A DECADE OF MONITORING AND MANAGEMENT OF FRESHWATER ALGAE, IN PARTICULAR CYANOBACTERIA, IN ENGLAND AND WALES

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Introduction

Many factors degrade waterbodies, the majority of which are now influenced by man; very few are strictly natural. Excessive growths of phytoplankton, exacerbated by eutrophication, reduce the amenity or conservation value of affected sites and contribute to problems during potable water treatment. Cyanobacteria (commonly referred to as blue-green algae) are arguably the most visible symptoms of eutrophication in fresh waters, and many have the potential to produce severely toxic chemicals affecting fish, livestock and humans (Heaney 1971; Codd & Bell 1985); also, they can accumulate through the food-chain (Codd & Bell 1996; Chorus & Bartram 1999). Moreover, cyanobacteria are highly successful due to a number of physiological adaptive features and become most visible when excessive growths (blooms) are concentrated under favourable weather conditions, forming surface scums. The latter are particularly significant because people, livestock and wild animals can come directly into contact with the concentrated material, which may be toxic.

The presence of cyanobacteria may contribute to the production of offensive, unsolicited taste and odour in drinking water, especially during bloom decay, and also may reduce the biodiversity of aquatic systems through exclusion of other biota. Moreover, the toxins produced by cyanobacteria pose very real, acute and chronic implications for human health.

Although the toxicity of cyanobacteria has been known for many years, cyanobacteria-related problems in the UK were generally limited in frequency (Heaney 1971; Reynolds 1980). However, this all changed and became of national concern following the exceptional environmental conditions in the autumn of 1989, when widespread cyanobacterial blooms and scums developed in fresh waters – one such affected site was Rutland

Water reservoir in Leicestershire. This prompted considerable efforts to be directed towards a better understanding of eutrophication, its causes, problems and solutions, by the National Rivers Authority, which has continued with the Environment Agency since its inception in 1996. Aspects of this phenomenon have been reviewed (National Rivers Authority 1990; Pearson & Ferguson 1995), but there has been no recent detailed account of the Environment Agency's algal and cyanobacterial monitoring activities in fresh water. In the following sections we briefly summarise the Agency's programme, covering the period 1991 to 1999. Details of the Agency's planktonic and benthic algal monitoring programmes in marine systems are not covered here.

The Environment Agency's monitoring procedures for algae in fresh water

In an attempt to identify high priority sites the initial monitoring programmes of 1989 and 1990 commenced with surveys of freshwater sites affected by algal blooms. Since 1991 a reactive monitoring strategy has been employed, in which sites are sampled in response to external enquiries; predominantly, therefore, sampled sites are those with visibly high numbers of algae (bloom conditions). Reactive monitoring is divided into "new sites", where there are no previous records for the presence of cyanobacteria, and "old sites" where, historically, cyanobacteria were known to occur. In addition to the reactive monitoring approach, certain sites are sampled routinely as part of specific Area and Regional investigations.

Each of the eight Regions of the Agency also undertake monthly monitoring at a designated long-term reference site, in order to provide a minimal national picture of geographical and temporal change in terms of cyanobacterial populations. The Front Cover of this volume of the Forum shows samples being taken from a typical example of a cyanobacterial bloom and surface scum in Farmoor Reservoir near Oxford.

Phytoplankton samples are generally preserved on-site with Lugol's iodine and enumerated microscopically at a later date using either the inverted microscope method (Lund et al. 1958; Uttermöhl 1958), Lund chambers (Lund 1959) or Sedgwick-Rafter cells, using standard methods (Standing Committee of Analysts 1990). Live phytoplankton examinations are also carried out to aid identification. Various taxonomic keys are used, ranging from general to more specialised texts (e.g. Desikachary 1959; Belcher & Swale 1976; Bellinger 1992; Canter-Lund & Lund 1995), including an interactive identification system on CD-ROM for cyanobacteria in the British Isles (Whitton et al. 2000). An interactive identification CD-ROM key for chlorophytes will be available early in 2002.

