Chapter 4: A world overview — One-hundred-twenty-seven years of research on toxic cyanobacteria — Where do we go from here?

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Introduction

Both marine and freshwater Harmful Algal Blooms (HABs) have been observed throughout history. The first literature reference for toxic cyanobacteria (CyanoHABs) was in 1878. George Francis issued a report on sheep and cattle deaths from the brackish water cyanobacteria *Nodularia spumigena* in *Nature* called "Poisonous Australian Lake". For the marine HABs, a 1928 report in the Journal of Preventive Medicine described human intoxication from mussel poisoning cases in the San Francisco area during July of 1927. This led to work that described the first phycotoxin group, Saxitoxins, by Edward Schantz in the 1950's. In response the occurrence of red tides in New England during 1972, the First International Conference on Toxic Dinoflagellate Blooms was held in 1974. Currently there are twelve international marine HAB conferences. The First International Conference on Toxic Cyanobacteria proceedings, "The Water Environment Algal Toxins and Health", was published in 1981. The 7th such conference is scheduled to be held in Brazil in 2007. United States (U.S.) HAB response resulted in the development of a U.S. National Plan for Marine Biotoxins and Harmful Algae (Anderson et al. 1993), which led to "The Harmful Algal Bloom and Hypoxia Research and Control Act of 1998 written by the U.S. Senate-Subcommittee on Oceans and Fisheries. In the 2003 revision of this act the U.S. house of representatives included freshwater algae especially the harmful cyanobacteria. The current national plan is called Harmful Algal Research and Response; a National Environmental Science Strategy 2005-2015 (HARRNESS) (Ramsdell et al. (eds) 2005). This CyanoHAB Overview will focus on occurrences of cyanobacteria and cyanotoxins that have been observed in freshwater, drinking water, recreational water, estuaries and marine water, as well as the impacts on health and/or ecosystem viability in the U.S. and worldwide.

Charge 1

What occurrences have been observed, and what were the conditions at the time that might provide insight into conditions that promoted these CyanoHABs? Highlight any differences between the U.S. and elsewhere in the world.

The terms Blue-greens, blue-green algae, *Myxophyceae*, *Cyanophyceae*, *Cyanophyta* and Cyanobacteria all refer to a group of freshwater cyanobacteria, found in a diverse range of water bodies in the United States (U.S.); most are photosynthetic autotrophs that share some properties with algae (i.e. they possess *chlorophyll-a* and liberate oxygen during photosynthesis). Cyanobacteria are widespread and found in a diverse range of environments, including soils, seawater and, most notably, freshwater environments. Some environmental conditions that can promote growth include sunlight, warm weather, low turbulence and high nutrient levels. Some taxa of cyanobacteria can release significant quantities of toxins (cyanotoxins) into water bodies as part of their normal lifecycle during or immediately following a planktonic (surface) bloom or benthic bloom. As a water basin ages, a condition called eutrophication occurs, primarily as a result of an increase in nutrients, in biological activity (productivity), and in sediments and organic matter from the watershed that fill the water basin. It is now accepted that cultural eutrophication--eutrophication from human activity--is a significant factor in the aging process of the world's water bodies. Some lakes are naturally eutrophic, but in many others cultural eutrophication has accelerated the aging process to such an extent that the term hypereutrophy (extreme eutrophy) has become synonymous with the affect of human activities on the aging process of water bodies. Human activities, include the discharge of wastewater (agricultural, municipal and domestic), impounding of rivers, off-river storage impoundments and other activities that alter the normal course of natural waters.

The occurrence and control of cyanobacteria and their toxins in water resources can result in animal and human exposure and cause adverse health effects. It is widely believed that the incidence of bloom formation and the threat posed by toxins has increased world-wide during the past 30 years as a result of cultural eutrophication. Health problems attributed to the presence of such toxins in drinking water have been reported world-wide. Cyanobacterial blooms and cyanotoxins been linked to the deaths of wild and domestic animals all over the world. They constitute a health-risk for human beings worldwide via recreational or drinking water through the production of a range of hepatotoxins and neurotoxins.

The relationship between the presence of cyanotoxins and human illness is unclear, and for studies to better identify and assess human health impacts have been identified in some reports are needed. The level of cyanotoxin exposure through consumption of drinking water remains largely unknown due to a lack of studies that report cyanotoxin levels in drinking water. The types of published surveys for cyanobacteria and cyanotoxins are primarily ecological and biogeographical. Early surveys in a number of countries involved toxicity testing of bloom or scum samples by mouse bioassay. More recent surveys have employed more sensitive and definitive characterization of the toxins by chromatographic or immunological methods.

