Freshwater Algae in Northwest Washington

Volume I. Cyanobacteria



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Chapter 1

Introduction

The idea for this guide began in 2006 when the Institute for Watershed Studies (www.wwu.edu/iws) expanded its Northwest Lakes monitoring project to collect water quality samples from more than 70 local lakes. Plankton samples collected from these lakes and other sites formed the basis for the Institute's online digital image library of freshwater algae and provided the material I needed to develop this guide.

The first version of this guide was finished in the spring of 2009 and used as a class reference for ESCI 428, *Freshwater Algal Bioindicators*. After much additional sampling and taxonomic effort, the guide expanded to the point where it was not feasible to print as a single volume. As a result, the current version has been separated into multiple volumes as described in Table 1.1 (page 6). Although the emphasize is on freshwater lakes, samples collected in streams, seeps, waterfalls, and other lotic systems are included, with comments on whether the taxa[1] are likely to be found in plankton samples.

All identifications represent my best effort to provide accurate classifications using major keys (John, et al., 2011; Komárek, 2013; Komárek & Anagnostidis, 1998; 2005; Prescott, 1962; Wehr, et al., 2015); and other taxonomic sources listed in Section 6 (page 481). Uncertain identifications were flagged using a "?" following the species name.[2] Unknown taxa that could be separated using

[1]The word "taxa" (singular "taxon") is used to distinguish unique groups of organisms.

[2]Taxonomists often use "cf" (Latin: *conferre* or *conformis*) or "aff" (Latin: *affinis*) to indicate taxonomic uncertainty, but these terms have distinctions that are beyond the scope of this guide.

morphological features were given a unique code (e.g., *Aphanocapsa* sp.1). The terms "sp" and "spp," indicate when one, or more one species were present, respectively.

Algal nomenclature has changed rapidly over the past few decades, largely due to the use of genetic analysis to separate algal species (see Brodie & Lewis, 2007, for a good discussion of recent changes in algal systematics). It has become increasingly difficult to keep up with changes in algal scientific names. My general approach was to follow the nomenclature in AlgaeBase (www.algaebase.org; Guiry & Guiry, 2016). But some genetic revisions separated algal that are so similar in appearance that it is difficult for students who are just beginning their study of algal taxonomy to separate the genera based on conventional light microscopy. If the revision applied to a small number of species, the revised species were kept in the same section with other morphologically similar species, and the revised name was included in the taxa list. For example, *Aphanothece clathrata* West & G. S. West is currently named *Anathece clathrata* (West & G. S. West) Komárek, Kastovsky & Jezberová, but this species was included with other species of *Aphanothece* in Section 2.2 (page 39). More extensive revisions were addressed by including both genus names in the section heading. For example, all of the planktonic species of *Anabaena* have been moved to the genus *Dolichospermum*, so these species were included with the remaining species of *Anabaena* in a combined section containing both *Anabaena* and *Dolichospermum* (Section 3.1, page 198). In all cases, remember that scientific names are a moving target, so check an authoritative source like AlgaeBase if you need to cite the correct scientific name.

Unless otherwise noted, all images in this manual were photographed by Dr. Robin Matthews using a Nikon Eclipse 80i with phase contrast and Nomarski (DIC) objectives equipped with either a QImaging or Nikon DS-Fi2 digital camera. The images may be used for noncommercial educational purposes under the Creative Commons license (www.creativecommons.org), with appropriate credit given to the author and Western Washington University. Comments and suggestions may be directed to R. Matthews, Western Washington University, 516 High Street, Bellingham, WA, 98225.

1.1 Collecting and Identifying Algae Samples

Guidelines for collecting algae: Collect your sample using a plankton net, by scraping visible algae from rocks or wet surfaces, or by collecting a small sample of shoreline vegetation. Put the sample into a clean, wide-mouth jar or bottle along with a small amount of clear water from the site. Leave 1–2 inches of air space and put it in a cool location away from direct sunlight. If the sample must be held for more than one day, you can preserve the algae using Lugol's iodine solution, but this may make the algae more difficult to identify.

- Algae that sit in a sealed jar may form oxygen bubbles in the chloroplast, especially if the jar sits in direct sunlight. This damages the chloroplast, and makes the specimen hard to identify.
- If the sample is sealed too long or gets too hot (sits in a hot car or in direct sunlight), the algae die and start to decompose. Not only does this smells really bad, the algae are nearly impossible to identify. If you can't examine your sample within an hour, loosen or remove the lid to allow fresh air to reach the water surface.
- Similarly, algae that sit too long (i.e., more than 10–15 minutes) on a hot microscope slide will be hard to identify. The cells may start shedding flagella or excreting mucilage, and will eventually be deformed or crushed by the cover slip as the slide dries.

Guidelines for identifying algae: Start your identification by reviewing Table 1.1 (page 6) to make sure you are using the correct volume of this series. Algae described in this volume lack starch, so they will not stain dark brown or purple in Lugol's iodine solution; the cells lack organelles like chloroplasts and pyrenoids; and the cells do not have flagella; any motility will be the result of twitching, spiraling, or gliding.

The preliminary key on page 9 separates algae based on whether the cells are solitary or form colonies or filaments. The keys in this guide are not dichotomous.[3] Instead, you are offered several choices among matching numbers or letters. The preliminary key directs you to more advanced keys that will take you to genus.

[3]Dichotomous keys are based on paired choices.

Here are a few guidelines to remember when identifying algae:

- Algae are diverse! You will almost certainly encounter specimens that do not match the figures or are not described in the text. Try to find several examples of the cell, colony, or filament.
- Many types of algae form resting cells or other specialized cells that look different than the vegetative cells. Where possible, I have included figures showing specialized cells that help distinguish different taxa.
- Try to work with *healthy*, live specimens. Preserved samples are fine for someone familiar with algae, but they are difficult to work with if you are a beginner.
- If possible, take photographs of your specimens. If you do not have access to a good camera on your microscope, carefully drawn illustrations can be a good alternative.
- Keep clear records of your observations, photographs, and drawings. Include the sampling location, date, and magnification.
- Take advantage of online image libraries like AlgaeBase (www.algaebase.org), PhycoTech (www.phycotech.com), PhycoKey (www.cfb.unh.edu/phycokey/phycokey.htm), or the Protist Information Server (http://protist.i.hosei.ac.jp).

  Nearly all online images are copyright-protected, so don't download and use them without permission.

  ⇒**Warning: not all online images are correctly identified!**

1.2 Recognizing the Algal Divisions

This guide is designed to be used by novices who are beginning their exploration of algal taxonomy. The taxonomic identifications are based on simple morphological features rather than genetic relationships. Photographs, cell dimensions, and biovolume estimates[4] are included for local taxa. Keeping with the goal of introducing new students to algal taxonomy, I have avoided the use of specialized taxonomic terms except when necessary for clarity. This guide emphasizes algae collected from lakes and ponds, so it contains fewer taxa than guides that cover all types of freshwater algae in broad geographic regions. If you are working outside this region, I recommend using a simple generic key like **Common Freshwater Algae of the United States** (Dillard, 2008) or **Freshwater Algae: Identification and Use as Bioindicators** (Bellinger and Sigee, 2015), or any of the advanced keys listed in Section 6 (page 481).

The first step in this book requires separating algae into major divisions. Even this broad separation can be difficult. Table 1.1 provides a summary of major distinguishing features for the divisions and indicates which volume describes each type of algae. If you are having difficulty separating by division, try using several keys or looking at photographs that show the different examples.

Motility as a key feature in algal taxonomy: Motility is very common in freshwater algae. Some algae are motile by means of flagella and may have a red eyespot that detects light. The presence of these features usually indicates potential motility, even if the cells in your sample are stationary. But flagella and eyespots are not necessary for motility. Many types of Cyanobacteria move by means of gliding, spiraling, or twitching.

Although motility can be a distinctive taxonomic feature, the lack of motility is not as helpful. Motile algae often respond to stress by shedding flagella and becoming nonmotile. Conversely, algae that glide across surfaces may need to settle on the slide before they start moving, and algae that spiral or twitch may become increasingly active as the slide warms and dries under the hot microscope light. And, just to keep things interesting, there are a few common nonmotile algae that have residual eyespots or nonfunctional structures that resemble flagella.

[4]The term "biovolume" refers to the volume of a cell or colony. It is estimated by measuring the width and length (± depth) of a cell or colony, then using a volume equation for a similar geometric shape (e.g., sphere). Biovolume calculations are discussed in more detail in Chapter 5.

Table 1.1: Summary of the Major Algal Divisions

Volume I	**Cyanobacteria** (blue-green algae): cells lack organelles like chloroplasts; no flagella (may move by gliding); starch absent.
Volume II*	**Chlorophyta** (green algae): chloroplasts often bright green; motile cells have two or four flagella; starch present.† **Rhodophyta** (red algae): chloroplasts red or blue-green; nonmotile; starch present.†
Volume III**	**Charophyta - Desmids:** nonmotile; chloroplasts often bright green; most form mirror image semicells; starch present.†
Volume IV**	**Chrysophyceae** (golden algae) and **Xanthophyceae** (yellow-green algae): chloroplasts golden-brown or yellow-green; motile cells with two unequal flagella; starch absent. **Haptophyta:** solitary cells; chloroplasts golden-brown; all cells motile with what looks like three flagella (two flagella + one haptomere); starch absent.
Volume V**	**Cryptophyta:** solitary cells; chloroplasts greenish, golden-brown, or brown; all cells motile with two nearly equal flagella; oral groove; starch present.† **Dinophyta:** solitary cells; chloroplasts golden-brown or brown; usually motile with visible trailing flagellum; second flagellum encircles cell; cell wall often plate-like; starch present.† **Euglenophyta:** solitary cells; chloroplast usually bright green; single visible flagellum; starch absent.

*Volume II includes non-desmid **Charophyta**; **Volumes currently in preparation.
†Cells with starch will stain dark purple/brown in Lugol's iodine solution.

1.3 Introduction to the Cyanobacteria

Cyanobacteria (blue-green "algae") are prokaryotes (bacteria), so they lack cell organelles such as chloroplasts, pyrenoids, or a nucleus. They form a diverse group of organisms that are adapted to a wide variety of environments. At any particular time of the year you can probably find Cyanobacteria present in almost any freshwater location; however, they are usually much more diverse and abundant in lakes during late summer and early fall. Cyanobacteria may also be abundant on damp soil, in seeps along trails, on stony surfaces like cliffs surrounding waterfalls, and in hot springs.

Some types of Cyanobacteria can become so abundant in lakes that they form nuisance blooms. These blooms may result in a build-up of sticky scum along shorelines, making it unpleasant to swim or boat, or may otherwise affect the recreational use of the lake. The blooms may cause taste and odor problems if the lake is used as a source of drinking water, or may degrade aquatic habitat, making it difficult for other organisms to survive in the lake. Some Cyanobacteria produce toxins that can harm people, pets, and wildlife (WHO, 1999). In local lakes, *Dolichospermum* and *Microcystis* are the most common Cyanobacteria associated with toxic blooms, but many other types of Cyanobacteria have been know to produce toxins.[5] It is important to note that not all blooms contain toxin-forming species, and toxin-forming species may bloom without producing toxins. But blooms that contain toxin-forming taxa are potentially harmful. The Washington State Department of Ecology maintains a web site that describes what to look for and how to report possible harmful Cyanobacteria blooms: www.ecy.wa.gov/programs/wq/plants/algae/monitoring/index.html.

Like most other freshwater algae, Cyanobacteria use chlorophyll *a* as the primary light gathering pigment. The cells also contain a variety of auxiliary pigments such as phycocyanins (blue pigments) and phycoerythrins (red pigments) to help capture light energy at different wavelengths and low light intensities. Many Cyanobacteria can photosynthesize under aerobic or anaerobic conditions and under low light conditions. This allows the cells to grow in deep, low-oxygen regions of the water column that often have higher concentrations of nutrients compared to water near the surface.

[5] Wikipedia provides a good description of toxins produced by different Cyanobacteria (https://en.wikipedia.org/wiki/Cyanotoxin).

The energy storage product resulting from photosynthesis is not true starch, but rather a starch-like compound called cyanophycean starch (Van den Hoek et al., 1995). As a result, Cyanobacteria cells will not stain dark purple or brown in the Lugol's iodine solution.

Slow, gliding motility is fairly common among Cyanobacteria, but active motility is best seen in *Arthrospira/Spirulina* (Section 4.1, page 356), *Oscillatoria* (Section 4.6, page 394), *Phormidium* (Section 4.7, page 414), and a few other filamentous taxa. Cyanobacteria do not have true flagella, so you will not see rapid tumbling or spiraling movement that is present in flagellated green algae like *Chlamydomonas*.[6]

Some Cyanobacteria are solitary[7] in the vegetative state, but most taxa form colonies or trichomes[8] (Figures 1.1–1.8). Cyanobacteria colonies may be spherical or semi-spherical; flat, consisting of a single layer of cells; or amorphous, formed from aggregations of cells held together by mucilage (Figures 1.2–1.4). Filamentous Cyanobacteria may be unbranched or branched (Figures 1.5–1.7), with the branches originating from lateral division of the vegetative cells (true branching) or at a break in the trichome (false-branching). Some filamentous Cyanobacteria form spherical or hemispherical colonies comprised of trichomes radiating from a common center (Figure 1.8). A few types of Cyanobacteria form pseudofilaments in which the cells are arranged end-to-end, but are slightly separated from each other (Figures 1.9–1.10). The cells, colonies, pseudofilaments, and trichomes are often surrounded by mucilage, which can be thick or very thin, firm or soft, colored or clear, and is occasionally difficult to see except under phase contrast or when stained with methylene blue (Figure 1.4).

Some filamentous Cyanobacteria can fix dissolved nitrogen gas (N_2) into usable forms of inorganic nitrogen by converting vegetative cells into specialized cells called heterocysts (Figure 1.11). The enzymes that fix N_2 are inhibited by oxygen. The heterocyst creates a special low oxygen environment inside the cell that allows nitrogen fixation to occur despite high oxygen concentrations in adjacent

[6] See **Freshwater Algae in Northwest Washington, Volume II. Chlorophyta and Rhodophyta**.

[7] Although solitary vegetative cells are somewhat uncommon, many Cyanobacteria form solitary resting cells near the end of their life cycle (e.g. *Aphanizomenon*, Section 3.3, page 250), and some Cyanobacteria release individual cells as a means of vegetative reproduction (e.g., *Woronichinia*; Section 2.18, page 181).

[8] The term "trichome" is used to describe chains of Cyanobacteria cells; the term "filament" is used to describe the trichome plus any associated mucilage layer or sheath that surrounds the trichome.

cells and the surrounding water. The process is metabolically costly (it takes energy), so you rarely see heterocysts when dissolved inorganic nitrogen (DIN)[9] concentrations are high. A few species of Cyanobacteria that lack heterocysts are able to fix nitrogen at night when photosynthetic oxygen is not generated, and one marine species has a different kind of specialized cell (diazocyte) that maintains a low oxygen microhabitat for nitrogen fixation (Lee, 2008).

Some heterocyst-forming filamentous Cyanobacteria can also form thick walled resting cells called akinetes that withstand desiccation, extreme temperatures, and other harsh environmental conditions (Figure 1.12). Akinetes are often formed late in the growing season when the Cyanobacteria bloom is beginning to die back (senescence phase). Species separation often requires being able to describe the size, shape, and position of the akinetes relative to heterocysts in the trichome.

As a group, Cyanobacteria are difficult to identify, even at the genus level. The following key will help you get started by separating the taxa using very basic structural features. The chapter keys will help you identify the individual taxa.

Table 1.2: Preliminary Key to the Cyanobacteria

A	Vegetative cells solitary, in colonies, or forming pseudofilaments[†] (Figures 1.1–1.4 and 1.9–1.10)	Solitary and Colonial Cyanobacteria; Table 2.1 (page 24)
B	Vegetative cells joined end-to-end in trichomes; filamentous structure should be obvious (Figures 1.5–1.8)	
B.1	Trichomes can produce heterocysts; akinetes may also be present (Figures 1.11–1.12)	Filamentous Cyanobacteria With Heterocysts; Table 3.1 (page 194)
B.2	Trichomes are not capable of producing heterocysts or akinetes (Figure 1.5)	Filamentous Cyanobacteria Without Heterocysts; Table 4.1 (page 354)

[†]Cells arranged end-to-end, but slightly separated from each other.

[9]DIN = ammonium + nitrite + nitrate



Figure 1.1: Typical solitary Cyanobacteria (*Cyanothece*).



Figure 1.2: Typical colonial Cyanobacteria (*Gomphosphaeria* - spherical colony).

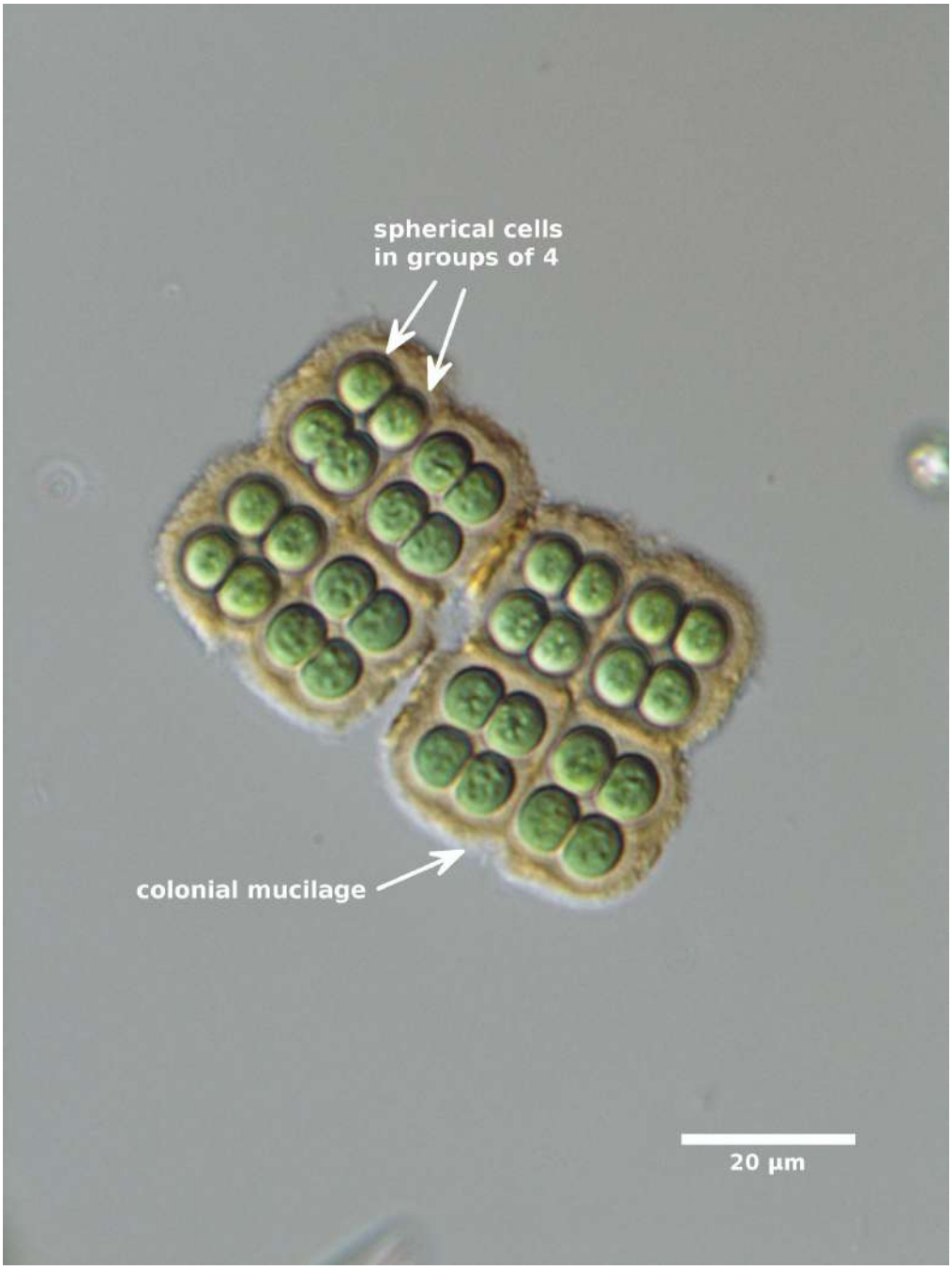


Figure 1.3: Typical colonial Cyanobacteria (*Merismopedia* - flat colony).

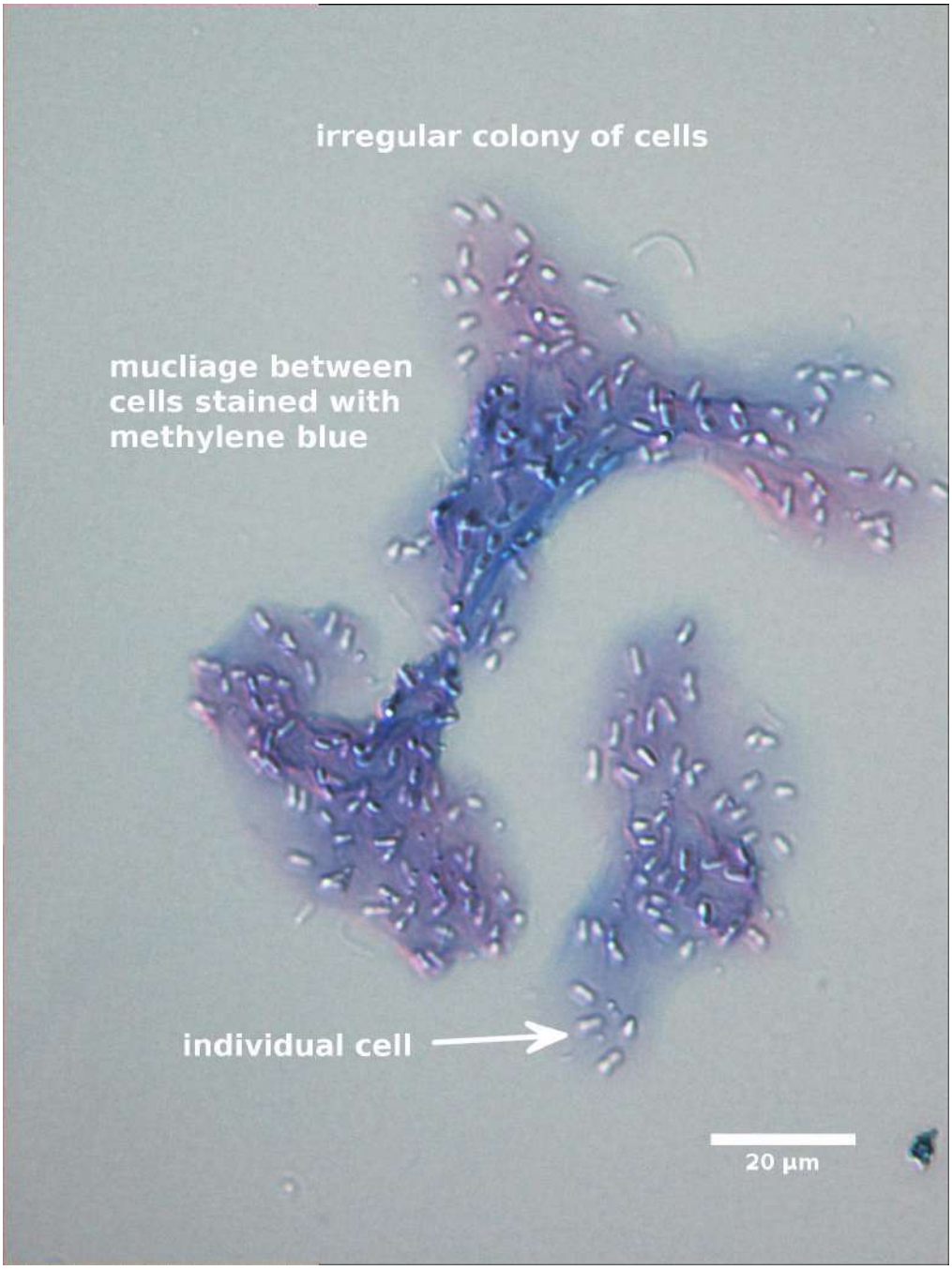


Figure 1.4: Typical colonial Cyanobacteria (*Aphanothece* - amorphous colony).



Figure 1.5: Typical filamentous Cyanobacteria (*Oscillatoria* - unbranched).



Figure 1.6: Typical filamentous Cyanobacteria (*Fischerella* - true branching).



Figure 1.7: Typical filamentous Cyanobacteria (*Tolypothrix* - false branching).



Figure 1.8: Typical filamentous Cyanobacteria (*Gloeotrichia* - filaments joined to form spherical colony).



Figure 1.9: Typical pseudofilamentous Cyanobacteria (*Cyanodictyon*).

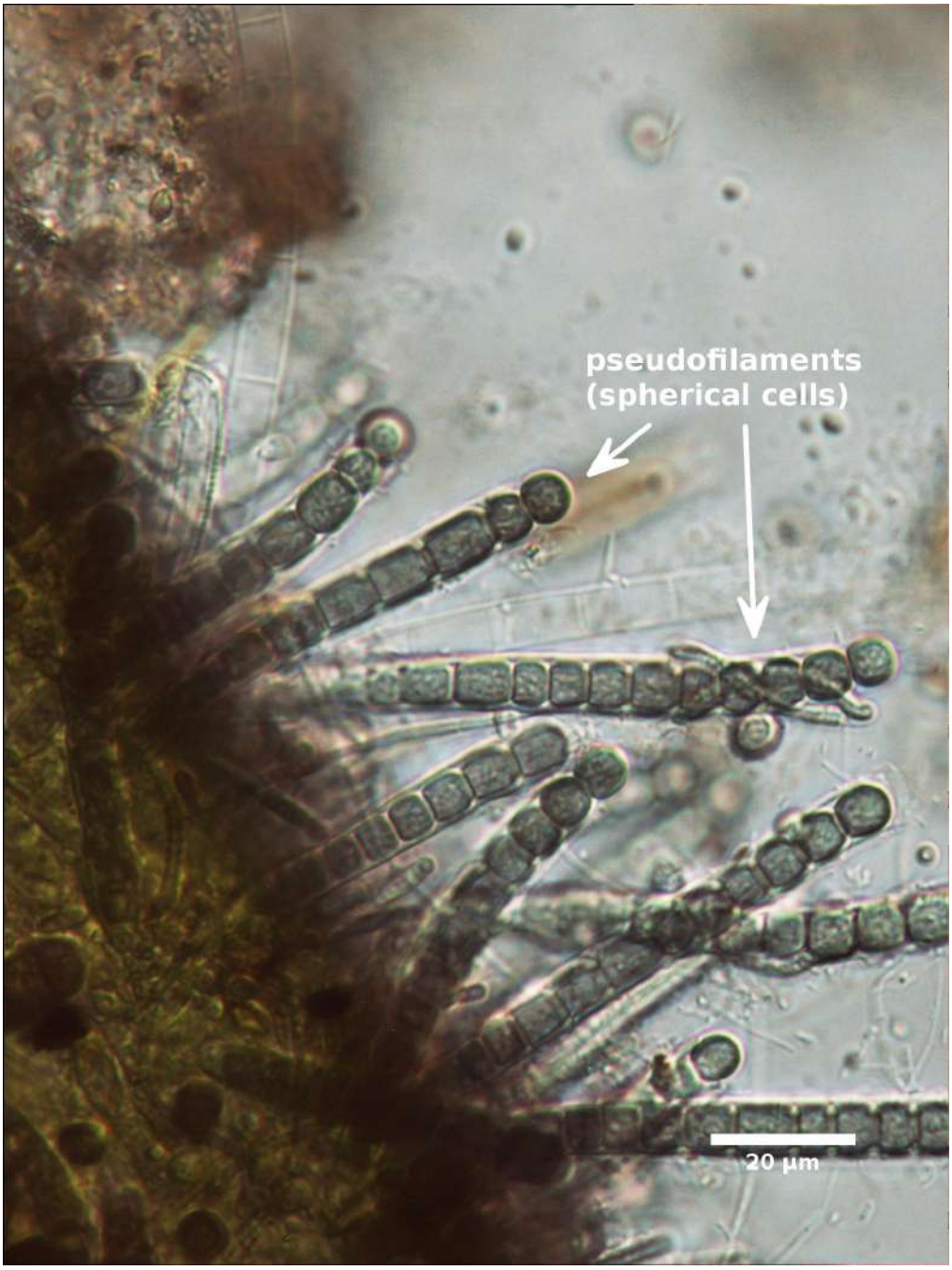


Figure 1.10: Typical pseudofilamentous Cyanobacteria (*Stichosiphon*).

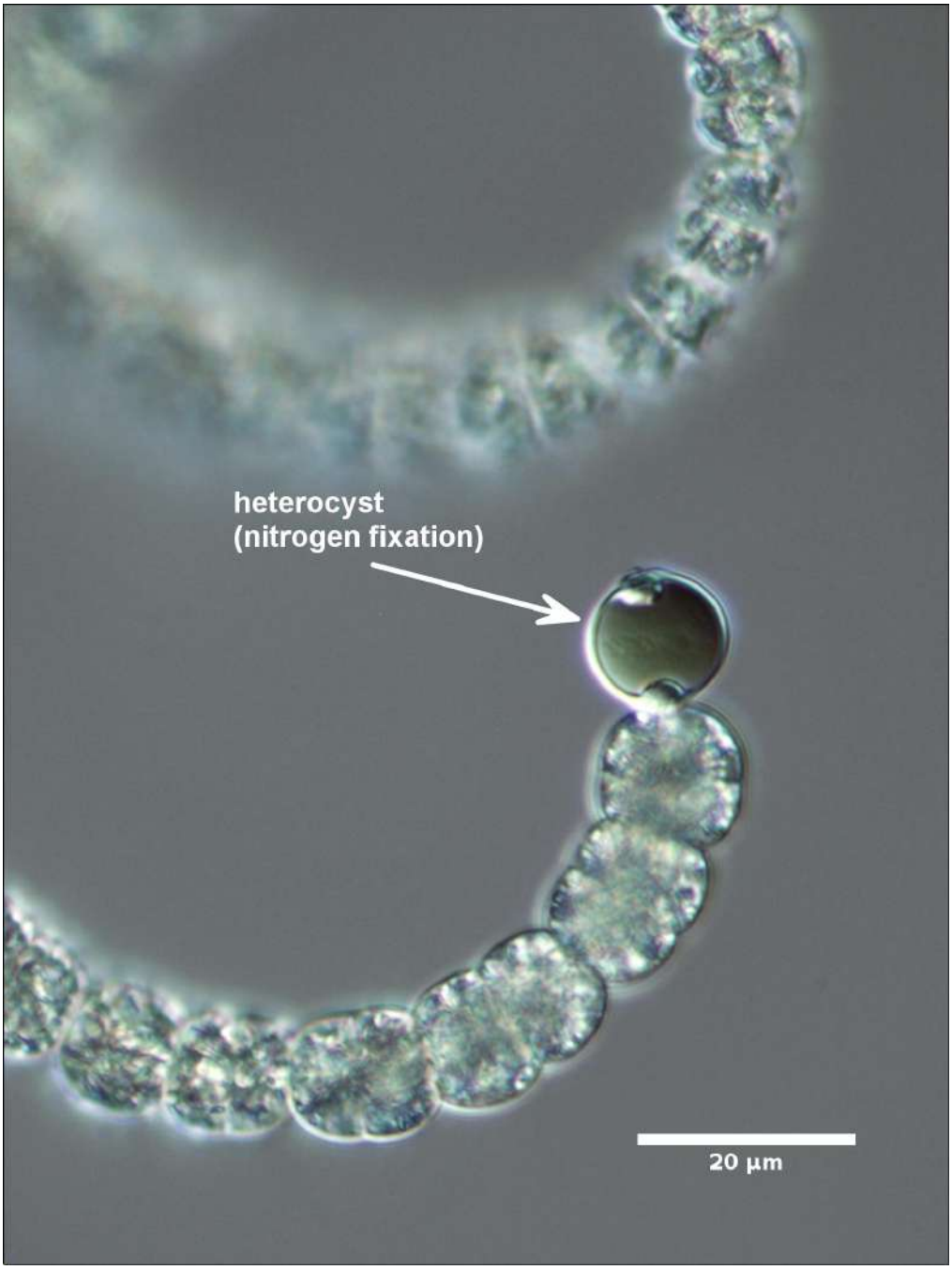


Figure 1.11: Typical heterocyst (*Dolichospermum*).

