Environmental Management (2023) 71:249–259
https://doi.org/10.1007/s00267-022-01736-2

Perceptions of Freshwater Algal Blooms, Causes and Health among New Brunswick Lakefront Property Owners

Sapriya Birk[1] · J. David Miller[2] · Aidan MacMullin[3] · R. Timothy Patterson[4] · Paul J. Villeneuve[1]

Received: 10 August 2022 / Accepted: 10 October 2022 / Published online: 1 November 2022

Abstract

Changes to water conditions due to eutrophication and climate change have resulted in the proliferation of algae blooms in freshwater and marine environments globally, including in Canadian lakes. We developed and administered an online survey to evaluate the awareness of these blooms and the perceptions of health risks in a sample of New Brunswick waterfront cottage and homeowners. The survey was distributed to lake and cottage associations in New Brunswick and was completed by 186 eligible respondents (18 years of age or older). Participants were asked about the water quality of their lake, awareness about algae blooms, sociodemographic and cottage characteristics, and to complete a self-rated measure of physical and mental health. While approximately 73% of participants reported that the quality of their lake water was good or very good, 41% indicated a concern about algae blooms. We found no differences in self-reported physical or mental health between those who were aware of algae blooms at their cottage and those who were not ($p > 0.05$). Participants expressed concerns about the impacts of algae blooms on the health of their pets, and wildlife. While climate change was the most frequently identified cause of algae blooms, there was substantial heterogeneity in the responses. In addition, the reporting of the presence and frequency of algae bloom varied between respondents who lived on the same lake. Taken together, the findings from our survey suggest that cottage owners in New Brunswick are aware and concerned about the impacts of algae blooms, however, there is a need to provide additional information to them about the occurrence and causes of these blooms.

Keywords Algae bloom · Survey · Lake · Wildlife · Climate change

Introduction

Cyanobacteria, also known as blue-green algae, are believed to be among the oldest microbes on the planet, dating from ~3.5 billion years (Rasmussen et al. 2008). These microbes are part of the natural ecosystem in freshwater all over the world (Paerl and Paul 2012). The rapid growth and accumulation of this algae produces harmful algal blooms (HABs) which have adverse impacts on human health, the economy, and ecosystems (Centers for Disease Control and Prevention 2022; Government of Canada 2020; US EPA 2013). The most common cause of increased algal blooms is eutrophication – the over-enrichment of water with nutrients such as nitrogen and phosphorus (O'Neil et al. 2012). This has been understood since the late 19th century, when lakes with nutrient overload in hot dry summers produced toxins that were capable of rapid deaths in domestic animals including dogs as well as humans (Gorham 1960). Human activities such as agricultural practices and the disposal of industrial waste contribute to the eutrophication of bodies of water (Anderson et al. 2002). Other factors such as sunlight and water temperature also play a role in HAB development (US EPA 2013). In recent years, climate change has been identified as a substantial

Supplementary information The online version contains supplementary material available at https://doi.org/10.1007/s00267-022-01736-2.

✉ Paul J. Villeneuve
PaulVilleneuve@cunet.carleton.ca

[1] Department of Neuroscience, Carleton University, Ottawa, ON, Canada

[2] Department of Chemistry, Carleton University, Ottawa, ON, Canada

[3] Sprott School of Business, Carleton University, Ottawa, ON, Canada

[4] Ottawa Carleton Geoscience Centre and Department of Earth Sciences, Carleton University, Ottawa, ON, Canada

contributing factor to the increased prevalence and persistence of algal blooms (Gobler 2020; Griffith and Gobler 2020; O'Neil et al. 2012).

It is necessary to accurately identify and manage HABs due to the possible health impacts. Although it tends to be obvious that a lake has an algal boom, it is perhaps less well-understood that water can remain toxic after a bloom has dissipated. This is due to the release of toxins such as microcystins by cyanobacterial cells. Microcystins are stable and resistant to common types of chemical breakdown. At typical ambient conditions, the half-life of microcystin is 10 weeks (Butler et al. 2009). However, toxins can persist for months to years if released in cool, dark, natural water. Exposure to toxins can occur through drinking water, eating fish and the consumption of produce irrigated with water from affected lakes as well as inhalation or skin contact (Lee et al. 2017). Acute human health effects include symptoms such as nausea, vomiting, abdominal pain and diarrhea, headache, fever, and skin rashes. In the case of microcystin exposure, there is evidence that risk is greater for those with pre-existing liver or gastrointestinal disease (Lad et al. 2022). Dog deaths from consuming affected lake water is not uncommon, and they experience similar acute health effects include vomiting, diarrhea, lethargy, and seizures (Hilborn and Beasley 2015). Marine invertebrates, such as mollusks, exposed to HABs may experience symptoms including feeding cessation, heart rate reduction, clogged gills, loss of muscle control, and paralysis (Turner et al. 2021).

Canadian researchers discovered the first blue-green algal toxin, microcystin from *Microcystis* (Bishop et al. 1959; Gorham and Carmichael 1980). In cooler climates including Canada, algal blooms remained rare until about 25 years ago. Global warming coupled with a combination of nutrients that have accumulated over time on lake bottoms (legacy phosphate), careless nutrient management from farms as well as poor sewage treatment including from septic tanks has changed this picture (Foulon et al. 2019; Pick 2016). Now, blooms and the associated toxins are an increasing problem from sea to sea including in New Brunswick (Brown et al. 2021; Orihel et al. 2012; Rashidi et al. 2021). In fact, Canada has seen an increased frequency with 150 HABs detected in waterbodies in 2018 (Rashidi et al. 2021; Winter et al. 2011). The Harmful Algal Event Database (HAEDAT) contains records of HAB related events in Canada since 1987. A 30-year review of records in this database from 1988 to 2017 revealed that there are over 40 species of harmful algae in Canadian water bodies that have resulted in harmful algal events across the Canadian Arctic, Atlantic, and Pacific regions (McKenzie et al. 2021). HAEDAT records, along with other Canadian publications, suggest that these events are widespread and have been recurring across Canada's Atlantic and Pacific coastal regions.

