Cyanobacterial Blooms in the Wetlands of the Perth region, Taxonomy and Distribution: an Overview

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Abstract

The distribution pattern (spatial and temporal) of cyanobacterial blooms in Perth wetlands and the Canning River in Western Australia has been investigated sporadically over a span of 20 years. The major bloom-forming species have been identified as *Microcystis aeruginosa*, *M. flos-aquae*, *Anabaena circinalis*, *A. spiroides* and *Nodularia spumigena*. Blooms of potentially toxic *Anabaena* spp. have occurred in the Canning River since 1993, and in many Perth wetlands for several years. For the first time, the Swan River estuary itself experienced a prolonged toxic bloom of *Microcystis flos-aquae* in February 2000. The two species of *Anabaena* and *Microcystis aeruginosa* blooms have occurred under salinity of less than 3 ppt, whereas blooms of *Microcystis flos-aquae* occurred in salinity above 3 ppt. *Microcystis* blooms were most common and persistent in most of the alkaline, shallow, mostly mesotrophic to eutrophic lakes but rarely in oligotrophic lakes. Both species of *Microcystis* were often found together, although *M. flos-aquae* appeared to be dominant in late summer and autumn, when salinity levels were at maximum. Shape and size of colonies and cells were the stable morphological features differentiating the two species of *Microcystis*. Microcystins associated with these blooms ranged from < 0.5 to 1 645 μg L^{-1} in wetlands and 0.05 to 124 μg L^{-1} in the Swan River estuary. *Nodularia spumigena* blooms were confined to two freshwater lakes with salinity slightly below 3 ppt. This is the first time *N. spumigena* blooms are reported in freshwater lakes. The hepatotoxin nodularin was also detected in these wetlands, but at low levels.

Keywords: cyanobacterial blooms, urban lakes, Swan-Canning estuary, *Anabaena, Microcystis*, *Nodularia*, taxonomy, toxicity

Introduction

The wetlands of the Perth metropolitan area are characteristically shallow (mean depth < 2 m), alkaline with a mean electrical conductivity close to 900 μS cm^{-1} (N = 80) and mostly mesotrophic, eutrophic or hypertrophic (Helleren 1993; John unpublished data 1998). They are surface expressions of superficial aquifers with their water levels under the influence of the water table and many receive substantial inputs from surface runoff. These wetlands experience a strong seasonal hydrologic cycle influenced by the Mediterranean-type climate with cool, wet winters and long hot, dry summers. Maximum water levels are observed from September to October, after the winter rains, and minimum levels in late autumn (March to April).

The Swan-Canning River estuary, the most prominent feature of the Perth metropolitan area, is a relatively shallow estuary with a strong seasonal flow of fresh and marine waters. Like most of the urban wetlands, the Swan River system itself has been experiencing harmful algal blooms in recent years. Minor blooms of *Microcystis* and *Anabaena* have occurred in the upper reaches of the Canning River (John 1987, 1994, 2000). Most of the surrounding wetlands in chains (east and west) located at both south and north of the estuary, are linked by common geological and hydrologic features (Fig. 1) (Seddon 1972). Subsequent to the European settlement of Western Australia in 1829, intense agriculture, deforestation, urbanisation and damming of streams have gradually caused the deterioration of the estuary and the wetlands. Although there have been sporadic recordings of cyanobacterial bloom events (Atkins *et al.* 2001), and popular reference to toxic algal blooms, there has been very little published information on the distribution pattern of such blooms focussing on the taxonomy, seasonality, toxicity and environmental factors associated with these blooms. It is crucial to have accurate taxonomically defined spatial and temporal distribution records of harmful algal blooms for the management of these wetlands (Skulberg *et al.* 1993). The term 'blooms' is used in this paper to refer to dense growth of planktonic algae producing noticeable discolouration of water dominated by mostly one species (Graham & Wilcox 2000; Sze 1993). The number of cells in a bloom – mostly above 10 000 cells mL^{-1} – varies according to the size of the cells and the dynamics of the bloom.