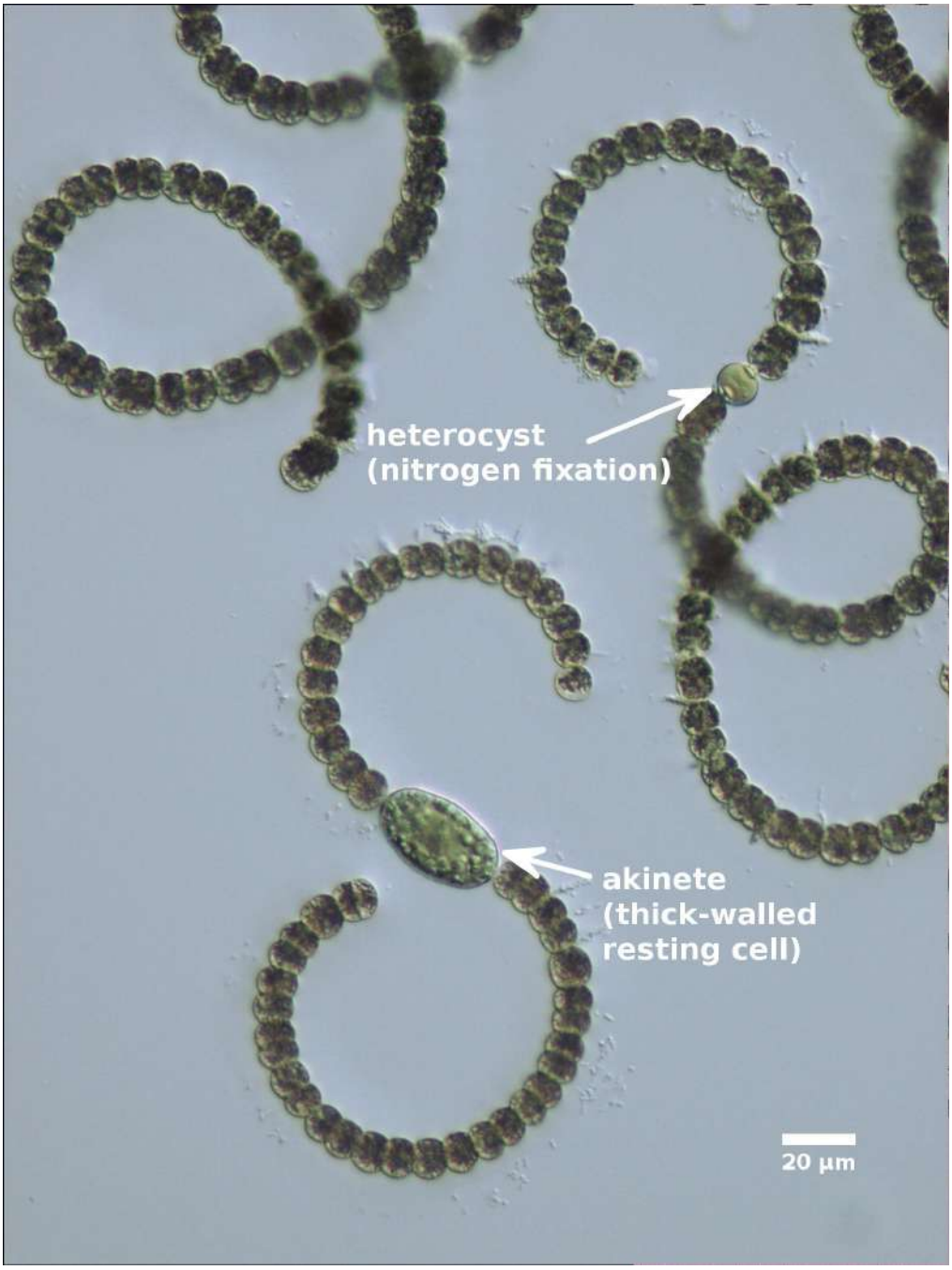


Figure 1.12: Typical akinete and heterocyst (*Dolichospermum*).

Chapter 2

Solitary and Colonial Cyanobacteria

The key on page 24 will help you identify solitary and colonial Cyanobacteria, including taxa that form pseudofilaments where the cells are arranged end-to-end, but slightly separated from each other. For filamentous Cyanobacteria, including taxa that form spherical or hemispherical colonies of radiating trichomes, go to Table 3.1 (page 194) if the trichome can produce heterocysts, and Table 4.1 (page 354) if the trichome does not produce heterocysts. Remember that heterocyst formation occurs when inorganic nitrogen concentrations are low, so specimens collected during winter and early spring may not contain heterocysts, even if the trichome is capable of producing heterocysts.

Most of the Cyanobacteria described in this chapter form flat, cubical, spherical, or irregular colonies. The colonies may contain only a few cells or $>$1000 cells. The individual cells are often tiny, making it difficult to see important morphological features. The cells and colonies may be surrounded by layers of mucilage, but the mucilage may not be visible without staining. These morphological distinctions are not rigid. Solitary cells may form small groups when they are reproducing, and cells surrounded by mucilage can stick together, forming large, temporary aggregations. Try to examine more than one specimen to determine whether you are looking at representative cells and colonies.

Table 2.1: Key to Solitary and Colonial Cyanobacteria

A		Cells not actually joined end-to-end, but loosely arranged in pseudofilaments	Go to page 25
B		Large, solitary, free-living cells (for solitary epiphytic cells, see page 25)	*Cyanothece* (page 90)
C		Flat (single-layer) colonies of cells	
	C.1	Rectangular colonies with cells in 4-cell groups	*Merismopedia* (page 118)
	C.2	Amorphous colonies with no obvious cell grouping	*Pannus* (page 155)
D		Small cubical or irregular colonies; many colonies only 2–4 cells; larger colonies with cells in groups of 2–4; cells large enough to count easily	Go to page 25
E		Spherical colonies with cells at end of mucilage strands that radiate from the colony center (strands may be hard to see except in flattened colony)	Go to page 26
F		Colonies large, amorphous, spherical or irregular, usually $\geq$50 cells; radiating mucilage strands absent or not visible except in flattened colonies	Go to page 26

continued on next page

Table 2.1: Key to Solitary and Colonial Cyanobacteria, continued

A	Cells not actually joined end-to-end, but loosely arranged in pseudofilaments	
A.1	Pseudofilaments formed by solitary, epiphytic basal cell that releases one or more spherical exocytes (daughter cells)	
	A.1a Cells enclosed in an open-ended sheath; long, club-shaped basal cell with numerous exocytes	*Chamaesiphon* (page 48)
	A.1b Cells enclosed in an open-ended sheath; spherical basal cell with numerous exocytes	*Stichosiphon* (page 173)
	A.1c Cells not enclosed in a sheath; long, club-shaped basal cell with numerous exocytes	*Cyanophanon* (page 82)
	A.1d Cells not enclosed in a sheath; short, club-shaped or cylindrical basal cell with solitary exocyte	*Geitleribactron* (page 107)
A.2	Filamentous structure obvious; cells rod-shaped, tiny ($\leq$1.5 μm wide), pseudofilaments dense, tangled; usually planktonic	*Cyanodictyon* (page 78)
A.3	Pseudofilament structure inconspicuous; cells oval or rod-shaped, $>$2.5 μm wide; colony usually contains $\leq$16 cells;	*Rhabdoderma* and *Rhabdogloea* (page 159)
D	Small cubical or irregular colonies; many colonies only 2–4 cells; larger colonies with cells in groups of 2–4; cells large enough to count easily	

continued on next page

Table 2.1: Key to Solitary and Colonial Cyanobacteria, continued

	D.1	Cells in multiples of 4 forming regular cubical blocks; individual cells and colony not surrounded by visible layers of mucilage	*Eucapsis* (page 101)
	D.2	Cells in multiples of 2 or 4, but not forming cubical blocks; colonies usually small; if >50 cells, small subcolonies should be obvious	*Chroococcus* (page 55)
E		Spherical colonies with cells at end of mucilage strands that radiate from the colony center (strands may be hard to see except in flattened colony)	
	E.1	Cells form heart-shaped pairs at ends of short, thick mucilage strands; strands narrower than cell pairs; colonies compact	*Gomphosphaeria* (page 111)
	E.2	Cells spherical or oval, forming groups of 4 at end of long, delicate mucilage strands; young colonies less compact than older colonies	*Snowella* (page 168)
	E.3	Cells oval or broadly elliptical, forming pairs at ends of short, thick mucilage strands; strands about as wide as cells	*Woronichinia*, in part (page 181)
F		Colonies large, amorphous, spherical or irregular, usually ≥50 cells; radiating mucilage strands absent or not visible except in flattened colonies	
	F.1	Cells densely packed, forming hollow, spherical colonies; individual cells closely spaced and difficult to count	

continued on next page

Table 2.1: Key to Solitary and Colonial Cyanobacteria, continued

	F.1a Colony dark brown or olive-green, planktonic; cells spherical or oval, at ends of wide mucilage strands (often not visible except in flattened colonies) older colonies often surrounded by wide mucilage layer	*Woronichinia*, in part (page 181)
	F.1b Colony pale or bright blue-green (or lavender); cells spherical or oval; not attached to radiating mucilage strands	*Coelosphaerium* (page 72)
F.2	Cells not forming hollow colonies; colony may be dense, but will have visible space separating cells	
	F.2a Cells dark brown; spherical or oval, with gas vacuoles (colony floats); young colonies spherical, becoming increasing irregular with age	*Microcystis* (page 141)
	F.2b Cells spherical; hemispherical after division; color variable, but not dark brown; colonies spherical to irregular; difficult to identify correctly	*Aphanocapsa* (page 28)
	F.2c Cells oval, elliptical, or rod-shaped; may be spherical after division, color variable, but not dark brown; colonies spherical to irregular; difficult to identify correctly	*Aphanothece* (page 39)

2.1 *Aphanocapsa* Nägeli

Local taxa
Aphanocapsa grevillei (Berkeley) Rabenhorst;
Aphanocapsa holsatica (Lemmermann) Cronberg & Komárek;
Aphanocapsa planctonica (G. M. Smith) Komárek & Anagnostidis;
Aphanocapsa sp.1

Abundance
Very common; may be present in large numbers but rarely forms blooms.

Local measurements		Width	Length	Biovolume[†]
Aphanocapsa grevillei	min	4.3 μm	–	41.6 μm^3
cells (sphere)	med	5.4 μm	–	82.4 μm^3
	max	6.5 μm	–	144 μm^3
Aphanocapsa holsatica	min	1.5 μm	–	1.77 μm^3
cells (sphere)	med	1.7 μm	–	2.57 μm^3
	max	1.9 μm	–	3.59 μm^3
Aphanocapsa planctonica	min	2.5 μm	–	8.18 μm^3
cells (sphere)	med	2.9 μm	–	12.8 μm^3
	max	3.3 μm	–	18.8 μm^3
Aphanocapsa sp.1	min	2.8 μm	–	11.5 μm^3
cells (sphere)	med	3.2 μm	–	17.2 μm^3
	max	3.7 μm	–	26.5 μm^3

[†]Calculated using original measurements, not summary values.

Description
Almost all of our lakes contain colonies of *Aphanocapsa*, *Aphanothece* (Section 2.2, page 39), and *Cyanodictyon* (Section 2.6, page 78). These three genera are quite similar in appearance, and are characterized by spherical, globular, or amorphous colonies containing many spherical, oval, elliptical, or rod-shaped cells surrounded by a colonial mucilage. *Aphanocapsa* cells are spherical before dividing and slightly hemispherical following division (Figures 2.1–2.9).

Aphanothece cells range from oval to rod-shaped, but will often be spherical immediately after division. *Cyanodictyon* cells are very tiny, oval to rod-shaped, and form pseudofilaments (cells not joined end-to-end) inside twisted mucilaginous strands.

Aphanocapsa grevillei colonies are usually not planktonic, but are common along shorelines, especially in association with macrophytes, detritus, or clumps of other algae. The colonies are amorphous, consisting of large, densely packed, bright green cells that are enclosed in a distinct colonial mucilage (Figures 2.2–2.3). This species is described as being associated with slightly acidic or "peaty" water bodies (Komárek & Anagnostidis, 1998), which characterizes many of the lakes and ponds in our region.

Aphanocapsa holsatica is a very common planktonic species that forms large, dense colonies of tiny, pale gray or blue-green cells surrounded by clear mucilage (Figures 2.4–2.5). Young colonies are often spherical, but the older colonies become irregular and clathrate (perforated or net-like).

Aphanocapsa planctonica is a moderately common planktonic species that forms spherical or irregular colonies of small, pale blue-green cells. The cells are widely separated inside a clear, diffuse colonial mucilage (Figures 2.6–2.7). John, et al. (2011) list this species as a variety of *Aphanocapsa elachista*, questioning whether the variety is sufficiently different to be assigned a new species name. But Komárek and Anagnostidis (1998) separate the two species based on habitat, suggesting that *Aphanocapsa planctonica* is found in temperate lakes and *Aphanocapsa elachista* is found in tropical regions.

Aphanocapsa sp.1 is planktonic, with cells that resemble *Aphanocapsa planctonica* in size and color, but are densely packed rather than widely spaced in the colony (Figures 2.8–2.9). The differences in cell spacing could represent natural variability in *Aphanocapsa planctonica*, or the specimens may be a different species or variety. Colonies of both types (dense and widely-spaced cells) are common in mesotrophic and slightly eutrophic low elevation lakes in our region, and both types of colonies can be found in a single lake at different times during the growing season.



Figure 2.1: *Aphanocapsa* spp. (200x DIC), Lone Lake, IWS water quality sampling site, Island County, September 30, 2009.

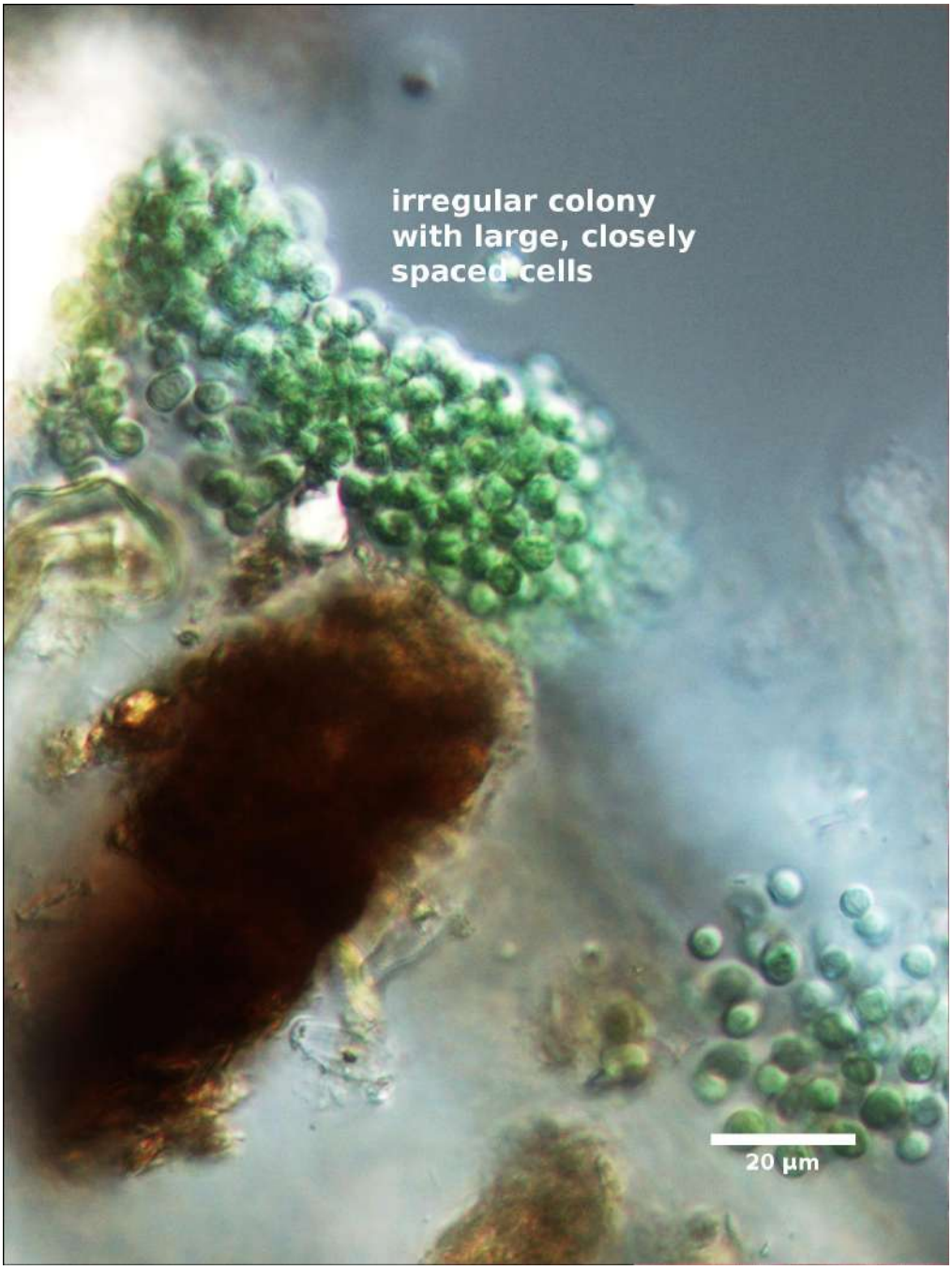


Figure 2.2: *Aphanocapsa grevillei* (400x DIC), Picture Lake, IWS water quality sampling site, Whatcom County, September 10, 2008.



Figure 2.3: *Aphanocapsa grevillei* (600x DIC), Crabapple Lake, IWS water quality sampling site, Snohomish County, September 22, 2009.

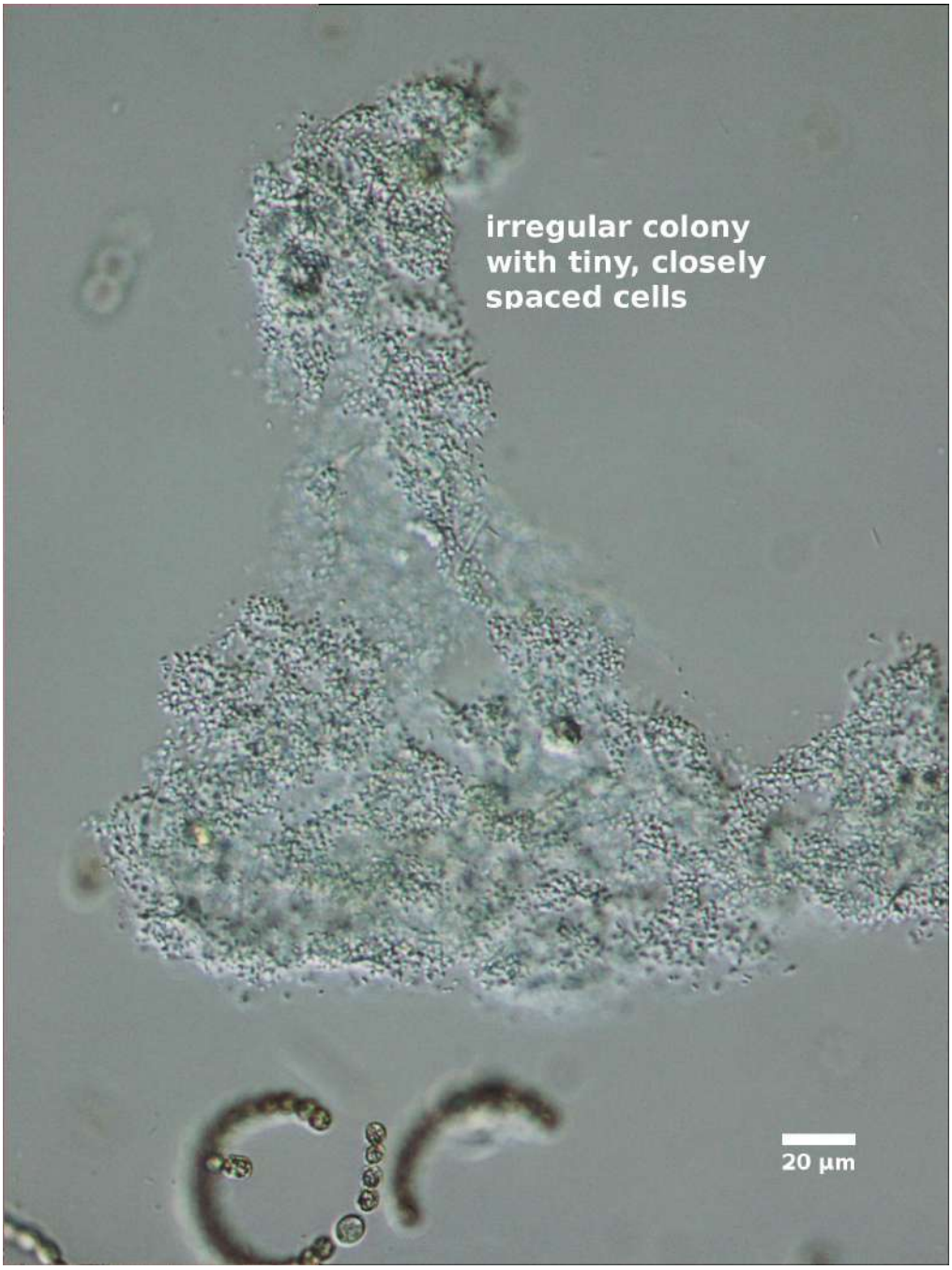


Figure 2.4: *Aphanocapsa holsatica* (200x DIC), Devil's Lake, Snohomish County, October 7, 2009.



Figure 2.5: *Aphanocapsa holsatica* (100x phase contrast), Lake Sixteen, IWS water quality sampling site, Skagit County, August 17, 2012.



Figure 2.6: *Aphanocapsa planctonica* (200x DIC), Lake Terrell, IWS water quality sampling site, Whatcom County, August 1, 2009.

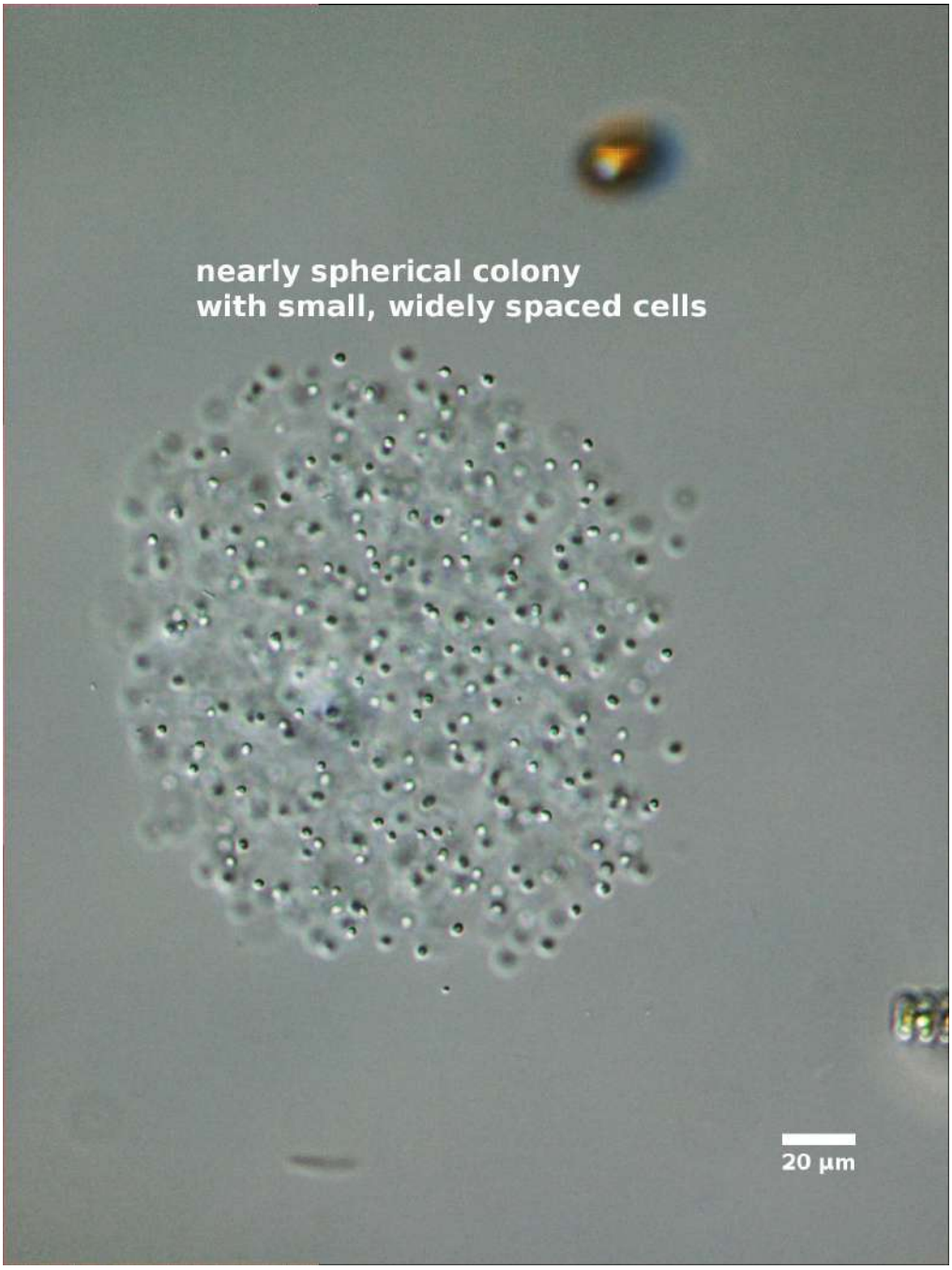


Figure 2.7: *Aphanocapsa planctonica* (200x DIC), Deer Lake, IWS water quality sampling site, Island County, October 6, 2009.

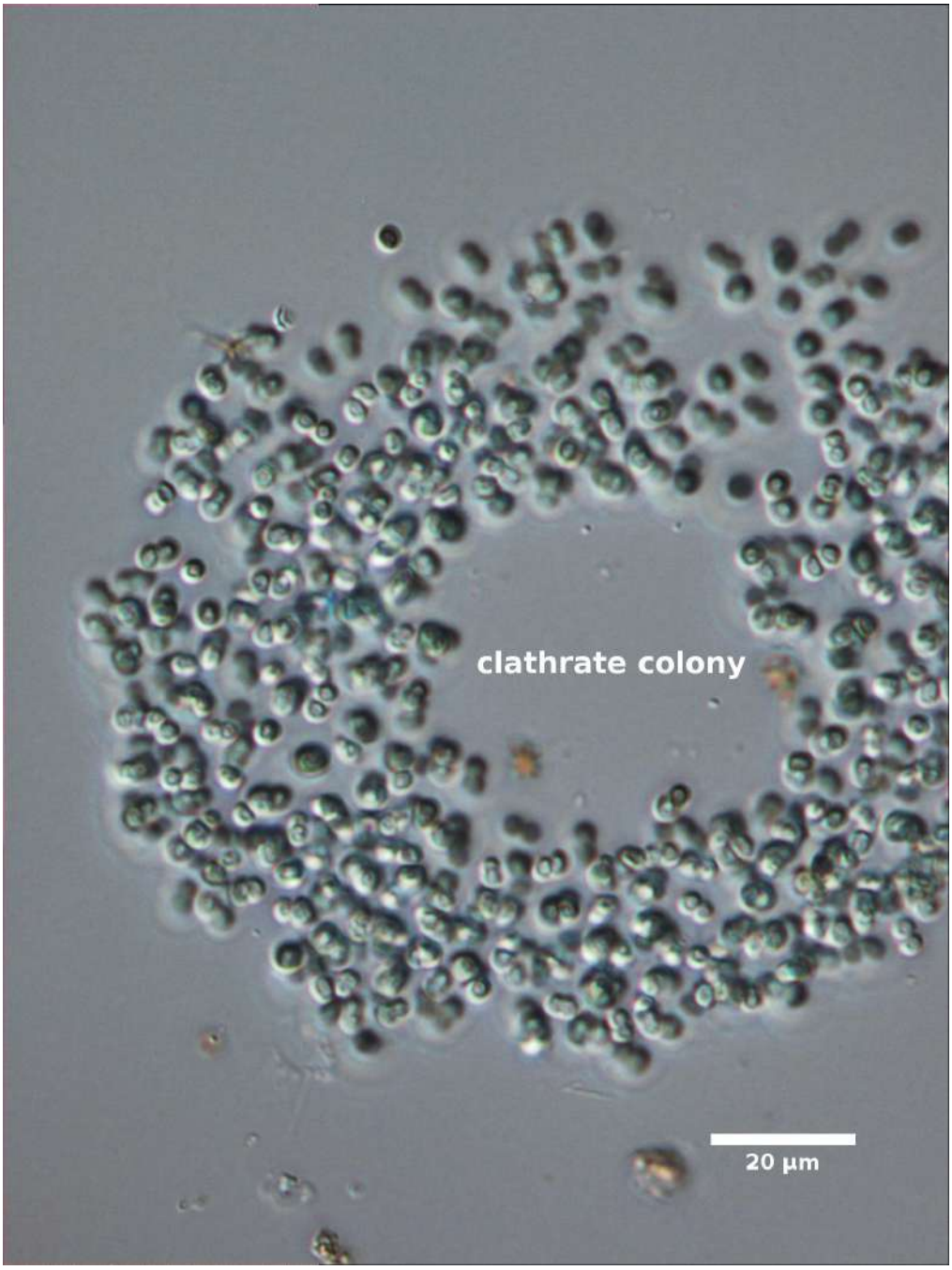


Figure 2.8: *Aphanocapsa* sp.1 (400x DIC), Lake Padden, IWS water quality sampling site, Whatcom County, October 21, 2009.



Figure 2.9: *Aphanocapsa* sp.1 (200x DIC), Lake Whatcom, IWS water quality sampling site, Whatcom County, September 17, 2009.

2.2 *Aphanothece* Nägeli

Local taxa
*Aphanothece clathrata*West & G. S. West
(=*Anathece clathrata* [West & G. S. West] Komárek, Kastovsky & Jezberová);
Aphanothece microscopica Nägeli;
Aphanothece stagnina (Sprengel) A. Braun

Abundance
Very common; may be present in large numbers but rarely forms blooms.

Local measurements		Width	Length	Biovolume[†]
Aphanothece clathrata	min	0.9 μm	2.0 μm	0.539 μm^3
cells (cyl + two $\frac{1}{2}$ spheres)[‡]	med	1.2 μm	2.6 μm	1.11 μm^3
	max	1.4 μm	3.3 μm	2.41 μm^3
Aphanothece microscopica	min	2.5 μm	3.4 μm	11.1 μm^3
cells (spheroid)	med	4.7 μm	6.1 μm	74.0 μm^3
	max	5.7 μm	7.9 μm	121 μm^3
Aphanothece stagnina	min	3.1 μm	4.6 μm	23.1 μm^3
cells (spheroid)	med	5.0 μm	7.6 μm	103 μm^3
	max	6.0 μm	9.1 μm	160 μm^3

[†]Calculated using original measurements rather than summary values.
[‡]Biovolume based on cylinder length (< cell length).

Description
Almost all of our lakes contain colonies of *Aphanothece*, *Aphanocapsa* (Section 2.1, page 28), and *Cyanodictyon* (Section 2.6, page 78). These three genera are quite similar in appearance, and are characterized by spherical, globular, or amorphous colonies containing many spherical, oval, elliptical, or rod-shaped cells surrounded by a colonial mucilage. *Aphanothece* cells range from oval to rod-shaped, but will often be spherical immediately after division (Figures 2.10–2.16). *Aphanocapsa* cells are spherical before dividing and slightly hemispherical following division. *Cyanodictyon* cells are very tiny, oval to rod-shaped, and form pseudofilaments (cells not joined end-to-end) inside twisted mucilaginous strands.

Aphanothece clathrata colonies are highly variable in shape, ranging from spherical to irregular or clathrate (net-like). The colony contains many tiny blue-gray or greenish-gray, rod-shaped cells that are embedded in a diffuse, clear mucilage (Figures 2.10–2.12). The cells are usually straight, but may also appear slightly bent.