New Brunswick is one Canadian province that has been experiencing HAB challenges. Blue-green algae exceeded federal HAB guidelines in both 2018 and 2019 in 17 different locations across New Brunswick (Rashidi et al. 2021). Additionally, there are roughly 2500 lakes and 60,000 km of rivers and streams in New Brunswick, suggesting that many residents live adjacent to or near affected bodies of water (Government of New Brunswick 2019). These characteristics make New Brunswick an ideal location to explore stakeholders' understanding of algal blooms. Therefore, the main purpose of this study is to investigate the extent to which New Brunswick cottage/waterfront homeowners are aware of HABs, their perceptions of the possible health risks as well as their understanding of the sources or causes of HABS. Herein, we present a quantitative and qualitative analysis of their survey responses.

Methods

This was a cross-sectional study, and the target population consisted of adults who owned a waterfront cottage or home in New Brunswick Canada in 2021. We designed an online survey using Qualtrics^{XM} (Qualtrics, Provo, UT) and it consisted of 39 questions divided across five sections. These sections collected data from respondents on (1) properties of their cottage or waterfront home (i.e. closest body of water, year built, years owned etc.), (2) their knowledge of and experiences with algal blooms, (3) concerns regarding water quality, (4) their health status, and (5) demographic characteristics including age, sex, and education level (Villeneuve 2022). We assessed the current health status of respondents with the 12-Item Short Form Survey (SF-12) which yields both a summary physical health score (PCS-12) as well as a mental (MCS-12) score. This survey instrument has been widely used and previously validated across a variety of study populations (Salyers et al. 2000).

To be eligible to participate in this survey, at the time of the survey, respondents had to be 18 years of age or older, own either a cottage or waterfront home in New Brunswick, be able to speak and understand English or French, and reside in Canada or the United States. The survey was initially distributed in English from September 16th to December 16th, 2021. A translated French version was subsequently created and made available online from November 10th, 2021, to December 16th, 2021 to by provide francophones an opportunity to participate. Local lake and cottage associations in New Brunswick were contacted through email, and informed about the study and were asked to distribute the survey to eligible individuals. The survey was advertised generally as a survey on health and the environment to avoid possible participation bias based on pre-existing knowledge and concerns about algal blooms.

Data Analysis

The flow chart provided in Fig. 1 displays the application of applying the inclusion and exclusion criteria for survey respondents. In total, responses were provided by 211 (192 English and 19 French) survey respondents. However, only 202 respondents satisfied the requisite eligibility criteria (age, and residency requirement). Some 16 respondents withdrew before providing sufficient data (attrition rate of 7.9%), leaving 186 respondents (170 English and 16 French) included in this analysis. Lastly, only 142 respondents completed the entire survey (127 English and 15 French). The remaining 44 surveys were incomplete. Of the 186 survey respondents, 48 (25.8%) did not complete the entire SF-12 and were excluded from analyses involving the SF-12. As a result, our analyses of self-reported health based on the SF-12 are based on 138 respondents.

Survey responses from Qualtrics^{XM} were imported into SPSS version 28.0.1.0 (IBM Corporation, Armonk, NY, USA) and formed the basis of our analysis. Data analyses focused on the results of the SF-12 and its association with (1) the level of concern for algal blooms, (2) the occurrence and frequency of algal blooms, and (3) the level of concern for pet(s) health. Responses to the SF-12 were scored using weighting based on the general United States population to generate a physical health (PCS-12) and mental health (MCS-12) score for each respondent (Ware et al. 1998). A higher score indicated better physical or mental health. Three levels of concern for algal blooms were identified (low, moderate, or high) based on responses to the survey question "To what extent do you believe algae blooms are a problem in the water at your cottage or waterfront home?". Those who responded with "insignificant issue", or "minor issue" were identified as having a low level of concern for algal blooms. Those who responded with "moderate issue", were categorized as having a moderate level of concern. Lastly, those who responded with "big issue", or "major issue" were classified as having a high level of concern. The frequency of algal blooms was categorized into three groups (often, rarely, or never). Respondents were asked "Over the past 10 years, what statement best describes algae blooms in the water at your cottage or waterfront home?". If they indicated that algal blooms occurred every year or every few years, they were assigned to the "often" group. If they responded "rarely" or "never", they were classified accordingly. Three levels of concern were identified for concern for pets' health (low, moderate, or high) based on responses to the question "Are you concerned that algae blooms may impact the health of your pet(s)?".

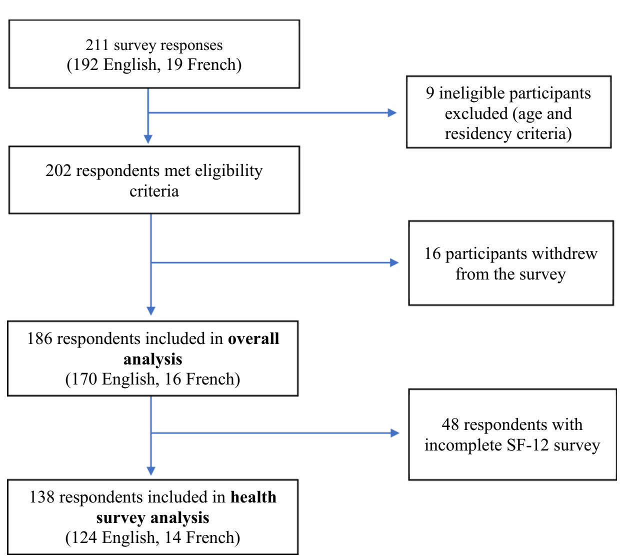

Fig. 1 Flowchart of participant inclusion and exclusion for 2021 New Brunswick Cottage and Waterfront Homeowner Survey

One-way analysis of variance (ANOVA) analyses were completed to evaluate if there were statistically significant differences in mean PCS-12 and MCS-12 scores across three groups with (1) differing levels of concern for algal blooms (low, moderate, high), (2) those with different frequencies of algal blooms occurrence (often, rarely, never), and (3) those with varying levels of concern for their pet(s) health (yes, somewhat, no). To account for covariates, one-way analysis of covariance (ANCOVA) analyses were also conducted. Covariates were measured categorically and included age (≤40, 41–50, 51–60, 61–70, or ≥71), gender (male or female), and highest education attained (high school, trade school, bachelor's degree, master's degree, or Ph.D. or higher). For all analyses, statistical significance was determined using a two-sided p-value of < 0.05. Analysis of qualitative responses involved inductive thematic analysis, which utilizes a bottom-up approach to determine relevant themes from the data. Responses were read in their entirety and subsequently open-coded by one researcher (SB) using NVivo (QSR International, version 12.0). Preliminary codes were reviewed and combined into common themes.

