Distribution Agreement

In presenting this thesis or dissertation as a partial fulfillment of the requirements for an advanced degree from Emory University, I hereby grant to Emory University and its agents the non-exclusive license to archive, make accessible, and display my thesis or dissertation in whole or in part in all forms of media, now or hereafter known, including display on the world wide web. I understand that I may select some access restrictions as part of the online submission of this thesis or dissertation. I retain all ownership rights to the copyright of the thesis or dissertation. I also retain the right to use in future works (such as articles or books) all or part of this thesis or dissertation.

Signature:

_________________________________ ________________

Sarah Verlander Date

Assessing Indicators of State Capacity for Harmful Algal Bloom Reporting Since the Launch of the CDC One Health Harmful Algal Bloom System in 2016

By

Sarah Verlander
Master of Science in Public Health

Environmental Health- Epidemiology

____

Stefanie Ebelt, ScD
Committee Chair

Assessing Indicators of State Capacity for Harmful Algal Bloom Reporting Since the Launch of the CDC One Health Harmful Algal Bloom System in 2016

By

Sarah Verlander

M.S.P.H., Emory University, 2022
B.S., Georgia Institute of Technology, 2020

Thesis Committee Chair: Stefanie Ebelt, ScD

An abstract of
a thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
Master of Science in Public Health
in Environmental Health- Epidemiology
2022

Abstract

Assessing Indicators of State Capacity for Harmful Algal Bloom Reporting Since the Launch of the CDC One Health Harmful Algal Bloom System in 2016

By Sarah Verlander

Background: Harmful algal blooms (HABs) are a major environmental hazard that impact all 50 U.S. states and pose a threat to the health of humans, animals and the shared ecosystem. The One Health Harmful Algal Bloom System (OHHABS) was established in 2016 to form a national public health system collecting information on HABs and the illnesses they can cause in humans and animals. The goal of this study is to assess a series of proxy indicators of state reporting capacity of harmful algal blooms for possible associations with adoption of the OHHABS national reporting mechanism. **Methods**: A series of indicators of HAB surveillance capabilities were developed based upon Centers for Disease Control and Prevention (CDC) funding sources, state public health department structure, and state-supported online HAB resources. Logistic regression was used to investigate associations between state participation in OHHABS and the indicators of HAB surveillance capabilities. A secondary analysis using Likelihood Ratio Tests (LRT) was conducted to determine whether a joint effect may exist between multiple funding sources or state public health department characteristics on state participation in OHHABS. **Results**: While the proposed HAB surveillance capacity indicators were not statistically associated with state OHHABS participation in the proposed model, several descriptive and unadjusted associations merit further research efforts regarding funding sources and online public reporting mechanisms. **Conclusion**: The results suggest a need for further investigation into the contribution of state funding sources, structural components of state health departments, and online informational resources to HAB surveillance and response capacity.

Assessing Indicators of State Capacity for Harmful Algal Bloom Reporting Since the Launch of the CDC One Health Harmful Algal Bloom System in 2016

By

Sarah Verlander

B.S.
Georgia Institute of Technology
2020

Thesis Committee Chair: Stefanie Ebelt, ScD

A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
Master of Public Health or Master of Science in Public Health
in Environmental Health- Epidemiology
2022

Acknowledgements

I want to thank my incredibly knowledgeable and insightful mentors in this process, Virginia Roberts and Dr. Stefanie Ebelt. I am incredibly grateful to have been able to collaborate with the entire HABs Team at CDC. I would like to acknowledge the immense help of Marissa Vigar in designing the thesis project and providing the OHHABS data for use. I would also like to thank Megan Gerdes, Shelly Gleason, and the entire NORS Team for their provision of NORS data. Thank you to Justin Gerding and Michele Monti for their expertise on the Environmental Health Capacity and National Environmental Public Health Tracking funding programs. To all of my grandparents, parents, siblings, and friends who have been with me every step of the way, I cannot thank you enough.

Disclaimer

The findings and conclusions in this report are those of the author(s) and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

Table of Contents

INTRODUCTION 1

Introducing the Problem: 1

National Efforts to Surveil the Public Health Impacts of Harmful Algal Blooms 4

HAB Reporting Capacity of State Public Health Departments 6

Purpose of Project 8

Projected Significance 9

METHODS 10

Data Collection 10

OHHABS Reporting 10

Funding Measures 10

State Indicators of Public Health Capacity 12

Additional Covariates of Consideration 13

Data Analysis 14

RESULTS 18

Logistic Regression Analysis 22

DISCUSSION 36

REFERENCES 40

APPENDICES 45

Appendix A: Abbreviations 45

Appendix B: Online Web Links to State HAB Resources 46

INTRODUCTION

Introducing the Problem:

Harmful algal blooms (HABs) are a growing environmental concern across the United States with far-reaching public health impacts to humans and ecosystems (Berdalet et al., 2016; Wells et al., 2020). Algal blooms are an environmental phenomenon characterized by the proliferation of photosynthetic microorganisms in a water body (US Department of Commerce, n.d.). These photosynthetic organisms represent an essential function of aquatic ecosystems by fixing carbon, producing oxygen, and constitute the building blocks of the aquatic food chain (Hallegraeff & Enevoldsen, 2004). However, these bloom events can be designated as 'harmful' when certain biogeochemical and environmental circumstances lead to the overabundance of some microorganismal taxa (Berdalet et al., 2016). Environmental conditions, such as the salinity of the water body, influence which taxa of phytoplankton propagate in harmful algal bloom occurrences. HAB events in freshwater environments are typically caused by cyanobacteria, also referred to as blue-green algae, while marine and brackish waters are commonly associated with blooms of the phytoplankton, dinoflagellates and diatoms (US Department of Commerce, n.d.). These proliferations of algae are known to produce toxins or lead to harmful health effects on people, fish, invertebrates, mammals, birds, or the environment (CDC, 2021c). According to the Environmental Protection Agency (EPA), all 50 U.S. states face the risk of major environmental concerns from harmful algal blooms (US EPA, 2013).

Humans can be exposed to the harmful effects of HABs through skin contact with toxin contaminated water while swimming or other recreational water activities, drinking of toxin-contaminated water, breathing in aerosolized droplets of toxins, eating fish or shellfish that contain toxins, or eating contaminated algae nutritional supplements (Berdalet et al., 2016). People who are exposed to blooms or suspect their occurrence are encouraged by federal agencies, such as the EPA and Centers for Disease Control and Prevention (CDC), to report their resulting illness or bloom location to the local or State Department of Health and/or Environmental Health (CDC, 2021c). However, HAB events and HAB-associated illnesses in humans and animals may be chronically underreported across the U.S (Anderson et al., 2021).

Difficulty of HAB-associated illness reporting partly stems from the nonspecific nature of symptoms which can result from exposure, especially those related to cyanobacterial blooms and toxin exposure route. While HAB–associated illnesses stemming from seafood poisoning and marine HABs can have distinct symptomology, the signs and symptoms typically resulting from contact with cyanobacterial blooms include skin rashes, nausea, or diarrhea, which are non-specific and associated with a wide variety of illnesses (Fleming et al., 2002). Physicians need to be aware of HAB-associated illnesses and inquire about relevant exposures in order to recognize potential HAB etiology in patients. States which do not have sufficient processes in place to inform physicians or veterinary services of these signs may suffer from under-reporting of these illnesses (Berdalet et al., 2016). In 2015, the New York State Department of Health conducted a pilot program to increase outreach on HAB-associated illnesses to the public, healthcare providers, and veterinarians (Figgatt et al., 2017). Prior to this initiative, no more than 10 illnesses had been identified within the State of New York in any given year. After the conclusion of the pilot program, 51 HAB-associated illnesses had been identified in 4-month period in 16 counties (Figgatt et al., 2017). The success of the pilot program suggests that activities and initiatives undertaken by State Departments of Health can reduce the gap of underreported HAB-associated illnesses.

In order for human or animal illnesses to be reported by states as associated with HAB events at the national level, the cases must meet certain criteria to be classified as suspect, probable, or confirmed as defined by CDC guidelines (CDC, 2018). In order for a case to be considered suspect or probable, the state submission must demonstrate that there was an exposure to known routes of cyanobacterial or algal toxins, self-reported symptoms consistent with toxin exposure, as well as a public health assessment to determine that the illness in question is likely related to a HAB event. Confirmed cases in humans require laboratory detection of cyanobacterial or algal toxins in the exposure source and the elimination of other more likely causes of illness, or direct clinical specimens that indicate the presence of cyanobacteria, other toxin-producing algae, or cyanobacterial/algal toxins. Berdalet et al. acknowledge that the process to confirm human illnesses as associated with HAB events is often costly and time-consuming to undergo (Berdalet et al., 2016). In some instances, human exposures to HAB may not require medical treatment and will not be formally diagnosed. The obstacles to confirm algal blooms as an etiological causative agent of disease often contribute to the underreporting of this illness.

Inclusion of animal morbidity and mortality cases in the public health surveillance of HAB events is critical to creating a holistic surveillance system. Approaching HAB surveillance through the lens of One Health, where the health of people is connected to the health of animals and the environment, can lead to a better understanding of the nature and patterns of HAB events and inform integrated responses to the public health impacts of HABs. A HAB surveillance system that is integrated across the One Health space allows domestic and wildlife animals to act as sentinels for potential human health risks and provide an early indication of environmental contamination to prevent future illnesses in humans (Backer et al., 2013). However, the adverse health impacts of HABs on domestic and wild animals are significantly underrecognized on account of misdiagnosis, the relatively low number of cases that are confirmed using laboratory testing, and an even smaller subset of cases are published in scientific literature or reported to animal health surveillance systems (Rabinowitz & Conti, 2010).

