CITIZEN SCIENCE:
THEORY AND PRACTICE

Adopt a Lake: Successfully Tracking Harmful Cyanobacterial Blooms in Canadian Surface Waters Through Citizen Science

CASE STUDIES

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ABSTRACT

The proliferation of harmful waterborne cyanobacterial algal blooms, some of which can produce potent toxins, poses severe risks to environmental and human health. Academic and governmental monitoring efforts may be constrained by budget, time, and staff, and thus miss otherwise significant pollution events. Here, we report on the implementation of a citizen science project to track harmful cyanobacterial blooms in lakes and waterways across Canada. Through both crowdsourcing and crowdfunding, the Adopt a Lake (Adopt a Lake 2022) campaign aimed to document the potential presence of cyanobacteria and toxins with the assistance of participants, thus improving public awareness of the issue of water quality preservation. Using social media, participants were encouraged to participate in the initiative by collecting samples during a bloom from a nearby pond or by making a financial contribution to support the initiative. Adopt a Lake benefitted from the analytical platform of Algal Blooms Treatment, Risk Assessment, Predictions, and Prevention (ATRAPP), a research project focused on the prediction and management of harmful cyanobacterial blooms. The presence of cyanotoxins, which can confirm whether a lake has a toxic bloom, was determined through high-resolution mass spectrometry analyses. This paper presents an overview of the implementation of the Adopt a Lake initiative, the campaign's status, and the lessons learned, and it argues the importance of continual monitoring of cyanobacterial blooms.

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INTRODUCTION

Citizen science has garnered considerable interest in recent decades, with the advent of the global web, smartphones, and social media enabling rapid access and sharing of information. The advantages for the research community are immeasurable. They primarily involve harnessing the efforts of participants to collect extensive data that would otherwise be limited by personnel, time, and budget constraints (Chase and Levine 2016). Citizen science benefits participants in numerous ways, including educational advantages, the opportunity to contribute to scientifically valuable datasets, and global engagement in a well-designed research project. Citizen science can be as rewarding, if not more so, than securing a grant, as it provides the opportunity to build collaborative ties with new partners and financial sponsors, establish unexpected research connections, and engage with the community. Science-related projects crowdfunded through specific web platforms (e.g., Experiment.com, SciFund Challenge) or diverse online social media can be successful and popular (Vachelard et al. 2016). Citizen science projects may increasingly involve basic scientific training of volunteers, possibly through open courses (Toerpe 2013).

Traditionally, in citizen science, knowledge is presumed to flow from the scientist to the participants. However, valuable knowledge flows from participants through traditional or contextual knowledge, and it is up to the researchers to incorporate this valuable information into their studies (Alexander et al. 2021; Jollymore et al. 2017). Contextual knowledge can explain outliers that might otherwise be challenging for scientists.

Citizen science projects have gained momentum, particularly in ecology and natural earth sciences, with several notable examples. These initiatives involve contributions such as direct observations for bird species censuses, monitoring invasive species, and mapping the overwintering grounds of migratory species (Giovos et al. 2019; McCaffrey 2005; Ries and Oberhauser 2015). In some cases, participants are also motivated to process scientific data, such as Galaxy Zoo project, where amateur astronomers visually classify millions of galaxies (Lintott et al. 2016).

Environmental monitoring efforts harness the power of citizen participation in a wide range of environmental observations. For instance, citizen science was used in air quality to validate the performance of sensor technologies for ozone monitoring (Ripoll et al. 2019). Internationally, there has been an increased effort to involve local communities in nature-based citizen science approaches, fostering local cooperation and environmental stewardship in water management in places like Ireland, and reassessing water quality protection in Chile through community-based water quality monitoring (Weiner et al. 2022; Yevenes, Pereira and Bermudez 2022). In the United States, a volunteer monitoring program developed by the Wabash River Enhancement Corporation helped to identify water-quality priorities across the watershed (Muenich et al. 2016). In Canada, organizations are committed to monitor and protect water through crowdsourced monitoring and knowledge transfer initiatives (G3E 2022; Ottawa Riverkeeper 2023; Our Living Waters 2022; Water Rangers 2022; Zhao, Liu and Wei 2020).These efforts are complemented by open free platforms such as DataStream, where water quality data collected from various community-gathered programs is curated, stored, and shared with the public (The Gordon Foundation 2023).

Given the critical importance of water resources and their diverse uses, including domestic wells, municipal drinking water production, fishing, recreational activities, and crop irrigation, it is essential to protect and monitor them. Lakes, often used for recreational activities and as drinking water sources, are susceptible to blooms of algae and cyanobacteria, particularly in warm, slow-moving, and nutrient-rich waters. These blooms can manifest as foam, scum, mats, or paint-like coatings on the water's surface and can produce cyanotoxins that pose health risks to humans and wildlife (Figure 1). The amount of cyanotoxins may vary between blooms, and not all cyanobacterial blooms produce toxins. Cyanotoxins include microcystins, cylindrospermopsin, and anatoxins, which, when ingested, can affect the liver or the nervous system, leading to symptoms like nausea, vomiting, abdominal pain, and diarrhea. Contact with water containing cyanotoxins can also result in eye, skin, and ear irritation. While most symptoms are mild and reversible, exposure to cyanotoxins can, in rare cases, lead to severe health issues, including death (BBC News 2020; Health Canada 2021; Kouakou and Poder 2019; Veerman, Kumar and Mishra 2022).