Two main factors appear to affect the potential for exposure to undesirable levels of cyanobacteria: (Anderson et al. 1993) the heterogeneity of cyanobacterial population distributions and (Ramsdell et al. (eds.) 2005) the human activities being undertaken. This heterogeneous distribution is a consequence of a number of factors:

- colonial growth patterns where "bloom" type growth can result in large colonies or filaments being formed
- buoyancy regulation that promotes aggregation of cells and colonies in the upper layers of the water column
- scum formation by the trapping of buoyant colonies on the water surface, initially, at least, by surface tension
- wind-driven accumulations and distribution which can result in the beaching of scums but can also be responsible for the mixing of cyanobacteria and for the establishment of more homogenous distributions

Since human activity is the primary cause of cultural eutrophication, the patterns of CyanoHAB occurrence and risks are basically the same throughout the world. Climate, topography and degree of cultural eutrophication have led to some geographical and cultural differences in type and degree of toxic occurrences. In North America, the major effect from CyanoHABs has been:

1. The loss of wild and domestic animals in man-made and natural water bodies
2. Domestic animal and human toxicity in recreational waters
3. Effects on aquacultured species
4. Increased expense for water treatment facilities to remove toxigenic cells and monitor for cyanotoxins.

This pattern has been seen worldwide, especially those warmer climes that have a higher degree of eutrophication, a longer bloom growing season; and tend to experience more problems with direct human exposure to CyanoHAbs (Chorus and Bartram (eds.) 1999, Codd et al. 2006, Yoo et al. 1995).

Charge 2

If possible, describe occurrences in freshwater, drinking water, recreational water, estuaries and marine water, and impacts on health and/or ecosystem viability in the U.S. and elsewhere in the world.

An individual description of each CyanoHAB event is beyond the scope of this expanded summary. A chronological listing of North American CyanoHAB events is given in Appendix A located in the Conclusion and Summary section of this paper. In addition, Fig. 1 shows those countries where cyanobacteria waterblooms producing cyanotoxins have occurred. Fig. 2 shows occurrence by U.S. EPA region, and Fig. 3 shows the North American occurrence of CyanoHAB events. Occurrences are based upon published reports of CyanoHAB events in "CyanoHAB Search," a reference data of all known CyanoHAB publications (Carmichael 2004).

Fig. 1. Countries where cyanobacteria waterblooms producing cyanotoxins have been documented. Dots do not indicate number of cyanoHAB occurrences. In most cases there have been multiple occurrences but not every occurrence has had a poisoning event documented.

