Cyanobacterial Blooms and Recreational Water Quality Monitoring in Canada

Ron Zurawell and Jennifer Graydon

History

For provincial and territorial governments and health agencies across Canada, the past decade has been a period of significant development and implementation of recreational water quality monitoring and surveillance programs. By area, Canada is the second largest country in the world at 9,984,670 Km^2 (3,855,100 mi^2) of which nearly ten (10) percent is covered by freshwaters. The more than two million Canadian lakes, reservoirs, and rivers span 20 ecozones, temperate, subarctic, and arctic climates, and represent a wide range in size, hydrology, water quality, and biological diversity. This great diversity in the quality and use of surface water resources along with massive differences in population density, creates significant challenges to protecting human health (Giddings et al. 2012).

Cyanobacterial blooms and toxic events are not new phenomena in Canada. Historically, they have been prominent across the prairie provinces of Alberta, Saskatchewan, and Manitoba whose ecozones are largely dominated by prairies in the south and boreal plains in the north (Figure 1a and 1b). Phosphorus-rich sedimentary bedrock predominates within these landscapes and in the transitional Parkland sub-region separating them and as a result, eutrophic lakes are common. These lakes often have shallow, polymictic basins that are highly susceptible to internal (sediment) phosphorus loading, which sustains significant growth of cyanobacteria (Figure 1b). In many cases, the nutrient-rich conditions are exacerbated by long water residence times exceeding 50 or even 100 years and for some, by anthropogenic land disturbance primarily relating to agricultural development and practices.

Figure 1. Cyanobacterial blooms western Canada: (a) Aphanizomenon bloom, Baptiste Lake, AB; (b) decaying bloom, Steele Lake, AB. Photo: R. Zurawell.

Early studies on cyanobacterial toxins began in Canada following investigations of animal poisonings on the prairies (ca. 1950s) and led to the discovery of both microcystin (originally called "fast-death factor") and another toxin originally coined "very fast-death factor" that was later named anatoxin-*a* (previously reviewed by Kotak and Zurawell, LRM 2007). By the late 1990s, growing concerns over the seasonal prevalence of microcystin in many of Canada's drinking water supplies led to the formation of The Federal-Provincial-Territorial (FPT) Committee on Drinking Water and resulted in the establishment of a national drinking water guideline (maximum acceptable concentration [MAC] of 1.5 µg/L) for microcystin-LR by Health Canada in 2002.

Increasing public awareness of cyanobacterial blooms and high-profile toxic bloom events emerging in other parts of Canada experiencing cultural eutrophication (including parts of the Great Lakes, Lake of the Woods, and impacted recreational lakes in Quebec), led to the formation of another FPT Working Group, this time focused on recreational water quality and risks to human health (Health Canada 2012, 2022). Following a review of approaches in use by other jurisdictions worldwide, the FTP concluded that recreational water quality guidelines for not only cyanobacterial toxins (i.e., microcystins), but cyanobacteria cells (i.e., cell count/density) were warranted. Guidelines were initially established (Health Canada 2012) for total microcystins (20 µg/L) and total cyanobacterial cell density (100,000 cells/mL). While the microcystin guideline provides a measure of protection against this family of toxins, the total cyanobacterial cell density guideline is intended to be used as a general indicator of the potential for bloom development; and as such, it is protective against exposure to both large amounts of cyanobacterial material and other toxins (besides microcystins) that may also be present.

Recently, the approach used to calculate the recreational guidelines was aligned with that used for drinking water. This resulted in the microcystin and cyanobacteria cell density guidelines being revised (lowered) to 10 µg/L and 50,000 cells/mL, respectively (Health Canada 2017). In addition, new guidelines for total cyanobacterial biovolume (4.5 mm^3/L) and total chlorophyll-*a* (33 µg/L) have been recently approved (Health Canada 2022). These two indicators were included to offer additional approaches to understanding potential bloom toxicity. While chlorophyll-*a* is relatively easy to measure (straightforward analytical methods and availability of hand-held meters), it is not unique to cyanobacteria, so it is most useful when used for early bloom detection along with additional methods of species identification (e.g., visual and microscopic assessment). Availability of multiple indicators of potential bloom toxicity and a microcystin-specific guideline provides flexibility to Canada's provincial/territorial authorities developing risk management plans appropriate to their respective jurisdictions.