Aphanothece microscopica is typically found associated with aquatic plants along the shorelines of oligotrophic, acidic (peaty) ponds and bogs (Komárek and Anagnostidis, 1998). The colonies are initially spherical, but can become large and irregularly shaped (Figures 2.13–2.14). The cells are bright blue-green, oval or broadly elliptical, and relatively large, despite the species name. The cells are embedded in a clear, diffuse colonial mucilage.

Aphanothece stagnina is characterized by large, olive-green or blue-green, oval or broadly elliptical cells embedded in a clear, colonial mucilage that has a distinct margin (Figures 2.15–2.16). The colonies are initially spherical, but can become very large (macroscopic) and irregularly shaped. This species closely resembles *Aphanothece microscopica*, but is associated with eutrophic lakes and ponds rather than oligotrophic, acidic peaty bogs and ponds.

Aphanothece microscopica and *Aphanothece stagnina* were separated based on collecting site because the cell sizes and colony descriptions for these two species are very similar (see Komárek and Anagnostidis, 1998). The specimens from oligotrophic, high elevation mountain lakes with peat bottoms were assigned to *Aphanothece microscopica*, while specimens from low elevation mesotrophic and eutrophic sites were assigned to *Aphanothece stagnina*.

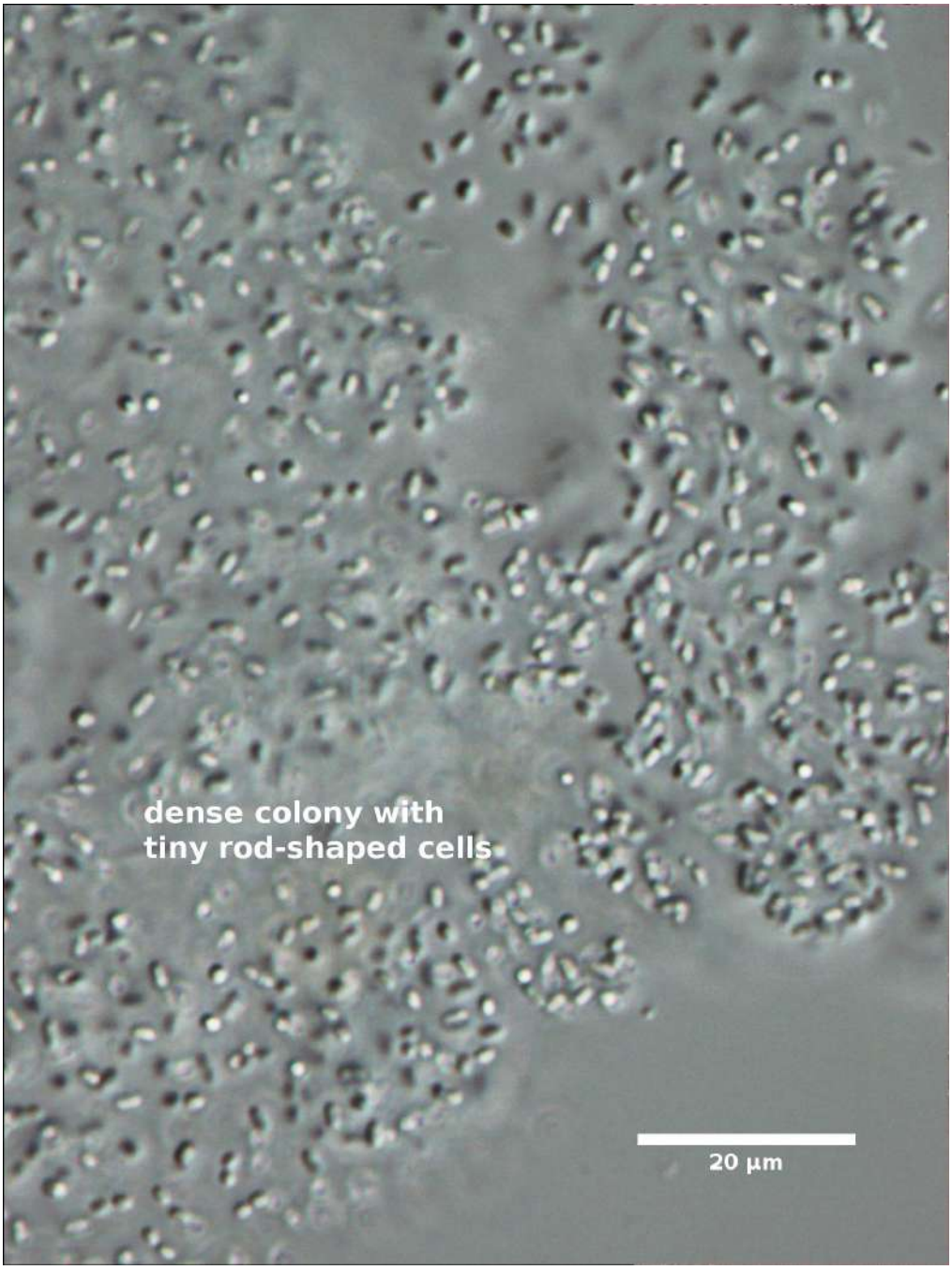


Figure 2.10: *Aphanothece clathrata* (600x DIC), Lake Louise, IWS water quality sampling site, Whatcom County, July 12, 2011.

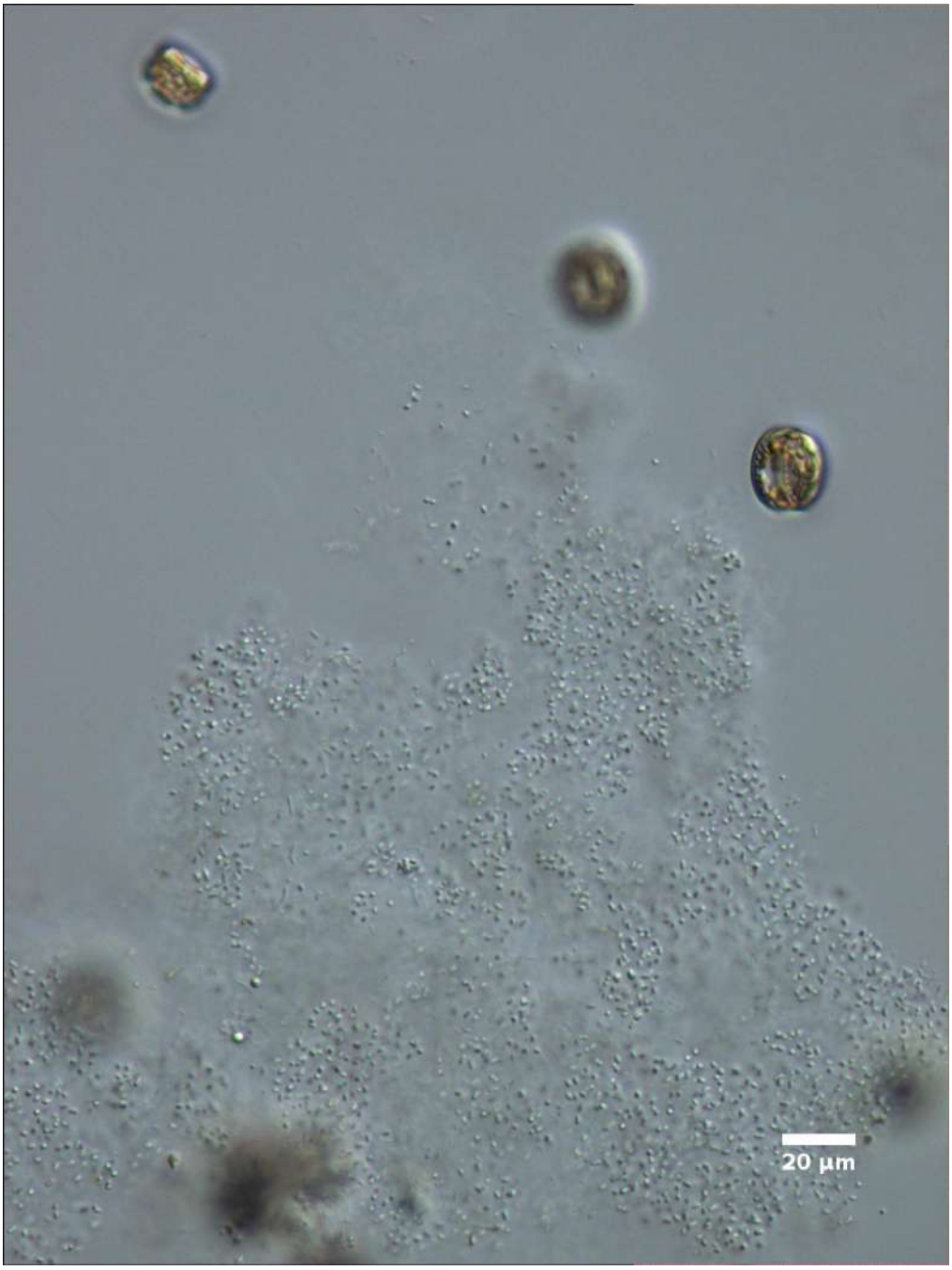


Figure 2.11: *Aphanothece clathrata* (200x DIC), Lake McMurray, IWS water quality sampling site, Skagit County, July 13, 2010.

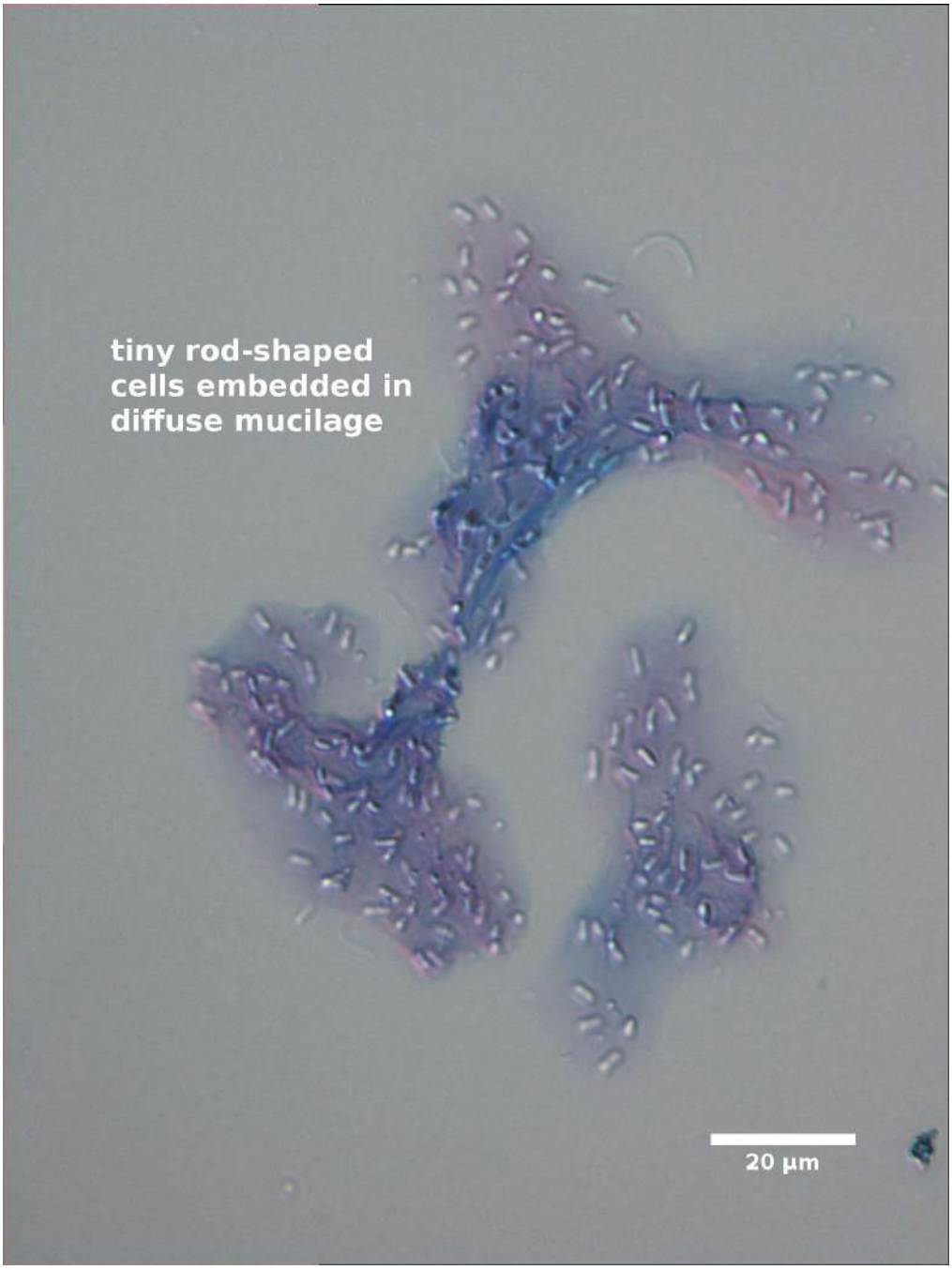


Figure 2.12: *Aphanothece clathrata* stained with methylene blue (400x DIC), Lake Whatcom, IWS water quality sampling site, Whatcom County, October 7, 2010.



Figure 2.13: *Aphanothece microscopica* (200x DIC), Picture Lake, IWS water quality sampling site, Whatcom County, August 31, 2011.

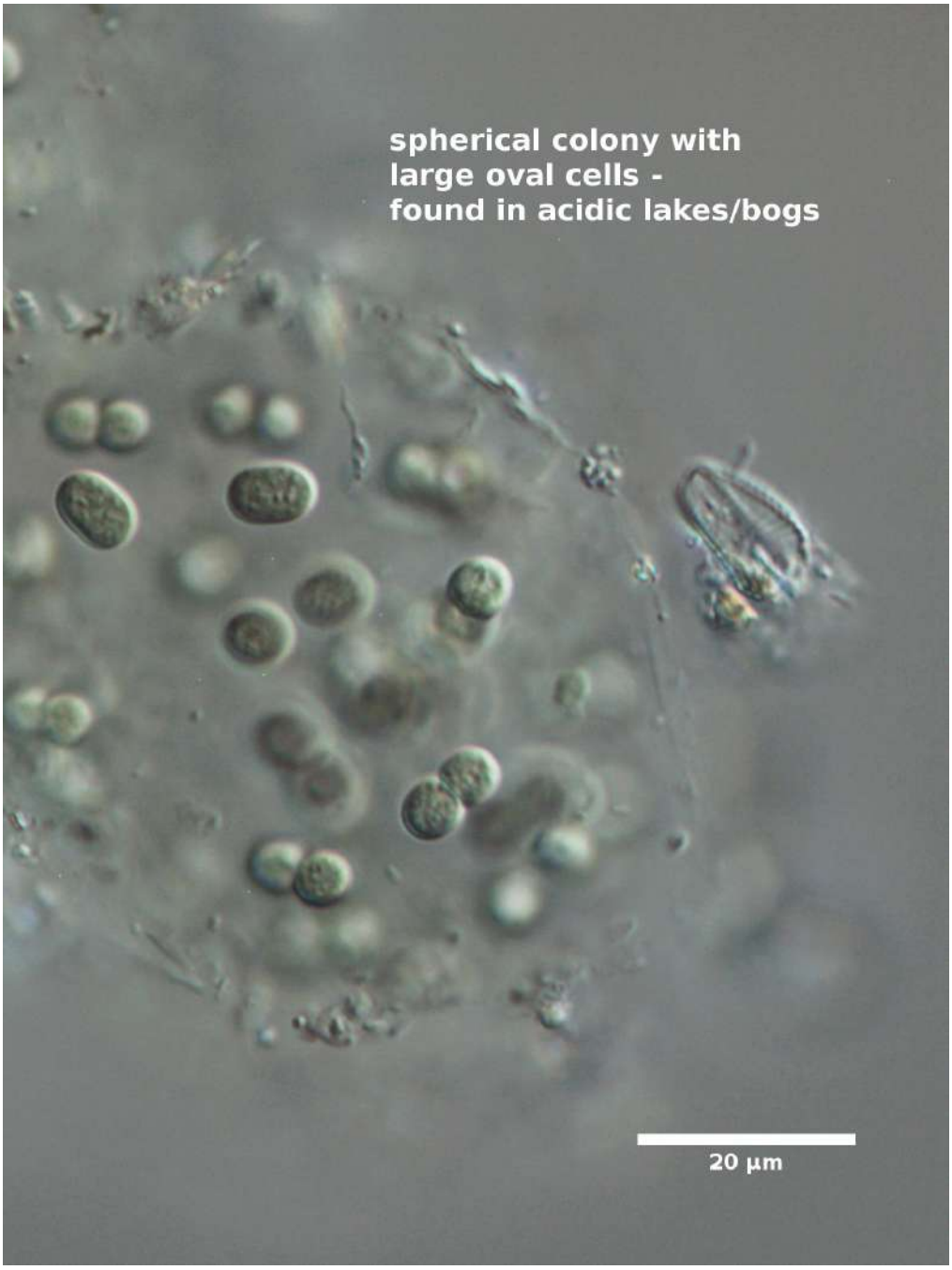


Figure 2.14: *Aphanothece microscopica* (600x DIC), Lower Watson Lake, North Cascades along Hwy 20, August 23, 2013.



Figure 2.15: *Aphanothece stagnina* (200x DIC), Ki Lake, IWS water quality sampling site, Snohomish County, July 11, 2013.

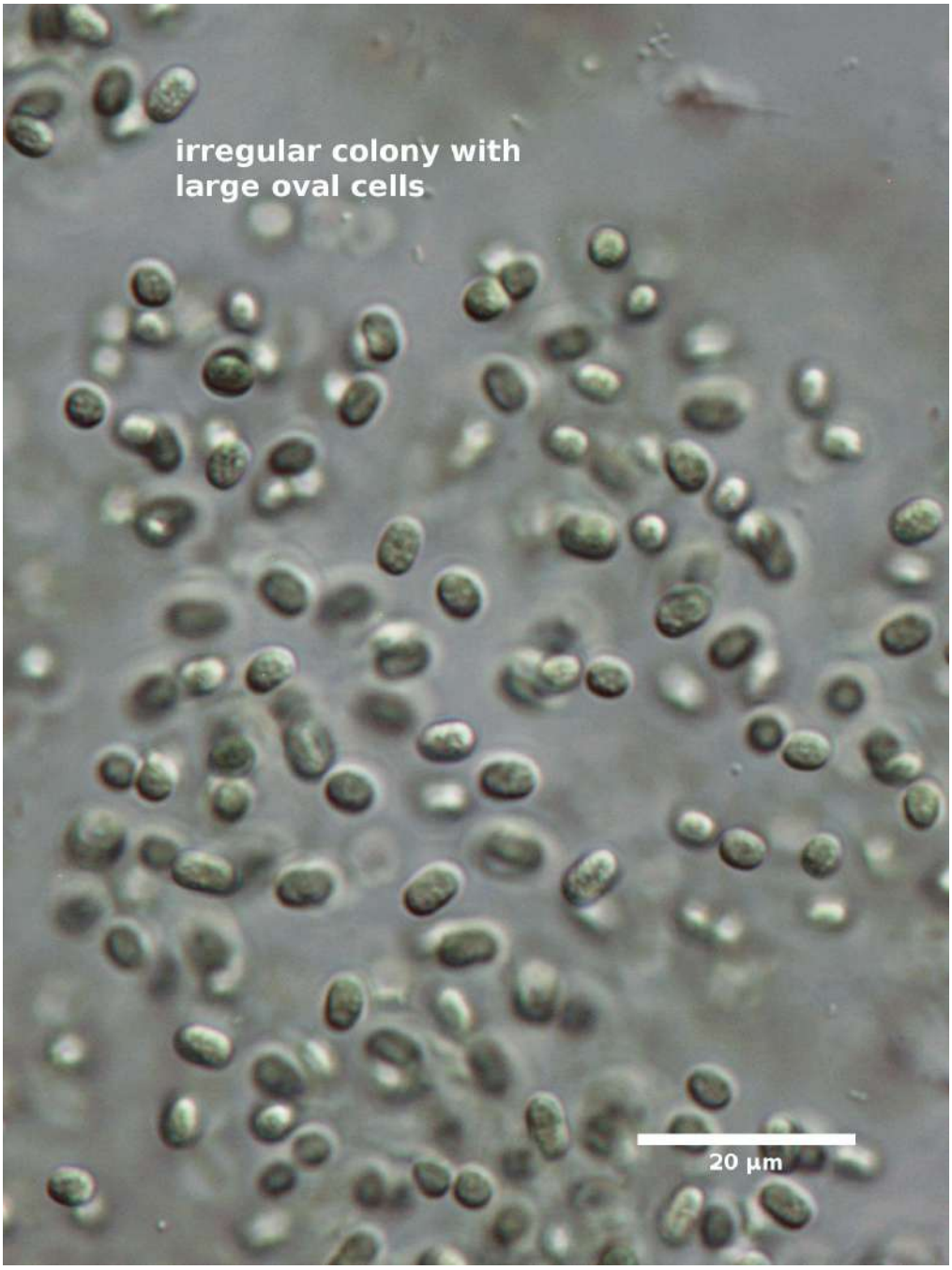


Figure 2.16: *Aphanothece stagnina* (600x DIC), Ki Lake, IWS water quality sampling site, Snohomish County, July 11, 2013.

2.3 *Chamaesiphon* A. Braun

Local taxa
Chamaesiphon confervicola A. Braun;
Chamaesiphon incrustans Grunow

Abundance
Infrequently collected in plankton samples; moderately common epiphyte.

Local measurements		Width	Length	Biovolume[†]
Chamaesiphon confervicola	min	5.9 μm	60.1 μm	1,920 μm^3
basal cells	med	7.2 μm	77.4 μm	2,790 μm^3
(cyl + two $\frac{1}{2}$ spheres)[‡]	max	9.9 μm	90.8 μm	3,590 μm^3
Chamaesiphon confervicola	min	4.0 μm	–	33.5 μm^3
exocytes (sphere)	med	4.7 μm	–	54.4 μm^3
	max	5.3 μm	–	78.0 μm^3
Chamaesiphon incrustans	min	1.8 μm	16.3 μm	47.5 μm^3
basal cells	med	2.2 μm	18.1 μm	54.7 μm^3
(cyl + two $\frac{1}{2}$ spheres)[‡]	max	2.8 μm	24.9 μm	117 μm^3
Chamaesiphon incrustans	min	2.1 μm	–	4.85 μm^3
exocytes (sphere)	med	2.3 μm	–	6.37 μm^3
	max	2.6 μm	–	9.20 μm^3

[†]Calculated using original measurements, not summary values.
[‡]Biovolume based on cylinder length (< cell length).

Description
Chamaesiphon is a fairly common epiphyte on filamentous algae and mosses (Figures 2.17–2.21). The basal cells are solitary, oval or cylindrical, and gray, blue-green, or pink. The basal cell divides transversely to form short pseudofilaments surrounded by a mucilaginous sheath that is open at the distal end. Cell division is asymmetric, resulting in the release of spherical exocytes (daughter cells) from the basal cell. The long basal cell distinguishes this genus from *Stichosiphon* (Section 2.17, page 173), which has a spherical basal cell that

resembles the spherical exocytes. *Chamaesiphon* and *Stichosiphon* also resemble *Cyanophanon* and *Geitleribactron* (Section 2.7, page 82), which do not have an open-ended sheath surrounding the pseudofilament.

Chamaesiphon confervicola is moderately common as an epiphyte on mosses, usually as a solitary pseudofilament, or in small groups (Figures 2.17–2.19). The basal cell is cylindrical or cub-shaped, narrowed near the point of attachment, and often curved. The exocytes are approximately spherical.

Chamaesiphon incrustans is much smaller than *Chamaesiphon confervicola*, but is otherwise similar is appearance (Figures 2.20–2.21). Although the individual basal cells are separated from each other, this species often forms dense groups, with each basal cell more or less parallel to the adjacent cells. The local specimens were attached to inorganic substrate rather than mosses, which is consistent with the substrates associated with this species (Komárek and Anagnostidis, 1998).

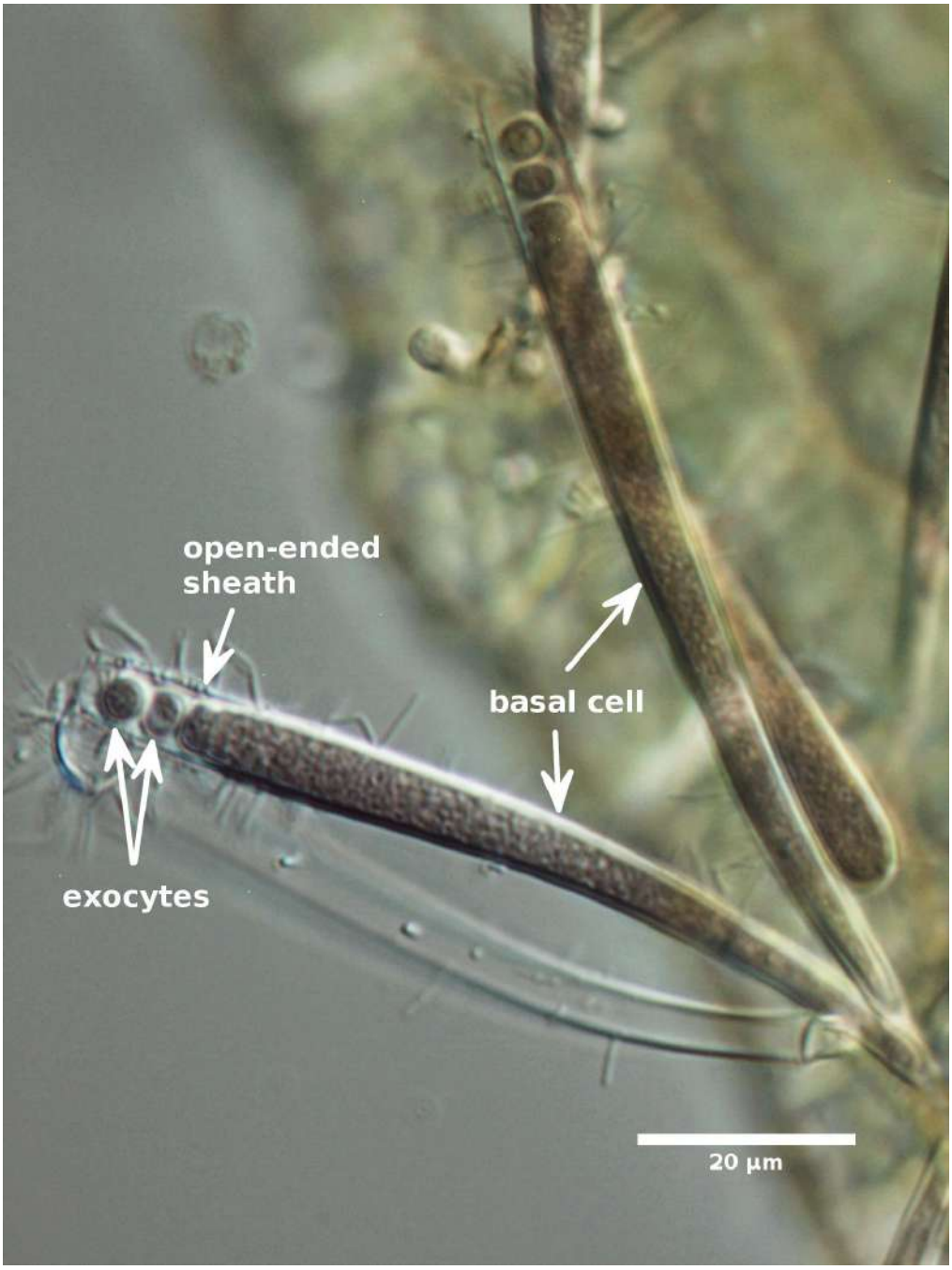


Figure 2.17: *Chamaesiphon confervicola* (600x DIC), trail to Lake Stewart (near Leavenworth), North Cascades along Hwy 2, September 12, 2013.

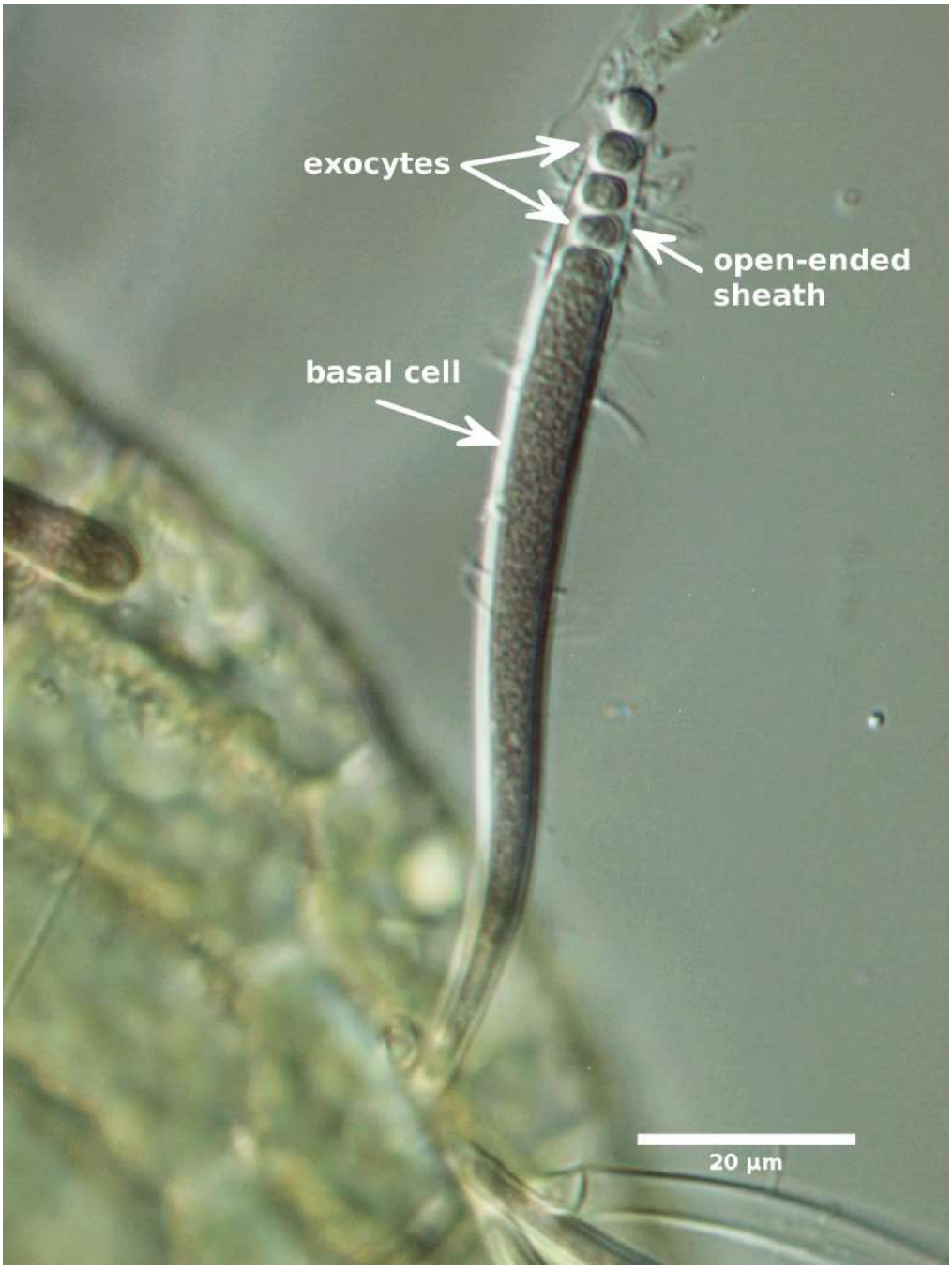


Figure 2.18: *Chamaesiphon confervicola* (600x DIC), trail to Lake Stewart (near Leavenworth), North Cascades along Hwy 2, September 12, 2013.