National Efforts to Surveil the Public Health Impacts of Harmful Algal Blooms

Efforts to measure the public health impact of harmful algal blooms in the United States at the federal level can be traced to the Centers for Disease Control and Prevention's Cooperative Agreements (Program Announcement Number 98019 (1998); Program Announcement Number 03102 (2003); CDC-RFA-EH08-801 (2009)). During this time, the National Center for Environmental Health (NCEH) within CDC created, in collaboration with interested state partners, the Harmful Algal Bloom-related Illness Surveillance System (HABISS) (Backer et al., 2015). The goals for HABISS included describing the temporal and geographic distribution of cyanobacteria and algal blooms as well as describing the suspected human and animal morbidity and mortality associated with bloom events. This surveillance initiative was uniquely designed to capture both environmental information and suspected cases of human and animal illness in a single database. Various other efforts have worked to capture environmental reports of bloom events, either through satellite surveillance technology or visual reporting of blooms; independent systems have focused on the public health consequences of algal blooms, such as reports of human health events associated with cyanobacterial or algal toxins within CDC's National Outbreak Reporting System (NORS). The HABISS program provided funding for 11 states to support surveillance and reporting activities from its initiation in 1998 until the program's discontinuation of data collection in 2013 when the funding period ended. From

2007-2011, Departments of Health and/or Environmental Health from 11 states gathered reports for 4534 events, 458 cases of suspected and confirmed human bloom-associated illnesses, and 175 animal morbidity or mortality events (Backer et al., 2015). Many of the environmental reports contributed were made up of routine monitoring (n=4245, 94%) (Backer et al., 2015). The operation of the HABISS program informed state participation on data entry of acute events, data-sharing partnerships, and familiarity with existing surveillance systems.

The CDC Waterborne Disease Prevention Branch is working to improve the surveillance of HAB events and associated HAB illnesses in humans and animals across the United States using the One Health structure established by the HABISS program. The CDC One Health Harmful Algal Boom System (OHHABS) was launched in 2016 as the first national public health system that collected information about HAB events and associated illnesses in humans and animals (CDC, 2021c). The development phases of the system were accelerated by leveraging the technological platform that supports NORS and assuring built-in integration with NORS reporting. The system currently operates on a voluntary basis with reporting recorded at the state and territory level. Information reported to OHHABS is used to better capture patterns of HAB occurrence, protect food and water supplies from toxin contamination, and improve communication with the general public to prevent further illnesses (CDC, 2021c). In the 2019 year, 14 states participated in OHHABS and reported 242 HAB events, 63 human cases of illness, and 367 animal cases (CDC, 2021b). None of the ill people were reported to have died while 207 animal deaths were recorded. Recordings of Harmful Algal Bloom events are expected to increase in the future due to increased monitoring, and the number of HAB events are expected to increase with human activities related to nutrient pollution and global climate change (Anderson et al., 2021). With the growing threat of HAB events, state participation in algal bloom surveillance will be key for public health protection. Further investigation is needed to determine what factors contribute to whether a state participates in HAB surveillance and OHHABS.

HAB Reporting Capacity of State Public Health Departments

The reporting of HABs is directly mediated by the state Department of Health and/or Environmental Health's capacity to conduct surveillance and report these types of events. Metrics to measure state public health capacity are typically created for evaluation purposes and rely on proxy indicators to rate their readiness (Boulton et al., 2011). These types of indicators can include types of funding sources available as well as state initiatives to improve HAB reporting, such as hotlines and interactive apps, and increase awareness of HAB events, such as live website dashboards.

Within the operating period of OHHABS from 2016 to 2020, numerous funding sources have been made available to state government applicants to expand environmental health operating capacity. One of these is the National Environmental Public Health Tracking Network, which had been formed in 2002 in response to the Pew Environmental Health Commission report, "America's Environmental Health Gap: Why the Country Needs a Nationwide Health Tracking Network" (The Pew Environmental Health Commission, 2000). The National Environmental Public Health Tracking Network was established to support the standardization of data from multiple health, exposure, and hazard information systems in order to better establish linkages among this type of data (CDC, 2014). The network was implemented to improve U.S. health tracking, hazard monitoring, and hazard response. The funding available via the National Environmental Public Health Tracking Network establishes a cooperative agreement with CDC and other partners to collaborate on building these statewide networks. The grantees of this program are responsible for the planning and capacity building activities outlined in their funding application. The program currently supports health departments in 25 states and 1 city to build and implement tracking programs and data networks related to environmental health issues (*CDC - EPHT Program*, 2020).

A second source of funding made available to State Departments of Health and/or Environmental Health is the Environmental Health Capacity (EHC) program (CDC-RFA-EH20-2005), which focuses on building the core capacity of EH programs to use EH data and information to drive decision-making, identify and respond to EH hazards, and assess current EH programs and interventions. The program provides funding to 31 State Health Departments, 13 local or regional Health Departments, 2 tribal organizations, and 3 non-profits (*EHC Recipients 2020-2025 | EHS | CDC*, 2020). While the program is set to distribute funding for the 2020-2025 period, the recipients of the EHC grant were formally evaluated by CDC reviewers for their demonstrated need to build core capacity to use EH data as well as the applicant's organizational capacity to implement the proposed projects (CDC, 2020). The ability of state health departments to compose strong applications to the 2020-2025 EHC program may indicate a certain degree of environmental health operating capacity.

The CDC Epidemiology and Laboratory Capacity for Prevention and Control of Emerging Infectious Diseases Cooperative Agreement (ELC) provides flexibility in financial support for health departments to respond to detect, prevent, and respond to emerging infectious diseases (CDC, 2021a). While this program is not an environmental health-targeted funding mechanism, it is designed to holistically address One Health issues. States who participate in this cooperative agreement with CDC are provided with annual funding, technical assistance, and strategic direction to support core epidemiologic capacities. Funding made available through ELC is the primary avenue to provide directed funding from CDC to support state HABs programs. As of 2021, 11 states have received ELC funding to support the ability of health departments to detect, respond to, and report the occurrence of HABs (CDC, 2021d).

Access to funding for State Departments of Health and/or Environmental Health regarding HAB interventions can directly expand the capacity of state responses to HABs. For example, in 2019, the Great Lakes Restoration Initiative provided funding to the HAB Program at the Wisconsin Department of Health Services, Division of Public Health to develop the state's first set of Blue-Green Algae Beach signs (Great Lakes Restoration Initiative, 2019). Initiatives such as these highlight the importance of funding sources to expanding the state level responses to HAB events as well as spreading awareness of their adverse health effects to constituents.

Purpose of Project

The purpose of this project is to identify factors, such as national funding sources and indicators of public health capacity, that influence the reporting status of a State Department of Health and/or Environmental Health to OHHABS. Results of this project are anticipated to provide a better understanding of the reporting capacity of states and to identify potential barriers to non-reporting states. Additionally, the results may lead to the development of interventions that could improve state participation and reporting capacity.

The project was designed to address two primary aims:

Aim 1: Perform a descriptive analysis of the variation in state reporting to the OHHABS examining the type of reports submitted (environmental, human case, or animal case).

Aim 2: Use logistic regression models to estimate the associations between OHHABS reporting status and multiple pre-determined factors that may impact state reporting capacity.

Projected Significance

The thesis project outlined is designed to assess differences in state reporting behaviors of HABs which might identify characteristics of non-participatory states to OHHABS, methods to improve state reporting capacity, and information is being prioritized for reporting by states. Identification of potential barriers to HAB reporting is an integral step to improving participation in OHHABS across the U.S. states and territories.

This project greatly contributes to the field of One Health, in which the health of humans, animals, and our shared environment are intersected. Surveillance of HAB events and associated illnesses in humans and wildlife can better predict future HAB events, inform public health policy, and reduce future HAB illnesses (Roberts et al., 2020).

METHODS

Data Collection

OHHABS Reporting

The reporting of HABs and associated illnesses at the national level are stored in the CDC One Health Harmful Algal Blooms System since 2016 (Roberts et al, 2020). HAB events are documented by states through a descriptive environmental form, with or without the addition of associated human and/or animal case forms. Reporting and adoption of each of these forms varies by state but this variability has not been formally characterized. The OHHABS data obtained for this analysis was retrieved on February 2, 2022 (CDC, 2022b). The outcomes of consideration in this analysis are the participation of states in the One Health Harmful Algal Bloom System (OHHABS) as indicated by the submission of environmental reports during the years 2016-2020, as well as submission of human and animal case reports. While states may submit HAB environmental forms exclusively to OHHABS, the human and animal case reports must accompany a descriptive environmental form. Therefore, any state that adopts OHHABS as a reporting system will have completed an environmental form. This analysis was limited to participation in OHHABS by health departments in U.S. states as no U.S. territories have submitted reports to OHHABS as of the time of this analysis. Outcomes for each state were summarized to a yes/no indicator of their OHHABS reporting status of the study period.

Funding Measures

A number of nationally available funding sources have been put forward to broadly supplement the capacity of environmental health surveillance, hazard response, and outreach. Reception of funds from these national sources may be correlated with state participation in OHHABS surveillance. The grantees of the National Environmental Public Health Tracking Network were obtained from the NEPHT webpage across two funding cycles in 2014 and 2017 (*CDC - EPHT Program*, 2020; CDC, 2014, 2017). Twenty-four states were grantees of the NEPHT program over the entire time period of interest beginning with the launch of OHHABS in 2016 until the end of 2020. Pennsylvania was a recipient of the 2014 NEPHT funding opportunity, but ceased participation in the program after the end of the funding period in July 2017 (CDC, 2014). The state of Arizona became a grantee of the NEPHT program in August, 2017 during the subsequent funding cycle (CDC, 2017).

The goal of the Epidemiology and Laboratory Capacity for Prevention and control of Emerging Infectious Diseases (ELC) program is to reduce the morbidity and mortality from associated infectious disease threats (CDC, 2021a). This funding source has been made available to support 11 state initiatives relating to HAB program capacity building as of the 2021 year (CDC, 2021d).

The Environmental Health Capacity program supports the capacity building efforts of 31 state environmental health programs. The complete list of EHC recipients were obtained from the CDC EHC webpage (*EHC Recipients 2020-2025 | EHS | CDC*, 2020). All the EHC participants developed projects on using Environmental Health data from existing data source or developing methods to collect new data.

These three funding sources do not represent an exhaustive list of funds available to support public health capacity, but a representative snapshot of CDC funding sources relevant to HAB events. The amount of funding made available to states from each of these sources was not made publicly available. For this analysis, we summarized the funding received from the EHC and

ELC funding sources for each state into a yes/no binary variable of participation over the study period. We summarized the funding received from the NEPHT program as the total number of years supported within the time 2016 to 2020.

State Indicators of Public Health Capacity

Pertinent indicators of Environmental Health Capacity were developed for use in this analysis. One indicator includes whether a state Department of Health and/or Environmental Health maintained and advertised a publicly available method to report the occurrence or sightings of HABs. In order to standardize the search of online website resources, only websites listed by the EPA as a state HAB resource were analyzed for HAB reporting mechanisms (US EPA, 2018). Four methods of reporting were documented in this analysis, including reports via website portal, phone hotline, email contact, and smartphone app. The same websites listed by the EPA HAB resource page were used to determine whether the state maintains an active, online dashboard of HAB-related hazards. Dashboards were determined to be active if the hazard warnings encompassed the present date (at the time of data collection, the current date was February 10, 2022). Dashboards were uniformly assessed for the inclusion of the current date in order to exclude websites that issued HAB warnings in the past, but are no longer being actively maintained. Links to the dashboard sites and reporting mechanisms are recorded in Appendix B. For this analysis, we summarized the presence or absence of a public HAB reporting mechanism and active HAB dashboard as yes/no binary variables.

