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RESEARCH ARTICLE

Eutrophic urban ponds suffer from cyanobacterial blooms: Dutch examples

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Abstract Ponds play an important role in urban areas. However, cyanobacterial blooms counteract the societal need for a good water quality and pose serious health risks for citizens and pets. To provide insight into the extent and possible causes of cyanobacterial problems in urban ponds, we conducted a survey on cyanobacterial blooms and studied three ponds in detail. Among 3,500 urban ponds in the urbanized Dutch province of North Brabant, 125 showed cyanobacterial blooms in the period 2009–2012. This covered 79 % of all locations registered for cyanobacterial blooms, despite the fact that urban ponds comprise only 11 % of the area of surface water in North Brabant. Dominant bloom-forming genera in urban ponds were *Microcystis*, *Anabaena* and *Planktothrix*. In the three ponds selected for further study, the microcystin concentration of the water peaked at 77 μg l^{-1} and in scums at 64,000 μg l^{-1}, which is considered highly toxic. Microcystin-RR and microcystin-LR were the most prevalent variants in these waters and in scums. Cyanobacterial chlorophyll-*a* peaked in August with concentrations up to 962 μg l^{-1} outside of scums. The ponds were highly eutrophic with mean total phosphorus concentrations between 0.16 and 0.44 mg l^{-1}, and the sediments were rich in potential releasable phosphorus. High fish stocks dominated by carp lead to bioturbation, which also favours blooms. As urban ponds in North Brabant, and likely in other regions, regularly suffer from cyanobacterial blooms and citizens may easily have contact with the water and may ingest cyanobacterial material during recreational activities, particularly swimming, control of health risk is of importance. Monitoring of cyanobacteria and cyanobacterial toxins in urban ponds is a first step to control health risks. Mitigation strategies should focus on external sources of eutrophication and consider the effect of sediment P release and bioturbation by fish.

Keywords Pond · Cyanobacteria · Bloom · Toxicity · Microcystin · Chlorophyll · Lake restoration · Phosphorus

Introduction

Ponds are important freshwater resources (Oertli et al. 2009), and worldwide, there are hundreds of millions of them (Downing et al. 2006). In urban areas, ponds contribute to biodiversity, but also provide societal benefits such as micro-climate regulation, rainwater drainage, recreation and cultural values (Bolund and Hunhammar 1999; Robitu et al. 2006; Gledhill et al. 2008; Downing 2010; Gledhill and James 2012). Because most urban ponds are small, shallow and stagnant, the effect of anthropogenic disturbances on these ponds can be large (Brönmark and Hansson 2002). Anthropogenic eutrophication is considered a major water quality issue in urban ponds (Klapwijk 1988; Roijackers et al. 1998; Smith and Schindler 2009). The main cause of eutrophication in urban ponds is nutrient loading, caused by for example sewage overflow, street dirt and bird droppings (Scherer et al. 1995; Stoianov et al. 2000; Waschbusch et al.

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2000). In addition to the external nutrient loading, the sediment can play an important role in eutrophication as an internal source of nutrients (Søndergaard et al. 1999). Furthermore, a dense fish stock can aggravate eutrophication effects (Meijer et al. 1999; Peretyatko et al. 2009). Eutrophication can result in cyanobacterial blooms, which in turn can cause hypoxia, fish kills and high turbidity (Fastner et al. 1999; Pearl et al. 2001; Scheffer 2004). Moreover, many cyanobacteria can produce potent toxins (Van Apeldoorn et al. 2007) which can reach levels hazardous to humans if ingested (Chorus et al. 2000). Globally, the most frequently reported and best known group of toxins are microcystins, which are produced by common genera such as *Microcystis*, *Anabaena*, *Nostoc* and *Planktothrix* (Carmichael 2001; Van Apeldoorn et al. 2007; Zurawell et al. 2005).

Toxin-producing cyanobacteria frequently bloom in lakes and reservoirs throughout Europe (Chorus 2001; Mankiewicz et al. 2005; Willame et al. 2005; Mooney et al. 2010). In many countries, the use of these waters for recreation is therefore regulated during cyanobacterial blooms (Chorus 2012). Urban ponds also enable public contact with surface water with a possibility of ingesting cyanobacterial material during activities as swimming and playing by children, possibly also angling and boating. Also pets, for example dogs, may ingest cyanobacterial material which poses a risk to their welfare. It is considered essential that the water quality of these ponds is maintained at a safe and aesthetically acceptable level (Birch and McCaskie 1999; Steffensen 2008). Despite the fact that recent studies indicate that toxic cyanobacterial blooms occur in urban ponds (Faassen et al. 2009; Lürling and Faassen 2012), the access to these waters is usually not restricted, and specific information, surveillance and control are generally lacking. There is little information on the frequency and intensity of cyanobacterial blooms in urban ponds. This study therefore aims to improve our understanding of the occurrence of cyanobacterial blooms in urban ponds. In this, we focus on the southern part of The Netherlands as an example of an urbanized area. Furthermore, we sought to determine the occurrence of microcystins and identify the possible causes of cyanobacterial blooms in urban ponds. To achieve this, we surveyed the occurrence of cyanobacterial blooms in the southern part of The Netherlands, and we studied three ponds in detail.