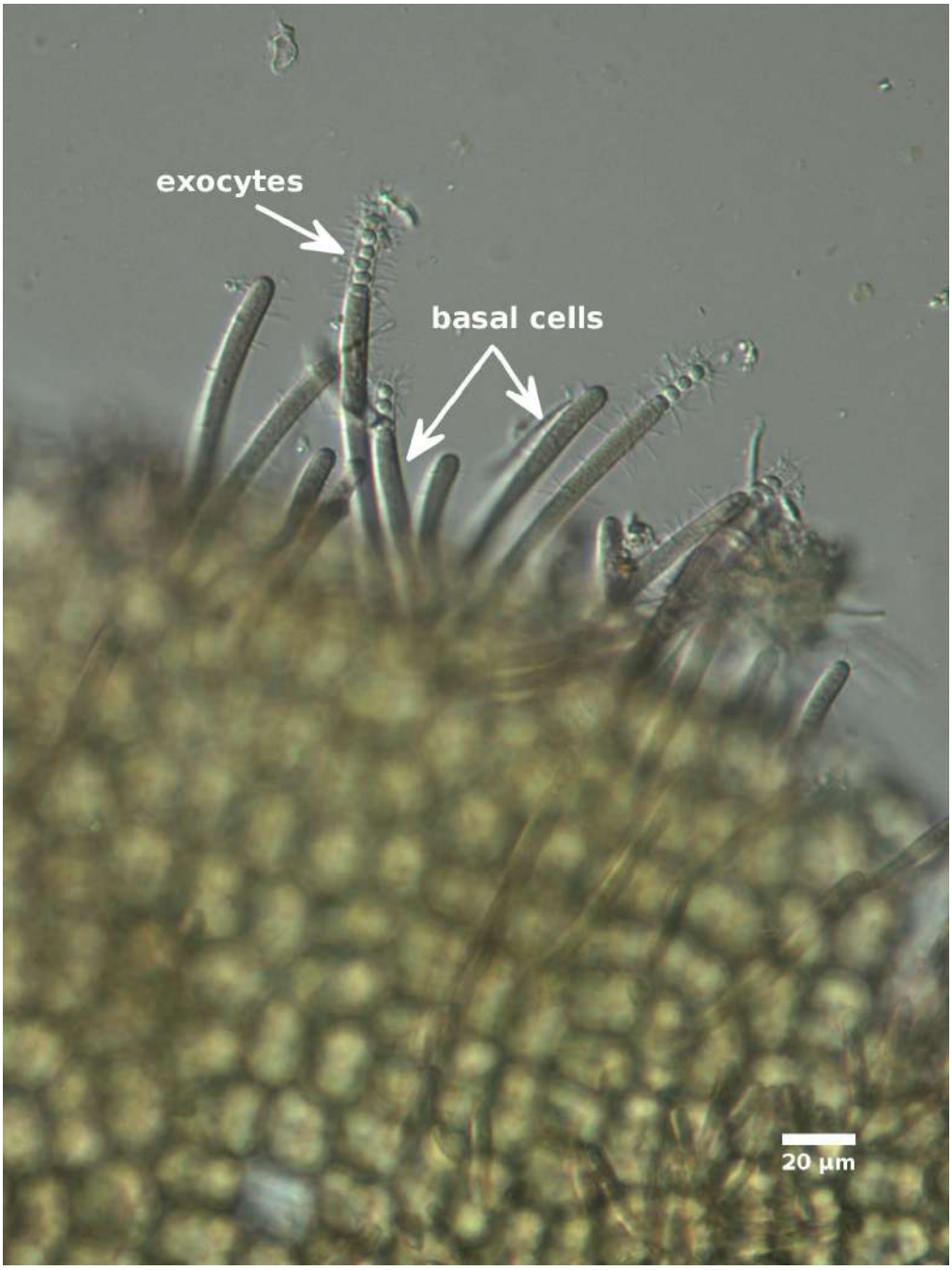


Figure 2.19: *Chamaesiphon confervicola* (200x DIC), trail to Lake Stewart (near Leavenworth), North Cascades along Hwy 2, September 12, 2013.

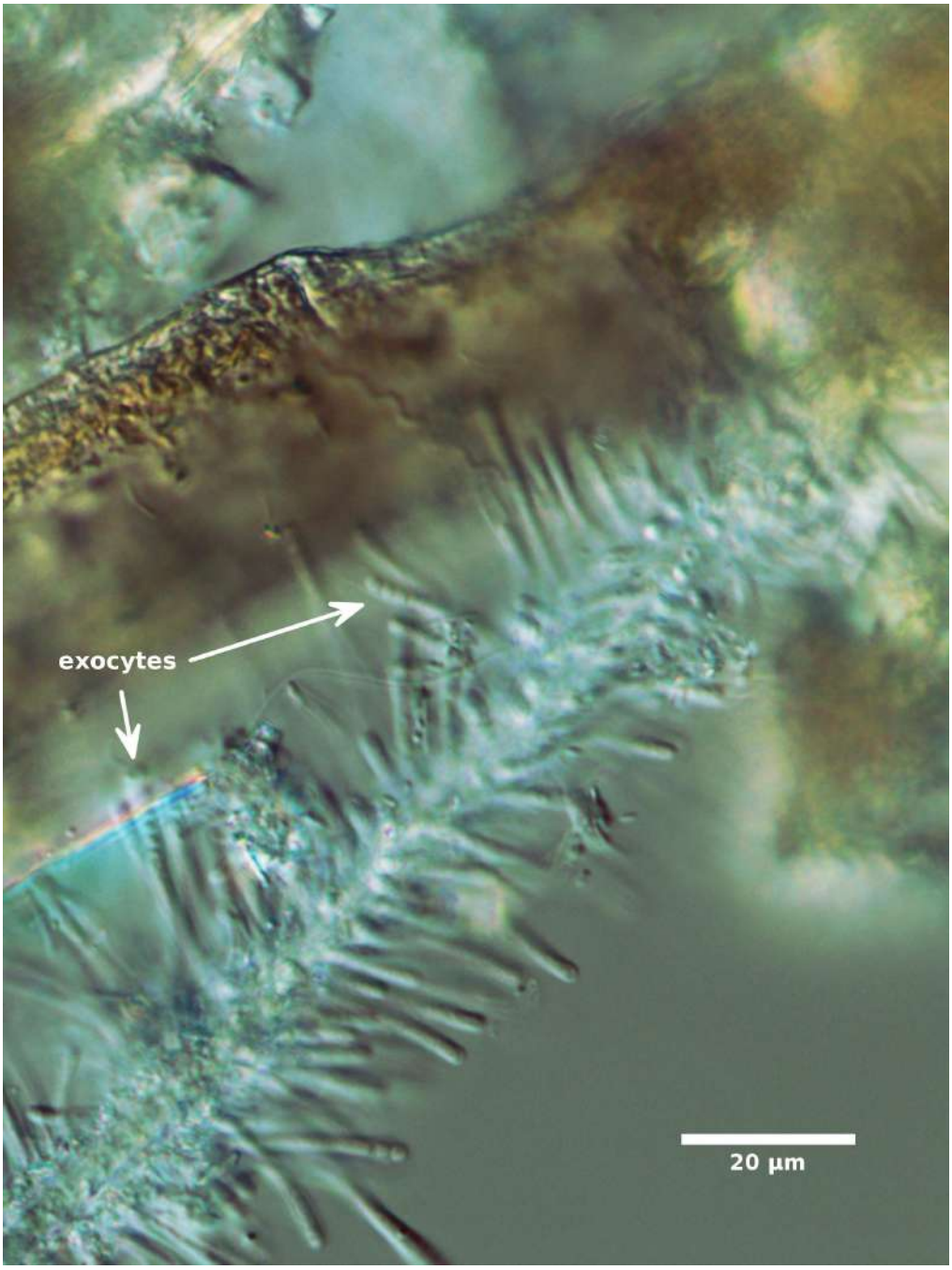


Figure 2.20: *Chamaesiphon incrustans* (600x DIC), Diablo Lake, Ross Lake National Recreational Area, July 8, 2015.

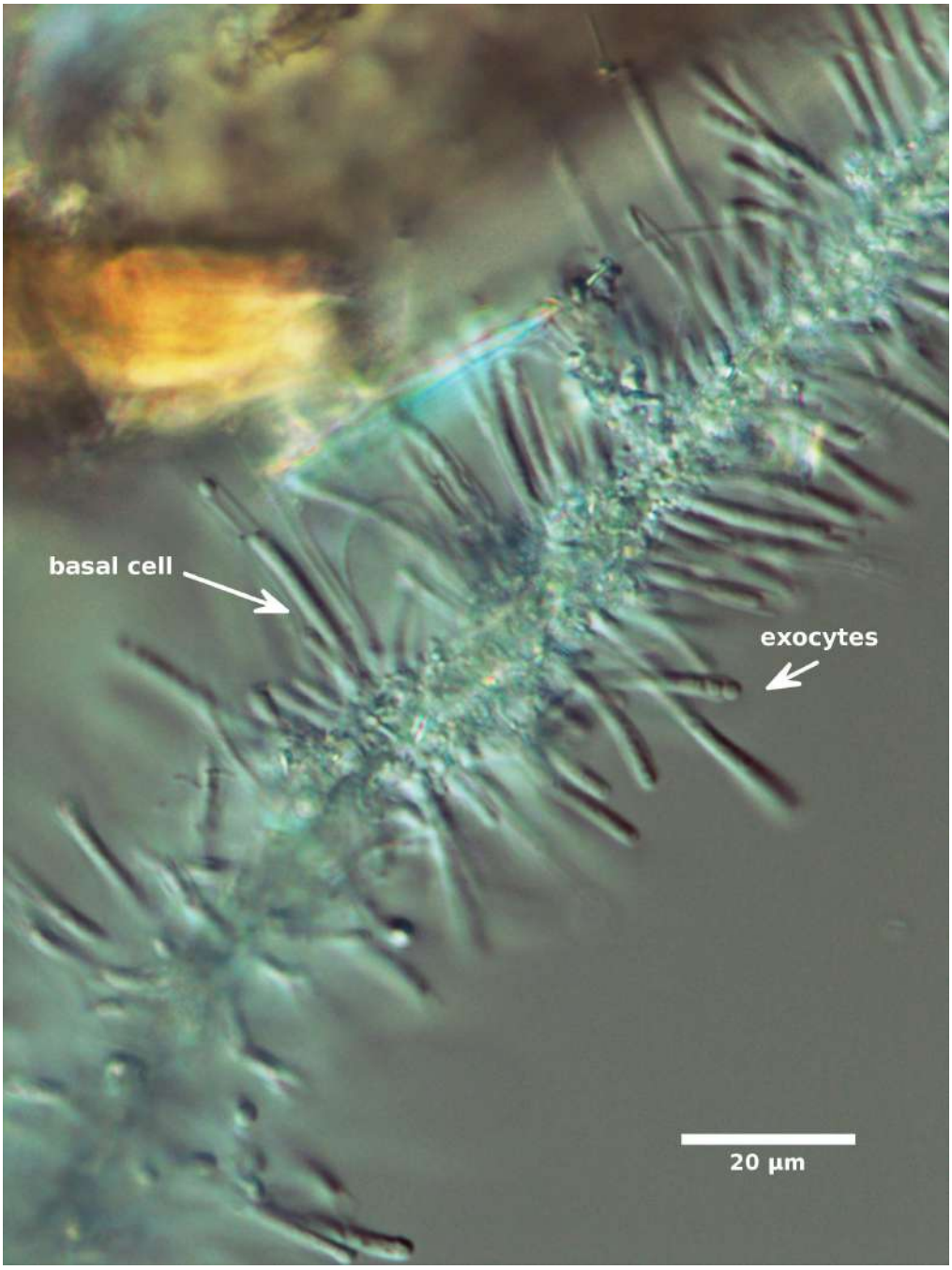


Figure 2.21: *Chamaesiphon incrustans* (600x DIC), Diablo Lake, Ross Lake National Recreational Area, July 8, 2015.

2.4 *Chroococcus* Nägeli

Local taxa
Chroococcus dispersus (Keissler) Lemmermann;
Chroococcus limneticus Lemmermann
(=*Limnococcus limneticus* [Lemmermann] Komárková, Jezberová, O. Komárek & Zapomelová);
Chroococcus limneticus var. *elegans* G. M. Smith;
Chroococcus minutus (Kützing) Nägeli;
Chroococcus turgidus (Kützing) Nägeli

Abundance
Moderately common; may be present in large numbers but rarely forms blooms.

Local measurements		Width	Length	Biovolume[†]
Chroococcus dispersus	min	3.4 μm	–	20.6 μm^3
cells (sphere)	med	4.0 μm	–	33.5 μm^3
	max	4.5 μm	–	47.7 μm^3
Chroococcus limneticus	min	6.1 μm	–	119 μm^3
cells (sphere)	med	8.8 μm	–	351 μm^3
	max	12.0 μm	–	905 μm^3
Chroococcus limneticus	min	15.0 μm	–	1,770 μm^3
var. *elegans*	med	16.4 μm	–	2,290 μm^3
cells (sphere)	max	18.8 μm	–	3,480 μm^3
Chroococcus minutus	min	6.9 μm	6.6 μm	227 μm^3
cells (spheroid)	med	10.1 μm	9.1 μm	465 μm^3
	max	15.4 μm	11.1 μm	1,150 μm^3
Chroococcus turgidus	min	9.7 μm	15.9 μm	783 μm^3
cells (spheroid)	med	15.7 μm	23.3 μm	3,120 μm^3
	max	24.3 μm	35.4 μm	10,900 μm^3

[†]Calculated using original measurements, not summary values.

Description

Chroococcus colonies are small, usually in multiples of 2–4, and occasionally occur as solitary cells (Figures 2.22–2.35). The colonies are surrounded by mucilaginous envelopes that may be distinct and concentrically layered or diffuse and difficult to see unless stained. The species of *Chroococcus* are subdivided by whether recently divided cells return to a spherical shape prior to the next division vs. species that begin the next division while the cells are still in hemispherical pairs. Some *Chroococcus* species can be difficult to distinguish from *Eucapsis* (Section 2.9, page 101), which divided very regularly in three planes to form cubical stacks of spherical cells.

Chroococcus dispersus cells are spherical, relatively small, and pale blue-green or olive-green, with a homogeneous cell content (Figures 2.22–2.24). The cells form small, compact groups of about 8–16 cells that do not show an obvious 4x arrangement. The cell groups may form larger assemblages enclosed in a common mucilage, with each group clearly separated from the other groups. Komárek and Anagnostidis (1998) describe the species as being planktonic in oligotrophic or mesotrophic lakes, which is consistent with the samples collected on multiple occasions in Vogler Lake.

Chroococcus limneticus is a highly variable species, with spherical, blue-green, olive-green, or yellow-green cells that are slightly granular (Figures 2.25–2.27). The cells form irregular colonies that do not display an obvious 4x cell arrangement. The colonies are surrounded by a clear, indistinct mucilage that may not be visible without staining. *Chroococcus limneticus* cells are slightly larger than *Chroococcus dispersus*, and do not form large aggregations of separate 8–16 cell subgroups. The samples from Lone Lake fit Komárek and Anagnostidis (1998) description for *Chroococcus limneticus* var. *elegans*, which has larger cells that form slightly more distinct 2–4 cell groups (Figures 2.28–2.29).

Chroococcus minutus is a very heterogeneous species that forms 2–8 cell planktonic colonies of spherical or hemispherical cells enclosed in a clear, but distinct mucilage layer (Figures 2.30–2.32). The mucilage may appear unstriated, but staining with methylene blue often reveals distinct striations surrounding the cells or cell groups. The cells are pale blue-green or olive-green, and usually appear to be slightly granular. Some colonies may form cubical arrangements that resemble *Eucapsis* (Section 2.9, page 101), but examining several colonies will reveal the heterogeneous morphology associated with this species.

Chroococcus turgidus forms groups of 2–8 cells (often 2) surrounded by a firm, distinct mucilage layer (Figures 2.33–2.35). The individual cells are spherical or hemispherical, bright blue-green or olive-green, and very large ($\geq$8 μm diameter). When *Chroococcus turgidus* is dividing rapidly the daughter cells do not return to a spherical shape, and will be hemispherical or in quarters. This species is associated with stagnant, peaty water and bogs. Most of the local specimens have been collected in standing water near high elevation lakes, and it will occasionally form visible blooms along boggy portions of mountain trails.

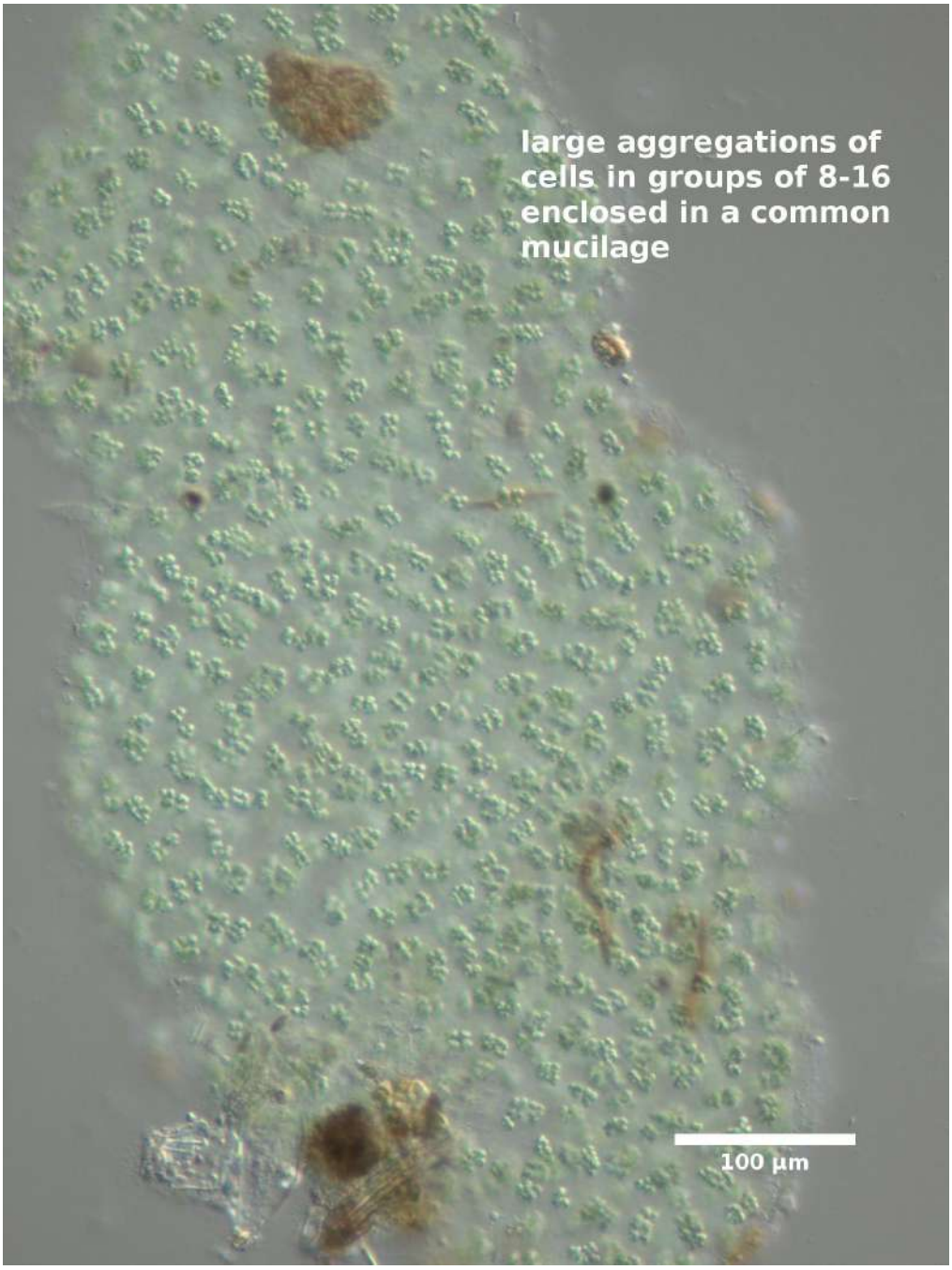


Figure 2.22: *Chroococcus dispersus* (100x DIC), Vogler Lake, IWS water quality sampling site, Skagit County, August 2, 2012.

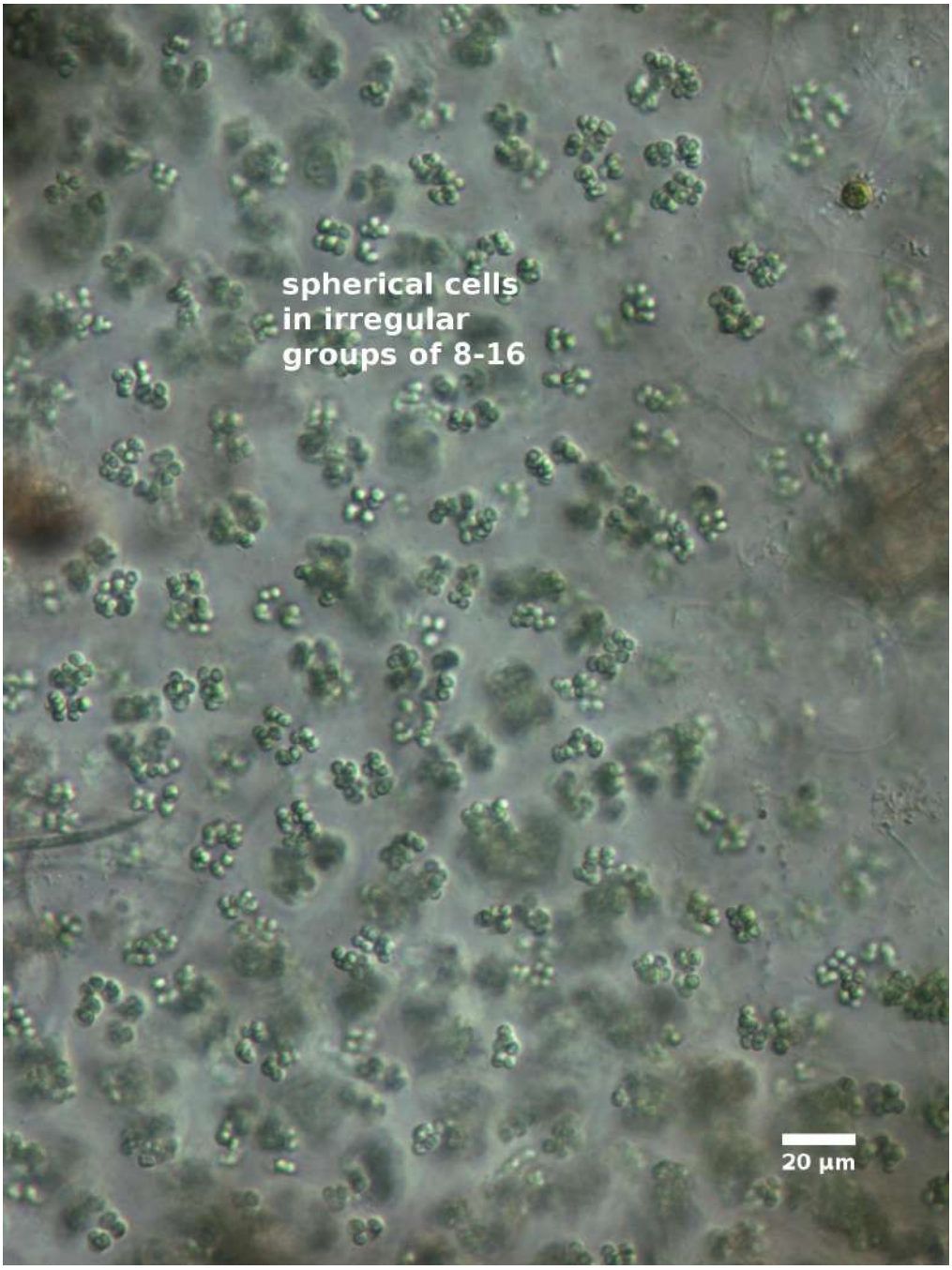


Figure 2.23: *Chroococcus dispersus* (200x DIC), Vogler Lake, IWS water quality sampling site, Skagit County, August 26, 2013.



Figure 2.24: *Chroococcus dispersus* (400x DIC), Vogler Lake, IWS water quality sampling site, Skagit County, September 9, 2009.

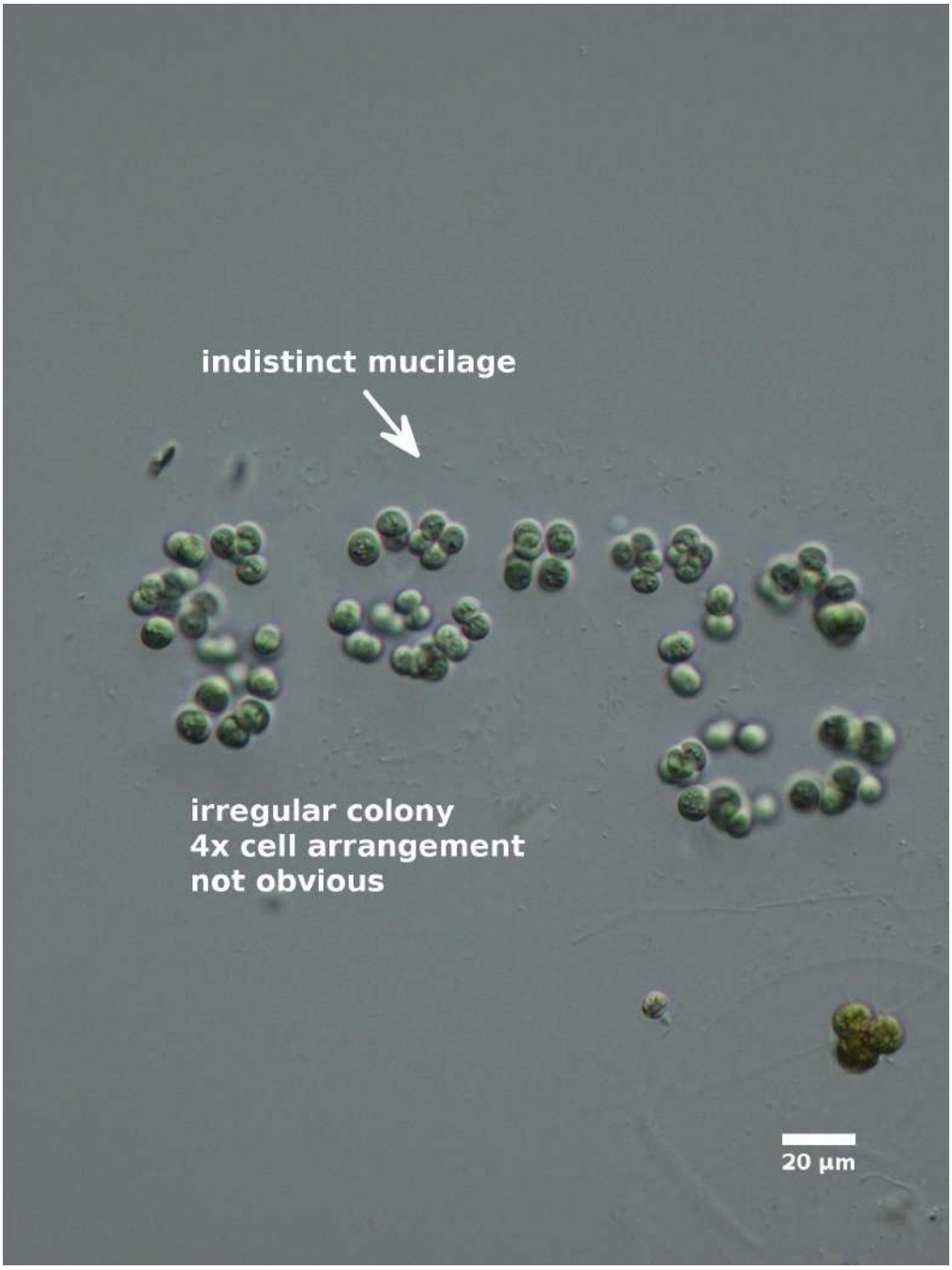


Figure 2.25: *Chroococcus limneticus* (200x DIC), Lake Terrell IWS water quality sampling site, Whatcom County, May 31, 2013.



Figure 2.26: *Chroococcus limneticus* (200x phase contrast), Devil's Lake, Snohomish County, October 7, 2009.



Figure 2.27: *Chroococcus limneticus* (600x DIC), Devil's Lake, Snohomish County, October 7, 2009.



Figure 2.28: *Chroococcus limneticus* var. *elegans* (200x DIC), Lone Lake, IWS water quality sampling site, Island County, July 22, 2013.

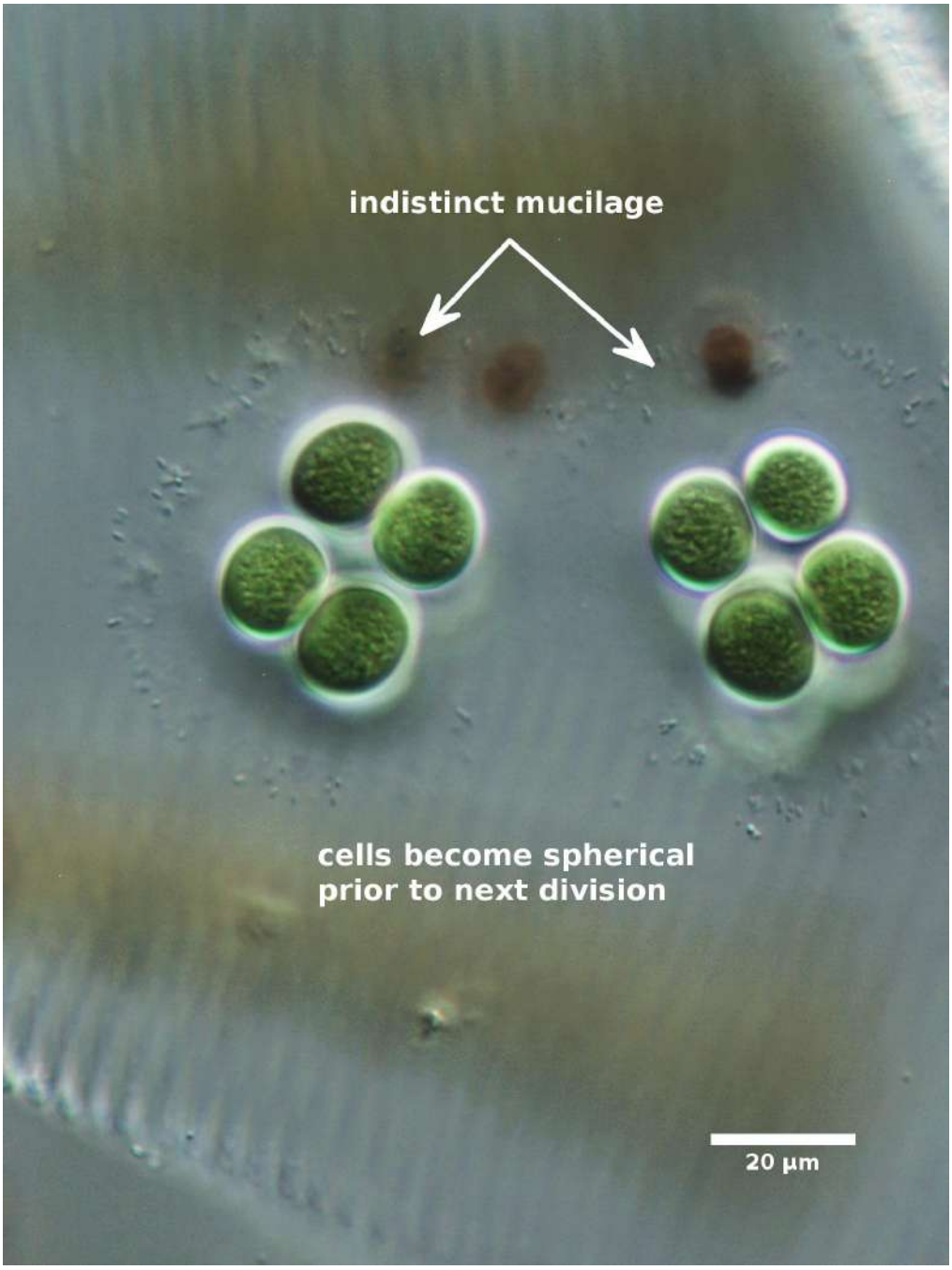


Figure 2.29: *Chroococcus limneticus* var. *elegans* (400x DIC), Lone Lake, IWS water quality sampling site, Island County, July 22, 2013.

