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Update on incidences of cyanobacteria (blue-green algae) in Scottish freshwaters

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ABSTRACT
An update on incidences of cyanobacteria (blue-green algae) in Scottish freshwaters is provided, highlighting the number of incidences and common cyanobacteria taxa recorded, and outlining potential effects of climate change on future bloom events.

INTRODUCTION

This article aims to provide an update to a previous review from the Scottish Environment Protection Agency (SEPA) on incidences of cyanobacteria (blue-green algae) in surface waters in Scotland (Krokowski *et al*., 2012).

Cyanobacteria (blue-green algae), but specifically the toxins cyanobacteria can produce, continue to pose a significant risk to water users, and to a wide range of animals that come into contact with blooms and scums (Svirčev *et al*., 2019). Exposure to these cyanotoxins has adverse health effects on animal and human health, and details are widely available for monitoring of cyanobacteria (Meriluoto *et al*., 2017) and management of incidents in recreational and drinking waters (Chorus & Bartram, 1999; Chorus & Welker, 2021). In most cases people who encounter potentially toxic cyanobacterial blooms and scums often report skin rashes, eye irritations, vomiting and diarrhoea, fever, and pains in muscles and joints. There are, however, many regional and worldwide reports and incidents annually of dead or ill animals associated with potentially toxic cyanobacterial blooms, scums and mats, in some cases resulting in the death of a range of wild animals, pets and livestock, and in rare cases humans (Wood, 2016).

Cyanobacteria are ubiquitous. An interplay of many complex factors affects their frequency and distribution in freshwaters. A supply of nutrients, mainly phosphorus (P) but also nitrogen (N), and light is a prerequisite, with highest growth rates shown under relatively warmer periods and under favourable hydro-physical conditions of the waterbody (Elser *et al.*, 1990). Several adaptive features allow cyanobacteria to dominate over true algae (Fogg, 1969). Specific studies across European and U.K. lakes (Carvalho *et al.*, 2013) demonstrated cyanobacteria to be more abundant in clear (10-20 Pt l^{-1}), neutral to alkaline waters (>1 mEq l^{-1}) with relatively long retention time (>30 days), with their biggest increase in abundance posing greatest risk where total phosphorus (TP) concentrations in waterbody are between 20-100µg l^{-1} TP.

Cyanobacterial blooms are, however, recorded more frequently in freshwaters due to increasing anthropogenic eutrophication (Huisman *et al.*, 2018), and increasingly due to changes posed by climate change (O'Neil *et al.*, 2012). Climate change is exacerbating the risks and impacts of freshwater eutrophication with increasing blooms of cyanobacteria becoming more likely (Wagner & Adrian, 2009) and is predicted to further increase the frequency and duration of cyanobacterial blooms regionally and worldwide (Jones *et al*., 2020). An increase in recreational use of waters by public and increasing awareness of blooms also brings the public into closer contact with cyanobacteria.

UPDATE

Climate change and cyanobacteria in Scotland

There is evidence for an association between climate change and outbreaks of cyanobacterial blooms in Scotland. Data from the Met Office (Metoffice.gov.uk, 2022) highlighted increasing mean air temperatures across the whole of Scotland, with a 0.1°C increase in 2021 compared with the 1991-2020 average. Northern and western areas were also sunnier than average, with sunshine duration 105-115% higher than the 1981-2020 average, with the western half of Scotland also drier than average in 2021, with rainfall 105-135% higher across most of the rest of Scotland compared to the average over the 1981-2010 period.

It is difficult to ascertain changes in algal and cyanobacterial concentrations across the 25,615 fresh waterbodies in Scotland with surface area greater than 0.01 km^2 (Hughes *et al*., 2004), but a few case studies highlight a spread in geographic distribution and an increase in frequency and duration of algae and cyanobacteria. The water-net, green alga *Hydrodictyon reticulatum* had a most northerly record in Strathclyde Loch, potentially in response to increasing temperatures and nutrient concentrations (McManus, 2012). An increase in cyanobacteria was correlated with climatic factors and increasing nutrient inputs in Loch Leven (May *et al*., 2012), and seasonal and temporal changes in phytoplankton were shown in Loch Flemington (Lang *et al.*, 2016).