In 2019, the Association of State and Territorial Health Officials (ASTHO) deployed the Environmental Health Programs and Services Survey to environmental health directors within state and territorial health agencies to document specific characteristics of state environmental health departments (Association of State and Territorial Health Officials, 2019). Several of these characteristics describe the foundational structuring and operating abilities of environmental health departments to respond to disease outbreaks. The EH agency structure (categorized as independent or umbrella agencies) refers to the placement of the public health agency within the larger organizational structure of the state. The governance type of EH systems (designated as centralized, decentralized, shared, or mixed) refers to the operational relationship between state health agencies and local or regional public health departments. Finally, the agency or division responsible for responding to recreational water hazards was designated as a potential indicator of EH capacity from the information reported by this survey.

The National Outbreak Reporting System (NORS) collects yearly data on outbreaks (>2 cases) of similar illnesses resulting from a common exposure. The system aggregates reports by the mode of transmission, including waterborne disease outbreaks. State health departments that report outbreaks of human illnesses related to untreated recreational water sources to NORS from 2016 to 2020 may be more likely to participate in OHHABS, a national reporting mechanism complementary to the data collected by NORS. The NORS data obtained for this analysis was retrieved on February 1, 2022 (CDC, 2022a).The NORS data was summarized as the total number of untreated recreational water outbreaks recorded by each state from 2016 to 2020.

Additional Covariates of Consideration

Multiple covariates were also considered as confounders in this analysis, including the percentage of water coverage in a state, the EPA region, and the numeric population per square mile of a state. The percentage of perennial water coverage for each state was sourced from measurements taken by the U.S. Census Bureau in the report, Geography: State Area Measurements (U.S. Census Bureau, 2010). The numeric population per square mile for each state was recorded from the 2010 U.S. Census data (US Census Bureau, 2021). The EPA Region, which groups states of similar geography, biologic characteristics, and environmental capacity, was taken from the EPA website (US EPA, 2020).

Data Analysis

To address estimate associations between state OHHABS reporting status and factors that may impact state reporting capacity, we developed a logistic regression model with OHHABS reporting status as the outcome and indicator variables representing funding participation, proxies of environmental health capacity, and relevant confounders. All states were randomly anonymized for an unbiased presentation of the results.

For confounder assessment, each independent variable was assessed for collinearity with all other covariates in the model and determined to be sufficiently different from one another. In order to conduct a logistic regression model, none of covariates can be a linear function of another. Potential confounders were then assessed using backwards elimination to determine whether their exclusion produced an estimate within 10% of the fully-adjusted model. Non-significant confounders (within 10% of the fully-adjusted model) were eliminated from the final model.

Models for consideration:

Model 1:

$$\log(odds\ of\ any\ OHHABS\ reporting) = \alpha + \beta_1(Dashboard) + \beta_2(PublicReporting) + \beta_3(PHSystem) + \beta_4(NORS) + \beta_5(EHC) + \beta_6(NEPHT) + \beta_7(AgencyStructure) + \beta_8(ELC) + \beta_9(DeptReponse) + \gamma_1(EPARegion) + \gamma_2(Pop) + \gamma_3(WaterCoverage) + \epsilon$$

Model 2:

$$\log(odds\ of\ human\ illness\ OHHABS\ reporting) = \alpha + \beta_1(Dashboard) + \beta_2(PublicReporting) + \beta_3(PHSystem) + \beta_4(NORS) + \beta_5(EHC) + \beta_6(NEPHT) + \beta_7(AgencyStructure) + \beta_8(ELC) + \beta_9(DeptReponse) + \gamma_1(EPARegion) + \gamma_2(Pop) + \gamma_3(WaterCoverage) + \epsilon$$

Model 3:

$$\log(odds\ of\ animal\ illness\ OHHABS\ reporting) = \alpha + \beta_1(Dashboard) + \beta_2(PublicReporting) + \beta_3(PHSystem) + \beta_4(NORS) + \beta_5(EHC) + \beta_6(NEPHT) + \beta_7(AgencyStructure) + \beta_8(ELC) + \beta_9(DeptReponse) + \gamma_1(EPARegion) + \gamma_2(Pop) + \gamma_3(WaterCoverage) + \epsilon$$

Where

α is the intercept

$\beta_{1,2,3,4,5,6,7,8,9}$ are independent variables

$\gamma_{1,2,3}$ are covariate estimates as confounders

ε is residual error

Any OHHABS Report (Y/N): Y if a state submitted a descriptive environmental form since the launch of the OHHABS System in 2016 until the end of the calendar year in 2020.

Human Illness Report (Y/N): Y if a state submitted a human case report since the launch of the OHHABS System in 2016 until the end of the calendar year in 2020.

Animal Mortality/Illness Report (Y/N): Y if a state submitted an animal case report since the launch of the OHHABS System in 2016 until the end of the calendar year in 2020.

Dashboard (Y/N): Y if a state government-owned website provides a continually updatable webpage displaying reports of HABs with the state jurisdiction.

PublicReporting (Y/N): Y if a state government-owned website provides a publicly available webpage or hotline to report sightings of HABs.

PHSystem (Centralized/Mixed/Decentralized/Shared):

DeptResponse (State EH Dept/Another State Dept/County/local health dept/Contracted out): The departments responsible for responding to outbreaks and hazards within recreational water sources.

NORS (numeric): Number of untreated recreational water outbreaks reported from 2016 to 2020 to NORS.

EHC (Y/N): Y if a state is a grantee of the 2020-2025 CDC Environmental Health Capacity Cooporative agreement

NEPHT (Years of funding): Number of years that a state is a grantee of the National Environmental Public Health Tracking Network within the time period of interest from 2016 to 2020.

ELC (Y/N): Y if a state receives ELC (Epidemiology and Laboratory Capacity Funding) for HAB activities.

EPARegion (1-10): Regional EPA office headquarters

Pop (Numeric): Population of a state per square miles.

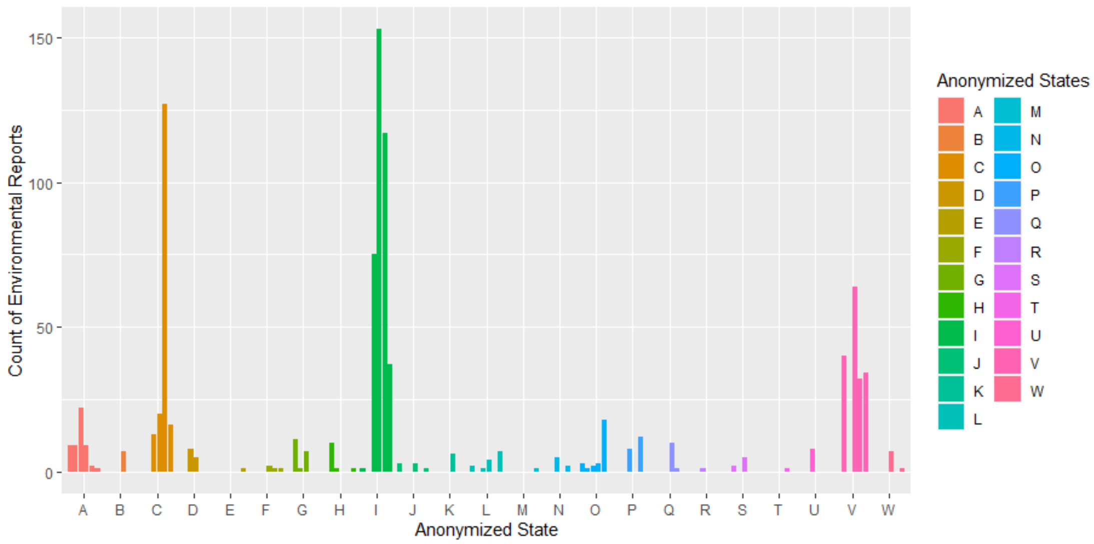
WaterCoverage (Percentage): Percentage of state land coverage designated as water.

All Analyses were conducted in RStudio, version 4.1.1

RESULTS

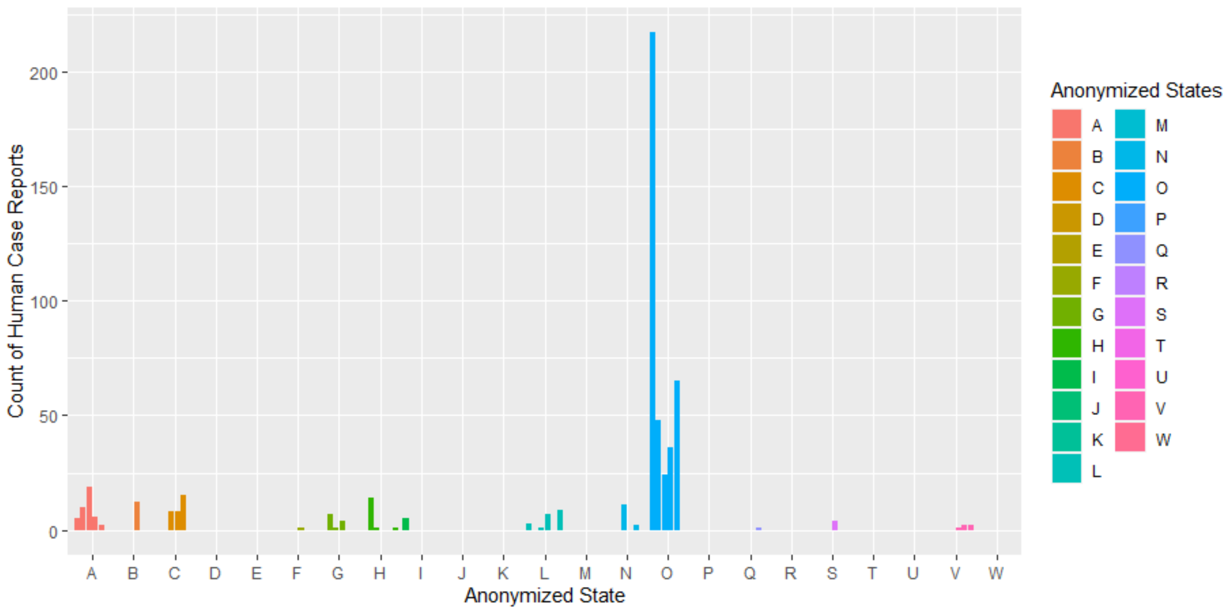
Participation within the One Health Harmful Algal Bloom System was found to vary across all 50 states within the United States. Overall, 23 (46%) states adopted OHHABS as a reporting mechanism of HAB-related surveillance between 2016 and 2021 (Plot 1). Ten states submitted at least one form of all three report types (environment description, human case report, and animal case report). Seven states only contributed environmental forms without reporting any animal or human HAB-associated illnesses. Three states documented HAB events as well as associated human illnesses cases. Three additional states logged animal case report forms and environment forms. No states were found to have submitted human or animal case reports without an accompanying environmental form. The structure of the OHHABS submission platform prompts users for the completion of an environment form before human or animal case reports can be finalized. Out of 955 finalized environmental reports, 780 (81.7%) were submitted by only 4 states. The remaining states (n=19) submitted less than 30 environmental reports each over the approximate five-year period.

