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Status of state cyanoHAB outreach and monitoring efforts, United States

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Abstract

A widespread effort is underway to improve awareness of cyanobacteria harmful algal blooms (cyanoHABs) across the United States using a variety of monitoring programs and public health outreach measures to protect people, pets, and livestock. To determine the status of cyanoHAB outreach and monitoring efforts, 2 questionnaires were distributed to health/environmental departments in 50 states and the District of Columbia (DC). One questionnaire focused on cyanoHAB exposure to humans from drinking water and the second targeted exposure through recreational activities. All states plus DC responded to the recreational survey; 46 states plus DC responded to the drinking water survey. All states except Alaska answered that microcystins were the cyanotoxins of greatest concern for recreational exposure; microcystins were also of greatest concern for drinking water with the exception of Utah (anatoxin-a in reservoirs was greatest concern) and Rhode Island (microcystins and anatoxin-a in reservoirs/ponds were greatest concern). Regional comparisons disclosed a lack of cyanoHAB programs in southern states relative to northern states that may be related to the higher percentage of water surface area in northern states. Interestingly, recreational outreach is more extensive than drinking water outreach (only 16 states reported having some type of drinking water outreach program, compared with 35 states with recreational outreach), and preferred outreach methods are websites and press releases. Additionally, respondents reported very limited funding for outreach and monitoring programs. Our results establish baseline information to help determine what future direction cyanoHAB outreach and monitoring programs can take at local, regional, and national levels.

Keywords

CyanoHABs; exposure; HABs; monitoring programs; outreach efforts

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Mounting evidence indicates that current environmental conditions are likely to support increased frequency, intensity, and geographic extent of cyanobacterial harmful algal blooms (cyanoHABs; Jöhnk et al. 2008, Kosten et al. 2012, Havens and Paerl 2015, Ho et al. 2019). Because cyanoHABs threaten the quality and safety of waters used for recreation, drinking, agriculture, and aquaculture, additional resources would be helpful in maintaining and expanding monitoring programs.

Guidelines are available for exposure to and public health protection from some cyanotoxins; nevertheless, there is a limited amount of available toxicological data to support this effort. For example, the World Health Organization (WHO; Chorus and Bartram 1999) provided provisional guidelines for lifetime exposure to microcystin-LR in drinking water (1 μg/L), but a lack of information at the time prevented creation of guidelines for other cyanotoxins. Since then, several US states have developed their own guidelines that apply to cyanotoxins (i.e., microcystin, anatoxin-a, cylindrospermopsin, and saxitoxin) in drinking water. In 2015, the US Environmental Protection Agency (USEPA) published drinking water health advisories for cylindrospermopsin and microcystin. Although not regulations, the health advisories serve as technical guidance for the protection of public health. However, the USEPA determined there was not enough data available to develop drinking water health advisories for other cyanotoxins (USEPA 2015).

The WHO has also developed a recreational exposure guideline value for microcystins of 10 μg/L (Chorus and Bartram 1999). More recently, the USEPA produced criteria for recreational exposure to 2 cyanotoxins, microcystin-LR (8 μg/L) and cylindrospermopsin (15 μg/L; USEPA 2019). Previously, a number of states developed their own guidance for cyanotoxins in recreational waters in the absence of federal standards or criteria. Although it is anticipated that some, if not all, states that completed the survey will adopt the new EPA criteria based on discussions with agency staff from several states, as of June 2020 states have a wide range of guidance values they use for health-based evaluation of cyanotoxins.

Building on cyanotoxin benchmarks established by WHO and EPA for drinking water and recreational exposures, the USEPA, Centers for Disease Control and Prevention (CDC), and North American Lake Management Society (NALMS) each developed materials to assist states in monitoring and responding to cyanotoxin presence. Included in these materials is a communication toolbox with examples of educational messages and outreach that can be used to inform the public of health risks while recognizing the need to address different target audiences using diverse methods or materials. Many states (USEPA 2020a) also provide state-specific cyanoHAB information on websites, but materials vary in quality and quantity from state to state and locating that information can be difficult. Of further concern, static files may not be up to date with the latest information from scientific studies and public health activities such as cyanoHAB-associated disease surveillance.

Increasing reports of human and animal illnesses resulting from cyanoHAB exposures in the United States and elsewhere (Backer et al. 2013, Hilborn et al. 2014, Trevino-Garrison et al. 2015) demonstrate the urgent need for outreach materials that are written in simple language and are easily available to the public. With adoption of national drinking water health advisories and recreational criteria for cyanotoxins, the next steps will be to

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provide appropriate and effective local and regional educational resources and to improve distribution of notification and monitoring information.

The goal of this investigation was to determine the status of outreach and monitoring programs by states and regions in the United States, with the following objectives: 1) collect, consolidate, and compare information on state cyanoHAB monitoring and outreach efforts, 2) identify toxins of concern by states and regions, 3) identify areas of the United States that are lacking outreach and education materials, and 4) identify future needs. Results from this effort provide baseline information to help identify what direction outreach and monitoring programs can take at local, regional, and national levels.

Materials and methods

Survey questionnaires

To determine cyanoHAB monitoring and outreach efforts by state, 2 survey questionnaires (i.e., a recreational survey and a drinking water survey) were developed and then distributed nationally to health/environmental departments through the SurveyMonkey platform. This project was not human subjects research and did not require institutional review board (IRB) review. Prior to distribution, draft questions were reviewed and edited by state and federal personnel familiar with cyanoHAB outreach and monitoring programs. In addition, pilot surveys were deployed to states in EPA Region 10 (Washington, Idaho, Oregon, Alaska). Results and comments from the pilot surveys were used to refine questions before national distribution. Links to the final surveys were distributed from October 2017 through March 2018 via e-mail to previously identified state contacts, through a general request for state and tribal responses via the USEPA's HAB newsletter, through listings on various cyanoHAB listservs, and through other cyanoHAB contact referrals. If a state had not replied to the survey link by March, an attempt was made to contact potential respondents using e-mail addresses or phone numbers found through internet searches or by collecting information via word of mouth. The project attempted to get responses to both surveys from all 50 states and the District of Columbia (DC). Tribes were also encouraged to participate in the surveys.