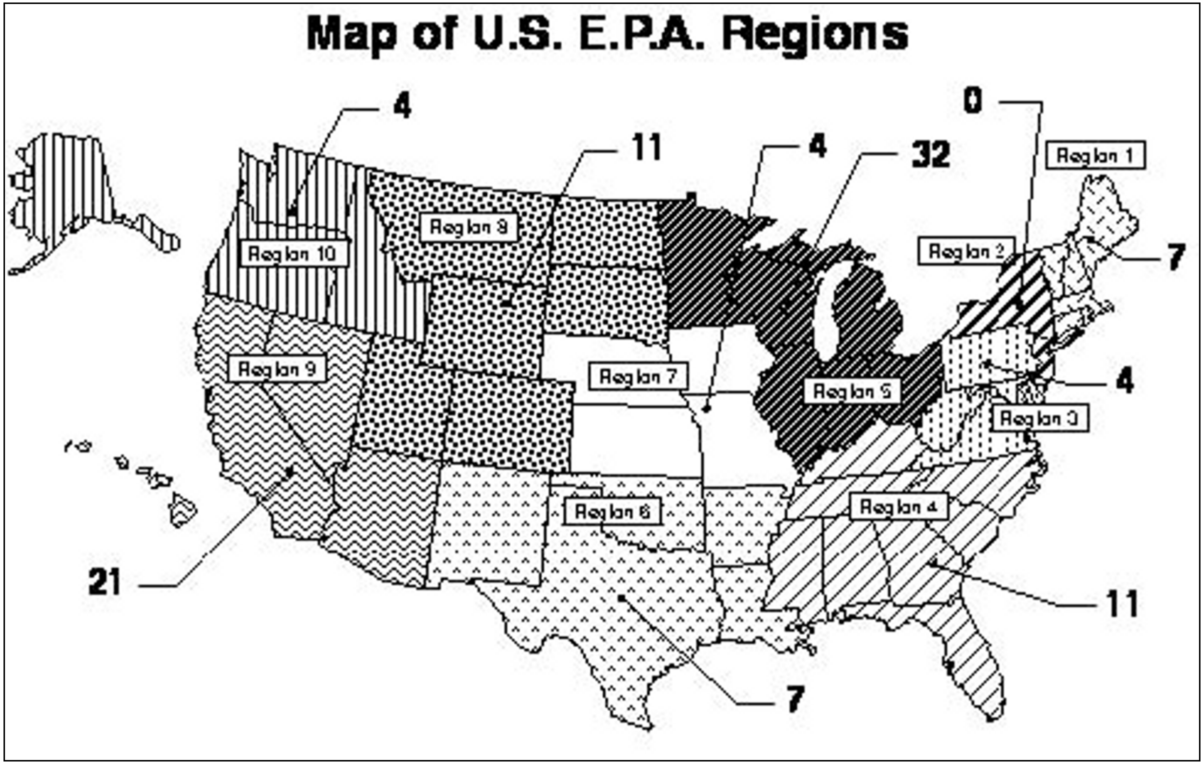


Fig. 2. Number of reported CyanoHAB events for each U.S. EPA region. Numbers in bold represent the number of articles published in the CyanoHAB database for each EPA Region.

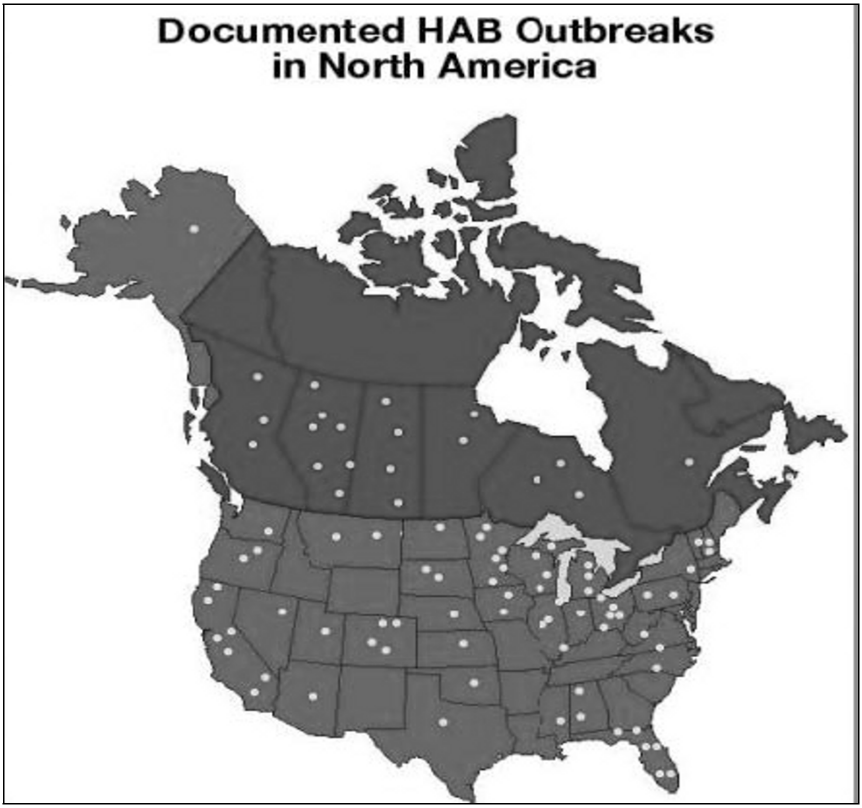


Fig. 3. North American frequency and approximate location of States and Provences reporting a CyanoHAB event.

Charge 3

If possible, address how common these occurrences are in the U.S. and elsewherein the world. Are they frequent, or rare, do they repeat at a given location, or occur sporadically at different locations?

An accurate statement of how common CyanoHAB events are is beyond the degree of understanding we currently have. A safe statement would be that CyanoHABs are an infrequent but repeated occurrence in all areas of the U.S. and around the world. They are seasonal occuring most often during the warmer, dryer times of the year. Frequency and intensity of the CyanoHAB waterbloom depends a lot on the conditions which selected for the waterbloom-i.e. nutrient status for the water body, use patterns, climate and degree of animal and human contact with the toxic waterbloom. (Carmichael and Stukenberg 2006, Carmichael 2001, Chorus and Bartram (eds.) 1999).