Results

Respondents

The demographic characteristics of the study participants are presented in Table 1. Approximately 90% of the respondents were roughly equally distributed in their 40 s, 50 s, 60 s, 70 s and 80 s with a median age of 62, half of whom had a university education. Table 2 outlines the characteristics of respondents' waterfront property. Approximately one-half of the respondents had owned their waterfront properties for less than 20 years. Most of the respondents used their properties all year round or most of

Table 1 Demographic characteristics of 186 respondents of the 2021 New Brunswick cottage survey

Characteristic	*n*	%
Age group		
≤40	9	4.8
41–50	14	7.5
51–60	39	21.0
61–70	43	23.1
71+	27	14.5
Missing	54	29.0
Sex		
Male	75	40.3
Female	62	33.3
Prefer not to say/ missing	49	26.3
Highest attained education		
High School	13	7.0
Bachelor's degree	62	33.3
Master's degree	27	14.5
Ph.D. or higher	9	4.8
Trade school	28	15.1
No response	47	25.3
Location of waterfront home		
Baker Lake	12	6.5
Davidson Lake	8	4.3
Lake George	9	4.8
Harvey Lake	10	5.4
Magaguadavic Lake	19	10.2
Oromocto Lake	18	9.7
Skiff Lake	15	8.1
Washdemoak Lake	9	4.8
Yoho Lake	9	4.8
Other	27	14.5
No response	50	26.9

the summer. Respondents owned their waterfront properties in four geographical areas (1) within 60 km north of St. George, NB, (2) 60 km of Fredericton SW and (3) 60 km NE of Fredericton, NB and (4) 50 km W of Edmundston, NB (Table S1). This represents a north-south gradient of ~300 km and an east-west gradient of ~110 km. Responses to questions regarding water quality at their cottage are also displayed in Table 2. 37.1% of waterfront properties were used year-round and 18.3% of respondents indicated that they used their property full time in the summer months. 156 respondents responded to the question about water quality. The average water quality score was 3.97. The most common response (41.0%) was "good quality". In fact, the median score was 4, indicating that most respondents (73.1%) reported that their water quality was good or very good.

Table 2 Characteristics of respondents' waterfront property and water quality/usage, New Brunswick cottage survey

Characteristic	Properties of cottage/home Response	*n*	%
Years owned	≤20 years	94	50.5
	21–40	30	16.1
	41–60	22	11.8
	61–80	14	7.5
	No response	26	14.0
Year built	≤1960	40	21.5
	1961–1980	44	23.7
	1981–2000	39	21.0
	2001–2021	30	16.1
	No response	33	17.7
Use of cottage/waterfront home	Year-round occupancy	69	37.1
	Full time in the summer	34	18.3
	Most of the summer	33	17.7
	For a portion of the summer	23	12.4
	No response	27	14.5
Weeks used in a year	< 16	50	26.9
	17–32	13	19.9
	33–48	17	9.1
	49–52	56	30.1
	No response	26	14.0
Number of different people using cottage/waterfront home in a year	1–5	77	41.4
	6–10	40	21.5
	11–15	14	7.5
	16–20	16	8.6
	≥ 21	7	3.8
	No response	32	17.2
Number of people at cottage/ waterfront home when it is in use	1–3	90	48.4
	4–6	56	30.1
	7–15	7	6.5
	No response	28	15.1
Water Quality and Usage			
What is the main source of drinking water at your cottage or waterfront home?	Tap water (no filter)	48	25.8
	Filtered tap water	37	19.9
	Bottled water	43	23.1
	Other	27	14.5
	No response	31	16.7
How would you rate the quality of water of your lake?	Very poor quality	5	2.7
	Poor quality	3	1.6

Table 2 (continued)

Characteristic	Properties of cottage/home Response	*n*	%
	Moderate quality	34	18.3
	Good quality	64	34.4
	Very good quality	50	26.9
	No response	30	16.1
What activities do you do on the water?	Swim	154	82.8
	Hike	66	35.5
	Walk	130	69.9
	Cycle	55	29.6
	Fish	91	48.9
	Motor boating	103	55.4
	Non-motor boating	136	73.1
	Water sports (water skiing, tubing)	66	35.5
	Other	27	14.5

Tables 3 and 4 provide the frequency distribution of responses to survey questions on the awareness and frequency of algae blooms and participants' concerns of the impact of algae blooms, respectively. Overall, awareness of algal blooms was high, with 152 (81.7%) respondents having heard of algal blooms at the time of completing the survey. More than half the respondents (54.8%) reported they believed that algal blooms have been occurring more frequently now than in the past. Approximately one-third (32.8%) of respondents reported the occurrence of algal blooms in the water at their cottage or waterfront home. When describing the frequency of algal blooms in the water over the past 10 years, 34.9% of respondents indicated that they have never happened, and 21.0% reported that they occur every year or every few years. 47.9% of respondents indicated that algal blooms are an insignificant or minor problem at their cottage or waterfront home. 14.5% indicated they are a moderate problem and 18.8% believe algal blooms are a big or major problem. Approximately 85% of respondents with a pet indicated some concern about the impact of algal blooms on the health of their pet(s).

