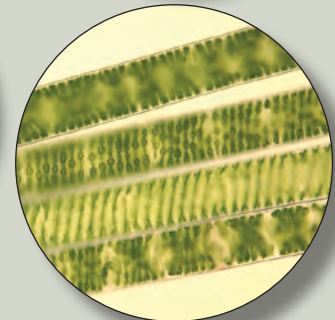
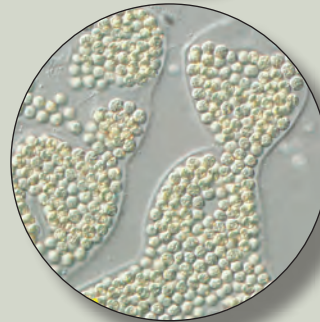
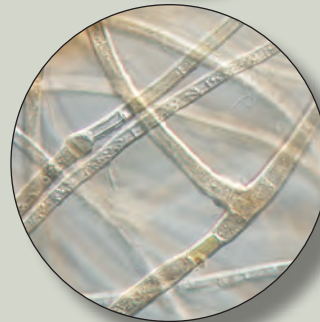
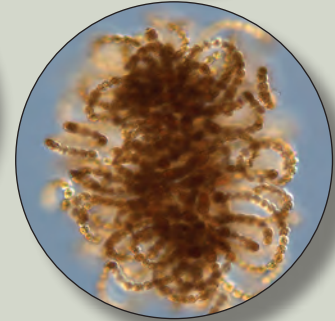
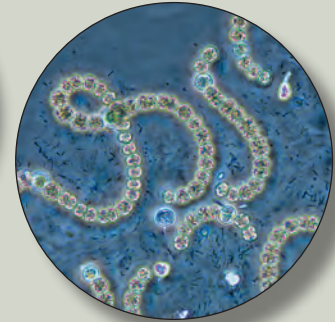
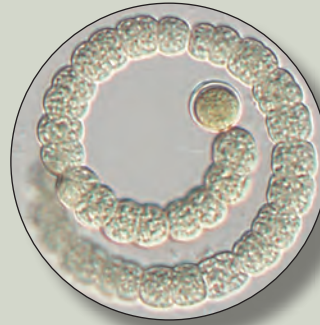
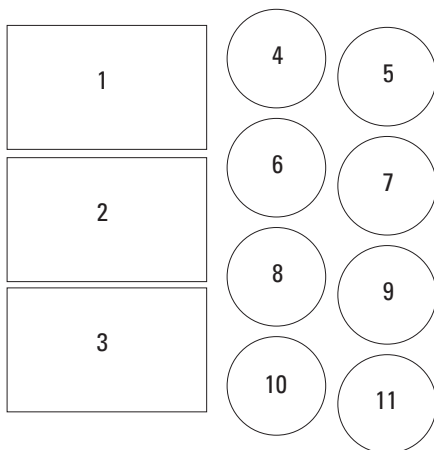


# Field and Laboratory Guide to Freshwater Cyanobacteria Harmful Algal Blooms for Native American and Alaska Native Communities



Open-File Report 2015–1164

U.S. Department of the Interior  
U.S. Geological Survey



**Cover.** Photographs showing

1. Cyanobacteria, *Gloeotrichia echinulata* (Midge Eliassen)
2. Euglenophyta, *Euglena* sp. (Ann St. Amand)
3. Euglenophyta, *Euglena sanguinea* (Barry H. Rosen)
4. *Anabaenopsis arnoldii* (Barry H. Rosen)
5. *Dolichospermum circinale* (Ann St. Amand)
6. *Dolichospermum crassum* (Ann St. Amand)
7. *Dolichospermum lemmermannii* (Ann St. Amand)
8. *Haplosiphon hibernicus* (Barry H. Rosen)
9. *Sphaerospermopsis torques-reginae* (Barry H. Rosen)
10. *Microcystis wesenbergii* (Barry H. Rosen)
11. *Spirogyra* sp. (Ann St. Amand)

# **Field and Laboratory Guide to Freshwater Cyanobacteria Harmful Algal Blooms for Native American and Alaska Native Communities**

By Barry H. Rosen and Ann St. Amand

Open-File Report 2015–1164

**U.S. Department of the Interior  
U.S. Geological Survey**

**U.S. Department of the Interior**  
SALLY JEWELL, Secretary

**U.S. Geological Survey**  
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2015

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment—visit <http://www.usgs.gov> or call 1–888–ASK–USGS.

For an overview of USGS information products, including maps, imagery, and publications, visit <http://www.usgs.gov/pubprod/>.

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Although this information product, for the most part, is in the public domain, it also may contain copyrighted materials as noted in the text. Permission to reproduce copyrighted items must be secured from the copyright owner.

Suggested citation:

Rosen, B.H., and St. Amand, Ann, Field and laboratory guide to freshwater cyanobacteria harmful algal blooms for Native American and Alaska Native Communities: U.S. Geological Survey Open-File Report 2015–1164, 44 p., <http://dx.doi.org/10.3133/ofr20151164>.

ISSN 0196-1497 (print)  
ISSN 2331-1258 (online)

ISBN 978-1-4113-3971-2

# Contents

Acknowledgments .....	v
Abstract .....	1
Introduction.....	1
Field Images.....	4
Microscope Images.....	16
Cyanobacteria Microscopic Identification Characteristics .....	16
Cyanobacteria .....	18
<i>Anabaenopsis</i> .....	18
<i>Aphanizomenon</i> .....	19
<i>Chrysochlorum (Anabaena)</i> .....	20
<i>Cuspidothrix (Aphanizomenon)</i> .....	20
<i>Cylindrospermopsis</i> .....	20
<i>Dolichospermum (Anabaena)</i> .....	21
<i>Gloeotrichia</i> .....	24
<i>Haplosiphon</i> .....	25
<i>Microcystis</i> .....	26
<i>Nodularia</i> .....	29
<i>Nostoc</i> sp. ....	30
<i>Oscillatoria</i> sp.....	31
<i>Planktothrix (Oscillatoria)</i> .....	31
<i>Plectonema (Lyngbya)</i> .....	32
<i>Raphidiopsis</i> .....	32
<i>Schizothrix</i> sp. ....	33
<i>Sphaerospermopsis (Anabaena)</i> .....	33
<i>Woronichinia (Coelospherium)</i> .....	35
Other Organisms Viewed Under the Microscope .....	36
Euglenophyta (Euglenoids).....	36
Pyrrhophyta (Dinoflagellates).....	37
Haptophyta (Golden Algae).....	38
Chlorophyta (Green Algae).....	39
References.....	41

## Figures

1. Cyanobacteria, <i>Dolichospermum lemmermannii</i> .....	4
2. Cyanobacteria, <i>Microcystis aeruginosa</i> .....	4
3. Cyanobacteria, <i>Microcystis aeruginosa</i> .....	4
4. Cyanobacteria, <i>Dolichospermum lemmermannii</i> .....	5
5. Cyanobacteria, <i>Dolichospermum lemmermannii</i> .....	5
6. Cyanobacteria, <i>Dolichospermum mendotae</i> .....	6
7. Cyanobacteria, <i>Gloeotrichia echinulata</i> .....	6
8. Cyanobacteria, <i>Microcystis viridis</i> .....	7
9. Cyanobacteria, <i>Dolichospermum lemmermannii</i> .....	7
10. Cyanobacteria, <i>Aphanizomenon flos-aquae</i> .....	8
11. Cyanobacteria, <i>Aphanizomenon flos-aquae</i> .....	8
12. Cyanobacteria, <i>Nodularia spumigena</i> .....	9
13. Cyanobacteria, <i>Plectonema wollei</i> .....	9
14. Cyanobacteria, <i>Woronichinia naegeliana</i> .....	9
15. Cyanobacteria, <i>Cylindrospermopsis raciborskii</i> .....	10
16. Cyanobacteria, <i>Planktothrix agardhii/prolifera</i> .....	10
17. Green algae, <i>Mougeotia</i> sp. ....	11
18. Green algae, <i>Spirogyra</i> sp. ....	11
19. Green algae, <i>Cladophora</i> sp. ....	11
20. Green algae, <i>Mougeotia</i> sp. ....	11
21. Duckweed: <i>Wolffia columbiana</i> .....	12
22. Duckweed: <i>Wolffia columbiana</i> , <i>Lemna minor</i> .....	12
23. Charophyta, <i>Chara</i> sp. ....	13
24. Charophyta, <i>Chara</i> sp. ....	13
25. Rooted macrophytes.....	13
26. Rooted macrophytes.....	13
27. Euglenophyta, <i>Euglena</i> sp. ....	14
28. Euglenophyta, <i>Euglena sanguinea</i> .....	14
29. Water fern, <i>Azolla</i> sp. ....	15
30. Pine pollen.....	15
31. Pyrrhophyta, <i>Durinskia dybowskii</i> .....	15
32. Morphology of cyanobacteria filaments.....	16
33. Morphology of cyanobacteria colonies.....	17
34. <i>Anabaenopsis arnoldii</i> .....	18
35. <i>Aphanizomenon flos-aquae</i> .....	19
36. <i>Aphanizomenon gracile</i> .....	19
37. <i>Chrysochlorum ovalisporum</i> .....	20
38. <i>Cuspidothrix issatschenkoi</i> .....	20
39. <i>Cylindrospermopsis raciborskii</i> .....	20
40. <i>Dolichospermum circinale</i> .....	21
41. <i>Dolichospermum crassum</i> .....	22
42. <i>Dolichospermum lemmermannii</i> .....	22
43. <i>Dolichospermum mendotae</i> .....	23

44.	<i>Dolichospermum planctonicum</i> .....	23
45.	<i>Gloeotrichia echinulata</i> .....	24
46.	<i>Haplosiphon hibernicus</i> .....	25
47.	<i>Microcystis aeruginosa</i> .....	26
48.	<i>Microcystis viridis</i> .....	27
49.	<i>Microcystis wesenbergii</i> .....	28
50.	<i>Nodularia spumigena</i> .....	29
51.	<i>Nodularia spumigena</i> .....	29
52.	<i>Nostoc</i> sp. ....	30
53.	<i>Oscillatoria</i> sp. ....	31
54.	<i>Planktothrix agardhii</i> .....	31
55.	<i>Plectonema wollei</i> .....	32
56.	<i>Raphidiopsis mediterranea</i> .....	32
57.	<i>Schizothrix</i> sp. ....	33
58.	<i>Sphaerospermopsis torques-reginae</i> .....	33
59.	<i>Sphaerospermopsis aphanizomenoides</i> .....	34
60.	<i>Woronichinia naegeliana</i> .....	35
61.	<i>Euglena</i> sp. ....	36
62.	<i>Euglena sanguinea</i> .....	37
63.	<i>Durinskia dybowskii</i> , <i>Peridinium</i> sp., <i>Ceratium hirundinella</i> .....	37
64.	<i>Prymnesium parvum</i> .....	38
65.	Green algae: <i>Spirogyra</i> sp., <i>Cladophora</i> sp., <i>Mougeotia</i> sp. ....	39
66.	Green algae: <i>Pithophora</i> sp. ....	40

## Tables

1.	Classification, common names, and synonyms for most freshwater algae .....	1
2.	Common cyanotoxin-producing cyanobacteria that are illustrated in this guide .....	3
3.	Cyanobacteria synonyms (see table 2) .....	3

## Abbreviations

EPA	U.S. Environmental Protection Agency
HAB	harmful algal bloom
sp.	species

## Acknowledgments

This project was funded by the U.S. Geological Survey, Office of Tribal Relations. The authors thank Monique Fordham and Keith Loftin, U.S. Geological Survey, for their advice and review comments. We also thank the numerous photograph contributors who are acknowledged in the captions of the figures. All photographs were used with written permission from the respective photographers.



# Field and Laboratory Guide to Freshwater Cyanobacteria Harmful Algal Blooms for Native American and Alaska Native Communities

By Barry H. Rosen<sup>1</sup> and Ann St. Amand<sup>2</sup>

## Abstract

Cyanobacteria can produce toxins and form harmful algal blooms. The Native American and Alaska Native communities that are dependent on subsistence fishing have an increased risk of exposure to these cyanotoxins. It is important to recognize the presence of an algal bloom in a waterbody and to distinguish a potentially toxic harmful algal bloom from a non-toxic bloom. This guide provides field images that show cyanobacteria blooms, some of which can be toxin producers, as well as other non-toxic algae blooms and floating plants that might be confused with algae. After recognition of a potential toxin-producing cyanobacterial bloom in the field, the type(s) of cyanobacteria present needs to be identified. Species identification, which requires microscopic examination, may help distinguish a toxin-producer from a non-toxin producer. This guide also provides microscopic images of the common cyanobacteria that are known to produce toxins, as well as images of algae that form blooms but do not produce toxins.

<sup>1</sup>U.S. Geological Survey.

<sup>2</sup>PhycoTech, Inc.

## Introduction

Algae are a group of organisms with similar traits that unify them as a group but with specific characteristics that are used to separate one organism from another. As an example, chlorophyll *a*, used by algae to capture sunlight for photosynthesis, is common to virtually all organisms called “algae.” One major separation of algae is the basic cellular organization into prokaryotic organisms, such as the cyanobacteria that do not have internal organelles, and eukaryotic organisms, which include all the rest of the algal groups. The eukaryotic organisms are further divided on the basis of pigments, cell wall composition, photosynthetic storage compounds, flagella, and genetics. Many flagellated forms have greater affinity and are often classified as Protozoa.

Most recently, genetic affiliations between the hierarchical organization of algae and the individual species has led to a continuous flux in the names of organisms. Many approaches are available for organizing these groups. Table 1, which is based on the “Freshwater Algae of North America, 2015” (Wehr and others, 2015), provides a list of the “groups” of algae as well as some common names and synonyms for most freshwater algae.

**Table 1.** Classification, common names, and synonyms for most freshwater algae.

Division, Phylum, Group, or Class	Common name	Synonyms
Cyanobacteria <sup>1</sup>	Blue-green algae, cyanobacteria, cyanophytes	Cyanophyta, Cyanophycota, Cyanophyceae
Chlorophyta <sup>2</sup>	Green algae	Chlorophycota
Charophyceae <sup>2</sup>	Stoneworts	Charophyta
Bacillariophyceae <sup>3</sup>	Diatoms	Bacillariophyta <sup>3</sup>
Rhodophyta <sup>3</sup>	Red algae	
Euglenophyta <sup>3</sup>	Euglenoids	Euglenophyta
Pyrrophyta <sup>3</sup>	Dinoflagellates	Dinophyta, Pyrrophyta, Dinophyceae <sup>3</sup>
Haptophyceae <sup>3</sup>	Golden algae	Haptophyta, Prymnesiophyta
Synurophyceae, <sup>3</sup> Chrysophyceae <sup>3</sup>	Golden or golden-brown algae	Chrysophytes, Synurophytes
Cryptophyta <sup>3</sup>	Cryptomonads	

<sup>1</sup>Oren (2004). <sup>2</sup>Leliaert and others (2012). <sup>3</sup>Wehr and others (2015).

## 2 Field and Laboratory Guide to Freshwater Cyanobacteria Harmful Algal Blooms for Native American and Alaska Native Communities

Algae are primary producers and serve as the base of the food web in most aquatic habitats. Phytoplankton is a term that describes the assemblage of algae that live in the water column of a waterbody, including ponds, lakes, reservoirs, rivers, and marine habitats. Periphyton are the algae attached to plants, rocks, sand, and wood in most aquatic habitats. For phytoplankton, each group of algae has unique qualities that allow it to thrive at a different time and under specific environmental conditions in a waterbody, typically seasonally, with one group giving way to another as conditions change in the process called succession. For example, diatoms typically dominate in colder months and cyanobacteria and green algae in warmer months. When the abundance of algae causes a “problem,” typically a surface scum or accumulation on or near a shoreline, it is given the name “algae bloom” and many times “harmful algae blooms” (HABs). An algae bloom forms under the correct environmental conditions, including nutrient abundance, stability of the water column, ample light, and optimal temperatures. Although many different types of algae are responsible for HABs, cyanobacteria pose the greatest problem and are the focus of this guide.

Cyanobacteria, also known as blue-green algae, are a group of microorganisms that live in moist terrestrial and aquatic habitats throughout the world. Several types of cyanobacteria are known to produce a variety of toxins that can cause a range of effects from simple skin rashes to liver and nerve damage and even mortality of fish, wildlife, and rarely, humans (Chorus and Bartram, 1999). The major groups of toxins are the microcystins, saxitoxins, anatoxins, cylindrospermopsins, nodularins, and dermatoxins. These toxins typically represent a family of structurally related compounds, termed derivatives, which have similar biological effects.

The complexity of these toxins and their derivatives makes attribution of a specific compound to a specific species difficult. A field sample is often a mixture of organisms, thus the toxin attribution to a given species in a sample is uncertain. The best method for attributing a specific compound to a specific species involves isolating an organism and culturing it to ascertain that it is the source of toxin production; however, this is a difficult task and creates a myriad of secondary issues. Much of the literature describes the dominant organism in a bloom and typically attributes the toxin present to that organism. Table 2 provides a synopsis of the toxins found in the 26 cyanobacteria illustrated in the Microscope Images section of this guide. Note that some species are known to produce multiple toxins, and it is beyond the scope of this report to identify all of the genera and species identified in the literature as toxin producers.

Added to this complexity is the definition of a species in the cyanobacteria. The long-standing identification of a species is dependent on the morphology of the organism, including the shape of the cells, the positioning of key features, size, and coloration. Some of these features are stable and conservative, while others are more unstable and change under certain environmental conditions. With the advent of genetic techniques, many of these traditional visual features

have become secondary to the genetic makeup of an organism; however, genetic affiliation relies on being able to analyze an individual isolated species. The cyanobacteria have undergone substantial name changes to align the genetically affiliated organisms into closely related taxa, especially at the genus level. Table 3 provides the current name of cyanobacteria described in this document, along with the synonyms used in the past, to assist in properly identifying organisms and interpreting the literature. It is beyond the scope of this report to identify all of the synonyms that are used for each purported toxin-producing species of cyanobacteria.