Practical approaches for application of these guidelines as part of a recreational water quality risk management plan for cyanobacteria, including advice on sampling, analytical methods and risk communication have been recommended by Health Canada (2022). A generalized recreational health risk monitoring procedure for blooms in Canada (Figure 2, Health Canada 2022) involves: visual identification of a potential bloom (e.g., Step 1, Figure 2; by a recreational site operator, public health inspector or community representative); sample collection along recreational beach areas and assessment of measured indicator(s), and confirmation of bloom presence (e.g., Step 3, Figure 2); comparison of measured indicator values against Canadian Recreational Water Quality Guidelines (e.g., Step 4, Figure 2); continued monitoring (e.g., Step 5, Figure 2); issuance and updating of public health advisories, messaging and signage to alert users (e.g., Step 7, Figure 2; Figure 3a); and rescinding of alerts when water quality is deemed satisfactory once again (e.g., Step 6, Figure 2).

Monitoring of blooms in recreational waterbodies across Canada

While the federal guideline values and supporting guidance provide recommendations for managing recreational risks from cyanobacterial blooms and their toxins, it is the responsibility of individual jurisdictions (Provinces and Territories) across Canada to develop management strategies specific and appropriate to their own unique context as waterbody characteristics (e.g., degree of eutrophication, bloom and toxin prevalence) and use (e.g., seasonality, primary vs. secondary contact activities), and other factors will determine the extent of bloom monitoring and management programs. As a result, there is no consensus on a single approach (Table 1).

Across the western prairie provinces of Alberta (AB), Saskatchewan (SK), and Manitoba (MB) and the east-central Province of Quebec (QC), proactive, routine monitoring (i.e., at selected sites on a recurring interval) is conducted for blooms at public beaches. Additionally, AB and SK have implemented the use of risk assessment-based tools that include historical bloom information and indicator datasets, beach usage and waterbody trophic status, to inform site selection before each annual monitoring season. MB mostly monitors the same sites each year with some sites being added and removed as necessary, while other Provinces have not implemented proactive monitoring (Gasman 2021). However, most provinces, including AB, SK MB, Ontario (ON), New Brunswick (NB), and Newfoundland/Labrador (NL), conduct monitoring at public beaches in response to complaints about blooms (Table 1). Nova Scotia (NS) and QC do not conduct response monitoring, while Prince Edward Island (PEI), who have yet to receive complaints of blooms, will respond should an event occur. Most provinces issue cyanobacterial bloom advisories or alerts in response to presence of blooms in recreational waters. However, both QC and NL do not issue public notices based on environmental monitoring, but rather share results with affected municipal jurisdictions or complainants (Table 1).

Visual monitoring for blooms is the most employed guideline/indicator because of the accessibility and simplicity of this approach and is used by all jurisdictions with the exception of PEI. In British Columbia, initial screening for suspected blooms includes visual checks for bloom formation and water testing to determine levels of nutrients (e.g., total nitrogen and total phosphorus) and/or low N:P ratios (< 23), which can be indicative of conditions conducive to bloom formation. Portable field kits are then used to test for microcystins near recreational beaches and if concentrations exceed the guideline, additional sampling and confirmatory laboratory testing is performed (BC 2018). Specific testing for microcystins also occurs in AB, SK, MB, ON, and NL and is supported using various analytical methods including liquid chromatography linked mass spectrometry (LC-MS/MS; ON), enzyme-linked immunosorbent assay (ELISA; SK and ON) and the protein phosphatase inhibition assay (PPIA; AB) (Table 2). Cyanobacterial cell counts and/or species determination are used in AB, MB, ON and NL. However, no jurisdictions have adopted the newly recommended cyanobacterial cell biovolume guideline to date, while only NL has implemented the new chlorophyll-*a* guideline (Table 2).