Materials and methods

Survey of locations with cyanobacterial blooms

The province of North Brabant, in the southern part of The Netherlands, was selected as the research area. In the period 2009–2012, cyanobacterial blooms were reported by three regional water authorities in this province (Brabantse Delta, De Dommel, Aa en Maas). As the water authorities do not operate an area-wide monitoring program for cyanobacterial blooms, we used an overview of registered reportings. In this, potential cyanobacterial blooms were reported after a field observation by the water authorities' field staff (turbid water with lumps and floating scums) and by complaints on blooms by citizens, anglers and farmers. When a potential cyanobacterial bloom was reported, an additional water sample (1 l, without scums) was taken by the water authorities to confirm whether it was a cyanobacterial bloom and to gain insight in the bloom-forming taxa. Locations in the jurisdiction of water authority Brabantse Delta (73 samples) were considered to have a cyanobacterial bloom when additional semi-quantitative microscopic investigation confirmed the abundant presence of at least one of the genera *Microcystis*, *Anabaena*, *Aphanizomenon*, *Planktothrix* and *Oscillatoria*. For the additional microscopy, 100 ml of water was filtered through a 0.45-μm membrane filter (Whatman MicroPlus-21STL), and the material gathered on the filter was microscopically investigated (magnification×40). Several fields of view (FOV) were investigated and each FOV had to show cyanobacteria to confirm a bloom. During 2013, a separate investigation showed a strong correlation (r^2=0.63, n=73, unpublished data) between this type of results of microscopy and the concentration of cyanobacterial chlorophyll-*a* (using a FluoroProbe, bbe Moldaenke GmbH, Schwentinental, Gemany; Catherine et al. 2012). Water authorities De Dommel and Aa en Maas (in total of 188 samples) used a different procedure to confirm a cyanobacterial bloom. They reported a bloom when ≥50,000 cells or filaments ml^{-1} (Utermöhl technique; since 2011 modified according to Lo et al. (2011)) of at least one of the genera *Microcystis*, *Anabaena*, *Aphanizomenon*, *Planktothrix* and *Woronichinia* were present.

The reportings give an impression of the extent of blooms rather than a quantification. Additionally, in 55 water bodies designated for recreation and under according surveillance (including seven urban ponds), blooms were registered by the three water authorities when the cyanobacterial chlorophyll-*a* concentration during the period April until September exceeded 12.5 μg l^{-1} in a two- or four-weekly monitoring program (using a FluoroProbe) or when the biovolume of *Microcystis*, *Anabaena*, *Aphanizomenon*, *Planktothrix* and *Woronichinia* (determined by microscopy) exceeded 2.5 mm^3 l^{-1}. These concentrations indicate the initial alert level for bathing water according to the current Dutch cyanobacteria protocol (Ibelings et al. 2012). Topographical maps (Top10N scale 1:10,000, and the Large Scale Base Map of The Netherlands GBKN) and aerial photographs (2012, resolution 10 cm) were used to determine the total number and surface area of urban ponds in North Brabant.

Selection of ponds

We selected three urban ponds for a more detailed study on the intensity and causes of the cyanobacterial problems. The ponds are spread over the province of North Brabant, one in each of the jurisdictions of the three water authorities, and they are representative for urban ponds in this part of the country: they are man-made, have a limited surface area (<1 ha), are shallow and contain water year round. The ponds are located in the cities of Dongen, Eindhoven and Heesch and are characterized in Table 1. The three ponds regularly show cyanobacterial blooms. Pond Dongen is an isolated pond without connection to other surface waters. The pond is characterized by infiltration. During dry periods, the water level is maintained by the supply of pumped groundwater. During wet periods, a surplus of water can be discharged through a one-way discharge connection with the local sewer system. The water level fluctuated in the period 2009–2012 with plus or minus 0.26 m compared to the mean water level. The pond received discharges from a mixed sewage overflow (domestic water and rainwater drainage) from 1970 until 2000. From 2000, no sewage water could enter pond Dongen. Pond Eindhoven is connected to watercourses which drain the excess of water from the pond. There is neither significant seepage nor infiltration. The major inflow comes from the rainwater drainage system in the adjacent residential area. The water level of pond Eindhoven fluctuated in the period 2009–2012 with plus or minus 0.26 m compared to the mean water level. Pond Heesch is a small isolated pond without connections to other surface water. The pond is strongly influenced by seepage during wet periods and by infiltration during dry periods, resulting in fluctuations in water level of plus or minus 0.50 m compared to the mean water level. The pond received discharges from a mixed sewage overflow from 1974 until 2009. Ponds Dongen and Eindhoven have never been dredged. Pond Heesch has last been dredged in the year 2000 and, following upon our survey, underwent thorough restoration in December 2009. All three ponds are used for angling. The edges of the ponds are hard, submerged macrophytes are lacking and residents intensively feed waterfowl, mainly malards (*Anas platyrhynchos*).

Water sampling and analysis

All three ponds were sampled only a few (one to four) times in 2006–2008 and biweekly in the period March 2009–August 2009. In each pond, dissolved oxygen concentration and saturation (Oxyguard, Birkerød, Denmark), conductivity (WTW-Cond 330i, WTW GmbH, Weilheim, Germany), pH (WTW-pH320, WTW GmbH, Weilheim, Germany) and water temperatures were measured at water depth 0.2 m and Secchi depths were determined. Two-litre water samples were taken from the ponds with a perspex sampling tube at water depth 0–1 m. From these samples, total and cyanobacterial chlorophyll-*a* concentrations were measured using a PHYTO-PAM phytoplankton analyser (Heinz Walz GmbH, Effeltrich, Germany). Turbidity was measured using a Hach 2100P Turbidity meter (Hach Company, Loveland, USA). When a cyanobacterial floating scum was present, a scum sample was taken as grab sample in a glass sampling bottle.