The objectives of the current project were to systematically study the ecology, taxonomy, seasonal (temporal) and geographic distribution and whenever feasible the toxicity of the cyanobacterial blooms. This paper presents an overview of the common cyanobacterial blooms in the Perth region, focussing on

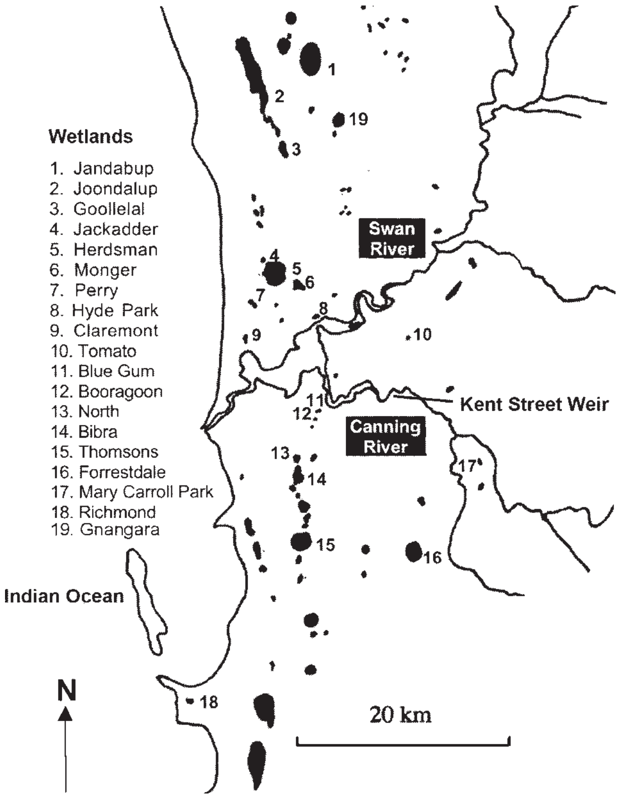

Figure 1. Map of the Swan Coastal Plain (Western Australia) showing the main wetlands and the Swan-Canning River estuary. The wetlands with *Microcystis* blooms recorded are indicated.

taxonomy and distribution, based on mostly unpublished data collected over the past 20 years.

Methods

Wetlands both south and north of the Swan River were investigated from 1985 to 2003. A total of 27 urban wetlands representing types both south and north of the river were seasonally surveyed for cyanobacterial blooms from 2000 to 2003. Toxic cyanobacterial blooms in the Canning River – the major tributary of the Swan River – were monitored from 1993 to 1994 and from 1996 to 2003. The environmental factors, taxonomy and dynamics of the first major toxic cyanobacterial bloom that resulted in the closure of the Swan River in February 2000 for several days were also studied. Integrated samples of phytoplankton representing the water column were collected at varying intervals (2 weeks to 3 months) mostly covering all the seasons, and water quality parameters (pH, Electrical Conductivity/salinity), nutrients (N and P), temperature, chlorophyll *a* and toxin concentrations in selected samples were determined according to standard methods (American Public Health Association 1975; Chorus & Bartram 1999; Chorus 2001). Water temperature, pH, electrical conductivity (EC) and salinity were measured using a portable TPS WP-81 meter in the field. Water samples from selected lakes were analysed for chlorophyll *a* and nutrients (inorganic and organic nitrogen and phosphorus) at the Chemistry Centre (Perth) or SGS Environmental Services (Welshpool). One-litre concentrated algal samples were used for the detection of the relevant cyanotoxin by High Performance Liquid Chromatography by the Australian Water Quality Centre (Bolivar).

Integrated water samples were used for enumeration of cells and net samples (mesh size 25 μm) were used for concentrating algae, which were used for determination of toxins. The morphology of the colony and cells was measured and the species were identified using specialised literature (Geitler 1932; Desikachary 1959; John 2002; Komárek & Anagnostidis 1998, 2005; Baker 1991, 1992; Baker & Fabbro 2002; McGregor & Fabbro 2001).