Currently, no jurisdictions conduct routine monitoring for other cyanobacterial toxins. However, AB will measure anatoxins and cylindrospermopsin in a unified analytical suite to support investigations of animal deaths/illnesses suspected from cyanotoxin poisoning using liquid chromatography-high resolution mass spectrometry (LC-HRMS). Other

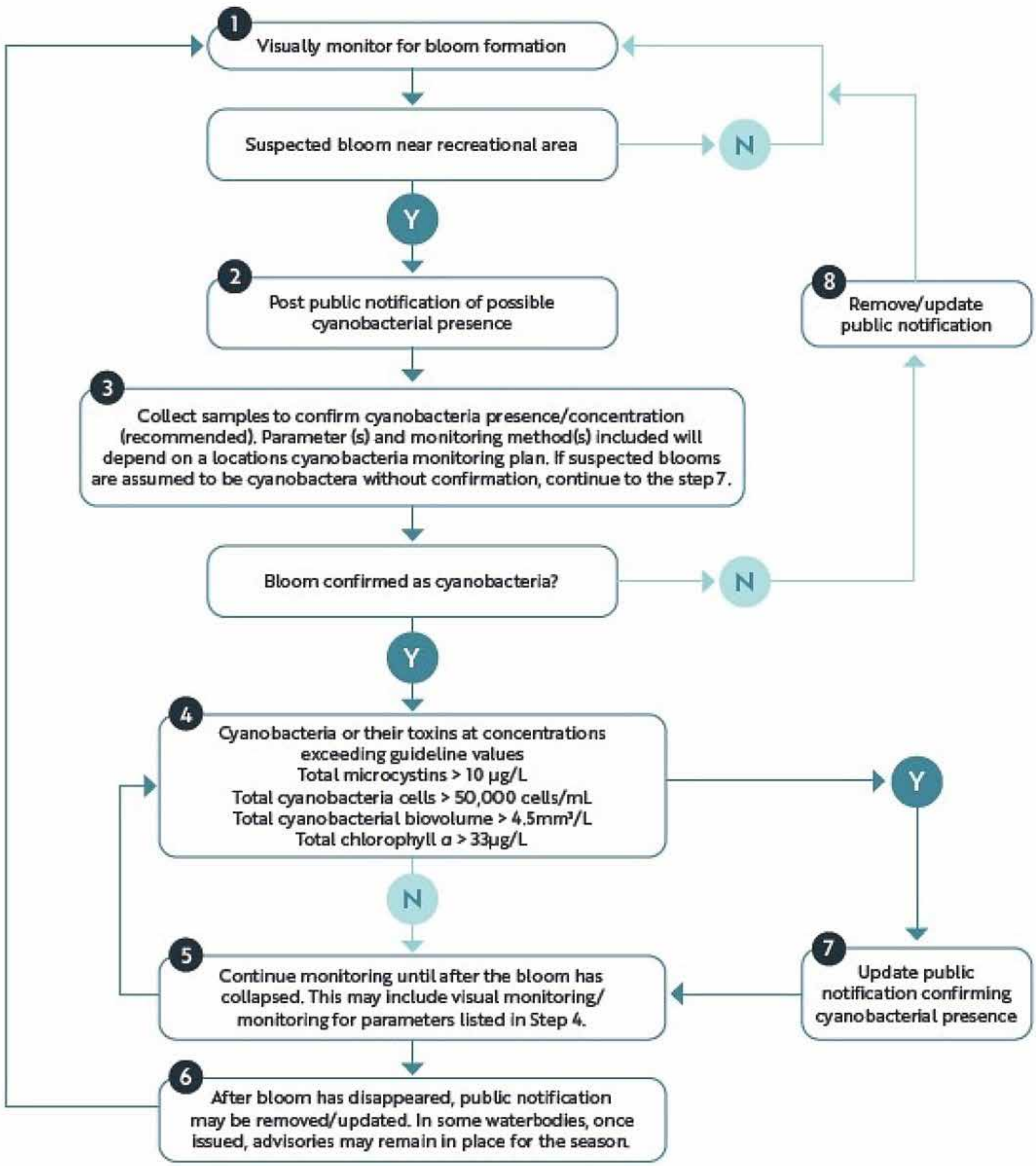

Figure 2. Flow chart for monitoring planktonic cyanobacterial and their toxins (Health Canada 2022).