Despite governmental and nongovernmental monitoring programs, there are often limitations in spatial and temporal coverage (Hyder et al. 2017) that can lead to missing important events. This is particularly critical for cyanobacterial blooms because of the narrow window in which these blooms peak. The challenges posed by cyanobacterial blooms underscore the importance of exploring citizen science initiatives that can help bridge knowledge gaps related to their occurrence and prediction (Cunha et al. 2017; Zhao, Liu and Wei 2020). Approaches involving community training for water sampling have also been reported under the FreshWater Watch (FWW) research project. For instance, trained participants provided samples and performed water quality analyses to evaluate the presence of cyanobacteria in urban streams

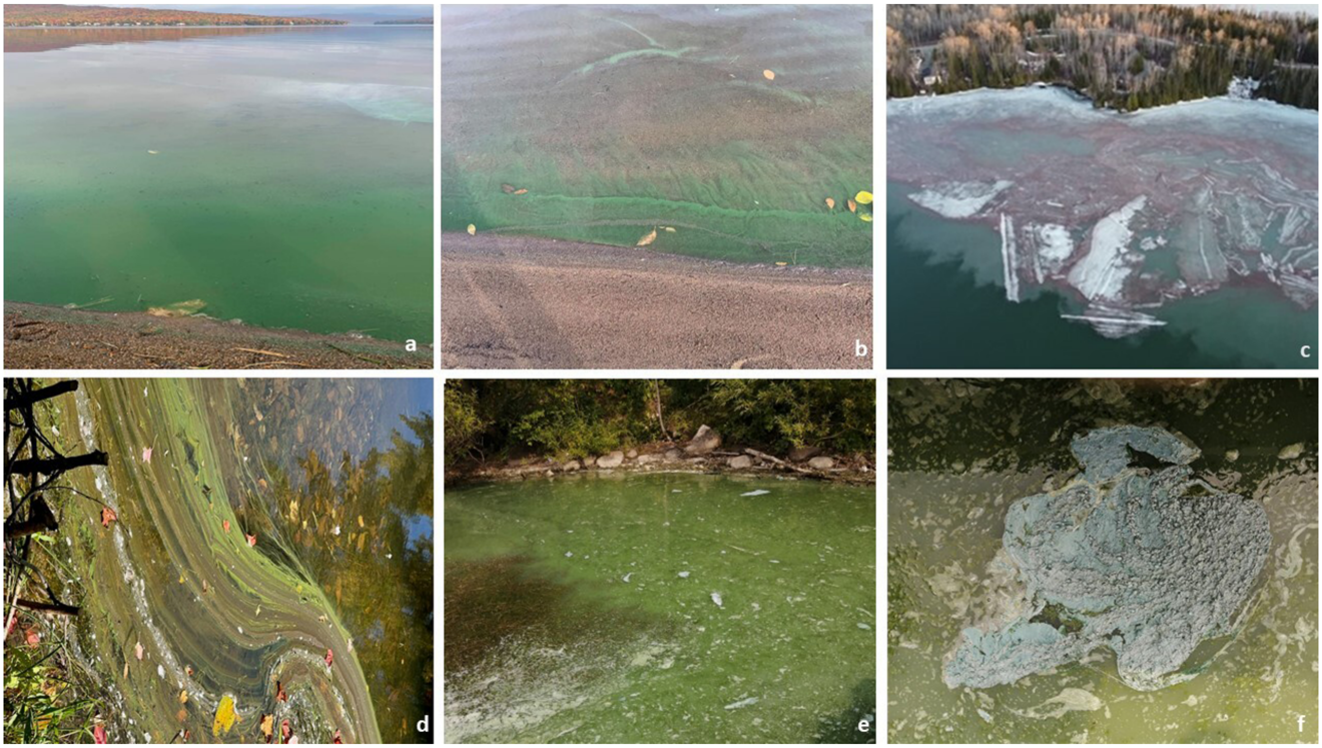

Figure 1 Pictures of cyanobacterial blooms taken by the citizens. ***(a, b)*** Lac Saint-Joseph, ***(c)*** Lac Fortune, ***(d)*** Lac Lovering, and ***(e, f)*** Lac Saint-Augustin.

of Brazil and Canada (Cunha et al. 2017; Lévesque et al. 2017). Lately, water monitoring initiatives rely more on smartphone applications (bloomWatch 2022; GLOBE Observer 2022; Water Rangers 2022; WATR 2023). For instance, the CyanTRACKER project in the United States enables users to report cyanobacterial bloom occurrences via a smartphone. The application allows them to upload a corresponding photograph, the metadata of which can help with site identification (Mishra et al. 2021; Scott, Ramaswamy and Lawson 2016). Similarly, a smart-app citizen science initiative in a lagoon near Abidjan, Ivory Coast effectively tracked cyanobacterial harmful blooms (Mitroi et al. 2020). In recent years, several projects related to water quality measurements have been published, underscoring the growing relevance and importance of population engagement in water protection (Bos et al. 2019; Herman-Mercer et al. 2018; Jollymore et al. 2017; Nanayakkara, Bos and Finlay 2017; Scott, Ramaswamy and Lawson 2016; Topping and Kolok 2021; Zhang et al. 2017).

Between 2016 and 2022, a large research project on harmful algal blooms was initiated in Canada, funded by Genome Canada and Genome Quebec. The goals of the ATRAPP project were (1) to establish a reliable and accurate diagnosis for cyanobacterial harmful blooms using a chemical-genomic toolkit, (2) to determine optimal management practices for drinking water treatment facilities in the event of a harmful cyanobacterial bloom outbreak, and (3) to propose cost-effective diagnostics and preventive measures to mitigate their occurrence and impact (ATRAPP 2022). The Adopt a Lake initiative emerged in response to requests from citizens who wanted their local lakes tested for the presence of cyanobacteria and cyanotoxins. It served as a valuable resource for optimizing ATRAPP project resources, particularly in addressing the complex challenges of timely testing of hard-to-reach waterbodies affected by blooms. Adopt a Lake is essentially the citizen science component of the ATRAPP project. Since its launch in 2018, the initiative has provided inhabitants, both as individuals and members of associations, to contribute to the ATRAPP project. Their contributions include providing field samples and in situ water quality measurements. Researchers subsequently analyze these samples for cyanotoxins, genomics, and nutrient content. Notably, the involvement of participants has allowed for the integration of a more extensive range of samples than initially envisioned in the ATRAPP project, surpassing what could have been achieved solely with academic research resources.

