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Emerging methods for monitoring cyanobacteria and cyanotoxin risks to Aotearoa New Zealand drinking water supplies

June 2024

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Abstract

Cyanobacterial blooms are an increasing public health risk to water supplies in Aotearoa New Zealand and it is of critical importance for water suppliers to be able to assess if, and when, there is a problem. Having a greater understanding of when there is a risk present will support the safety and sufficiency of the water supply while also minimising public health risks. The purpose of this literature review was to identify emerging technologies and monitoring approaches to detect, and subsequently manage, cyanobacterial blooms in drinking water supplies with the goal of assessing if improvements can be made to the management of cyanobacteria and cyanotoxins risks in New Zealand.

Context

Cyanobacterial blooms are increasing in frequency and are expanding to more countries and territories across the globe[1,2] as a result of climate change. It is understood that changes in climate including increasing water temperatures, thermal stratification, and precipitation are associated with conditions that cause cyanobacterial blooms.[3] There is specific concern that this increase in cyanobacterial blooms is also reflected in freshwater systems utilized as drinking supplies.[4] Cyanobacteria pose significant public health risks to drinking water supplies and managing these risks is often complex due to the range of species and the variations in toxin release.

In addition, it is recognised that climate change is likely to result in an increase in cyanobacteria blooms in Aotearoa New Zealand. It is projected that across the country, there will be an increase of up to 70 "extra" days with temperatures of over 25°C by 2090.[5] Such increases in temperature will contribute to eutrophication of lakes which directly contributes to cyanobacterial blooms.[5] It is also projected that precipitation and wind will increase which will contribute to nutrient loading and increased water turbidity respectively.[5] Combined, these will provide increasingly favourable conditions for cyanobacterial growth and proliferation.[3–5]

Given these projected increases in risk, it is of critical importance that drinking water suppliers have the tools to identify when there is a problem. This will ensure that it is possible to take adequate steps to mitigate risk of cyanobacteria in the water supply and maintain the safety, sufficiency, and aesthetic quality of the drinking water they supply. Additionally, it is important that New Zealand's water suppliers' risk management strategies are effective in minimising risks to public health. Consequently, this review seeks to evaluate advances and emerging technologies for monitoring cyanobacteria and cyanotoxins in water sources which will enable rapid, accessible, and more expansive surveillance. The identified methods could improve monitoring and management plans and contribute to updated cyanobacterial risk management in New Zealand.

Methods

A review of the literature was undertaken in order to identify existing and emerging technologies and monitoring approaches to identify and manage cyanobacteria and cyanotoxins in drinking water supplies with the goal of assessing if improvements can be made to the management of cyanobacteria and cyanotoxin risks in New Zealand.

Literature search and text review strategy:

The literature review search was conducted through OVID MEDLINE using search terms pertinent to cyanobacteria and cyanotoxins found in New Zealand,[5] along with terms to identify emerging monitoring and surveillance methods (Table 1).

Table 1: Literature review search terms and keywords

Concept 1: Water Sources	Concept 2: Terms adjacent to "water"	Concept 3: Cyanobacteria and cyanotoxins	Concept 4: Detection, screening, and monitoring
river*	surface	algal bloom	earl*
dam*	source*	blue-green algae	initial
lake*	ground	anatoxin*	primary
pond*	recreational	cyanobacter*	first
estuar*	drinking	cyanotox*	preliminary
stream*	body	cylindrosperm*	warn*
waterbod*	bodies	deoxy-cylindrosperm*	monitor*
ditch*	suppl*	deoxycylindrosperm*	test*
canal*	catchment*	dolichosperm*	sample*
drinking-water	potable	microcysti*	manage*
freshwater	reservoir*	nodulari*	measure*
	fresh	nostoc*	screen*
		oscillator*	scan*
		planktothri*	detect*
		raphidiops*	surveil*
		saxitoxi*	analys*
		scytonem*	analyz*
			evaluat*
			assess*

* = Used to indicate a wildcard to truncate the search term.

The search was limited to texts written in the English language published between 2014 and 2024 to select for emerging methods. The search strategy described in Table 1 yielded 23 results. Excluded texts did not describe methods pertaining to cyanobacteria and cyanotoxin monitoring, surveillance, or testing methods. Eight publications relevant to this review were retained for final analysis. Methods identified through the literature search, along with Analogous monitoring and surveillance methods available in New Zealand are described in Table 2.

