Microcystin in Midwestern Lakes

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Algal blooms in both marine and freshwater environments cause ecologic, economic, and public health concerns. Blooms reduce water quality, negatively impact recreational and aquacultural industries, and may also produce toxins that poison both aquatic and terrestrial animals, including humans. Marine algae were first noted to produce toxins potent enough to kill humans in 1793, and in 1878 freshwater algae were implicated in animal deaths (Francis 1878, Hallegraeff 1993). Globally, toxic algal blooms have increased in occurrence over the past several decades. To date, toxic incidents have been reported in over 50 countries, spanning six continents at latitudes from Argentina to Norway. Both marine and freshwater species of cyanobacteria (blue-green algae), dinoflagellates, and diatoms produce toxins, but the majority of marine incidents are associated with dinoflagellates, while the majority of freshwater incidents are caused by cyanobacteria.

Cyanotoxic Incidents

Cyanobacteria produce a diverse group of toxins that target fundamental cellular processes and affect a wide range of organisms. Several animal poisonings involving cyanobacterial toxins (cyanotoxins) have recently drawn attention, prompting many states to include cyanotoxins in their routine monitoring programs. Although cyanotoxins are the focus of recent attention, toxic cyanobacterial blooms are not a new phenomenon. Cyanotoxic incidents have been reported in the Midwestern United States for over a century. Some of the earliest records of poisonings are from Minnesota in the late 1800s. Since then, toxic cyanobacterial blooms have regularly been reported throughout the Midwestern United States (Yoo et al. 1995). In some cases, toxic episodes were frequent enough to warrant routine monitoring. For example, in the 1940s and 1950s several beaches in Iowa were regularly monitored for the presence of cyanotoxins and, when detected, public notices were posted and beaches were closed (Rose 1953).

Microcystin, produced by at least 13 cyanobacterial genera including *Anabaena*, *Microcystis*, and *Oscillatoria*, is one of the most common cyanotoxins. Toxic incidents involving microcystin have been reported in a variety of freshwater environments ranging from oligotrophic alpine lakes to hypereutrophic tropical reservoirs. Microcystin targets the liver (hepatotoxic) and has been implicated in human and animal illness and death in over 20 countries worldwide, including the United States. The major routes of human exposure to microcystin are through recreation and drinking water. The adverse health effects caused by ingestion or inhalation of high concentrations of microcystin (acute exposure) include rash, inflammation of membrane tissues, vomiting, and diarrhea. The effects of exposure to low levels of microcystin over an extended period of time (chronic exposure) are currently unknown, but

Microcystis bloom in a Missouri reservoir. Toxic incidents involving microcystin are often associated with large cyanobacterial genera that are easy to see; however, not all bloom are toxic.

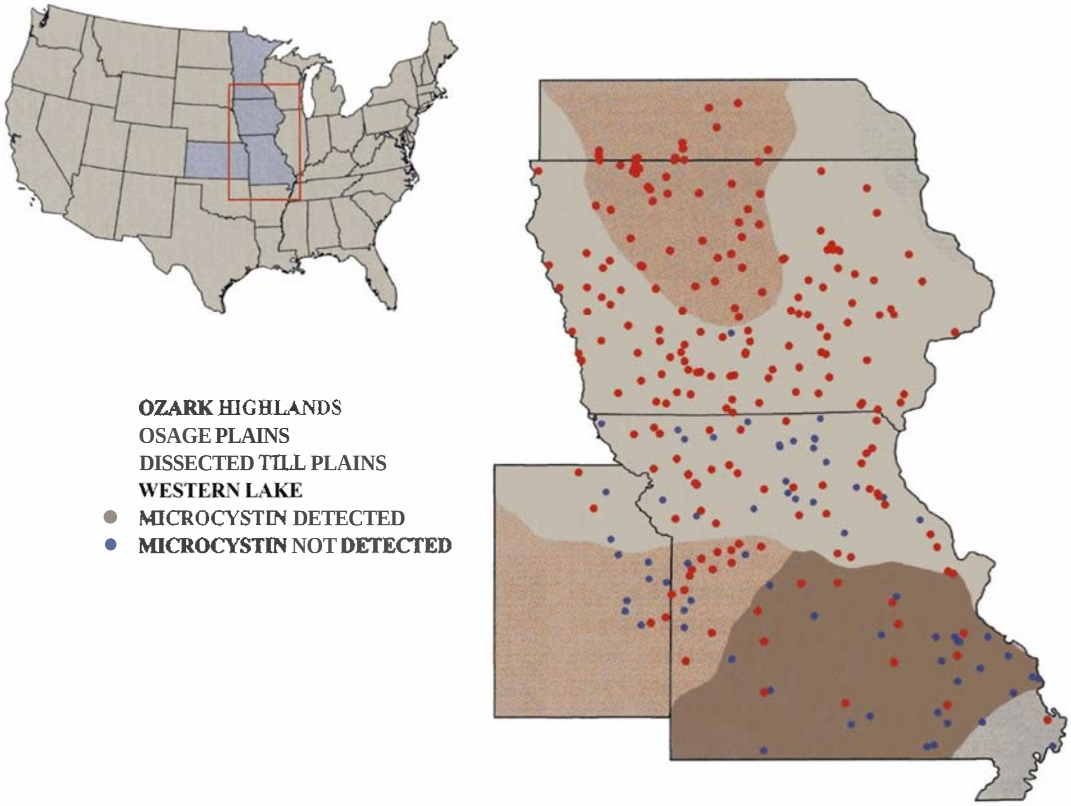
microcystin is considered to promote the growth of tumors.