Initial monitoring, in 1989 and 1990

Monitoring began in September–December 1989 and was carried out on 909 waterbodies, the majority of which were dominated by cyanobacteria. In January to November 1990, 1,724 sites were sampled of which only 38% were identified as containing abundant populations of cyanobacteria. During this period several different monitoring procedures were employed and results can not be directly compared with those obtained after 1990.

Reactive monitoring programme, 1991–2000

The reactive monitoring programme commenced in 1991 and has continued to date. In total, the Agency has sampled 3,220 waterbodies as part of its reactive monitoring programme (Table 1 and Fig. 1). No distinct annual trend is evident for numbers of sites dominated by cyanobacteria, but between 219 and 417 waterbodies were sampled annually in response to external enquiries. The highest number of sampled sites (417) was in 1995, due to the high number of phytoplankton (and cyanobacterial) blooms reported from lotic systems, the result of reduced river flows during a relatively warm year.

Annually, two-thirds of the monitored sites were dominated by cyanobacteria, and approximately three-quarters exceeded the Agency's warning thresholds, which are used as an action level (detailed later). The dominant cyanobacterial genera were *Anabaena, Aphanizomenon* (mostly *A. flos-aquae), Microcystis* and *Oscillatoria*. Groups other than cyanophytes, reported as causing nuisance and aesthetic problems, were bacillariophytes, cryptophytes, chlorophytes, xanthophytes and haptophytes.

As described above, the total number of sites sampled annually as part of the reactive monitoring programme can be divided into new sites (waterbodies sampled for the first time) and old sites (those which have had cyanobacterial blooms or scums in past years and have been re-sampled). Details are listed in Table 1, which shows that the programme has been dominated by sampling new sites, where no cyanobacterial-related problems have been recorded in the past. However, the number of old sites found to contain cyanobacteria in past years and later re-sampled (old sites), has more than halved between 1995 (136) and 2000 (60). This may indicate that either no cyanobacterial problems have reoccurred at the sites or, if they have, the sites have not been reported to the Agency, or the Agency has not re-sampled them.

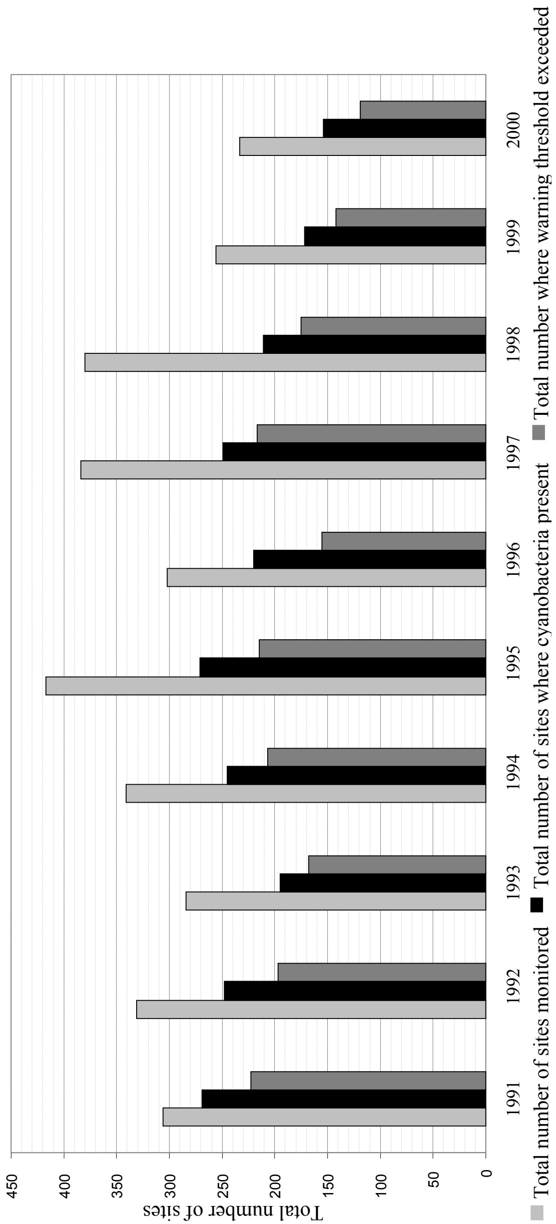

FIG. 1. Annual fluctuations in total numbers of freshwater sites monitored by the Environment Agency in response to external enquiries (left-hand histograms), numbers of sites dominated by cyanobacteria (central, black histograms) and numbers of sites dominated by cyanobacteria where warning thresholds were exceeded (right-hand, grey histograms).