A summary of CyanoHABs for the U.S. is excerpted below from Carmichael and Stukenberg (2006). The earliest reference to toxic cyanobacteria was in the late 1800's from Minnesota (Arthur 1883). The earliest documented investigation in the U.S., into the poisonous potential of blue-green algae recorded a 1925 outbreak in Big Stone Lake in South Dakota when a farmer lost 127 hogs and 4 cows after they drank from lake water. The livestock deaths were attributed to algae poisoning (Wilmot Enterprise 1925).

The first described instance of *human* illness due to algal toxins occurred in Charleston, West Virginia, in 1931 (Tisdale 1931). A massive *Microcystis* bloom in the Ohio and Potomac Rivers caused intestinal illness in an estimated 5,000 to 8,000 people. According to the article, though the drinking water taken from these rivers was treated by precipitation, filtration and chlorination, these treatments were not sufficient to remove the toxins. Very few actual algal outbreaks were reported during the next two decades

The 1950s showed a marked increase in the number of reported blue-green algae studies in the United States, publishing a total of nine articles including one outbreak case concerning some domestic animal deaths from algal poisoning in Illinois (Scott 1955). Again, there was a decrease in reported cases published from the 1960s through the 1980s. In the 1990's, published accounts of algal outbreaks jumped to 19 in the 1990s. It should be acknowledged that there is a potential reporting artifact in these statistics, as reporting such events in the United States has always been voluntary.

Since 1971, however, in a USEPA and CDC cooperative effort, surveillance data from waterborne outbreaks have been more consistently compiled and more conclusively upheld as cyanobacteria-related. On August 25th, 1975, for example, a gastrointestinal outbreak occurred in Sewickley, Pennsylvania. Though the CDC's epidemiological study ruled out blue-green algae as the contaminant at the time, a subsequent analysis posited *Schizothrix* and *Calcicola* as causative agents (Lippy and Erb 1976).

In the survey *Outbreaks of Waterborne Disease in the United States: 1989-90* one "cyanobacteria-like body" outbreak was reported out of 26 total outbreaks due to ingestion of water intended for drinking. Protozoologists later confirmed this case was actually caused by the protozoan *Cyc-*

lospora and not a cyanobacterium. In the 1990s, 19 individual studies were published on U.S. cyanobacterial cases, in Alabama, Arizona, Arkansas, Colorado, Florida, Illinois, Kansas, Michigan, Mississippi, Nevada, Ohio, Oklahoma, Vermont, Washington and Wisconsin.

Clearly, through not only increased occurrence, but also through a combination of increased awareness, vigilance and reporting, more and more incidents of cyanobacterial outbreaks have come to be published. More than fifteen times as many articles on individual United States cyanobacterial outbreaks were published in the 1900s as in the 1800s; as many in the 1990s as in the 2 decades that preceded it combined; and already fifteen articles on individual outbreaks of cyanobacteria in the United States have been published since between 2000 and 2004. Since the number of articles in the entire CyanoHAB Search© database (Carmichael 2004) has increased more than 3 fold in the last ten years, it is likely that the subset of individual outbreak incidents reported will increase proportionally over the next ten years, not only in the United States, but worldwide.

Charge 4

Over the last 10-20 years, has the incidence of cyanobacterial HABs increased,remained constant, or decreased on spatial and temporal scales in the U.S. and elsewhere in the world?

Based upon the number of published papers and CyanoHAB event reports their incidence has increased dramatically since the 1960's. Fig. 4 shows this dramatic trend for all countries based upon published reports. The U.S. pattern is very much the same as the rest of the world. In all areas the increase in reported CyanoHAB events coincides with the increased realization that eutrophication of natural waters was a significant factor in decreased water quality around the world.

Charge 5

Are HABs of cyanotoxin-producing cyanobacteria a regional or worldwide problem? Identify areas in the U.S. and the rest of the world that appear to have the highest incidence of toxigenic HABs.

CyanoHABs occur worldwide and therefore should be considered a worldwide problem. Based upon a 2004 literature search (Carmichael 2004) it is possible to make some general conclusions about the occurrence of CyanoHABs. The reference is called “CyanoHAB Search” and it evolved from over 30 years of studies of toxic blue-green algae, and contains 3,063 references citing 705 journals written by 4,687 authors and editors. Figs. 4 and 5 detail some the findings from a search of references in this database.

Highest occurrences of CyanoHABs in the U.S. seem to coincide with two main factors:

1. areas of highest eutrophication coupled with a climate most favorable to extended waterblooms i.e. Florida
2. areas of driest summer conditions that favor longer retention times within the water body coupled with eutrophication i.e. southwest and west.

Other factors that favor a CyanoHAB event in a given area include mainly local weather and water use patterns along with eutrophication.