Plot 1: *Environmental Event Reports of HABs by states over the years 2016 to 2021*



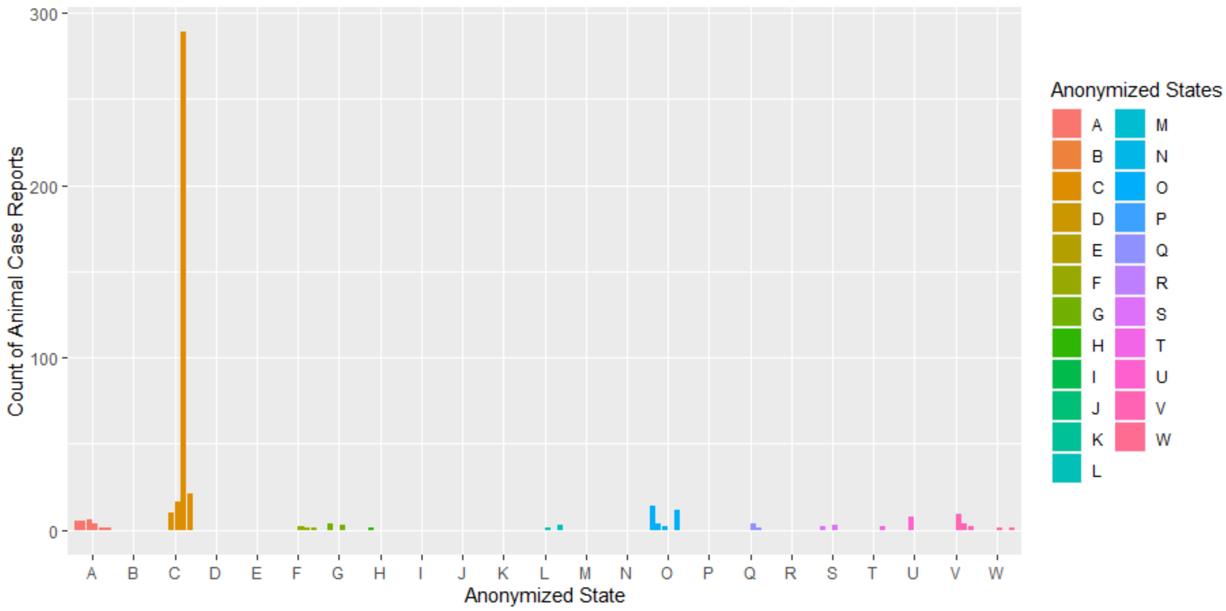
In terms of the human case reports associated with HAB events, 552 cases were identified over the study period of interest (Plot 2). 390 (70.7%) of these cases were submitted by a single reporting state, State O. Twelve additional states recorded human cases associated with HABs, each submitting less than 50 reports between 2016 and 2021.

Plot 2: *Human Case Report Forms associated with HABs submitted by states from the years 2016 to 2021*



443 animal morbidity and mortality case report forms associated with HAB events were submitted since 2016. 336 (75.8%) of these cases were submitted by a single reporting state, State C (Plot 3). Twelve additional states recorded animal cases associated with HABs and each submitted less than 35 reports between 2016 and 2021.

Plot 3: *Animal Case Report Forms associated with HABs submitted by states from the years 2016 to 2021*



The descriptive features included in this model as proposed indicators of HAB surveillance capacity differed across all 50 states (Table 1). Three funding sources were considered in this analysis, which provided financial support ranging from 11 states to 31 states. Exact funding amounts made available to states were not disclosed for this analysis. Fifteen states did not receive any of the three funding sources identified in this analysis to holistically support HAB surveillance capacity. Although ten states acquired only one of the funding sources, seven states were successfully able to obtain financial support from all three sources. All of the states that received ELC Funding for HAB programs also secured funding from an additional grant program. The 2019 ASTHO Survey published that 60% of State Environmental Health Departments operate in an independent capacity rather than under an umbrella organization. 34 (68%) of states respond to recreational water outbreaks through the State EH Agency or in collaboration with another State Agency. Over half (52%) of states contain a decentralized public health structure, while 25% (n=14) operate in a centralized capacity. The average number of untreated recreational water outbreaks reported to NORS by states who also participated in OHHABS was 1.91, in comparison to the average of 0.56 outbreaks reported by non-participatory states. The majority of states either support an online reporting mechanism for HABs (72%, n=36) or an online dashboard displaying current state HAB conditions (48%, n=24).

Table 1: *Distribution and frequency of OHHABS adoption by states and indicators of public health capacity for HAB surveillance included in the logistic regression models*

Outcome	Frequency (%)
Submission of Environmental Reports	23 (46%)
Submission of Human Case Reports	13 (26%)
Submission of Animal Case Reports	13 (26%)
Funding Sources	Frequency (%) Or Mean (Range)
ELC Funding for HABs Program	11 (22%)
Years of NEPHT Funding	2.5 years (0-5)
EHC Funding	31 (62%)
EH Department Structure	Frequency (%)
Agency Structure:	
Independent	30 (60%)
Umbrella	20 (40%)
Who Responds to Recreational Water Outbreaks?	
Another State Agency	15 (30%)
Contracted Out	1 (2%)
County/local health agency	4 (8%)
Not Applicable	5 (10%)
State EH Agency	9 (18%)
State EH Agency and another State Agency	10 (20%)
Unknown	6 (12%)
Public Health System	
Centralized	14(28%
Decentralized	26 (52%)
Mixed	6 (12%)
Shared	4 (8%)
Online Resources	Frequency (%)
HABs Dashboard	24 (48%)
HABs Reporting Mechanism	36 (72%)
Outbreaks Reported to Other National Surveillance Systems	Mean (Range)
Untreated Recreational Water Outbreaks Recorded by National Outbreak Reporting System (NORS)	1.18 (0-18)

Logistic Regression Analysis

Logistic regression analysis was used to determine if there was a statistical association between the reporting of HAB events, human cases, and animal cases to OHHABS and numerous proxy indicators of State Departments of Health and/or Environmental Health. The logistic regression models outlined in this analysis did not yield Odds Ratios with significance below a p-value of 0.05 (Table 2). Without statistical significance, the regression coefficients are statistically indistinguishable from 0, excluding the ability to estimate associations among the indicator characteristics and OHHABS participation. However, single indicator models and a descriptive analysis of OHHABS participation may indicate relationships for further investigation.

Table 2: *Estimated regression coefficients and odds ratios with 95% confidence intervals of the model estimating state OHHABS participation*

Public Health Capacity Indicator	Estimated Regression Coefficient	Pr(>|z|)	Estimated Odds Ratio	2.50% CI	97.50% CI
(Intercept)	-22.98	0.19	1.05E-10	7.14E-32	0.0044
HABs Monitoring Dashboard	-1.51	0.43	0.22	0.0019	4.09
HABs Reporting Mechanism	13.45	0.17	695282.76	26.05	5.32E+17
Public Health System (Centralized)	-0.91	0.77	0.40	0.00010	391.38
Public Health System (Mixed)	8.95	0.15	7678.37	4.65	2.46E+13
Public Health System (Shared)	-0.95	0.78	0.39	0.00013	675.68
NORS Untreated Recreational Water Outbreaks	-4.85	0.41	0.0078	3.81E-12	0.92
EHC Funding Recipient	8.33	0.21	4148.97	6.26	7.72E+15
ELC for HABs initiative Recipient	134.89	0.98	3.82E+58	1.24E-192	NA
Years of NEPHT Funding	-0.98	0.42	0.37	0.017	1.33
EH Agency Structure (Umbrella)	0.076	0.97	1.08	0.014	31.54
Response to Rec. Water Outbreaks (Contracted Out)	-109.27	0.99	3.50E-48	0	Inf

Response to Rec. Water Outbreaks (County or local health department)	-21.03	0.99	7.36E-10	NA	1.92E+187
Response to Rec. Water Outbreaks (EH Agency)	8.36	0.31	4274.65	0.59	1.67E+17
Response to Rec. Water Outbreaks (EH Agency and another Agency)	2.12	0.61	8.38	0.024	9815675.43
Response to Rec. Water Outbreaks (NA)	3.48	0.35	32.34	0.095	419172.4

The high variability and uncertainty of the Odds Ratios produced in the full models prompted the exploration of single indicator models. These models individually assessed each independent variable without adjusting for any of the other independent variables included in the full models. Several independent variables were determined to have a statistical association with OHHABS adoption using this method (Table 3). The odds of OHHABS participation are 15 times higher in states who provide a public, online reporting mechanism than states who did not have one available without adjusting for any other independent variables identified in this analysis (p=0.0066, 95% CI: 2.75-165.85). The odds of OHHABS participation are 8.8 times higher for states who are a part of the EHC funding agreement (p=0.0083, 95% CI: 1.98-53.02). Odds of OHHABS participation also increases by 30% for each year of NEPHT funding provided between 2016 and 2020 (p=0.03, 95% CI: 1.03-1.74).