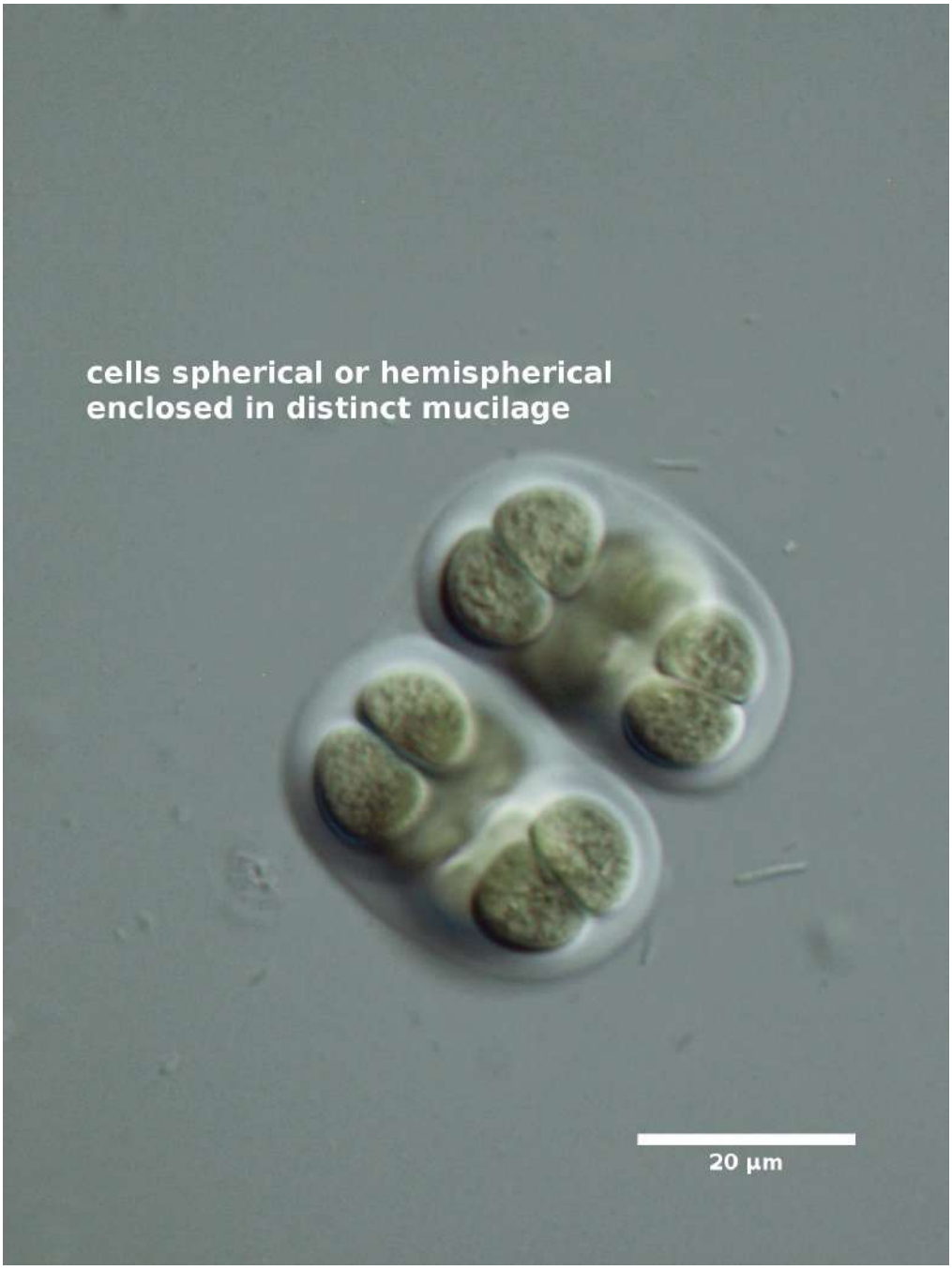


Figure 2.30: *Chroococcus minutus* (600x DIC), Lake Cavanaugh, IWS water quality sampling site, Skagit County, August 16, 2012.

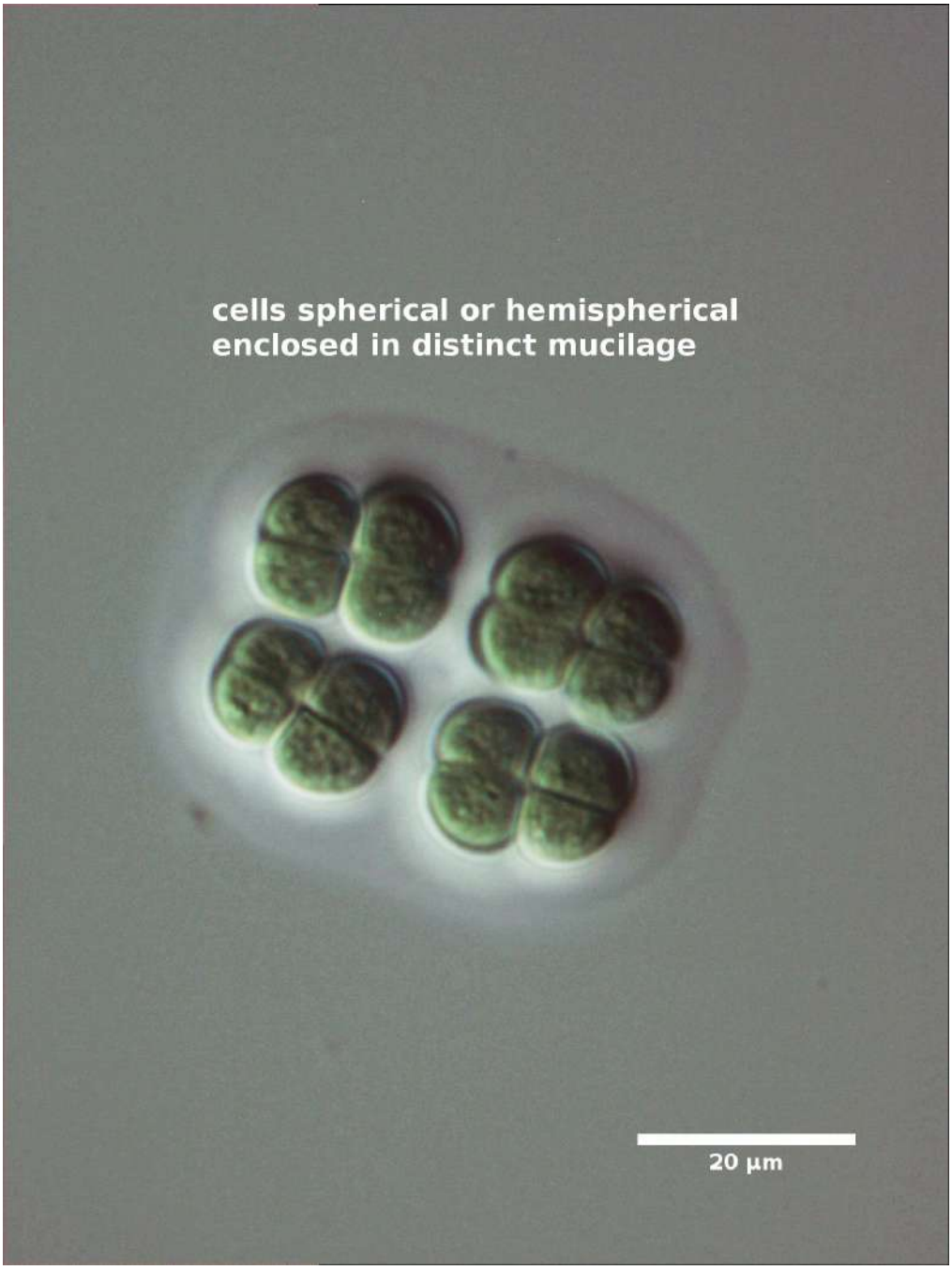


Figure 2.31: *Chroococcus minutus* (600x DIC), Judy Reservoir, IWS water quality sampling site, Skagit County, July 6, 2011.

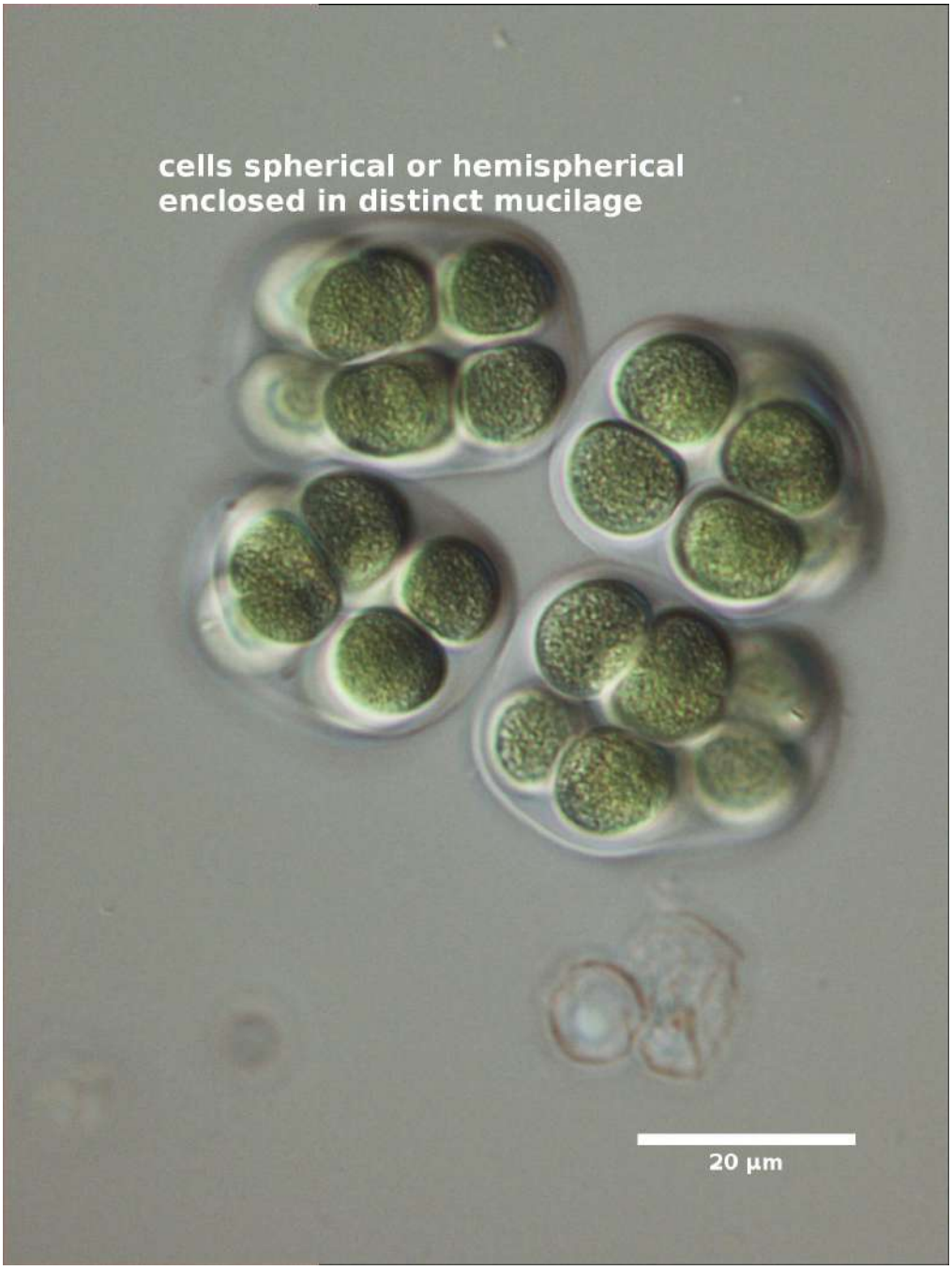


Figure 2.32: *Chroococcus minutus* (600x DIC), Judy Reservoir, IWS water quality sampling site, Skagit County, July 6, 2011.

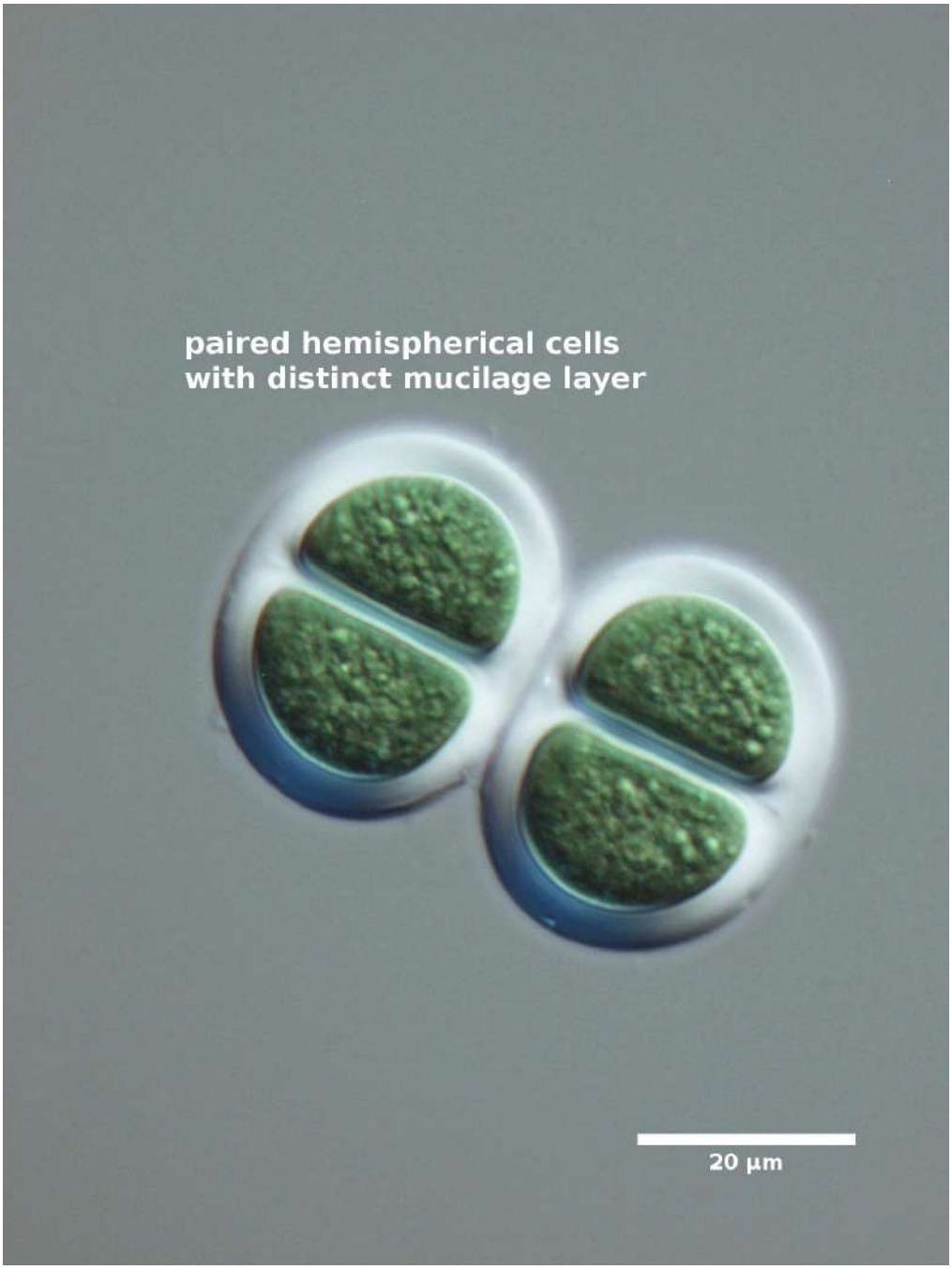


Figure 2.33: *Chroococcus turgidus* (600x DIC), boggy seep on trail to Lake Anderson, North Cascades along Hwy 20, September 3, 2012.



Figure 2.34: *Chroococcus turgidus* (600x DIC), Lake Evan, IWS water quality sampling site, Snohomish County, August 3, 2012.

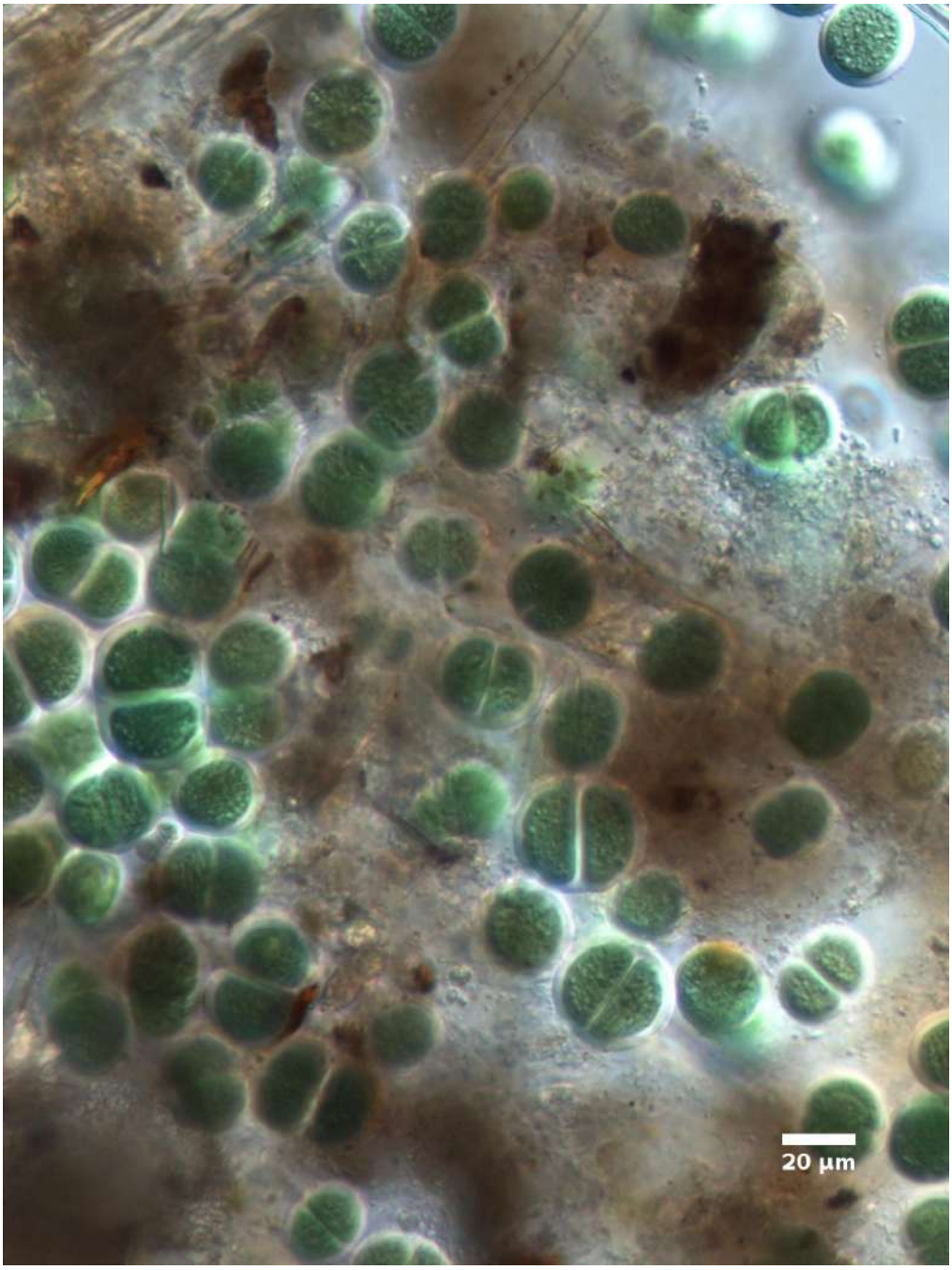


Figure 2.35: *Chroococcus turgidus* (200x DIC), boggy seep on trail to Lake Anderson, North Cascades along Hwy 20, September 3, 2012.

2.5 *Coelosphaerium* Nägeli

Local taxon
Coelosphaerium aerugineum Lemmermann?

Abundance
Moderately common; rarely present in large numbers.

Local measurements		Width	Length	Biovolume[†]
Coelosphaerium aerugineum?	min	2.6 μm	3.2 μm	12.0 μm^3
cells (spheroid)	med	3.4 μm	3.8 μm	22.7 μm^3
	max	5.0 μm	6.7 μm	87.7 μm^3
Coelosphaerium aerugineum?	min	26.5 μm	27.3 μm	–
colonies[‡]	med	34.2 μm	38.9 μm	–
	max	48.4 μm	49.3 μm	–

[†]Calculated using original measurements, not summary values.
[‡]Colony biovolume can be estimated using a spherical or spheroid shape.

Description
Coelosphaerium colonies are spherical or oval, and contain a single peripheral layer of cells around a hollow colony center (Figures 2.36–2.39). The colony may be surrounded by a diffuse mucilage layer, but the mucilage is rarely visible without staining. The individual cells are spherical (hemispherical after division) and closely arranged, but not densely packed in the peripheral layer, so there are often small spaces between cells. The cells are not formed at the end of radiating mucilage strands, which distinguishes *Coelosphaerium* from *Gomphosphaeria* (Section 2.11, page 111), *Snowella* (Section 2.16, page 168), and *Woronichinia* (Section 2.18, page 181), all of which have cells that form at the ends of mucilage strands that radiate from the colony center.

The local specimens are tentatively identified as *Coelosphaerium aerugineum* based on the size and general appearance of the cells, which are slightly granular and pale or bright blue-green. This species is common in mesotrophic and eutrophic lakes in North America (Komárek and Anagnostidis, 1998). A similar species, *Coelosphaerium kuetzingianum* Nägeli, is found in similar habitats, but

has smaller cells (Komárek and Anagnostidis, 1998; Wehr, et al., 2015). The local specimens occasionally display a lavender variation, which is usually present in the same sample with the more common blue-green variation (Figures 2.38–2.39). The lavender variation is presumably the same species because all other cell and colony features are similar to the blue-green variation.



Figure 2.36: *Coelosphaerium aerugineum*? (600x DIC), Lake Terrell, IWS water quality sampling site, Whatcom County, July 31, 2013.



Figure 2.37: *Coelosphaerium aerugineum*? (600x DIC), Picture Lake, IWS water quality sampling site, Whatcom County, August 17, 2012.

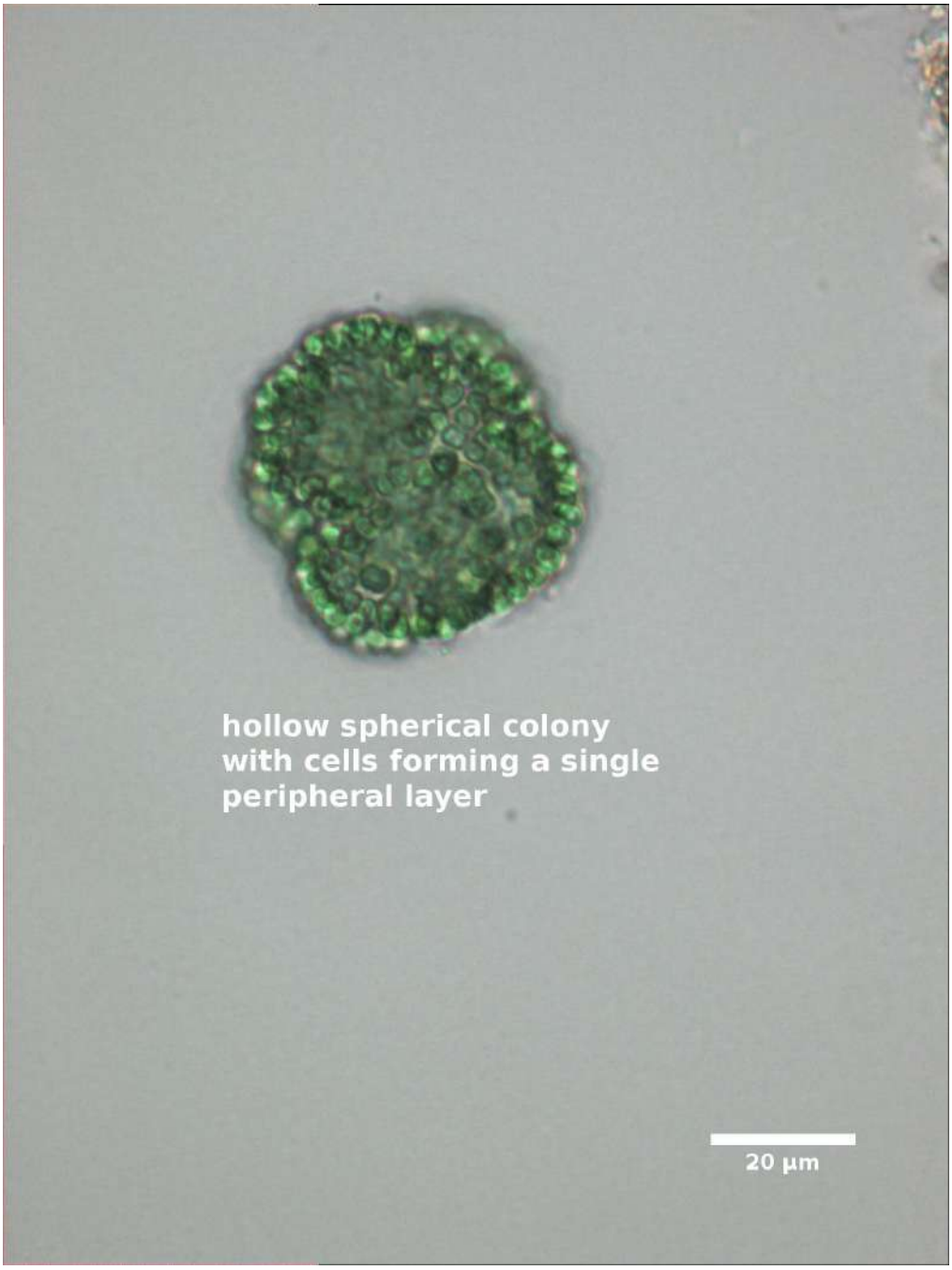


Figure 2.38: *Coelosphaerium aerugineum*? (400x brightfield), Lake Terrell, IWS water quality sampling site, Whatcom County, April 23, 2008.



Figure 2.39: *Coelosphaerium aerugineum*? (600x DIC), Lake Terrell, IWS water quality sampling site, Whatcom County, April 23, 2008.

2.6 *Cyanodictyon* A. Pascher

Local taxon
Cyanodictyon planctonicum Meyer

Abundance
Moderately common, but easily overlooked.

Local measurements		Width	Length	Biovolume[†]
Cyanodictyon planctonicum	min	1.0 μm	1.7 μm	0.226 μm^3
cells (cyl + two $\frac{1}{2}$ spheres)[‡]	med	1.2 μm	2.2 μm	0.656 μm^3
	max	1.5 μm	3.5 μm	1.81 μm^3

[†]Calculated using original measurements, not summary values.
[‡]Biovolume based on cylinder length ($<$ cell length).

Description
Almost all of our lakes contain colonies of *Cyanodictyon*, *Aphanocapsa* (Section 2.1, page 28), and *Aphanothece* (Section 2.2, page 39). These three genera are quite similar in appearance, and are characterized by spherical, globular, or amorphous colonies containing many spherical, oval, elliptical, or rod-shaped cells surrounded by a colonial mucilage. *Cyanodictyon* cells are oval to rod-shaped, and form twisted pseudofilaments inside mucilaginous strands. *Aphanocapsa* cells are spherical before dividing and slightly hemispherical following division. *Aphanothece* cells range from oval to rod-shaped, but will often be spherical immediately after division.

Cyanodictyon planctonicum forms amorphous, three-dimensional colonies made up of many gelatinous pseudofilaments (Figures 2.40–2.42). The individual cells are oval or rod-shaped and yellowish, pale blue-green, or gray. Although the pseudofilament structure is apparent when you look at individual strands (e g., Figure 2.42), the general colony appearance resembles *Aphanothece* (Section 2.2). *Cyanodictyon planctonicum* is very common in Lake Whatcom and other local lakes during summer and early fall, but its small size and gray coloration makes it easy to overlook.



Figure 2.40: *Cyanodictyon planctonicum* (400x DIC), Lake Whatcom, IWS water quality sampling site, Whatcom County, July 31, 2009.

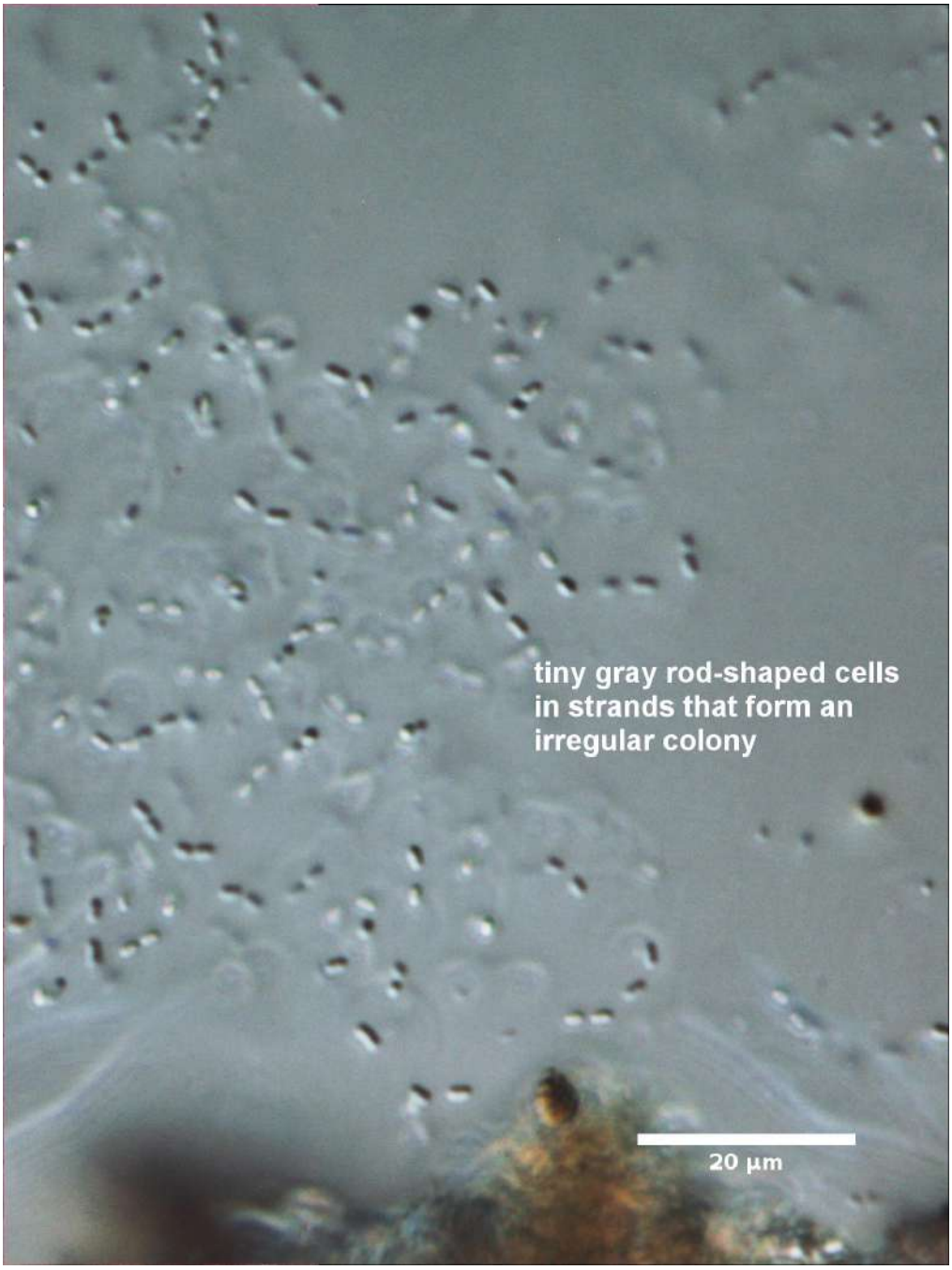


Figure 2.41: *Cyanodictyon planctonicum* (600x DIC), Lake Erie, IWS water quality sampling site, Skagit County, August 25, 2009.