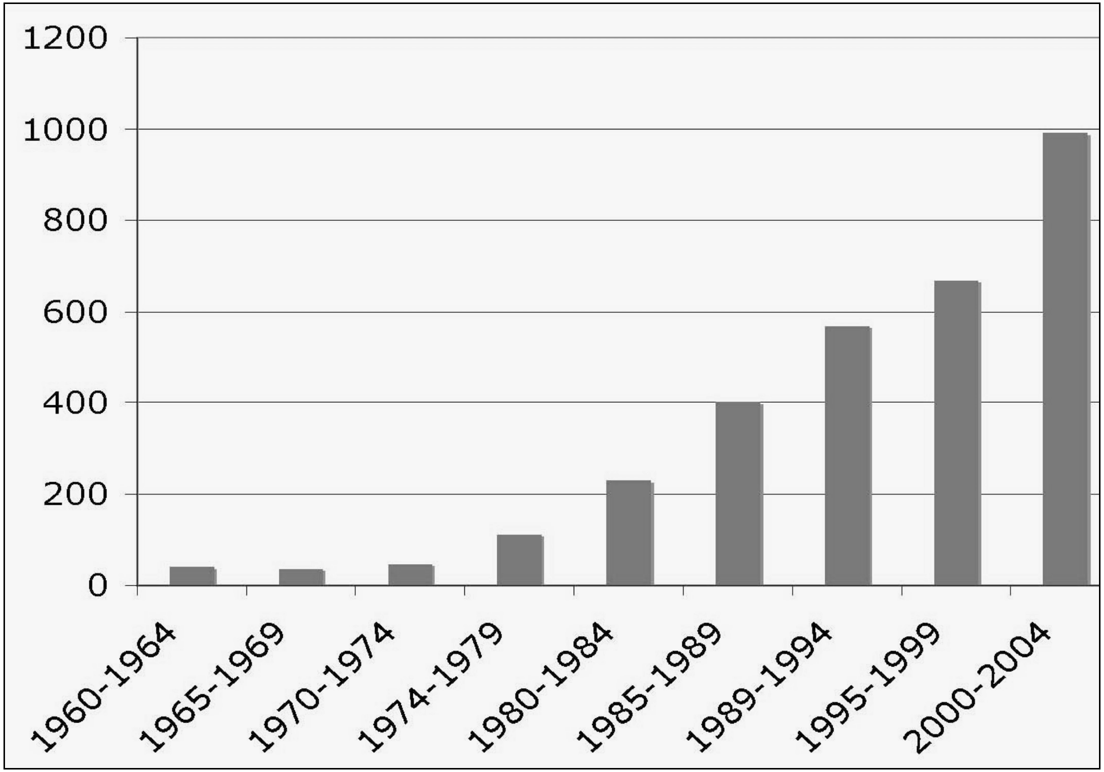
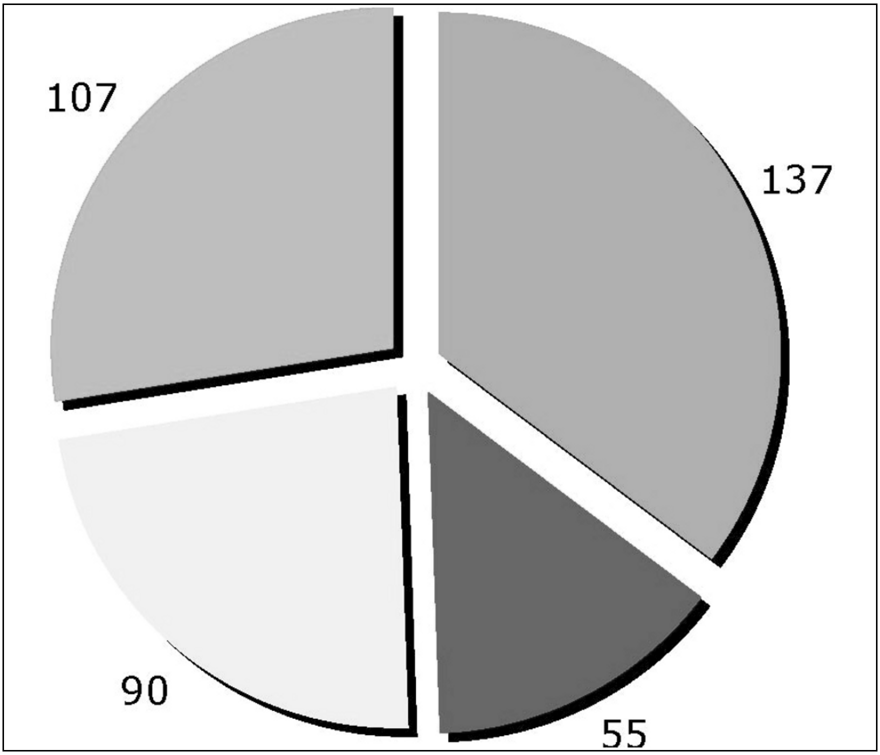


Fig. 4. Histogram of published CyanoHAB events by date.