Utilising SEPA data from 142 lochs and reservoirs monitored between 1989-2018, May *et al.* (2022) predicted increased development of algae and cyanobacteria in response to climate change, specifically increasing air and corresponding water temperatures and increased nutrient inputs. Water temperature increases were 0.25-1.0°C per year for most of the lochs over the period, with cyanobacterial blooms specifically shown to increase where monthly water temperatures exceeded 17°C. Knock-on effects across the freshwater communities at shorter and longer timescales were highlighted, threatening loss in biodiversity and causing phenological changes across food-webs. Modelling showed a corresponding rise in water temperatures by 3°C in Scottish lochs over the period 2020-2080, with most impacts (increasing algal and cyanobacterial concentrations) likely to affect shallow (depth 3-15 m) and very shallow (depth <3 m) waterbodies, and those of medium alkalinity (200-1,000 µEq l^{-1}), where management action should be focused (May *et al.*, 2022).

SEPA and cyanobacteria

SEPA provide scientific information and advice to help support the public and public health bodies in keeping people and livestock safe from potentially toxic algal blooms in lochs, reservoirs, and rivers. SEPA provide advice and assistance in analysis of *ad hoc* samples from suspected cyanobacterial blooms in recreational waters following the Scottish Government guidance (Ramsay *et al.*, 2012), based on the World Health Organisation guidance on assessment and minimisation of risks to public health (Chorus & Bartram, 1999; Chorus & Welker, 2021).

Cyanobacteria incidents in Scotland

In the period 2008-2010 SEPA analysed 130-181 water samples per year that were received in response to visual algal problems in lochs, rivers and reservoirs (Krokowski *et al.*, 2012). Results indicated that 35-54% samples were reported to contain cyanobacteria at concentrations exceeding set thresholds as set out in the Scottish Government guidance to minimise risks to public health (concentrations in excess of 20,000 cyanobacterial cells ml^{-1}).

In subsequent years, the number of reports and samples analysed and reported by SEPA varied with blooms generally reported in the same waterbodies year after year with most reports increasing from May onwards and concentrated during the summer and autumn periods. Reports are however not uncommon during the winter months. In general, approximately one third of all samples had cyanobacteria in excess of the 20,000 cyanobacterial cells ml^{-1} threshold (Fig. 1).

In 2014 there was a significant increase in samples analysed and reported by SEPA due to the Glasgow Commonwealth Games, with a significant number of samples analysed from recreational waterbodies at regular frequency throughout the year, the numbers of which more than doubled compared with previous years (Fig. 1). By 2018 and 2019, the number of samples analysed was similar to that from the late 2000s and early 2010s. In 2019, SEPA received nearly 300 samples of which only 48 were reported to exceed the threshold of 20,000 cyanobacterial cells ml^{-1} set by Scottish Government (the lowest proportion as a total of all samples since 2008).