Results

Emerging technologies pertaining to the monitoring and surveillance of cyanobacteria and cyanotoxins can be summarised into four major monitoring categories: synoptic, routine, passive, and predictive (Table 2). All methods aim to make monitoring more accessible than current conventional methods. Synoptic monitoring can be characterised by surveying and obtaining data for large areas or whole bodies of water.[6–8] While advances have been made in the use of satellite technology for cyanobacteria monitoring purposes,[7] there may be limitations in its use as the technology was not constructed for water-based studies. More localised methods of synoptic monitoring can be conducted via unmanned aerial systems with a high degree of accuracy.[6,9]

Emerging routine microcystin-LR monitoring strategies privilege low-to-moderate-cost rapid[10] or on-site methods.[11] Methods described in Table 2 have suitable ranges of detection, with lower limits of detection being several-fold under 1 µg/L[10,11], however are limited by their shelf life[10] and methods of storage.[11] A similar rapid testing method for algal toxins produced by Gold Standard Diagnostics available in New Zealand has the ability to detect a range of algal toxins and is not limited by storage conditions.[12] Passive monitoring strategies have the advantage of being able to integrate into existing drinking water infrastructure for long-term monitoring.[13] Passive samplers have good sensitivity and there are options to monitor for both microcystins[13] and anatoxins.[2] Predictive monitoring is emerging as a way to establish early warning systems based on existing water quality data.[14] The scope of predictive modelling is limited in its use but there are promising projects that are incorporating machine learning to improve predictive capabilities.[15]

Results table:

Table 2: Literature review data extraction

Title	Monitoring strategy - Stage of monitoring	Description of strategy	Accuracy/sensitivity	Time to results	Limitations	Cost	Similar methods currently available or described in New Zealand
Effective aerial monitoring of cyanobacterial harmful algal blooms is dependent on understanding cellular migration.[6]	Aerial survey – Synoptic.	A case study in using a small unmanned aerial system (octo-rotor, DJI Phantom 2) with a consumer grade camera (GoPro 3+, GoPro 4, Sony ILCE-6000) to conduct surveys over bodies of water covering up to 1 km^2 per survey to monitor cyanobacterial harmful algal blooms (CHABs).	The average accuracy of cyanobacteria detection per aerial survey was 86%.	Aerial survey to results was approximately 2 hours.	Environmental conditions can affect the distribution of CHABs. Calm conditions with minimal wind are optimal as wind can disperse or even completely move the location of a CHAB.	Low cost - initial set up of small unmanned aerial system plus consumer grade camera; image analysis.	The use of drones for the monitoring of benthic cyanobacteria in New Zealand has been described by Dr. Mark Heath[9].
Monitoring algal blooms in drinking water reservoirs using the Landsat 8 Operational Land Imager[7]	Satellite remote sensing – Synoptic.	A case study and validation of the use of spectral data from the Landsat-8 Operational Land Imager (OLI) to estimate chlorophyll-a concentrations in bodies of water by using a reflectance-based algorithm.	A spectral algorithm was validated through this research to predict the concentration of chlorophyll-a in bodies of water.	Data analysis time.	The OLI is designed to carry out land-based studies rather than water-based studies and is not fitted out with the spectral bands needed for water-based atmospheric correction algorithms.	Low cost - data analysis cost.	The University of Waikato is running the Eye on Lakes: National Monitoring of Cyanobacterial Blooms project which is investigating the use of satellite surveillance and monitoring[16].
Bloom-forming toxic cyanobacterium *microcystis*: Quantification and monitoring with a high-frequency echosounder.[8]	Acoustic technology – Synoptic.	An evaluation of the use of a high-frequency scientific ecosounder as a method for scanning bodies of water for gas-bearing *microcystis*. The ecosounder was evaluated by obtaining data for *microcystis* biomass (B) and the ratio between the volume backscattering coefficient (S_v) and *microcystis* biovolume proxy *microcystis*-bound chlorophyll-a (Chl a_{Micro}).	Increases in *microcystis* biomass (B) and the ratio between the volume backscattering coefficient (S_v) and *microcystis* biovolume proxy *microcystis*-bound chlorophyll-a (Chl a_{Micro}) was identified as an indication of the accumulation of *microcystis* colonies.	Ecosounder scanning time.	A specific footprint ratio between the volume backscattering coefficient (S_v) and *microcystis* biovolume proxy *microcystis*-bound chlorophyll a (Chl a_{Micro}) was not determined.	Low cost - initial cost of ecosounder; scanning time; analysis cost.	On-site synoptic monitoring has been described in New Zealand by Echenique-Subiabre et al.[17] (BenthoTorch for benthic cyanobacteria) and Thomson-Laing et al.[4] (CyanoFluor for cyanobacteria).
Cost-effective screen-printed carbon electrode biosensors for rapid detection of microcystin-LR in surface waters for early warning of harmful algal blooms.[10]	Biochemical – Routine.	The fabrication and characterization of a screen-printed carbon electrode (SPCE) biosensor for the detection of microcystin-LR in water samples. The SPCE biosensor was coated in Anti-MC-LR/MC-LR/Cysteamine.	The SPCE biosensor was shown to have a working range of microcystin-LR detection for concentrations between 0.1 µg /L and 100 µg /L.	90 minutes lab processing and analysis time.	The fabricated SPCE biosensor has a shelf life of about 12 weeks.	Moderate cost - SPCE biosensor cost; lab processing and analysis cost.	Similar results can be obtained using Gold Standard Diagnostics ABRAXIS® Test Strips which have a test range of 0.2 - 10.0 ppb depending on the algal toxin (anatoxin-a, cylindrospermopsin, microcystins/nodularins, saxitoxin) being tested[12].
Open surface droplet microfluidic magnetosensor for microcystin-LR monitoring in reservoir.[11]	Biochemical – Routine.	The construction and validation of a smartphone-based fluorimetric magnetosensor (SFMS) to quantify microcystin-LR in water samples. The constructed apparatus can produce rapid results *in situ* at the water sampling site.	The SFMS has a microcystin-LR detection range of 10^{-4} µg/L to 100 µg/L.	15 minute incubation.	The integrated biosensor must remain in cold storage when not in use and reduces in response from 95.6% after 3 weeks of storage down to 80% after 8 weeks of storage.	Low cost - initial build of the SFMS; test reagents and biosensor cost.	Similar results can be obtained using Gold Standard Diagnostics ABRAXIS® Test Strips which have a test range of 0.2 - 10.0 ppb depending on the algal toxin (anatoxin-a, cylindrospermopsin, microcystins/nodularins, saxitoxin) being tested[12].