Two separate questionnaires were designed to obtain information on state outreach and education efforts for: 1) recreational cyanoHAB exposure, and 2) drinking water cyanoHAB exposure. Each survey asked participants to identify the types of outreach and communication methods their respective jurisdiction uses to communicate information about cyanoHABs. Each survey was divided into 4 sections: 1) exposure concerns, 2) outreach and communication methods, 3) inland cyanobacteria monitoring programs, and 4) summary questions. The recreational survey comprised 37 questions while the drinking water survey contained 32 questions (SSI 1, SSI 2).

Exposure-related questions focused on determining whether a jurisdiction had an outreach program, the primary cyanotoxins and cyanobacteria genera of concern, the entity in the state responsible for outreach programs, and the type and amount of funding provided. Outreach and communication-related questions determined specific methods for outreach and the most effective or preferred communication methods employed by each state. Inland

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cyanobacteria monitoring-related questions asked whether toxins are monitored and the methodology used for testing toxins, whether a state has cyanotoxin guidelines in place, and how closure decisions are made for recreational areas and/or drinking water systems if cyanotoxins are present. Finally, summary questions asked whether recreational or drinking water exposure is thought to be a public health concern in the state, whether cyanoHABs are considered a growing problem, and other open-ended questions.

Question types included fixed-response questions requiring respondents to use a Likert scale, yes/no questions, forced answer questions, and open-ended questions (Fleming et al. 2007, Kuhar et al. 2009, Smith et al. 2014). Open-ended questions were used to encourage respondents to provide additional information that might be useful in understanding responses to fixed-response questions.

Data analysis

To determine whether there were any regional variations in survey responses, states were categorized 4 ways based on geography: 1) states east (n = 37) and west (n = 13) of the Rocky Mountains, 2) states east (n = 26) and west (n = 24) of the Mississippi River, 3) the USEPA's 10 regions, and 4) northern (n = 31) versus southern states (n = 19) to determine whether there were regional differences in survey response questions. Northern and southern states were divided based on the US Climate Regions identified by the National Oceanic and Atmospheric Administration (NOAA 2019). Southern states were defined as those in the West, Southwest, South, and Southeast climate regions. Northern states were defined as those in the Northwest, West North Central, East North Central, Central, and Northeast climate regions. Since there were no significant differences or patterns in the first 2 categories for any analyses and we did not have enough data to conduct meaningful statistical analysis for the third category, only the fourth category (northern vs. southern states) was assessed further. Fisher's exact test (one-tailed) was used to compare the presence of recreational and drinking water outreach programs in northern versus southern states. All statistical analyses were conducted using R statistical software.

Several states provided responses from more than one contact with different answers for one or more questions; for example, one contact would answer yes and the other contact would answer no for a particular question. When multiple answers occurred, states were re-contacted to clarify their response and only one answer was used for analyses. Open-ended questions did not undergo statistical analyses, and answers from these questions were used to understand answers to fixed-response questions.

Results

All 50 states plus DC responded to the recreational survey. Forty-six states plus DC responded to the drinking water survey; responses were not received from Georgia, Kentucky, Mississippi, or Oklahoma (Figure 1).

Although the primary objective of this study was to gather information on state cyanoHAB outreach programs, tribes were also encouraged to respond to the surveys. Two Indian Nations, Big Valley Band of Pomo Indians and the Elem Indian Colony of Pomo Indians

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from Clear Lake, California, completed the recreational and drinking water surveys. A summary of tribal survey results is presented; however, such limited data are not representative of regional or national tribal programs and perspectives.

Exposure

Recreation—Respondents were asked whether there is an outreach program in their state addressing recreational exposure to cyanoHABs. Significantly more recreational cyanoHAB outreach programs exist in northern states compared to southern states ($P = 0.03$; Figure 1).

Most states have multiple departments working together to run their recreational cyanoHAB outreach programs. The Department of Health was the department most frequently identified as being in charge of recreational outreach efforts or as a collaborative partner. Thirty-five states reported having a recreational cyanoHAB outreach program and, in general, funding for recreational programs has remained the same or increased over the past decade (Table 1). The amount of funding available for recreational outreach programs was relatively low for most states (i.e., $0–10,000).

Jurisdictions were asked to identify freshwater cyanobacteria and cyanotoxins of primary concern. All states except one responded that microcystins were the cyanotoxins of greatest concern; saxitoxin was identified as the primary concern in Alaska, apparently a result of this state's concern with paralytic shellfish poisoning in marine shellfish. States identified cylindrospermopsin, anatoxin-a, homoanatoxin, and saxitoxin as additional "cyanotoxins of concern." Eight states did not identify any specific cyanobacteria genera associated with recreational exposure, and remaining states identified *Microcystis* as the genera of greatest concern (Table 2). In addition to the genera listed (Table 2), *Planktothrix*, *Woronichinia*, *Aphanocapsa*, *Gloeotrichia*, *Aphanothece*, *Coelosphaerium*, and *Nodularia* were identified by several states as "genera of concern" for recreational exposure.

Drinking water—For drinking water exposure, respondents were asked whether there was a state outreach program addressing cyanoHABs. Similar to the recreational survey, a "yes" answer may indicate outreach efforts are underway but no formal statewide outreach program is in place, or a "no" answer may indicate that limited efforts are underway without an outreach program. Only 16 states reported having some type of outreach program addressing cyanoHABs in drinking water (Figure 1). Four of 19 southern states had a drinking water outreach program, compared to 11 of 31 northern states with a drinking water outreach program. Although the northern states had more drinking water outreach programs than the southern states, no significant difference was found between the 2 regions ($P = 0.445$).