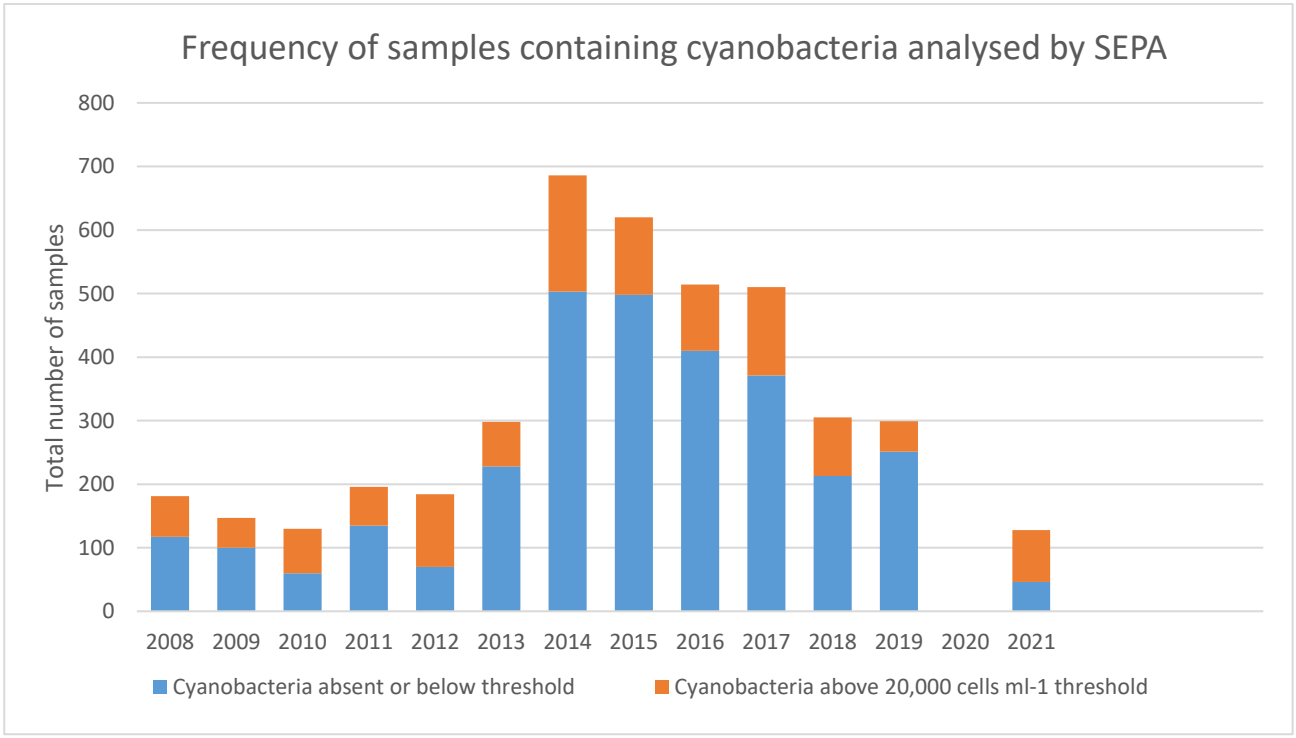

Fig. 1. Number of algal samples analysed by SEPA showing percentage where cyanobacteria were absent or below the 20,000 cells ml^{-1} threshold, and where cyanobacteria exceeded the warning threshold.

There were no records available for 2020 during the time of the COVID-19 pandemic. In 2021, SEPA received 128 samples, the lowest number since 2008 but with the highest proportion of samples found to exceed the 20,000 cyanobacterial cells ml^{-1} threshold. This may be attributed to the period following COVID lockdowns with access to recreational waters and limited office accessibility for staff to sample and analyse samples, with the majority of samples sent for analysis containing visual cyanobacteria and fewer samples containing non-cyanobacteria. There were at least two separate events in July 2021 where reports of the death of dogs were associated with high concentrations of cyanobacteria in Pollok Park, Glasgow, and Loch Airigh na Lic, Stornoway, Isle of Lewis, with other unsubstantiated reports, for which no analyses were possible, of swimmer's itch in Loch Lomond and Loch Ard, Stirlingshire, and reports of dead birds in Carron Valley reservoir, Stirlingshire and Linlithgow Loch, West Lothian.

Data continue to be subjective as only sites with perceived or visual algal or cyanobacterial problems were investigated. Sites where perennial cyanobacterial blooms were present may not have been monitored, in such cases notices were erected warning the public of the risks posed by cyanobacteria without the need to analyse samples. Fig. 2 illustrates typical cyanobacterial blooms.

Common cyanobacteria taxa

Cyanobacteria are very morphologically diverse, with approximately 370 freshwater cyanobacteria species in the British Isles (Whitton *et al*., 2014). Their nomenclature is dynamic and relies on morphological and ecological features, and more recently changes have occurred using molecular phylogenomic approaches for identification (John *et al*., 2011, 2022), with a polyphasic concept adopted (Komárek, 2013). Using the recent and widely adopted nomenclature (Meriluoto *et al*., 2017; John *et al*., 2022) the commonest cyanobacteria taxa routinely detected continue to belong to genera of *Aphanocapsa*, *Anathece*, *Microcystis*, *Woronichinia*, *Planktothrix*, *Dolichospermum*, *Aphanizomenon* and *Gloeotrichia*. There have been no new records or unusual taxa recorded for Scotland since the last update (Krokowski *et al*., 2012), and recent records for new taxa recorded in the British Isles are detailed by John *et al*. (2022). These are potentially all toxin-producing taxa, but with more than 100 cyanobacteria species and genera producing toxins (Meriluoto *et al.*, 2017), the list of taxa is not exhaustive as new toxin-producing taxa are likely to be identified in the near future.