Total phosphorus (TP) and total nitrogen (TN) were analysed in unfiltered samples by a Skalar SAN + segmented flow analyser (Skalar Analytical BV, Breda, The Netherlands) following the Dutch standard protocols (NNI 1986, 1990). After filtration through a 0.45-μm membrane filter (Whatman, NC45), nitrite, nitrate, ammonium and ortho-phosphate were analysed (Skalar SAN + segmented flow analyser, NNI 1986, 1990, 1997). Filters with seston and scum samples were stored at −20 °C until extraction for microcystin (MC) analysis. The frozen filters with seston were extracted as described in Lürling and Faassen (2013).

Scum materials were prepared for MC analysis by freeze-drying. Aliquots of 5 mg freeze-dried material were transferred to 2 ml Eppendorf vials. MCs were extracted three times at 60 °C in 0.5 ml 75 % methanol-25 % Millipore water (*v*/*v*). Extracts were dried in a Speedvac (Thermo Scientific Savant SPD121P, Waltham, USA) and reconstituted in 600 μl methanol. The reconstituted samples were transferred to 2 ml

Table 1 Characteristics for ponds Dongen, Eindhoven and Heesch

	Pond Dongen	Pond Eindhoven	Pond Heesch
Coordinate North	51° 37′ 48.00″	51° 48′ 96.57″	51° 41′ 43.70″
Coordinate East	4° 56′ 27.30″	5° 47′ 65.31″	5° 32′ 10.50″
Area (m^2)	2,500	6,500	1,600
Mean water depth (m)	0.7	1.5	1.0
Age of pond (years)	55	20	40
Discharges	Mixed sewer overflow (1970–2000)	Rainwater drainage (1994–present)	Mixed sewer overflow (1974–2009)
Average number of water birds during sampling events	19	17	10

Eppendorf vials with a cellulose-acetate filter (0.2 μm, Grace Davison Discovery Science, Deerfield, USA) and centrifuged for 5 min at 16,000×*g* (VWR Galaxy 16DH, Radnor, USA). Filtrates were transferred to amber glass vials before analysis.

MC analysis was performed as described in Lürling and Faassen (2013). In short, samples were analysed for eight MC variants (dm-7-MC-RR, MC-RR, MC-YR, dm-7-MC-LR, MC-LR, MC-LY, MC-LW and MC-LF) by LC-MS/MS. The LC-MS/MS analysis was performed on an Agilent 1200 LC and an Agilent 6410A QQQ (Agilent Technologies, Santa Clara, USA). The compounds were separated on an Agilent Eclipse XDB-C18 4.6×150 mm, 5 μm column by Millipore water with a gradient of 0.1 % formic acid and acetonitrile with 0.1 % formic acid. The LC-MS/MS was operated in positive mode with an ESI source. For each compound, two transitions were monitored in MRM mode. We extended the data range for variables of pond Heesch as reported for July and August 2009 by Lürling and Faassen (2012).

Sediment sampling and analysis

In each pond, sediment cores were taken from different sites at approximately 1 m water depth (pond Dongen four cores, ponds Eindhoven and Heesch each three cores) using a Uwitec Core sampler (Uwitec, Mondsee, Austria). In pond Eindhoven, six additional cores were collected along a transect in the deepest part (approximately 2 m water depth) of the pond. The top 5 cm of each sediment core was homogenized, where after a subsample was subjected to sequential P extraction using H_2O, bicarbonate/dithionite (BD, 0.11 M), NaOH (1 M), HCl (0.5 M) and persulfate ($K_2S_20_8$) as subsequent extractants (Psenner et al. 1984; Hupfer et al. 1995). In each fraction, TP and, after filtration through a 0.45-μm membrane filter (Whatman, NC45), soluble reactive P (SRP) were determined using a Skalar segmented flow analyser with the UV/ persulfate destruction integrated in the system. Nonreactive P was calculated as the difference between SRP and TP. The mobile P pool was estimated from the content of the H_2O-P, BD-P and NaOH-NRP fractions (Schauser et al. 2006). Sediments were also subjected to persulfate oxidation digestions for TP analysis.

Fish sampling

The fish community was sampled on April 6th 2009 in pond Heesch, on April 7th 2009 in pond Dongen and on April 8th 2009 in pond Eindhoven by a professional fishery company (Visserijbedrijf P. Kalkman, Moordrecht, The Netherlands). The samplings were performed first by seine-haul fishing (75 m net, 8 to 12 mm mesh size) and followed by electrofishing (5 kW) along the banks. In each pond, the species composition was determined. The biomasses were determined as fresh weight by weighing all the caught fishes per species on an industrial balance. A known factor was used to correct for the efficiency of the capture rigs that were used (STOWA 2002).

Results

Survey of cyanobacterial presence

In the period 2009–2012, a total of 158 different locations with cyanobacterial blooms were recorded in the province of North Brabant (Fig. 1), 125 of which were urban ponds including seven designated bathing waters. The total number of urban ponds in North Brabant is 3,473. The total area covered by urban ponds in the province is 956 ha and the total area of the surface water is 8,663 ha. Over 80 % of the blooms in ponds were reported in the months July, August and September, while the most abundant cyanobacterial genera differ per bloom and *Microcystis*, *Anabaena* and *Planktothrix* dominating most often (Table 2).