Additional single indicator models were used to examine the association with the submission of human and animal case reports to OHHABS. These unadjusted models indicate a higher likelihood of reported human cases to OHHABS with EHC funding (OR= 5.91, 95% CI: 1.19-40.76) and additional years of NEPHT funding (OR=1.38, 95% CI: 1.03-1.91). The odds of a state reporting HAB-associated human cases are 1.63 times higher for every disease outbreak in untreated, recreational water sources reported by the state to NORS (p=0.035, 95% CI: 1.13, 2.95). Increased odds of submitting animal case report to OHHABS were associated with EHC funding (OR=8.01, 95% CI: 1.49-70.16) and each year of NEPHT funding (OR=1.67, 95% CI: 1.21-2.54).

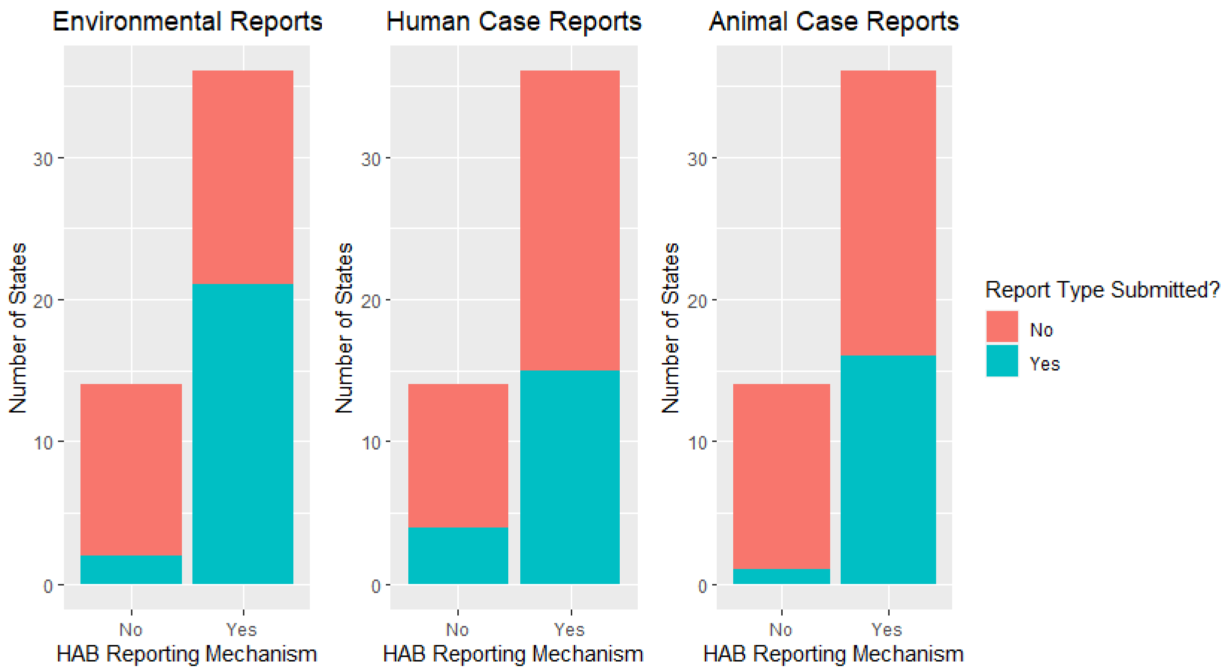
Table 3: *Estimated regression coefficients and odds ratios with 95% confidence intervals of the unadjusted, single indicator models estimating state OHHABS participation*

Public Health Capacity Indicator	Estimated Regression Coefficient	Pr(>|z|)	Estimated Odds Ratio	2.50% CI	97.50% CI
HABs Monitoring Dashboard	0.602	0.31	1.83	0.57	5.99
HABs Reporting Mechanism	2.71	0.0066	15.01	2.75	165.85
Public Health System (Decentralized)	1.55	0.062	4.71	1.019	28.93
Public Health System (Mixed)	2.14	0.057	8.48	1.04	98.55
Public Health System (Shared)	1.45	0.24	4.25	0.36	54.52
NORS Untreated Recreational Water Outbreaks	0.23	0.19	1.26	0.97	2.00
EHC Funding Recipient	2.17	0.0083	8.79	1.98	53.02
Years of NEPHT Funding	0.28	0.03	1.33	1.03	1.74
EH Agency Structure (Umbrella)	0.23	0.71	1.26	0.38	4.22
Response to Rec. Water Outbreaks (Another State Agency)	1.02	0.12	2.78	0.29	38.32
Response to Rec. Water Outbreaks (Contracted Out)	17.83	0.99	5.54E+07	8.21E-121	NA
Response to Rec. Water Outbreaks (County or local health department)	1.12	0.46	3.06	0.16	72.60
Response to Rec. Water Outbreaks (EH Agency)	0.79	0.53	2.19	0.20	31.91
Response to Rec. Water Outbreaks (EH Agency and another Agency)	1.16	0.37	3.19	0.28	51.15
Response to Rec. Water Outbreaks (Unknown)	0.47	0.74	1.61	0.095	1.00

A descriptive analysis of OHHABS participation was undertaken to further examine trends of state OHHABS participation. Of the 23 states who submitted descriptive environmental forms of

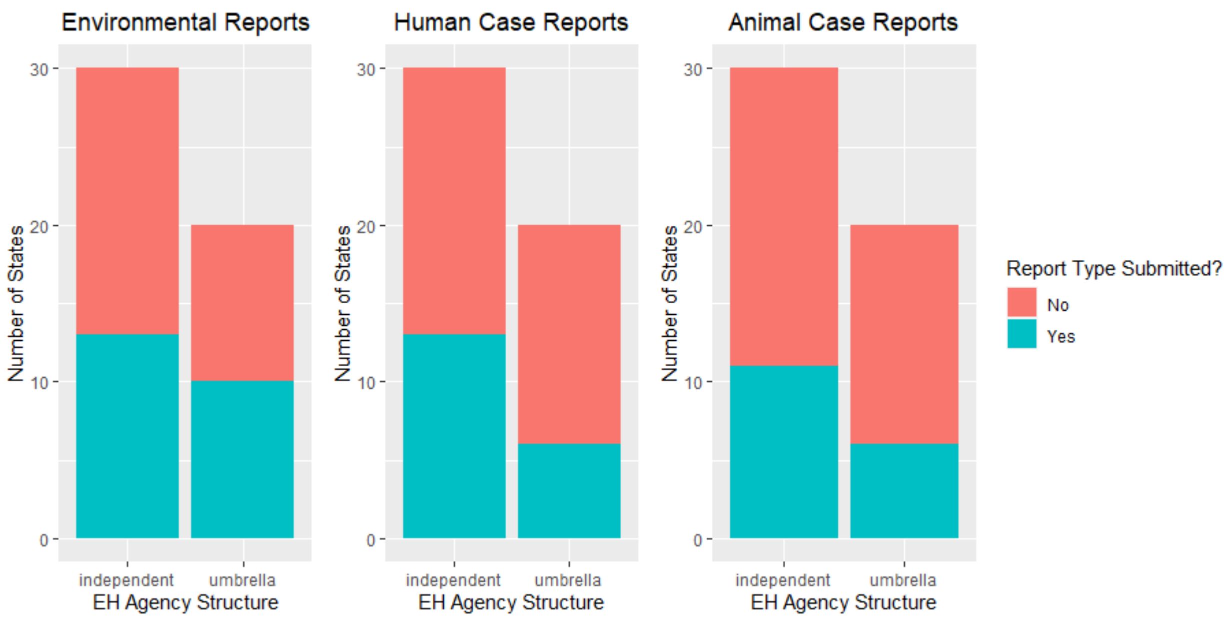
HABs, 21 states (91%) advertised a method on a public webpage to submit sightings of HAB occurrences (Plot 4). Two of the 14 states (14%) that did not adopt OHHABS as a reporting system provided a method to report HAB occurrences online. Over half of the states that maintain a public dashboard of on-going HAB events participated in OHHABS (Plot 5). Only 3 of the 14 centralized state health departments contributed to the OHHABS database, while other public health systems (decentralized, shared, mixed) participated around half of the time (Plot 7). Using the data available from the 2019 ASTHO survey, EH Directors who indicated that it was unknown or not applicable which State or Local Agency in their jurisdiction is responsible for responding to outbreaks associated with recreational water were tied to states who submitted to OHHABS less than a third of the time (Plot 8). States who submitted the highest number of untreated recreational water outbreaks to NORS (>6 outbreaks) during the period from 2016 to 2020, were found to all participate in OHHABS (Plot 9). All (100%) of the states who received ELC Funding regarding HABs projects completed at least one environmental report and animal case report within OHHABS (Plot 10). 58% (n=14) of states that received at least five years of funding as part of the NEPHT grant reported HAB occurrences in comparison to 29% (n=7) states who received 0 years of funding (Plot 11).

Plot 4: *Submissions of OHHABS report type by state availability of a public, online HAB reporting mechanism*

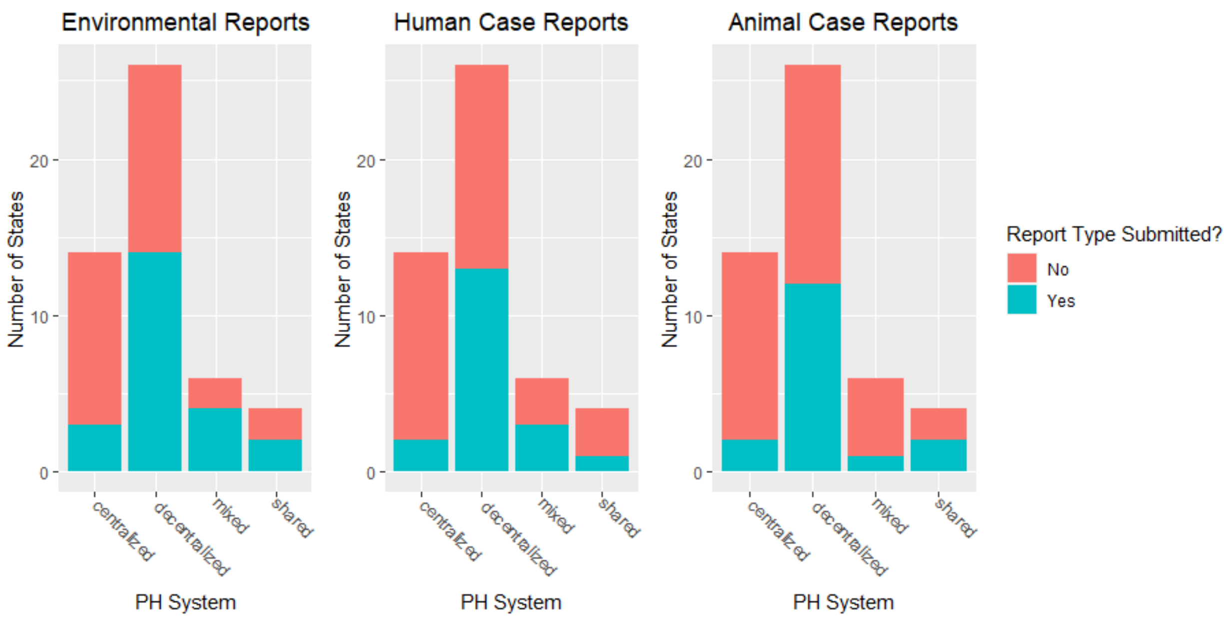


Plot 5: *Submissions of OHHABS report type by state availability of an active, online HAB Dashboard*