Risk Categories

The greatest risk of exposure to high microcystin concentrations is probably through accidental ingestion and inhalation of cyanobacteria during recreational activities. The World Health Organization (WHO) has defined low, moderate, high, and very high risk categories for adverse health effects during recreational exposure to microcystin. Based on the WHO risk categories, microcystin concentrations < 10 μg/L have a low risk, 10 to 20 μg/L a moderate risk, 20 to 2,000 μg/L a high risk, and > 2,000 μg/L a very high risk for adverse health effects. The WHO has also set a provisional guideline of 1 μg/L for microcystin in drinking water. Microcystin has been detected in tap water, but modern drinking-water treatment capabilities substantially reduce the risk of exposure to high concentrations. These guidelines will probably change as more information about the health effects of microcystin exposure becomes available (Chorus and Bartram 1999).

Midwestern Studies

Because microcystin is a potential health risk in Midwestern lakes and reservoirs we have conducted several studies to determine how frequently microcystin occurs and if concentrations are high enough to cause concern. During summers 1999-2001, and again in 2004, 278 lakes in Missouri, Iowa, southern Minnesota, and eastern Kansas were sampled. Most lakes were sampled two to four times in one or all years. The study region is divided into four major provinces based on physical geography. From south to north the provinces are: the Ozark Highlands (southern Missouri), the Osage Plains (west-central Missouri and east-central Kansas), the Dissected Till Plains (northern Missouri, Iowa, and southern Minnesota), and the Western Lake Section (north-central Iowa and south-central Minnesota). Differences in water quality among these provinces generally are associated with geology and land use. Because of rich glacial soils and a landscape dominated by row-crop agriculture, the Western Lakes Section (the northern-most province) has nutrient enriched lakes that support high levels of algal biomass. In contrast, the Ozark Highlands (the southern-most province), with thin soils and little row-crop agriculture, tends to have lakes with low nutrient levels and algal biomass. The Osage and Dissected Till Plains are intermediate between the southern- and northern-most provinces (Jones and Bachmann 1978, Jones and Knowlton 1993). Generally, nutrients increase and Secchi depths decrease (conditions that favor cyanobacteria) as you move northward through the provinces. The majority of lakes in the Ozark Highlands are classified as oligotrophic or mesotrophic, while in all other provinces most lakes are classified as eutrophic or hypereutrophic.



Map of physiographic provinces and lakes sampled during 1999-2004 (map after Graham and others, 2004). Red circles indicate lakes where microcystin was detected. Blue circles indicate lakes where microcystin was not detected.

Microcystin was common in the region and 76 percent of the 278 lakes sampled had detectable concentrations of microcystin at least once. In addition, 72 percent of the 137 lakes sampled for three to four years always had detectable microcystin during summer. Although common throughout the region, microcystin occurred more frequently in the eutrophic and hypereutrophic lakes of the northern provinces: 83 percent of Dissected Till Plain and 100 percent of Western Lake Section lakes had detectable microcystin, compared to 30 percent in the Ozark Highlands and 52 percent in the Osage Plains.

