Factsheet

Recent Australian research on cyanobacteria with implications for risk management within the water industry

Cyanobacteria, also known as blue-green algae, are a diverse group of photosynthetic bacteria with the ability to colonise a range of environmental niches. They range in size from very small solitary cells to large visible colonies and are present in almost all aquatic habitats. Given the right environmental conditions they can grow rapidly, forming blooms which impact the environment and a range of water uses. As a taxonomic group, the cyanobacteria are capable of producing a large variety of bioactive compounds (Huang and Zimba, 2019), including cyanotoxins (defined herein as compounds known to cause harm to humans or animals as a result of environmental exposure) and a large variety of taste-and-odour (T&O) compounds (Watson and Jüttner, 2019), including the well-known compounds geosmin and MIB (2-methylisoberneol).

Frequently detected cyanotoxins:

- Hepatotoxic microcystins and cylindrospermopsin, which mainly damage the liver, pancreas and can promote the formation of tumours (microcystins only).
- Neurotoxic saxitoxins and anatoxins, which disrupt neurotransmission generating numbness, muscle tremors and at high doses can cause rapid death through asphyxiation.
- Cytotoxins, which affect cells in various ways and can generate skin and eye irritation and gastroenteritis. The mechanism of toxicity of these molecules is less known.

New discoveries

Anatoxin-a

Previously thought to be absent from Australia (Testai et al., 2016; NHMRC, NRMMC, 2011), anatoxin-a (ATX) has recently been detected in both planktonic and benthic samples originating from various surface waterbodies (Gaget et al., 2018; Nijoy et al., 2019), including drinking water reservoirs (Gaget et al., 2018). Further information on the Australian occurrence of ATX and its analogues will allow comparison to published toxicities for toxin variants found overseas (Lovin and Brooks, 2019)

Benthic cyanobacteria

Benthic mats are complex biofilms present at the water–sediment interface that can be dominated by both cyanobacteria and algae (Gaget et al., 2019). Benthic cyanobacteria have been shown to produce T&Os and toxins in various parts of the world, and recently determined to be a source of toxins in Australian source waters (Gaget et al., 2018). Little is known about the rate of toxin production and release from benthic cyanobacteria, while more is known about their production of T&O metabolites. Evaluating the significance and fate of benthically produced toxins in source waters is difficult given the current state of knowledge.

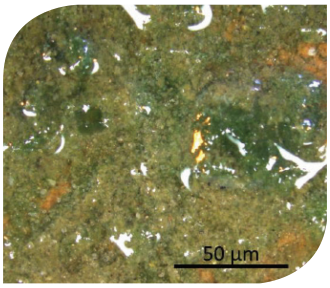
Key Points:

- Anatoxin-a discovered in Australian waters for the first time
- If you are having cyanobacterial issues, then consider looking for anatoxin-a as well.
- Do you have unexplained taste-and-odour (T&O) spikes?
- Have you thought about benthic cyanobacteria as a source of problems?
- Benthic cyanobacteria have now been shown to produce all major cyanotoxins.

Future direction:

- Rapid toxin measurement and toxicity and toxigenicity detection instead of, or to complement, cell counts.
- New instrument and sampling for rapid benthic monitoring.

Further, the growth of benthic cyanobacteria is not readily captured through current recommended monitoring practices. Benthic types are uncommonly resuspended into the water column, however their breakthrough into water treatment plants has occasionally been observed. Within Australia and throughout much of the world, cyanotoxin monitoring relies upon the identification of cyanobacteria present in the plankton whereas sampling of benthic cyanobacteria is rarely undertaken.



Relevance to Australian water utilities

The recent detection of ATX in Australia highlights a new unknown toxic risk for water utilities and monitoring may need to be adjusted. If a utility decides to test for the presence of ATX genes, or the ATX toxin by ELISA, it is recommended that LC/MSMS is subsequently performed to confirm and more reliably quantify the ATX toxin. The LC/MSMS quantification should preferably be performed with isotopically-labelled standards (Haddad et al., 2019)

Benthic cyanobacteria are not currently included in monitoring practices. The identification and enumeration of benthic cyanobacteria is not straightforward due to the complex nature of the mat (i.e. a mass of overlapping filaments in layers). Given there are no simple and standard sampling and monitoring techniques, the growth of benthic cyanobacteria can regularly go unnoticed both in source waters and inside treatment plants, which in turn can lead to unidentified aesthetic and toxic issues.

Breakthrough of cyanobacteria cells (both toxins and nontoxic cells) into water treatment plants, even in low cell numbers, lead to accumulation of cells in plants potentially leading to breakthrough of combined chemical and/or microbial contaminants into treated water (Zamyadi et al., 2019).