State outreach programs addressing cyanoHAB drinking water exposure are led by multiple agencies, including Departments of Health, Environmental Conservation, Environmental Protection, Environmental Quality, and/or State Water Boards. Eight states reported funding for outreach efforts, including 2 that did not answer "yes" to having an outreach program (Florida, New Mexico). Most states do not have funding for drinking water programs (Table 1). Only 2 reported funding over $10,000 per year, and in most cases, funding appears to be from small grants, set-asides, or study-based funds (data not shown).

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Microcystins were the cyanotoxin of primary concern in drinking water, with the exception of Utah (anatoxin-a in reservoirs) and Rhode Island (microcystins and anatoxin-a in reservoirs and ponds). Lakes and reservoirs were reported by most states as waterbodies of most concern for drinking water and cyanoHABs; however, rivers and ponds were also mentioned by 22 states.

Outreach and communication methods

Recreation—States use a variety of outreach and education techniques to reach recreational users of waterbodies to alert them of cyanoHAB presence (Figure 2). Primary methods to notify the public include press releases, social media, and posters, followed by brochures and veterinary outreach. According to respondents, the most preferred outreach methods for recreational exposure to cyanoHABs are press releases, websites, and social media; 15 states use more than 5 methods to communicate information on cyanoHAB recreational exposure.

Drinking water—Most outreach efforts associated with drinking water focused on public water systems. States listed multiple methods of outreach techniques to reach the public and professionals regarding cyanotoxins in drinking water (Figure 2). Primary methods used nationally are workshops, conferences, press releases, and websites; 6 states use more than 5 methods to communicate information on cyanoHAB drinking water exposure. The 2 most preferred methods as reported by those surveyed were websites and press releases.

Inland cyanobacteria monitoring programs

Recreation—Toxin monitoring primarily focused on microcystins, followed by anatoxin-a and cylindrospermopsins (Table 3). Several states also monitor saxitoxins, lyngbyatoxins, or β-methylamino-l-alanine (BMAA), in addition to the more commonly monitored toxins.

States were also asked whether monitoring programs were routine or opportunistic. Twelve states use both types of monitoring programs for recreational waters. Eleven reported using routine monitoring programs, while 7 states sample in response to complaints or when blooms are observed. Several states are in the process of developing monitoring programs for waterbodies used for recreation.

Twenty-two states use cell counts to trigger advisories (n = 48 responses; Table 4). As an alternative to cell counts for advisories, health-based cyanotoxin guidance values are used by 24 states (n = 45 responses); 21 states do not use guidance values in lake management (the survey did not ask how guidance values were developed). Various concentrations are reported as guidance values for each of 4 cyanotoxins: microcystins, anatoxin-a, saxitoxins, and cylindrospermopsins. For microcystins, 8 states use USEPA (2016) draft criteria for microcystin-LR (i.e., 4 μg/L) in some part of their management strategy. Other microcystin action levels range from 0.8 to 20 μg/L, and 7 states use 2- or 3-tiered action levels for microcystins. For anatoxin-a, one state (Utah) uses the detection level as a guidance value and only 7 (California, Michigan, Missouri, New Jersey, Pennsylvania, Vermont, and Washington) have a numeric action level for anatoxin-a (range: 1 – 90 μg/L). Just 4 states (Missouri, Pennsylvania, Washington, and West Virginia) provided information on action

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levels for saxitoxins (range: 0.8 – 75 μg/L), while 13 states provided information on action levels for cylindrospermopsins (range: 1.0 – 20 μg/L). One state (Kentucky) uses remote sensing for screening.

Many states are working on procedures to close waterbodies in recreational areas in response to toxic blooms; however, several states have no protocols for closing recreational areas. Twenty-six states have procedures in place to close waterbodies if there is a toxic bloom, whereas 10 states do not implement closures. In general, state-level agencies have the authority to close waterbodies if there is a toxic bloom. However, in some states, the authority to close beaches or lakes lies with local authorities such as municipal boards of health, local health jurisdictions, and towns, rather than with a state-level agency.

Data from recreational monitoring programs are used by states for several purposes, primarily notification, general information, and to determine next steps (Table 5). Monitoring data are also used for research and trend analysis of blooms and toxic blooms.

Drinking water—Respondents were asked whether toxins are monitored in waters used for drinking water and, if so, which toxins. Of the 17 states that monitor drinking water for cyanoHABs, the majority monitor for microcystins and cylindrospermopsins (Table 3). Eight of the 17 states have routine programs and 9 have opportunistic sampling programs (monitor in response to a bloom) or use a combination of routine and opportunistic sampling. Of the states that responded to the question ($n = 45$), most states (31) have not developed their own drinking water guidance values, while 8 have their own drinking water guidance. The remainder (6) use the USEPA drinking water guidance values.

Data produced by monitoring of waters used for drinking water are used by states for notification, for general information, for trend analyses, to determine next steps, and for research (Table 5).

Summary questions

Recreation—States were asked to what extent recreational exposure to cyanoHABs is a public health concern. Most states that responded to this question believe recreational exposure is an important public health concern ($n = 26$ of 44 total responses; Table 6). Another 16 states believe recreational exposure is very important or extremely important, while only 2 thought recreational exposure was not important or of little importance in their state. Twenty states reported that recreational exposure to freshwater cyanoHABs has become more common over the past decade, while 12 states thought that exposure was the same. Eleven states either did not collect this information or did not have enough data to determine exposure trends.

Comments responding to open-ended questions in the recreational outreach questionnaire included a request for a risk communication toolkit. Another comment emphasized the need for communication on methods by which cyanoHAB events, fish kills, and health effects may be reported. Some states noted the importance of balancing cyanoHAB education and information on risks with the potential of scaring recreational lake users, particularly with posting too often at lakes with blooms.