Results

Microcystis aeruginosa Kützing (Fig. 2A) was present in almost all wetlands except the acidic Lake Gnangara (pH 3.5) irrespective of the nutrient status, but has occurred in bloom proportions (more than 20 000 cells mL^{-1}) during spring to autumn (September to April) in most of the alkaline mesotrophic to hypertrophic lakes. Over 85% of the urban lakes experienced *Microcystis* blooms. In hypertrophic lakes south of the Swan River (Bibra Lake, Thomsons Lake), *M. aeruginosa* blooms were persistent throughout the year and declined only during the mid-winter, with chlorophyll *a* values peaking to above 700 μg L^{-1} in 1993 (Fig. 3). Other wetlands in which *M. aeruginosa* blooms occurred are: Lake Richmond (1985, 1999), Herdsman Lake (1985, 2000–2003), North Lake (1990), Jandabup and Joondalup

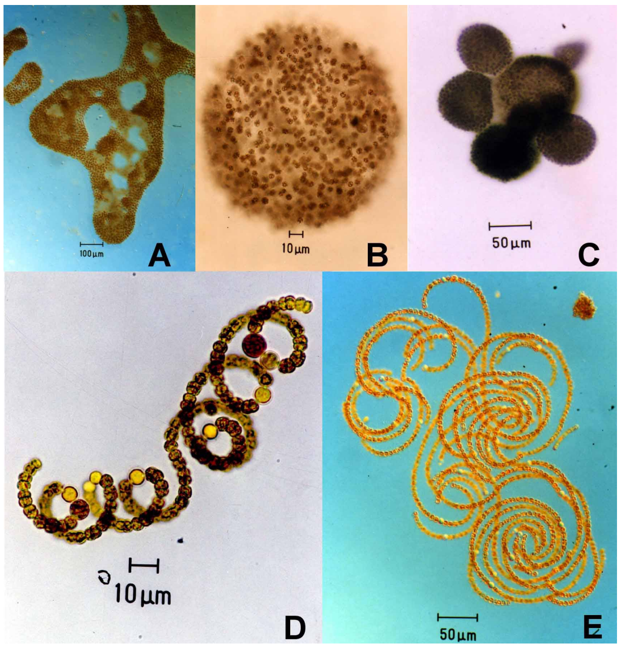

Figure 2. Cyanobacteria in wetlands and the Canning River in the Swan Coastal Plain. A, *Microcystis aeruginosa* Kützing (note the clathrate (gaps) nature of the colonies); B, a single colony of *Microcystis flos-aquae* (Wittrock) Kirchner; C, a cluster of colonies of *Microcystis flos-aquae* (note the compact nature of the colonies without gaps); D, *Anabaena spiroides* (Elenkin) Komárek; E, *Anabaena circinalis* Rabenhorst.

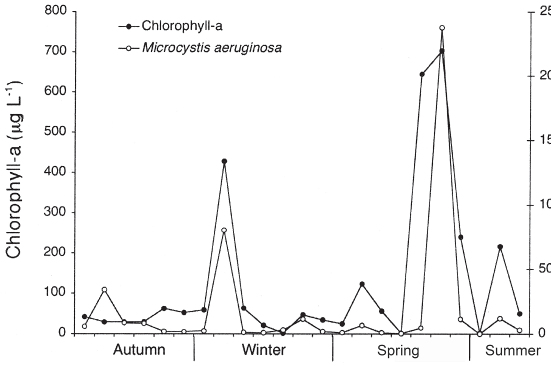

Figure 3. Seasonal distribution of *Microcystis aeruginosa* in Bibra Lake (a hypertrophic lake) in 1993 (integrated samples from 4 sites).