Title	Monitoring strategy - Stage of monitoring	Description of strategy	Accuracy/sensitivity	Time to results	Limitations	Cost	Similar methods currently available or described in New Zealand
Multimedia distributions and the fate of microcystins from freshwater discharge in the Geum river estuary, South Korea: Applicability of POCIS for monitoring of microalgal biotoxins.[18]	Biochemical – Passive.	An evaluation of the use of passive sampling device, polar organic chemical integrative sampler (POCIS), for the monitoring of microcystins in freshwater discharge. Samplers were deployed for 7-day periods at multiple sites in an estuary dam. Samplers were analysed for microcystin content using high-performance liquid chromatography with tandem mass spectrometry (HPLC-MS/MS).	The time-weighted average concentration of microcystins captured by the POCIS did not reflect the microcystin concentration in water samples obtained from the same sampling region.	7 day sampler deployment plus lab processing and analysis time.	The POCIS system has limited utility for monitoring as it is not able to capture the concentration of microcystins in particulate form.	Moderate cost - Sampler construction; lab processing and analysis cost.	Passive monitoring of *Microcoleus autumnalis*-produced anatoxins via solid phase adsorption tracking technology (SPATT) in New Zealand has been described by Wood et al[2].
Application of passive sampling for sensitive time-integrative monitoring of cyanobacterial toxins microcystins in drinking water treatment plants.[13]	Biochemical – Passive.	A case study in using passive sampling in the monitoring of microcystins within the context of drinking water treatment plants. Absorption-based passive samplers were constructed and deployed for 14-day periods in drinking water reservoirs. Samplers were analysed for microcystins content through high-performance liquid chromatography (HPLC) and liquid chromatography with tandem mass spectrometry (LC-MS/MS).	Passive samplers were shown to capture microcystins with a sensitivity of <1 ng/L in combination with LC-MS/MS.	14-day sampler deployment plus lab processing and analysis time.	None identified in the literature.	Moderate cost - Sampler construction; lab processing and analysis cost.	Passive monitoring of *Microcoleus autumnalis*-produced anatoxins via solid phase adsorption tracking technology (SPATT) in New Zealand has been described by Wood et al[2].
Early warning of limit-exceeding concentrations of cyanobacteria and cyanotoxins in drinking water reservoirs by inferential modelling.[14]	Inferential modelling – Predictive.	A case study in using inferential modelling built through the hybrid evolutionary algorithm (HEA) to predict concentrations of cyanobacteria and cyanotoxins. The models utilize *in situ* water quality data (e.g. temperature, turbidity, pH, dissolved oxygen, electrical conductivity) obtained from YSI sondes.	Validated models were able to provide short-term forecasts. Models created for *Dolicospermum circinale* were able to provide up to a 10-days-ahead forecast, whereas models for *Cylindrospermopsis raciborskii* were able to provide up to a 30-days-ahead forecast.	Data analysis time.	Scope of modelling is limited as this case study only validated models for *Dolicospermum circinale* and *Cylindrospermopsis raciborskii*.	Moderate cost - Research and development cost to expand scope of models; *in situ* water monitoring infrastructure cost; data analysis cost.	The use of machine learning to build a predictive model which can inform understanding of cyanobacteria blooms has been described by Graffeuille et al[15].