Cyanobacterial presence and microcystin concentrations

In pond Dongen, chlorophyll-*a* concentrations increased from March to August 2009. In July and August, the dominant species *Microcystis aeruginosa* formed a surface scum. In August 2009, the cyanobacterial chlorophyll-*a* concentration reached 962 μg l^{-1} (Fig. 2). MC concentrations in the water column in July 22nd and August 26th 2009 were 56.7 and 48.5 μg l^{-1} with MC-RR and MC-LR as the dominant variants (Fig. 3).

In pond Eindhoven, maximum chlorophyll-*a* concentrations in the water column remained well below 250 μg l^{-1} during the research period (Fig. 2). Cyanobacterial chlorophyll-*a* concentrations reached approximately 100 μg l^{-1} during the summers of 2006, 2008 and 2009 (Fig. 2) and surface scums were formed every year. The scum of July 2009 consisted of *Aphanizomenon flos-aquae*, *Anabaena flos-aquae*, *M. aeruginosa* and *Microcystis flos-aquae*. MC concentrations in the water column increased from 0.3 μg l^{-1} on March 23rd to 5.8 μg l^{-1} on August 31st 2009 (Fig. 3). The surface scums contained concentrations between 1,500 and 7,400 μg MC l^{-1} (Fig. 4).

In pond Heesch, chlorophyll-*a* concentrations showed no obvious trend between March and August 2009 with a mean chlorophyll-*a* concentration of 283 μg l^{-1}, of which 57 % was cyanobacterial chlorophyll-*a* (Fig. 2). From March to May 2009, a *Pseudoanabaena* species dominated this pond. MC concentrations increased from 4.8 μg l^{-1} in March to 15.8 μg l^{-1} in the beginning of May 2009, where after MC concentrations declined to 0.4 μg l^{-1} on July 1st. During this period, only the MC variants dm-7-MC-RR and MC-RR were detected, with dm-7-MC-RR being the most prominent variant (Fig. 3). In July 2009, *M. aeruginosa* and *Woronichinia*

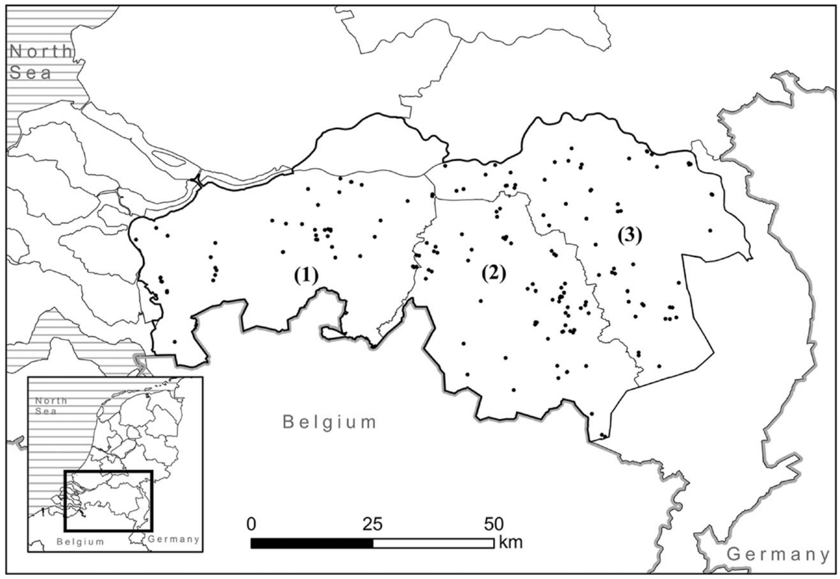

Fig. 1 Locations with reported cyanobacterial blooms during the period 2009–2012 in the province of North Brabant, The Netherlands. Regional water authorities: *1* = Brabantse Delta, *2* = De Dommel, *3* = Aa en Maas

naegeliana became dominant and MC concentrations increased rapidly to 77 μg l^{-1} on August 19th 2009. MC-RR was the most dominant variant, followed by MC-LR (Fig. 3). The scum sample of pond Heesch from August 10th 2009 was dominated by *M. aeruginosa* and contained 64,000 μg MC l^{-1}. Also in this sample, MC-RR and MC-LR were the most abundant variants (Fig. 4).

Water quality

Table 3 shows that all three ponds are hypertrophic with mean TP concentrations ranging from 0.16 to 0.44 mg P l^{-1}. In 2009, maximum concentrations reached 0.82 mg P l^{-1} in pond Dongen, 0.35 mg P l^{-1} in pond Eindhoven and 1.90 mg P l^{-1} in pond Heesch. The minimum TP concentrations in 2009 were 0.12 mg P l^{-1} in pond Dongen and pond Heesch and 0.05 mg P l^{-1} in pond Eindhoven. The mean ortho-phosphate concentrations varied between 23 and 50 μg P l^{-1}, whereas the maximum concentrations in 2009 reached 114 μg P l^{-1} in pond Dongen, 220 μg P l^{-1} in pond Eindhoven and 131 μg P l^{-1} in pond Heesch. The minimum ortho-phosphate concentrations in 2009 were 2 μg P l^{-1} in pond Dongen and pond Heesch and 10 μg P l^{-1} in pond Eindhoven. All three ponds were turbid and mean Secchi depths varied between 22 and 30 cm. Pond Dongen had on average the lowest pH value that ranged from 5.14 immediately after the supply of groundwater to 8.51 during a cyanobacterial bloom. The pH values in pond Eindhoven ranged between 7.34 and 8.93 and in pond Heesch between 6.76 and 8.97. The mean TN concentrations varied between 1.40 and 3.27 mg N l^{-1} (Table 3), while the minimum TN concentrations in 2009 were 0.32 mg N l^{-1} in pond Dongen, 0.30 mg N l^{-1} in pond Eindhoven and 0.81 mg N l^{-1} in pond Heesch.