Management of cyanobacteria

There are several viable methods and techniques for managing and reducing algae and cyanobacteria in waters, but it is beyond the scope of this article to extensively discuss them. Primarily, aggressive reduction in nutrient inputs to waterbodies and P in particular must happen to reduce algal and cyanobacterial growth, as P appears to be the nutrient controlling most waterbody productivity. Even then, there is very strong chance that cyanobacteria will return, as other unknown factors may have affected the phytoplankton community structure (Ouellette *et al*., 2006). Waterbodies may also be N-limited, or co-limited with N and P or other nutrients, and/or light limited, so there needs to be a sound ecological understanding of

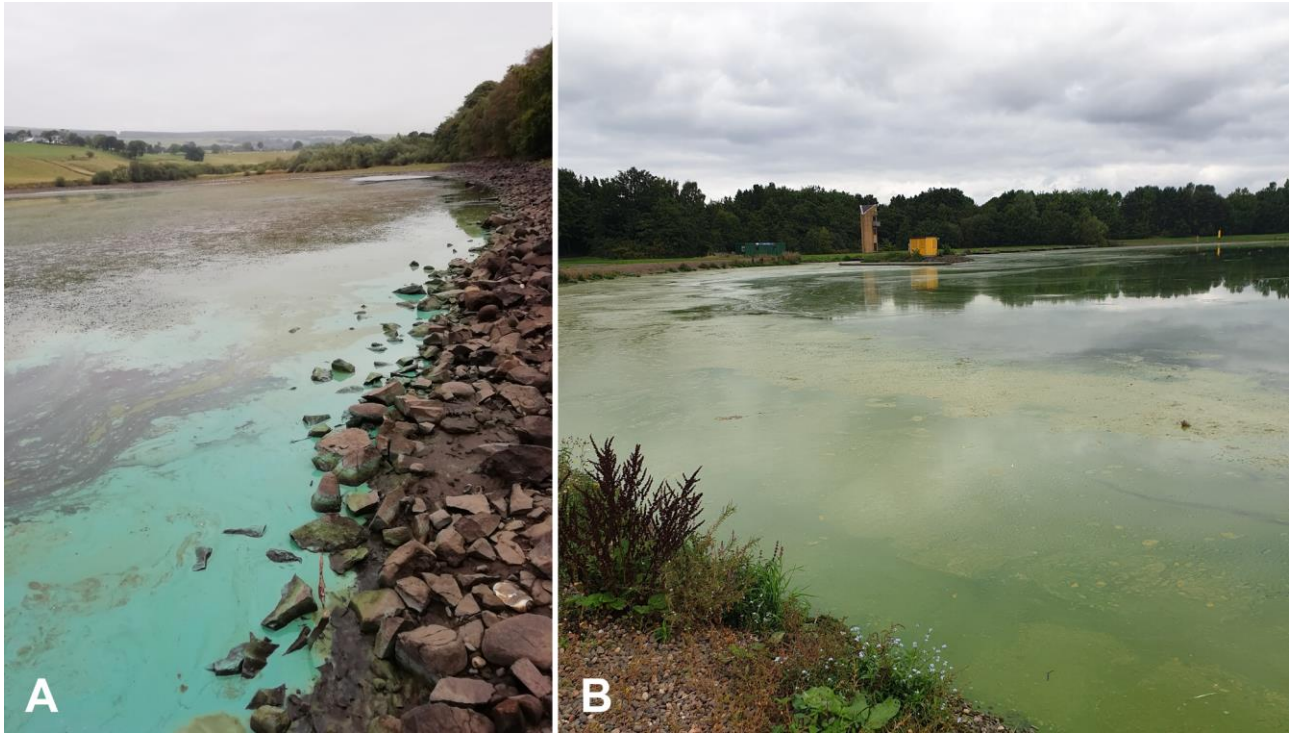

Fig. 2. Examples of cyanobacterial blooms in North Lanarkshire, Scotland. (A) Banton Loch, August 2021. (B) Strathclyde Loch, September 2021. (Photos: SEPA)