approaches to bloom monitoring are also being developed and used in some provinces. For example, AB has been developing a cell-based toxicity (cytotoxicity) test for saxitoxin (Table 2) and is investigating the use of satellite remote sensing for chlorophyll-*a* and other pigments to forecast blooms (Figure 3b), while NL is using drone surveillance and measurements of the cyanobacteria-specific pigment, phycocyanin.

A unique approach to recreational water monitoring

In Alberta, recreational water monitoring is carried out to assess the exposure risk of lake users to cyanobacterial blooms and fecal contamination according to guidance

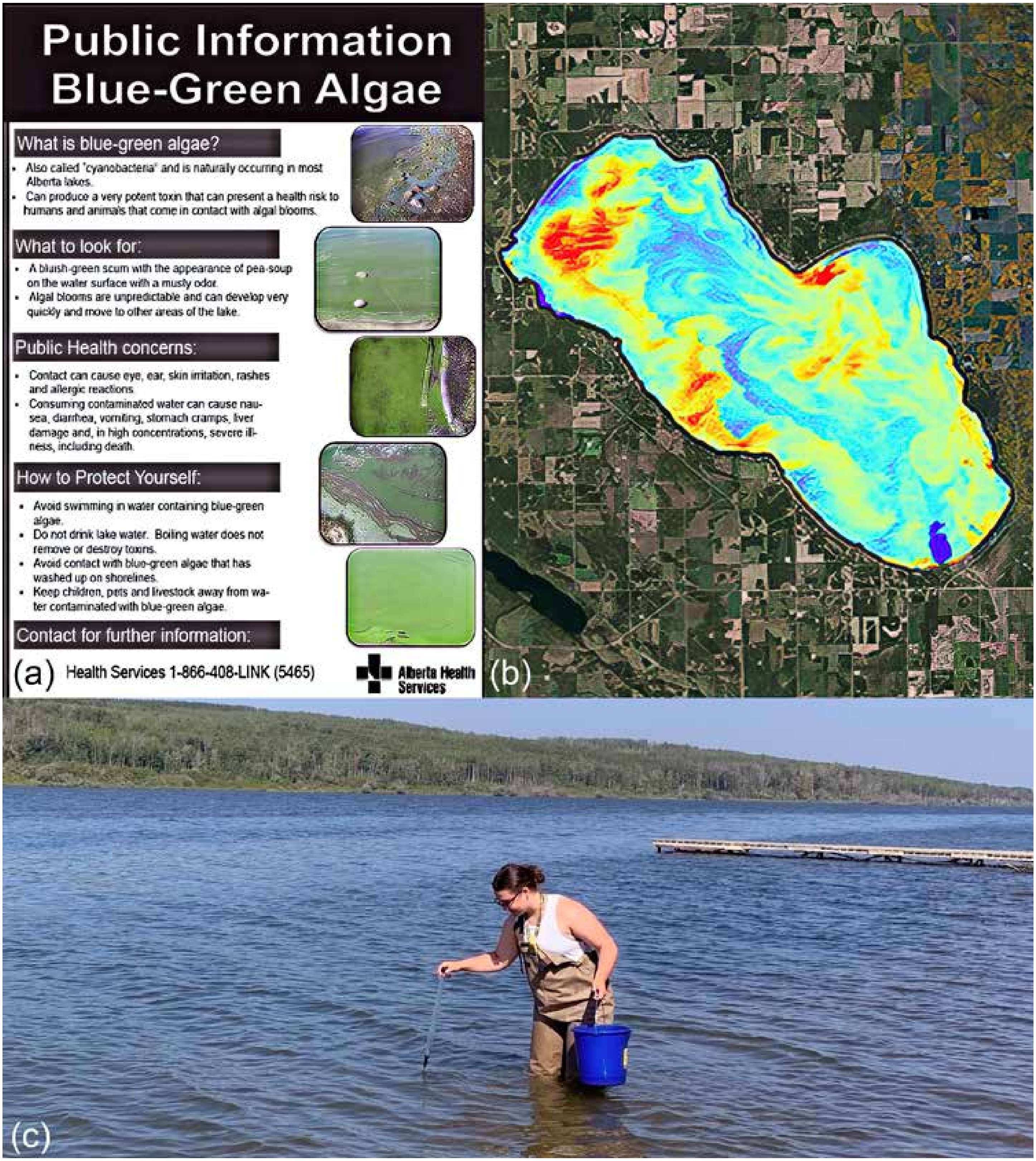

*Figure 3. (a) Public health risk information signage in Alberta (Alberta Health Services); (b) satellite-based remote sensing for chlorophyll-*a *pigment to track and forecast blooms in Pigeon Lake, AB (R. Vinebrooke, University of Alberta); (c) ALMS Recreational Water Technician, Sarah Klimchuk, performing bloom indicator sampling.* Photo: ALMS.

Table 1. Implementation of Provincial Cyanobacteria Recreational Water Monitoring.									
	AB	SK	MB	ON	QC	NB	NS	PEI	NL
Proactive routine monitoring (e.g., selected sites on a reoccurring interval) at public beaches	Yes: ~40 sites, weekly, May-Aug	Yes: microcystin at select areas; freq. depends on risk factors[a]	Yes: 60 sites	No	Yes[b]	No	No	No	No
Response monitoring in response to bloom complaints	Yes	Yes	Yes	Yes	No[c]	Yes	No	No[e]	Yes
Issuance of public advisories	Yes	Yes: microcystin >10 μg/L	Yes	Yes	Yes/No[d]	Yes: based on confirmed presence of cyanobacteria (no toxin analysis)	Yes	Yes	No[f]

[a] Ministry of Health monitors designated public swimming areas only.

[b] No provincial monitoring program, only regular visual inspections by bathing site managers (prohibit bathing in areas of beaches affected by blooms corresponding to more than 100,000 cells.