What to do about it

Benthic mat monitoring can be implemented by conducting sediment core sampling and incubating devices at the bottom of reservoirs (Gaget et al., 2019), or where available by divers to collect samples. Furthermore, real time monitoring options and remote sensing options like satellite imagery are available but they are more suitable for monitoring planktonic cyanobacteria rather than the benthics. Remote sensing has not been used widely, requires familiarity with an entire new set of technologies and expertise, and needs to be adapted to benthic growth conditions; however, satellite imagery data accessibility and affordability is improving rapidly. Phycocyanin quantification probes have been optimised to benthic conditions and once validated could enhance routine survey of overall benthic algal growth. Control approaches are rarely documented in the literature. Some utilities have lowered the level of their reservoirs, only to observe a growth once the level was heightened again. Mechanical dragging can also be attempted, but growth eventually seem to reoccur.

The options for controlling cyanobacteria in source waters are limited and site-specific. Long-term options are anchored in reducing nutrient inputs from sources in catchments, however it is problematic to achieve nutrient concentrations at a low enough level to eliminate the growth of cyanobacteria. Some utilities have the ability and approval to use algicides or precipitation chemicals, however this varies between states and is controlled by permits and environmental considerations. Mixing and circulation with aerators and mixers can assist in reducing growth, but only in deep reservoirs and must be well designed. In the downstream treatment, conventional treatment supplemented with additional measures of either powered activated carbon (PAC) or granular activated carbon (GAC) is effective for removal of a range of cyanobacterial metabolites. Recently, a guidance for pre-oxidants (free chlorine, NH_2Cl, ClO_2, O_3, $KMnO_4$, H_2O_2 and $CuSO_4$) of cyanobacterial cells with respect to release and oxidation of toxins has been published and oxidant:DOC ratios that can cause release of toxins were identified (Wert et al. 2019).

Conclusions

Recent analytical advances had made it possible to monitor for a broader range of cyanotoxins leading to discovery of ATX in Australian waters for the first time. Also, contribution of benthic cyanobacteria to toxin production and breakthrough of cells and toxins into water treatment plants have been documented recently. Utilities and regulatory agencies are advised to consider the need to adapt their monitoring and management strategies to these new findings to provide safe drinking water and recreational access.

Further info

Gaget et al. (2018) Bad tastes, odours and toxins in our drinking water reservoirs: are benthic cyanobacteria the culprits? Water Research Australia (WaterRA) Project 1059 – Final report.

Gaget et al. (2019) Toolbox for the sampling and monitoring of benthic cyanobacteria. *Water Research*, 169, 115-222.

Haddad et al. (2019) Determination of microcystins, nodularin, anatoxin-a, cylindrospermopsin, and saxitoxin in water and fish tissue using isotope dilution liquid chromatography tandem mass spectrometry. *Journal of Chromatography* A, 1599, 66-74.

Huang and Zimba (2019) Cyanobacterial bioactive metabolites – a review of their chemistry and biology. *Harmful Algae*, 83, 42–94.

Lovin and Brook (2019) Global scanning of anatoxins in aquatic systems: environment and health hazards, and research needs. *Marine and Freshwater Research*.

Main et al. (2018) Detection of the suspected neurotoxin b-methylamino-L-alanine (BMAA) in cyanobacterial blooms from multiple water bodies in Eastern Australia. *Harmful Algae*, 74, 10-18.

NHMRC, NRMMC (2011) Australian Drinking Water Guidelines Paper 6 National Water Quality Management Strategy. National Health and Medical Research Council, National Resource Management Ministerial Council, Commonwealth of Australia, Canberra.

Nijoy et al. (2019) First report of anatoxin-a producing cyanobacteria in Australia illustrates need to regularly up-date monitoring strategies in a shifting global distribution. *Nature Scientific Reports*, 9, 10894.

Testai et al. (2016) Risk to human health associated with the environmental occurrence of cyanobacterial neurotoxic alkaloids anatoxins and saxitoxins. *Critical reviews in toxicology*, 46.5, 385-419.

Watson and Jüttner (2019) Biological production of taste and odour compounds. In: Lin, T.F., Watson, S., Dietrich, A.M. and Suffet, I.M. (Eds), Taste and Odour in Source and Drinking Water. Causes, controls and consequences. IWA Publishing, London, UK.

Zamyadi et al. (2019) Diagnosing water treatment critical control points for cyanobacterial removal: Exploring benefits of combined microscopy, next-generation sequencing, and cell integrity methods. *Water Research*,152, 96-105.

Wert et al. (2019) Utility guidance manual for the management of intracellular cyanotoxins. The Water Research Foundation (WRF) Project 4692 – Final report and guidance document.