Figure 2.42: *Cyanodictyon planctonicum* (600x DIC), Lake Whatcom, IWS water quality sampling site, Whatcom County, October 5, 2011.

2.7 *Cyanophanon* Geitler

Local taxa
Cyanophanon minus Geitler;
Cyanophanon mirabile Geitler;
Cyanophanon sp.1

Abundance
Infrequently collected in plankton samples; moderately common epiphyte.

Local measurements		Width	Length	Biovolume[†]
Cyanophanon minus	min	2.8 μm	12.0 μm	63.3 μm^3
basal cells	med	3.0 μm	13.2 μm	63.8 μm^3
(cyl + two $\frac{1}{2}$ spheres)[‡ §]	max	3.2 μm	14.5 μm	64.2 μm^3
Cyanophanon minus	min	1.8 μm	2.1 μm	4.82 μm^3
exocytes (spheroid)	med	2.1 μm	2.3 μm	5.31 μm^3
	max	2.3 μm	2.9 μm	6.65 μm^3
Cyanophanon mirabile	min	1.8 μm	6.7 μm	14.2 μm^3
basal cells	med	2.0 μm	13.1 μm	27.2 μm^3
(cyl + two $\frac{1}{2}$ spheres)[‡]	max	2.5 μm	70.0 μm	306 μm^3
Cyanophanon mirabile	min	3.4 μm	2.3 μm	13.9 μm^3
exocytes (spheroid)	med	3.7 μm	2.5 μm	17.4 μm^3
	max	4.0 μm	2.7 μm	22.6 μm^3
Cyanophanon sp.1	min	1.0 μm	3.0 μm	1.47 μm^3
basal cells	med	1.2 μm	3.7 μm	1.87 μm^3
(cyl + two $\frac{1}{2}$ spheres)[‡]	max	1.2 μm	4.1 μm	2.83 μm^3
Cyanophanon sp.1	min	1.1 μm	–	0.697 μm^3
exocytes (sphere)	med	1.2 μm	–	0.905 μm^3
	max	1.3 μm	–	1.15 μm^3

[†]Calculated using original measurements, not summary values.
[‡]Biovolume based on cylinder length ($<$ cell length).
[§]Biovolume estimates based on $<$5 cells.

Description

All *Cyanophanon* species are tiny, inconspicuous epiphytes that form short pseudofilaments attached to algae and mosses (Figures 2.43–2.48). The pseudofilaments consist of pale gray or blue-green basal cells that release more or less spherical exocytes (daughter cells). *Cyanophanon* is very similar in appearance to *Chamaesiphon* (Section 2.3, page 48); both have enlarged, club-shaped basal cells and spherical exocytes. The primary difference is that *Cyanophanon* pseudofilaments are not enclosed in an open-ended sheath, which is a distinguishing characteristic for *Chamaesiphon*. Early stages of *Cyanophanon* resemble *Geitleribactron* (Section 2.10, page 107), but the *Geitleribactron* exocytes do not remain attached to the basal cell, so the pseudofilamentous structure is less obvious.

Cyanophanon minus is usually epiphytic on filamentous algae in stagnant lakes and ponds (Figures 2.43–2.44). The pseudofilament consists of a thickened, club-shaped basal cell and up to 8 tiny, nearly spherical exocytes. The basal cell is wider than the exocytes, and forms Y-shaped branches. The local specimens were collected from a small, nutrient-rich urban pond.

Cyanophanon mirabile is can be attached to any solid surfaces in cold, clear streams and waterfalls; all of the local specimens were collected from a stream near the top of a waterfall. The individual cells are gray, blue-gray, or pinkish, and the basal cells become exceeding long (Figures 2.45–2.47). The basal cell should produce 8–16 short, rounded, cylindrical exocytes (Komárek and Anagnostidis, 1998). None of the local specimens contained exocytes associated with the basal cells, but there were many regularly-spaced, button-like exocytes attached to the algal host, which is a diagnostic feature for this species.

Cyanophanon sp.1 resembles *Cyanophanon minus*, but the cells are smaller, the pseudofilament contains fewer exocytes, and there is no evidence of Y-shaped branching (Figures 2.48). The local specimens were collected in a small, shallow, nutrient-rich lake.



Figure 2.43: *Cyanophanon minus* (600x DIC), Chambers Lake, Olympia, Thurston County, May 27, 2015.

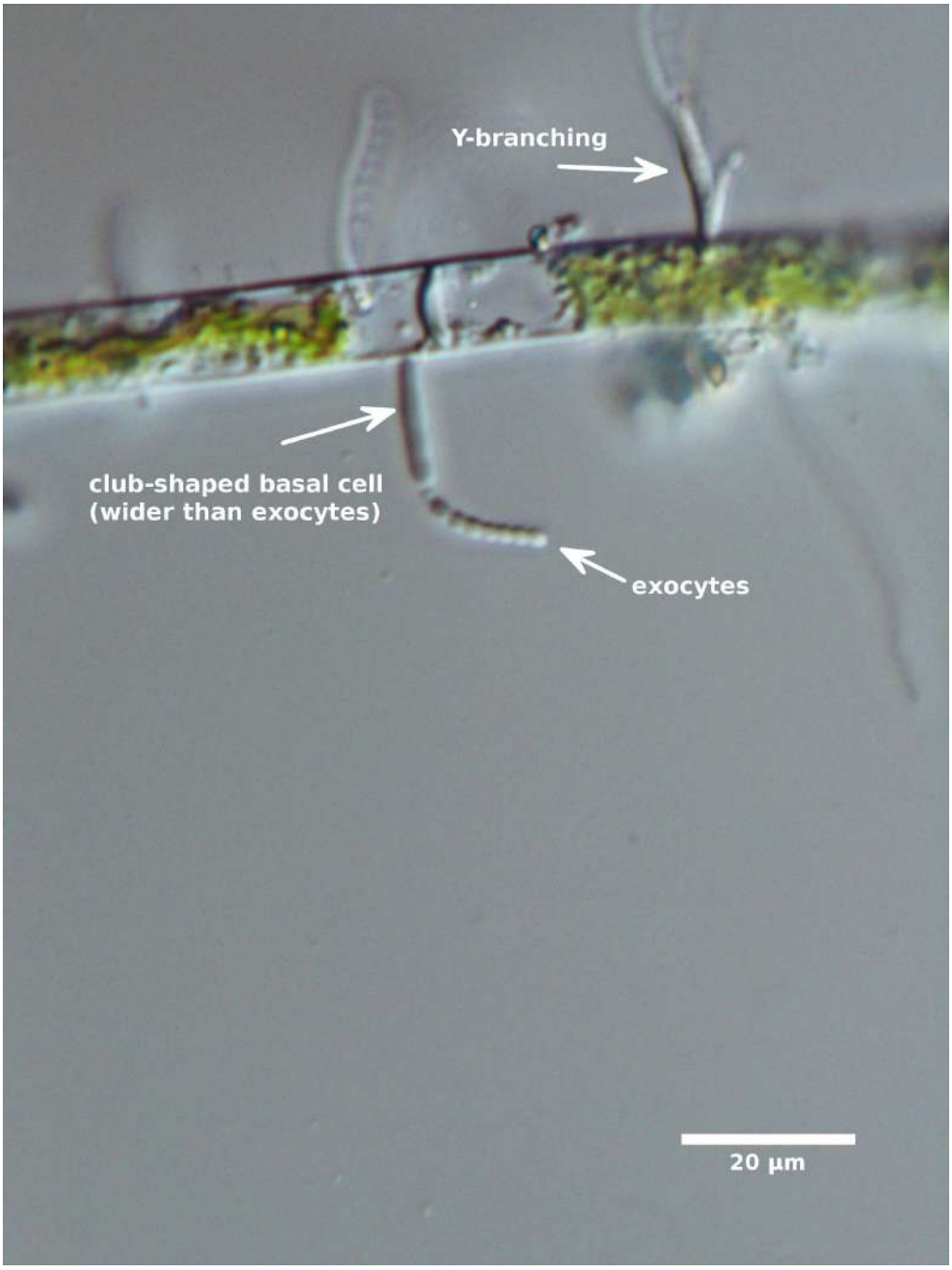


Figure 2.44: *Cyanophanon minus* (600x DIC), Chambers Lake, Olympia, Thurston County, May 27, 2015.

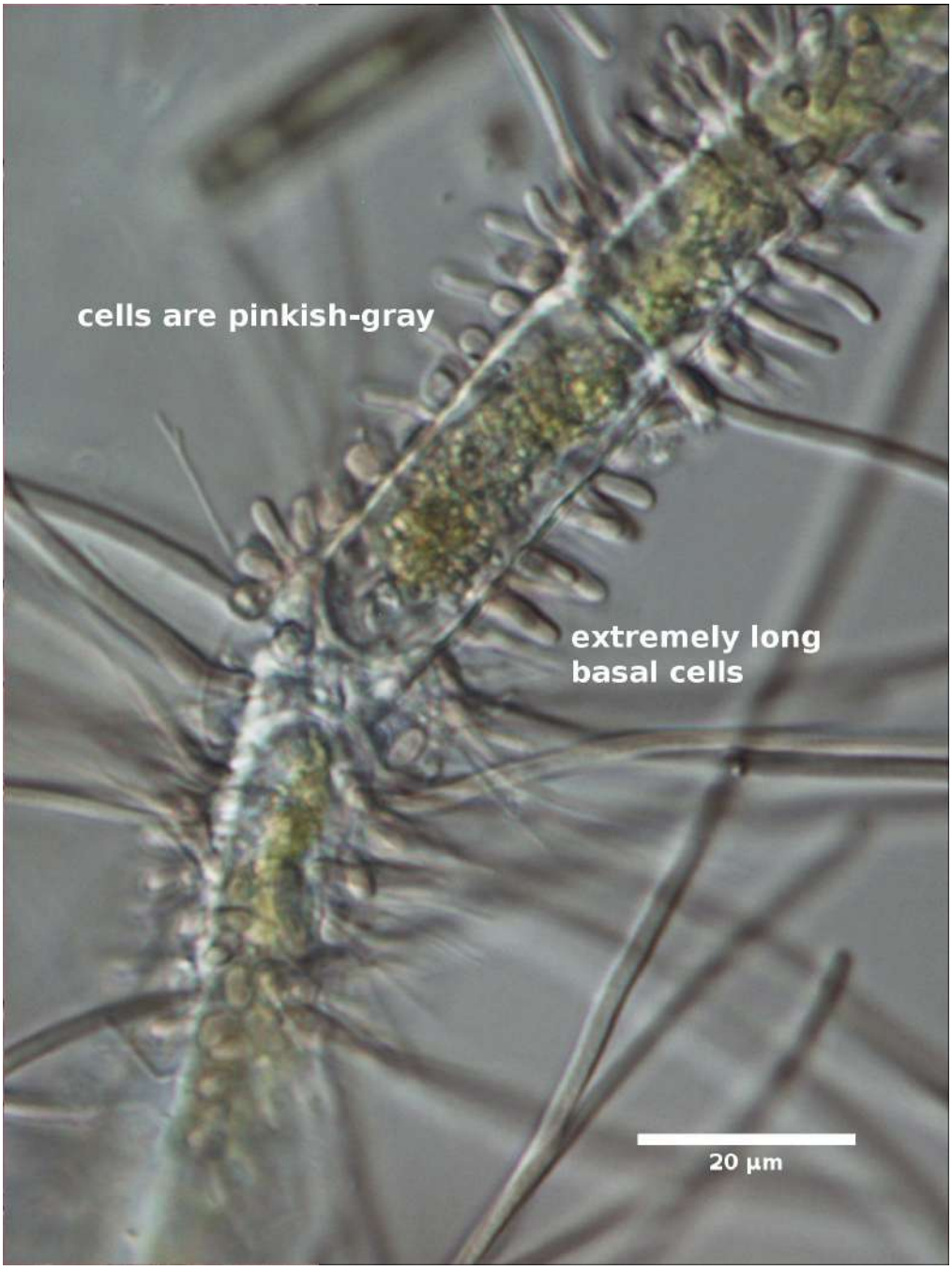


Figure 2.45: *Cyanophanon mirabile* (600x DIC), Bridal Veil Falls outlet (on trail to Lake Serene), Mt. Loop Hwy, August 15, 2011.

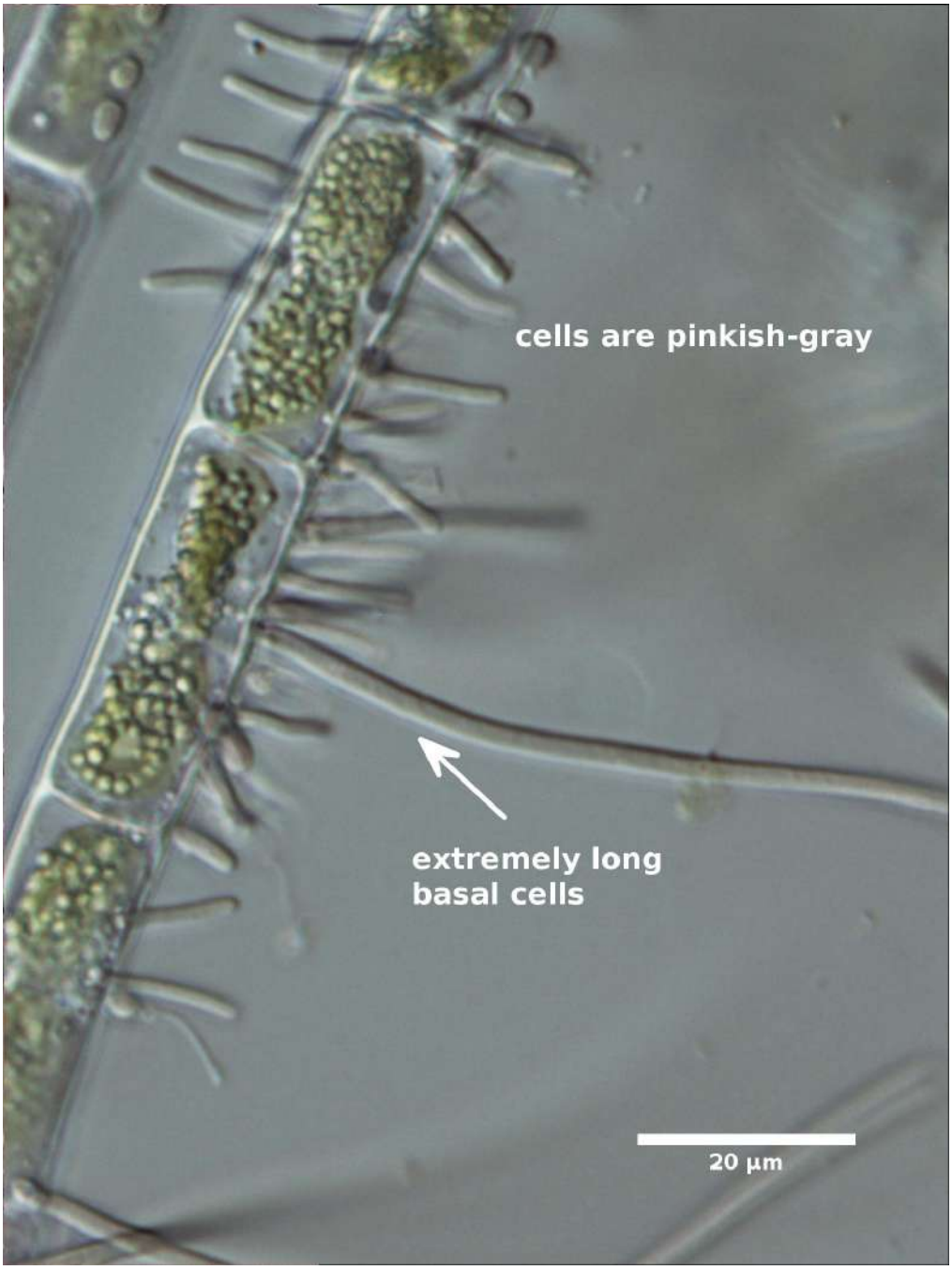


Figure 2.46: *Cyanophanon mirabile* (600x DIC), Bridal Veil Falls outlet (on trail to Lake Serene), Mt. Loop Hwy, August 15, 2011.

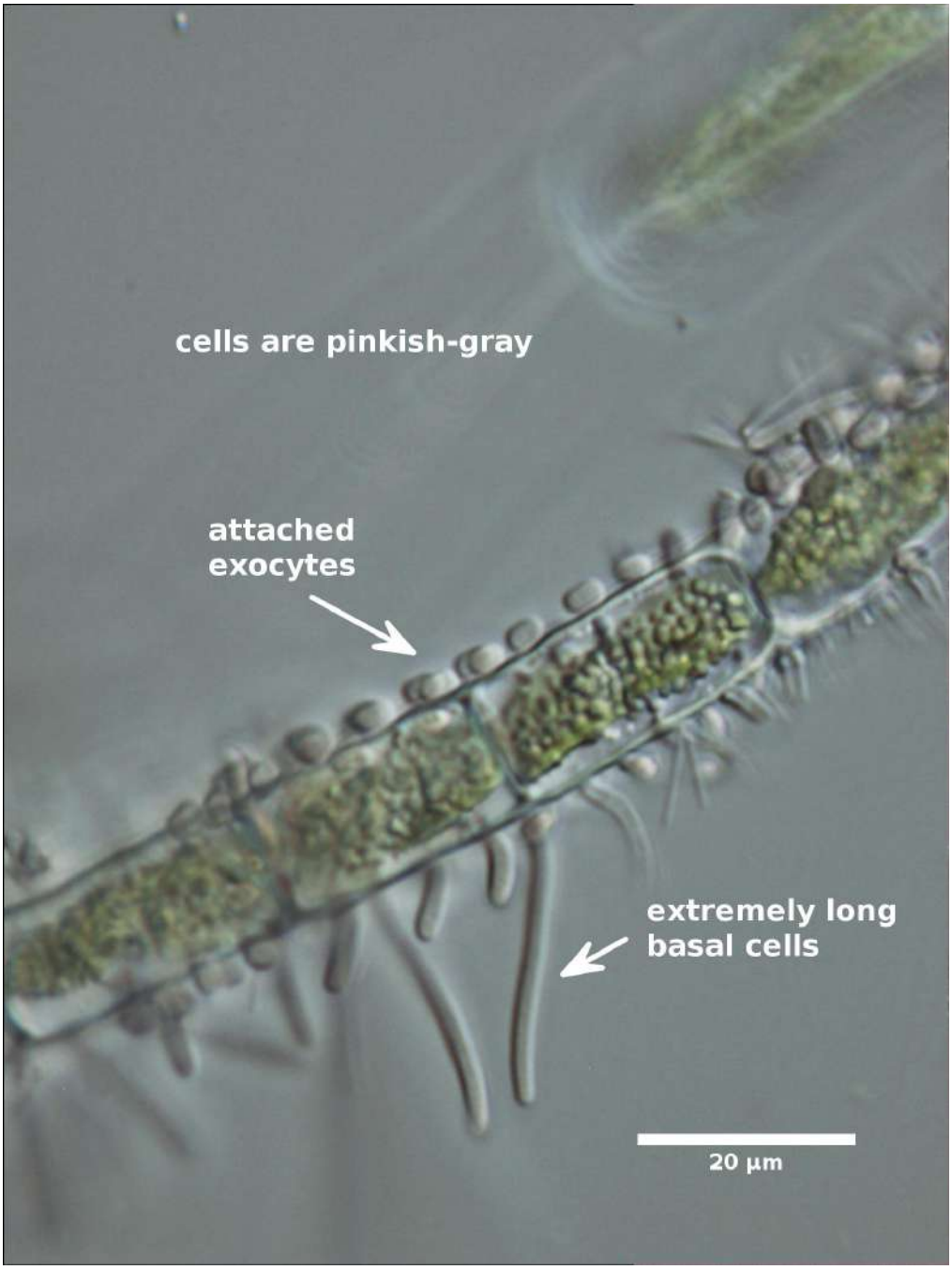


Figure 2.47: *Cyanophanon mirabile* (600x DIC), Bridal Veil Falls outlet (on trail to Lake Serene), Mt. Loop Hwy, August 15, 2011.

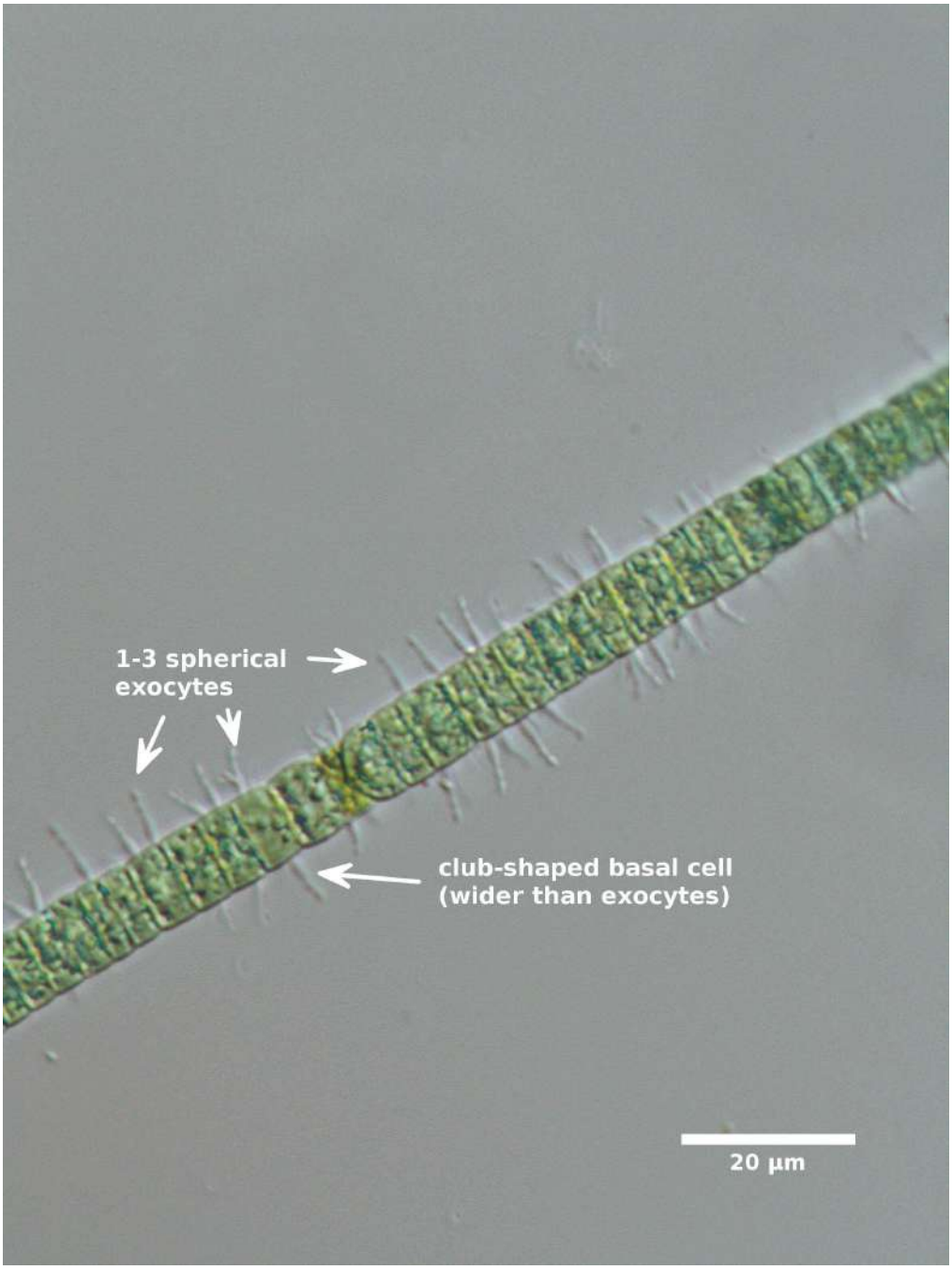


Figure 2.48: *Cyanophanon* sp.1 (600x DIC), Lake Terrell, IWS water quality sampling site, Whatcom County, April 4, 2014.

2.8 *Cyanothece* Komárek

Local taxa
Cyanothece aeruginosa (Nägeli) Komárek;
Cyanothece majus (Schröter) Komárek?;
Cyanothece sp.1

Abundance
Infrequently collected in plankton samples; occasionally collected in shoreline samples from mountain lakes.

Local measurements		Width	Length	Biovolume[†]
Cyanothece aeruginosa	min	18.7 μm	35.0 μm	6,910 μm^3
cells (spheroid)	med	22.9 μm	39.0 μm	10,400 μm^3
	max	25.5 μm	46.3 μm	15,800 μm^3
Cyanothece majus?	min	10.7 μm	11.0 μm	659 μm^3
cells (spheroid)	med	15.5 μm	16.4 μm	2,060 μm^3
	max	18.8 μm	19.3 μm	3,570 μm^3
Cyanothece sp.1[‡]	min	4.9 μm	6.6 μm	85.5 μm^3
cells (spheroid)	med	6.5 μm	6.9 μm	153 μm^3
	max	7.0 μm	8.2 μm	210 μm^3

[†]Calculated using original measurements, not summary values.
[‡]Biovolume estimates based on $<$5 cells.

Description
Cyanothece cells are spherical, oval or broadly elliptical, and solitary except for brief pairing during division (Figures 2.49–2.57). Cell division is always centered and perpendicular to the long axis of the cell, forming distinctive cross-walls in the center of the cell.

Cyanothece aeruginosa cells are bright blue-green or olive-green, distinctly granular, and sometimes reticulated (Figures 2.49–2.52). Live specimens are slightly motile (gliding and twitching). The cells are broadly elliptical when fully developed, but during division the paired daughter cells may be spherical and

slightly asymmetric. *Cyanothece aeruginosa* is usually found in unpolluted bogs and swampy locations, and most of the local specimens were collected in mid- to high-elevation lakes and ponds.

The specimens in Figures 2.53–2.55 were also collected in boggy, high elevation lakes. The cells are smaller, more spherical, and more distinctly vacuolated (keritomized) than *Cyanothece aeruginosa*. The general cell appearance and habitat fits the description for *Cyanothece majus*, but the local specimens are about half the reported size for this species (28–52 μm $\times$ 30–70 μm; Komárek and Anagnostidis, 1998).

Cyanothece sp.1 cells are very small, broadly elliptical prior to division, with a granular, gray-green cell content (Figures 2.56–2.57). These specimens might be *Cyanothece notata* (Skuja) Komárek (=*Cyanobacterium notatum* [Skuja] Komárek, Kopeck & Cepák), which has tiny (5–7 μm $\times$ 6–12 μm), broadly oval, olive-green cells that contain a few large granules and is usually associated with found in peaty lakes and bogs (Komárek and Anagnostidis, 1998).

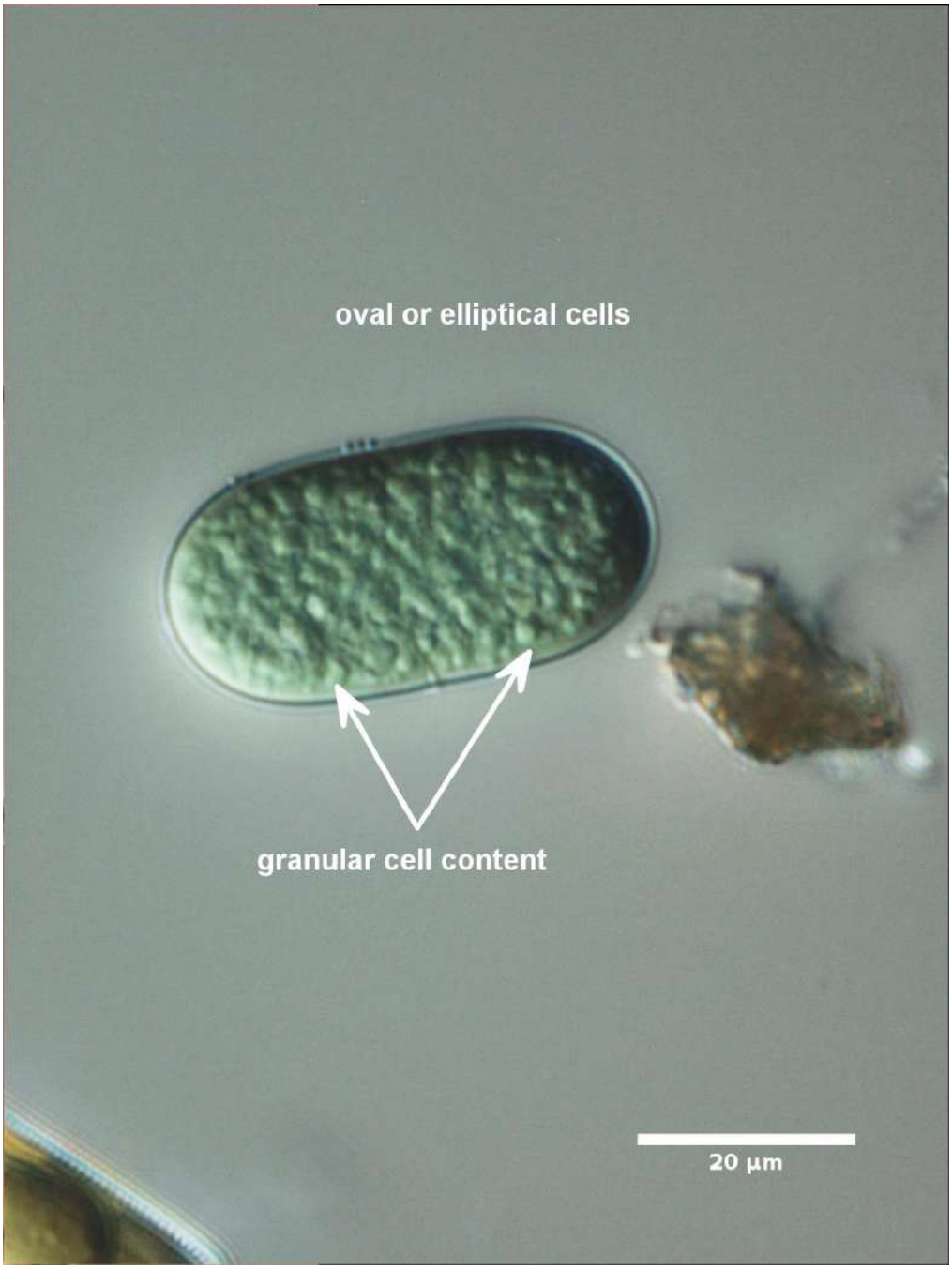


Figure 2.49: *Cyanothece aeruginosa* (600x DIC), snow melt pond on Railroad Grade trail (Park Butte), North Cascades near Mt. Baker, September 7, 2011.



Figure 2.50: *Cyanothece aeruginosa* (200x DIC), small pond near Lake Anderson, North Cascades along Hwy 20, August 23, 2013.



Figure 2.51: *Cyanothece aeruginosa* (600x DIC), snow melt pond on Railroad Grade trail (Park Butte), North Cascades near Mt. Baker, September 8, 2011.