[c] There is no response monitoring program except in lakes with designated criteria, including: Canada/U.S. transboundary lakes (ex. Memphrémagog and Missisquoi); some municipal drinking water sources; in situations requested by health agencies (ex. swimming competition); and in lakes experiencing extreme blooms.

[d] No post-monitoring public notifications – cell count results are transmitted to concerned territories (ex. Municipalities) and directly to individuals filing the complaint.

[e] There have never been bloom complaints to date.

[f] Newfoundland and Labrador Environment and Climate Change Water Resources Management Division will test sites and provide results to municipal governments who then issue notices to the public.

Information on approaches to recreational bloom monitoring presented in Tables 1 and 2 was obtained by direct polling from representatives from AB, SK, QC, NB, PEI, and NL. Information for BC, MB, ON, and NS was obtained from publicly available information online (BC 2018) and from a recently published pan-Canadian comparison of cyanobacterial bloom management policies, programs, and practices (Gasman 2021).

Table 2. Implementation of Provincial Cyanobacteria Recreational Water Guidelines/Indicators.									
	AB	SK	MB	ON	QC	NB	NS	PEI	NL
Visual	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Microcystin	Yes: PPIA	Yes: ELISA[b]	Yes	Yes: ELISA, LC-(ESI) MS/MS	No	No	No	No	Yes[c]
Cell count/species	Yes	No	Yes	Yes	No	No	No	No	Yes
Cell biovolume	No	No	No	No	No	No	No	No	No
Chlorophyll-*a*	No	No	No	No	No	No	No	No	Yes
Other Toxins	Yes[a]	No	No	No	No	No	No	No	No
Other metric/indicator	Satellite, cytotoxicity-based test for saxitoxin	No	No	No	No	Taxon ID	No	No	Phycocyanin drone surveillance

[a] Anatoxin-*a*, homo-anatoxin-*a*, dihydro-anatoxin-*a*, cylindrospermopsin (LC-HRMS).