Most bloom-forming cyanobacteria can regulate their buoyancy to optimize their position in the water column and float to the surface. Wind can also cause massive accumulations of phytoplankton on downwind shorelines. Improperly treated drinking water containing toxic cyanobacteria can cause liver and nervous system impairment in mammals including humans (Chorus and Bartram, 1999). Although many cyanobacteria often produce taste and odor compounds as well, the presence or absence of taste and odor compounds is not predictive of the presence of algal toxins.

The human consumption of fish and shellfish exposed to a cyanobacteria (and cyanotoxins) is poorly documented. Only a few studies have been conducted to examine fish and shellfish concentrations for key compounds, such as the microcystins (*shrimp*: Zimba and others, 2006; *Ibelings* and Chorus, 2007; *catfish*: Zimba and others, 2001; *carp*: Li and others, 2004), the nodularins (*muller*: Stewart and others, 2012), and the saxitoxins (*freshwater mussel*, Pereira and others, 2004). In a report by the National Environmental Justice Advisory Council (2002), which provided advice to the “Environmental Protection Agency (EPA) on how to improve the quality, quantity, and integrity of our Nation’s aquatic ecosystems in order to protect the health and safety of people consuming or using fish, aquatic plants, and wildlife,” HABs are not discussed. This report does recognize that many Native American and Alaska Native communities are dependent on subsistence fishing, creating an increased risk of exposure to traditional toxins, such as mercury and dioxins, which accumulate in the aquatic food webs. By comparison, the impact of HABs and cyanotoxins on humans, especially the Native American and Alaska Native communities, warrants additional study.

Warming global temperatures may exacerbate the growth of cyanobacterial blooms (Paerl and Huisman, 2009). One reason is that cyanobacteria proliferate in warm water temperatures, generally above 25 degrees Celsius (Robarts and Zohary, 1987), and are more tolerant of these warmer conditions than their competitors, such as the green algae (Elliott and others, 2006; Jöhnk and others, 2008). Warmer surface waters also augment vertical stratification (Jöhnk and others, 2008), giving the cyanobacteria a unique advantage over eukaryotic algae because many of the cyanobacteria are able to regulate their buoyancy and overcome vertical stratification. Numerous other physiological adaptations will give cyanobacteria an advantage as global climate changes occur (Carey and others, 2012).

**Table 2.** Common cyanotoxin-producing cyanobacteria that are illustrated in this guide.

<i>Anabaenopsis</i> sp.	microcystins (Lanaras and Cook, 1994) saxitoxins (Ballot and others, 2010b-[genes present])	<i>Microcystis aeruginosa</i>	microcystins (Rinehart and others, 1994)
<i>Aphanizomenon flos-aquae</i>	saxitoxins (Ferreira and others, 2001; Ballot and others, 2010b-[genes present]) cylindrospermopsins (Preussel and others, 2006)	<i>Microcystis viridis</i>	microcystins (Watanabe and others, 1986; Kusumi and others, 1987)
<i>Aphanizomenon gracile</i>	saxitoxins (Ballot and others, 2010b) cylindrospermopsins (Kokociński and others, 2013)	<i>Microcystis wesenbergii</i>	microcystins (Namikoshi and others, 1992; Tanabe and others, 2009)
<i>Chrysochlorum ovalisporum</i>	cylindrospermopsins (Akcaalan and others, 2014)	<i>Nodularia spumigena</i>	nodularins (Carmichael and others, 1988; Sivonen and others, 1989b; Stewart and others, 2012)
<i>Cuspidothrix issatschenkoi</i>	saxitoxins (Ballot and others, 2010b-[genes present]) anatoxin-a (Ballot and others, 2010a)	<i>Nostoc</i> sp.	microcystins (Sivonen and others, 1990, 1992b) nodularins (Gehring and others, 2012)
<i>Cylindrospermopsis raciborskii</i>	cylindrospermopsins (Sinha and others, 2014)	<i>Oscillatoria</i> sp.	anatoxin-a (Aráoz and others, 2005)
<i>Dolichospermum circinale</i>	saxitoxins (D'Agostino and others, 2014) microcystins (Vezie and others, 1998; D'Agostino and others, 2014) anatoxin-a (Sivonen and others, 1989a, 1992a)	<i>Planktothrix agardhii</i>	microcystins (Sivonen and others, 1990)
<i>Dolichospermum crassum</i>	anatoxin-a(s) (Becker and others, 2010)	<i>Plectonema wollei</i>	saxitoxins (Mez and others, 1996)
<i>Dolichospermum lemmermannii</i>	anatoxin-a(s) (Henriksen and others, 1997)	<i>Raphidiopsis mediterranea</i>	anatoxin-a (Namikoshi and others, 2003; Watanabe and others, 2003)
<i>Dolichospermum mendotae</i>	cylindrospermopsins (Akcaalan and others 2014) anatoxin-a (Rapala and others, 1993)	<i>Schizothrix</i> sp.	dermatotoxins (Lippy and Erb, 1976; Mynderse and others, 1977)
<i>Dolichospermum planctonicum</i>	anatoxin-a (Bruno and others, 1994)	<i>Sphaerospermopsis torques-reginae</i>	anatoxin-a(s) (Molica and others, 2005)
<i>Gloeotrichia echinulata</i>	microcystins (Carey and others, 2007)	<i>Sphaerospermopsis aphanizomenoides</i>	microcystins (Bittencourt-Oliveira and others, 2011) cylindrospermopsins (Bittencourt-Oliveira and others, 2011)
<i>Haplosiphon hibernicus</i>	microcystins (Prinsep and others, 1992)	<i>Woronichinia naegeliana</i>	microcystins [perhaps] (Faassen and Lüring 2013)

**Table 3.** Cyanobacteria synonyms (see table 2).

Currently accepted genus/species	Synonym	Reference
<i>Chrysochlorum ovalisporum</i>	<i>Aphanizomenon ovalisporum</i>	Zapomelová and others, 2012
<i>Cuspidothrix issatschenkoi</i>	<i>Anabaena issatschenkoi</i> <i>Aphanizomenon issatschenkoi</i>	Rajaniemi and others, 2005
<i>Dolichospermum</i> (many species)	<i>Anabaena</i> (most planktonic forms)	Wacklin and others, 2009
<i>Planktothrix agardhii</i> (and many other species)	<i>Oscillatoria agardhii</i>	Anagnostidis and Komárek, 1988
<i>Sphaerospermopsis aphanizomenoides</i>	<i>Aphanizomenon aphanizomenoides</i>	Zapomelová and others, 2010
<i>Sphaerospermopsis torques-reginae</i>	<i>Anabaena torques-reginae</i>	Werner and others, 2012
<i>Woronichinia</i>	<i>Coelosphaerium</i>	Komárek and Hindák, 1988 (for many species)

In an effort to help Native American and Alaska Native communities develop an awareness of what HABs look like in the field and distinguish HABs from a non-toxic bloom, the U.S. Geological Survey has developed this guide to illustrate the appearance of both typical algal and cyanobacteria blooms. Many of the organisms require the use of a microscope to correctly determine the type of bloom that is present. Included in this guide are microscopic images that illustrate many of the most common HABs and others that are known to be a nuisance or produce toxins that are not obvious surface bloom-forming organisms. Graham and others (2008) provide guidelines for the design and sampling for cyanotoxins in lakes and reservoirs.

## Field Images

When approaching a water bloom, caution and safety procedures should be used to prevent direct contact with the bloom because some cyanotoxins can be absorbed through the skin. These field photographs illustrate the color, “texture,” and general appearance of water blooms, both harmful and non-toxic, including nuisance blooms of green algae, certain floating plants, and other known blooms that may be encountered. Recognizing a cyanobacterial bloom in a waterbody and distinguishing it from other blooms that may or may not be harmful is the first step in becoming aware of the potential risk in surface water blooms. Figure 1 illustrates the common coloration of a blue-green algae bloom, or cyanobacterium; many variations of blue-green algae exist as illustrated in figures 2–16. Coloration is not an indicator of the genus of the organism(s), although repeated sampling and microscopic confirmation from the same waterbody should increase the likelihood of correctly identifying the key organisms seen when in the field.



**Figure 1.** Cyanobacteria, *Dolichospermum lemmermannii*. (Photograph: Ann St. Amand)

Many cyanobacteria float and often accumulate along the shoreline as illustrated in figures 2–7. These accumulations often appear clumped or scummed (figs. 3–5). Cells stranded on the shoreline often leak their pigments. Phycocyanin is a blue pigment and can turn a waterbody or shoreline turquoise (fig. 6) or chartreuse (fig. 7). Blooms can also be evenly dispersed in the water (figs. 8–10) or evenly dispersed as clumps (fig. 11). Some cyanobacteria appear brown in color due to the red pigment phycoerythrin and its combination with other pigments (figs. 12–15). Red to pink blooms are another phenomenon due to phycoerythrin (fig. 16).



**Figure 2.** Cyanobacteria, *Microcystis aeruginosa*. (Photograph: Ann St. Amand)



**Figure 3.** Cyanobacteria, *Microcystis aeruginosa*. (Photograph: Ann St. Amand)



**Figure 4.** Cyanobacteria, *Dolichospermum lemmermannii*. (Photograph: Ann St. Amand)



**Figure 5.** Cyanobacteria, *Dolichospermum lemmermannii*. (Photograph: Ann St. Amand)



**Figure 6.** Cyanobacteria, *Dolichospermum mendotae*. (Photograph: Ann St. Amand)



**Figure 7.** Cyanobacteria, *Gloeotrichia echinulata*. (Photograph: Midge Eliassen)



**Figure 8.** Cyanobacteria, *Microcystis viridis*. (Photograph: Ann St. Amand)



**Figure 9.** Cyanobacteria, *Dolichospermum lemmermannii*. (Photograph: Ann St. Amand)



**Figure 10.** Cyanobacteria, *Aphanizomenon flos-aquae*.  
(Photograph: Ann St. Amand)



**Figure 11.** Cyanobacteria, *Aphanizomenon flos-aquae*. (Photograph: Jacob Kann)





**Figure 12.** Cyanobacteria, *Nodularia spumigena*.  
(Photograph: Wayne Wurtsbaugh)



**Figure 13.** Cyanobacteria, *Plectonema wollei*.  
(Photograph: Ken Wagner)



**Figure 14.** Cyanobacteria, *Woronichinia naegeliana*. (Photograph: Ann St. Amand)



**Figure 15.** Cyanobacteria, *Cylindrospermopsis raciborskii*. (Photograph: Ann St. Amand)



**Figure 16.** Cyanobacteria, *Planktothrix agardhii/prolifera*. (Photograph: Richard Holmes)

Other types of HABs and floating plants can be distinguished from cyanobacteria blooms by color and texture. Green algae commonly are encountered and typically are grass-green in color (figs. 17–19). Many types of green algae consist of long, stringy filaments (fig. 20) that feel either slippery or like cotton. Some floating aquatic plants may look like algae (fig. 21), but close examination shows that individual plants are present, such as watermeal (fig. 22) and duckweed. One group of algae, the charophytes, are macroscopic and typically are rooted but can get dislodged and float in a waterbody (fig. 23). Although they may look like vascular plants, a closer look shows their characteristic features (fig. 24). Aquatic plants are distinct from algae (figs. 25–26). Another group of algae, the euglenoids (Euglenophyta), often form surface blooms—some are green in color (fig. 27), and others are red (fig. 28). *Azolla*, a small floating aquatic fern also forms a red surface mat (fig. 29). Occasionally, pollen from plants can form a thick accumulation, typically with a distinct yellowish color (fig. 30). Dinoflagellate (Pyrrophyta) blooms, although typically found in saline waters, occasionally bloom in freshwater and typically have a tan-brown and sometimes blackish appearance (fig. 31).



**Figure 17.** Green algae, *Mougeotia* sp. (Photograph: Steve Heiskary, Minnesota Pollution Control Agency)



**Figure 18.** Green algae, *Spirogyra* sp. (Photograph: Ken Wagner)



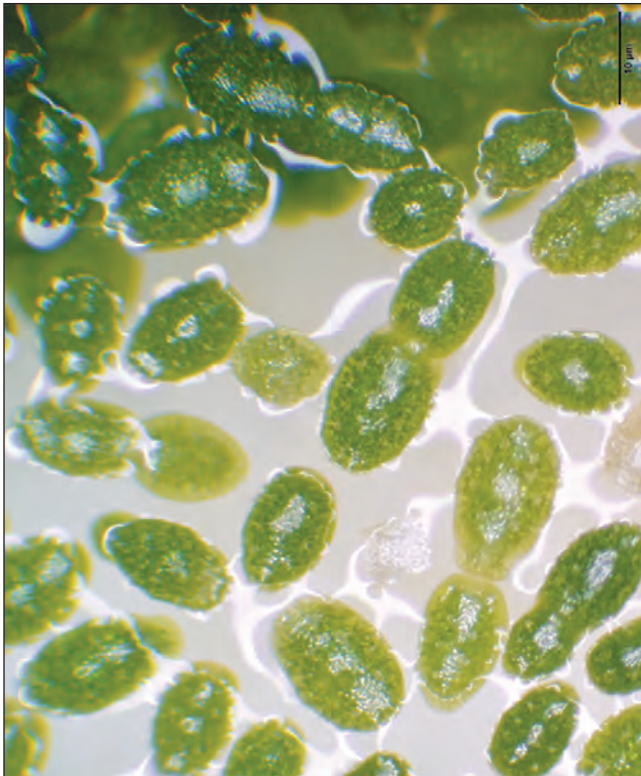
**Figure 19.** Green algae, *Cladophora* sp. (Photograph: Ann St. Amand)



**Figure 20.** Green algae, *Mougeotia* sp. (Photograph: Steve Heiskary, Minnesota Pollution Control Agency)



**Figure 21.** Duckweed: *Wolffia columbiana* (also called watermeal). (Photograph: Ann St. Amand)



**Figure 22.** Duckweed: Left, *Wolffia columbiana*; Right, *Lemna minor*. (Photographs: Barry H. Rosen)



Figure 23. Charophyta, *Chara* sp. (Photograph: Barry H. Rosen)



Figure 24. Charophyta, *Chara* sp. (Photograph: Ann St. Amand)



Figure 25. Rooted macrophytes. (Photograph: Ann St. Amand)



Figure 26. Rooted macrophytes. (Photograph: Ann St. Amand)



**Figure 27.** Euglenophyta, *Euglena* sp. (Photograph: Ann St. Amand)



**Figure 28.** Euglenophyta, *Euglena sanguinea*, a known toxin producer. (Photograph: Barry H. Rosen)

**Figure 29.** Water fern, *Azolla* sp. (Photograph: Bob Kirschner, Chicago Botanic Garden, Illinois)



**Figure 30.** Pine pollen. (Photograph: Linda Green, University of Rhode Island Watershed Watch)



**Figure 31.** Pyrrhophyta, *Durinskia dybowskii*. (Photograph: Brian Magott, Oklahoma Department of Environmental Quality)

## Microscope Images

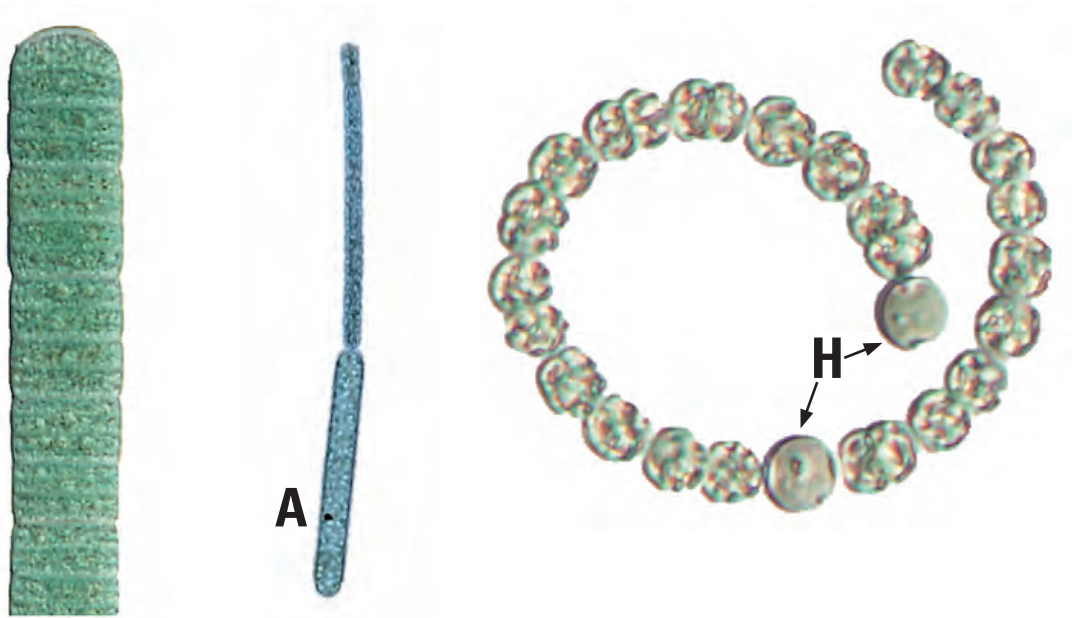
Field collections of potentially HABs need followup examination with a microscope to determine that the bloom is in fact cyanobacteria and if it is or is not a known toxin producer. The following collection of images include some of the same organisms in the field image section of this guide, as well as additional organisms that are of importance because of the toxins they produce. In addition, some of the harmless organisms are illustrated so the user can distinguish between harmful and non-toxic organisms. Various laboratories are located around the country that specialize in the identification of organisms and perform toxin analyses. Each laboratory has a preferred collection methodology and preservation techniques that should be followed for the most accurate results.

### Cyanobacteria Microscopic Identification Characteristics

Recognizing a cyanobacterium under the microscope involves observing characteristics associated with that morphology. Proper identification often relies on a species dichotomous key (Komárek and Anagnostidis, 2001, 2005; Komárek, 2013) to determine what the organism might be. Often times the shape and dimensions of the cells (length and width) are required for resolving a specimen to the species level.