Respondents were asked to rank the sources that they believe contributed most to algal blooms as well as the areas that are most impacted by algal blooms. Average scores for both questions are displayed in Table 4. Six contributing causes of algal blooms were given and were ranked from 1 to 6 (1 = biggest contributor and 6 = smallest contributor). The average scores calculated across all respondents were as follows: industrial pollution from factories (3.75), home water usage and lawn care (2.96), agricultural/farming practice (2.76), city wastewater treatment plans and sewer systems (4.11), changes in the lake causes by invasive fish/mussel species (4.48), and climate change (2.94). This suggest that, overall, respondents believe agricultural/farming practices to be greater contributors to algal blooms, while invasive fish/mussel species are considered smaller contributors. Five areas that are impacted by algal blooms were listed and respondents were asked to rank the impact of algal blooms on each area from 1 to 5 (1 = very low and 5 = very high). Mean scores were: drinking water (2.59), lake and wildlife (3.38), public resources (3.48), public health (3.42), and property values (3.43), indicating that, overall, respondents thought algal blooms have a modest impact on all areas. However, the impact on public resources was ranked the highest while the impact on drinking water was the lowest.138 respondents completed the SF-12 portion of the online survey. The means and standard deviations of respondents' PCS-12 and MCS-12 scores were 43.99 (5.78) and 51.92 (10.24), respectively. Those expressing moderate concern for algal blooms had a mean PCS-12 score of 42.50 which was 1.46 and 2.54 lower compared to those with low and high concern, respectively. Difference in PCS-12 score was also 1.08 higher in those with high level of concern compared to those with low concern. Mean MCS-12 score in those with moderate concern for algal blooms was 50.22, which was 1.88 and 3.17 lower compared to those with low and high concern, respectively. MCS-12 score was 1.30 higher in those with high level of concern compared to those with low concern. Results of one-way ANOVA revealed no significant differences in PCS-12 ($p = 0.269$) or MCS-12 score ($p = 0.512$) between those with low, moderate, and high concern for algal blooms. After adjusting for covariates (age, gender, and highest education attained), the ANCOVA also resulted in non-significant results for differences in PCS-12 ($p = 0.284$) and MCS-12 scores ($p = 0.579$) across groups.

The mean PCS-12 score was 44.22 in those who reported algal blooms occurring rarely and was 0.17 and 0.55 higher compared to those who reported algal blooms occurring often and never, respectively. Those who experienced algal blooms often also reported marginally higher PCS-12 score compared to those who reported algal blooms never occurring (difference of 0.37). Average MCS-12 score in those who reported algal blooms occurring often was 54.20. This score was 3.67 and 2.41 higher compared to those reporting algal blooms occurring rarely and never, respectively. Those who reported never experiencing algal blooms had a mean MCS-12 score 1.26 higher than those who reported experiencing algal blooms rarely. One-way ANOVA revealed non-significant differences in PCS-12 ($p = 0.899$) and MCS-12 ($p = 0.30$) scores between those who reported algal blooms occurring often, rarely, or never. Similarly, the ANCOVA was non-significant for PCS-12 ($p = 0.993$) and MCS-12 ($p = 0.16$) scores.

Table 3 Responses to questions on awareness and frequency of algae blooms

Awareness and Frequency of Algae Blooms			
Question	Response	*n*	%
Have you heard of algae blooms before doing this survey?	Yes	152	81.7
	No	5	2.7
	No response	29	15.6
If you answered yes to the previous question, where did you previously hear of algae blooms? (check all that apply)	Local news/radio	106	57.0
	From the internet	74	39.8
	From cottage neighbours	69	37.1
	From friends or family	51	27.4
	Announcements by governments	73	39.2
	Announcements by lake associations	91	48.9
	Other	8	4.3
	NA/No response	34	18.3
Are you aware of the occurrence of any previous algae blooms in the water at your cottage or waterfront home?	Yes	61	32.8
	No	95	51.1
	No response	30	16.1
If you answered yes to the previous questions, when was the last time an algae bloom occurred?	Rarely	21	34.4
	A few times	20	32.8
	Several times	7	3.8
	Almost every year	12	19.7
	NA/No response	126	67.7
Over the past 10 years, what statement best describes algae blooms in the water at your cottage or waterfront home?	They happen every year	14	7.5
	They happen every few years	25	13.4
	They rarely occur	37	19.9
	They have never happened	65	34.9
	Other	12	6.5
	No response	33	17.7
Do you think algae blooms occur more frequently than they have in the past?	Yes	102	54.8
	No	12	6.5
	I don't know	41	22.0
	No response	31	16.7

Those who had a high level of concern for their pet(s) had a PCS-12 score of 44.13 and an MCS-12 score of 48.73. Mean PCS-12 scores were 1.35 and 1.54 lower in those with moderate and low levels of concern, respectively. The difference in PCS-12 scores between those with moderate and low levels of concern was minor (0.18). Mean MCS-12 scores were 3.38 and 6.39 higher in those with moderate and low levels of concern, respectively, compared to those with a high level of concern. MCS-12 scores were also 3.01 higher in those with moderate concern compared to low concern. One-way ANOVA revealed that these differences in PCS-12 ($p = 0.594$) and MCS-12 score ($p = 0.134$) were not statistically significant. The ANCOVA also resulted in non-significant results for both PCS-12 ($p = 0.599$) and MCS-12 ($p = 0.223$) scores.