[b] Provincial Lab.

[c] Testing occurs at York-Durham Regional Environmental Laboratory.

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provided in the Alberta Safe Beach Protocol (https://open.alberta.ca/publications/9781460145395). Monitoring at priority beach locations across Alberta is coordinated by Alberta Health (AH, Provincial Ministry of Health) and Alberta Health Services (AHS, Provincial Agency with responsibility for operational aspects of provincial health care and public health) and occurs annually from late May to early September. While recreational site (beach) owner/operators are the primary target groups, logistical and resource limitations sometimes preclude their routine participation in the annual monitoring program. To fill these gaps, AH funds the Alberta Lake Management Society (ALMS), to hire seasonal Recreational Water Technicians that coordinate a network of lake stewards (including Watershed Stewardship Groups, Watershed Planning and Advisory Councils and individual volunteers) to sample priority beaches throughout the province for public health targets (Figure 3c).

With their extensive history of fieldwork on lakes throughout Alberta, ALMS is uniquely qualified to support the establishment of a long-term, sustainable provincial monitoring network. For example, throughout the 2020, 2021, and 2022 recreational water seasons, ALMS coordinated the collection of 127, 80 and 137 samples for analysis of cyanobacterial bloom indicators from 52, 30, and 45 recreational beach locations, respectively. ALMS participates in steering committee and seasonal work planning activities with AH, AHS, and program partner analytical laboratories for the implementation of the Alberta Safe Beach Protocol. The Society helps establish processes/protocols for communication with beach monitors and educates beach owners/operators and other sample collectors through hands-on and webinar training sessions. In addition, ALMS supports completion of site assessments for the evaluation of public health hazards at recreational beaches, provides technical support for bloom complaint investigations by AHS Public Health Inspectors, conducts follow-up sampling at locations with active public health advisories and collaborates with Academic and Government researchers on scientific studies related to recreational water management and public health.

Recent activities include processing pelagic and beach water samples using Quantitative Polymerase Chain Reaction (qPCR) technology to support development of novel DNA-based public health targets (indicators) and validation of satellite imagery methods for detecting harmful cyanobacterial blooms.

Future trends and challenges in protecting Canada's recreational water quality

It is clear Canada's landscapes and water resources are not immune to impacts of a changing climate that are being documented globally including rising temperatures and atmospheric CO_2 levels, altered hydrologic patterns and eutrophication (reviewed by Visser et al. 2016). On the prairies, recent warmer-than-average winters and lower annual snowfall has seen a rise in the occurrence of toxic *Planktothrix* blooms both during the fall freeze-up period and under ice in late winter (Figure 4). Low spring seasonal precipitation combined with warmer-than average temperatures is causing earlier onset of cyanobacterial blooms, greater bloom intensity and a protracted growing/bloom season in eutrophic lakes – and increasing the occurrence of wildfires, which could exacerbate nutrient loading to surface waters (Carignan et al. 2000). These