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Drinking water—The majority of jurisdictions reported exposure to cyanoHABs in drinking water is an important public health concern (Table 6), of which 11 states reported it was very or extremely important. Nine other states reported that cyanoHABs in drinking water are of little or no importance as a public health concern. In response to a question on changing rates of toxic blooms, 20 states reported that cyanoHABs in drinking water are more common over the past decade, 12 states believe that cyanoHABs occur at about the same rate, while 11 states do not know or do not have any data to evaluate whether cyanoHABs are considered a growing problem. The survey did not ask whether responses were based on professional opinion or on trend data.

Most states did not answer the question “has the monitoring program for cyanoHABs in drinking water been evaluated?” Eleven states answered that their program has not been evaluated. Only California, Wisconsin, and Hawaii have programs that have been evaluated; a follow-up question asked how their program was evaluated. For one of the 3 states, the program is under review by independent experts, another state has program staff annually evaluate and modify the program as appropriate, and the third said that its cyanoHAB response strategy is reviewed and updated annually.

Several respondents commented that their state is developing a drinking water cyanoHABs monitoring program; thus, results for numerous questions may be changing soon (or may have changed while this publication was in preparation). Another respondent commented that federal funding for the development of cyanoHAB monitoring programs would be very helpful in identifying threats and justifying future state-funded programs.

Tribal summary

Recreation—Two tribes on Clear Lake, California, responded to the recreational survey; both have funding for cyanoHAB outreach programs. Microcystin is the cyanotoxin of most concern, with *Microcystis*, *Dolichospermum* (formerly *Anabaena*), and *Aphanizomenon* listed as genera of concern. The tribes also test for anatoxin-a and cylindrospermopsin. Both tribes use 0.8 μg/L microcystin as a health-based standard to post advisories in addition to using cell densities in advisory decisions. Outreach is conducted by workshops, public meetings, posters, and press releases, with preferred methods being social media and websites. Monitoring data are used for notification, for general information, for research, and to advise the community on cyanoHAB risks. The tribes consider recreational exposure to cyanoHABs to be an extremely important public health concern. Their outreach programs are evaluated by the number of hits on website posts.

Drinking water—The one tribe that responded to the drinking water outreach and monitoring survey has an outreach program with funding and considers microcystins of primary concern. Clear Lake, California, is the waterbody being monitored; the tribe has not developed health advisories for drinking water and considers this route of exposure to be “a little important” in terms of a public health concern. The tribe’s primary approach used in drinking water education and outreach is its website, along with workshops and press releases. The tribe is collaborating with county and state public health agencies on developing regional websites to address drinking water and cyanoHABs.

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Discussion

As cyanoHABs continue to proliferate in waterbodies worldwide, the need for outreach programs to communicate health risks associated with the blooms will continue to grow (Kirkpatrick et al. 2004, Fleming et al. 2007, Smith et al. 2014, Hardy et al. 2016). The most important outcome from this study is the summary of wide-ranging and detailed baseline information that can be used to direct prospective attempts to identify and evaluate outreach methods for effectiveness. In addition, survey results can be used by jurisdictions to develop new or expanded cyanoHAB monitoring and educational programs. For example, our study indicated that the most useful methods to provide cyanoHAB-related information as identified by respondents include press releases and websites, along with conferences/workshops for drinking water outreach. Press releases may help reach others who do not necessarily use the internet but who receive information via radio or television. Further, connecting educational materials to data in relatable ways is critical and often overlooked. Adding materials to existing state and local websites can help website visitors already used to looking for health-related information at those sites.

This study revealed the extent of US outreach programs by state and highlighted different approaches used for notifying residents of health threats associated with cyanotoxin exposure. One of the more interesting findings was the lack of cyanoHAB outreach programs in southern states relative to northern states. Reasons for this geographical difference in outreach efforts are unknown. A comparison shows that northern states have 9.3% of total surface area covered by water whereas southern states (not including Hawaii) have only 4.8% covered by water (USGS 2020). Thus, the greater frequency of cyanoHAB outreach programs in the north may be related to the amount or percentage of water surface area in those states. However, this is not always true because several northern states with high percentages of water surface area, such as Michigan (41%) and Alaska (14.2%), did not report having cyanoHAB outreach programs at the time of the surveys. Further, the 2012 National Lakes Assessment conducted by the USEPA (2020b) showed that most natural lakes are in the Upper Midwest, Northern Appalachians, Temperate Plains, Coastal Plains, and the Western Mountains. Thus, there might be a tendency for states with more water and natural lakes to have cyanoHAB outreach programs, but there are exceptions. An additional factor might be differences in recreational pressure and demand between states. Another consideration is that the presence or absence of outreach programs is associated with weather and/or climate conditions over the past decade. For example, many of the states considered “southern states” in our analysis were in severe to exceptional drought conditions in the last decade, including during October 2017 when the survey was initiated (United States Drought Monitor 2020). Severe drought may divert resources from cyanoHAB-related issues as states deal with the higher priority issue of drought. Interestingly, drought is often associated with greater cyanoHAB occurrences (e.g., Lürling et al. 2018, Walter et al. 2018).

The 2012 National Lakes Assessment provided a summary of water quality results (e.g., percent of lakes with cyanobacteria problems, percent of lakes most disturbed or percent eutrophic, percent of lakes with phosphorus as the most important nutrient problem) by different ecoregions (coastal plains, northern Appalachian, northern plains, southern Appalachian, southern plains, temperate plains, upper Midwest, western mountains, and

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xeric). While interesting patterns were determined in the assessment, the findings did not fall into a northern versus southern configuration, likely since the ecoregions were not organized by state and thus did not reflect similar regional groups. Another reason why our data and the National Lakes Assessment may be different is that each considered a different aspect of cyanoHABs. We examined outreach programs within state, regional, and tribal agencies, whereas the National Lakes Assessment used monitoring data by state and federal agencies to gauge water quality. Water quality monitoring may be a priority for one agency in a state, while outreach programs may not receive the resources to be a priority for a different agency within the same state.