*Filament – a chain or stack of cells*

- Some of these filaments consist of cells stacked like a roll of coins, with the individual cells being a single coin (fig. 32, image on the left).
- Some are round cells attached end to end like a string of pearls (fig. 32, image on the right).
- Some filaments are straight, some are coiled (fig. 32, the two images on the left and on the right, respectively).
- Some species make a resting spore, an *akinetete* (fig. 32, label A) along the length or at the end of a filament.
- Some species have *heterocytes*, specialized cells in the filament that fix atmospheric nitrogen (previously termed heterocysts) (fig. 32, label H), along the length or at the end of a filament.

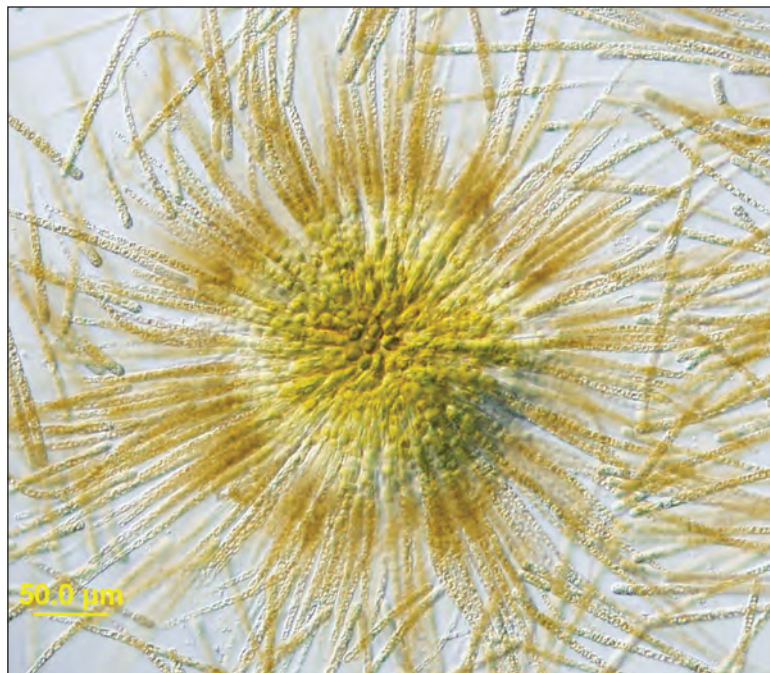
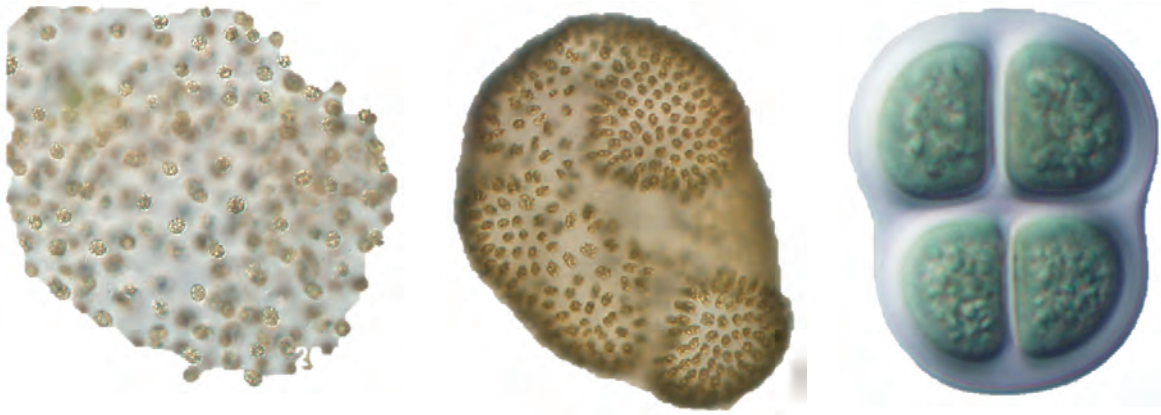


**Figure 32.** Morphology of cyanobacteria filaments. Straight and coiled forms, as well as features important in distinguishing the grouping of organisms. (Photographs: Left and right, Barry H. Rosen; Center, Ann St. Amand)



*Colony – a collection of cells, most with a distinct or irregular pattern*

- Many species are embedded in a common mucilaginous matrix that may or not be visible under the microscope (fig. 33).
- Some species have a set number of cells per colony, others are more heterogeneous.
- Some colonies are made up of filaments (fig. 33, bottom image).

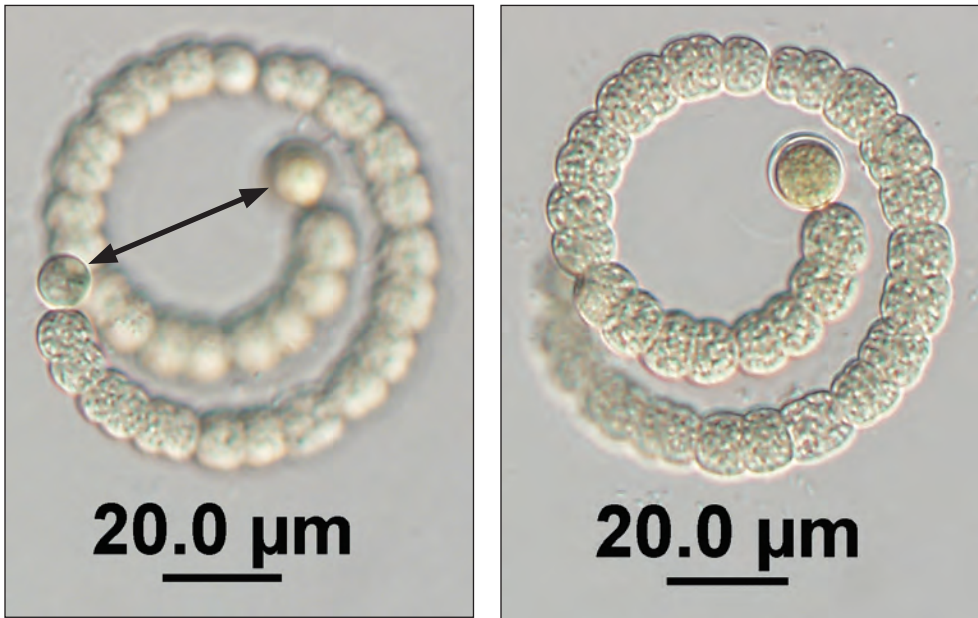


**Figure 33.** Morphology of cyanobacteria colonies. Round to oval cells or filaments embedded in a mucilaginous matrix; features important in distinguishing the grouping of organisms. (Photographs from Rosen and others, 2010)

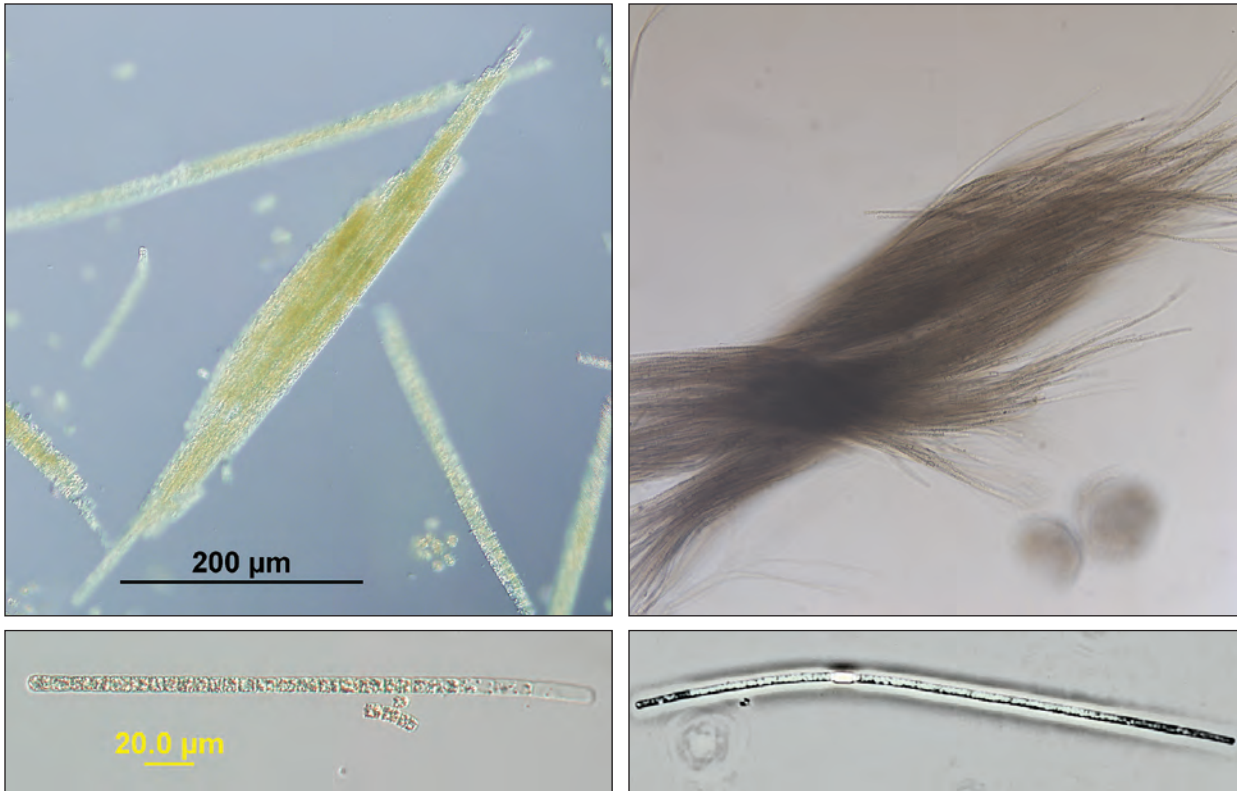
## Cyanobacteria

The following images are grouped alphabetically by genus and are based on the latest naming conventions at the time of publication. The recent use of genetics has led to the renaming of many organisms and the traditional genera; where appropriate, the previous name is included in parentheses.

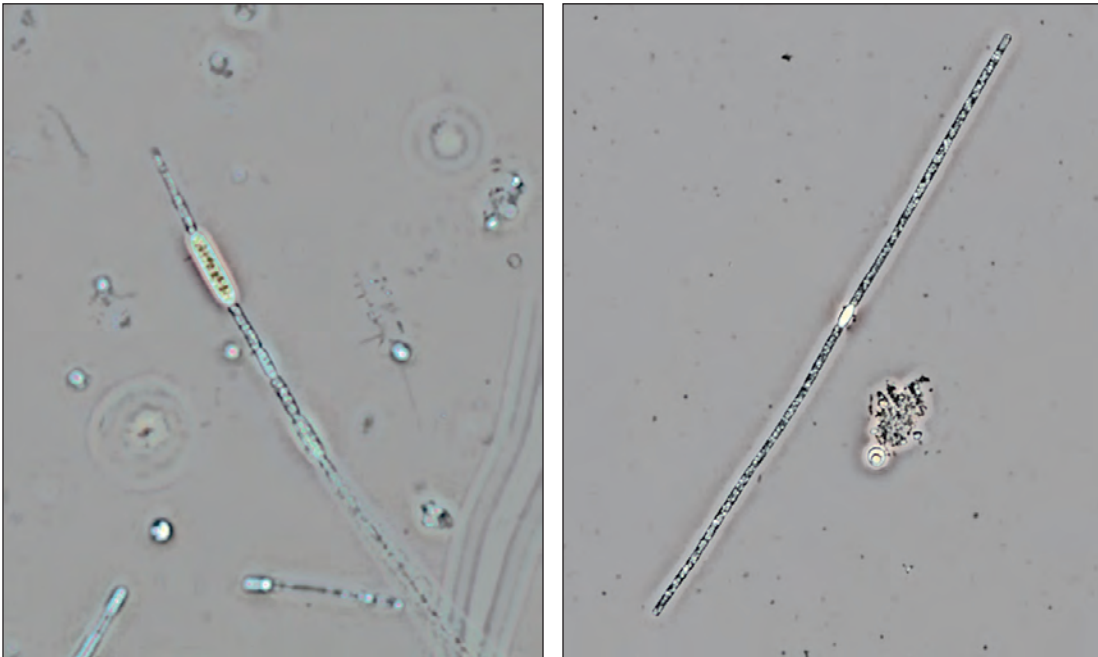
### *Anabaenopsis*



**Figure 34.** *Anabaenopsis arnoldii*. Two focal planes of the same filament. Note the heterocyst at both ends of this curled filament in the image on the left (arrow). (Photographs: Barry H. Rosen)

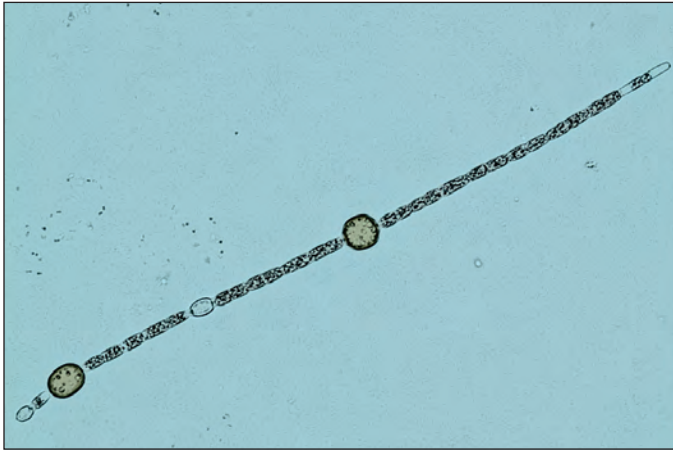
*Aphanizomenon**Aphanizomenon flos-aquae*

**Figure 35.** *Aphanizomenon flos-aquae*. Filaments clustered in bundles (upper) and individual filaments (lower). (Photographs: Left, Barry H. Rosen; Right, Ann St. Amand)

*Aphanizomenon gracile*

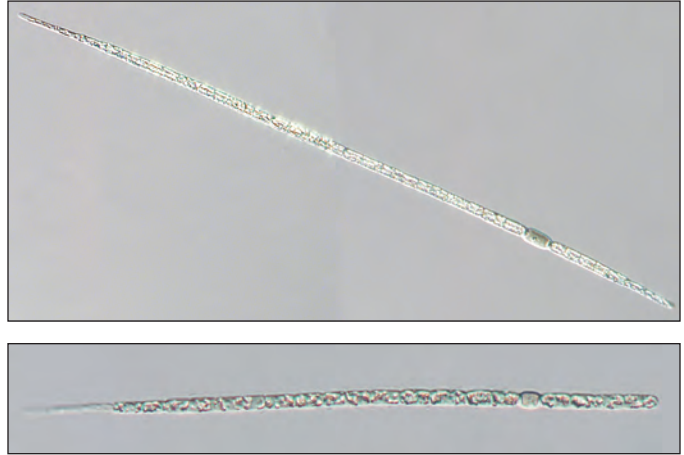
**Figure 36.** *Aphanizomenon gracile*. Filament showing akinetes (left) and a heterocyst (right). (Photographs: Ann St. Amand)

*Chrysoosporum (Anabaena)*



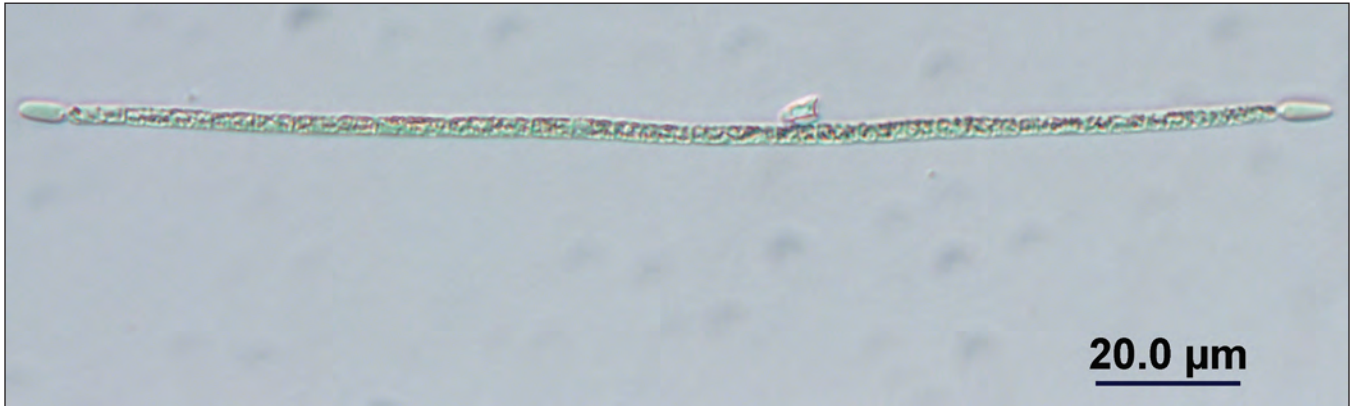
**Figure 37.** *Chrysoosporum ovalisporum*. Filament showing akinetes and heterocytes. (Photograph: Ann St. Amand)