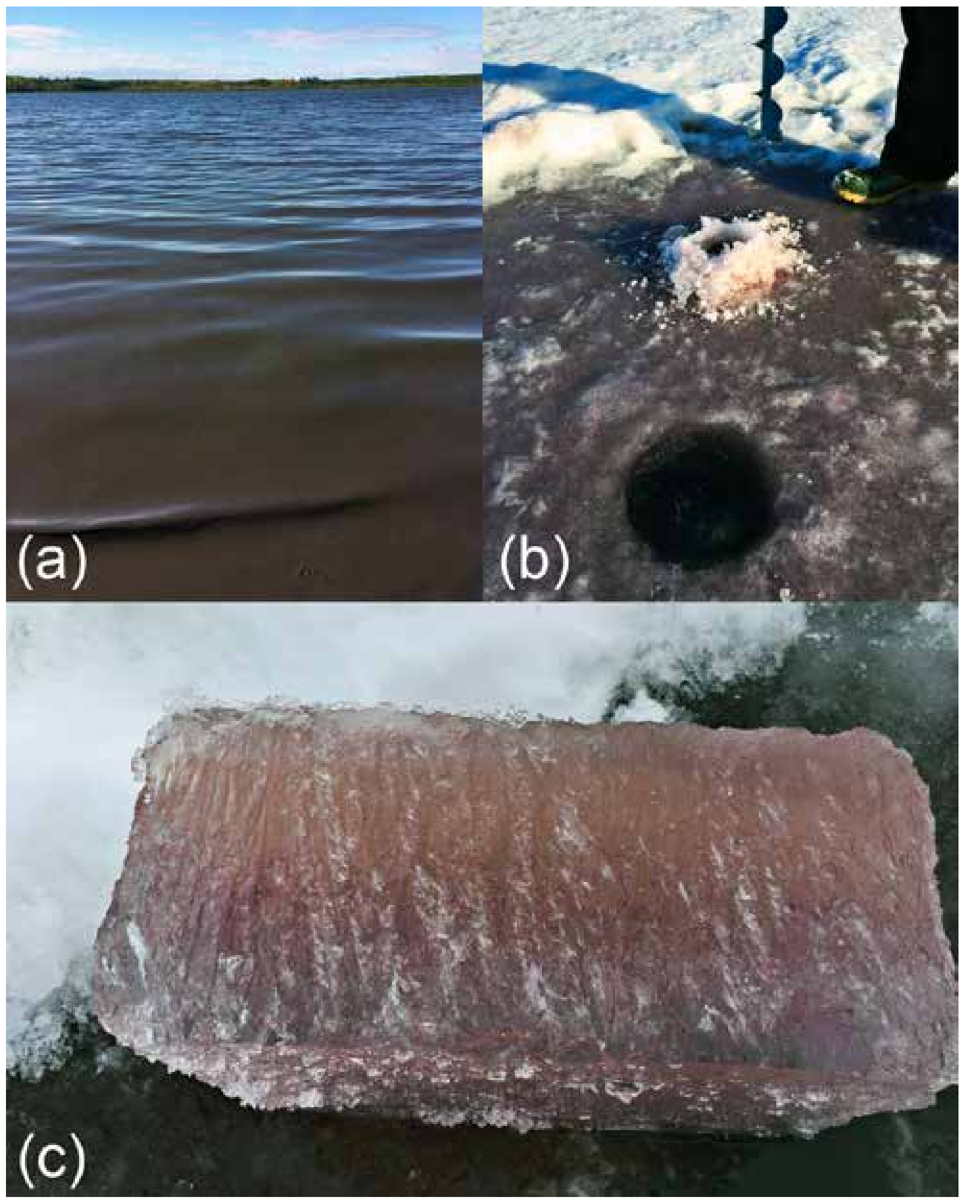

Figure 4. Planktothrix bloom, Matchayaw Lake, AB: (a) Bloom onset, September (photo: J. Fearnehough); (b&c) bloom captured in ice during fall freeze, November. Photo: D. Gullion.

conditions are also impacting mesotrophic waters across the country with blooms periodically occurring in lakes and now evidence suggesting that low, clear river water conditions are leading to blooms of potentially toxic benthic cyanobacteria in oligotrophic foothill streams in the west, to large rivers in eastern Canada that are being linked to pet mortalities and human illness (McCarron et al. 2023).

These events send a clear signal that more research is required to understand what future impacts can be expected and how best to counter them. Responsible authorities need to continue adapting monitoring strategies to protect recreational users of Canada's surface waters. Another FPT committee, led by the Canadian Council of Ministers of the Environment (CCME), is currently developing guidance for managing harmful cyanobacterial algal blooms and benthic mats in inland waters, in a changing climate. Additional monitoring and research will likely not be enough as the active management of lakes in Canada – that includes in-lake treatment options to control nutrients and harmful algal blooms – is largely in its infancy as our environmental laws largely preclude modification of natural aquatic ecosystems.