the waterbody. Ultimately, management should focus on reducing both N and P external inputs. External inputs of P are easier to manage than those of N, but the role of sediments in nutrient release should not be discounted. These may also be a main source of nutrients (P) even when all direct point and diffuse sources have been reduced.

Internal P control may be carried out through sediment removal, sediment treatment with P-binding agents and suppressing P-release from sediment surface through the use of chemical compounds. Such measures may supress internal P loading where sediments are a major source of P but should be used alongside other measures to reduce cyanobacteria and improve water quality (Mackay *et al.*, 2014).

The use of other chemical controls to lyse cyanobacterial cells or inhibit their growth will require approval and expert guidance for use on or near water, since during lysis cyanotoxins may be released. Hydrogen peroxide has been shown to be selective in suppressing cyanobacteria and has the advantage in that it quickly degrades to water and oxygen (Matthijs *et al.*, 2012; Barrington *et al.*, 2012), and was one of a number of measures used in Strathclyde Loch to abate cyanobacteria in a section of the loch used for swimming events (SNIFFER, 2013).

Biomanipulation through enhancing loss rates of cyanobacteria or supporting their predators to reduce phytoplankton abundance is a well know intervention measure (Jeppesen *et al.*, 2012), and has been shown to be most effective in smaller waterbodies where a reduction in phytoplankton and cyanobacteria may occur only below a threshold of P-loading. The use of other biological control interventions such as using barley straw is variably effective and again only in smaller waterbodies (Ball *et al.*, 2001).

Other measures to suppress growth and dominance of cyanobacteria over other phytoplankton through artificial destratification (water mixing) are effective in relatively deeper waterbodies. Reducing water retention time is also a measure to reducing amount of time cyanobacteria spend growing and is effective in reducing their biomass.

Techniques such as sonication may be costly and impractical in larger waterbodies and it has not been demonstrated that they are effective and practical over the long-term (Rajasekhar *et al.*, 2012). Similarly, the use of dyes and use of shading and shade-balls in an attempt to reduce cyanobacteria have not been fully evaluated, and are costly and controversial (Martínez-Espinosa, 2021).

Recording of incidents

As described, SEPA provided a robust and efficient service responding and analysing algal incidents. It is anticipated that requests for analysis will increase as the effects of climate change lead to an increase in frequency and duration of cyanobacterial blooms, and an increase in water-based recreational activities (May *et al.*, 2022). SEPA are therefore investigating and working towards providing an even more enhanced and robust monitoring and analytical service as effects of climate change lead to more cyanobacterial incidents, working closely in partnership with internal colleagues, as well as with external colleagues, including Local Authorities.

To assist and provide a rapid and more comprehensive picture of harmful algal blooms across Scottish waters, a *Bloomin' Algae* app developed by the U.K. Centre for Ecology and Hydrology can be downloaded and used to report harmful algal and cyanobacterial blooms. Using the citizen science app is quick and easy, and helps inform SEPA, the Local Authority or the landowner of potential public health risks, and, if needed, provides an early warning to the public. The *Bloomin' Algae* app is available from Google Play or App Store (search for "Bloomin' algae").

CONCLUSION

There is no silver bullet that will reduce potentially toxic cyanobacterial blooms in freshwaters, with a site-specific approach required to manage and control cyanobacteria on an individual basis. As there are likely to be continued reports of harmful algal and cyanobacterial blooms across Scottish lochs, recreational waters and reservoirs, work continues by SEPA and others within the river basin management plan (RBMP) which sets out a framework for protecting and improving the benefits provided by the water environment across Scotland (SEPA, 2021).

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