At the end of the survey, respondents were asked to share any additional comments they wanted to add, and 39 respondents (21.0%) provided further details. Thematic analysis of these responses revealed other factors that residents believe have influenced the occurrence of algal blooms, as well as the overall health of their lake. These included: (1) old and poorly regulated septic systems, (2) logging, (3) waterfront land clearing, (4) overcrowding of properties and people, (5) owners not picking up after their

Table 4 Responses to questions about the concern and impact of algae blooms

Concern and Impact of Algae Blooms			
Question	Response	*n*	%
To what extent do you believe algae blooms are a problem in the water at your cottage or waterfront home?	Insignificant	47	25.3
	Minor	42	22.6
	Moderate	27	14.5
	Big	22	11.8
	Major	13	7.0
	No response	35	18.8
Do you have any pets?	Yes	90	48.4
	No	60	32.3
	No response	36	19.4
If you answered yes to the previous question, are you concerned that algae blooms may impact the health of your pet(s)?	Yes	56	30.1
	Somewhat	20	10.8
	No	14	7.5
	No response	96	51.6
Ranking Questions	**Item**		**Mean**
Rank the impact of algae blooms on the following areas 1 = very low, 2 = low. 3 = moderate, 4 = high 5 = very high	Drinking water		2.59
	Lake and wildlife		3.38
	Public resources		3.48
	Public health		3.42
	Property values		3.43
Please rank the sources you believe contribute the most to Algae Blooms 1 – Biggest contributor 6 – Smallest contributor	Industrial pollution from factories		3.75
	Home water usage and lawn care		2.96
	Agricultural/ farming practice		2.76
	City wastewater treatment plans and sewer systems		4.11
	Changes in the lake by invasive fish/mussel species		4.48
	Climate change		2.94

dogs on the beach, and (5) spraying of flora and woods with glyphosate. Many respondents also called on the government and environmental association to implement additional regulations or protective activities.

Discussion

The findings from our survey indicate that a large portion of cottage and waterfront homeowners believe algal blooms are a problem, and that many are aware of the increasing frequency of algal blooms in recent years. However, in this study, many respondents did not consider algal blooms to be a large problem. Generally, people recognize blooms when they occur in their lakes. However, even in regions where blooms occur, people who live near lakes that have not yet been obviously affected are less concerned (Do et al. 2021). A potential reason for this could be related to property values. Waterfront properties are typically more valuable compared to those on adjacent land due to easy access to swimming, boating, and fishing. Poor water quality is known to affect both enjoyment and property values of waterfront property (Hjerppe et al. 2016; Nicholls and Crompton 2018). Therefore, perceptions of algal blooms are modified by the risks of loss of value of their properties. In this study, property owners may have chosen to understate their worries regarding algal blooms due to their concern for their property values.

In addition to characterizing concern for algal blooms, this study also sought to explore health risks associated with algal blooms and living near bodies of water. Compared to the average PCS-12 and MCS-12 scores in the general United States population (score of 50), the sample in this study had worse physical health, but slightly better mental health (Ware et al. 1998). Reasons for poorer physical health could include the high mean and median age of this sample, which is 60.2 and 61.0, respectively. Additionally, living near bodies of water and coastal regions has been shown to improve mental health outcomes, especially in elderly individuals (Chen and Yuan 2020; Garrett et al. 2019; Gascon et al. 2017). This may have resulted in a slightly higher average mental health score in this population. At the time of the study, no significant association between health and concern for algal blooms was found. However, data from Canada and elsewhere demonstrate that living near water has an important beneficial effect on health from non-accidental causes (Crouse et al. 2018). It is possible that the negative physical and mental health impacts caused by concern for algal blooms are negated by the beneficial health effects granted by living near a body of water.

A key finding of this study was that a large portion of this population demonstrated concern for their pet(s) health as it relates to HABs. This concern is well-founded as studies have suggested that animal illness and death related to algal blooms are closely linked to human health risks (Hilborn and Beasley 2015). Interestingly, in this study, mental health scores were notably lower in those who indicated concern for their pets' health as a result of algal blooms. Studies on algal blooms and mental health are not nearly as common as those focused on physical health symptoms as a result of exposure to HABs (Grattan et al. 2016; Trevino-Garrison et al. 2015). The few studies which have looked at mental health primarily explore the impacts as they relate to advisories or closures resulting from high levels of cyanobacteria in water supplies or fisheries (McCarty et al. 2016; Ritzman et al. 2018). This study's results may demonstrate a need to explore mental health impacts preceding algal bloom events, in individuals living in areas that are at high-risk of being affected by algal blooms. Additional education surrounding protective actions and identification of algal blooms should also be considered to help mitigate concern and potentially improve the mental health of cottage/waterfront homeowners.

Respondents in this study were also asked about the causes of algal blooms. There was substantial heterogeneity across these responses. At least 10% of the participants identified 5 of the 6 listed options as the most important contributor to algae blooms. Our study participants were drawn from several lakes across the province, and this may contribute to some of these observed differences. Despite this, perceptions of the causes of algal blooms tended to fall into two categories, those supported by evidence and a number lacking known scientific foundation. The 'most important causes' consistent with evidence listed, included municipal wastewater plants, farming, and lawn care as well as climate change. Some, but not all, respondents recognized the contribution of climate change on their frequency. Nutrient overload coupled with warming temperatures have driven the increase of freshwater algal blooms across Canada. Sediment cores taken across Canada and the northeast USA have reported algal toxins in cores dated pre-European settlement (Ewing et al. 2020; Pilon et al. 2019; Zastepa et al. 2017). Nutrients and temperature drive these changes. In the early days, nutrients from farming played the major role but as waterfront property was developed in rural areas, septic tanks became major driver of blooms in inland lakes (Celikkol et al. 2021; Mrdjen et al. 2018). Climate change has brought warmer summer temperatures which accelerates bloom growth. In areas where lakes freeze (as in New Brunswick) warmer temperatures have resulted in earlier ice-out dates thus lengthening the season (Ewing et al. 2020; Patterson and Swindles 2015; Walsh and Patterson 2022).

Respondents also identified lawn care as a large contributor to algal blooms. This is a contributing cause which has been the target of some lake preservation efforts. In fact, some jurisdictions in Canada encourage or require shoreline naturalization to limit nutrient flux into the lake or river from fertilizer as well as wild animal waste (Foulon et al. 2019). Despite their importance as precipitating causes of freshwater algal blooms, only a few respondents identified old or not to code septic tanks. Several people listed logging as a contributing factor. Recent studies of the impact of forestry on the watersheds indicated that in well-managed forestry operations in New Brunswick, nutrient flux into the adjacent watershed had little effect on the biota in the streams (Erdozain et al. 2018, 2021). One person suggested the use of glyphosate as a contributing factor. This speculation was the subject of an opinion paper suggesting that glyphosate use on farms contributed to phosphate loading (Hébert et al. 2018). However, a careful analysis of phosphate loading in agricultural areas by the US Geological Survey dismissed this as a relevant factor (Stackpoole et al. 2019).