Table 2 Dominant genera in cyanobacterial blooms in urban ponds (2009–2012) for three water authorities (as % of all reported blooms in urban ponds per water authority)

	Water authority		
	Brabantse Delta	De Dommel	Aa en Maas
Anabaena	26	26	22
Aphanizomenon	15	13	7
Microcystis	36	17	30
Planktothrix	22	26	24
Woronichinia	1	19	17

Sediment quality

The mean mass fraction of total sediment P for pond Dongen was 0.26 mg g^{-1} dry sediment (DW). In pond Eindhoven, the sediment contained 0.43 mg P g^{-1} DW at 1 m depth and 1.11 mg P g^{-1} DW at 2 m depth. The P content of pond Heesch was lowest with 0.11 mg P g^{-1} DW (Table 4). Sediment digestion yielded similar TP amounts. P-fractionation indicated that the potentially releasable P was on average 42 % of the sediment P pool in pond Dongen, varied from 10 to 50 % in pond Eindhoven and was 28 % in pond Heesch (Table 4).

Fish stock

All three ponds were heavily stocked with fish (>900 kg ha^{-1}, Table 5). In all three ponds, the fish community was dominated by carp (*Cyprinus carpio*). Carp and Gibel carp (*Carassius gauratus gibelio*) made up 84 % of the fish biomass of pond Dongen, 77 % of pond Eindhoven and 85 % of pond Heesch (Table 5).

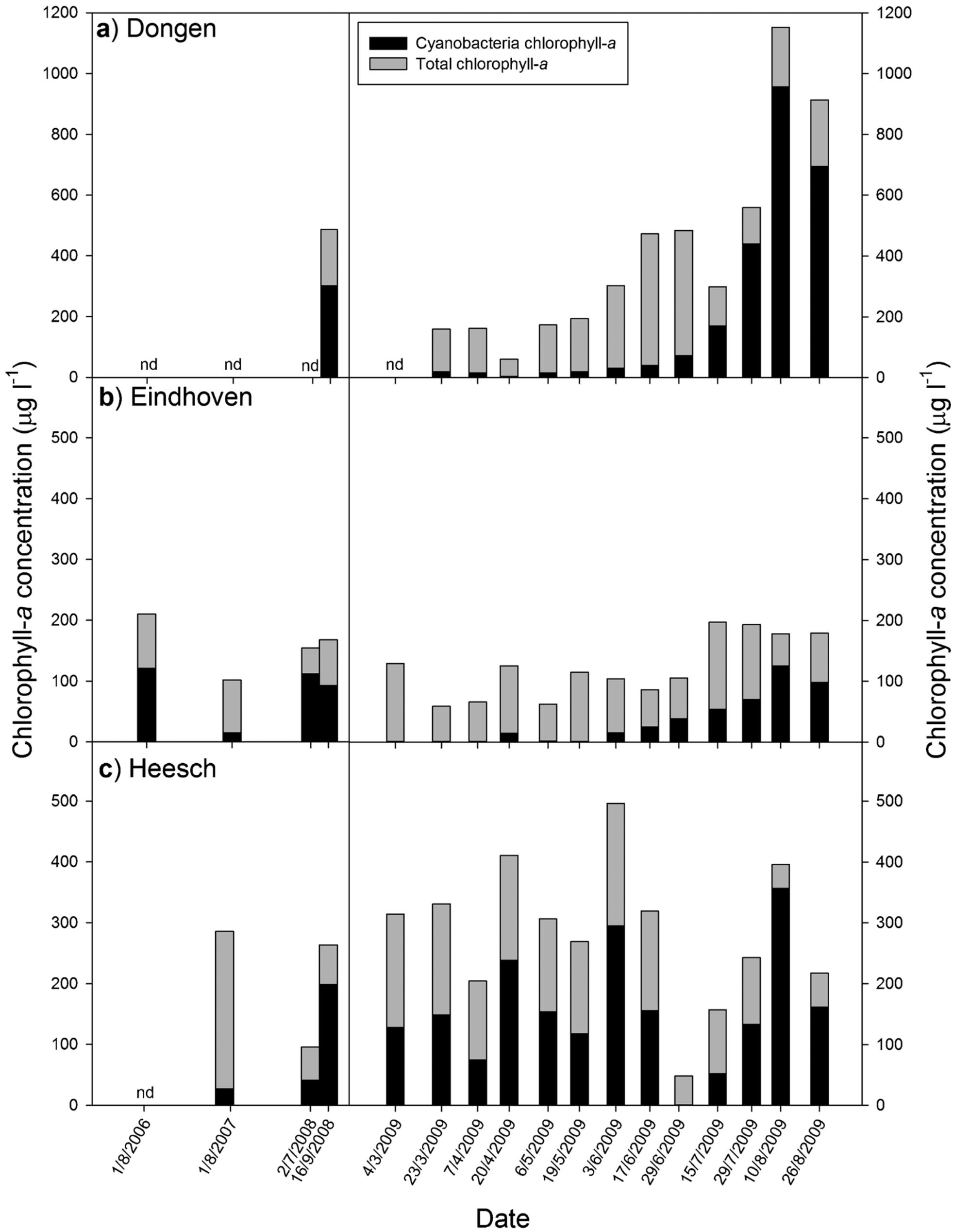

Fig. 2 Cyanobacteria (*black bars*) and eukaryote algae (*gray bars*) chlorophyll-*a* concentrations (μg l^{-1}) in the water from pond Dongen (**a**), pond Eindhoven (**b**) and pond Heesch (**c**) in 2008 and 2009 (*nd* = not detected)

Discussion

Many water bodies in the Dutch province of North Brabant suffer from cyanobacterial blooms, and with blooms in 125 urban ponds out of a total of 158 reported sites, blooms are reported more frequently in urban ponds than in other types of water bodies. As urban ponds represent only 11 % of the total area of fresh surface water within the province, the high proportion of reported blooms in urban ponds is in contrast to their limited area. Because a structural monitoring program on blooms is lacking, we suspect that the actual frequency of cyanobacterial blooms in urban ponds is underestimated in our study. Indeed, observations by the authors indicate that blooms occur in more urban ponds than reported by the public and field staff.