Microcystin concentrations in lake water ranged from 0 to 52 μg/L and, like occurrence, concentrations were greatest in the eutrophic and hypereutrophic lakes of the northernmost provinces. Only 30 percent of lakes had microcystin concentrations greater than 1 μg/L, and only 4 percent had concentrations that were in the moderate (10 to 20 μg/L) or high-risk (20 to 2,000 μg/L) categories for adverse health effects through recreational exposure. Concentrations high enough to be considered a very high risk were never observed. Therefore, although microcystin was common it was generally not detected in concentrations high enough to cause acute human health concerns.

Table 1. Regional means and ranges of microcystin concentrations during 1999-2004.

		Microcystin (µg/L)	
Region	*Number of Samples*	*Mean*	*Range*
Ozark Highlands	807	0.0	0-3
Osage Plains	220	0.0	0-1
Dissected Till Plains	151	0.4	0-31
Western Lake Section	314	0.8	0-52

Regional studies conducted around the world also have noted that microcystin is widespread, but generally only detected in low concentrations with a few high values. Maximum microcystin concentrations observed in our study are similar to maxima reported from elsewhere in the United States and Canada, but several orders of magnitude less than the maxima reported from other continents, including Europe and Asia. For example, microcystin concentrations greater than 450 µg/L have been reported from Germany and concentrations greater than 1,300 µg/L have been reported from Japan (Chorus 2001).

Cyanobacteria Presence and Toxin Detection

Toxic incidents involving microcystin are most frequently associated with large cyanobacterial genera that form surface blooms, such as *Anabaena* and *Microcystis.* During 1999-2001, algal samples for microcystin analysis were concentrated with plankton nets when cyanobacteria were visible in the lakes. Microcystin was detected in almost all (98 percent) of the algal samples collected, which suggests that microcystin is likely present when cyanobacteria can be easily seen in a lake. Although there was a strong relation between visible cyanobacteria and microcystin detection, cyanobacterial abundance was not necessarily related to microcystin concentrations. Not all cyanobacteria produce microcystin, so the relationship between cyanobacterial abundance and microcystin concentration is not always straightforward; the toxicity of a bloom cannot be determined visually.

Spatial and Temporal Variation

Microcystin concentrations are highly variable both spatially and temporally. Extensive surface scums of cyanobacteria may develop and dissipate over a 24-hour period. Lakes may experience a single peak in microcystin concentrations, lasting a few days to weeks, or several peaks may occur throughout the year. Peak microcystin concentrations in Midwestern lakes typically occur during summer-fall, but several exceptions have been noted and the potential for problems associated with microcystin exists yea. round. For example, in a Missouri lake sampled weekly during 2004, microcystin was not detected until mid-October and concentrations peaked in December..

Late October cyanobacterial bloom in a Missouri reservoir.

Monthly sampling during summer, the approach used in our regional studies, will not detect maximal microcystin concentrations in all lakes. In addition, most of these samples were collected at open-water locations to avoid surface scum. Microcystin concentrations in scums may be much greater than at pelagic locations.

Summary

Microcystin, and other cyanotoxins, are potential health risks in recreational lakes and drinking-water supplies. While the majority of lakes sampled in these studies had relatively low microcystin concentrations, the toxin was widespread, particularly in the eutrophic and hypereutrophic lakes of the region. Concentrations may only occasionally be classified as a high risk for adverse health effects, but monitoring programs can ensure that human (and animal) exposure to microcystin is minimized.

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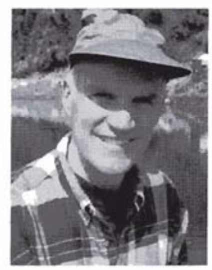

For the past 30 years, **Jack Jones** has taught limnology at the University of Missouri Department of Fisheries and Wildlife sciences. He has studied nutrient-algal relations in reservoirs and running waters in the Midwest. Studies in Asian countries have emphasized how the summer monsoon influences lake processes, including the occurrence of algal toxins in Nepal with Susan Jones. Jack is an associate editor of Lake and *Reservoir Management* and editor of the Proceedings of the *International* Association of Theoretical *and* Applied *Limnology*.

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