*Cuspidothrix (Aphanizomenon)*

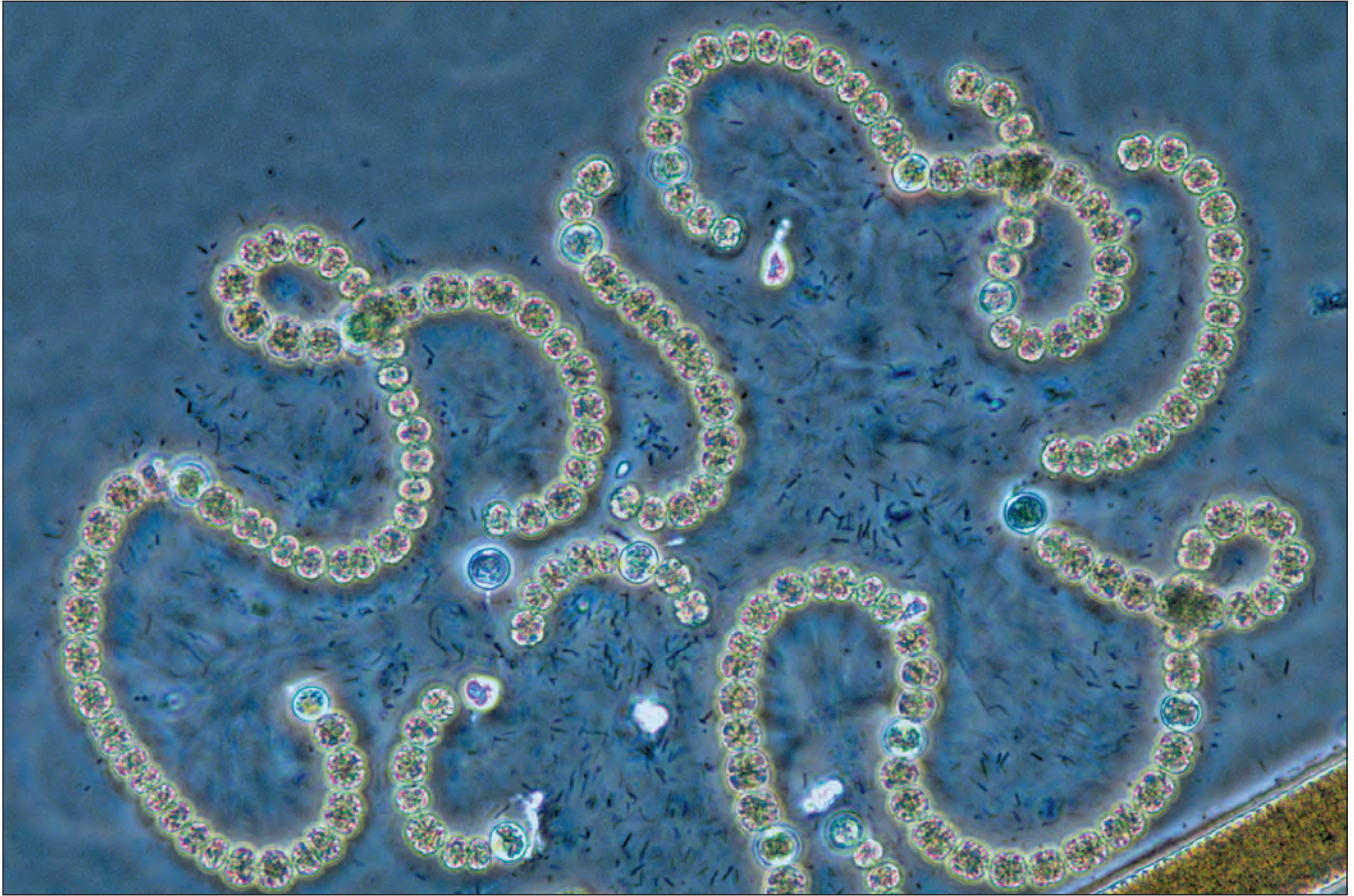


**Figure 38.** *Cuspidothrix issatschenkoi*. Filament showing a heterocyte. (Photographs: Barry H. Rosen)

*Cylindrospermopsis*



**Figure 39.** *Cylindrospermopsis raciborskii*. Filament showing straight and curled morphs. Heterocytes are found at the end of the filaments; akinete found adjacent to heterocyte (lower left). (Photographs: Barry H. Rosen)

*Dolichospermum (Anabaena)**Dolichospermum circinale*

**Figure 40.** *Dolichospermum circinale*. Spherical cells in the curved filaments. Heterocysts are along the length of the filaments and are about the same size as the vegetative cells. (Photograph: Ann St. Amand)

*Dolichospermum crassum*



**Figure 41.** *Dolichospermum crassum*. Spherical cells in the coiled filament. Heterocysts are along the length of the filaments and are about the same size as the vegetative cells. (Photograph: Ann St. Amand)

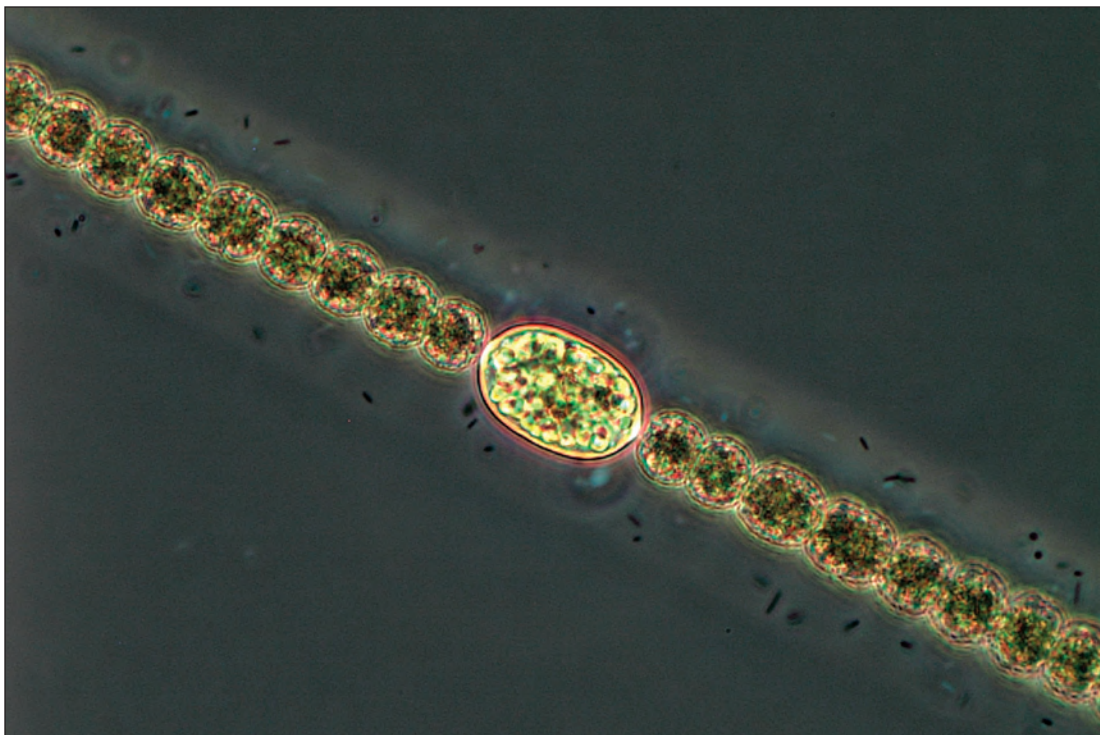
*Dolichospermum lemmermannii*



**Figure 42.** *Dolichospermum lemmermannii*. Coiled filaments connecting to form a colony. Akinetes enlarged, slightly bent (right image). (Photographs: Left, Ann St. Amand; Right, Margaret K. Spoo-Chupka)

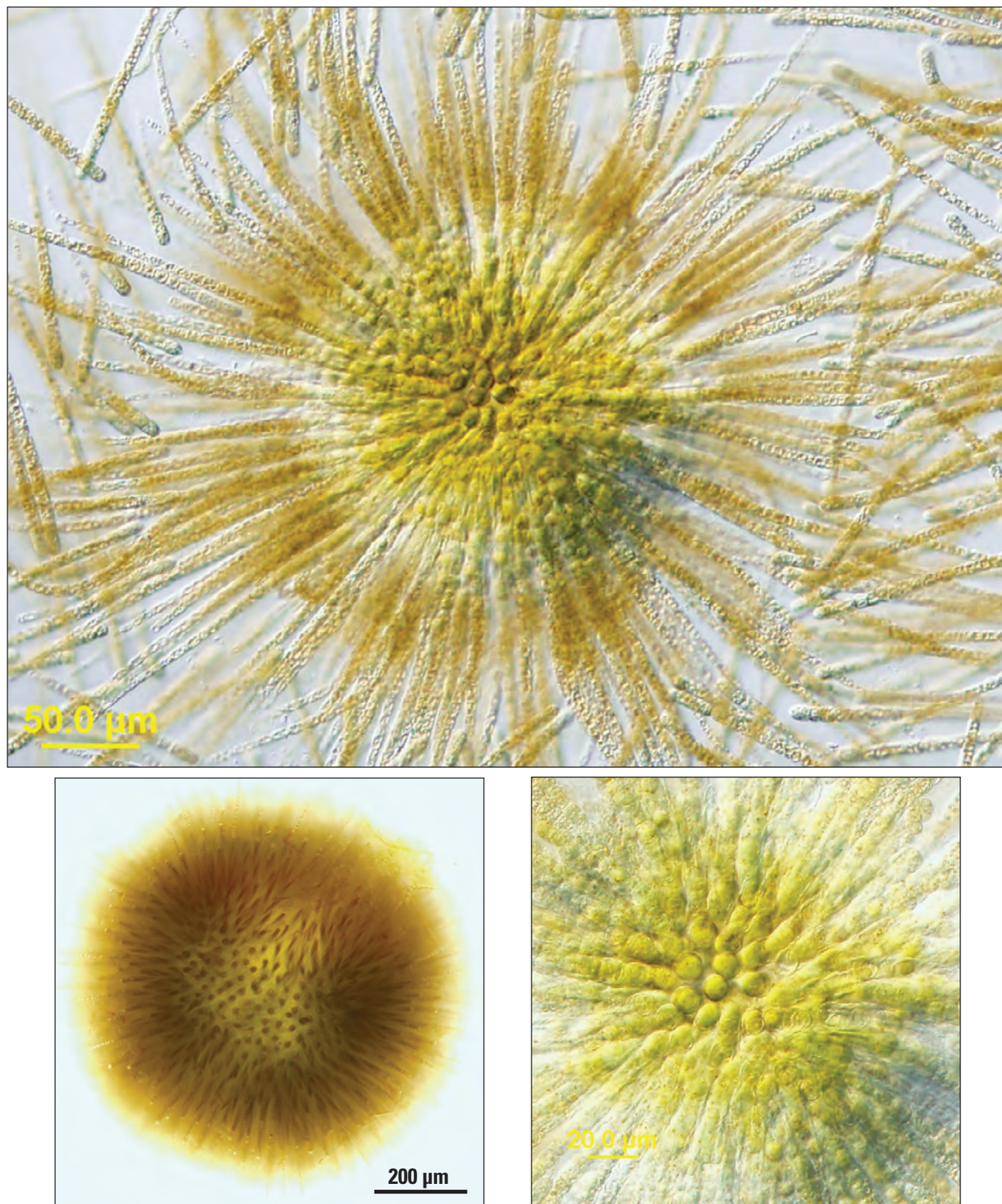
*Dolichospermum mendotae*

**Figure 43.** *Dolichospermum mendotae*. Irregularly coiled filaments with heterocysts and elongated akinetes. (Photograph: Andrew Chapman)

*Dolichospermum planctonicum*

**Figure 44.** *Dolichospermum planctonicum*. Round cells in a straight filament; enlarged akinetes. (Photograph: Ann St. Amand)

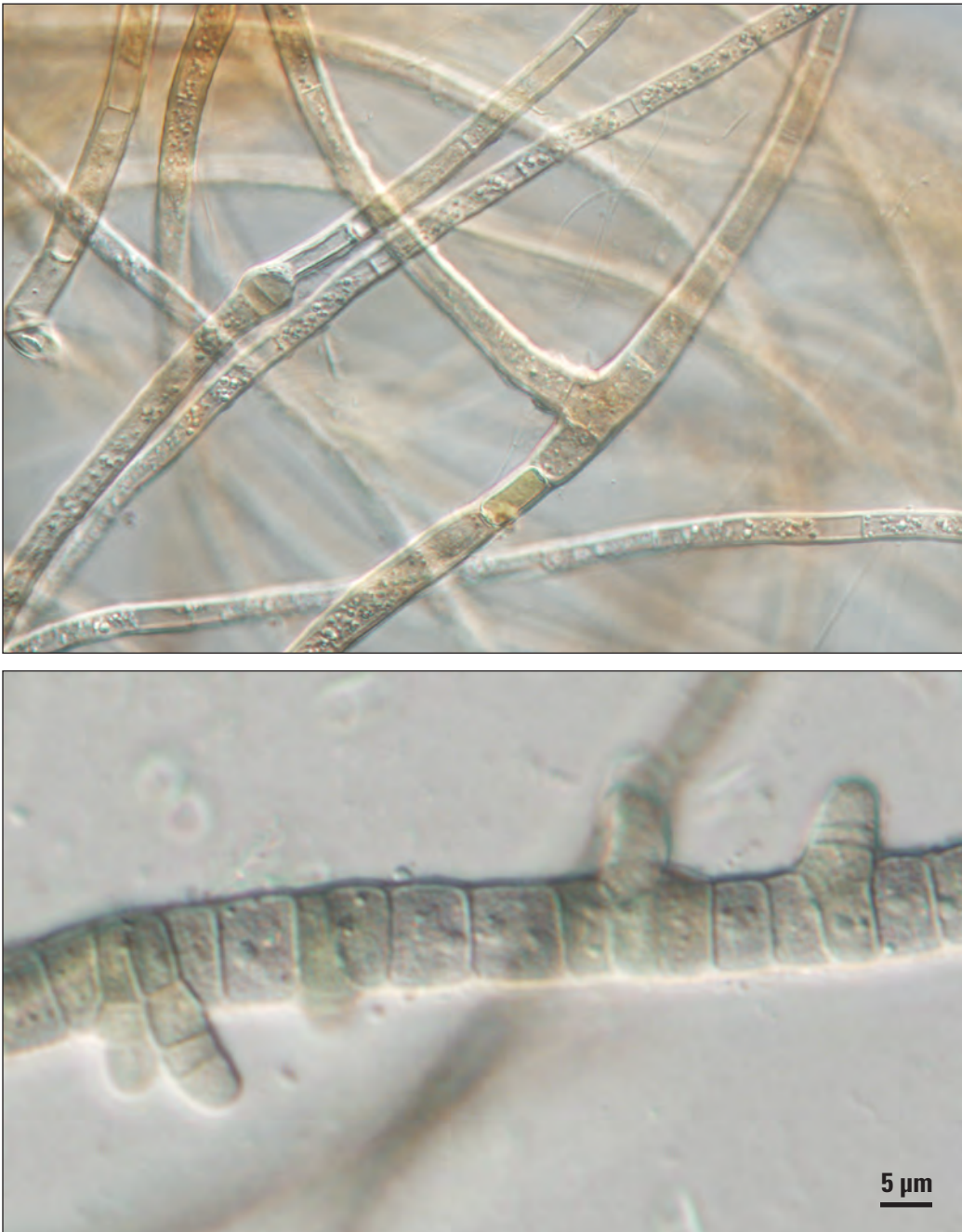
*Gloeotrichia*



**Figure 45.** *Gloeotrichia echinulata*. Filaments tapered, forming a colony, with an overall appearance of a pin cushion (lower left image). The base of each filament terminates in a heterocyte (lower right image). (Photographs: Barry H. Rosen)



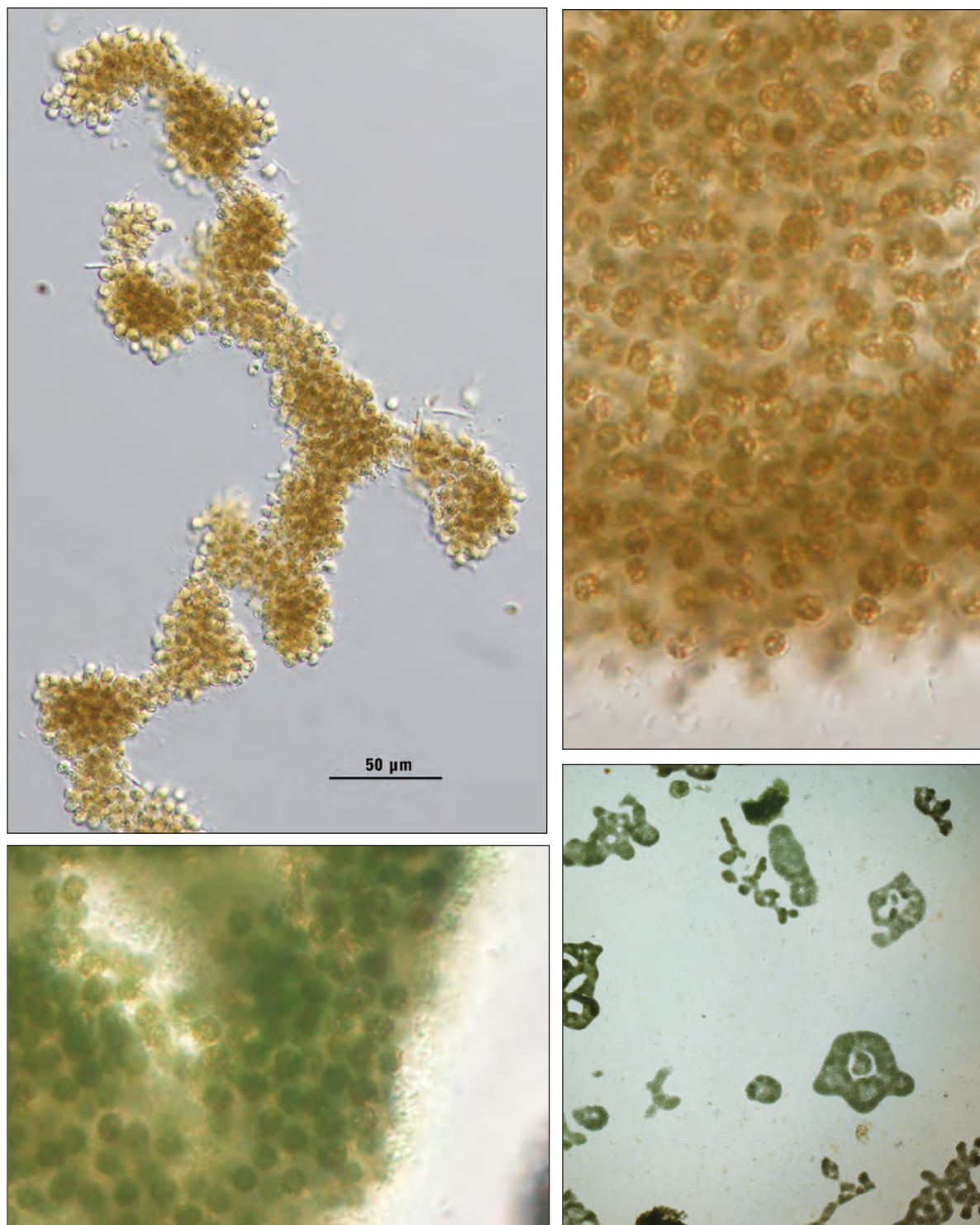
*Haplosiphon*



**Figure 46.** *Haplosiphon hibernicus*. Filament has true branching and rectangular heterocytes. (Photographs: Barry H. Rosen)