Over 70 % of the registered blooms in urban ponds were dominated by the genera *Microcystis*, *Anabaena* or *Planktothrix*, genera which tend to dominate in ponds also in neighboring countries (Willame et al. 2005). These three genera are frequent in nutrient-enriched lakes (Wetzel 2001). The ponds that were investigated in detail showed high nutrient levels of water and sediment, a prerequisite for cyanobacterial blooms. Dominance of *Microcystis* is associated with thermal stratification and the genus is considered to be sensitive to mixing (Reynolds et al. 2002). Our results show that many of the shallow urban ponds provide a suitable

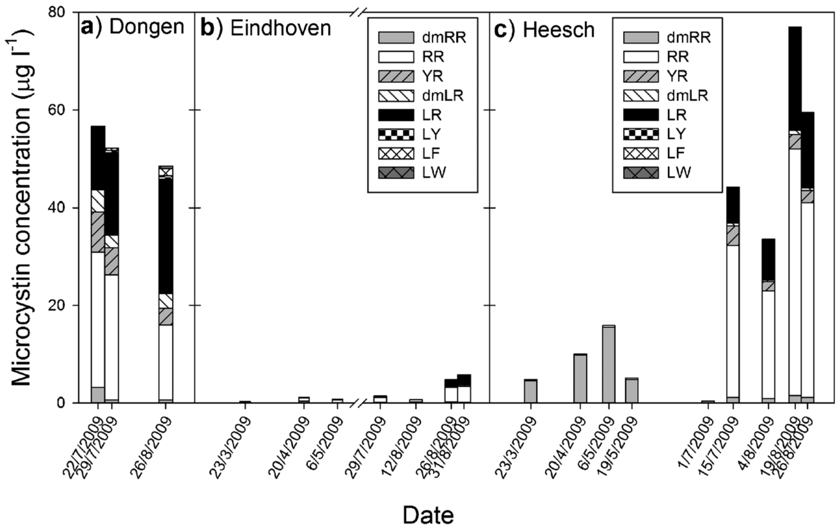

Fig. 3 Concentrations of eight microcystin variants (μg l^{-1}) in the water from pond Dongen (**a**), pond Eindhoven (**b**) and pond Heesch (**c**; partly modified from Lürling and Faassen 2012) in spring and summer 2009

habitat for *Microcystis*. In addition to high nutrient levels, urban ponds are often surrounded by buildings, trees and shrubs which provide wind-sheltered situations. Low wind speeds favour stratification which in turn favours algal blooms (Condie and Webster 2001). *Planktothrix agardhii* is reported for mixed situations, while *Anabaena* spp. occur both under mixed and stratified conditions (Reynolds et al. 2002; Padisák et al. 2009). As species are favoured with different needs regarding the mixing of the water, we conclude that there is a variety in environmental conditions in urban ponds which supports functionally different cyanobacteria.

Besides the nutrient status and mixing conditions, the high fish community of urban ponds with a high abundance of carp (*C. carpio*) will be of influence on the phytoplankton: sediment resuspension by bottom-dwelling species such as carp causes high turbidity of the water (Scheffer et al. 1993). Many cyanobacteria (e.g. *Microcystis*) are adapted to low light situations as they show an adaptive buoyancy (Reynolds et al. 2002; Visser et al. 2005). Secondly, in the presence of fish, small zooplankton is favoured (Meijer et al. 1990) which, in turn, is less effective in controlling large-sized cyanobacterial colonies (Gliwicz 1990). Being less vulnerable to grazing, cyanobacteria can be enhanced.

The cyanobacteria we found dominantly in the urban ponds are known as potential MC producers (Carmichael 2001; Van Apeldoorn et al. 2007). MCs are potent inhibitors of protein phosphatases and tumor promoters (Kuiper-Goodman et al. 1999; Zurawell et al. 2005). They have been implicated in human fatalities (Pouria et al. 1998) and in animal mortalities, for example in otters (Miller et al. 2010), turtles (Nasria et al. 2008), dogs (Lürling and Faassen 2013) and birds (Matsunaga et al. 1999). The highest MC concentration found outside of scums in the water column of our three selected ponds was 77 μg l^{-1}, which is similar to most of the highest values recently reported from a survey in 86 Dutch surface waters (Faassen and Lürling 2013). Although the concentrations did not exceed 100 μg l^{-1}, which has been suggested a safe concentration for a single intake (Fromme et al. 2000), the ponds showed considerable spatial heterogeneity in cyanobacterial density. Ponds Eindhoven and Heesch had