This article presents the Adopt a Lake initiative's establishment, growth, and plans. The initiative successfully collects and analyses samples (162, between 2018 and 2021), and it combines crowdsourcing and crowdfunding to achieve its results (Figure 2). In this context, citizen science is defined as collaborative public participation, and participants are individuals or associations involved in research by collecting samples or by making a monetary contribution (Eitzel et al. 2017). Crowdsourcing for this project involves an appeal for the participation of a large

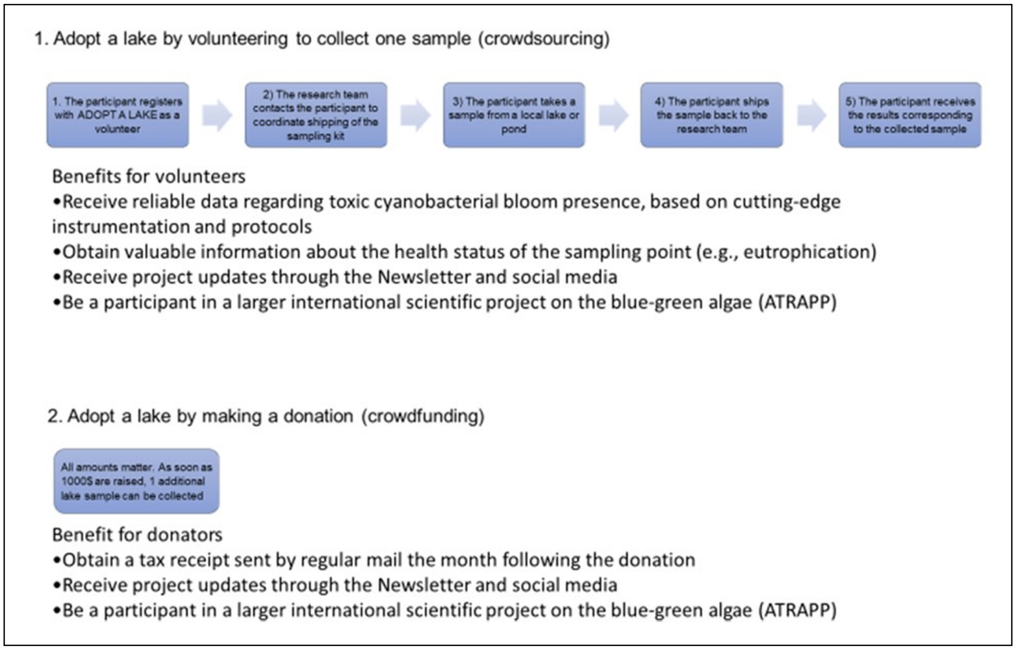

Figure 2 Crowdsourcing/crowdfunding framework of the Adopt a Lake program citizen science campaign.

group of people to collect and ship water samples to be tested when a harmful cyanobacterial algal bloom in a water body is suspected on the basis of visual assessment. Crowdfunding entails raising funds so that additional candidate lakes could eventually be sampled and analyzed.

MATERIALS AND METHODS

Following the initiation of the ATRAPP project in 2016 and its subsequent media coverage, citizens began to inquire whether their local lakes were included in this project. Initially, the project focused on specific sites with a history of harmful blooms and easy sampling access. However, as citizens learned that their lakes were not initially part of the research, many expressed interest in participating. The Adopt a Lake initiative started in 2018 to accommodate the growing demand.

COMMUNICATION AND EXPANDING PARTICIPATION

The initial stages of Adopt a Lake necessitated extensive preparation involving a collaborative effort from a team of scientists, stakeholders, and communication experts at Université de Montréal, who assisted in carefully crafting of the initiative. During this time, several key concerns emerged : (1) explaining the scientific goals of the campaign in simple terms and highlighting the benefits for participants; (2) clarifying the scope of the results participants could expect and emphasizing that the initiative output did not substitute for private labs or government analyses; and (3) developing a clear and concise report format that included site-specific information and details about toxins, cyanobacteria, nutrients levels, and on-site measurements along with explanation about the results and how they aligned with global regulations and guidelines. To address these concerns, a bilingual (French/English) website was created to provide comprehensive information helping participants understand the initiative's objectives. During the registration phase, participants were reminded that the results would be included in a public database. All participants consented to voluntarily participate in this collection effort by registering on the program website.

Regular close communication (phone calls and text messages) and project updates (e.g., newsletters delivered through common mailing lists and website updates) allowed participants to track the progress of the project (Figure 3; see also Supplemental File 1). Many participants in the initial campaign volunteered again in subsequent years, indicating their continued interest in this project and in maintaining collaborative ties. Videos were made publicly available through social media for those interested in learning more about the closely related ATRAPP project. In addition to the initial registration of participants that initiated this citizen science project, participants were recruited mostly through word-of-mouth referrals. Media interventions in the local press (Blais and Langlois 2020; Blais and Mathieu 2022; Colpron 2022; Deshaies 2020; Savard-Fournier 2021) aimed at raising awareness about harmful blooms attracted more participants.