Conclusions

The risk of cyanobacterial blooms will continue to increase, posing an active risk to New Zealand water supplies.[1–5] Consequently, monitoring and surveillance for these increased risks must be updated with emerging methods and technologies to ensure the quality and safety of water supplies. The future of cyanobacteria and cyanotoxin surveillance and monitoring in New Zealand has the potential to be multifaceted and synergistic with a range of emerging technologies. While monitoring bodies of water for indications of planktonic or benthic cyanobacteria can be challenging, inaccessible, and costly, there is a push to innovate how monitoring is conducted to identify the risk of cyanobacterial blooms early and accurately.

Through this review emerging monitoring technologies were identified covering four major categories: synoptic; routine; passive; and predictive monitoring (see Table 2). This range of methods supports current efforts to conduct on-site water sampling to create a more comprehensive assessment of risk. Routine on-site water sampling can be challenging and there is a need to support water suppliers in implementing alternative methods to flag if on-site water sampling is needed. Synoptic monitoring via satellite remote sensing[7] and aerial survey[6] both offer the opportunity to scan large areas quickly, and at a low cost, to identify if further water sampling is required. The use of drones is being trialled for this purpose in New Zealand by Dr. Mark Heath.[9] Passive sampling integrated into drinking water treatment plants has the ability to provide long-term monitoring of toxin levels in the water supply.[2,13] This could be a critical integration into the New Zealand water supply infrastructure to flag water quality concerns and identify when further on-site sampling by water suppliers is required. On-site sampling can also be supported by using routine rapid methods that do not require lab processing.[10–12] While rapid methods are not as accurate as standard laboratory testing, they can highlight if there is a risk present that requires further assessment. While not in a ready-to-use state, predictive modelling that uses ‘in situ’ water data to provide cyanobacterial bloom forecasts[14,15] may eventually become a useful early warning system.

The emerging methods identified in this review are possible to replicate in New Zealand, with most having similar methods already being researched and trialled in this country. Most emerging methods in the literature focused on techniques identifying planktonic cyanobacterial toxins, however, there is a gap pertaining to the monitoring of benthic cyanobacteria. The future of monitoring cyanobacterial blooms in New Zealand will need to be an integrated and multifaceted program similar to the program proposed by The State of California’s Surface Water Ambient Monitoring Program (SWAMP) and the Southern California Costal Water Research Project (SCCWRP)[19,20] (see Appendix 1).

Appendix 1: Case Study of the Southern California Costal Water Research Project

The State of California's Surface Water Ambient Monitoring Program (SWAMP) and the Southern California Costal Water Research Project (SCCWRP) collaboratively produced the California Water Boards' *Framework and Strategy for Freshwater Harmful Algal Bloom Monitoring* (monitoring strategy) as a conceptual document to collate all possible monitoring options for 'freshwater and estuarine harmful algal blooms' (FHAB).[19] The report recommends six actions for building an effective FHAB monitoring program[20]:

1. Develop and implement an FHAB partner program;
2. Strengthen remote sensing program;
3. Implement field surveys to assess FHAB status focused on human health;
4. Conduct focused assessments of FHAB drivers;
5. Synergize incident response with ambient monitoring; and
6. Work to integrate FHAB monitoring elements into all relevant water boards' programs, permits, and policies.

The proposed program would create a multifaceted approach to FHAB monitoring that implements methods of detection ranging in scope from satellite surveillance to citizen-submitted observations in addition to standard water quality sampling.[20] This system would also be integrated into existing State infrastructures to ensure it is cost effective and sustainable.[20]

Abbreviations

Term	**Abbreviation**
Cyanobacterial harmful algal blooms	CHABs
Freshwater and Estuarine Harmful Algal Bloom	FHAB
High-performance liquid chromatography (HPLC)	HPLC
High-performance liquid chromatography with tandem mass spectrometry	HPLC-MS/MS
Hybrid evolutionary algorithm	HEA
Liquid chromatography with tandem mass spectrometry	LC-MS/MS
Microcystis biomass	B
Microcystis-bound chlorophyll-a	$\text{Chl a}_{\text{Micro}}$
Operational Land Imager	OLI
Parts per billion	ppb
Polar organic chemical integrative sampler	POCIS
Screen-printed carbon electrode	SPCE
Smartphone-based fluorimetric magnetosensor	SFMS
Solid phase adsorption tracking technology	SPATT
Southern California Costal Water Research Project	SCCWRP
Surface Water Ambient Monitoring Program	SWAMP
Volume backscattering coefficient	S_v

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