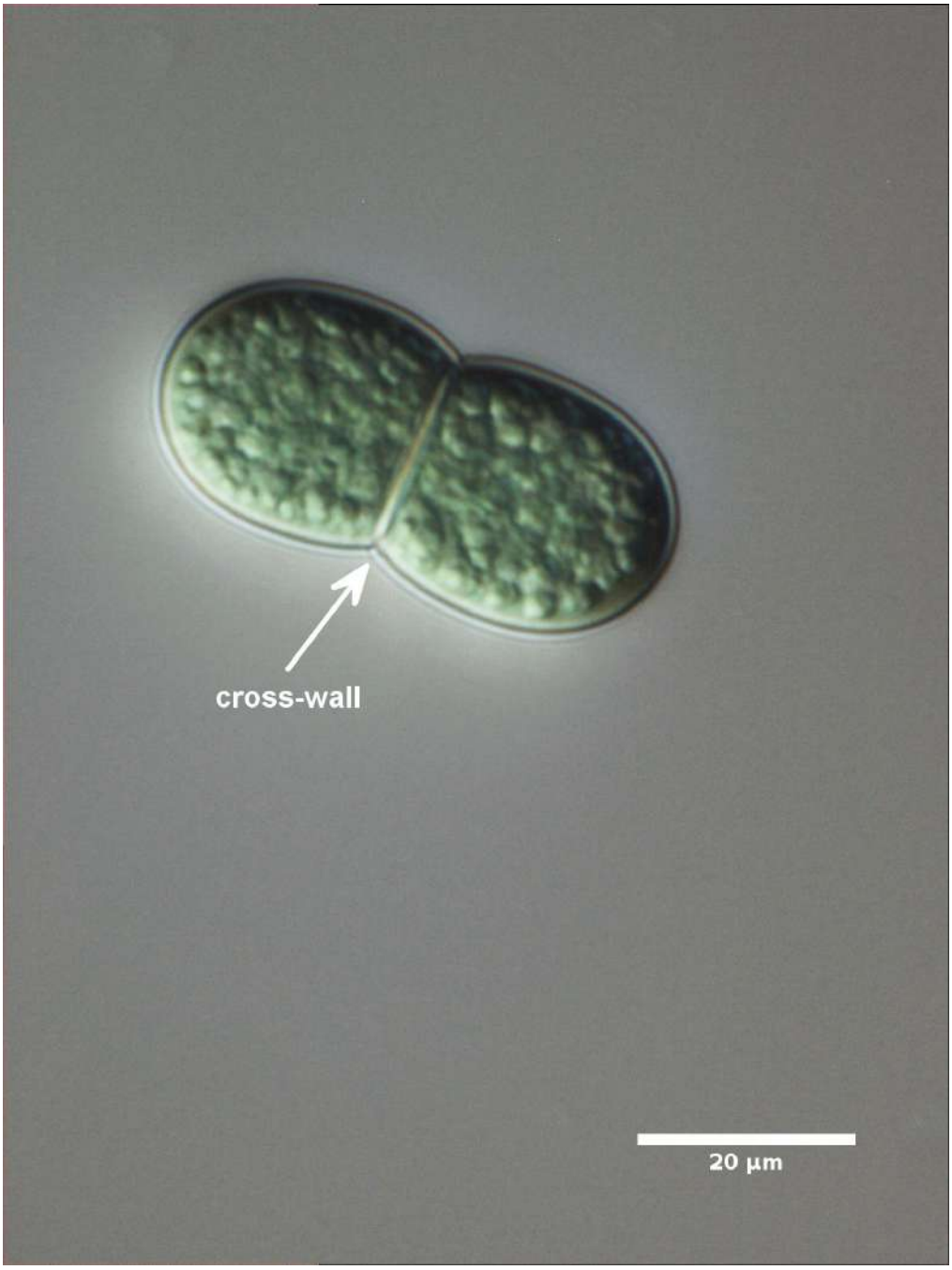


Figure 2.52: *Cyanothece aeruginosa* dividing cells (600x DIC), snow melt pond on Railroad Grade trail (Park Butte), North Cascades near Mt. Baker, September 7, 2011.

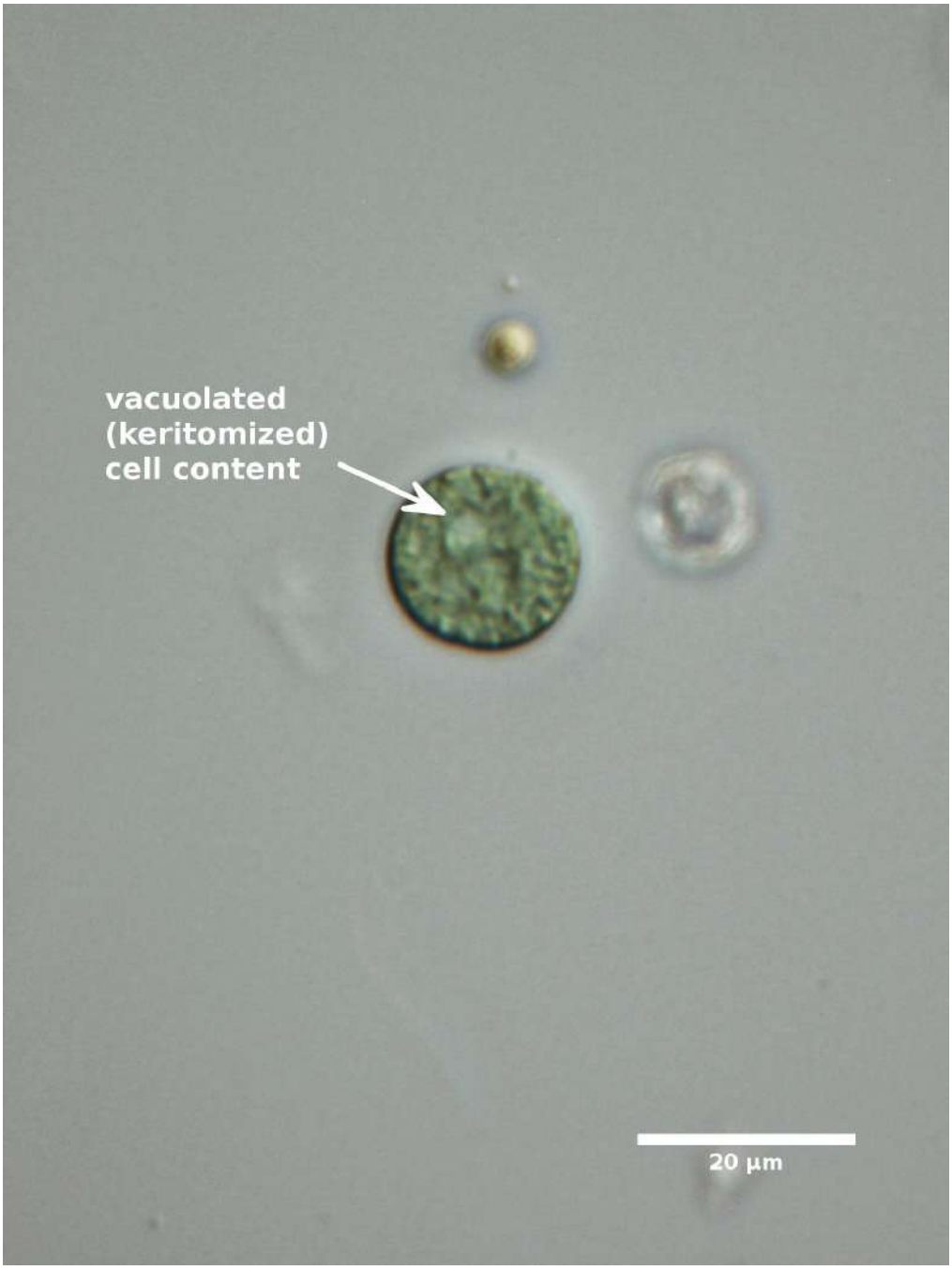


Figure 2.53: *Cyanothece majus*? (600x DIC), Lake Evan, IWS water quality sampling site, Snohomish County, August 6, 2012.



Figure 2.54: *Cyanothece majus*? (600x DIC), Lake Evan, IWS water quality sampling site, Snohomish County, August 16, 2012.



Figure 2.55: *Cyanothece majus*? (200x DIC), Lower Ashland Lake, Mt. Loop Hwy, July 31, 2015.



Figure 2.56: *Cyanothece* sp.1 or *Cyanobacterium notatum* (600x DIC), small pond near Yellow Aster Butte, North Cascades near Mt. Baker, September 3, 2013.



Figure 2.57: *Cyanothece* sp.1 or *Cyanobacterium notatum* (600x DIC), small pond near Yellow Aster Butte, North Cascades near Mt. Baker, September 3, 2013.

2.9 *Eucapsis* Clements & Shantz

Local taxa
Eucapsis alpina Clements & Shantz;
Eucapsis minor (Skuja) Elenkin

Abundance
Infrequently collected in plankton samples; occasionally collected in shoreline samples from mountain lakes.

Local measurements		Width	Length	Biovolume[†]
Eucapsis alpina	min	4.3 μm	5.2 μm	55.2 μm^3
cells (spheroid)	med	5.3 μm	6.2 μm	91.4 μm^3
	max	6.8 μm	8.0 μm	194 μm^3
Eucapsis minor	min	2.5 μm	2.5 μm	8.18 μm^3
cells (spheroid)	med	3.3 μm	3.8 μm	22.3 μm^3
	max	4.9 μm	5.0 μm	62.9 μm^3

[†]Calculated using original measurements, not summary values.

Description
Eucapsis colonies contain groups of cells in multiples of 4 arranged to form regular, cubical colonies (Figures 2.58–2.61). The individual cells are spherical or slightly oval, not hemispherical. The colonial mucilage is usually indistinct. *Eucapsis* can be difficult to distinguish from *Chroococcus* (Section 2.4, page 55), especially *Chroococcus prescottii* Drouet & Daily (no image available). Colonies with hemispherical cells that form irregular rather than cubical groups, or have a firm, clearly visible colonial mucilage are more likely to be *Chroococcus*. Most species of *Eucapsis* are cold *stenotherms* (require cold temperatures) and are found in acidic, peaty water in mountainous areas (Komárek & Anagnostidis, 1998; John, et al. 2011).

Eucapsis alpina forms small colonies containing 8–16 cells (Figure 2.58). The individual cells are spherical or oval, and range from pale blue-green to olive-green in color. This species is a cold stenotherm (Komárek and Anagnostidis, 1998); the sample from Judy Reservoir (Figure 2.58) was collected in November,

and although the reservoir is located at a low elevation, the reservoir source water often comes from cold, high elevation streams.

Eucapsis minor colonies often contain >64–128 cells, with the cells forming dense cubical subgroups of 8–16 cells (Figures 2.59–2.61). The individual cells are small, approximately spherical (hemispherical just before division), and blue-green in color. *Eucapsis minor* is a cold stenotherm from "extreme" environments (psychrophiliac) associated with peaty water in mountainous areas; the local samples were all collected in high elevation, slightly acidic or boggy lakes.

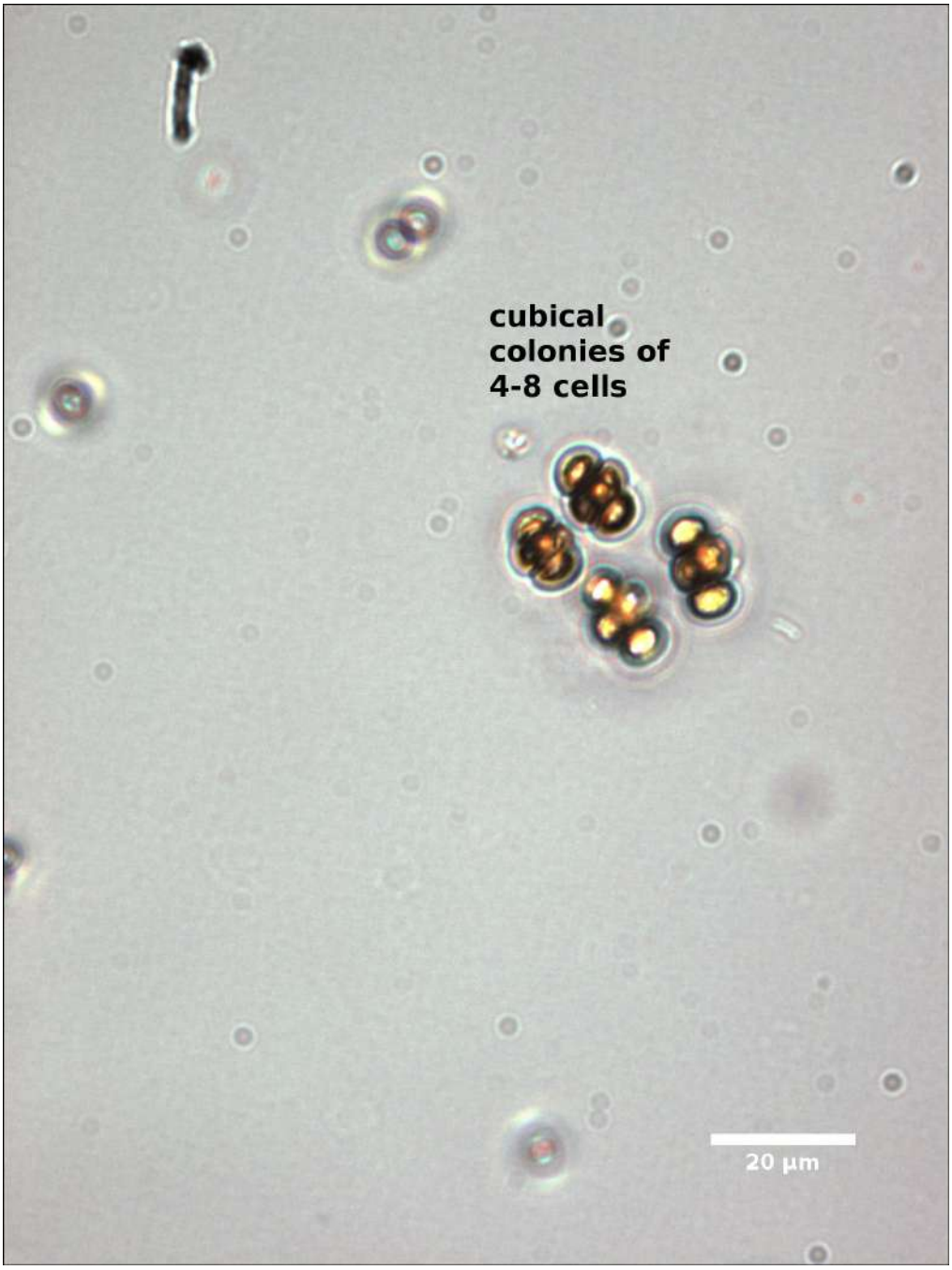


Figure 2.58: *Eucapsis alpina* in Lugol's iodine solution (400x brightfield), Judy Reservoir, IWS water quality sampling site, Skagit County, November 8, 2006.

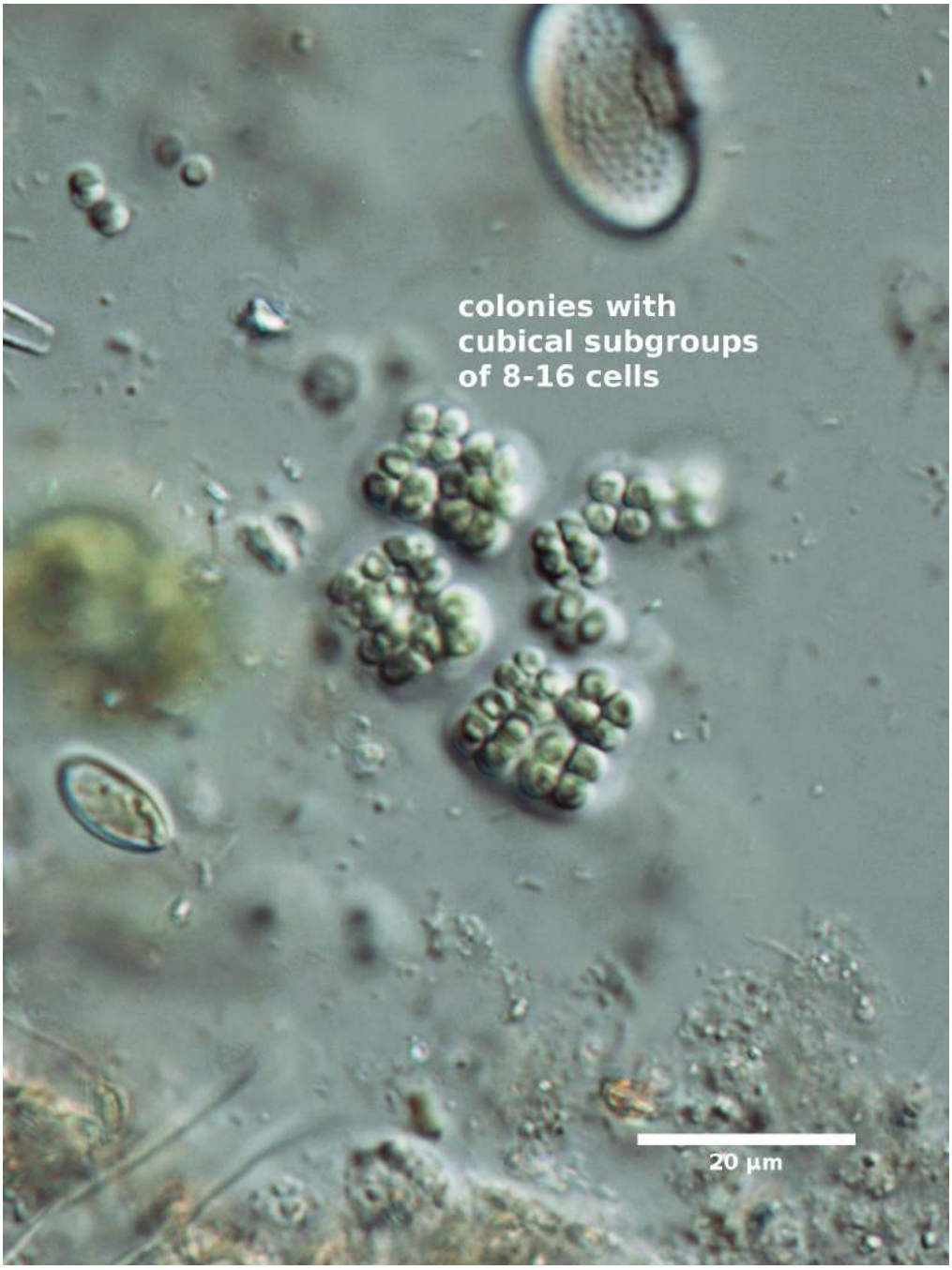


Figure 2.59: *Eucapsis minor* (600x DIC), Picture Lake, IWS water quality sampling site, Whatcom County, August 17, 2012.



Figure 2.60: *Eucapsis minor* (600x DIC), Bear Lake, Alpine Lakes Wilderness Area, July 12, 2013.

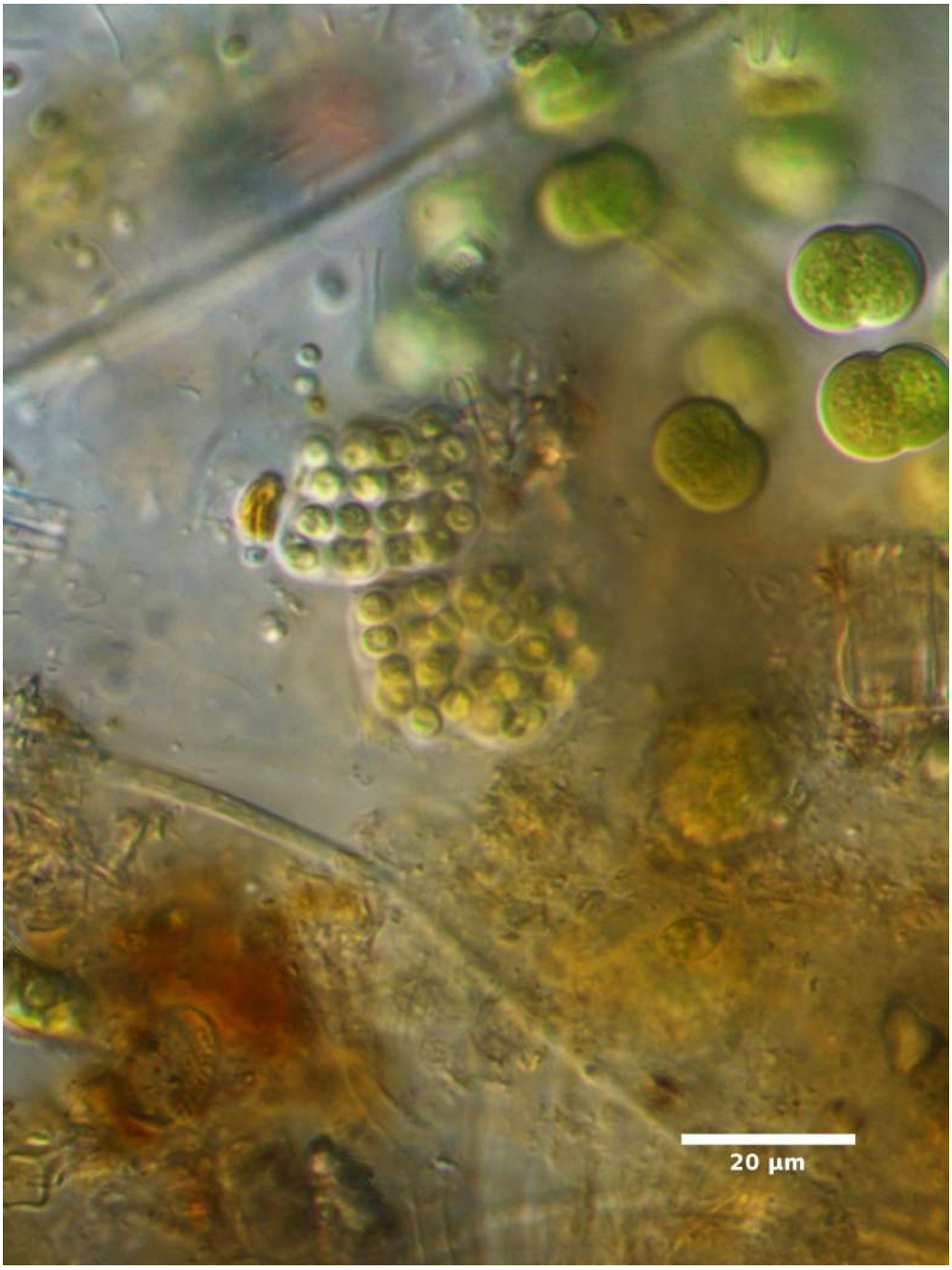


Figure 2.61: *Eucapsis minor* (600x DIC), Bear Lake, IWS water quality sampling site, Snohomish County, August 28, 2014.

2.10 *Geitleribactron* Komárek

Local taxon
Geitleribactron periphyticum Komárek

Abundance
Infrequently collected; easily overlooked

Local measurements		Width	Length	Biovolume[†]
Geitlerbactron periphyticum	min	2.0 μm	5.8 μm	13.4 μm^3
basal cells	med	2.5 μm	8.2 μm	22.2 μm^3
(cyl + two $\frac{1}{2}$ spheres)[‡]	max	3.1 μm	14.3 μm	65.8 μm^3
Geitlerbactron periphyticum	min	2.2 μm	–	5.58 μm^3
exocytes (sphere)	med	2.4 μm	–	7.24 μm^3
	max	3.2 μm	–	17.2 μm^3

[†]Calculated using original measurements, not summary values.
[‡]Biovolume based on cylinder length ($<$ cell length).

Description
All *Geitleribactron* species are tiny, inconspicuous epiphytes that form short pseudofilaments attached to algae and mosses (Figures 2.62–2.64). The pseudofilaments consist of pale gray or blue-green basal cells that release spherical exocytes (daughter cells). *Geitleribactron* resembles the early stages of *Cyanophanon* (Section 2.7, page 82), but unlike *Cyanophanon*, the *Geitleribactron* exocytes do not remain attached to the basal cell, so the pseudofilamentous structure is less obvious.

Geitleribactron periphyticum forms dense assemblages of individual cells attached to the surface of many types of freshwater substrates (Figures 2.62–2.64). The local specimens were collected from the sides of a freshwater aquarium and from shoreline vegetation and debris in small, low-elevation lakes and ponds. The basal cells are pale or bright blue-green, rod-shaped, and bluntly rounded. The exocytes are spherical and usually separated from the basal cell.

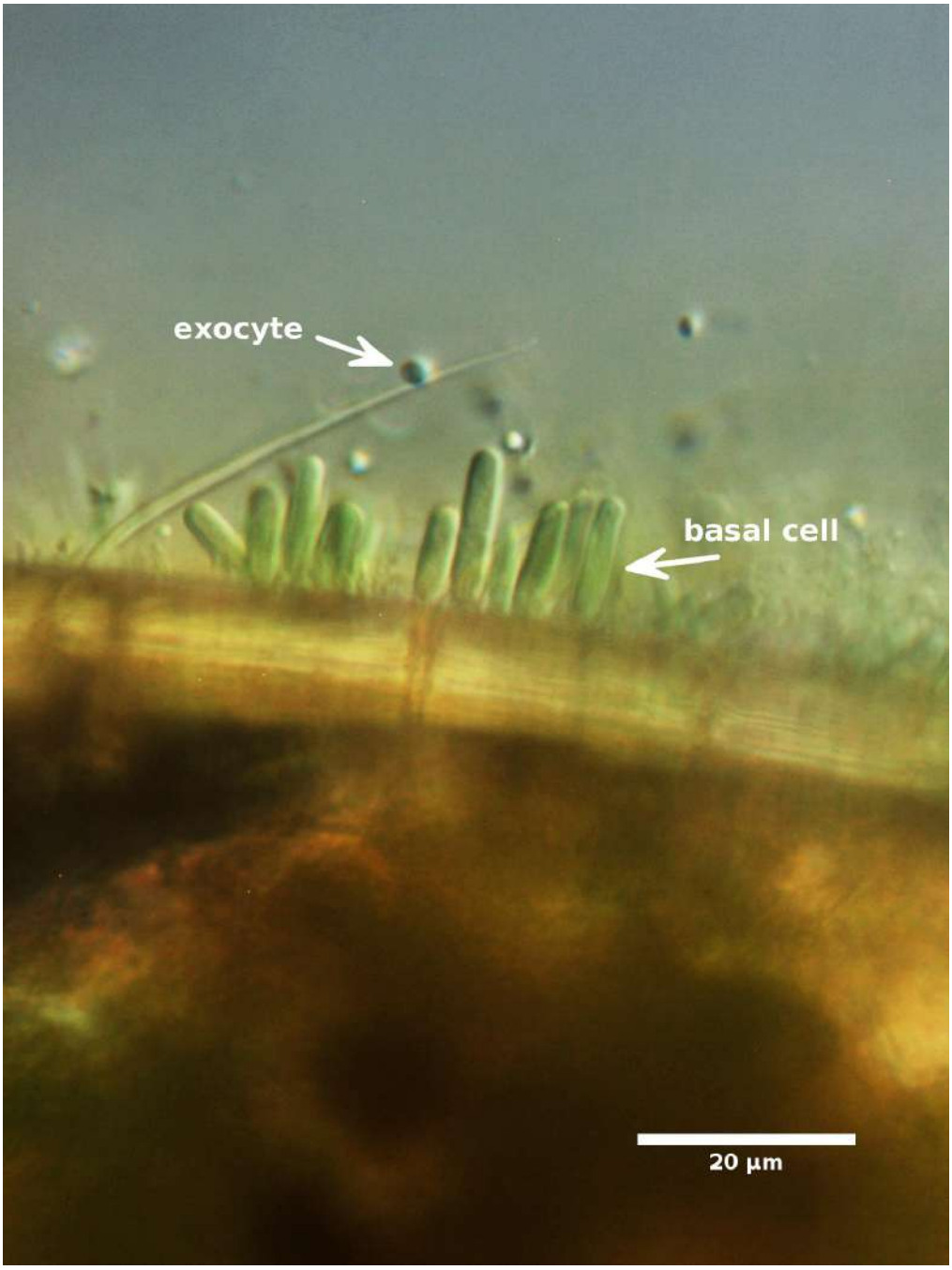


Figure 2.62: *Geitleribactron periphyticum* (600x DIC), Heart Lake, IWS water quality sampling site, Skagit County, October 8, 2013.

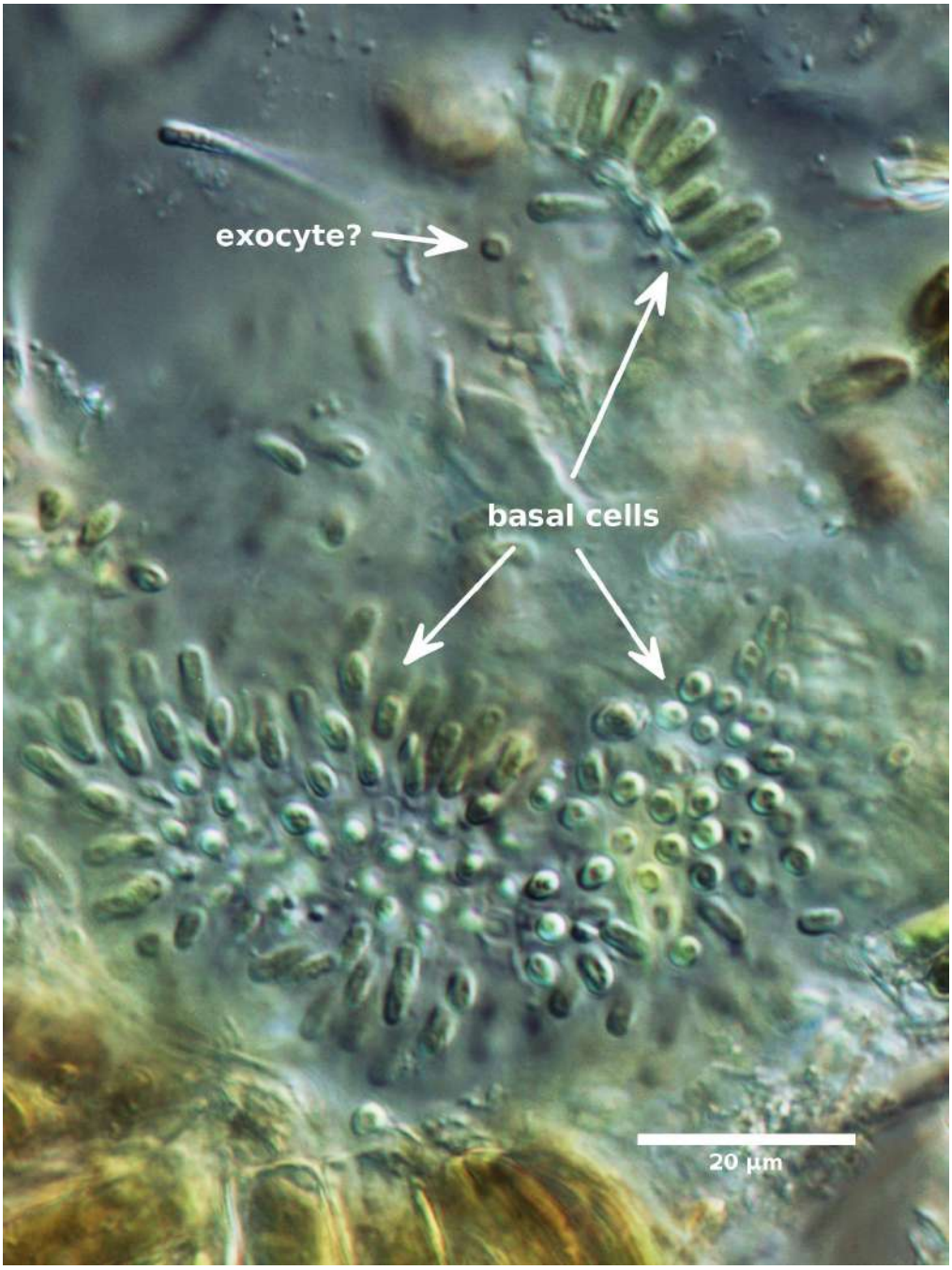


Figure 2.63: *Geitleribactron periphyticum* (600x DIC), freshwater aquarium, April 8, 2013.