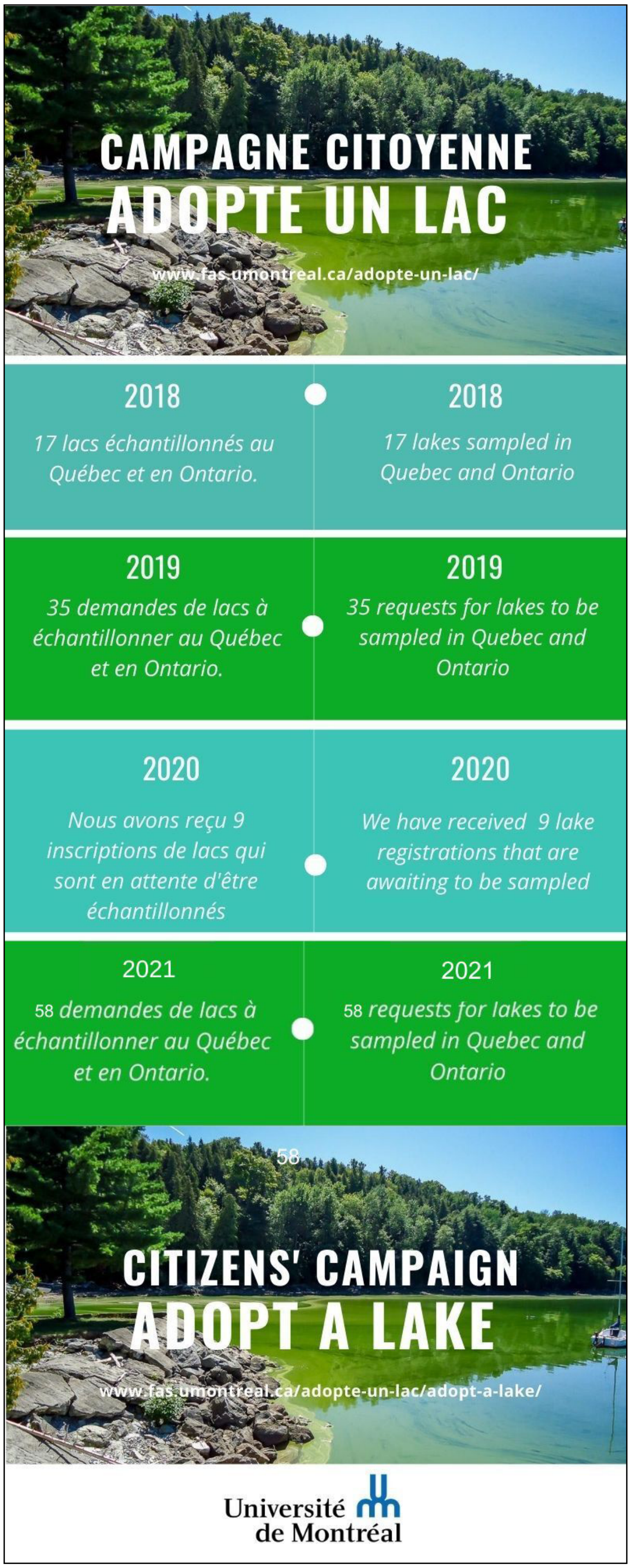

Figure 3 Infographics created as part of the Adopt a Lake program updates sent to the participants.

In Adopt a Lake, personalized reports written in simple terms highlighting the key findings from their sample analyses were prepared for each participant. Participants were trained for sampling through basic tutorials and straightforward protocols, and they received necessary follow-up support. Additionally, the development of a new massive open online course (MOOC) on water contaminants developed at Université de Montréal included a module dedicated to cyanobacteria and their endotoxins, further enhancing participants' knowledge about this issue (Université de Montreal 2021).

PROJECT OVERVIEW AND COORDINATION

When implementing a citizen-science project, common hurdles and limitations may arise regarding the handling and organization of the project, data repository and accessibility, and the reliability of the generated results. One question that often arises is to what extent a sample taken by a citizen who typically lacks extensive scientific training is reliable. There are many caveats relating to the representativity of collected samples, and subsequent issues during the handling and storage of water samples (Dinh et al. 2021; Kamp et al. 2016). Protocols should be specific enough to ensure sample and data quality but must remain relatively simple and understandable. With this in mind, we consulted with other crowdsourcing campaign management teams in Canada to understand the requirements for establishing a successful sampling operation adapted to enthusiastic volunteers with little or no scientific background (Ministère de l'Environnement 2004–2020; Water Rangers 2022). Highlighted among the recommendations were clear and simple sampling protocols and channels to facilitate communications with researchers (e.g., rapid communication tools such as instant messaging applications).

The participants are residents who live near the sampled lakes or have cottages in proximity. Consequently, they were well positioned to collect samples promptly upon observing a bloom. We developed a custom sampling kit that was sent to participants a few weeks before. This kit contained the materials to sample for presence of cyanotoxins and for nutrient and genomic analysis, and to measure in situ parameters (temperature, alkalinity, hardness, pH). It also included a detailed written procedure for field sampling (Supplemental File 2 and Supplemental File 3). For improved clarity, a short tutorial video illustrating the basic steps of surface water sampling was posted online (Adopt a Lake 2022). Additionally, we regularly communicated with the participants to address any concerns they might have regarding sample protocols, handling and storage of samples prior to shipment, recommended holding times, and other considerations. The participants had to sample a lake and send the samples box back (at their expense), while the analytical cost of the laboratory analyses was assumed through research funds and crowdfunding donations.