While approximately 41% of respondents indicated that algae blooms posed a problem to the water quality of their lake, we observed substantial heterogeneity in their responses to the reported frequency of algae blooms over the last 10 years. This was consistently observed across all lakes for which multiple respondents participated in the survey. This could be due to a number of factors including localized blooms on larger lakes, and lack of communication amongst cottage owners about blooms. This finding underscores the need to increased dissemination about algae bloom occurrences throughout the province.

Overall, responses from the survey suggest that public policy and lake associations should prioritize lake conservation efforts and develop better policies to address algal blooms. In Canada, strategies used to ameliorate the effect of blooms have included regulation, incentives and outreach, engagement, and education. Thus far, this approach has only been partially successful (Foulon et al. 2019). As was the case here, a survey of lakefront property owners in New York State as to the causes of algal blooms reported factors supported by scientific evidence and opinions of a subset of the lay public (Armstrong et al. 2022). The authors reported that the differences in causal attributions resulted in "widespread intracommunity disagreement" which hampered management efforts. This demonstrated the need for meaningful public engagement in water management addressing causal beliefs within the community regardless of the science. Armstrong et al. (2022) suggested the need for the development of more appropriate educational materials on the impact of blooms and how to limit their occurrence as well as on community engagement. In addition to educational materials, respondents in this survey indicated a desire for more policies regarding septic systems and waterfront development. Work done in Quebec revealed that most but not all waterfront property owners are willing to pay for the improvements necessary to ameliorate problems with algal blooms (Schinck et al. 2020). This suggests that engagement of waterfront property owners is a key step in developing policies, initiatives, and activities that can effectively address and/or limit the negative impacts of HABs.

Limitations

A limitation of this study is the use of convenience sampling. Those who chose to participate in this survey may have done so because of their interest in and awareness of the environmental concerns. Therefore, caution should be used when generalizing the results and opinions of study respondents to all New Brunswick waterfront cottage and homeowners. However, to mitigate this, the survey was advertised generally and did not specifically mention algal blooms to avoid attracting respondents who were already aware of or concerned about algal blooms. Additionally, this study was not able to account for the many confounding factors that influence physical and mental health status, including the ongoing COVID-19 pandemic. Lastly, the survey relied on self-reported measures of health which are subject to social desirability bias.

Conclusions

Governments and local lake/cottage associations should bolster the monitoring of water bodies in New Brunswick and continue to communicate closely with waterfront property owners. Additional knowledge translation and community engagement activities need to be implemented to improve community understanding of the occurrence, identification, prevention, and management of algal blooms. Ways to reduce the impact of algal blooms on pets' and wildlife health is a key consideration as it may have implications on the mental health of waterfront property owners. Future research activities that monitor changes in health and activities following the occurrence of an algae bloom should be pursued to provide greater insights on the immediate impacts of these occurrences.

Acknowledgements The authors would like to thank Charlotte Salmon, Ph.D. student at the Institut National de la Recherche Scientifique (INRS) in Montreal Canada, for her assistance in translating the online survey from English to French.

Author contributions PJV, RTP, and JDM contributed to the conceptualization of this study and funding acquisition. PJV was responsible for project supervision. AM and PJV contributed to material preparation, including creation of the online survey. Sapriya Birk completed data analyses and writing of a first draft of the manuscript. JDM contributing to writing of the introduction and discussion sections. All authors reviewed the first and subsequent drafts and provided comments. The final manuscript was read and approved by all authors.

Funding This research was supported by funding from Carleton University's Multidisciplinary Catalyst Research Funding program (2020).

Compliance with Ethical Standards

Conflict of Interest The authors declare no competing interests.

Ethics Approval This study was approved by Carleton University's Research Ethics Board- B (Clearance #116123). The online survey included a statement on informed consent and explained the study's purpose, how anonymity and confidentiality will be maintained, and respondents' right to withdraw from the study at any time.

References

Anderson DM, Gilbert PM, Burkholder JM (2002) Harmful algal blooms and eutrophication: Nutrient sources, composition, and consequences. https://doi.org/10.1007/BF02804901

Armstrong A, Stedman RC, Sweet S, Hairston N (2022) What Causes Harmful Algal Blooms? A Case Study of Causal Attributions and Conflict in a Lakeshore Community. Environ Manag 69(3):588–599. https://doi.org/10.1007/s00267-021-01581-9

Bishop CT, Anet EF, Gorham PR (1959) Isolation and identification of the fast-death factor in Microcystis aeruginosa NRC-1. Can J Biochem Physiol 37(3):453–471

Brown, K H, Rossella C, Adrian R-P, & Janice L. (2021, September 7). Seasonality and distribution of cyanobacteria and microcystin toxin genes in an oligotrophic lake of Atlantic Canada. https://doi.org/10.1111/jpy.13210

Butler, N., Carlisle, JC, Linville, R., & Washburn, B. (2009). MICROCYSTINS: A Brief Overview of their Toxicity and Effects, with Special Reference to fish, Wildlife and Livestock (p. 21). California Environmnetal Protection Agency.