Also of note is that the majority of jurisdictions responding to each survey reported that exposure to cyanoHABs is an important or very important public health concern, reflecting growing awareness at the state level of this issue. Nevertheless, several states reported that exposure is not important or a little important; it would be helpful to provide more outreach and education in these states. There was no apparent pattern in characteristics (e.g., region, amount of shoreline) across the states that responded this way.

Most states focus on microcystins for both recreational and drinking water monitoring. Microcystins are reported as the most prevalent cyanotoxin worldwide (Boyer 2007, Harke et al. 2016) and in numerous states (e.g., Burns 2008, Graham et al. 2010, Ohio Environmental Protection Agency 2012, Trainer and Hardy 2015), while cylindrospermopsins have been problematic in Texas, Florida, Ohio, Indiana, and Kentucky, with saxitoxins more common in the upper Midwest and south (Graham and Loftin 2014). To date, microcystins have been somewhat easily analyzed (using enzyme-linked immunosorbent assay, ELISA) which may also explain the focus on microcystin testing compared with other cyanotoxins. Newer, relatively inexpensive monitoring tools such as qPCR and DNA probes may allow broader testing of recreational and drinking waters, resulting in more frequent observations of other cyanotoxins, although these techniques require skilled technicians using specialized equipment that states may not have.

The biggest limitation of this project is that survey answers represent states' cyanoHAB outreach status during a brief period (Nov 2017–Mar 2018). Recently, work has been underway in many jurisdictions to develop or improve monitoring and outreach methodologies. Thus, results should be interpreted as a snapshot of efforts from which to compare future developments as cyanoHAB problems continue to gain public awareness. Another limitation is that the survey question regarding whether exposure to cyanoHABs has become more common over the past decade does not differentiate whether increases are due to increased toxic blooms or to behavioral changes resulting in heightened awareness as the public receives more information on the topic. A third project uncertainty is that some respondents had greater knowledge of their state's outreach programs than did others. The survey asked what department or agency respondents represented but did not ask the role of each respondent in terms of cyanoHAB efforts. Thus, answers for more active states likely reflect respondents' greater knowledge of those states' cyanoHAB activities, while answers by respondents in less active states may reflect a respondent's best guess. This reveals the importance of providing cyanoHAB information to state and local (i.e., county) staff

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members who work with the public on water-related issues so they may inform residents of precautions that can be taken when interacting with cyanoHAB-contaminated waters.

The status of tribal efforts to document cyanoHABs based on these surveys is largely unknown since only 2 tribes responded to national distribution requests for survey responses, with both addressing one lake in California. Their monitoring programs are thorough and outreach efforts for recreational exposure are extensive. Nonetheless, knowledge of tribal outreach and education efforts represents an important data gap. Requests for participation used several methods, including e-mails to known contacts, an open request for state and tribal responses on the USEPA's HAB newsletter, and notifications on several cyanoHAB listservs. These methods were not sufficient to obtain representative tribal contacts; the limited response rate may be due to the lack of a central repository of tribal contacts for those working on freshwater cyanotoxin education. Asking states and local agencies for tribal contacts could help in future efforts. Numerous tribal populations work on cyanoHABs across the country: for example, the Yurok and Karuk Tribes on the Klamath River, Confederated Tribes of the Colville Reservation in northeast Washington, and Colorado River Indian Tribes (Chemehuevi, Hopi, Mojave, Navajo). Future research must identify risks and support appropriate communication tools associated with cyanoHAB exposures for tribal communities working directly with tribal leadership to understand their needs.

Survey results highlight several future needs. First, funding for monitoring is often needed before meaningful outreach and education can be undertaken. Second, additional outreach and education efforts associated with each type of cyanoHAB exposure would be helpful in reducing public health risks. This study identified that funding for education about cyanoHABs in drinking water is very limited. Members of local agencies as well as the public would benefit from basic education about drinking water exposure before incidents occur to help them understand risks and prepare for the event of drinking water contamination. Recent unprecedented large-scale incidents where cyanotoxins were found in drinking water leading to drinking water closures in Ohio (2014) and Oregon (2018) illustrate the need for educating the public on potential risks before a contamination event. Funding for recreational outreach and education is intermittent in some states and nonexistent in others (20 states report no funding), an important gap because information about potential risks of recreating in waters with blooms is critical for primary public health protection, that is, preventing exposure. Further, basic education is essential to improve opportunistic monitoring, given that the public is often the first to observe blooms and then alert agencies tasked with testing for toxicity and posting of potential risks. Resources that provide information, funding, and appropriate tools to agencies responsible for protecting human health can help develop effective outreach systems to educate residents.

Few states have conducted evaluation of outreach effectiveness; only 3 reported having an evaluation component as part of their education program. Without evaluation or feedback of some kind, states cannot determine whether their program is effective and successful. Important next steps in cyanoHAB outreach and education will be evaluating effectiveness on target audiences. The USEPA (2020c) provides a guide to evaluate effectiveness of outreach in a watershed. The guide, which can be used to incorporate evaluation of cyanoHAB programs, emphasizes the importance of building an evaluation component

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into outreach plans at the beginning of a program to allow adaptive management based on new information. The USEPA suggests incorporating 3 types of evaluation: 1) process evaluation—has a focus on implementation of the program; 2) impact evaluation—relates to achievement of project goals and objectives; and 3) context evaluation—has a focus on how the project functions in a community. An evaluation uses indicators to assess and communicate how a program is doing, and the USEPA lists 3 types of indicators: administrative indicators (i.e., bean-counting approach, such as number of people trained, number of public meetings, number of press releases), social indicators (i.e., measures of changes in attitudes or behaviors, such as number of hotline calls, number of people surveyed with increased knowledge of issues), and environmental indicators (i.e., measures of environmental improvements, such as number of people who purchased rain barrels). Assessment tools include activities such as focus groups, surveys, interviews, and water quality data. The USEPA evaluation guidance will be useful in evaluating the most preferred methods of notification and education identified from the surveys: websites, press releases for both recreation and drinking water outreach, and workshops/conferences for drinking water outreach.