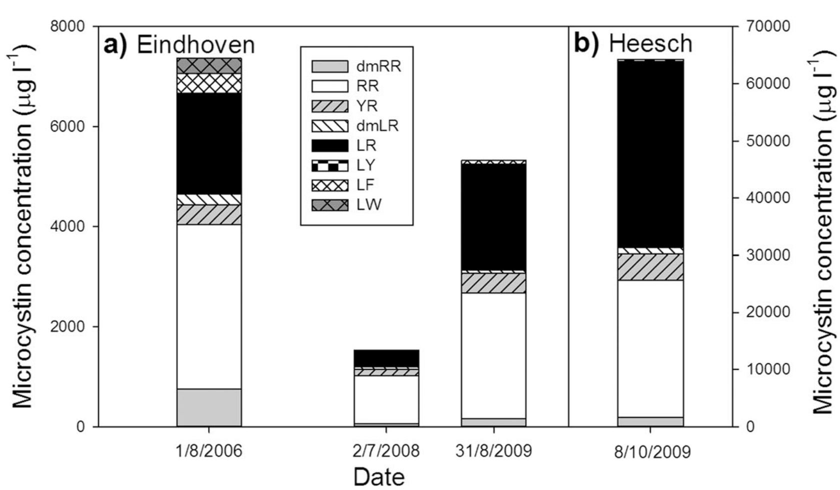

Fig. 4 Concentrations of eight microcystin variants (μg l^{-1}) in surface scums from pond Eindhoven (**a**; 2006, 2008, 2009) and pond Heesch (**b**; 2009)

Table 3 Overview of water quality variables presented as means of all samples (±1 SD) determined in three urban ponds. Research periods: pond Dongen—September 2008, March until August 2009; pond Eindhoven—August 2006, August 2007, July + September 2008, March until August 2009; pond Heesch—July 2007, July + September 2008, March until August 2009

Water quality variable	Pond Dongen	Pond Eindhoven	Pond Heesch
Total phosphorus (mg P l^{-1})	0.37 (±0.24)	0.16 (±0.10)	0.44 (±0.46)
Ortho-phosphate (μg P l^{-1})	23 (±30)	24 (±53)	50 (±33)
Secchi depth (cm)	22 (±9)	30 (±9)	22 (±9)
Turbidity (NTU)	92 (±54)	44 (±17)	81 (±53)
pH	6.82 (±0.86)	8.25 (±0.45)	7.69 (±0.68)
Total nitrogen (mg N l^{-1})	3.27 (±1.87)	1.40 (±0.68)	2.55 (±1.03)
Nitrite + nitrate (mg N l^{-1})	0.09 (±0.04)	0.07 (±0.07)	0.43 (±0.34)
Ammonium (mg N l^{-1})	1.31 (±1.14)	0.10 (±0.10)	0.22 (±0.48)
O_2 (mg l^{-1})	6.5 (±2.5)	9.5 (±2.8)	9.99 (±3.7)
O_2 (%)	68 (±25)	102 (±27)	105 (±41)
EC (μS cm^{-1})	450 (±48)	331 (±74)	320 (±22)

local surface scums that contained MC concentrations from 1,500 to 64,000 μg l^{-1} (Fig. 4; Lürling and Faassen 2012). If a child would ingest less than 1 ml of such a scum, the suggested no adverse effect level of 25 μg MC for a single intake by children (Fromme et al. 2000) would already be exceeded. These high MC concentrations are similar to MC concentrations found in other ponds, e.g. 14,000 μg l^{-1} in a pond in Deurne (The Netherlands) (Faassen and Lürling 2013), 38,000 μg l^{-1} in a pond in Eke (Belgium) (Descy et al. 2011) and 77,000 μg l^{-1} in a pond in Kluisbergen (Belgium) (Van Gremberghe et al. 2007). As the urban ponds are intensively used, and citizens (often children) are exposed to pond water through particularly swimming without surveillance and possibly also through angling and boating, we conclude that cyanobacterial blooms in urban ponds are a threat to citizen's health if cyanobacterial material is ingested.

All eight MC variants included in the analysis were detected albeit not always simultaneously. In the blooms and scums, the variants MC-RR and MC-LR were the most abundant MCs, which was also observed in other studies (Mankiewicz et al. 2005; Willame et al. 2005; Mazur-Marzec et al. 2008). The variant dm-7-MC-RR and to a far less extent MC-RR were found to co-occur with almost complete dominance of *Pseudoanabaena* in pond Heesch at that time (some Scenedesmaceae co-occurred). In general, *Pseudoanabaena* is not often listed as a MC producer (e.g. Van Apeldoorn et al. 2007), but there are a few studies that have shown *Pseudoanabaena* can produce MCs (Oudra et al. 2001; Teneva et al. 2009). Also this study suggests *Pseudoanabaena* might produce MCs, but solid proof can only be obtained from cultured isolates. Inasmuch as the MC profile deviated from usually encountered in Dutch surface waters when *Planktothrix* is present (always consist of 15–30 % of dm-7-MC-LR), *Anabaena* is dominant (virtually no dm-7-MC-RR and 50–80 % MC-RR) or *Microcystis*/*Woronichinia* are present (MC-LR dominating) and the detection limit of the MC analysis is low enough to detect these other variants (Lürling and Faassen 2013), the possibility that some of these 'usual suspects'—in such low abundance that they were not detected by microscopy—were responsible for the MC profile in spring in pond Heesch is highly unlikely. The seston MC profile in pond Heesch completely shifted in summer towards one in which MC-RR, MC-LR and MC-YR were most abundant (Fig. 3). These MC variants are most frequently encountered in many water bodies (Sivonen and Jones 1999; Graham et al. 2010; Faassen and Lürling 2013), particularly when *Microcystis* is the chief MC producer in them. In about a quarter of the samples in the latter study, also the variants MC-LW and MC-LF were detected that might be more toxic than MC-LR, the variant that is mostly used for risk assessments (Fischer et al. 2010; Vesterkvist et al. 2012). Also in the current study, we found these two variants in several samples from pond Dongen (Fig. 3) and in a surface scum in pond Eindhoven (Fig. 4). Although in the latter situation these variants made up only 9.4 % of the total MC pool, using a toxicity conversion factor (Faassen and Lürling 2013), they probably contributed at least 65 % to the overall toxicity.