Celikkol S, Fortin N, Tromas N, Andriananjamanantsoa H, Greer CW (2021) Bioavailable Nutrients (N and P) and Precipitation Patterns Drive Cyanobacterial Blooms in Missisquoi Bay, Lake Champlain. Microorganisms 9(10):2097. https://doi.org/10.3390/microorganisms9102097

Centers for Disease Control and Prevention. (2022, March 1). Causes and Ecosystem Impacts | Harmful Algal Blooms | CDC. https://www.cdc.gov/habs/environment.html

Chen Y, Yuan Y (2020) The neighborhood effect of exposure to blue space on elderly individuals' mental health: A case study in Guangzhou, China. Health Place 63:102348. https://doi.org/10.1016/j.healthplace.2020.102348

Crouse D, Balram A, Hystad P, Pinault L, Chen H, van den Bosch M, Rainham D, Thomson E, Close C, van Donkelaar A, Martin R, Menard R, Robichaud A, Villeneuve PJ (2018, July 24). Associations between Living Near Water and Risk of Mortality among Urban Canadians—PubMed. https://pubmed.ncbi.nlm.nih.gov/30044232/

Do H, Mishra P, Yang L (2021) Mining Social Media to Assess Public PERCEPTION of Water Quality. https://dukespace.lib.duke.edu/dspace/handle/10161/22666

Erdozain M, Kidd KA, Emilson EJS, Capell SS, Kreutzweiser DP, Gray MA (2021) Forest management impacts on stream integrity at varying intensities and spatial scales: Do abiotic effects accumulate spatially? Sci Total Environ 753:141968. https://doi.org/10.1016/j.scitotenv.2020.141968

Erdozain M, Kidd K, Kreutzweiser D, Sibley P (2018) Linking stream ecosystem integrity to catchment and reach conditions in an intensively managed forest landscape. Ecosphere 9(5):e02278. https://doi.org/10.1002/ecs2.2278

Ewing H, Weathers KC, Cottingham KL, Leavitt PR, Greer ML, Carey CC, Steele BG, Fiorillo AU, Sowles JP (2020, June 17). "New" cyanobacterial blooms are not new: Two centuries of lake production are related to ice cover and land use—Ewing—2020—Ecosphere—Wiley Online Library. https://doi.org/10.1002/ecs2.3170

Foulon E, Rousseau A, Benoy G, North R (2019) A global scan of how the issue of nutrient loading and harmful algal blooms is being addressed by governments, non-governmental organizations, and volunteers. *Water Quality Research Journal*, 55. https://doi.org/10.2166/wqrj.2019.013

Garrett JK, Clitherow TJ, White MP, Wheeler BW, Fleming LE (2019) Coastal proximity and mental health among urban adults in England: The moderating effect of household income. Health Place 59:102200. https://doi.org/10.1016/j.healthplace.2019.102200

Gascon M, Zijlema W, Vert C, White MP, Nieuwenhuijsen MJ (2017) Outdoor blue spaces, human health and well-being: A systematic review of quantitative studies. Int J Hyg Environ Health 220(8):1207–1221. https://doi.org/10.1016/j.ijheh.2017.08.004

Gobler CJ (2020) Climate Change and Harmful Algal Blooms: Insights and perspective. Harmful Algae 91:101731. https://doi.org/10.1016/j.hal.2019.101731

Gorham PR (1960) Toxic Waterblooms of Blue-Green Algae. Can Vet J 1(6):235–245

Gorham P, Carmichael W (1980) Phycotoxins from blue-green algae. https://doi.org/10.1351/pac198052010165

Government of Canada. (2020, September 1). Remote sensing of algal blooms. Government of Canada. https://www.canada.ca/en/environment-climate-change/services/water-overview/satellite-earth-observations-lake-monitoring/remote-sensing-algal-blooms.html

Government of New Brunswick, C. (2019, November 4). Report released on water quality in province's lakes and rivers. https://www2.gnb.ca/content/gnb/en/departments/elg/news/news_release.2019.11.0572.html

Grattan LM, Holobaugh S, Morris JG (2016) Harmful algal blooms and public health. Harmful Algae 57:2–8. https://doi.org/10.1016/j.hal.2016.05.003

Griffith AW, Gobler CJ (2020) Harmful algal blooms: A climate change co-stressor in marine and freshwater ecosystems. Harmful Algae 91:101590. https://doi.org/10.1016/j.hal.2019.03.008

Hébert M-P, Fugère V, Gonzalez A (2018) The overlooked impact of rising glyphosate use on phosphorus loading in agricultural watersheds. Front Ecol Environ. 17. https://doi.org/10.1002/fee.1985

Hilborn ED, Beasley VR (2015) One Health and Cyanobacteria in Freshwater Systems: Animal Illnesses and Deaths Are Sentinel Events for Human Health Risks. Toxins 7(4):1374–1395. https://doi.org/10.3390/toxins7041374

Hjerppe T, Seppala E, Vaisanen S, & Marttunen M (2016) Monetary assessment of the recreational benefits of improved water quality – description of a new model and a case study. https://www.tandfonline.com/doi/abs/10.1080/09640568.2016.1268108

Lad A, Breidenbach JD, Su RC, Murray J, Kuang R, Mascarenhas A, Najjar J, Patel S, Hegde P, Youssef M, Breuler J, Kleinhenz AL, Ault AP, Westrick JA, Modyanov NN, Kennedy DJ, Haller ST (2022) As We Drink and Breathe: Adverse Health Effects of Microcystins and Other Harmful Algal Bloom Toxins in the Liver, Gut, Lungs and Beyond. Life (Basel, Switz) 12(3):418. https://doi.org/10.3390/life12030418

Lee J, Lee S, Jiang X (2017) Cyanobacterial Toxins in Freshwater and Food: Important Sources of Exposure to Humans. Annu Rev Food Sci Technol 8(1):281–304. https://doi.org/10.1146/annurev-food-030216-030116

McCarty CL, Nelson L, Eitniear S, Zgodzinski E, Zabala A, Billing L, DiOrio M (2016) Community Needs Assessment After Microcystin Toxin Contamination of a Municipal Water Supply—Lucas County, Ohio, September 2014. Morbidity Mortal Wkly Rep. 65(35):925–929

McKenzie CH, Bates SS, Martin JL, Haigh N, Howland KL, Lewis NI, Locke A, Peña A, Poulin M, Rochon A, Rourke WA, Scarratt MG, Starr M, Wells T (2021) Three decades of Canadian marine harmful algal events: Phytoplankton and phycotoxins of concern to human and ecosystem health. Harmful Algae 102:101852. https://doi.org/10.1016/j.hal.2020.101852