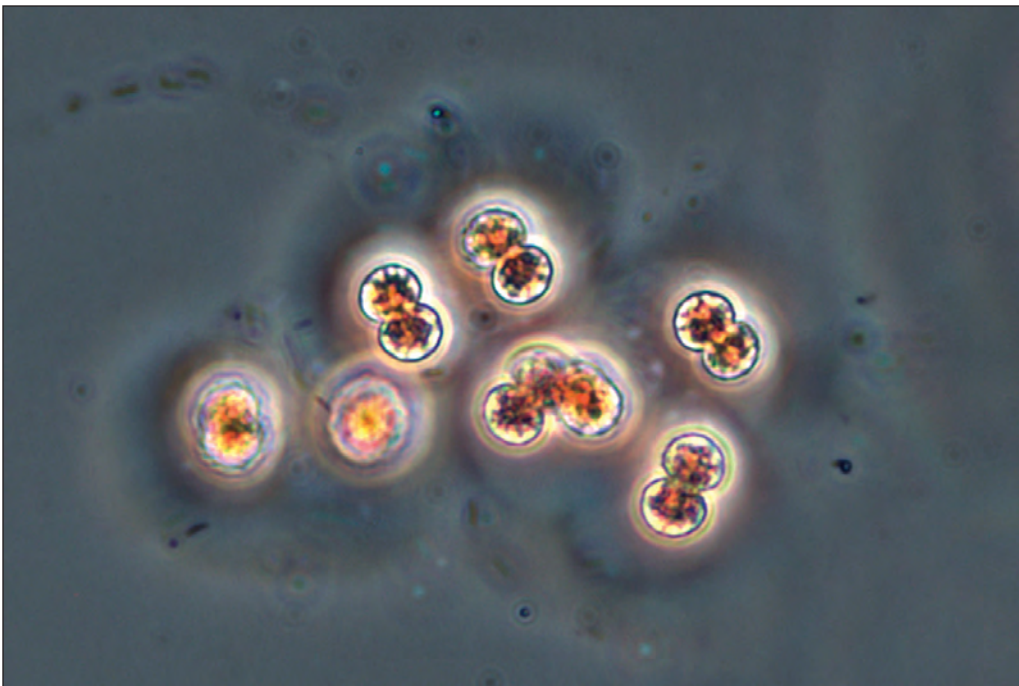
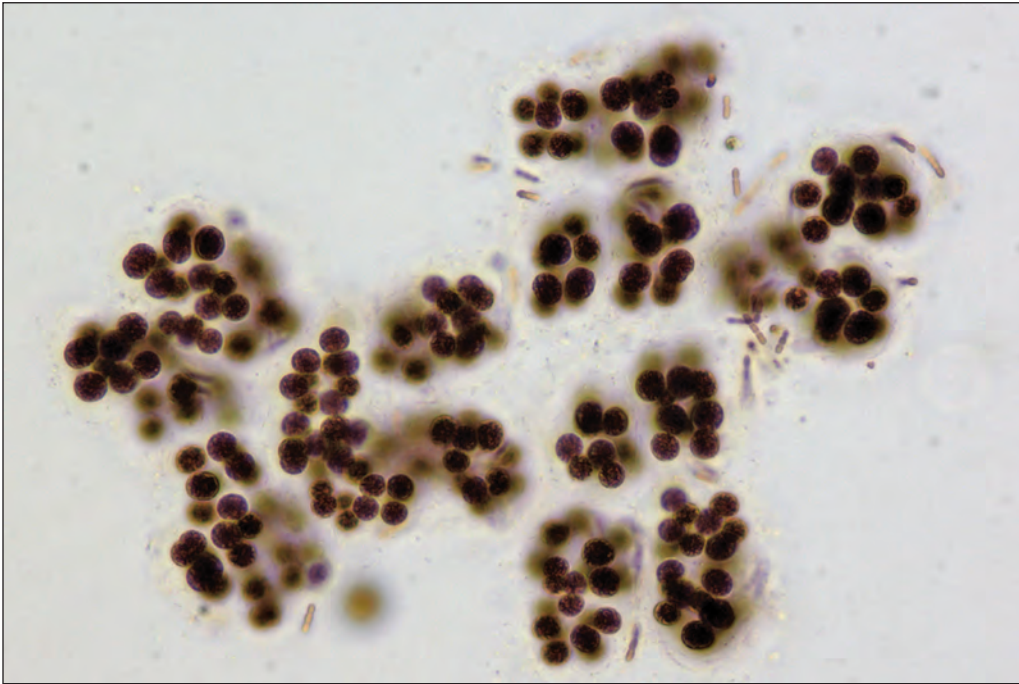
## *Microcystis*

### *Microcystis aeruginosa*



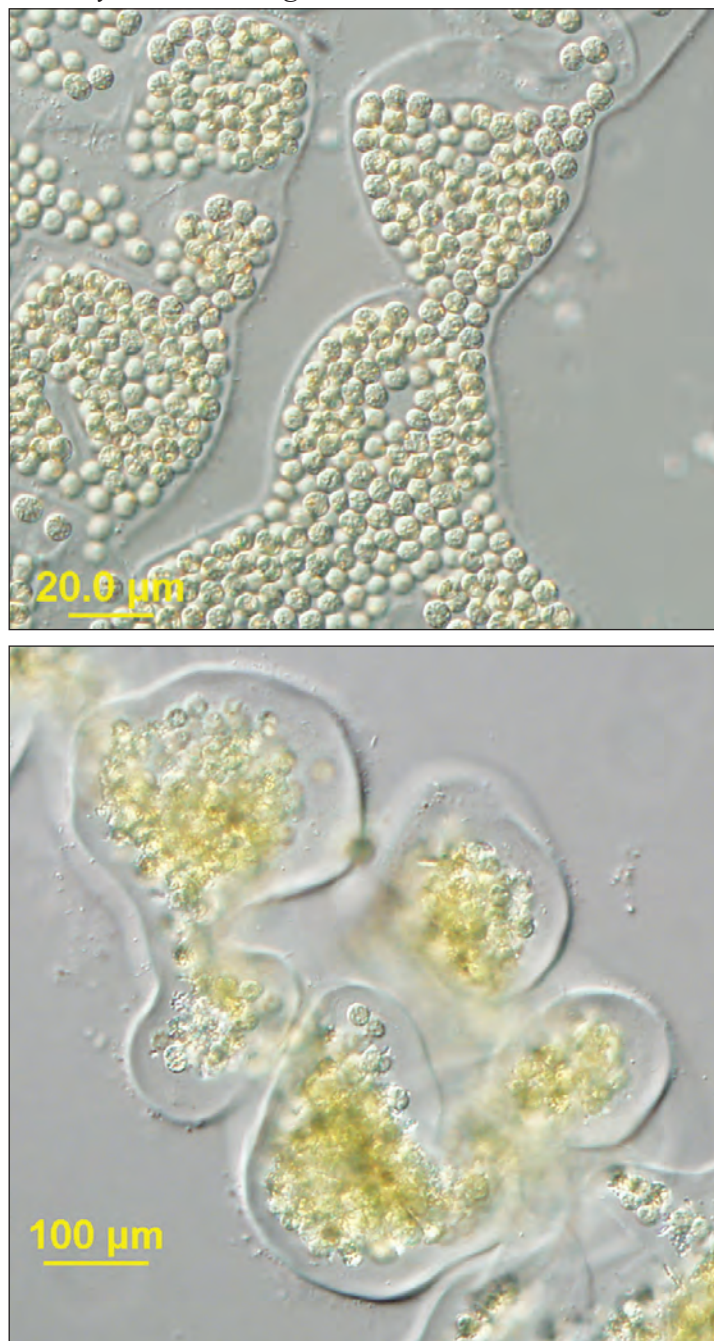
**Figure 47.** *Microcystis aeruginosa*. Round to oval cells embedding a mucilaginous matrix. Cell color varies from brown to various shades of green and blue-green. (Photographs: Barry H. Rosen)

*Microcystis viridis*

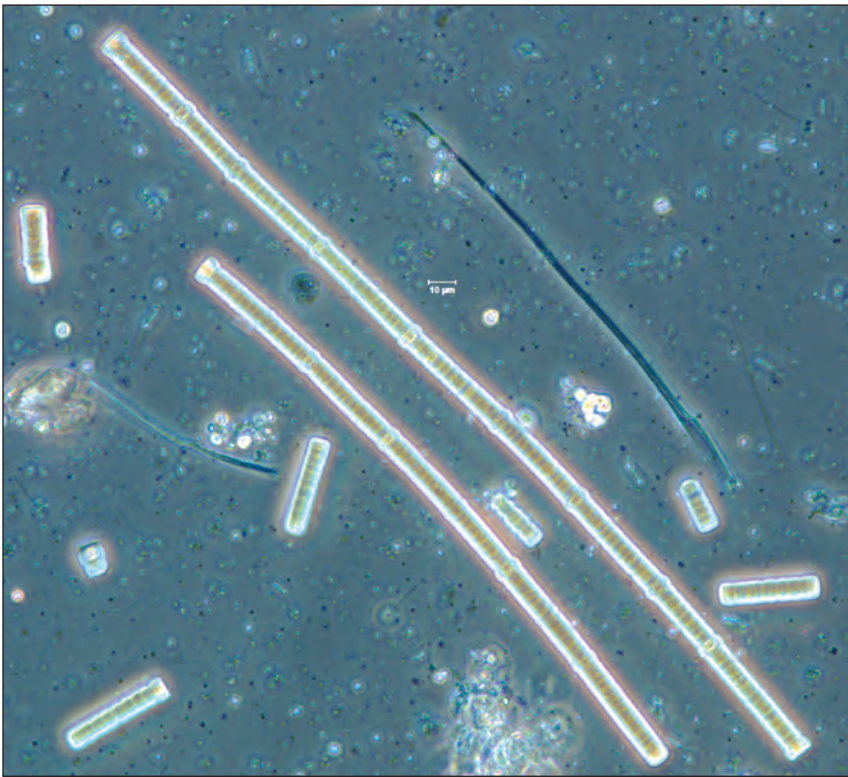


**Figure 48.** *Microcystis viridis*. Paired cells round to oval cells in “packets” embedded in a mucilaginous matrix. (Photographs: Ann St. Amand)

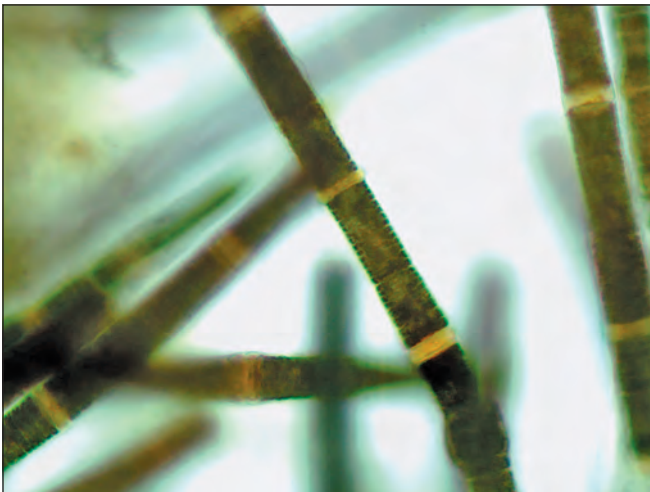
*Microcystis wesenbergii*



**Figure 49.** *Microcystis wesenbergii*. Round cells dispersed in a robust, well defined common mucilaginous envelope; individual. (Photographs: Barry H. Rosen)

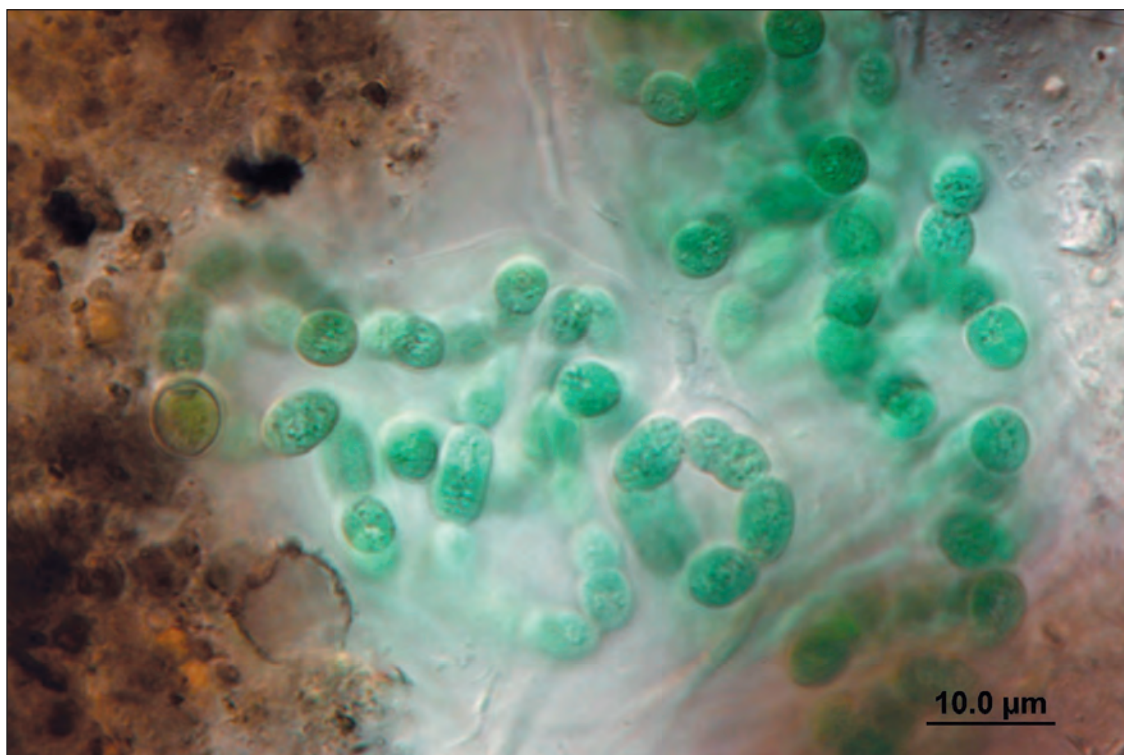
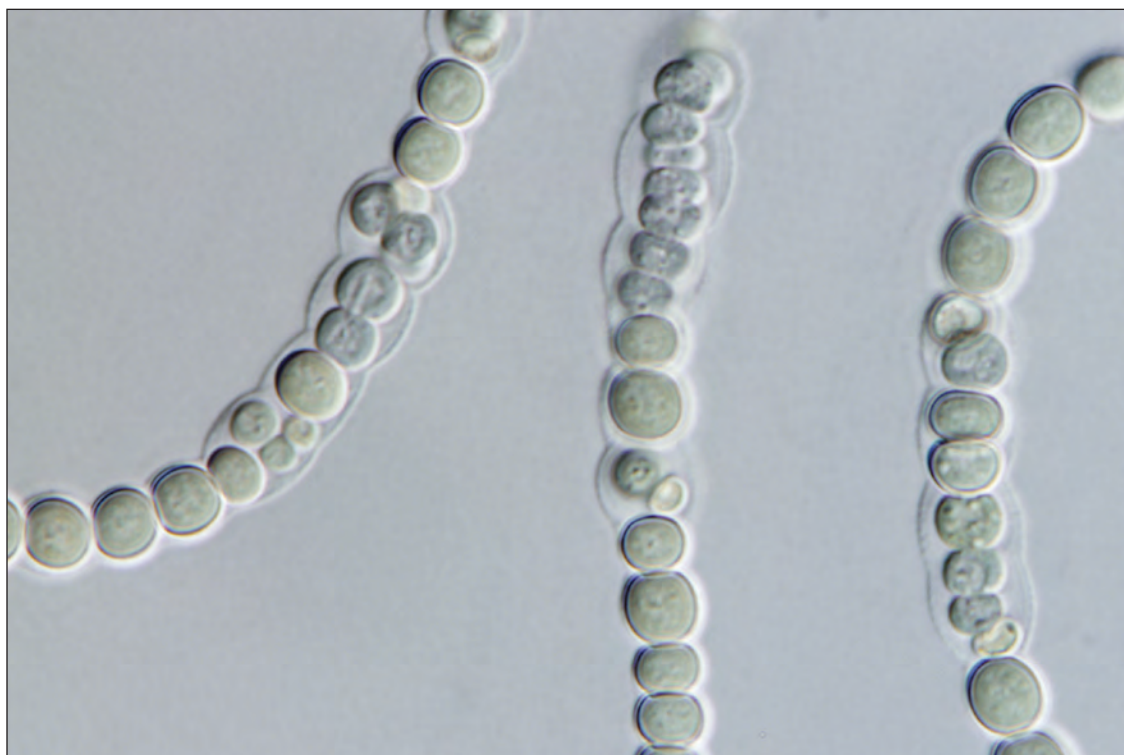
*Nodularia**Nodularia spumigena*

**Figure 50.** *Nodularia spumigena*. Cells arranged in filaments, heterocytes common and at somewhat regular intervals, with distinct constrictions at the junction between barrel-shaped cells. (Photograph: Ann St. Amand)

*Nodularia spumigena*

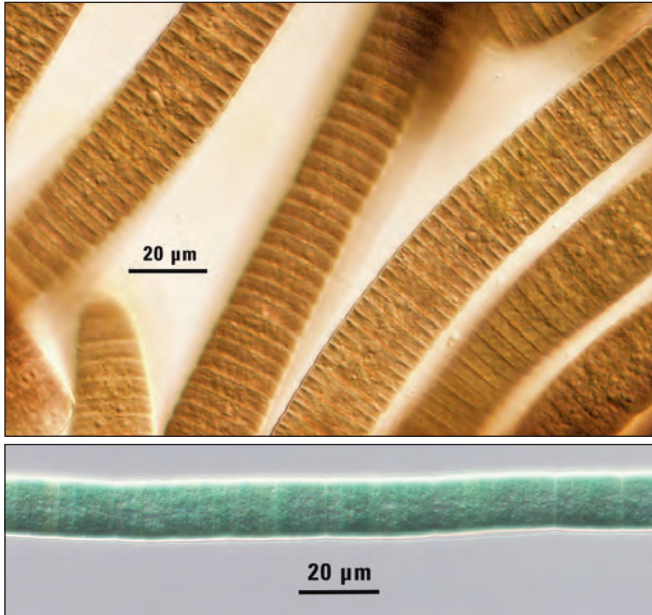
**Figure 51.** *Nodularia spumigena*. Cells arranged in filaments, heterocytes common, with distinct constrictions at the junction between cells. (Photograph: Ann St. Amand)

*Nostoc* sp.