Table 1. Annual fluctuations in the numbers of sites sampled by the Agency as part of its reactive monitoring programme. The table lists: (1) the total numbers of sites sampled each year; (2) numbers of sites sampled for the first time (new sites), and expressed as percent of the yearly totals; (3) numbers of sites containing cyanobacteria in past years and re-sampled during the year shown (old sites).

Year	(1) Total	(2) New sites	(3) Old sites
1991	306	216 (71%)	90
1992	331	218 (66%)	113
1993	284	201 (71%)	83
1994	341	217 (64%)	124
1995	417	281 (67%)	136
1996	302	190 (63%)	112
1997	384	269 (70%)	115
1998	380	300 (79%)	80
1999	256	190 (74%)	66
2000	219	159 (73%)	60

Table 2. Annual summary of waterbodies sampled routinely by the Agency. The table lists: (1) total numbers of waterbodies sampled; (2) numbers containing cyanobacteria (also expressed as percent of the yearly totals); (3) numbers containing cyanobacteria where warning thresholds were exceeded (percent of new sites); (4) numbers where bloom/scum was present (percent of new sites).

Year	(1) Total	(2) New sites	(3) Exceeding thresholds	(4) Bloom/scum
1991	137	101 (74%)	71 (70%)	44 (44%)
1992	69	43 (62%)	31 (72%)	23 (53%)
1993	80	61 (76%)	60 (98%)	40 (66%)
1994	70	50 (72%)	36 (72%)	46 (92%)
1995	44	35 (80%)	22 (63%)	16 (46%)
1996	39	26 (67%)	12 (46%)	20 (77%)
1997	33	27 (82%)	19 (70%)	21 (78%)
1998	21	18 (86%)	12 (66%)	6 (33%)
1999	15	8 (53%)	4 (50%)	5 (62%)
2000	14	14 (100)	12 (86%)	13 (93%)

Routine monitoring, 1991–1999

Results of monitoring undertaken as part of routine work are summarised in Table 2. Each year, a relatively high percentage of sites contained cyanobacteria, although the total number of sites sampled routinely has steadily declined.

Cyanobacterial toxicity testing and assessments

In 1990, a programme of research on the occurrence, production and fate of microcystins (a common group of cyanobacterial toxins) was commissioned from the University of Dundee, and is summarised by Codd & Bell (1996). The results indicated that cyanobacterial blooms and scums are likely to be toxic; 51% of analysed samples indicated evidence of hepatotoxicity, neurotoxicity, or both. Furthermore, the incidence of toxicity in the UK, based on samples analysed by the University of Dundee for the Environment Agency, has remained high and is comparable to that found in other European fresh waters (Lawton & Codd 1991).

Currently, some 96 cyanobacterial toxin variants are known (neurotoxins, hepatotoxins, and endotoxin lipopolysaccharides), the most dominant of which (>60) are the microcystin variants. More than one species in each genus of cyanobacteria may be toxic and capable of producing several toxins simultaneously (Codd et al. 1999). The number of confirmed cyanobacterial toxin variants is likely to increase in the future, due to the discovery and isolation of new species and strains, and improvements in analytical methods. Therefore, the Agency continues to adopt a precautionary approach, recognising the need to regard all cyanobacterial species and strains as capable of producing toxins, and potentially posing a threat to animal and human health and safety .

Environment Agency actions

The Agency has defined warning thresholds for individual taxa of cyanobacteria. These indicate the likelihood of bloom and scum formation, and are used in determining the action to be taken. This includes informing the waterbody owners, local authorities, DEFRA (Department for Environment, Food and Rural Affairs) officers, and other pertinent organisations and/or individuals. Standard letters are issued, including the results of analyses, particularly when cyanobacterial populations exceed the warning thresholds.