In situ sampling and measurements performed by participants

The participants were requested to provide contextual sampling metadata such as the Global Positioning System (GPS) coordinates, information on weather during and 24 hours before the sampling, UV Index, wave type, wind direction, and wind speed by filling out a pictographic form prepared for this purpose (SI Figure S2). Also provided in the box were three pairs of nitrile gloves, two 125-ml square bottles for toxin analysis, two 500-ml wide-mouth bottles for nutrient analysis, and an Eppendorf® tube for genomic (16S rRNA) analysis. The bottles for cyanotoxin analysis (polyethylene terephthalate-G [PETG] copolymer) were selected to reduce the risk of sorption during the storage of water samples (Kamp et al. 2016). The test kits included multi-purpose six-way test strips (HTH pools) and a thermometer so that physicochemical data could be measured in situ at the time of sampling, including water hardness, pH, alkalinity, and water and air temperature. Through personal communication, we also identified volunteers who were willing to take transparency measurements with the Secchi disk that was provided to them in the test kit. In addition to the protocol, we provided the return address and shipping instructions in a separate sheet. Recommendations for sample collection were simplified as much as possible and are reproduced in the appendix (Supplemental File 2). Participants were instructed to collect water samples near the algal bloom at the water subsurface using gloved hands without disturbing sediments. Most participants sampled at the shore of the lake or near where blooms typically occur due to nutrient enrichment from the watershed. Whenever possible, participants were encouraged to collect samples for genomic analysis. This involved using a provided sterile wooden spatula to collect algal scum or surface water bloom and placing the sample in a sterile Eppendorf® tube. Samples were to be stored in a cooler box with a freeze pack to maintain sample integrity while on site. The toxin and genomic samples were to be frozen overnight, and the nutrients samples were to be stored at 4°C. As short storage times are favored (Dinh et al. 2021), participants were encouraged to ship samples as soon as possible, preferably the day following sample collection. Throughout the process, we communicated with the participants to track packages, and answer sampling questions and other concerns. The main questions for the sampling procedure concerned when the sampling should be done (morning or during the day) and how to proceed if the water was turbid but without apparent surface bloom or when the water was clear. In such cases, the participants were encouraged to sample only when there was a visible surface bloom and turbidity present. For the shipping, the participants were instructed to send the samples at the beginning of the week to avoid weekend storage in the carrier warehouse and sample loss due to improper storage.

Laboratory analyses

Cyanotoxins were measured using validated methods at the Université de Montréal, Chemistry Department. Water samples were analyzed for total microcystins (MCtot) using the Lemieux oxidation method and subsequent determination of the 2-methyl-3-methoxy-4-phenylbutyric acid (MMPB) moiety via liquid chromatography tandem mass spectrometry (Thermo UHPLC TSQ Quantiva) (Munoz et al. 2017), while individual microcystins and the cyanotoxins cylindrospermopsin, anatoxin-a, homoanatoxin-a, anabaenopeptins A and B were determined using liquid chromatography high-resolution mass spectrometry (Thermo UHPLC Orbitrap Q-Exactive) (Roy-Lachapelle et al. 2019).

PRELIMINARY RESULTS AND COST SAVINGS ESTIMATION

Participants conducted sampling activities at 18 sites in 2018, 55 sites in 2019, 31 sites in 2020, and 58 sites in 2021, predominately in Quebec, with a few in Ontario and Nova Scotia (Figure 4). As some of the lakes were sampled at multiple sites or multiple times, 162 individual water samples were collected in 86 lakes. Eighteen lakes were sampled for two years, and six lakes were sampled for three years. The data showed that cyanotoxins, together with phosphorus and nitrogen concentrations, generally indicated eutrophic lake status, and that cyanotoxins were present in almost all samples.

Cyanotoxin results revealed that 122 of the 162 samples tested positive for microcystins (Figure 5). Anabaenopeptin A (AP-A) & anabaenopeptin B (AP-B) were detected in 39 and 31 samples, respectively. Notably, 20 of the 162 had total microcystins concentrations exceeding 1 µg l^{-1} with the maximum observed value reaching 2600 µg l^{-1}. While the World Health Organisation (WHO) guidelines recommend a maximum acceptable concentration of 1 µg l^{-1} microcystins (WHO 2020), Health Canada established a maximum acceptable concentration of 1.5 µg l^{-1} total microcystins in drinking water and 20 µg l^{-1} total microcystins in surface water for recreational activities (Health Canada 2021). Adopt a Lake proved instrumental in identifying samples with critical cyanotoxin concentrations, some of which were orders of magnitude higher than Canadian or international recommendations. The collaboration with participants and the identification of problematic sites were a success, motivating efforts to transform this citizen