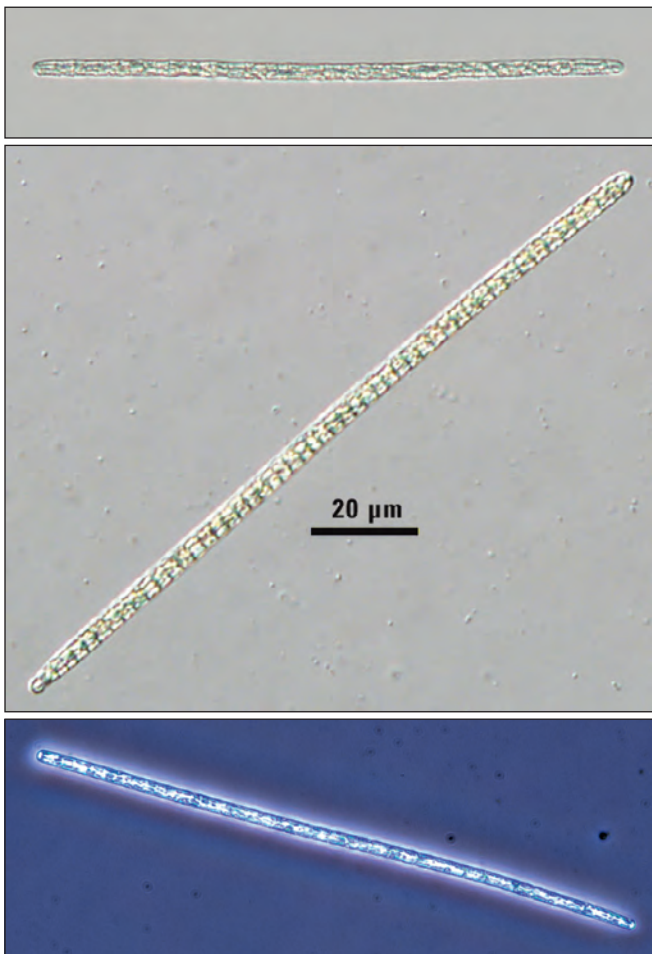
**Figure 52.** *Nostoc* sp. Filaments have round cells (elongated before cell division). Filaments embedded both individual and a common mucilaginous matrix. (Photographs: Barry H. Rosen)

*Oscillatoria* sp.



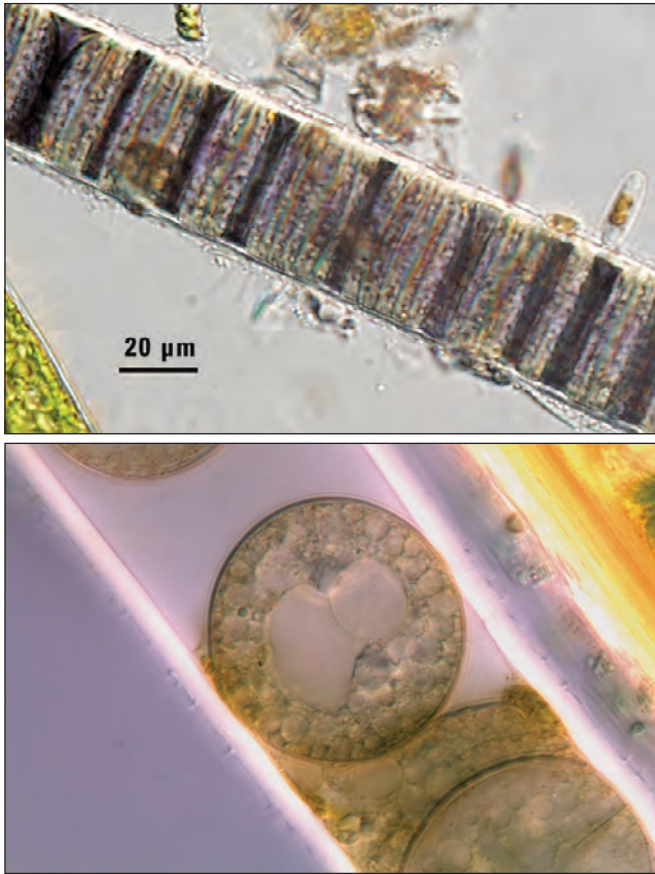
**Figure 53.** *Oscillatoria* sp. Cells in filaments, shorter than wide. Color varies from green, blue-green, to dark brown. Upper photograph is *O. limosa*. (Photographs: Barry H. Rosen)

*Planktothrix* (*Oscillatoria*)



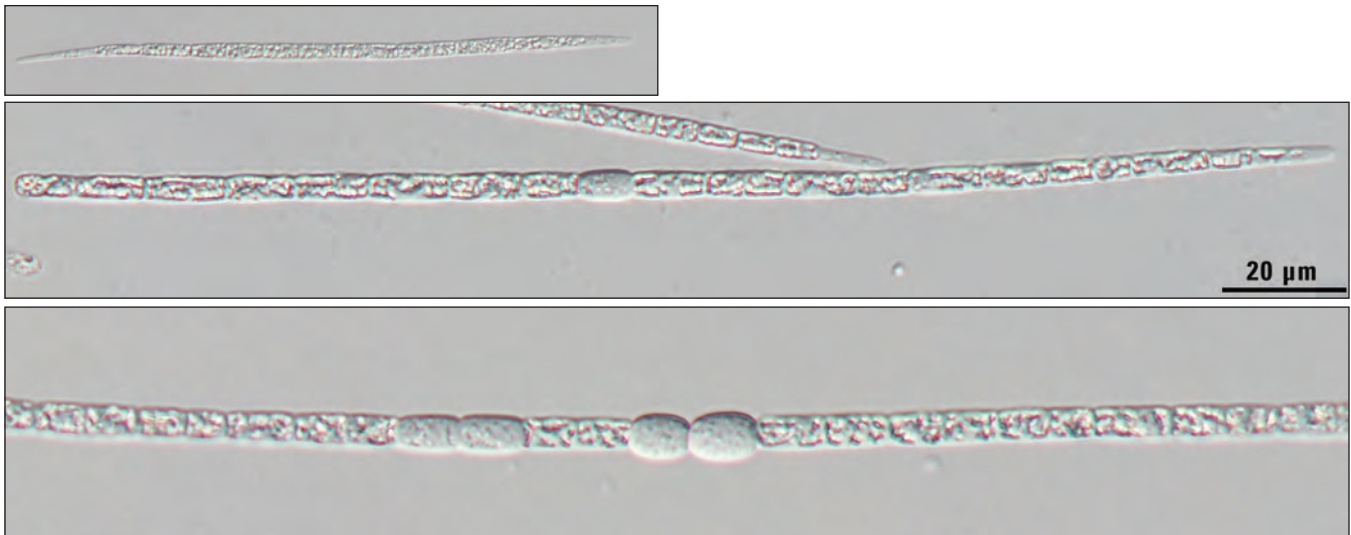
**Figure 54.** *Planktothrix agardhii*. Filaments composed of cells that range from longer than wide to slightly shorter than wide. Lightly pigmented. Can have both terminal cells tapered; often one end of a filament is rounded and the other end tapered. (Photographs: Upper and middle, Barry H. Rosen; Bottom, Ann St. Amand)

*Plectonema* (Lyngbya)



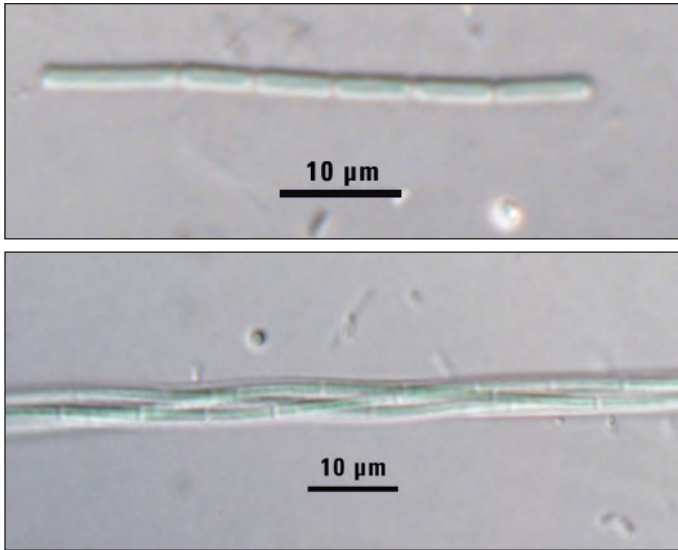
**Figure 55.** *Plectonema wollei*. Cells in filaments with sheaths. Large diameter filaments, with cells stacked like coins in the filaments. Bottom image illustrates a cell turned on its side. Most dark brown in color. (Photographs: Top, Barry H. Rosen; Bottom, Ann St. Amand)

*Raphidiopsis*



**Figure 56.** *Raphidiopsis mediterranea*. This genus is characterized by curving filaments and the presence of akinetes but not heterocytes. This genus may eventually be merged with *Cylindrospermopsis*. (Photographs: Barry H. Rosen)



*Schizothrix* sp.

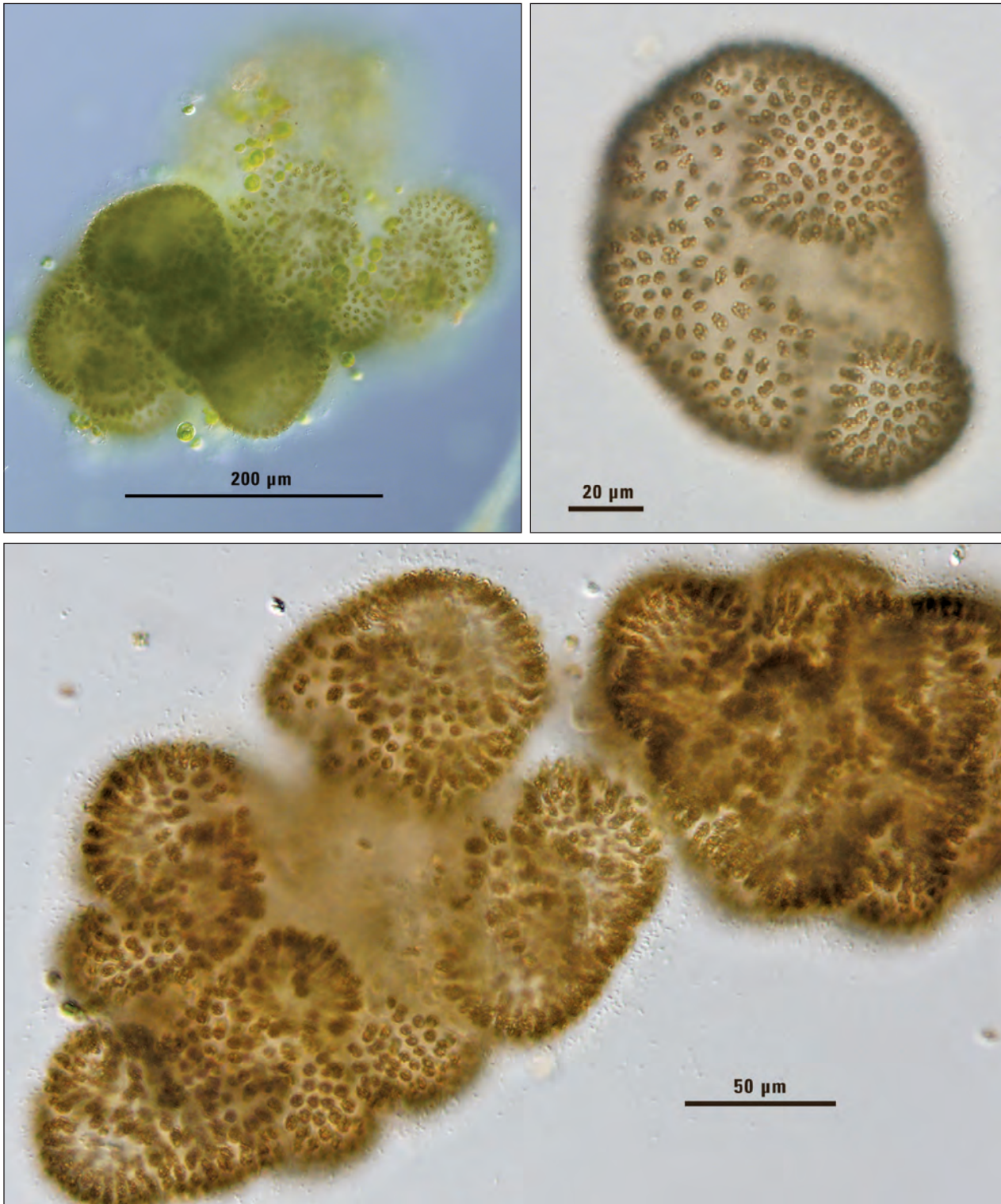
**Figure 57.** *Schizothrix* sp. Thin, slender filaments with cells longer than wide, within a sheath and typically multiple filaments intertwined. (Photographs: Barry H. Rosen)

*Sphaerospermopsis (Anabaena)*

**Figure 58.** *Sphaerospermopsis torques-reginae*. Filaments composed of round cells and coiled, with some regularity. Heterocyst with two adjacent, spherical akinetes (top image), often on both sides of the heterocyst. (Photographs: Barry H. Rosen)



**Figure 59.** *Sphaerospermopsis aphanizomenoides*. Filaments composed of rounded cells but not coiled, akinetes adjacent to both sides of heterocytes (not in this image). (Photograph: Ann St. Amand)

*Woronichinia (Coelospherium)*

**Figure 60.** *Woronichinia naegeliana*. Cells, round to oval, in colonies embedded on the outer edge of the mucilaginous matrix (not throughout like *Microcystis*). (Photographs: Barry H. Rosen)

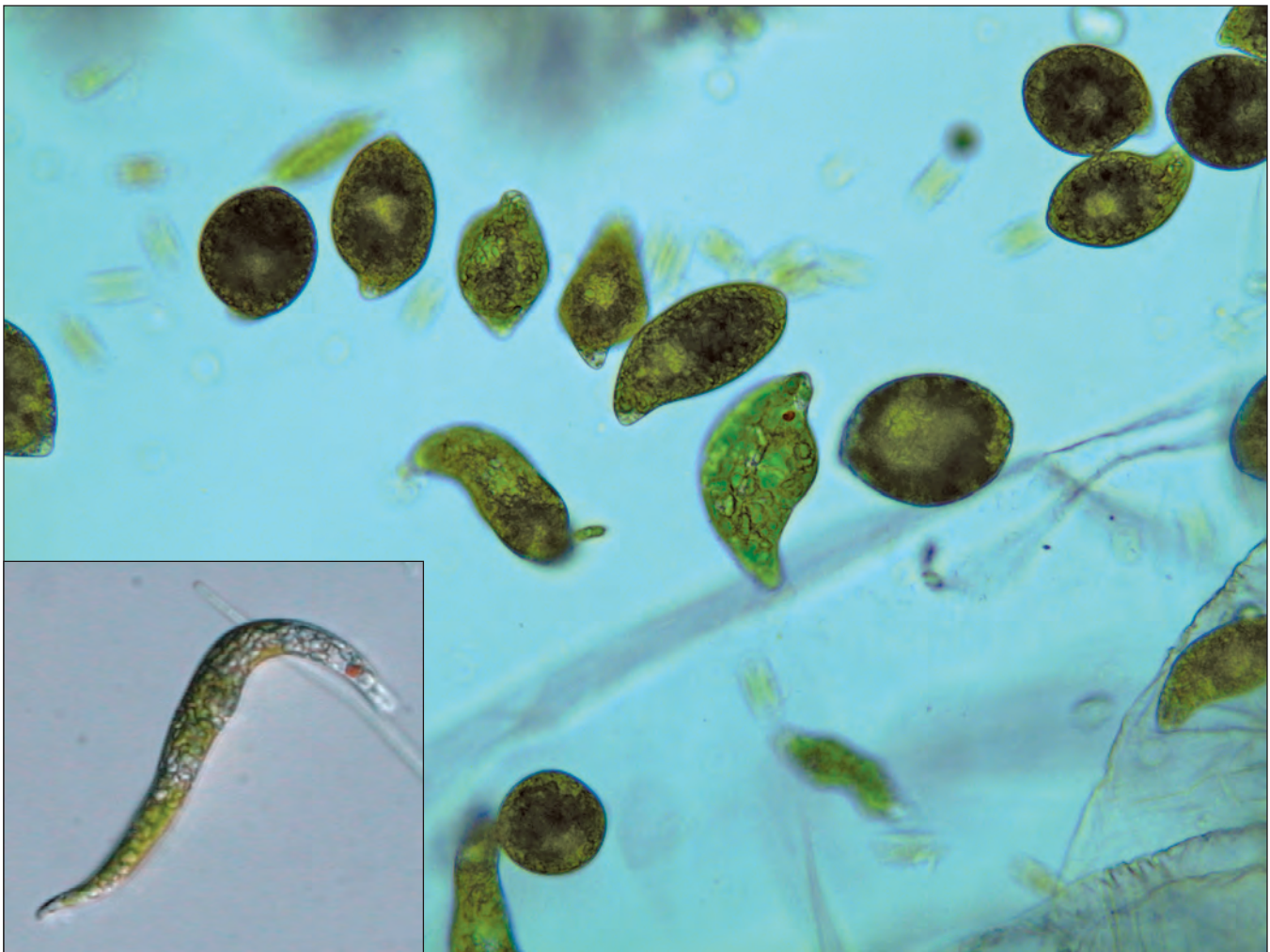
## Other Organisms Viewed Under the Microscope

The remaining collection of images include some of the same organisms in the field image section of this guide, as well as additional organisms that are of importance because they can cause issues in a waterbody or may be an indicator of a water quality concern. In addition, some of the harmless organisms are illustrated so the user can distinguish between harmful and harmless organisms.