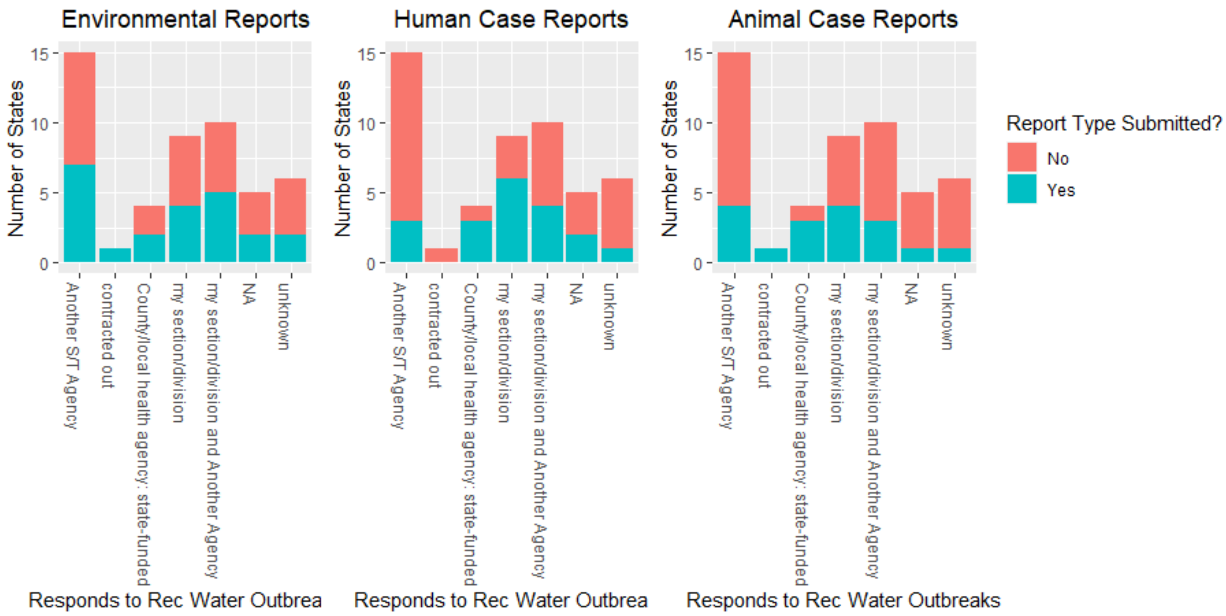
Plot 6: *Submissions of OHHABS report type by state environmental health agency structure*



Plot 7: *Submissions of OHHABS report type by state public health system type*

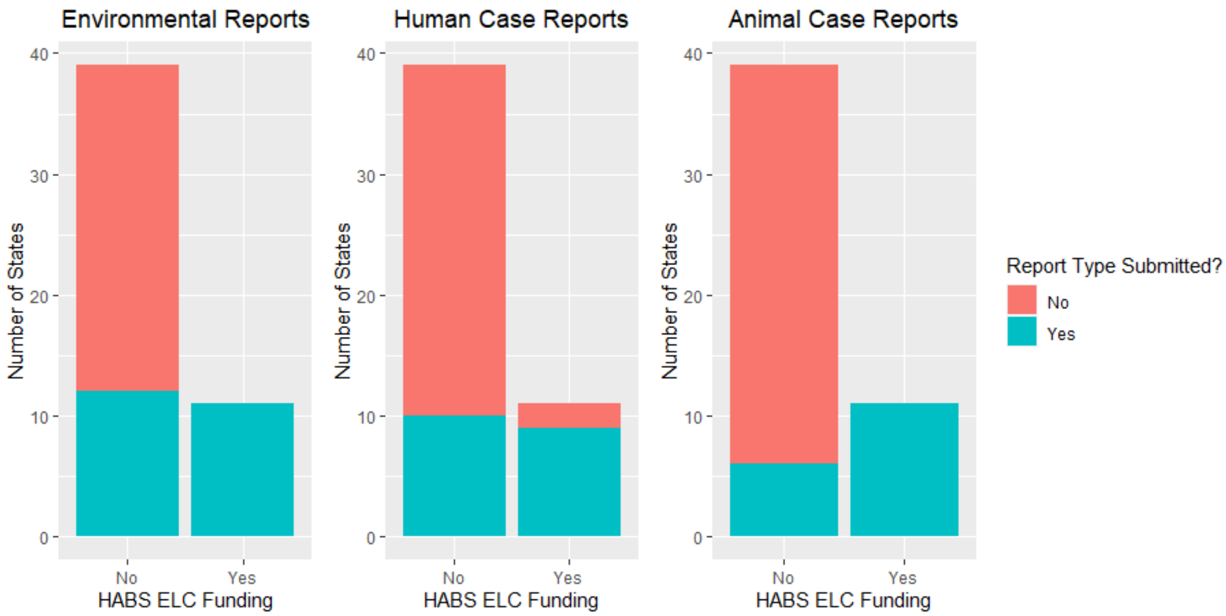


Plot 8: *Submissions of OHHABS report type by the public health agency or division responsible for responding to recreational water outbreaks within a state*

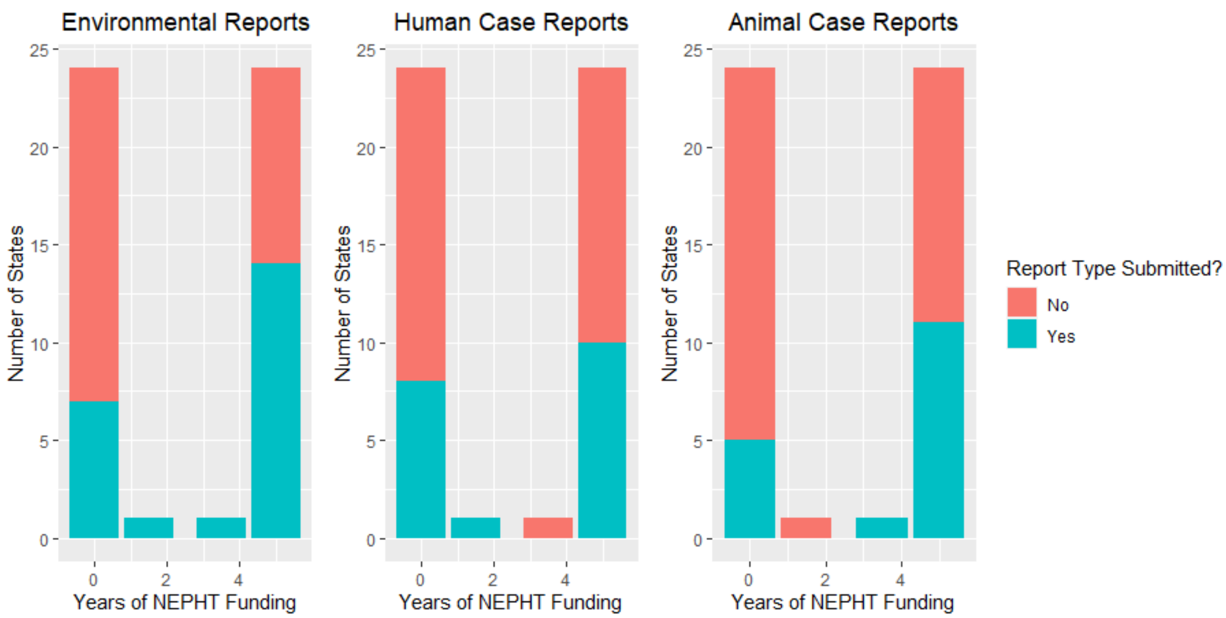


Plot 9: *Submissions of OHHABS report type by the number of untreated, recreational water outbreaks reported to NORS*

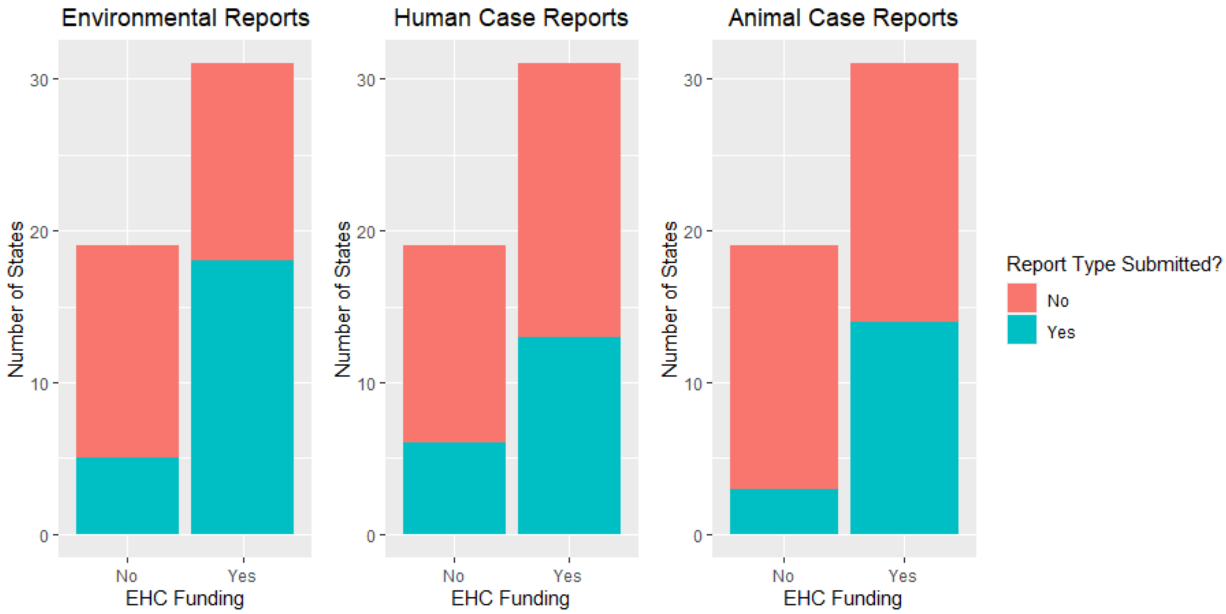
Plot 10: *Submissions of OHHABS report type by state recipience of ELC Funding for HAB activities.*