Legend:
North America (107)
Europe (137)
South America (55)
Australia (90)

Fig. 5. Pie chart showing number of published CyanoHAB events by continent.

Charge 6

Do cyanobacterial HABs that present a health risk occur often enough to warrant regulation, or are general guidelines or advisories on an as-needed basis adequate?

Animal health risks from CyanoHABs are much easier to define than risks for humans as animals are more likely to come in contact with cyanotoxin-contaminated water. Action levels for CyanoHABs have been defined in Chorus and Bartram (1999), but these levels certainly need reassessment as more information becomes available. Nonetheless they are a good starting point for the U.S. to begin assessing risk to humans in the U.S. Human exposures range from accidental ingestion of water from recreational activities, ingestion of cyanotoxin-contaminated drinking water, low level consumption of cyanotoxins in algal nutritional products and from water used in medical treatments (i.e. medical dialysis). At this time insufficient information is available on exposure risk for the various cyanotoxins to warrant regulation. The number and type of documented exposures however do warrant guidelines and advisories for all the major groups of cyanotoxins identified in U.S. waters, (*i.e.* microcystins, cylindrospermopsins, anatoxins and saxitoxins). Table 1 is a summary of known human exposures from CyanoHABs in U.S. waters (Carmichael and Stukenberg 2006, Codd et al. 2006, Yoo et al. 1995), while Appendix A is a chronological list of published articles on CyanoHAB outbreaks in the U.S.

Table 1. Acute intoxications of humans from cyanobacteria U.S. and Canada

	U.S.
1931	A massive Microcystis bloom in the Ohio and Potomac Rivers caused illness in 5,000 to 8,000 persons whose drinking water was taken from these rivers. Drinking water treatment by precipitation, filtration and chlorination was not sufficient to remove the toxins.
1968	Numerous cased of gastrointestinal illness after exposure to mass developments of cyanobacteria in drinking water were compiled by Schwimmer and Schwimmer.
1975	Endotoxic shock of 23 dialysis patients in Washington, D.C. is attributed to a cyanobacterial bloom in a drinking water reservoir.
1975	"Gastrointestinal illness at Sewickley, Pa, Cyanobacterial waterborne disease outbreak which struck 62 percent of the population served by the Sewickley water utility.
1980	Water-associated human illness in northeast Pennsylvania and its suspected association with blue-green algae blooms.
1992	Carmichael unpublished - case studies on nausea, vomiting, diarrhea, fever and eye, ear and throat infections after exposure to mass developments of cyanobacteria in drinking water.
	Canada
1959	In spite of livestock deaths and warnings against recreational use, people did swim in a lake infested with cyanobacteria. Thirteen persons became ill (headaches, nausea, muscular pains, painful diarrhea). In the excreta of one patient—a medical doctor who had accidentally ingested 300mL of water—numerous cells of Microcystis spp. And some tricomes of Anabaena circinalis could be clearly identified.

Conclusion and Summary

CyanoHABs are an intermittent but repeated occurrence throughout the world. They have been documented to impact water quality through production of compounds affecting taste and odor. Selected species within about 40 genera can produce potent toxins that can cause chronic, acute and acute lethal poisonings to wild and domestic animals and humans. Direct and indirect evidence indicates that the incidence, duration and intensity of CyanoHABs is increasing throughout the world, due largely to a decline in the quality of water supplies. While significant effort has gone into defining the chemistry and toxicology of cyanotoxins, a worldwide effort from scientists and environmental agencies to map their occurrence and environmental health risk is needed. An unprioritized listing for those efforts is suggested below (Ramsdell et al. (eds.) 2005):

1. Improved Ability to Detect HAB Species and Analyze CyanoHAB Toxins.
2. Improved Capability for Monitoring and Forecasting CyanoHABs in a Cost Effective and Timely Manner.
3. Improved Protection of Human Health.
4. Improved Protection of Endangered Species and Improved Ecological Health.
5. Improved Prevention and Mitigation Strategies.
6. Improved Economic Cost Estimates of CyanoHAB Events.
7. Improved Economics for Aquaculture and Shellfish Safety
8. An Educated and Informed Public.

