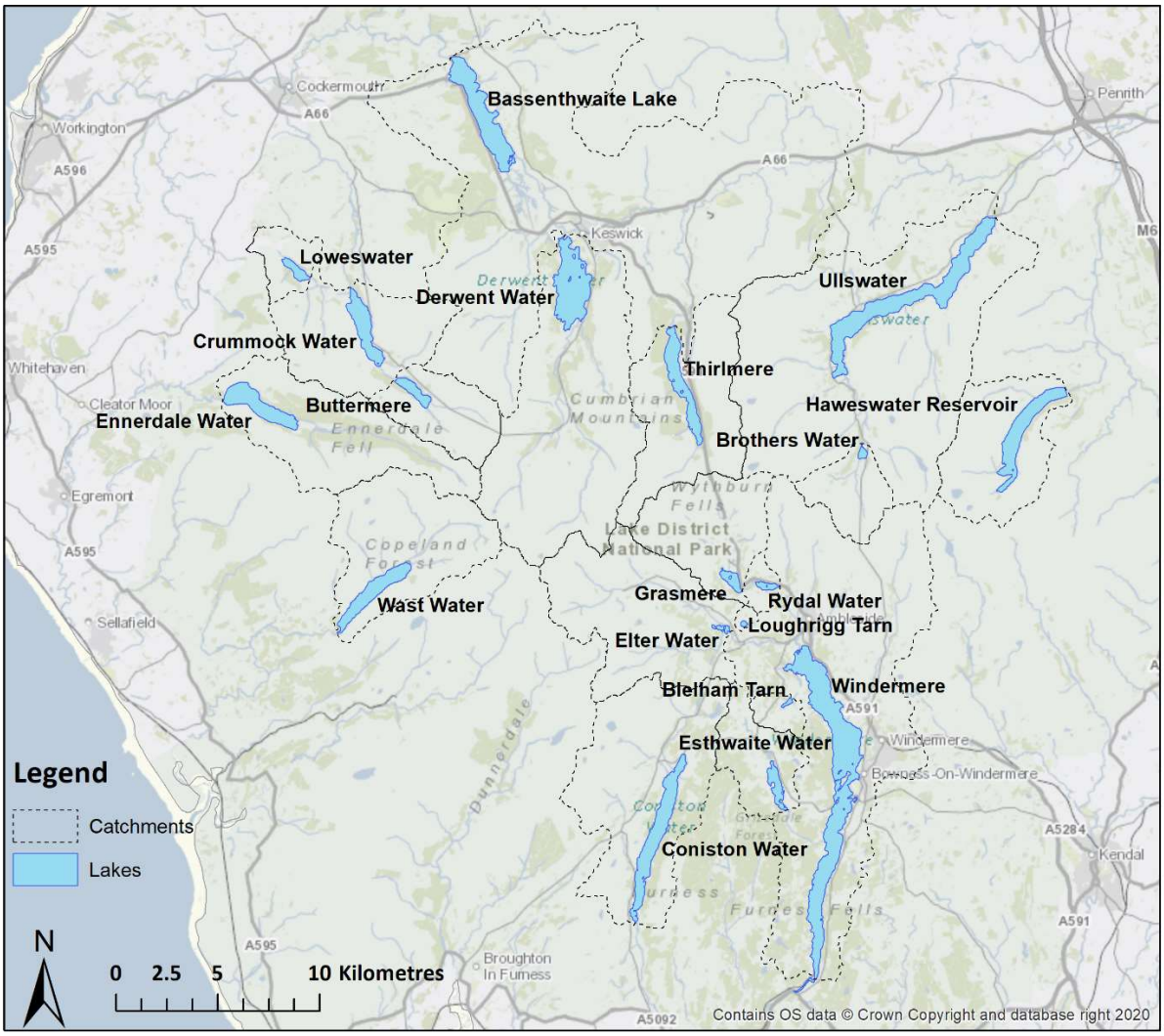

Figure 1 Location of the 20 lakes that make up the Lakes Tour sites and their catchment boundaries

In each seasonal sampling campaign, the following measurements were taken:

Secchi depth: To measure water transparency, a metal disc (known as a Secchi disc) is lowered into the water until it disappears. The disc is then raised slightly until it is visible and that depth recorded.

Water temperature and oxygen concentration: Where possible, each lake is sampled from approximately the deepest point and the temperature of the water and levels of dissolved oxygen recorded over the full depth of the water column.