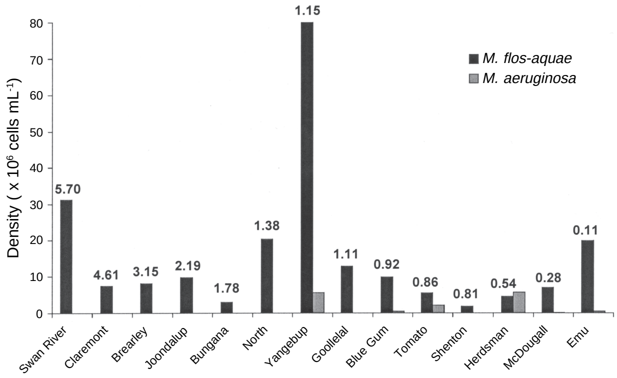

Figure 5. Distribution of *M. aeruginosa* and *M. flos-aquae* according to salinity of 14 wetlands (0.11–5.70 ppt) from 2000 to 2003, arranged in decreasing salinity.

(2003), Lake Goollelal (2000, 2001), Hyde Park (2000–2002), Lake Monger (1987), Perry, Blue Gum, Booragoon and Jackadder Lakes (2003) (Fig. 1).

The *Microcystis* blooms observed in Lake Richmond in 1985 and 1999 were mild and co-existed with unicellular green algae. Chlorophyll *a* levels from 3.7 to 12.9 µg L^{-1} and nutrient levels measured seasonally indicated it was an oligotrophic lake.

M. aeruginosa typically displayed spherical cells (diameter 4.8 to 5.3 µm) arranged in lobed clathrate colonies with distinct gaps of varying size and were found in blooms in most of the wetlands and Canning River in the salinity range of 0.11 to 1.15 ppt.

Microcystis flos-aquae (Wittrock) Kirchner (Fig. 2B & C) coexisted with *M. aeruginosa* in most of the wetlands and caused a massive bloom in the Swan River estuary in February 2000, following a record rainfall of 102–206 mm in January with numbers up to 3 million cells mL^{-1}. The colonies were spherical without fenestrations (gaps) and the daughter colonies tended to bud-off with compactly arranged spherical cells (cell diameter 2.9 to 3.6 µm) (Fig. 4). Although *M. flos-aquae* coexisted with *M. aeruginosa* at lower salinity levels, the former dominated the wetlands only at higher salinity levels.

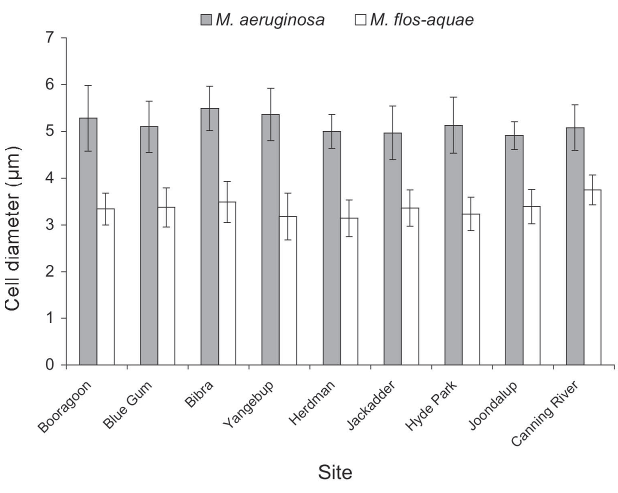

Figure 4. Mean diameter of cells of *Microcystis aeruginosa* and *M. flos-aquae* from 9 wetlands, 2000 to 2003, with standard deviation (N = 50 for each lake).

The species was found in a salinity range of 0.12 to 5.7 ppt (Fig. 5). Those sites dominated by *M. flos-aquae* also had *Anabaenopsis elenkinii* (Fig. 6A) – a cyanobacterium species with moderate salinity tolerance.