Mrdjen I, Fennessy S, Schaal A, Dennis R, Slonczewski JL, Lee S, Lee J (2018, August 7). Tile Drainage and Anthropogenic Land Use Contribute to Harmful Algal Blooms and Microbiota Shifts in Inland Water Bodies—PubMed. https://pubmed.ncbi.nlm.nih.gov/29952549/

Nicholls S, Crompton J (2018) A Comprehensive Review of the Evidence of the Impact of Surface Water Quality on Property Values. Sustainability 10(2):500. https://doi.org/10.3390/su10020500

O'Neil JM, Davis TW, Burford MA, Gobler CJ (2012) The rise of harmful cyanobacteria blooms: The potential roles of eutrophication and climate change. Harmful Algae 14:313–334. https://doi.org/10.1016/j.hal.2011.10.027

Orihel D, Bird D, Brylinsky M, Chen H, Donald D, Huang D, Giani A, Kinniburgh D, Kling H, Kotak B, Leavitt P, Nielsen C, Reedyk S, Rooney R, Watson S, Zurawell R, Vinebrooke R (2012) High microcystin concentrations occur only at low nitrogen-to-phosphorus ratios in nutrient-rich Canadian lakes. Can J Fish Aquat Sci 69:1457–1462. https://doi.org/10.1139/F2012-088

Paerl HW, Paul VJ (2012) Climate change: Links to global expansion of harmful cyanobacteria. Water Res 46(5):1349–1363. https://doi.org/10.1016/j.watres.2011.08.002

Patterson RT, Swindles GT (2015) Influence of ocean–atmospheric oscillations on lake ice phenology in eastern North America. Clim Dyn 45(9):2293–2308. https://doi.org/10.1007/s00382-014-2415-y

Pick FR (2016) Blooming algae: A Canadian perspective on the rise of toxic cyanobacteria. Can J Fish Aquat Sci 73(7):1149–1158. https://doi.org/10.1139/cjfas-2015-0470

Pilon, S., Zastepa, A., Taranu, ZE, Gregory-Eaves, I., Racine, M., Blais, JM, Poulain, AJ, & Pick, FR. (2019 February 12). Contrasting histories of microcystin-producing cyanobacteria in two temperate lakes as inferred from quantitative sediment DNA analyses: Lake and Reservoir Management: Vol 35, No 1. https://doi.org/10.1080/10402381.2018.1549625?journalCode=ulrm20

Rashidi H, Baulch H, Gill A, Bharadwaj L, Bradford L (2021) Monitoring, Managing, and Communicating Risk of Harmful Algal Blooms (HABs) in Recreational Resources across Canada. Environ Health Insights 15:11786302211014400. https://doi.org/10.1177/11786302211014401

Rasmussen B, Fletcher IR, Brocks JJ, Kilburn MR (2008) Reassessing the first appearance of eukaryotes and cyanobacteria Nature 455(7216):1101–4. https://doi.org/10.1038/nature07381

Ritzman J, Brodbeck A, Brostrom S, McGrew S, Dreyer S, Klinger T, Moore SK (2018) Economic and sociocultural impacts of fisheries closures in two fishing-dependent communities following the massive 2015 U.S. West Coast harmful algal bloom. Harmful Algae 80:35–45. https://doi.org/10.1016/j.hal.2018.09.002

Salyers MP, Bosworth HB, Swanson JW, Lamb-Pagone J, Osher FC (2000) Reliability and Validity of the SF-12 Health Survey among People with Severe Mental Illness. Med Care 38(11):1141–1150

Schinck M-P, L'Ecuyer-Sauvageau C, Leroux J, Kermagoret C, Dupras J (2020) Risk, Drinking Water and Harmful Algal Blooms: A Contingent Valuation of Water Bans. Water Resour Manag 34:1–15. https://doi.org/10.1007/s11269-020-02653-x

Stackpoole SM, Stets EG, Sprague LA (2019) Variable impacts of contemporary versus legacy agricultural phosphorus on US river water quality. Proc Natl Acad Sci 116(41):20562–20567. https://doi.org/10.1073/pnas.1903226116

Trevino-Garrison I, DeMent J, Ahmed FS, Haines-Lieber P, Langer T, Ménager H, Neff J, Van der Merwe D, Carney E (2015) Human Illnesses and Animal Deaths Associated with Freshwater Harmful Algal Blooms—Kansas. Toxins 7(2):353–366. https://doi.org/10.3390/toxins7020353

Turner AD, Lewis AM, Bradley K, Maskrey BH (2021) Marine invertebrate interactions with Harmful Algal Blooms–Implications for One Health. J Invertebr Pathol 186:107555. https://doi.org/10.1016/j.jip.2021.107555

US EPA, O. (2013, June 3). Harmful Algal Blooms [Collections and Lists]. United States Environmental Protection Agency. https://www.epa.gov/nutrientpollution/harmful-algal-blooms

Villeneuve, PJ (2022, May 31). New Brunswick Cottage and Waterfront Home Survey. Environmental & Occupational Epidemiology. https://carleton.ca/eoel/NB_CottageSurvey

Walsh CR, Patterson RT. (2022) Regional impact of large-scale climate oscillations on ice out variability in New Brunswick and Maine. PeerJ 10:e13741

Ware J, Kosinski M, Keller S. (1998). SF-12: How to Score the SF-12 Physical and Mental Health Summary Scales. Second Edition. The Health Institute, New England Medical Centre Boston, Massachusetts.

Winter JG, DeSellas AM, Fletcher R, Heintsch L, Morley A, Nakamoto L, Utsumi K (2011) Algal blooms in Ontario, Canada: Increases in reports since 1994. Lake Reserv Manag 27(2):107–114. https://doi.org/10.1080/07438141.2011.557765

Zastepa A, Taranu ZE, Kimpe LE, Blais JM, Gregory-Eaves I, Zurawell RW, Pick FR. (2017, February 1). Reconstructing a long-term record of microcystins from the analysis of lake sediments—ScienceDirect. https://www.sciencedirect.com/science/article/abs/pii/S0048969716324093

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.