Each survey allowed for general comments by respondents. Remarks from jurisdictions indicate the importance of balancing education of the public on cyanotoxins and potential health risks with scaring people from using water for recreation. An anecdotal observation is that care needs to be taken in posting lakes with blooms to prevent “sign fatigue,” a situation reported by local health agencies in which recreational users get so used to signs that they ignore blooms unless press coverage reports dead animals or human illnesses.

Current efforts to communicate cyanoHAB risks

An important finding from the surveys is that the most preferred outreach and education methods for recreational exposure to cyanoHABs by state and tribal respondents are press releases, websites, and social media. For drinking water, 2 preferred methods are websites and press releases, but conferences and workshops play a larger role in targeting specific audiences. In general, states used a greater variety of methods to address recreational exposure than drinking water exposure. It is important to distinguish between education efforts versus notification of toxic events. Hardy et al. (2016) ranked effectiveness of various approaches in 3 Washington State counties and found listserv notification of toxicity tests and a web-based cyanoHAB database worked best for actual bloom events, while press releases were valuable when used sparingly for severe blooms in larger lakes. E-blasts or weekly e-mails were most effective at the county level, and the study concluded that the simultaneous use of multiple notification approaches was most productive.

With no standardized outreach and education approaches in place at the national level, states are left to develop their own outreach methods or use sample tactics given by the CDC, NALMS, and USEPA. Several federal agencies have developed resources to support states and regions in their cyanoHAB outreach and education. Most relevant is the CDC’s online toolkit directed to public health professionals to help with communication regarding cyanoHABs (CDC 2020a). Sample messages for Twitter and Facebook are provided for a variety of topics such as general awareness, recreational water, pets, illnesses, and

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surveillance. The CDC (2020b) also provides a Clear Communication Index, a tool to help assess public communication materials. The USEPA (2020d) has an online interactive map with links to cyanoHAB information in each state that can effectively connect those interested in current efforts at the state level with resources within states. The USEPA (2020e) also has a link to information on drinking water and cyanoHABs. Background information on cyanoHABs and links to programs in the United States and Canada are available at websites such as those of the North American Lake Management Society (NALMS 2020) and National Oceanic and Atmospheric Administration (NOAA 2020) as well as many state websites.

Examples from 3 states, given next, illustrate that there are various target audiences to consider when developing unique materials to meet outreach goals, and this study and others emphasize that education strategies must consider advances in communication technologies (NSB 2002, Nierenberg et al. 2011, NASEM 2016). Previous assessments of cyanoHAB outreach recognized that different target audiences may be addressed using diverse methods or materials (Kirkpatrick et al. 2004, Smith et al. 2014, Hardy et al. 2016). In Louisiana, researchers surveyed needs of people in fishing areas before creating an educational brochure focused on algae and HABs to distribute to regional contacts, then evaluated effectiveness (Smith 2014, Smith et al. 2014). Florida investigators developed unique products to enhance information sharing and convey research results to the public (Kirkpatrick et al. 2004, Florida Health 2020). Activities in Florida include basic print material, an interactive website, and video and social networking. In an assessment of cyanoHAB education and notification efforts in 3 Washington State counties, 3 target audiences were identified: technical professionals, external or general lake users, and lake residents (Hardy et al. 2016). For technical professionals, several approaches were identified as most effective for this audience, including technical support and educational materials, along with workshops and webinars, professional conferences, and stake-holder involvement. For external or general lake users, educational activities, informational signs, lake management protocol signs, and press releases work best for notification and education. The third target audience was lake residents, who likely use lakes frequently, with resulting outreach goals being notification to reduce exposure while increasing general HAB awareness. The study recommended using preseason mailers, responsive mailers, electronic alerts, and websites for this group. Another possible method to conduct outreach with lake residents is to involve them in citizen science activities to monitor waterbodies for cyanoHABs.

Lessons learned and next steps

A 2016 report on HABs recommended actions to improve communication about HAB exposure risks (NSTC 2016). Authors of the Harmful Algal Blooms and Hypoxia Comprehensive Research Plan and Action Strategy developed by the National Science and Technology Council Subcommittee on Ocean Science and Technology state that most HAB toxicity studies focus on information for scientists but not for the public, although public education is the goal of most state and local agency outreach programs. The report also recommends that the most effective communication of science to the public should use

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evidence-based information, a suggestion that would help improve cyanoHAB outreach education and notification if adopted by jurisdictions.

Approaches used for other environmental health issues such as fish advisories and outdoor smoke warnings provide useful tips for developing products for public health education. For example, fish advisories aim to educate consumers on risks and benefits of eating fish, which is a more complicated message than educating lake users about cyanoHAB risks (Burger and Gochfeld 2009). Recent evaluation efforts on fish advisories highlight their poor performance even though agencies have been issuing fish consumption advice for 40 years (Teisl et al. 2011). Scherer et al. (2008) suggest that because messages on risks and benefits of fish consumption are uneven across the United States, agencies should collaborate to share lessons learned using workshops or online forums, including the development of best practices for specific media (e.g., web-based, print). These recommendations also apply to messages about cyanoHABs. Another study attempted to evaluate the effectiveness of public health messaging during smoke events caused by wildfires since 2009 and concluded that messages with simple language result in better compliance, social media platforms may be useful, and experimental research and evaluations are required to determine effectiveness of various outreach techniques (Fish et al. 2017). Researchers also concluded that multiple methods of communication, including bidirectional means, may be useful for reaching a wide audience; a similar conclusion was reached by those working on cyanoHAB messaging (Hardy et al. 2016). The 2 examples illustrate important lessons jurisdictions can learn from groups that have evaluated messaging for other environmental health issues to allow collective improvement of cyanoHAB message clarity.