References

British Columbia. 2018. Decision protocols for cyanobacterial toxins in B.C. drinking water and recreational water. Health Protection Branch. August 2018. https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-quality/recreational-water-quality

Carignan, R., P. D'Arcy and S. Lamontagne. 2000. Comparative impacts of fire and forest harvesting on water quality in Boreal Shield lakes. *Canadian Journal of Fisheries and Aquatic Sciences, 57*(S2), pp.105-117.

Gasman, R. 2021. A Pan-Canadian Comparison of Cyanobacteria Bloom Management Policies, Programs, and Practices. Master of Arts Thesis. Geography. York University. Toronto, Ontario.

Giddings, M., R. Aranda-Rodriguez, G. Yasvinski, S.B. Watson and R. Zurawell. 2012. CANADA: Cyanobacterial Toxins: Drinking and Recreational Water Quality Guidelines. In: Current Approaches to Cyanotoxin Risk Assessment, Risk Management and Regulations in Different Countries, 2nd ed. I Chorus Ed. Federal Environment Agency (Umweltbundesamt), pp. 29-39.

Health Canada. 2012. Guidelines for Canadian Recreational Water Quality. Ottawa, Ontario. https://www.canada.ca/content/dam/canada/health-canada/migration/healthy-canadians/publications/healthy-living-vie-saine/water-recreational-recreative-eau/alt/pdf/water-recreational-recreative-eau-eng.pdf.

———. 2017. Guidelines for Canadian drinking water quality: guideline technical document – cyanobacterial toxins. Ottawa, Ontario. https://publications.gc.ca/collections/collection_2018/sc-hc/H144-38-2017-eng.pdf.

———. 2022. Guidelines for Canadian recreational water quality: guideline technical document – cyanobacteria and their toxins. Ottawa, Ontario. https://www.canada.ca/content/dam/hc-sc/documents/services/publications/healthy-living/guidance-canadian-recreational-water-quality-cyanobacteria-toxins/water-quality-cyanobacteria-toxins-en.pdf

Kotak, B.G. and R.W. Zurawell. 2007. Cyanobacterial toxins in Canadian freshwaters: A review. *Lake and Reserv Manage*, *23*:109–122.

McCarron, P., C. Rafuse, S. Scott, J. Lawrence, M.R. Bruce, E. Douthwright, C. Murphy, M. Reith and D.G. Beach. 2023. Anatoxins from benthic cyanobacteria responsible for dog mortalities in New Brunswick, Canada. *Toxicon. 227*: 107086.

Visser P.M., J.M.H. Verspagen, G. Sandrini, L.J. Stal, H.C.P. Matthijs, T.W. Davis, H.W. Paerl and J. Huisman. 2016. How rising CO_2 and global warming may stimulate harmful cyanobacterial blooms. *Harmful Algae, 54*:145-159. doi: 10.1016/j.hal.2015.12.006. PMID: 28073473.

Ron Zurawell is an aquatic scientist with the government of Alberta (Alberta Environment and Protected Areas), where he manages provincial lentic monitoring and research and leads aquatic invasive species monitoring. He has a 30-year history researching and monitoring cyanobacterial blooms and was integral in the design and implementation of the Province's Recreational (Beach) Monitoring Program. Ron is a strong advocate of community-based monitoring and citizen science programs and is a past board member with the Alberta Lake Management Society and NALMS. He can be reached at: ron.zurawell@gov.ab.ca.

Jennifer Graydon is an environmental public health scientist with the government of Alberta (Alberta Health). She has 11 years of experience working on Alberta's recreational water quality monitoring program. Jennifer supports scientific research on cyanobacterial blooms including methods for detection using satellite imagery and molecular and cytotoxicity approaches. She has been involved with development and implementation of novel indicators of fecal contamination and Alberta's operational policies related to recreational water (Alberta Safe Beach Protocol). Jennifer can be reached at: jennifer.graydon@gov.ab.ca.

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