Initially a warning threshold was derived from information based on the mass-specific toxicity of *Microcystis aeruginosa,* its rate of buoyant migration to the surface and horizontal fetch to the shore. Consequently,

this threshold was scaled proportionately higher for other cyanobacterial taxa to take into account their differences in floatation rate (Pearson 1996; Reynolds 1998). However, it is recognised that even when a particular warning threshold is exceeded, development of a full or even partial bloom is not inevitable, nor is it certain that one will occur at all, or that blooms are always toxic.

Recreational safety guideline values for safe practice in managing bathing waters with cyanobacteria present have been produced recently by the World Health Organisation (Chorus & Bartram 1999), based on probabilities of causing adverse health effects to humans. These are similar to the Agency's warning thresholds, but the guidelines refer to the total numbers of cyanobacteria present and the corresponding concentrations of chlorophyll-*a*. For example, the World Health Organisation Guidance Level I is based on 20,000 cyanobacterial cells per ml, equivalent to a concentration of 10 µg per litre of chlorophyll-*a*. This is similar to the Agency's warning threshold derived for *Microcystis.*

Frequency of sites affected by freshwater algal blooms and eutrophication

The Royal Commission on Environmental Pollution in the UK has inferred that the increased incidence of algal blooms, in particular cyanobacteria, is widespread as a result of increasing eutrophication (Royal Commission on Environmental Pollution 1992), and sites of special scientific interest (SSSIs) are known to be adversely affected by eutrophication (Carvalho & Moss 1995). However, many other and complex interactive factors affect the incidence of algal blooms, which are site-specific; hence it is difficult to assess accurately the national distribution of sites affected by algal blooms and related to eutrophication *per se*.

Data from the Agency's algal monitoring programme also indicates that a large number of sites contain cyanobacteria, possibly as a result of eutrophication (Environment Agency 2000a,b). However, the Agency's monitoring programme is a selective procedure, as only those sites reported to have a problem with algal blooms and surface scums are investigated. Sites that do not have a visible algal bloom or scum present, or which have had historical cyanobacterial problems, are rarely investigated.

The number of external enquiries received by the Agency has been highest from central and south-eastern areas of England (Environment Agency 2000a), possibly for several reasons. A larger number of sites may be affected by eutrophication to a greater extent than sites elsewhere in England and Wales. In addition, a more vigilant, aware public (whose population density is greater than elsewhere in the country) may be reporting the visible symptoms of eutrophication (algal blooms) more frequently. Conversely, many of the sites that were previously sampled for cyanobacteria might not have been reported again in the following year, so the number of recurrent incidents may be an underestimation. The Agency's approach to algal monitoring is to be reviewed as part of a wider review of eutrophication.

The use of Agency data as a robust indicator of the incidence of algal blooms and the extent of eutrophication in England and Wales must be treated with caution, bearing in mind the range of factors that may influence the frequency of blooms and that data are collected from a primarily reactive monitoring programme. The collation of such data, and hence of sites affected by eutrophication, continues, since this is the best available national information on the incidence of algal blooms. Such algal monitoring provides an early detection of toxic species, making it possible to take fast, initial action before cell numbers reach dangerous levels, and helps to provide information on risks, and how to minimise them, to water users and owners. However, further work is still required, especially to expand our knowledge on the types of toxins produced, their occurrence and levels, exposure routes, and their acute and chronic effects. This information is needed for setting policies and guidelines (see Codd 2000).

Indeed, the Agency has identified eutrophication and its symptoms as a priority environmental issue and ranks it as one of ten major water quality problems (Environment Agency 1998). Moreover the Agency has published a strategy for assessing and managing eutrophication in England and Wales (Environment Agency 2000c). This is available on the Agency's website (www.environment-agency.gov.uk/envinfo). The management of eutrophication comprises national action to reduce nutrient inputs to water, complemented by local, catchment-level efforts centred around eutrophication control action plans (ECAPs) from a variety of waterbody types, to test and refine tools and techniques for assessing and managing eutrophication.

Furthermore, the Agency aims to identify a set of priority issues (including tackling eutrophication) that require further action, as set out in its latest report (Environment Agency 2001). This complements the Agency's Environmental Vision setting out long-term goals and objectives to be achieved, which is a contribution to sustainable development and is centred around nine themes (Environment Agency 2001).

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