A number of concepts can help states with cyanoHAB messaging. For example, an article in *The Nation's Health*, a publication of American Public Health Association (APHA; Krisberg 2015), focused on new ways to communicate about environmental health issues to engage people and connect with healthy communities. APHA along with the Frame Works Institute released "Framing Environmental Health," a toolkit with research, communication samples, and messaging recommendations to help partners develop better outreach strategies. The report recommended including 3 main tools for reframing public dialogue about environmental health work: values, explanatory metaphors, and solutions. Among the many values that researchers tested, the idea of "fairness across places" can be an effective way to frame conversations about environmental health. Other investigators have analyzed word patterns in multiple health messages and identified several concepts as essential elements in health messages. The 4 common ideas include a message recipient, threats to health, actions to be performed to reduce the threat, and benefits achieved from performing the actions (Morrison et al. 2005).

Summary and conclusions

Recreational and drinking water cyanoHAB survey results identified a wide variety of outreach and notification efforts used by the 50 states surveyed. Recreational outreach is more extensive than drinking water efforts, but activities range from extensive in some states to nonexistent in others for both types of notification and awareness education. A fundamental issue is that funding for outreach and notification of cyanoHAB blooms is

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rare and inconsistent in most jurisdictions. Additional assistance to states and regions to address this growing public health threat for both drinking water education and recreational notification could help the programs address this issue. While some national materials are available to assist with communication, a federal approach alone is not enough because in most cases specific target audiences need to be identified at a local level. Our study found that the most preferred outreach methods by states and tribes include websites and press releases, forms of communication that can be tailored to focus on local- or regional-level interests while utilizing the scientific information available at the national level.

Human population growth and more frequent, intensive, and geographically extensive cyanoHABs are amplifying human health risks from cyanotoxin exposures. Thus, there is a growing urgency to improve policies and public health education to help lake, reservoir, and river users make informed choices to reduce cyanoHAB-associated health risks.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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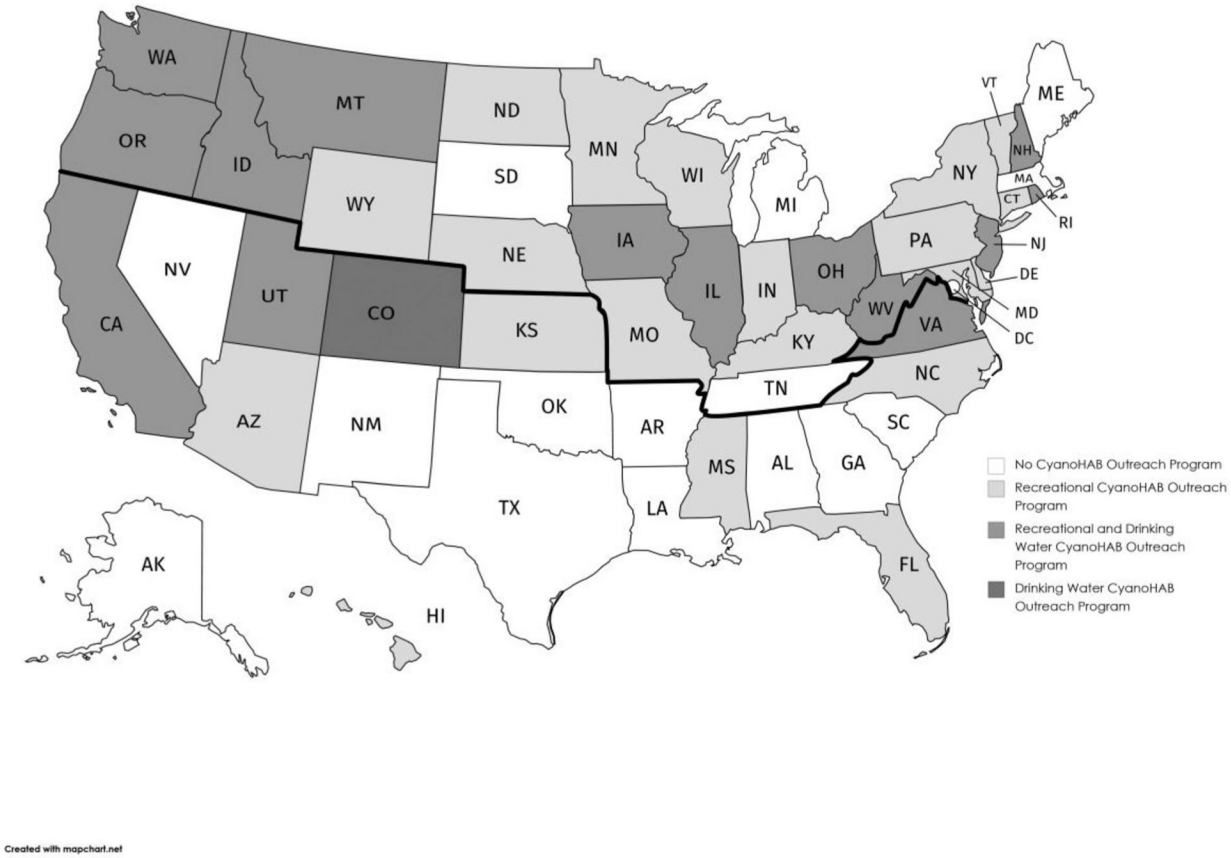

Figure 1.