Temporally, both species of *Microcystis* caused blooms in spring to autumn; *M. flos-aquae* during the summer-autumn period when the salinity level increased to the maximum. Although *Microcystis* species were present in spring to autumn in almost all the wetlands and Canning River, they persisted in the hypertrophic lakes such as Lake Bibra, Hyde Park and Thomsons Lake, almost throughout the year.

Most dominant filamentous cyanobacterial blooms were caused by species of *Anabaena* (Nostocales). *Anabaena spiroides* (Elenkin) Komárek (Fig. 2D) and *A. circinalis* Rabenhorst (Fig. 2E) were observed in blooms from September to April in many of the wetlands (Herdsman Lake, Lake Joondalup, Lake Claremont, Tomato Lake, North Lake and Mary Carroll Park from 2000 to 2003) and the Canning River upstream of the Kent Street Weir from 1993 to 1994 and 1996 to 2003.

Apart from the hypertrophic wetlands, the most severe *Anabaena* blooms were in the upper Canning River from 1993 to 1994 following the removal of a massive *Hydrocotyl* infestation in 1993. Cell numbers up to 2 x 10^5 cells mL^{-1} and chlorophyll *a* up to 820 µg L^{-1} were recorded in the autumns of 1994 and 1995. The nutrient levels in the upper Canning River in 1994 showed the highest concentrations were associated with *Anabaena* blooms (Table 1). Since then there have been such blooms in the Canning River almost every year. Warning signs against swimming have become a permanent feature of

Table 1

Nutrients (µg L^{-1}) and nutrient ratios in the Canning River from February to December 1994, covering seasonal variation.

Nutrients	Surface		Bottom	
	Min	Max	Min	Max
TP	30	710	30	11000
FRP	<10	170	<10	8100
TN	230	9600	840	80
TIN	<10	2000	10	13
TN:TP	0.25	53	9	0.10

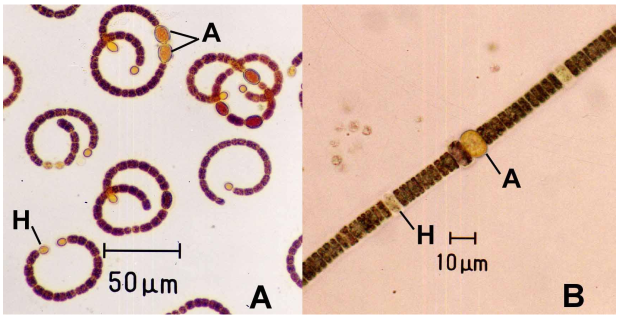

Figure 6. A, *Anabaenopsis elenkinii* (note the position and size of the akinetes (A) and heterocysts (H)); B, *Nodularia spumigena* (note the akinetes and heterocysts).

the upper Canning River due to the toxic *Anabaena* blooms.

Anabaena spiroides was often seen to coexist with *A. circinalis*. The shape of the akinete (broadly ovate in the former and oblong ovate in the latter) appears to be a more reliable character to separate the two, rather than the nature of the spiral, which can vary a lot in the latter.

Other *Nostocales* species observed in the wetlands in minor blooms were *Anabaena flos-aquae* (Lyngbye) de Brébisson et ex et Flahault, *Anabaena oscillarioides* Bory, *Anabaenopsis arnoldii* Aptekarj (Lake Claremont, 2001), *Anabaena bergii* var. *limnetica* Ostenfeld (Mary Carroll Park, 2003), *Anabaenopsis elenkinii* Miller (Lake Joondalup, Bibra Lake, 2003), *Aphanizomenon gracile* Lemmermann (Bibra Lake, 2000), *A. ovalisporum* (Bibra Lake, Emu Lake, 2002) and *Cylindrospermopsis raciborskii* (Bibra Lake, 2001). In addition to Mary Carroll Park, this species has also been observed in Lake Joondalup, Lake Brearely, Lake Coogee and Emu Lake.