Table 4 Mean total sediment P (mg g^{-1} DW) and potential releasable sediment P (mg g^{-1} DW) in shallow sediments (~1 m water depth) in cores from pond Dongen, pond Eindhoven and pond Heesch and deeper sediment (~2 m water depth) from pond Eindhoven. Figures in parentheses indicate ±1 SD

	P content (mg g^{-1} DW)			
	Pond Dongen	Pond Eindhoven		Pond Heesch
Water depth	~1 m	~1 m	~2 m	~1 m
Total sediment P	0.26 (0.12)	0.43 (0.10)	1.11 (0.08)	0.11 (0.04)
Potential releasable sediment P	0.11 (0.07)	0.04 (0.01)	0.55 (0.06)	0.03 (0.02)

Table 5 Fish community composition and biomass of the species (fresh weight FW kg ha^{-1}) in the three selected urban ponds in April 2009 (Kalkman 2009a, b, c)

Species		Fish biomass (kg ha^{-1} FW)		
		Pond Dongen	Pond Eindhoven	Pond Heesch
Abramis bjoerkna	Silver bream	1.8		
Abramis brama	Bream	22.3	81.7	3.4
Anarhichas lupus	Catfish			47.1
Carassius auratus gibelio	Gibel carp	16.3	265.4	218.0
Cyprinus carpio	Carp	1109.9	450.6	1011.5
Esox lucius	Pike		20.9	
Gobio gobio	Gudgeon			0.1
Hypophthalmichthys molitrix	Silver carp			124.6
Lepomis gibbosus	Sunfish			0.8
Leuciscus idus	Ide			0.4
Perca fluviatilis	Perch		3.7	2.6
Rutilus rutilus	Roach	178.1	94.6	30.2
Scardinius erythrophthalmus	Rudd	2.9	1.7	5.0
Tinca tinca	Tench		8.5	
	Total	1,331	927	1,444

To minimize the risk of human exposure to cyanobacterial toxins in urban ponds, cyanobacterial blooms should be controlled. Urban ponds often receive high nutrient loads (Scherer et al. 1995; Stoianov et al. 2000; Waschbusch et al. 2000). Furthermore, most urban ponds are shallow, stagnant and small with a mean area of 2,750 m^2 as determined in this study for North Brabant. These conditions favour cyanobacterial growth (Huisman et al. 2004; Pearl and Huisman 2008). Controlling cyanobacterial blooms in a specific pond firstly requires a thorough system analysis that identifies the most important causes of the bloom. TP concentrations well above 0.1 mg P l^{-1} and concentrations of chlorophyll-*a* rarely below 100 μg l^{-1} show these ponds to be hypertrophic. Nutrient levels hardly seem to be limiting for phytoplankton biomass. Sediment concentrations of TP reflect that they were in a similar range as in other eutrophic waters (Esten and Wagner 2010; Zhou et al. 2008; Hill and Robinson 2012). Furthermore, the dense, carp-dominated fish stocks keep the ponds turbid by resuspending the sediment, thereby preventing submerged macrophytes to establish (Cline et al. 1994; Meijer et al. 1999; Zambrano and Hinojosa 1999; Persson and Svensson 2006; Roozen et al. 2007). This indicates that for this type of ponds, mitigation strategies should not only focus on external sources of eutrophication, but should also consider the effect of sediment P release and bioturbation by fish.

Furthermore, we recommend that the toxicity of urban ponds is monitored. Despite their important role, ponds generally receive less attention from freshwater biologists (Céréghino et al. 2008; Oertli et al. 2009) and water managers (Boix et al. 2012) than other water types. This is also the case in The Netherlands, where the water authorities, following the European Water Framework Directive (WFD; European Union 2000), primarily focus on large water bodies. An appropriate approach would start with the development and application of a monitoring program based on a uniform set of assessment criteria. Furthermore, when potential toxin-producing cyanobacteria are found to be abundant, it is recommended to screen for the toxins that could be produced by the present species. At present, most water authorities focus only on concentrations of cyanobacteria and on the toxin MC-LR. Our study underpins the importance of identifying different MC variants in water samples, but also highlights that in surface accumulations, MC concentrations might pose a risk to human health and animal welfare. Furthermore, other cyanobacterial toxins have also been detected in Dutch surface waters (Faassen et al. 2009; Kosten et al. 2011), sometimes at levels toxic to dogs (Faassen et al. 2012).

We conclude that many urban ponds in the Dutch province of North Brabant, and likely in other regions as well (Stoianov et al. 2000; Ibelings et al. 2012; Faassen and Lürling 2013), suffer from cyanobacterial blooms. Because these blooms can be highly toxic, they can threaten citizens' health if ingested. Therefore, eutrophication control and reducing cyanobacterial blooms in urban ponds should be of importance to water managers. Dependent on the local uses and interests involved, their relevance can be similar to that of lakes and streams for which eutrophication control has become an important topic in the WFD.

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