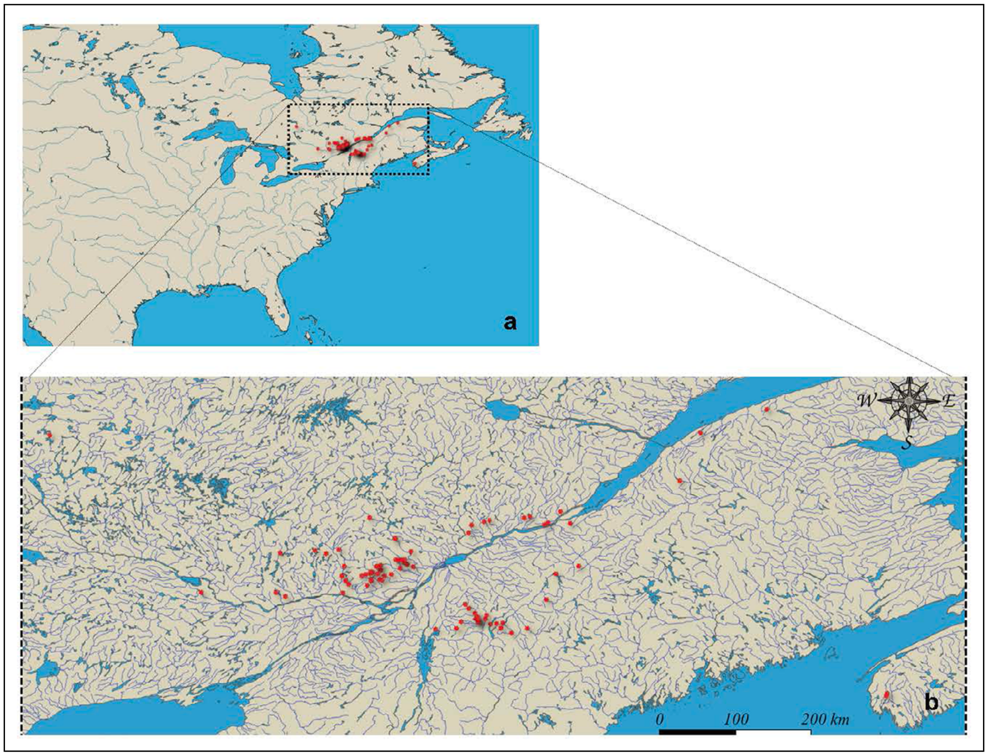

Figure 4 Map showing the geographical distribution of water samples collected as part of the Adopt a Lake citizen science campaign. **(*a*)** Overall location within North America; **(*b*)** Zoom-in on the study area, including lakes, rivers, and creeks of Nova Scotia, Ontario, and Quebec. Maps were drawn with Quantum GIS (QGIS 3.6 Noosa), and vector layers were retrieved from naturalearthdata.com and the Ministère des Ressources Naturelles et des Forêts (MRNF).

science initiative into a sustainable monitoring program. This initiative underscores the need for constant monitoring of cyanobacterial bloom events in problematic sites, and the uses of advisories to protect lake users.

COST SAVINGS ESTIMATION

Many citizen science articles mention the cost-benefit potential of these initiatives (Encarnação et al. 2021; San Llorente Capdevila et al. 2020). However, a new approach to evaluate cost-benefit potential that takes into consideration the effectiveness of citizen science observations in supplementing existing data in terms of temporal and spatial coverage, and the associated costs of data production, indicates that establishing a citizen science initiative solely for data collection can be a costly endeavour impacting both the data users and the initiative itself (Alfonso, Gharesifard and Wehn 2022). In our study, we estimated the potential cost savings achieved when involving participants, contributing their time and effort to collect samples from various lakes, rather than relying on paid personnel. The participants, through their dedication and contribution, allowed us to conduct extensive fieldwork efficiently. This approach has several facets worth considering. We acknowledge that the participants may vary in their level of training and expertise compared with professional researchers, and thus, there may be uncertainty about data quality and reliability (Riesch and Potter 2013).

Costs were estimated for a subset of 19 lakes analyzed during the 2018 sampling season, assuming proximate sampling sites would have been visited during the same sampling trip. Estimated sampling costs included car rental with insurance (C$110 per day), car fuel (C$0.10 per kilometer), hotel (C$165 per day), and meal allowance (C$45 per person per day). For six field trips covering 19 lakes and 3,200 km, the logistics costs are as high as C$3,050. When extrapolated to 86 lakes, the estimated cost rises to approximately C$13,800. Factoring in personnel time (2–2.5 months per year) and stipends/salaries for students or post-doctoral fellows (C$15,000 and C$42,000), the estimated sampling cost for the four years to sample 86 lakes is between C$28,800 and C$48,800. This raises an ethical question of whether citizen science might replace jobs that would otherwise employ scientists (Walker, Smigaj and Tani 2021). In this case, the sampling timing is crucial because harmful algal blooms occur unpredictably and often have a short duration. As participants are residents who live near the sampled lakes or have cottages in proximity, it enables them to collect samples promptly upon bloom detection. Additionally, given the extensive

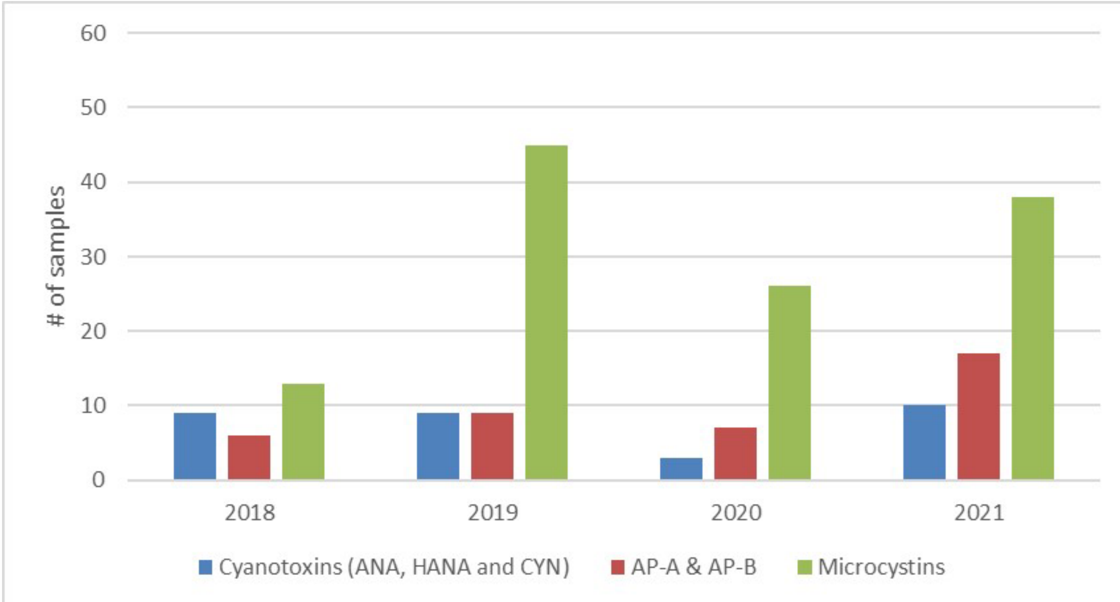

Figure 5 Samples with detected concentrations of microcystins, anabaenopeptins A and B (AP-A and AP-B) and other monitored cyanotoxins (anatoxin A [ANA], Homo-anatoxin (HANA) and cylindrospermopsin [CYN]).

territory covered, the logistics involved are considerably complex, raising questions about the overall project feasibility.