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Tisdale ES (1931) "Epidemic of intestinal disorders in Charleston, W. Va., occurring simultaneously with unprecedented water supply conditions." Am. J. Pub. Health 21: 198-200.

Wilmot Enterprise (1925) One hundred twenty seven hogs, 4 cows die after drinking water from (Big Stone) lake, stock stricken, last Saturday, all die in short time, lake water sent in for analysis. *Wilmot Enterprise*. Wilmot, South Dakota.

Yoo RS, Carmichael WW, et al. (1995) Cyanobacterial (Blue-Green Algal) Toxins: A Resource Guide. Denver, Colorado. AWWA Research Foundation and AWWA Association.

Chapter 4 Appendix A

Chronology of Published Articles on Cyanobacterial Outbreaks in the U.S. 1883-2003 (Carmichael and Stukenberg 2006)

Date	Article Title
1883	Some algae of Minnesota supposed to be poisonous.
1887	Some algae of Minnesota supposed to be poisonous.
1887	Second report on some algae of Minnesota supposed to be poisonous
1887	Investigation of supposed poisonous vegetation in the waters of some of the lakes of Minnesota.
1903	Observations upon some algae which cause water bloom(Fergus Falls, Minnesota)
1925	Farmer tells some news (on stock poisoning in Big Stone Lake) (South Dakota)
1925	One hundred twenty seven hogs, 4 cows die after drinking water from (Big Stone) lake, stock stricken, last Saturday, all die in short time, lake water sent in for analysis. (South Dakota)
1927	Plants of Michigan poisonous to livestock.
1931	Epidemic of intestinal disorders in Charleston, W. Va., occurring simultaneously with unprecedented water supply conditions.
1934	Waterbloom as a cause of poisoning in domestic animals (Minnesota)
1939	Toxic algae in Colorado.
1940	Toxic algae in Colorado.
1943	Sheep poisoning by algae(Montana)
1947	Waterbloom as a cause of poisoning in livestock in North Dakota.
1948	A heavy mortality of fishes resulting from the decomposition of algae in the Yahara River, Wisconsin
1952	Illustrations of fresh water algae toxic to animals. Cincinnati, Ohio.
1953	Toxic algae in Iowa lakes.
1953	Rice fields study report: blue-green algae—a possible anti-mosquito measure for rice fields (California)
1954	Blue-green algae control at Storm Lake. (Iowa)
1955	Further studies during 1954 on blue-green algae—a possible anti-mosquito measure for rice fields (California)
1955	Domestic animal deaths attributed to algal toxins. (Illinois)
1956	Present knowledge concerning the relationship of blue-green algae and mosquitoes in California rice fields.
1959	A dermatitis-producing alga in Hawaii.
1959	Dermatitis escharotica caused by a marine alga.(Hawaii)
1960	Water poisoning — a study of poisonous algae blooms in Minnesota.
1960	Algae and other interference organisms in the waters of the South-Central United States
1961	Klamath Lake, an instance of natural enrichment. (Oregon)
1964	Blue-greens. Waterfowl Tomorrow. (Minnesota)
1966	Toxicity of a Microcystis waterbloom from an Ohio pond.
1971	Dermatitis-producing alga Lyngbya majuscula Gomont in Hawaii. I. Isolation and chemical characterization of the toxic factor.
1971	Dermatitis-producing alga Lyngbya majuscula Gomont in Hawaii. II. Biological properties of the toxic factor.