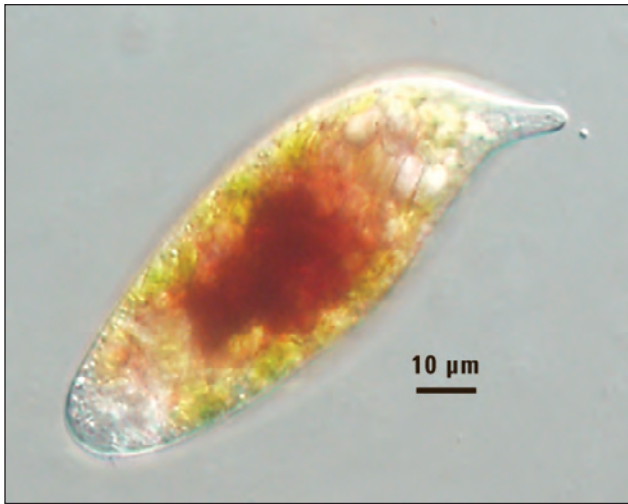
### Euglenophyta (Euglenoids)

#### *Euglena*

This organism can form a surface scum on waterbodies that have been enriched with nutrients that look almost oily. One species, *Euglena sanguinea*, is known to produce the alkaloid fish and mammal toxin, euglenophycin (Zimba and others, 2010).



**Figure 61.** *Euglena* sp. (see figure 27). Surface scums indicate nutrient enrichment. *Euglena* cells can swim using a long flagellum, and they typically have a visible red eyespot (inset). (Photograph: Ann St. Amand; Inset photograph: Barry H. Rosen)

*Euglena sanguinea*

**Figure 62.** *Euglena sanguinea* (see figure 28). This organism accumulates the pigment astaxanthin and imparts a red color to individual cells and to surface scums. (Photograph: Barry H. Rosen)

## Pyrrhophyta (Dinoflagellates)

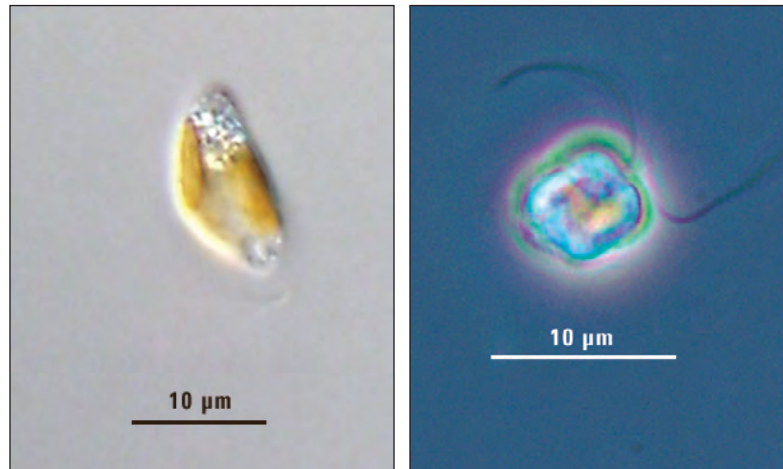
The Pyrrhophyta, more commonly called dinoflagellates, include both freshwater and marine representatives. In the marine environment, approximately 5 percent are known to produce toxins. These toxins are associated with red tides and shellfish poisoning. Saxitoxin is a common and potent paralytic neurotoxin produced by some marine species. The following figure illustrates some common freshwater dinoflagellates that may bloom, but they are not known to produce toxins.



**Figure 63.** Left: *Durinskia dybowskii* (see figure 31). Right: *Peridinium* sp.; Bottom: *Ceratium hirundinella*. (Photographs: Top left, Ann St. Amand; Top right and bottom: Barry H. Rosen)

## Haptophyta (Golden Algae)

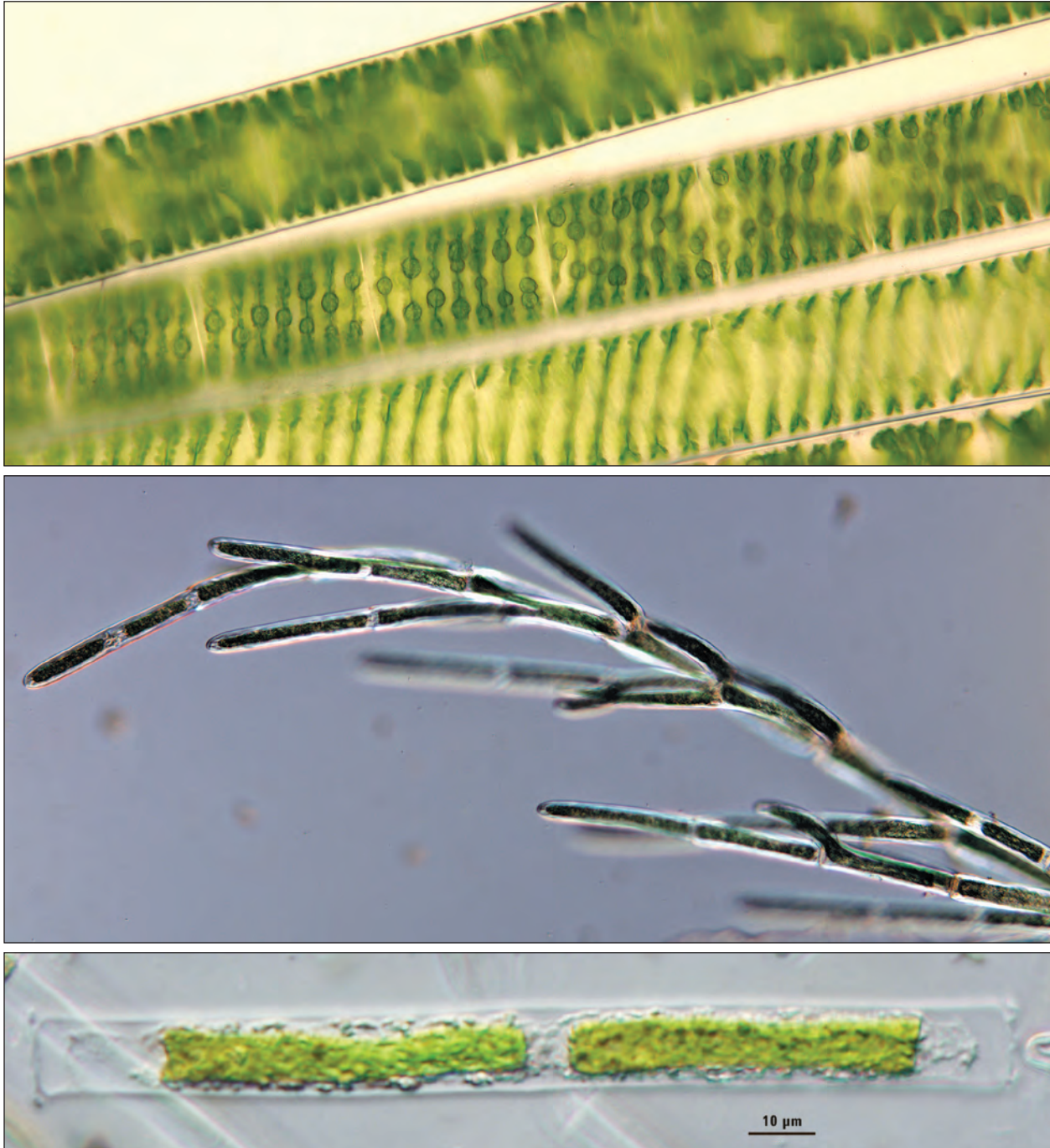
This group of algae is infamous because of one species, *Prymnesium parvum*. It is known to cause large fish kills in brackish waters and is widely distributed, but does not seem to affect humans. Texas, Oklahoma, New Mexico, Colorado, Wyoming, North Carolina, South Carolina, Georgia, Arkansas, and Alabama have all reported waterbodies with this organism.



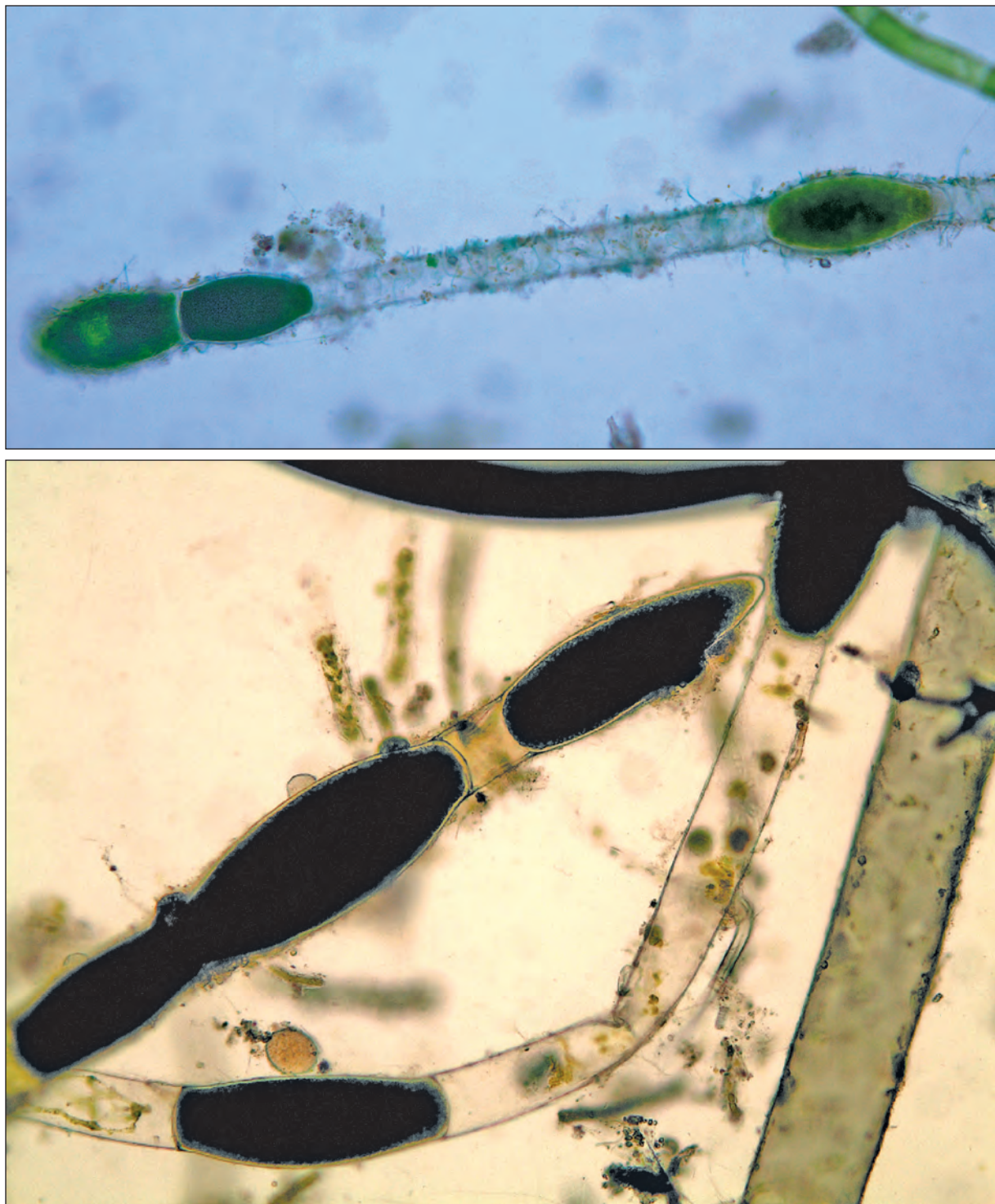
**Figure 64.** *Prymnesium parvum*. Note the color of the chromoplast (left) and the two flagella (right) that allow this organism to swim. (Photographs: Left, Barry H. Rosen; Right, Ann St. Amand)

## Chlorophyta (Green Algae)

The green algae generally do not produce toxins; however, enriched waterbodies often experience excess green algal growth, visible as long bright or grassy green and sometime dark green filaments. These filaments are typically slippery or cottony to the touch, depending on which group of organisms they are associated with. The following figure shows three characteristic filamentous green algae and can be compared to the cyanobacteria images.



**Figure 65.** Green algae. Top: *Spirogyra* sp., with helical or spiral chloroplast (see figure 19). Middle: *Cladophora* sp., showing branched filaments (see figure 18). Bottom: *Mougeotia* sp., with flat, plate-like chloroplast (see figure 20). (Photographs: Top and middle, Ann St. Amand; Bottom, Barry H. Rosen)



**Figure 66.** Green algae, *Pithophora* sp. with characteristic swollen “akinetes” (Photographs: Ann St. Amand)



## References

- Akcaalan, R., Köker, L., Oğuz, A., Spoof, L., Meriluoto, J., and Albay, M., 2014, First report of cylindrospermopsin production by two cyanobacteria (*Dolichospermum mendotae* and *Chrysochlorium ovalisporum*) in Lake Iznik, Turkey: *Toxicon*, v. 6, no. 11, p. 3173–3186.
- American Public Health Association, 2012, Standard methods for the examination of water and wastewater (22d ed.): Washington D.C.
- Anagnostidis, K., and Komárek, J., 1988, Modern approach to the classification system of cyanophytes. 3. Oscillatoriales: *Archiv für Hydrobiologie*, Supplement 80, p. 327–472.
- Aráoz, R., Nghiem, H.O., Rippka, R., Palibroda, N., de Marsac, N.T., and Herdman, M., 2005, Neurotoxins in axenic oscillatorian cyanobacteria—Coexistence of anatoxin-a and homoanatoxin-a determined by ligand-binding assay and GC/MS: *Microbiology*, v. 151, pt. 4, p. 1263–1273.
- Ballot, A., Fastner, J., Lentz, M., and Wiedner, C., 2010a, First report of anatoxin-a-producing cyanobacterium *Aphanizomenon issatschenkoi* in northeastern Germany: *Toxicon*, v. 56, no. 6, p. 964–971.
- Ballot, A., Fastner, J., and Wiedner, C., 2010b, Paralytic shellfish poisoning toxin-producing cyanobacterium *Aphanizomenon gracile* in northeast Germany: *Applied and Environmental Microbiology*, v. 76, no. 4, p. 1173–1180.
- Becker, V., Ihara, P., Yunes, J.S., and Huszar, V.L.M., 2010, Occurrence of anatoxin-a(s) during a bloom of *Anabaena crassa* in a water-supply reservoir in southern Brazil: *Journal of Applied Phycology*, v. 22, p. 235–241.
- Bittencourt-Oliveira, M.C., Piccin-Santos, V., Kujbida, P., and Moura, A.N., 2011, Cylindrospermopsin in water supply reservoirs in Brazil determined by immunochemical and molecular methods: *Journal of Water Resource Protection*, v. 3, p. 349–355.
- Bruno, M., Barbini, D.A., Pierdominici, E., Serse, A.P., and Ioppolo, A., 1994, Anatoxin-a and previously unknown toxin in *Anabaena planctonica* from blooms found in Lake Mulargia (Italy): *Toxicon*, v. 32, p. 369–373.
- Carey, C.C., Haney, J.F., and Cottingham K.L., 2007, First report of microcystin-LR in the cyanobacterium *Gloeotrichia echinulate*: *Environmental Toxicology*, v. 22, no. 3, p. 337–339.
- Carey, C.C., Ibelings, B.W., Hoffmann, E.P., Hamilton, D.P., and Brookes, J.D., 2012, Eco-physiological adaptations that favour freshwater cyanobacteria in a changing climate: *Water Research*, v. 46, no. 5, p. 1394–1407.
- Carmichael, W.W., Beasley, V.R., Bunner, D.L., Eloff, J.N., Falconer, I., Gorham, P., Harada, K.I., Krishnamurthy, T., Yu, M.J., Moore, R.E., Rinehart, K., Runnegar, M., Skulberg, O.M., and Watanabe, M., 1988, Naming of cyclic heptapeptide toxins of cyanobacteria (blue-green algae): *Toxicon*, v. 26, p. 971–973.
- Carmichael, W.W., Evans, W.R., Yin, Q.Q., Bell, P., and Mocaikowski, E., 1997, Evidence for paralytic shellfish poisons in the freshwater cyanobacterium *Lyngbya wollei* (Farlow ex Gomont) comb. nov.: *Applied and Environmental Microbiology*, v. 63, p. 104–110.
- Carty, S., 2014, Freshwater dinoflagellates of North America: Ithaca and London, Comstock Publishing Associates, A division of Cornell University Press, 272 p.
- Chorus, I., and Bartram, J., eds., 1999, Toxic cyanobacteria in water: New York, E&FN Spon, 416 p.
- D'Agostino, P.M., Song, X., Neilan, B.A., and Moffitt, M.C., 2014, Comparative proteomics reveals that a saxitoxin-producing and a nontoxic strain of *Anabaena circinalis* are two different ecotypes: *Journal of Proteome Research*, v. 13, no. 3, p. 1474–1484.
- Elliott, J.A., Jones, I.D., and Thackeray, S.J., 2006, Testing the sensitivity of phytoplankton communities to changes in water temperature and nutrient load, in a temperate lake: *Hydrobiologia*, v. 559, p. 401–411.
- Faassen, E.J., and Lürling, M., 2013, Occurrence of the microcystins MC-LW and MC-LF in Dutch surface waters and their contribution to total microcystin toxicity: *Marine Drugs*, v. 11, p. 2643–2654.
- Ferreira, F.M., Franco Soler, J.M., Fidalgo, M.L., and Fernández-Vila, P., 2001, PSP toxins from *Aphanizomenon flos-aquae* (cyanobacteria) collected in the Crestuma-Lever reservoir (Douro River, northern Portugal): *Toxicon*, v. 39, no. 6, p. 757–761.
- Gehring, M.M., Adler, L., Roberts, A.A., Moffitt, M.C., Mihali, T.K., Mills, T.J., Fieker, C., and Neilan, B.A., 2012, Nodularin, a cyanobacterial toxin, is synthesized *in planta* by symbiotic *Nostoc* sp.: *International Society for Microbial Ecology Journal*, v. 6, no. 10, p. 1834–1847.
- Graham, J.L., Loftin, K.A., Ziegler, A.C., and Meyer, M.T., 2008, Guidelines for design and sampling for cyanobacterial toxin and taste-and-odor studies in lakes and reservoirs: U.S. Geological Survey Scientific Investigations Report 2008–5038, 39 p.
- Henriksen P., Carmichael W.W., An, J., and Mostrup, Ø., 1997, Detection of an anatoxin-a(s)-like anticholinesterase in natural blooms and cultures of cyanobacteria/blue-green algae from Danish lakes and in the stomach contents of poisoned birds, *Toxicon*, v. 35, p. 901–913.