Plot 11: *Submissions of OHHABS report type by years of state recipience of NEPHT funding*



Plot 12: *Submissions of OHHABS report type by grantees of the EHC funding agreement*



While the multicollinearity diagnostic assessment did not indicate the occurrence of collinear factors, the inclusion of 9 independent variables in the model may obscure the effects of each individual factor. A global likelihood ratio test was completed to consider whether at least one of the coefficients for the independent variables of the full models is not equal to zero. The full models estimating the completion of environmental reports, animal case reports, and human case reports yielded an indication that at least one coefficient was not equal to 0 (p-values < 0.001). Additional incremental Likelihood Ratio Tests using Chi-Square analysis were completed to determine whether a joint effect of funding sources or State Department of Health and/or Environmental Health structure may yield statistically significant results. A Likelihood Ratio Test was conducted on Models 1-3 to compare the full proposed models and models with all funding variables removed. The joint effect of the three funding sources, ELC, EHC, and NEPHT, are estimated to produce at least one regression coefficient that is not equal to 0 (p-value = 0.002 and p-values < 0.001). The joint effect of State Department of Health and/or

Environmental Health characteristics, including public health system (decentralized/centralized/mixed/shared), agency responsible for responding to outbreaks from recreational water sources, and EH department structure (independent versus umbrella) was measured. The joint effect of these public health structural characteristics did not suggest that at least one regression coefficient was significantly distinguishable from zero for the submission of environmental reports ($p=0.09$), but was significant in regards to the completion of animal and human case reports ($p<0.001$).

DISCUSSION

This study provided an in-depth analysis of the patterns of state participation in OHHABS and factors that may correlate with state participation. The analysis found that the large majority of reports sent to OHHABS are submitted by a small number (<5) of participating states. This large discrepancy suggests that there may be significant under-reporting of HAB events, associated human case reports, and animal case reports in the United States. As a relatively newly established national surveillance system using voluntary reporting, OHHABS has been adopted by 46% of all U.S. states within 5 years of its launch in 2016. The underreporting of HAB events in a national surveillance system may not necessarily signify that these events are underreported at the state or county level or directly attributable to limited state capacity, level of state monitoring efforts, availability of educational resources, or implementation of initiatives to promote reporting by healthcare services, veterinarians, or the public. This analysis sought to determine whether some of these state-level attributes can be associated with reporting at a national level.

While this study was not able to determine a statistical association between multiple proxy indicators of state environmental health capacity and OHHABS submissions, analyses of individual factors may indicate future relationships to explore. Without adjusting for any other factors, EHC and NEPHT funding sources were correlated with the submission of HAB event reports, human case reports, and animal case reports. ELC Funding designated for HAB responses that contained stipulations for OHHABS adoption were found to successfully garner participation from all recipients. There is evidence that the joint effects of these three different funding sources available to support state environmental health capacity may be associated with OHHABS participation.

The states who submitted reports of HAB events to OHHABS were found to have a higher likelihood of advertising a public reporting mechanism online. The maintenance of an online dashboard displaying ongoing HAB events was found to be uniformly higher in OHHABS-participating states, but did not represent a statistically significant relationship when assessed in a single indicator model. This discrepancy may have been impacted by the chance that states maintaining an active HAB dashboard were under recorded. States without active HAB warnings at the time of data collection were excluded even though the site may have been actively maintained, but may not have been experiencing any HAB events due to the seasonality or other environmental factors.

The states who report a higher number of outbreaks in untreated, recreational waters to the National Outbreak Reporting System are more likely to submit case reports of human illnesses associated with a HAB event to OHHABS. This association is likely related to the original design of OHHABS as an analogous system to NORS with built-in integration of the systems and use of the same technological platform. States who already report waterborne outbreaks to national surveillance systems may be able to transition more easily to reporting within an additional, more specialized system, such as OHHABS, if it emphasizes congruity with the existing surveillance systems.

The analysis in this thesis is subject to several limitations. The sample size was capped at 50 observations (each of the U.S. States), which can limit the statistical robustness of the models of consideration. Measurements of numerous factors, such as the availability of public reporting mechanisms and online HAB dashboards, were based on qualitative evaluative criteria introducing the possibility of exposure misclassification. However, since all of the evaluations were conducted by one investigator, this reduces discrepancy between variable classifications.

Parts of this analysis was conducted using publicly available information from third-party sources and not collected by the investigators themselves. Results obtained from third-party sources, such as the 2019 ASTHO Survey may not accurately reflect how State Environmental Health Departments are structured or which departments conduct outbreak investigations in untreated recreational waters. The exclusion of all unfinalized reports submitted to OHHABS resulted in the removal of 130 environmental forms and consideration of 4 states as non-participants in OHHABS, although the majority of these states had submitted to OHHABS for the first time in the 2021 calendar year.

This study is the first to statistically assess whether metrics such as funding resources, informative online capabilities, and public health department structure contributed to adoption of a national surveillance system on the public health impacts of HABs. Although there are no current tools available to assess state HAB surveillance capacity, this analysis provides a quantitative approach to HAB program evaluation. This methodology may be used to rapidly identify statistical associations related to program outcomes of interest, which can be used to supplement or initiate formal program evaluations in order to explore complex issues and interactions (Holland & Campbell, 2005).

The predicted increase in future algal bloom occurrences stresses the importance of developing metrics to evaluate the capacity of states to conduct, report, and respond to HAB events and associated illnesses. However, limited research efforts have been undertaken to characterize the attributes of states who participate in HAB national surveillance through OHHABS. More rigorous modeling studies may better explain the role of multiple federal funding sources, online educational and informative resources, and organizational structure of public health agencies on

HAB surveillance capabilities. This study highlights the need for future works expanding the knowledge base related to surveillance on the public health impacts of HABs.

REFERENCES

Anderson, D. M., Fensin, E., Gobler, C. J., Hoeglund, A. E., Hubbard, K. A., Kulis, D. M., Landsberg, J. H., Lefebvre, K. A., Provoost, P., Richlen, M. L., Smith, J. L., Solow, A. R., & Trainer, V. L. (2021). Marine harmful algal blooms (HABs) in the United States: History, current status and future trends. *Harmful Algae*, *102*, 101975. https://doi.org/10.1016/j.hal.2021.101975

Association of State and Territorial Health Officials. (2019). *ASTHO Environmental Health Programs and Services Survey*. ASTHO. https://www.astho.org/topic/environmental-health/programs-and-services-portal/

Backer, L. C., Landsberg, J. H., Miller, M., Keel, K., & Taylor, T. K. (2013). Canine Cyanotoxin Poisonings in the United States (1920s–2012): Review of Suspected and Confirmed Cases from Three Data Sources. *Toxins*, *5*(9), 1597–1628. https://doi.org/10.3390/toxins5091597

Backer, L. C., Manassaram-Baptiste, D., LePrell, R., & Bolton, B. (2015). Cyanobacteria and Algae Blooms: Review of Health and Environmental Data from the Harmful Algal Bloom-Related Illness Surveillance System (HABISS) 2007–2011. *Toxins*, *7*(4), 1048–1064. https://doi.org/10.3390/toxins7041048

Berdalet, E., Fleming, L. E., Gowen, R., Davidson, K., Hess, P., Backer, L. C., Moore, S. K., Hoagland, P., & Enevoldsen, H. (2016). Marine harmful algal blooms, human health and wellbeing: Challenges and opportunities in the 21st century. *Journal of the Marine Biological Association of the United Kingdom*, *96*(1), 61–91. https://doi.org/10.1017/S0025315415001733

Boulton, M. L., Hadler, J., Beck, A. J., Ferland, L., & Lichtveld, M. (2011). Assessment of Epidemiology Capacity in State Health Departments, 2004–2009. *Public Health Reports*, *126*(1), 84–93. https://doi.org/10.1177/003335491112600112

CDC. (2014). *Implementation of the Environmental Public Health Tracking Network*. CDC-RFA-EH14-1405. https://www.cdc.gov/nceh/tracking/pdfs/FOA_2014.pdf

CDC. (2017). *Enhancing Innovation and Capabilities of the Environmental Public Health Tracking Network*. CDC-RFA-EH17-1702. https://www.cdc.gov/nceh/tracking/pdfs/CDC-RFA-EH17-1702.pdf

CDC. (2018, October 16). *One Health Harmful Algal Bloom System (OHHABS) – Harmful Algal Bloom (HAB) Event and Case Definitions*. https://www.cdc.gov/habs/pdf/ohhabs-case-and-event-definitions-table-508.pdf

CDC. (2020, September 25). *Environmental Health Capacity (EHC) Notice of Funding Opportunity (NOFO)*. CDC-RFA-EH20-2005. https://www.cdc.gov/nceh/ehs/news/features/ehc-nofo.html

CDC. (2021a, September 13). *ELC 5-year Focus, Funding, and Impact | DPEI | CDC*. https://www.cdc.gov/ncezid/dpei/elc/history-of-elc.html

CDC. (2021b, September 27). *Summary Report – One Health Harmful Algal Bloom System (OHHABS), United States, 2019 | CDC*. https://www.cdc.gov/habs/data/2019-ohhabs-data-summary.html

CDC. (2021c, October 7). *About OHHABS | Harmful Algal Blooms | CDC*. https://www.cdc.gov/habs/about-ohhabs.html

CDC. (2021d, December 14). *Building Public Health Capacity for Harmful Algal Blooms | CDC*. https://www.cdc.gov/habs/public-health-capacity.html

CDC. (2022a). *National Outbreak Reporting System*. Department of Health and Human Services; Data received 02/01/2022.

CDC. (2022b). *One Health Harmful Algal Bloom System*. Department of Health and Human Services; Data received 02/02/2022.