In comparison, shipping the sampling kits to participants, including both shipping and personnel expenses, was much lower—from C$3,000 to C$6,000. As of July 2022, the crowdfunding campaign had raised C$27,900 in donations, with 26% of the participants contributing monetarily. Through crowdsourcing and crowdfunding, total savings are between C$58,000 and C$78,000 during the four-year campaign. The participants were informed that they were required to cover the sample shipping costs. The cost of sample shipping to the university laboratory varied between C$25 and C$100 depending on the locality (remote localities being more expensive). In terms of equity and inclusivity, we recognise that asking the participant to cover the costs of sample shipping have created disparities in participation because individuals and associations might have varying levels of financial resources, potentially leading to unequal access to this initiative. Regarding the ethical oversight, the participants were not pressured to enrol in this initiative, the information is displayed on the initiative website, and the participant must register voluntarily to be enrolled in the program (Riesch and Potter 2013).

DISCUSSION

Consistent with other citizen science initiatives, the successful implementation of the Adopt a Lake program suggests that citizens are concerned about water quality and want to be involved in water monitoring and protection (Rich 2019; Water Rangers 2022).

BENEFITS FOR RESEARCHERS AND PARTICIPANTS

This citizen science initiative has yielded substantial benefits for researchers and participants. For researchers, the advantages are multifaceted. Firstly, acquiring lake samples and in situ analysis through citizen participation is a cost-effective alternative compared with relying solely on paid professional researchers. Secondly, considering the unpredictable timing of cyanobacterial bloom, which can last for only several days or hours, the citizen science program offers an advantage that would have been otherwise unattainable from a budget and time perspective. Thirdly, some of these lakes that were not previously reported for developing toxic cyanobacterial blooms are now part of a list of sites to be monitored, fostering strong collaborations between participants and researchers. This continuous tracking of harmful blooms in select lakes enables researchers to discern whether the issue is sporadic or chronic, contributing to a deeper understanding of the problem beyond anecdotal perceptions. It emphasizes integrating traditional and local knowledge with the scientific approach. The Adopt a Lake initiative offers participants tangible and potential benefits (Walker, Smigaj and Tani 2021). The tangible benefits include receiving a site-specific report and the opportunity for participants to engage in discussions about their results. These reports provide valuable information that participants can share within their communities, increasing social learning and empowerment. This encourages participants to engage in public meetings to raise awareness and to advocate for their concerns. In addition to these concrete advantages, there are potential benefits as well. Participation in the program can enhance knowledge and scientific literacy, fostering community engagement and ultimately contributing to advancements in the field of harmful algal blooms. By contributing to Adopt a Lake, the participants are involved in advancing the science of blue-green algae, a problem that exists in Quebec, Canada, and internationally (e.g., Australia, Brazil, and other countries).

We agree with Chase and Levine (Chase and Levine 2016) when they argue that citizen science programs should "seek to complement, rather than duplicate," monitoring efforts already being conducted. Citizen science complements official data sources that serve as evidence for policies and practices to improve water quality (König et al. 2021). Citizens may play a role in areas where government agencies cannot (or will not) take action. For instance, when North Carolina's Legislature scaled back funding for air quality monitoring, the Gardenroots project received a grant from the state's Environmental Protection Agency (EPA) to conduct research in response to public concern, a task that the EPA could not undertake on its own (Ramirez-Andreotta et al. 2015; Wyeth et al. 2019). Adopt a Lake does not duplicate governmental or academic efforts—quite the opposite. With this project, the community fills a gap in harmful cyanobacterial blooms monitoring and lists new sites to monitor. In Quebec, in the late 1990s, following the acquisition of new scientific knowledge and reporting certain cases of blue-green algae blooms, the provincial government implemented the Blue-Green Algae Bloom Episode Management Plan. Implementation of the management plan began in 2004. Based on the knowledge acquired, the government reduced its interventions, resulting in fewer lakes being monitored over the years as the focus gradually shifted from monitoring to remediation. This resulted in the identification of more than 500 affected water bodies in a document entitled *List of Water Bodies Affected by a Blue-Green Algae Bloom from 2004 to 2017 and Recurring Water Bodies Reported from 2013 to 2015*. (Le ministère de l'Environnement et de la Lutte contre les changements climatiques [MELCC] 2018). The list indicates whether the body of water has been affected (minimum threshold of 20,000 cells of blue-green algae per millilitre), but there is no indicator of the proliferation intensity. Despite the termination of the monitoring program in 2017, citizens still have the option to report the occurrence of blooms by contacting their regional directorate or submitting a visual report form. However, the current criteria for testing waterbodies for cyanobacterial harmful blooms in Quebec, Canada, are highly restrictive. This limitation hampers the effective tracking of harmful algal blooms, potentially resulting in the under detection of toxic blooms and, consequently, downplaying the severity of the issue (Pick 2016). Under this initiative, the participants played a crucial role in scientifically documenting the presence of cyanobacterial harmful blooms in 86 lakes across Eastern Canada, specifically in Quebec, Ontario, and Nova Scotia, from 2018 to 2021. This collaborative effort ensured the ongoing acquisition of valuable data. It was observed that some of these lakes serving as domestic water sources for residents. This is of high concern as relevant exposure pathways to cyanotoxins include ingestion of contaminated drinking water and dermal contact or accidental ingestion of surface water during recreational activities (dermal contact, accidental ingestion). In these problematic cases, the participants provided additional samples and the monitoring was continued.

CHALLENGES

As observed in other monitoring programs (Bos et al. 2019; Nanayakkara, Bos and Finlay 2017; Rich 2019), the principal challenge was to provide adequate, sufficient, and easy-to-understand information. To address this, we employed consistent terminology and utilized various communication methods, such as emails, text messages, and phone calls, while maintaining a balance in the frequency of communication. It was crucial to be accessible to participants during bloom periods to address their concerns and to answer their questions.