Summary of states with cyanoHAB outreach programs (2018) for recreation ($n = 50$) and drinking water ($n = 46$) (Georgia, Kentucky, Mississippi, and Oklahoma did not complete the drinking water survey). Colorado is the only state that has a drinking water program but not a recreational water program.

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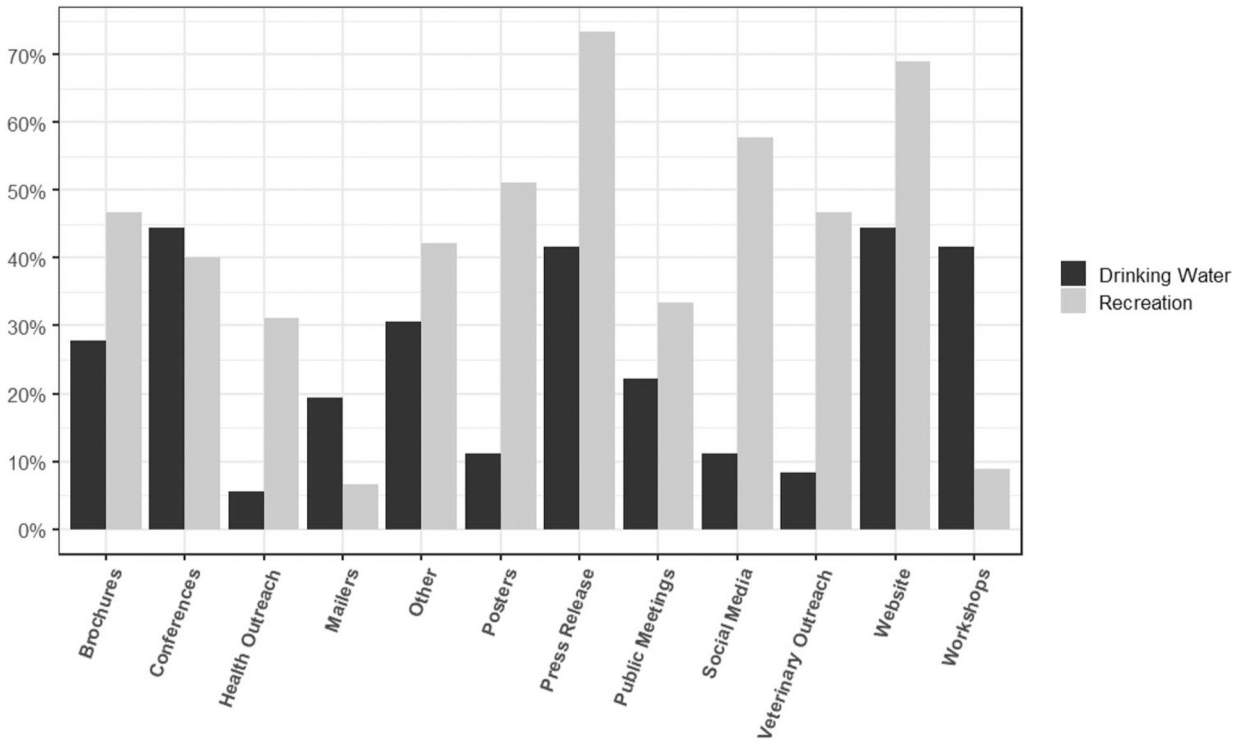

Figure 2.

Outreach and communication techniques reported by states (2018) to address recreation (n = 45) and drinking water (n = 36) cyanoHAB issues. Survey participants were given the option to choose more than one technique per state.

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Table 1.

Trend of funding changes over the past decade and the amount of funding for recreational and drinking water outreach programs.

Funding changes over the past decade		
	Number of states	
Trend	**Recreational programs (*n* = 44)**	**Drinking water (*n* = 35)**
No funding	20	21
Less funding	5	0
Same funding	11	8
More funding	8	6
Available funding amount		
	Number of states	
Amount	**Recreational programs (*n* = 25)**	**Drinking water programs (*n* = 21)**
0–$10,000	18	19
$10–25,000	3	1
$25–50,000	2	0
> $50,000	2	1

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Table 2.

Genera and percent of states concerned about recreational exposure to each category.

Genera	Percent of states that identified the genera as a concern
Aphanizomenon	50%
Cylindrospermopsis	38%
Dolichospermum/Anabaena	66%
Lyngbya	24%
Microcystis	88%
Oscillatoria	30%

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Table 3.

Number of states in which various cyanotoxins are monitored in waterbodies used for recreation or for drinking water.

Cyanotoxin	Number of states: recreation	Number of states: drinking water
Microcystins	33	15
Anatoxin-a	22	8
Cylindrospermopsins	23	13
Saxitoxins	9	3
Lyngbyatoxins	1	0
BMAA	2	0

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Table 4.

Number of states using cell counts and/or cyanotoxin guidance values in advisories, and number of states using cyanotoxin guidance values for specific cyanotoxins.

Lake management alternatives		
Advisories	**Number of states**	**Sample size**
Use cell counts	22	$n = 48$
Use health-based cyanotoxin guidance values	24	$n = 45$
Use cyanotoxin guidance values	**Number of states**	**Range**
Microcystins	26	0.8–20 μg/L
Anatoxin-a	8	1–90 μg/L
Saxitoxins	4	0.8–75 μg/L
Cylindrospermopsins	13	1.0–20 μg/L

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Table 5.

How monitoring data are used by recreational and drinking water programs.

How are data used?	Recreational sampling	Drinking water sampling
Notification	30	15
General information	25	14
Trend analyses	14	12
Figure out next steps	24	14
Research	16	12
Other (education, compliance)	2	2

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Table 6.

The extent of public health concerns for recreational or drinking water exposure in each state.

Level of public health concern	Recreational exposure: number of states	Drinking water exposure: number of states
Not important	1	1
A little important	1	8
Important	26	21
Very important	10	8
Extremely important	6	3