CDC - EPHT Program: Grants & Contacts. (2020, June 16). https://www.cdc.gov/nceh/tracking/grants.htm

EHC Recipients 2020-2025 | EHS | CDC. (2020, December 1). https://www.cdc.gov/nceh/ehs/ehc/recipients.html

Figgatt, M., Hyde, J., Dziewulski, D., Wiegert, E., Kishbaugh, S., Zelin, G., & Wilson, L. (2017). Harmful Algal Bloom–Associated Illnesses in Humans and Dogs Identified Through a Pilot Surveillance System—New York, 2015. *Morbidity and Mortality Weekly Report*, *66*(43), 1182–1184. https://doi.org/10.15585/mmwr.mm6643a5

Fleming, L. E., Backer, L., & Rowan, A. (2002). The Epidemiology of Human Illnesses Associated with Harmful Algal Blooms. In E. J. Massaro (Ed.), *Handbook of Neurotoxicology: Volume I* (pp. 363–381). Humana Press. https://doi.org/10.1007/978-1-59259-132-9_19

Great Lakes Restoration Initiative. (2019). *Wisconsin Develops State's First Set of Blue-Green Algae Beach Signs | Great Lakes Restoration Initiative*. https://www.glri.us/node/246

Hallegraeff, G. M., & Enevoldsen, H. O. (2004). Harmful algal blooms: A global overview. In *Manual on harmful marine microalgae* (pp. 25–50). UNESCO Publishing.

Holland, J., & Campbell, J. (2005). *Methods in development research: Combining qualitative and quantitative approaches*.

Rabinowitz, P. M., & Conti, L. A. (2010). *Human-animal medicine: Clinical approaches to zoonoses, toxicants, and other shared health risks*. Saunders/Elsevier.

The Pew Environmental Health Commission. (2000). *America's environmental health gap: Why the country needs a nationwide health tracking network*. Johns Hopkins School of Hygiene and Public Health. http://healthyamericans.org/reports/files/healthgap.pdf

U.S. Census Bureau. (2010). *The Water Area of Each State | U.S. Geological Survey*. Geography: State Area Measurements. https://www.usgs.gov/special-topics/water-science-school/science/how-wet-your-state-water-area-each-state

US Census Bureau. (2021). *Historical Population Density Data (1910-2020)*. Census.Gov. https://www.census.gov/data/tables/time-series/dec/density-data-text.html

US Department of Commerce, N. O. and A. A. (n.d.). *Harmful Algal Blooms (Red Tide)*. Retrieved October 23, 2021, from https://oceanservice.noaa.gov/hazards/hab/

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

US EPA, O. (2018, December 10). *State HABs Resources* [Collections and Lists]. https://www.epa.gov/cyanohabs/state-habs-resources

US EPA, O. (2020, September 2). *Regional and Geographic Offices* [Collections and Lists]. https://www.epa.gov/aboutepa/regional-and-geographic-offices

Wells, M. L., Karlson, B., Wulff, A., Kudela, R., Trick, C., Asnaghi, V., Berdalet, E., Cochlan, W., Davidson, K., De Rijcke, M., Dutkiewicz, S., Hallegraeff, G., Flynn, K. J., Legrand, C., Paerl, H., Silke, J., Suikkanen, S., Thompson, P., & Trainer, V. L. (2020). Future HAB science: Directions and challenges in a changing climate. *Harmful Algae, 91*, 101632. https://doi.org/10.1016/j.hal.2019.101632

APPENDICES

Appendix A: Abbreviations

ASTHO	Association of State and Territorial Health Officials
CDC	Centers for Disease Control and Prevention
EH	Environmental Health
EHC	Environmental Health Capacity
ELC	Epidemiology and Laboratory Capacity for Prevention and Control of Emerging Infectious Diseases Cooperative Agreement
EPA	Environmental Protection Agency
HAB	Harmful Algal Bloom
HABISS	Harmful Algal Bloom-related Illness Surveillance System
NEPHT	National Environmental Public Health Tracking
NORS	National Outbreak Reporting System
OH	One Health
OHHABS	One Health Harmful Algal Bloom System

Appendix B: Online Web Links to State HAB Resources

State	HAB Reporting Mechanism	HAB Dashboard
Alaska	https://legacy.aoos.org/alaska-hab-network/	https://legacy.aoos.org/alaska-hab-network/report/
Arizona	https://azdeq.gov/node/3464	
Arkansas	https://www.adeq.state.ar.us/complaints/forms/algae_complaint.aspx	
California	https://mywaterquality.ca.gov/habs/do/bloomreport.html	https://mywaterquality.ca.gov/habs/data_viewer/
Florida	https://www.floridahealth.gov/environmental-health/aquatic-toxins/updates-report-and-contact/index.html#Report-Contact	https://floridadep.gov/AlgalBloom
Georgia	https://coastalhealthdistrict.org/programs-services/environmental-health-2/harmful_algal_bloom_hab/red-tide-algal-blooms/	
Idaho	https://www.deq.idaho.gov/report-a-potential-cyanobacteria-algal-bloom/	https://www.deq.idaho.gov/water-quality/surface-water/cyanobacteria-harmful-algal-blooms/
Illinois	https://www2.illinois.gov/epa/topics/water-quality/monitoring/algal-bloom/Pages/reporting.aspx	https://www.deq.idaho.gov/water-quality/surface-water/cyanobacteria-harmful-algal-blooms/
Iowa	https://idph.iowa.gov/Environmental-Health-Services/Reportable-Conditions/Harmful-Algal-Blooms	
Kansas	https://survey123.arcgis.com/share/5b5aeea4205c411d97cbeb173a5d6d96	https://www.kdhe.ks.gov/777/Harmful-Algal-Bloom
Kentucky	https://eec.ky.gov/Environmental-Protection/Water/Monitor/Pages/HABS.aspx	https://kygis.maps.arcgis.com/apps/webappviewer/index.html?id=b4cecafe06ee4e9187b5bc4589006e1e/
Maine	https://www.maine.gov/dep/water/lakes/reportbloom.html	https://mainedmr.shinyapps.io/bph_phyto/
Maryland	https://dnr.maryland.gov/waters/bay/Pages/algal_blooms/Algae-Bloom-FAQ.aspx	
Massachusetts		https://www.mass.gov/alerts/harmful-cyanobacterial-bloom-advisories-in-massachusetts-current-as-of-december-9-2021#933161
Michigan	https://www.michigan.gov/egle/0,9429,7-135-3313_3681_3686_3728-383630--,00.html	https://www.egle.state.mi.us/beach/
Minnesota	https://www.pca.state.mn.us/water/blue-green-algae-and-harmful-algal-blooms	
Missouri	https://dnr.mo.gov/water/hows-water/pollutants-sources/cyanobacteria-harmful-algal-blooms-blue-green-algae/report-algal-bloom	
Montana	https://mtdphhs.maps.arcgis.com/apps/MapSeries/index.html?appid=e8ac7302f8cd4d778461d422492a9d7f	https://mtdphhs.maps.arcgis.com/apps/MapSeries/index.html?appid=e8ac7302f8cd4d778461d422492a9d7f
Nebraska	http://deq.ne.gov/NDEQProg.nsf/OnWeb/ENV042607	https://deq-iis.ne.gov/zs/bw/
Nevada	https://ndow-production-media.s3-us-gov-west-1.amazonaws.com/wp-content/uploads/2021/11/Fisheries-PJS-Be-Algae-Aware-Brochure-Current.pdf	
New Hampshire	https://www.des.nh.gov/water/healthy-swimming/harmful-algal-blooms	https://www4.des.state.nh.us/WaterShed_BeachMaps/
New Jersey	https://www.state.nj.us/dep/wms/bfbm/cyanohabreporting.html	https://njdep.maps.arcgis.com/apps/dashboards/49190166531d4e5a811c9a91e4a41677
New York	https://www.dec.ny.gov/chemical/77118.html	https://www.dec.ny.gov/chemical/83310.html
North Carolina	https://epi.dph.ncdhhs.gov/oee/a_z/algal_blooms.html	https://ncdenr.maps.arcgis.com/apps/dashboards/index.html#/7543be4dc8194e6e9c215079d976e716
North Dakota	https://deq.nd.gov/WQ/3_Watershed_Mgmt/8_HABS/Habs.aspx	https://deq-ndgov.maps.arcgis.com/apps/Shortlist/index.html?appid=9b28a6b198f24847be68742d3eb5b927
Ohio	https://survey123.arcgis.com/share/ac459f1f0b344bfa93c0486b028fbba6	https://geo.epa.ohio.gov/portal/apps/opsdashboard/index.html#/e72499f345ec43579513da521d83347e
Oklahoma		https://www.travelok.com/state-parks/lake-conditions#current
Oregon		https://www.oregon.gov/oha/PH/HEALTHYENVIRONMENTS/RECREATION/HARMFULALGAEBLOOMS/Pages/Blue-GreenAlgaeAdvisories.aspx
Pennsylvania	https://www.health.pa.gov/topics/envirohealth/Pages/HABs.aspx	
Rhode Island		https://health.ri.gov/data/beaches/
South Carolina		https://sc-dhec.maps.arcgis.com/apps/webappviewer/index.html?id=a34a994444df4234b4b3f87b55eeac54
Tennessee	https://www.tn.gov/health/cedep/waterborne-diseases/harmful-algal-blooms.html	
Texas	https://tpwd.texas.gov/landwater/water/environconcerns/hab/	

Utah	http://health.utah.gov/enviroepi/appletree/HAB/HAB_Guidance_Summary_2017.pdf#page=3-of-the-environment-report/harmful-algal-blooms-habs-2018-state-of-the-environment-report-wq	https://utahdeq.maps.arcgis.com/apps/webappviewer/index.html?id=245ef0eef973461c8bb403d8b5449f8c
Vermont	https://ahs-vt.maps.arcgis.com/apps/GeoForm/index.html?appid=d5027ec671864780991f18be3e71d893	
Virginia	https://www.vdh.virginia.gov/waterborne-hazards-control/harmful-algal-bloom-online-report-form/	https://www.vdh.virginia.gov/waterborne-hazards-control/algal-bloom-surveillance-map/
Washington	https://www.nwtoxicalgae.org/Default.aspx	https://www.nwtoxicalgae.org/FindLakes.aspx
West Virginia	https://dep.wv.gov/WWE/watershed/Algae/Pages/default.aspx	
Wisconsin	http://www.surveygizmo.com/s3/3649314/Harmful-Algae-Bloom-HAB-Illness-or-Sighting-Survey-F-XXXXX	
Wyoming	http://wyospills.org/	https://wdeq.maps.arcgis.com/apps/Shortlist/index.html?appid=342d22d86d0048819b8dfa61dd3ff061