Integrated surface water sampling: Surface water samples are taken using a 5m or 7m weighted tube, lowered vertically into the water until full and then sealed. A chemical analysis is carried out on the surface water samples to determine pH, alkalinity and concentrations of major ions (nitrate, bicarbonate, chloride, sulphate, sodium, calcium, magnesium and potassium) and nutrients (ammonium, dissolved reactive silicate and phosphorus). During the July sampling, the water collected was also tested for heavy metals and micro-organic pollutants.

Of these measurements, total phosphorus (TP) – a measure of both dissolved and particulate forms of phosphorus – is an important nutrient, which frequently determines the amount of algal growth in the open water, more correctly phytoplankton, that occurs in the lakes, either alone or in combination with other nutrients, temperature and light, depending on the time of year.

The surface water samples were also analysed for the concentration of a pigment, chlorophyll *a*, which is a proxy for the amount of phytoplankton present in the lake. In addition, the species of phytoplankton present were identified.

Finally, the microscopic animals, the zooplankton, which graze on the phytoplankton, were sampled. At the deepest point of each lake, a specialist net was lowered to two thirds of the maximum lake depth and then hauled steadily to the surface. These samples were analysed to determine both the abundance and the species present in each lake.

Lakes Tour 2021-22 findings: patterns and trends

The following provides an overview of the findings across all the lakes included in the Lakes Tour survey.

1. All lakes in the survey thermally stratified; surface water temperature and the temperature difference between the surface and bottom water were both at their maximum during the summer. Oxygen depletion at depth occurred for the more productive lakes during summer and autumn.

2. Water transparency as measured by Secchi depth varied across the lakes from over 10m in the unproductive lakes such as Buttermere, Crummock Water and Wastwater, to under 2m in more productive lakes such as Blelham Tarn and Esthwaite Water. There has been a significant decline in water transparency over the long term at some of the unproductive lakes.

3. The concentration of major ions in the lakes has been significantly declining over time. The general pattern of major ion concentration varies across the lakes as a function of the underlying geology. The generally softer geologies in the south result in higher ion concentrations in those lakes. The more acidic Borrowdale volcanics and igneous intrusions of the western and central lakes have a lower buffering capacity, resulting in greater sensitivity of lake water pH to acidity changes.

4. Nutrient concentrations varied during the year. Peaks in nutrient concentration tended to occur during the winter period and seasonal nutrient draw down for phytoplankton growth was evident for soluble reactive phosphorus, nitrate and silica. The highest total phosphorus (TP) concentrations were measured in Bassenthwaite Lake, Elterwater and Esthwaite Water. Loughrigg Tarn had the highest concentration of nitrate. Ammonium was only detected in seven lakes above the limit of detection and could be indicative of internal nutrient supply in these systems. Silica concentrations were highest in Bassenthwaite Lake and Blelham Tarn in the winter.

5. Large seasonal variations of phytoplankton chlorophyll *a* were seen, with peaks generally associated with spring and summer communities. Large phytoplankton blooms occurred in summer samples at Blelham Tarn, Elterwater, Esthwaite Water and Loughrigg Tarn.

6. Long-term trends in the concentrations of nutrients and chlorophyll *a* were largely not significant, apart from nitrate, although there was a tendency for a long-term decline in concentrations. However, over the short term, TP concentrations have increased in some lakes. This change needs

to be watched since phosphorus availability is a key driver of phytoplankton growth across these lakes. The survey also found a long-term change in the TP : chlorophyll *a* ratio, which implies that more phytoplankton growth may be expected for the same amount of phosphorus.

7. The phytoplankton community across all the lakes was diverse, with representatives from all the major groups. The communities within each lake showed patterns of seasonal succession with varying dominance by different groups or individual taxa in each season. The most diverse period was typically the summer and the least diverse was the winter. There was some indication that the number of species of cyanobacteria (often known as blue-green algae) was higher in more productive lakes. Cyanobacteria are of particular interest since some species are capable of producing toxins that may be harmful to humans and other animals.

8. Zooplankton communities showed some similarities among lakes. In most lakes, the crustacean calanoid copepods were dominant in spring, autumn and winter. The numbers of cladocera (water fleas) and rotifera (wheel animals) varied a great deal among lakes. Seasonal peaks for the water fleas *Ceriodaphnia*, *Bosmina*, and *Daphnia* and the wheel animal *Asplanchna* occurred in some lakes.

9. Heavy metal concentrations were measured in the summer only. Concentrations were generally low, with most being below the limit of detection. The concentrations were similar to those reported in 2015. Ennerdale Water and Loweswater were the lakes where the heavy metal concentrations most frequently exceeded the limit of detection.