Nodularia spumigena Mertens blooms (Fig. 6B) were first recorded in 1993 in two southern freshwater wetlands (Forrestdale Lake and Thomsons Lake), located close to the Canning River. These were short-lived blooms and lasted for 4 weeks. Since then, every spring-summer these blooms have been observed. Before and after the *Nodularia* blooms, *M. flos-aquae* blooms were commonly observed in these wetlands. Salinity close to 3 ppt was associated with *Nodularia* blooms. Both lakes are shallow, often less than 1 m deep, and dry up during severe summers.

Nodularia spumigena was also observed in low numbers along with the bloom of *Microcystis flos-aquae* in the Swan River estuary in February 2000, most likely derived from the close-by riverine wetlands or flushed from the Avon River.

The hepatotoxins, microcystin and nodularin, were associated with the selected blooms analysed. Microcystin concentrations in the Swan River in February 2000 ranged from 0.05 to 124.16 $\mu g\ L^{-1}$. In the wetlands from 1999 to 2000, microcystin concentrations of 0.5 to 1645 $\mu g\ L^{-1}$ and nodularin concentrations from 0.5 to 2.11 $\mu g\ L^{-1}$ were recorded (Kemp & John 2006). Nodularin was detected in two southern lakes in association with a *Nodularia spumigena* bloom. As with the rest of Australia, the neurotoxin, anatoxin, was not yet detected in the blooms of *Anabaena*.

Table 2

Summary of nutrients of selected Perth wetlands affected by cyanobacterial blooms in 1985, 1993 and 1998 (seasonal data for 1985 & 1993; summer data for 1998).

Nutrients ($\mu g\ L^{-1}$)		
Lake Richmond	1985	1998
TP	1-3.7	<10
TN	86-376	900
Chl-*a*	3.7-12.9	3.4
Forrestdale Lake	1993	1998
TP	25-350	100
TN	1400-4850	8900
Chl-*a*	0.4-61.8	3
Bibra Lake	1993	1998
TP	30-260	20
TN	1200-9000	1400
Chl-*a*	1.6-702.9	18
Thomsons Lake		1998
TP		170
TN		3100
Chl-*a*		20

High pH (7.5–9), high temperature (24–28 °C), chlorophyll *a* values from 7 to 700 $\mu g\ L^{-1}$ and eutrophic conditions were associated with most of the recorded blooms. Lake Richmond was an exception: nutrient concentrations pointed to an oligotrophic status, although mild blooms were persistent in 1985. A summary of water chemistry of selected wetlands is presented in Table 2.

Discussion

Nuisance cyanobacterial blooms in freshwater wetlands are generally indicative of degraded eutrophic systems (Boulton & Brock 1999). Trophic status (trophy) of freshwater lakes can be determined by chlorophyll *a*, TP and TN according to OECD boundary values (Ryding & Rast 1989). The type of algal blooms associated with mesotrophic and eutrophic conditions are well recorded in the literature (Wetzel 1983). The data collected over the past 20 years on cyanobacterial blooms as shown above reflect the mesotrophic to eutrophic status of most Perth wetlands. Many of the freshwater species are able to synthesise toxins (cyanotoxins) that affect the liver (microcystins and nodularins) or nervous system (saxitoxin), making such blooms a health hazard. Although no anatoxins have been reported from *Anabaena* blooms in Australia (Beltran & Neilan 2000), mouse assay tests have been confirmed to be positive in many of the blooms e.g. *Anabaena* blooms in the Canning River (Hosja & Deeley 1994).

The minor species, those that have not yet caused severe blooms, may present a future threat (Falconer 1993). In Australia, *Cylindrospermopsis raciborskii* blooms are more common in the eastern states, especially in drinking water sources in subtropical and tropical Queensland (McGregor & Fabbro 2000). In temperate Australia, blooms have been restricted to the summer months when water temperatures reach the mid twenties (Bowling 1994; Hawkins *et al.* 1997). *Cylindrospermopsis raciborskii* was detected in Bibra Lake during autumn to late winter when water temperatures were generally less than 17 °C. This species is a threat due to its invasive potential and reports of both animal and human poisonings due to cylindrospermopsin, a distinct alkaloid hepatotoxin present in this species. Cylindrospermopsin production has also been demonstrated in Australian strains of *A. bergii* var. *limnetica* (Schembri *et al.* 2001). *Aphanizomenon ovalisporum* is a relatively new species identified in Australian waters and is also capable of producing cylindrospermopsin (Shaw *et al.* 1999). The toxins produced by these two species are a major health concern in the eastern states (Jones 2003).