- Ibelings, B.W., and Chorus, I., 2007, Accumulation of cyanobacterial toxins in freshwater “seafood” and its consequences for public health—A review: *Environmental Pollution*, v. 150, no. 1, p. 177–192.
- Jöhnk, K.D., Huisman, J., Sharples, J., Sommeijer, B., Visser, P.M., and Stroom, J.M., 2008, Summer heatwaves promote blooms of harmful cyanobacteria: *Global Change Biology*, v. 14, p. 495–512.
- Kokociński, M., Mankiewicz-Boczek, J., Jurczak, T., Spooł, L., Meriluoto, J., Rejmonczyk, E., Hautala, H., Vehniäinen, M., Pawełczyk, J., and Soininen, J., 2013, *Aphanizomenon gracile* (Nostocales), a cylindrospermopsin-producing cyanobacterium in Polish lakes: *Environmental Science and Pollution International*, v. 20, no. 8, p. 5243–5264.
- Komárek, J., 2013, Cyanoprokaryota III. Teil. Heterocystous genera, Süßwasserflora von Mitteleuropa: Heidelberg, Springer Spektrum, v. 19, 1,130 p.
- Komárek, J., and Anagnostidis, K., 2001, Cyanoprokaryota I. Teil. Chroococcales, in Ettl, H., Gartner, G., Heynig, H., and Mollenhauer, D., eds., Süßwasserflora von Mitteleuropa, v. 19, no. 1, Gustav Fischer, Jena-Stuttgart-Lübeck-Ulm, 548 p.
- Komárek, J., and Anagnostidis, K., 2005, Cyanoprokaryota II. Teil. Oscillatoriales, in Büdel, B., Gärtner, G., Krienitz, L., and Schagerl, M., eds., Süßwasserflora von Mitteleuropa: Heidelberg, Elsevier, v. 19, no. 2, 759 p.
- Komárek, J., and Hindák, F., 1988, Taxonomic review of natural populations of the cyanophytes from the *Gomphosphaeria*-complex: *Algological Studies/Archiv für Hydrobiologie, Supplement*, v. 50–53, p. 203–225.
- Komárek, J., Kastovsky, J., Mares, J., and Johansen, J.R., 2014, Taxonomic classification of cyanoprokaryotes (cyanobacterial genera) using a polyphasic approach: *Preslia*, v. 86, p. 295–335.
- Kusumi, T., Ooi, T., Watanabe, M.M., Takahashi, H., and Kakisawa, H., 1987, Cyanoviridin RR, a toxin from the cyanobacterium (blue-green alga) *Microcystis viridis*: *Tetrahedron Letters*, v. 28, p. 4695–4698.
- Lanaras, T., and Cook, C.M., 1994, Toxin extraction from an *Anabaenopsis milleri*-dominated bloom: *Science of the Total Environment*, v. 142, no. 3, p. 163–169.
- Leliaert, F., Smith, D.R., Moreau, H., Herron, M.D., Verbruggen, H., Delwiche, C.F., and de Clerck, O., 2012, Phylogeny and molecular evolution of the green algae: *Critical Reviews in Plant Sciences*, v. 31, p. 1–46.
- Li, X.Y., Chung, I.K., Kim, J.I., and Lee, J.A., 2004, Subchronic oral toxicity of microcystin in common carp (*Cyprinus carpio* L.) exposed to *Microcystis* under laboratory conditions: *Toxicon*, v. 44, no. 8, p. 821–827.
- Lippy, E.C., and Erb, J., 1976, Gastrointestinal illness at Swrickley, Pa.: *Journal of the American Water Works Association*, v. 68, p. 606–610.
- Mez, K., Hanselmann, K., Naegeli, H., and Preisig, H.R., 1996, Protein phosphatase inhibiting activity in cyanobacteria from alpine lakes in Switzerland: *Phycologia*, v. 35, p. 133–139.
- Molica, R.J.R., Oliveira, E.J.A., Carvalho, P.V.V.C., Costa, A.N.S.F., Cunha, M.C.C., Melo, G.L., and Azevedo, S.M.F.O., 2005, Occurrence of saxitoxins and an anatoxin-a(s)-like anticholinesterase in a Brazilian drinking water supply: *Harmful Algae*, v. 4, p. 743–753.
- Mynderse, J.S., Moore, R.E., Kashiwaga, M., and Norton, T.R., 1977, Antileukemia activity in the Oscillatoriaceae—Isolation of debromoaplysia toxin from *Lyngbya*: *Science*, v. 196, p. 538–540.
- Namikoshi, M., Murakamia, T., Watanabe, M.F., Oda, T., Yamada, J., Tsujimura, S., Nagaia, H., and Oishi, S., 2003, Simultaneous production of homoanatoxin-a, anatoxin-a, and a new non-toxic 4-hydroxyhomoanatoxin-a by the cyanobacterium *Raphidiopsis mediterranea* Skuja: *Toxicon*, v. 42, p. 533–538.
- Namikoshi, M., Rinehart, K.L., Sakai, R., Stotts, R.R., Dahlem, A.M., Beasley, V.R., Carmichael, W.W., and Evans, W.R., 1992, Identification of 12 hepatotoxins from a Homer lake bloom of the cyanobacteria *Microcystis aeruginosa*, *Microcystis viridis*, *Microcystis wesenbergii*; nine new microcystins: *Journal of Organic Chemistry*, v. 57, p. 866–872.
- National Environmental Justice Advisory Council (NEJAC), 2002, Fish consumption and environmental justice: A report developed from the National Environmental Justice Advisory Council Meeting of December 3–6, 2001, Federal Advisory Committee to the U.S. Environmental Protection Agency.
- Oren, A., 2004, A proposal for further integration of the cyanobacteria under the Bacteriological Code: *International Journal of Systematic Bacteriology*, v. 54, pt. 5, p. 1895–1902.
- Paerl, H.W., and Huisman, J., 2009, Climate change—A catalyst for global expansion of harmful cyanobacterial blooms: *Environmental Microbiology Reports*, v. 1, no. 1, p. 27–37.
- Pereira, P., Dias, E., Franca, S., Pereira, E., Carolino, M., and Vasconcelos, V., 2004, Accumulation and depuration of cyanobacterial paralytic shellfish toxins by the freshwater mussel *Anodonta cygnea*: *Aquatic Toxicology*, v. 68, no. 4, p. 339–350.

- Preussel, K., Stüken, A., Wiedner, C., Chorus, I., and Fastner, J., 2006, First report on cylindrospermopsin producing *Aphanizomenon flos-aquae* (Cyanobacteria) isolated from two German lakes: *Toxicon*, v. 47, no. 2, p. 156–162.
- Prinsep, M.R., Caplan, F.R., Moore, R.E., Patterson, G.M.L., Honkanen, R.E., and Boynton, A.L., 1992, Microcystin-LR from a blue-green alga belonging to the Stigonematales: *Phytochemistry*, v. 31, p. 1247–1248.
- Rajaniemi, P., Komárek, J., Hoffmann, L., Hrouzek, P., Kastocská, K., and Sivonen, K., 2005, Taxonomic consequences from the combined molecular and phenotype evaluation of selected *Anabaena* and *Aphanizomenon* strains: *Algological Studies*, v. 117, p. 371–391.
- Rapala, J., Sivonen, K., Luukkainen, R., and Niemelä, S.I., 1993, Anatoxin-a concentration in *Anabaena* and *Aphanizomenon* at different environmental conditions and comparison of growth by toxic and non-toxic *Anabaena* strains, a laboratory study: *Journal of Applied Phycology*, v. 5, p. 581–591.
- Rinehart, K.L., Harada, K.-I., Namikoshi, M., Chen, C., Harvis, C.A., Munro, M.H.G., Blunt, J.W., Mulligan, P.E., Beasley, V.R., Dahlem, A.M. and Carmichael, W.W., 1988, Nodularin, microcystin, and the configuration of Adda: *Journal of the American Chemical Society*, v. 110, p. 8557–8558.
- Rinehart, K.L., Namikoshi, M., and Choi, B.W., 1994, Structure and biosynthesis of toxins from blue-green algae (Cyanobacteria): *Journal of Applied Phycology*, v. 6, p. 159–176.
- Roberts, R.D., and Zohary, T., 1987, Temperature effects on photosynthetic capacity, respiration, and growth rates of bloom-forming cyanobacteria: *New Zealand Journal of Marine and Freshwater Research*, v. 21, p. 391–399.
- Rosen, B.H., Loftin, K.A., Smith, C.E., Lane, R.F., and Keydel, S.P., 2010, Microphotographs of cyanobacteria documenting the effects of various cell-lysis techniques: U.S. Geological Survey Open-File Report 2010–1289, 203 p.
- Sinha, R., Pearson, L.A., Davis, T.W., Muenchhoff, J., Pratama, R., Jex, A., Burford, M.A., and Neilan, B.A., 2014, Comparative genomics of *Cylindrospermopsis raciborskii* strains with differential toxicities: *BioMed Central Genomics*, v. 15, p. 83.
- Sivonen, K., 1990, Effects of light, temperature, nitrate, orthophosphate, and bacteria on growth of and hepatotoxin production by *Oscillatoria agardhii* strains: *Applied Environmental Microbiology*, v. 56, p. 2658–2666.
- Sivonen, K., Carmichael, W.W., Namikoshi, M., Rinehart, K.L., Dahlem, A.M., and Niemelä, S.I., 1990, Isolation and characterization of hepatotoxic microcystin homologues from the filamentous freshwater cyanobacterium *Nostoc* sp. strain 152: *Applied Environmental Microbiology*, v. 56, p. 2650–2657.
- Sivonen, K., Himberg, K., Luukkainen, R., Niemelä, S.I., Poon, G.K., and Codd, G.A., 1989a, Preliminary characterization of neurotoxic blooms and strains from Finland: *Environmental Toxicology and Water Quality*, v. 4, no. 3, p. 339–352.
- Sivonen, K., Kononen, K., Carmichael, W.W., Dahlem, A.M., Rinehart, K.L., Kiviranta, J., and Niemelä, S.I., 1989b, Occurrence of the hepatotoxic cyanobacterium *Nodularia spumigena* in the Baltic Sea and the structure of the toxin: *Applied Environmental Microbiology*, v. 55, p. 1990–1995.
- Sivonen, K., Namikoshi, M., Evans, W.R., Carmichael, W.W., Sun, F., Rouhiainen, L., Luukkainen, R., and Rinehart, K.L., 1992a, Isolation and characterization of a variety of microcystins from seven strains of the cyanobacterial genus *Anabaena*: *Applied Environmental Microbiology*, v. 58, p. 2495–2500.
- Sivonen, K., Namikoshi, M., Evans, W.R., Färdig, M., Carmichael, W.W., and Rinehart, K.L., 1992b, Three new microcystins, cyclic heptapeptide hepatotoxins, from *Nostoc* sp. strain 152: *Chemical Research in Toxicology*, v. 5, p. 464–469.
- Stewart I., Eaglesham, G.K., McGregor, G.B., Chong, R., Seawright, A.A., Wickramasinghe, W.A., Sadler, R., Hunt, L., and Graham, G., 2012, First report of a toxic *Nodularia spumigena* (Nostocales/Cyanobacteria) bloom in sub-tropical Australia. II. Bioaccumulation of nodularin in isolated populations of mullet (Mugilidae): *International Journal of Environmental Research and Public Health*, v. 9, no. 7, p. 2412–2443.
- Tanabe, Y., Sano, T., Kasai, F., and Watanabe, M.M., 2009, Recombination, cryptic clades and neutral molecular divergence of the microcystin synthetase (mcy) genes of toxic cyanobacterium *Microcystis aeruginosa*: *BioMed Central Evolutionary Biology*, v. 9, p. 115.
- Vezie, C., Brient, L., Sivonen, K., Bertru, G., Lefeuvre, J.C., and Salkinoja-Salonen, M., 1998, Variation of microcystin content of cyanobacterial blooms and isolated strains in Grand-Lieu lake (France): *Microbial Ecology*, v. 35, p. 126–135.
- Wacklin, P., Hoffmann, L., and Komárek, J., 2009, Nomenclatural validation of the genetically revised cyanobacterial genus *Dolichospermum* (Ralfs ex Bornet et Flahault) comb. nova: *Fottea*, v. 9, no. 1, p. 59–64.

- Watanabe, M.F., Oishi, S., Watanabe, Y., and Watanabe, M., 1986, Strong probability of lethal toxicity in the blue-green alga *Microcystis viridis* Lemmermann: *Journal of Phycology*, v. 22, p. 552–556.
- Watanabe, M.F., Tsujimura, S., Oishi, S., Niki, T., and Namikoshi, M., 2003, Isolation and identification of homoanatoxin-a from a toxic strain of the cyanobacterium *Raphidiopsis mediterranea* Skuja isolated from Lake Biwa, Japan: *Phycologia*, v. 42, p. 364–369.
- Wehr, J.D., Sheath, R.G., and Kociolek, J.P., 2015, *Freshwater algae of North America, Ecology and classification* (2d ed.): New York, Academic Press, 1,066 p.
- Werner, V.R., Laughinghouse, H.D., IV, Fiore, M.F., Sant'Anna, C.L., Hoff, C., de Souza Santos, K.R., Neuhaus, E.B., Molica, R.J.R., Honda, R.Y., and Echenique, R.O., 2012, Morphological and molecular studies of *Sphaerospermopsis torques-reginae* (Cyanobacteria, Nostocales) from South American water blooms: *Phycologia*, v. 51, no. 2, p. 228–238.
- Willame, R., Jurczak, T., Iffly, J-F., Kull, T., Meriluoto, J., and Hoffmann, L., 2005, Distribution of hepatotoxic cyanobacterial blooms in Belgium and Luxembourg: *Hydrobiologia*, v. 551, p. 99–117.
- Zapomelová, E., Jezberová, J., Hrouzek, P., Hisem, D., Reháková, K., and Komárková, J., 2010, Nomenclatural note—Polyphasic characterization of three strains of *Anabaena reniformis* and *Aphanizomenon aphanizomenoides* (cyanobacteria) and their reclassification to *Sphaerospermum* gen. nov. (incl. *Anabaena kisseleviana*): *Journal of Phycology*, v. 45, no. 45, p. 1363–1373.
- Zapomelová, E., Skaácelová, O., Pumann, P., Kopp, R., and Janecek, E., 2012, Biogeographically interesting planktonic Nostocales (Cyanobacteria) in the Czech Republic and their polyphasic evaluation resulting in taxonomic revisions of *Anabaena bergii* Ostefeld 1908 (*Chrysochlorum* gen. nov.) and *A. tenericaulis* Nygaard 1949 (*Dolichospermum tenericaule* comb. nova): *Hydrobiologia*, v. 698, p. 353–365.
- Zimba, P.V., Camus, A.A., and Burkholder, J.M., 2006, Co-occurrence of white shrimp, *Litopenaeus vannamei*, mortalities and microcystin toxin in a southeastern U.S.A. shrimp facility: *Aquaculture*, v. 261, no. 3, p. 1048–1055.
- Zimba, P.V., Khoo, L., Gaunt, P.S., Brittain, S., and Carmichael, W.W., 2001, Confirmation of catfish, *Ictalurus punctatus* (Rafinesque), mortality from *Microcystis* toxins: *Journal of Fish Diseases*, v. 24, no. 1, p. 41–47.
- Zimba, P.V., Moeller, P.D., Beauchesne, K., Lane, H.E., and Triemer, R.E., 2010, Identification of euglenophycin—A toxin found in certain euglenoids: *Toxicon*, v. 55, p. 100–104.

Manuscript was approved on August 24, 2015.

Prepared by the U.S. Geological Survey Science Publishing  
Network, Raleigh Publishing Service Center

For more information concerning this publication, contact

Barry Rosen, Biologist  
U.S. Geological Survey  
Caribbean-Florida Water Science Center  
12703 Research Parkway  
Orlando, FL 32826  
(407) 803-5508  
[brosen@usgs.gov](mailto:brosen@usgs.gov)

ISSN 0196-1497 (print)  
ISSN 2331-1258 (online)  
<http://dx.doi.org/10.3133/ofr20151164>