The planning and coordination of citizen science activities proved to be time consuming. It necessitated meticulous planning by providing detailed yet clear instructions to volunteers and allocating time for effective interaction. This initial investment in time was crucial to ensure that participants correctly understood the instructions, especially given the need for different sampling protocols for various parameters (e.g., nutrients, toxins, and DNA analysis) and the inclusion of on-site measurements requested. This requires significant human resource management as participants need close and rapid accompaniment when sampling and often request specifics on sample handling and storage. Depending on the degree of involvement, varying degrees of accuracy/precision were expected, as seen in the analysis of field sample duplicates (Roy-Lachapelle et al. 2019). A certain degree of flexibility is also necessary as protocols may need to be dynamic rather than static; for instance, sampling/storage procedures may need to be adapted as our understanding of cyanobacteria/cyanotoxin science evolves.

There are additional limitations associated with the design of the citizen science approach. While the acquired data is valuable, we refrained from providing a definitive trophic classification of lakes. Since water samples were mostly collected from one-time measurements and retrieved from the near shore, further temporal investigation of the lake (e.g., seasonal monitoring) and space (e.g., throughout the water column and at different sampling points) would be needed for this purpose. In addition, in terms of sampling methodologies, we are looking to improve DNA sampling and are currently testing new methodologies with the participants.

PERENNITY PLAN

To ensure the long-term sustainability of the initiative and to address the identified gaps, we aim for a perennity plan that focuses on improving communications, expediting lab analysis, enhancing the reporting process, and transitioning into a continuous monitoring program. The program was broadcast in the media when the problem with cyanobacteria was raised (Blais and Langlois 2020; Blais and Mathieu 2022; Colpron 2022; Deshaies 2020; Savard-Fournier 2021). Following each broadcast by published articles in the media, we noticed an increase in enrolment. Similarly, a study identifying the toxins of concern by state and region in the United States and the level of monitoring and outreach efforts for blooms, concluded that the preferred outreach and education method for the community is via press release (Hardy, Preece, and Backer 2021). The success of the program in attracting participants through media coverage indicates the value of ongoing media engagement to maintain awareness and encourage engagement.

A survey conducted among the participants (26% response rate) informed us about the gaps and strong points of the program. According to the survey, the participants found the protocol clear (91%), the sampling time reasonable (95%), and the sampling kit complete (100%). The communication pace with the coordinator was rapid (68%), and 59% of stakeholders felt that communications about the program were right. Only 45% of participants thought the time to receive the results was acceptable and that the report received was complete and detailed. In the past three years, the pandemic hindered the in-lab analysis; there is room for improvement to expedite the generation of lab results and issuance of the report document. As the program relies on participant engagement, fostering partnerships with local communities and stakeholders will be essential for its long-term success. Collaborating with local organizations such as water conservation agencies and citizen watershed or lake protection associations will enable us to tap into existing networks and to expand outreach efforts. By actively involving participants in the monitoring process and valuing their contributions, we can harness their passion for water resources protection and cultivate a sense of ownership in the program.

Continuous evaluation and improvement will be integrated into the perennity plan. Regular feedback from participants and stakeholders will enhance the program advancement. By adapting to emerging challenges and incorporating best practices, the initiative will evolve into a well-implemented community monitoring program that remains relevant and essential in tracking harmful algal blooms over the years. Overall, the perennity plan aims to ensure the long-term sustainability and success of the program by refining communications strategies, expediting lab analysis, enhancing reporting practices, fostering partnership, and embracing continuous improvement. With these measures in place, we are confident in the program's ability to make a lasting impact on water resources management and to contribute to the well-being of the communities.

CONCLUSION

Here, we report on the implementation of an initiative for tracking harmful algal blooms. With the recognition that these blooms can cause health risks and with the lack of existing monitoring programs, concerned citizens have taken the initiative to track and monitor these occurrences. By collaborating closely with the research team, data analysis has proven to be of immense value to participants and researchers. The partnership highlights the complementary nature of the citizen science initiative in research. Citizens are uniquely positioned to provide real-time data, capturing critical information precisely when and where it is needed. The contribution has played a pivotal role in building a robust dataset that is indispensable for predicting and effectively managing cyanobacterial blooms. The lessons learned from this project emphasize the importance of community involvement and the value of collaborative efforts between citizens and researchers when sampling timing is essential. Establishing a community monitoring program is essential for advancing and sustaining initiatives that encourage community participation in research efforts. This will help leverage the combined strengths of both communities and researchers.

DATA ACCESSIBILITY STATEMENT

The sampled lakes are available upon request. The data will be made available through the Gordon Foundation platform (The Gordon Foundation 2023).

SUPPLEMENTARY FILES

The Supplementary files for this article can be found as follows:

- **Supplementary File 1.** Example newsletter sent to participants presenting updates of Adopt a Lake. (Adopt a Lake 2022). DOI: https://doi.org/10.5334/cstp.655.s1
- **Supplementary File 2.** Sampling protocol sent to volunteer citizens of Adopt a Lake. DOI: https://doi.org/10.5334/cstp.655.s2
- **Supplementary File 3.** Contextual sampling metadata to be filled out by the volunteer during the sampling. DOI: https://doi.org/10.5334/cstp.655.s3

ETHICS AND CONSENT

The participants agreed that the information obtained through the analysis is available to the researcher for publications and data sharing with the public.

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COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR CONTRIBUTIONS

DFS was responsible for writing, design, and data collection and treatment; GM provided extensive edits; QTD and SVD provided the analysis; KK was consulted for the initiation of the program; RB was consulted for the cost saving estimation; BH provided edits; and SS was involved in design and providing the financial support.

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