The shallow, alkaline wetlands in the Swan Coastal Plain are 'designed' for cyanobacterial blooms with the sandy soil permitting easy leaching of phosphorus and nitrogen from a catchment depleted of native vegetation and subjected to urbanisation and intense farming. Prolonged periods of high temperature (spring to autumn) and winter rains discharging nutrients into the wetlands have provided the most conducive conditions for autochthonous cyanobacterial blooms. The high EC of the wetlands tends to favour salt tolerant species like *Nodularia spumigena* and *Microcystis flos-aquae*, the latter forming widespread opportunistic allochthonous blooms even in the most unlikely environments such as the Swan River estuary. The link between Perth wetlands and the Swan River estuary was well established by the unusual high rainfall in summer-autumn of 2000 followed by the above bloom. Microcystin concentrations of cyanobacterial blooms in the southwest of Western Australia have been recently reviewed by Kemp & John (2006). The Swan River estuary is vulnerable to most of the freshwater cyanobacterial blooms discussed in this paper, if alterations in nutrients and salinity occur. The urban wetlands have not received adequate attention as a source of cyanotoxins hazardous to human health. Regular monitoring for toxins is required.

The upper reaches of the Canning River, since the establishment of the Kent Street Weir with its annually adjusted height, and Canning Dam, have been transformed into an impoundment of eutrophic freshwater 'wetland' – somewhat similar to the shallow hypertrophic southern wetlands close-by. Prolonged *Anabaena* blooms in the Canning River point to the similarity in water quality between the river and nearby wetlands. Increasing salinity during spring-summer in the southern wetlands provides ideal conditions for *Nodularia* blooms to occur and they are likely to become widely distributed as the wetlands become more eutrophic and saline.

Nodularia spumigena blooms are often associated with saline wetlands and estuaries. The Peel-Harvey system had experienced severe blooms of *N. spumigena* in a salinity range from 3 to 30 ppt (Lukatelich & McComb 1986; McComb & Lukatelich 1995) since the late 1970s to 1993 when the Dawesville Channel was built.

This is the first time *Nodularia* blooms have been recorded in such low salinity waters in Australia. *Nodularia* blooms have been reported from saline waterbodies from other parts of Australia (Jones 2003) and not from freshwater bodies. The fact that short-lived *Nodularia* blooms were observed in two Perth freshwater wetlands whose salinity levels rose to 3 ppt before the blooms, should be a matter of great concern. The recurrence of such blooms for prolonged periods in the future is very likely, as salinity and phosphorus levels increase in the wetlands.

Conclusions

1. *Microcystis aeruginosa* and *M. flos-aquae* are the most ubiquitous bloom-forming cyanobacteria in the Perth region. Both *M. aeruginosa* and *M. flos-aquae* coexist in most of the wetlands with peaks in spring to autumn but the latter forms blooms in lakes of higher salinity (above 3 ppt).
2. The upper Canning River in summer becomes a eutrophic freshwater impoundment resembling the shallow wetlands nearby and *Anabaena* and *Microcystis* blooms have been common in the Canning River since 1993.
3. *Nodularia* blooms are confined to the hypertrophic southern wetlands with salinity close to 3 ppt and are short lived. As salinity increases in the eutrophic wetlands, there is the likelihood of more prolonged *Nodularia* blooms.
4. Many of the minor toxic blooms of *Anabaenopsis*, *Aphanizomenon* and *Cylindrospermopsis* are likely to increase as eutrophication increases.

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