10. Four micro-organic compounds were detected at levels above the detection limit at some sites in the summer of 2021. These were the insecticide Diazinon, the herbicides 2,4-Dichlorophenoxyacetic acid and 2-methyl-4-chlorophenoxyacetic acid (MCPA) and the biocide peracetic acid (PAA). Of these, PAA was detected most frequently, occurring at measurable concentrations in 11 lakes.

11. Comparing water quality classifications across the Lakes Tour surveys, there have been contrasting changes in the number of lakes classified as having Good ecological status or above since the last survey. There has been an overall decline in the number of lakes achieving this level based on TP concentrations. However, there has been a continued improvement in the number of lakes at Good or better ecological status based on the measured chlorophyll *a* concentration.

Discussion and recommendations

Long-term monitoring data are essential if we are to identify patterns and trends in how lake ecosystems have changed over time. Where trends are relatively strong and distinct it may also be possible to at least partially determine what may be driving the responses seen.

The most coherent pattern of change across the varied lakes included in the Lakes Tour survey is the decline in major ion concentrations. This is likely to be due to a driver that has a regional scale influence on

water chemistry. There are a number of factors that may have contributed to this pattern, although the one most likely to have had the largest effect over this period is the well-established reduction in industrial pollutant deposition, principally sulphur dioxide and nitrogen oxides in rainwater.

The significant decline in nitrate concentrations across the Lakes Tour lakes is more difficult to assign to one specific factor. It is likely that this pattern is a result of several underlying causes happening at the same time, including changes in industrial pollution and agricultural fertiliser applications.

The relationship between total phosphorus and chlorophyll *a* concentration was identified in previous Lakes Tour reports as the key driver of lake productivity and this is still a clear pattern in the dataset. This relationship shows that, on average, as phosphorus concentrations increase, so too does the amount of phytoplankton that a lake can support.

Secchi depth is also significantly related to lake productivity. Analysis in the previous Lakes Tour report in 2016 revealed a clear relationship between declining Secchi depth and increasing phytoplankton abundance. What is currently less clear is whether a non-algal driver of Secchi depth, such as concentration of dissolved organic carbon (DOC), is having an impact on the relationship. DOC hasn't been monitored as part of the Lakes Tour surveys, however there are a number of international studies that show that DOC concentrations are increasing across large areas in response to the reductions in acid deposition, discussed above. Research also indicates that climate warming may increase DOC exported from organic soils.

Oxygen is essential to animal life in freshwater environments. The concentration of oxygen is also a sensitive indicator of change occurring in lake ecosystems. Across the Lakes Tour dataset, once annual average chlorophyll *a* concentrations are below around eight micrograms per litre (~8 µg/l), the lake is likely to experience significant oxygen depletion.

Within the Water Framework Directive (WFD), on which the status of the majority of water bodies are assessed, the most important boundary is between Good and Moderate status. If lakes fall below Good status, the Directive requires measures to improve ecological status to be put in place.

The official WFD classification made by the Environment Agency uses monthly data averaged over three years. This is different to the single year of seasonal data gathered in the Lakes Tour survey and as such, classifications made as part of the Lakes Tour should not be compared with or equated to official classifications. However, classifications made using the Lakes Tour datasets can be compared over time, qualitatively, to provide a useful picture of how the status of the lakes are changing.

Within the WFD, if one parameter falls short of the desired quality, it leads to the downgrading of the entire water body's ecological status. As such, ten lakes which have Moderate or Poor status for TP based on Lakes Tour data would be classified as below Good ecological status overall. This means that the 2021/22 Lakes Tour represents a decline in water quality compared to surveys in 2010 and 2015 for TP, but an improvement on the 2005 values. In addition, one lake (Esthwaite Water) has been classified as being in poor status for TP, the first time any lake has been in this category since 2000.

In contrast, 2021/22 shows a steady improvement in status for the observed chlorophyll *a* measure, with over three quarters of lakes now at Good status or above compared to less than half in 2010 and 2005.

Based on the findings from the 2021/22 Lakes Tour survey, further work is needed to investigate the following:

1. Declines in water transparency, including the role of DOC
2. Increased chlorophyll *a* : TP ratio
3. Declines in minimum oxygen concentration
4. Increasing nutrient concentrations at some sites
5. Deteriorating water quality at Esthwaite Water

The fish populations and how they are changing is an important aspect of the health of the lakes which is not currently part of the survey. Inclusion of this in future Lakes Tours would help to address this gap.

For more information on the Lakes Tour survey and to see the full dataset and findings, please contact Dr Eleanor Mackay via ellcka@ceh.ac.uk