Date	Article Title
1975	Pyrogenic reactions during hemodialysis caused by extramural endotoxin. (Washington, D.C.)
1976	Gastrointestinal illness at Sewickley, Pa.
1977	Toxic blooms of blue-green algae. (New Hampshire)
1977	Are algae toxic to honey bees? (Arizona)
1978	Dermatitis from purified sea algae toxin (debromoaplysiatoxin) (Hawaii)
1979	Lytic organisms and photooxodative effects: influence on blue-green algae (cyanobacteria) in Lake Mendota, Wisconsin.
1980	Blue-green algae and selection in rotifer populations (Florida)
1981	A toxic bloom of Anabaena flos-aquae in Hebgen Reservoir Montana in 1977.
1981	Studies on aphantoxin from Aphanizomenon flos-aquae in New Hampshire.
1981	Water-associated human illness in northeast Pennsylvania and its suspected association with blue-green algae blooms.
1982	Seaweed itch on Windward Oahu.
1984	Toxic algae. Montana Water Quality
1984	Antineoplastic evaluation of marine algal extracts (Hawaii)
1986	Toxicity of a clonal isolate of the cyanobacterium (blue-green alga) Microcystis aeruginosa from Lake Erie. (Ohio)
1987	Blue green algae (Microcystis aeruginosa) hepatotoxicosis in cattle (Illinois)
1988	Modeling blue green algal blooms in the lower Neuse River.(North Carolina)
1988	Anticholinesterase poisonings in dogs from a cyanobacterial (blue-green algae) bloom dominated by Anabaena flos-aquae (South Dakota)
1989	Consistent inhibition of peripheral cholinesterases by neurotoxins from the freshwater cyanobacterium Anabaena flos-aquae: studies of ducks, swine, mice and a steer (EPA Region 5)
1990	Isolation, characterization and detection of cyanobacteria (blue-green algae) toxins from freshwater supplies.(Ohio)
1990	Blue-green algae toxicosis in Oklahoma.
1992	Identification of 12 hepatotoxins from a Homer Lake bloom of the cyanobacteria Microcystis aeruginosa, Microcystis viridis, and Microcystis wesenbergii: nine new microcystins.(Illinois)
1992	Neurotoxic Lyngbya wollei in Guntersville Reservoir, Alabama.
1992	Outbreaks of waterborne disease in the United States: 1989-90
1993	Chemical study of the hepatotoxins from Microcystis aeruginosa collected in California.
1993	Toxicosis due to microcystin hepatotoxins in three Holstein heifers. (Michigan)
1994	Algal toxins in drinking water? Research in Wisconsin.
1995	Cascading disturbances in Florida Bay, USA: cyanobacteria blooms, sponge mortality and implications for juvenile spiny lobsters, Panulirus argus.

Date	Article Title
1995	Seven more microcystins from Homer Lake cells: application of the general method for structure assignment of peptides containing a-b-dehydroamino acid unit(s). (Illinois)
1996	Assessment of blue-green algal toxins in Kansas
1996	Aplysiatoxin and debromoaplysiatoxin as the causative agents of a red alga: Gracilaria coronopifolia poisoning in Hawaii.
1997	Mechanisms of ecosystem change: the role of zebra mussels in Saginaw Bay.(Michigan)
1997	Evidence for paralytic shellfish poisons in the freshwater cyanobacterium Lyngbya wollei (Farlow ex Gomont) comb. nov.(Alabama)
1997	Recent appearance of Cylindrospermopsis (cyanobacteria) in five hypereutrophic Florida lakes.
1997	Occurrence of the black band disease cyanobacterium on healthy coral of the Florida Keys.
1998	Blue-green algae toxicosis in cattle. (Colorado)
1999	Effect of surface water on desert Bighorn sheep in the Cabeza-Prieta National Wildlife Refuge, Southwestern Arizona.
1999	Spread of toxic algae linked to zebra mussels. (Ohio)
2000	New malyngamides from the Hawaiian cyanobacterium Lyngbya majuscula.
2000	Harvesting of Aphanizomenon flos-aquae Ralfs ex. Born. and Flah. var. flosaquae (cyanobacteria) from Klamath Lake for human dietary use. (Oregon)
2000	Desert Bighorn sheep mortality due to presumptive type-C botulism in California.
2001	Microcystin algal toxins in source and finished drinking water. (Wisconsin)
2001	Confirmation of catfish, Ictalurus punctatus (Rafinesque) mortality from Microcystis toxins (South Central U.S.)
2001	Assessment of Blue-Green Algal Toxins in Raw and Finished Drinking Water.Denver, Colorado
2001	Zebra mussel (Driessena polymorpha) selective filtration promoted toxic Microcystis blooms in Saginaw Bay (Lake Huron) and Lake Erie
2002	Possible importance of algal toxins in the Salton Sea, California.
2002	Clinical and necropsy findings associated with increased mortality among American alligators of Lake Griffin, Florida.
2002	Removal of pathogens, surrogates, indicators and toxins using riverbank filtration (California)
2002	Dreissenid mussels increase exposure of benthic and pelagic organisms to toxic microcystins. (Michigan)
2003	Natural algacides for the control of cyanobacterial-related off-flavor in catfish aquaquaculture (South Central U.S)
2003	A synoptic survey of musty/muddy odor metabolites and microcystin toxin occurrence and concentration in southeastern USA channel catfish (Ictalurus punctatus Rafinesque) production ponds

Date	Article Title
2003	Variants of microcystin in south-eastern USA channel catfish (Ictalurus punctatus Rafinesque) production ponds
2003	Cyanobacterial toxicity and migration in a mesotrophic lake in western Washington,