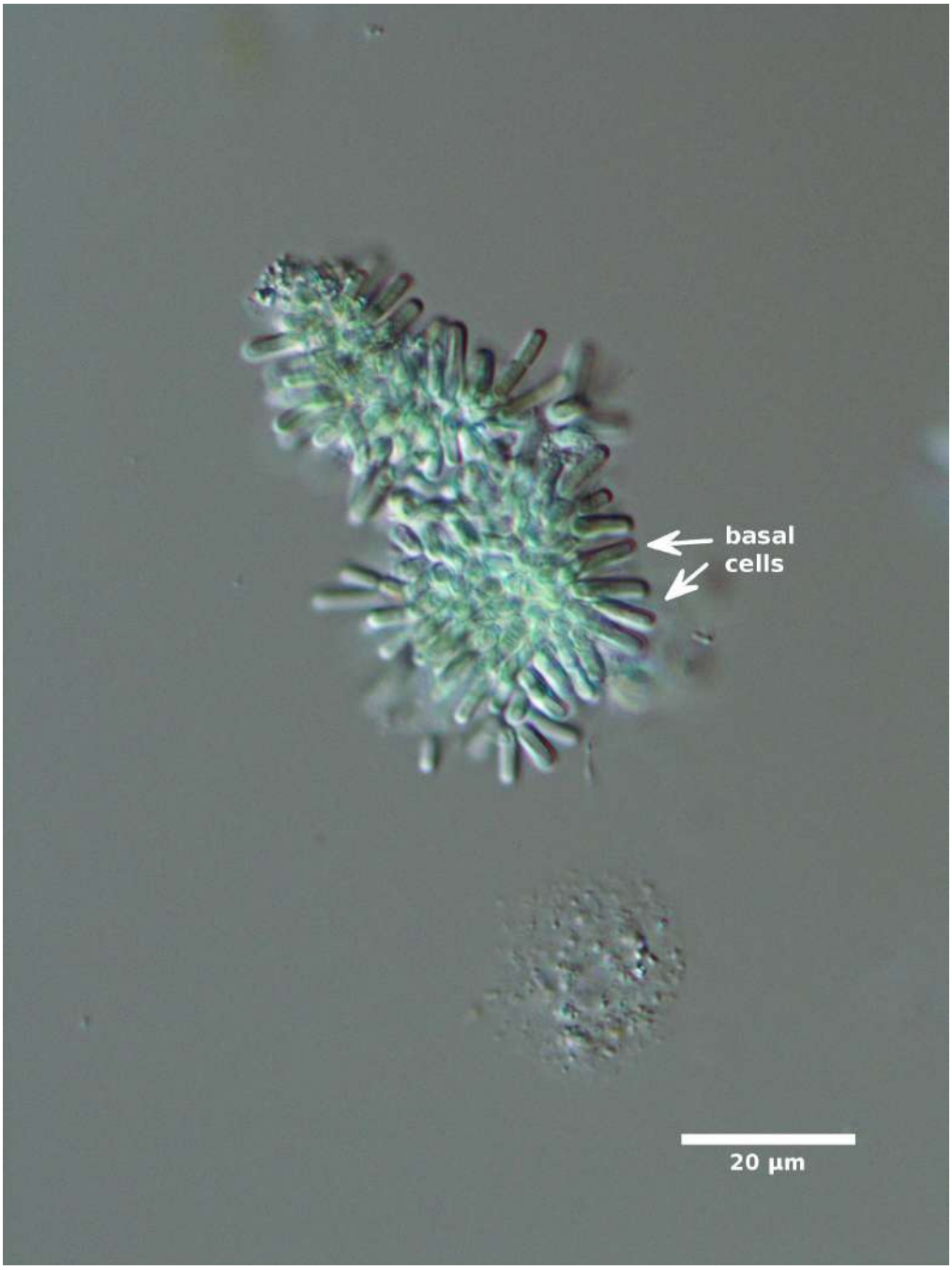


Figure 2.64: *Geitleribactron periphyticum* (600x DIC), storm water treatment pond, Whatcom County, February 9, 2016.

2.11 *Gomphosphaeria* Kützing

Local taxon
Gomphosphaeria aponina Kützing

Abundance
Moderately common; may be present in large numbers but rarely forms blooms.

Local measurements		Width	Length	Biovolume[†]
Gomphosphaeria aponina	min	5.6 μm	8.2 μm	149 μm^3
cells (spheroid)	med	7.2 μm	10.2 μm	316 μm^3
	max	9.9 μm	13.9 μm	671 μm^3
Gomphosphaeria aponina	min	25.1 μm	29.6 μm	–
colonies[‡]	med	35.6 μm	37.9 μm	–
	max	63.5 μm	72.6 μm	–

[†]Calculated using original measurements, not summary values.
[‡]Colony biovolume can be estimated using a spherical or spheroid shape.

Description
Gomphosphaeria colonies are more or less spherical, with broadly elliptical cells at the end of repeatedly branched mucilage strands that radiate from the center of the colony (Figures 2.65–2.69). The strands, while thick and distinctly visible, will be thinner than the cell width. The cells divide along the long axis, but remain attached, forming characteristic heart-shaped cell pairs.

Gomphosphaeria resembles *Coelosphaerium* (Section 2.5, page 72), which lacks radiating mucilage strands, and *Snowella* (Section 2.16, page 168), which has cells that form groups of 2 or 4 at the end of thin, delicate mucilage strands. *Gomphosphaeria* is particularly difficult to distinguish from *Woronichinia* (Section 2.18, page 181), which has densely packed cells attached to thick, mostly unbranched mucilage strands that are about as wide as the cells.

Gomphosphaeria aponina (Figures 2.65–2.69) is characterized by asymmetric, oval cells that are bright blue-green or olive-green and have a slightly granular cell content. The cells divide along the long axis and remain attached to the adjacent cell, forming the heart-shaped cell pairs that distinguishes this genus. The cells

are attached to radiating mucilage strands that divide repeatedly to form clusters of cell pairs. The colonies are surrounded by a diffuse, indistinct mucilage layer. *Gomphosphaeria* colonies are often colonized by epiphytes. Figure 2.69 shows an example of *Gomphosphaeria aponina* colonized by *Epipyxis aurea*, a single-cell golden algae epiphyte, and *Chlorogonium*, a single-cell green flagellate that is commonly associated with the mucilage layer surrounding other types of algae.[10]

[10]See **Freshwater Algae in Northwest Washington, Volume IV. Chrysophyceae, Xanthophyceae, and Haptophyta** and **Freshwater Algae in Northwest Washington, Volume II. Chlorophyta and Rhodophyta**.



Figure 2.65: *Gomphosphaeria aponina* (600x DIC), Pass Lake, IWS water quality sampling site, Skagit County, July 14, 2015.



Figure 2.66: *Gomphosphaeria aponina* (600x DIC), Lake Campbell, IWS water quality sampling site, Skagit County County, July 214, 2015.

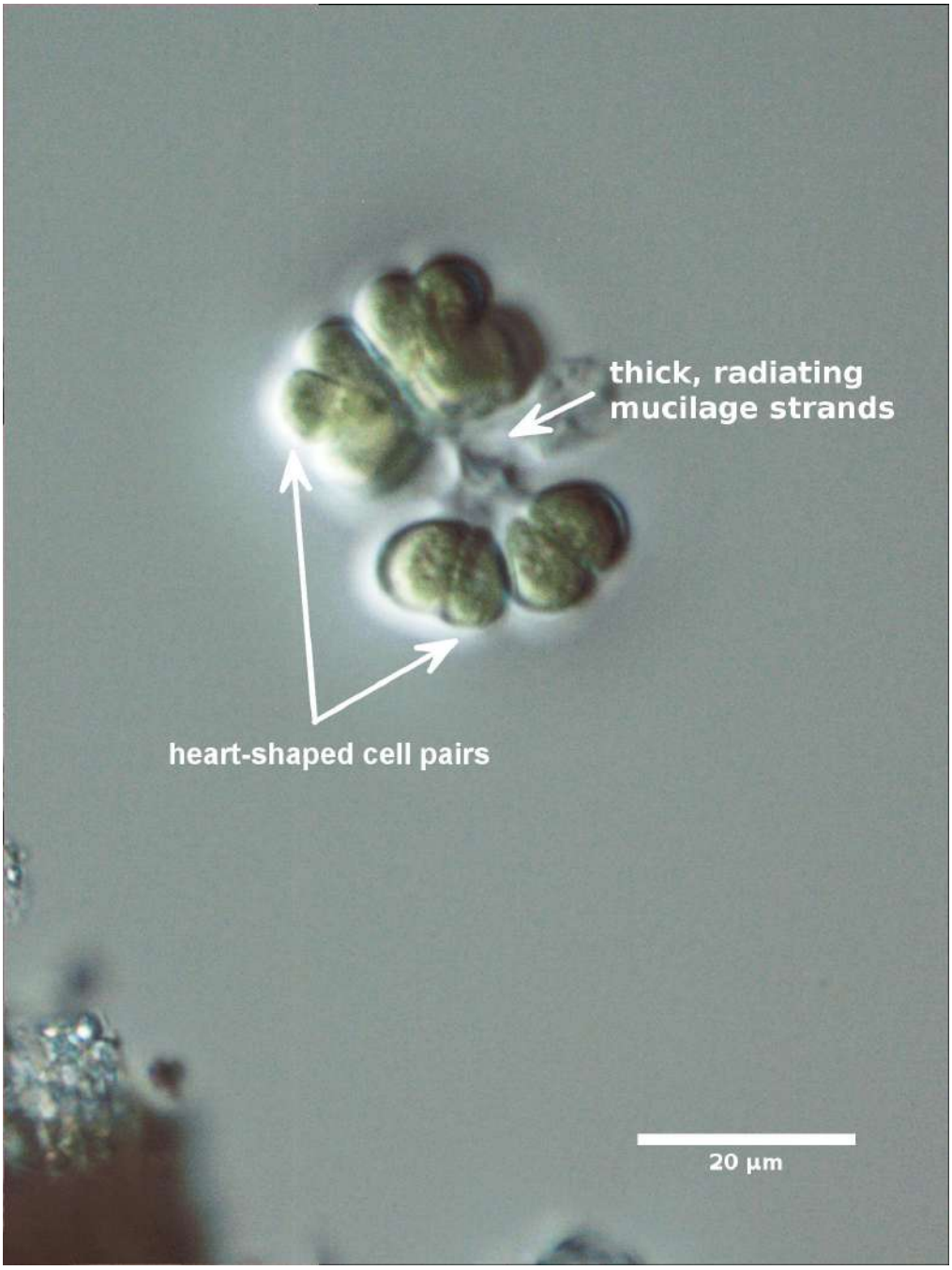


Figure 2.67: *Gomphosphaeria aponina* (600x DIC), Lake Goodwin, IWS water quality sampling site, Snohomish County, July 26, 2011.



Figure 2.68: *Gomphosphaeria aponina* (400x DIC), Ross Lake, Ross Lake National Recreation Area, June 1, 2009.

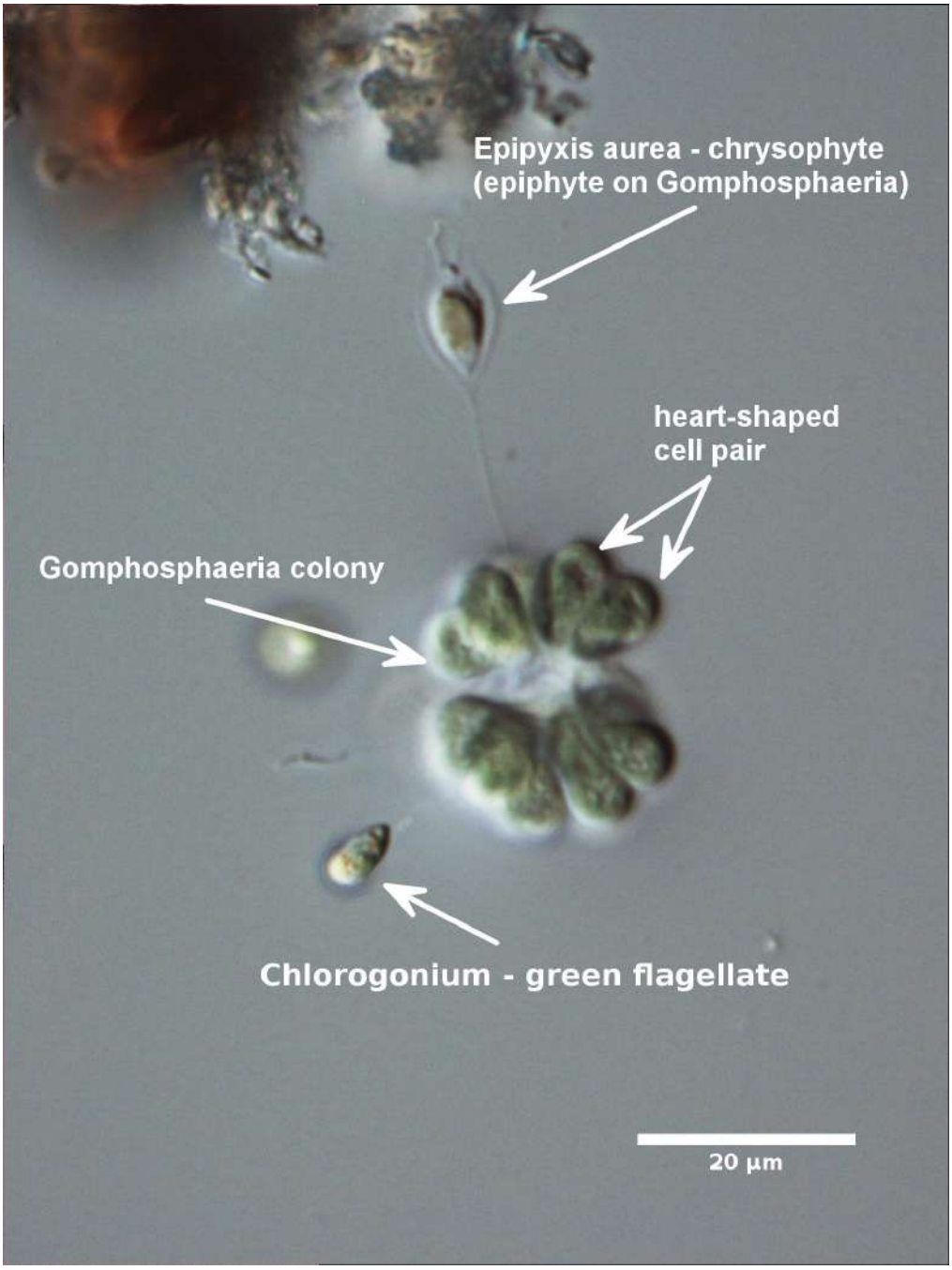


Figure 2.69: *Gomphosphaeria aponina* epiphytes (600x DIC), Deer Lake, IWS water quality sampling site, Island County, July 19, 2011.

2.12 *Merismopedia* Meyen

Local taxa
Merismopedia convoluta Brébisson ex Kützing;
Merismopedia elegans A. Braun ex Kützing;
Merismopedia glauca (Ehrenberg) Kützing;
Merismopedia punctata Meyen;
Merismopedia tenuissima Lemmermann;
Merismopedia spp.

Abundance
Moderately common; rarely present in large numbers, but some taxa may form large colonies.

Local measurements		Width	Length	Biovolume[†]
Merismopedia convoluta	min	4.1 μm	4.7 μm	47.6 μm^3
cells (spheroid)	med	5.3 μm	6.0 μm	94.8 μm^3
	max	6.0 μm	7.5 μm	128 μm^3
Merismopedia elegans	min	6.2 μm	8.2 μm	165 μm^3
cells (spheroid)	med	7.5 μm	9.4 μm	284 μm^3
	max	8.1 μm	12.2 μm	409 μm^3
Merismopedia elegans?	min	4.5 μm	5.0 μm	53.0 μm^3
cells (spheroid)	med	5.1 μm	5.9 μm	79.0 μm^3
	max	6.6 μm	7.4 μm	164 μm^3
Merismopedia glauca?	min	5.3 μm	5.6 μm	82.4 μm^3
lavender variation	med	6.3 μm	7.0 μm	149 μm^3
cells (spheroid)	max	6.9 μm	7.3 μm	177 μm^3
Merismopedia punctata?	min	2.3 μm	2.6 μm	7.20 μm^3
cells (spheroid)	med	3.1 μm	3.5 μm	18.4 μm^3
	max	3.8 μm	4.4 μm	33.3 μm^3

continued on next page

Local measurements		Width	Length	Biovolume[†]
Merismopedia tenuissima	min	1.3 μm	1.4 μm	1.24 μm^3
cells (spheroid)	med	1.4 μm	1.8 μm	2.09 μm^3
	max	2.0 μm	2.2 μm	4.61 μm^3
Merismopedia tenuissima?	min	1.3 μm	1.5 μm	1.42 μm^3
cells (spheroid)	med	1.6 μm	1.9 μm	2.56 μm^3
	max	1.7 μm	2.0 μm	3.03 μm^3
Merismopedia sp.1	min	2.0 μm	2.3 μm	4.82 μm^3
cells (spheroid)	med	3.0 μm	3.7 μm	16.9 μm^3
	max	5.3 μm	6.3 μm	92.7 μm^3
Merismopedia sp.2	min	5.4 μm	6.7 μm	110 μm^3
cells (spheroid)	med	6.0 μm	7.3 μm	139 μm^3
	max	6.5 μm	7.7 μm	166 μm^3
Merismopedia sp.3	min	4.9 μm	5.7 μm	77.2 μm^3
cells (spheroid)	med	5.2 μm	6.3 μm	92.8 μm^3
	max	5.7 μm	6.9 μm	107 μm^3

[†]Calculated using original measurements, not summary values.

Description

Merismopedia cells divide in two alternating planes, forming groups of 4 or 16 cells that collectively form distinctive, flat colonies (Figures 2.70–2.88). The individual cells may be spherical or oval, granular or homogeneous, and range from bright blue-green to gray or pinkish-lavender. The cells are embedded in a colonial mucilage that may be visible at the edges of the colony. Although the genus is easy to identify, species identification can be difficult because many of the species exhibit a considerable amount of morphological variation.

Merismopedia convoluta forms very large, wavy (convoluted!) colonies (Figures 2.70–2.72). The individual cells are blue-green or greenish-gray, slightly granular, approximately spherical (hemispherical when dividing), and moderately large ($\geq$4 μm wide). The colony is surrounded by a clear mucilage layer that may have a wavy margin. This species is typically associated with stagnant or flowing water, often in association with other aquatic plants (Komárek & Anagnostidis, 1998).

Merismopedia elegans forms large flat colonies containing many densely packed cells. The individual cells are large (≥5 μm wide), broadly oval (not spherical), and usually bright blue-green or green, with a homogeneous or slightly granular cell content (Figures 2.73–2.74). The colony is surrounded by a distinct mucilage layer that extends beyond the edge of the colony. Cell size and colony appearance suggests that the specimens in Figures 2.75–2.77 may also be *Merismopedia elegans*, but possibly a subspecies or variety. The cells are slightly smaller and more granular than the specimens in Figures 2.73–2.74, but otherwise resemble the published descriptions for this species (Komárek & Anagnostidis, 1998).

The specimen in Figure 2.78 is tentatively identified as the pinkish-gray or lavender form of *Merismopedia glauca*, which is thought to be associated with deep water sites (see discussion by Komárek & Anagnostidis, 1998). This species forms small planktonic colonies (≤64 cells) containing spherical or oval cells (hemispherical when dividing) with a homogeneous cell content. The sample was collected from Lake Whatcom, a large, deep, meso-oligotrophic lake.

Merismopedia punctata forms small (≤64 cells), planktonic colonies surrounded by a clear, indistinct mucilage (Figures 2.79–2.80). The individual cells are relatively small (≤4 μm diameter), spherical or oval (hemispherical when dividing), and pale blue-gray. The species description for *Merismopedia punctata* overlaps considerably with *Merismopedia glauca* (John, et al., 2011).

Merismopedia tenuissima forms small, planktonic colonies (≤16 cells) containing tiny (≤2 μm diameter), spherical, blue-gray or blue-green cells (Figures 2.81–2.82). The colonies may aggregate into larger groups containing 16-cell subgroups. This species is relatively common in plankton samples from mesotrophic or eutrophic lakes. The colonies in Figure 2.83 were collected from the shoreline of a boggy, high elevation lake. The cells and colony match the general description for *Merismopedia tenuissima*, but the habitat was distinctly different from the other collection sites.

The *Merismopedia* specimens in Figures 2.86–2.88 were all collected from the shoreline of boggy, high elevation lakes. All of these taxa form small colonies (≤32 cells) with distinctive morphological features that suggest that they represent different species. *Merismopedia* sp.1 has the smallest cells, which are oval or slightly rectangular, pale blue-green, with a distinctly granular cell content (Figures 2.84–2.85). The colonies are surrounded by a clear, diffuse mucilage layer. *Merismopedia* sp.2 can by distinguished by its larger, bright blue-green

cells that are nearly spherical and only faintly granular (Figures 2.86–2.87). All of the *Merismopedia* sp.2 colonies are surrounded by a thick, coarse, yellowish mucilage layer. *Merismopedia* sp.3 is represented by a single colony collected from a small, high elevation pond (Figure 2.88). This species forms small colonies of oval, bright green cells that are faintly granular; the colonies lack any visible mucilage layer.

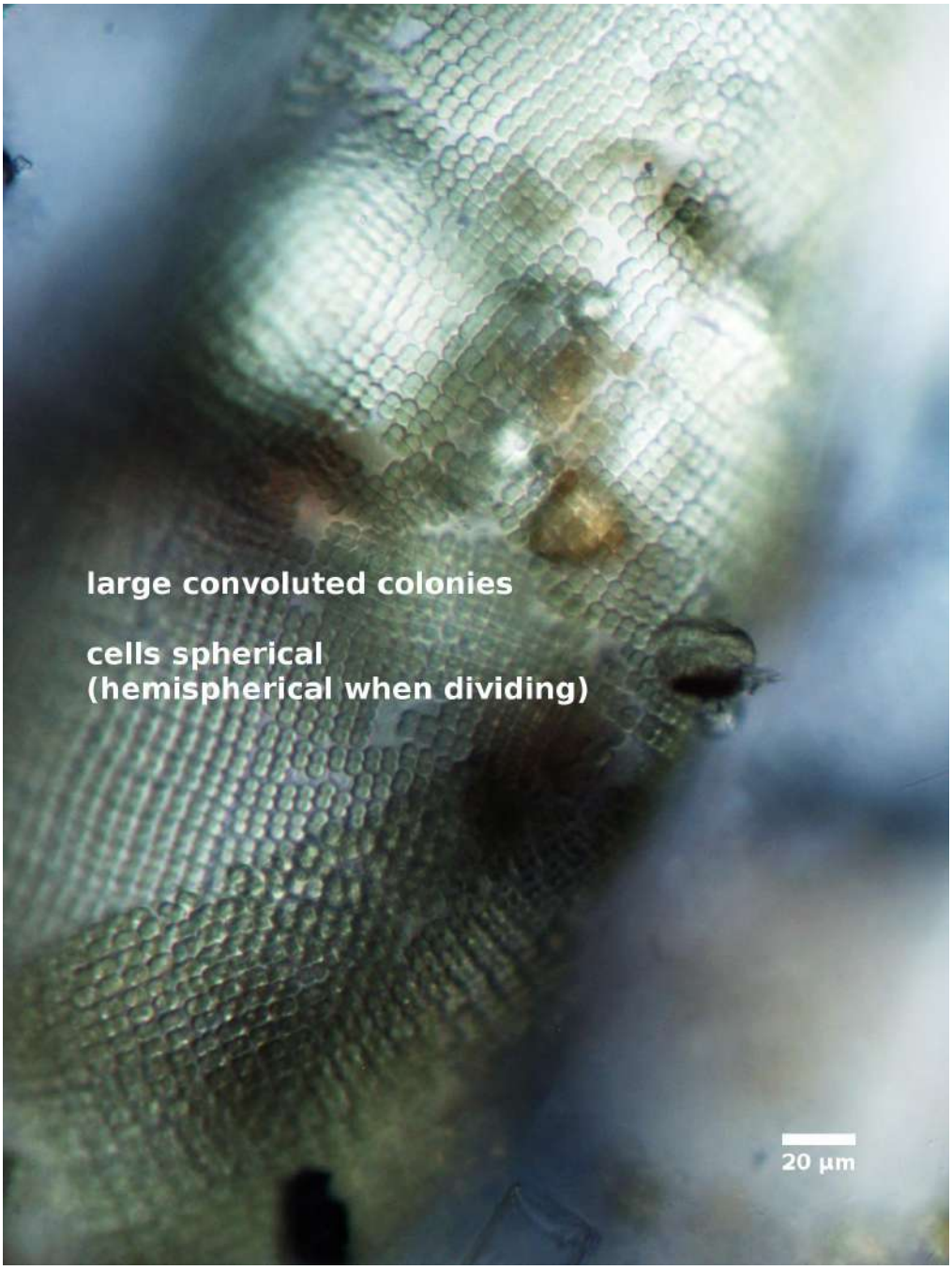


Figure 2.70: *Merismopedia convoluta* stained with methylene blue (200x DIC), Lake Padden, IWS water quality sampling site, Whatcom County, September 12, 2012.

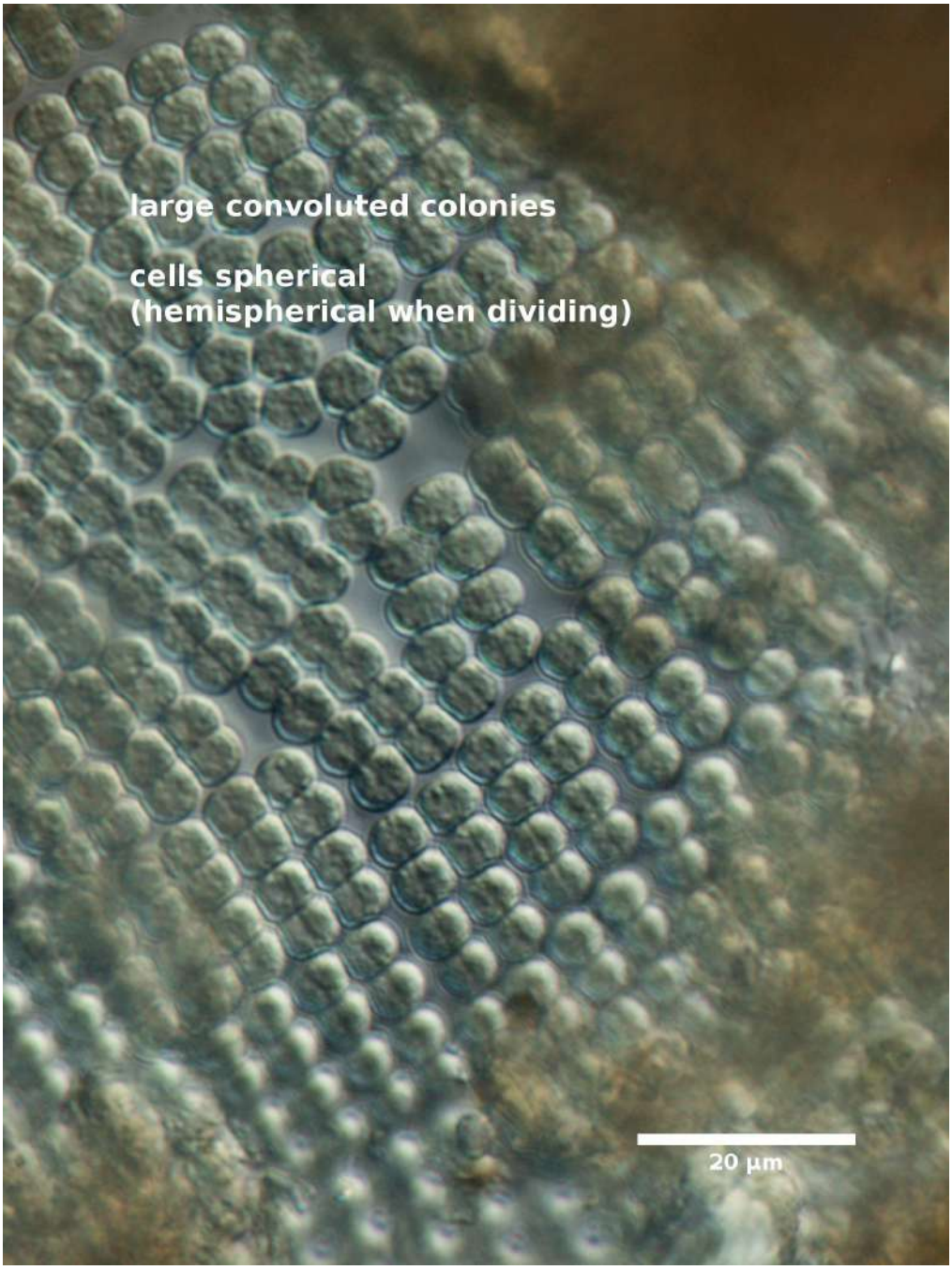


Figure 2.71: *Merismopedia convoluta* (600x DIC), Lake Padden, IWS water quality sampling site, Whatcom County, September 12, 2012.

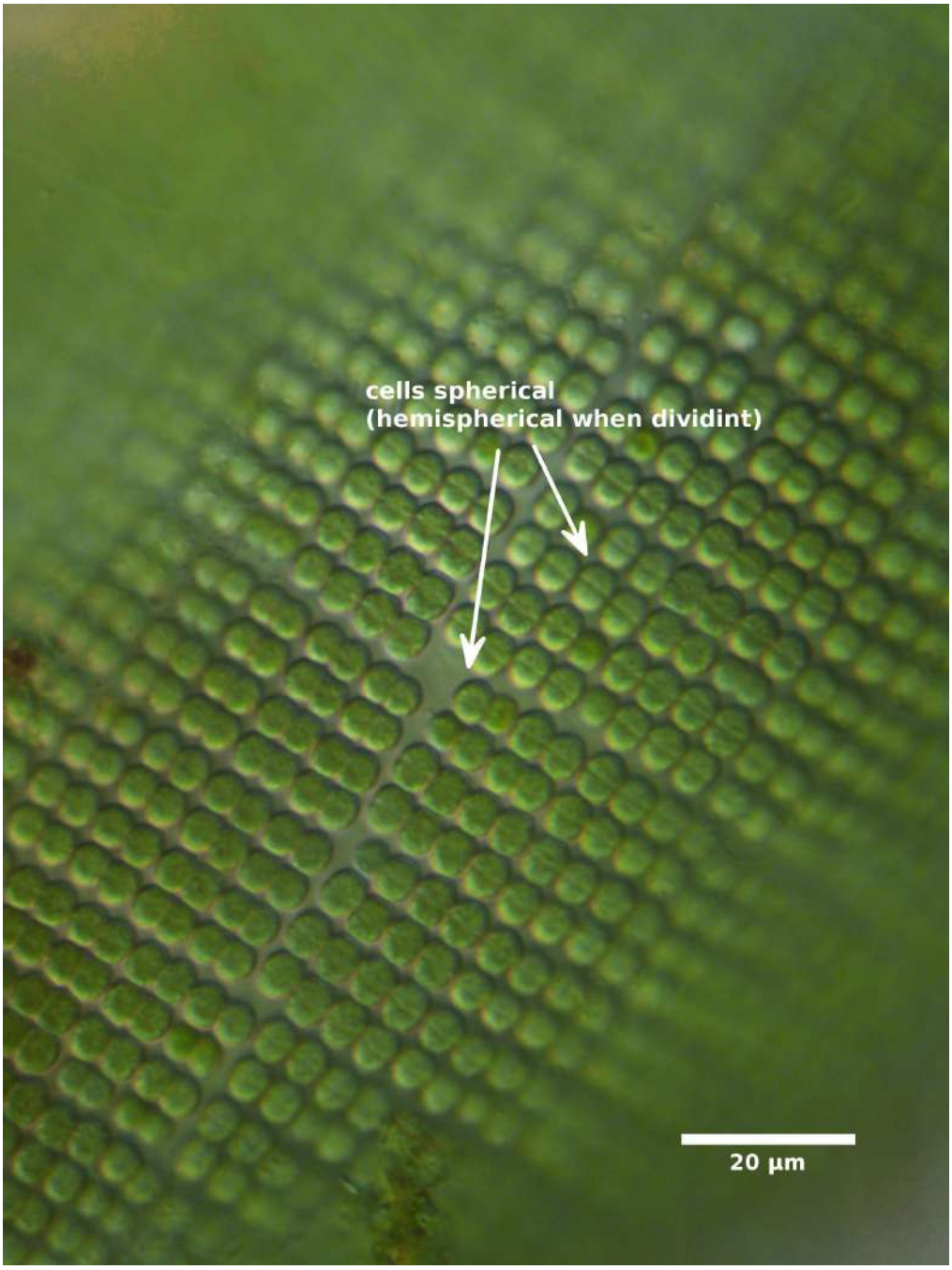


Figure 2.72: *Merismopedia convoluta* (600x DIC), Lake Sixteen, IWS water quality sampling site, Skagit County, July 21, 2015.

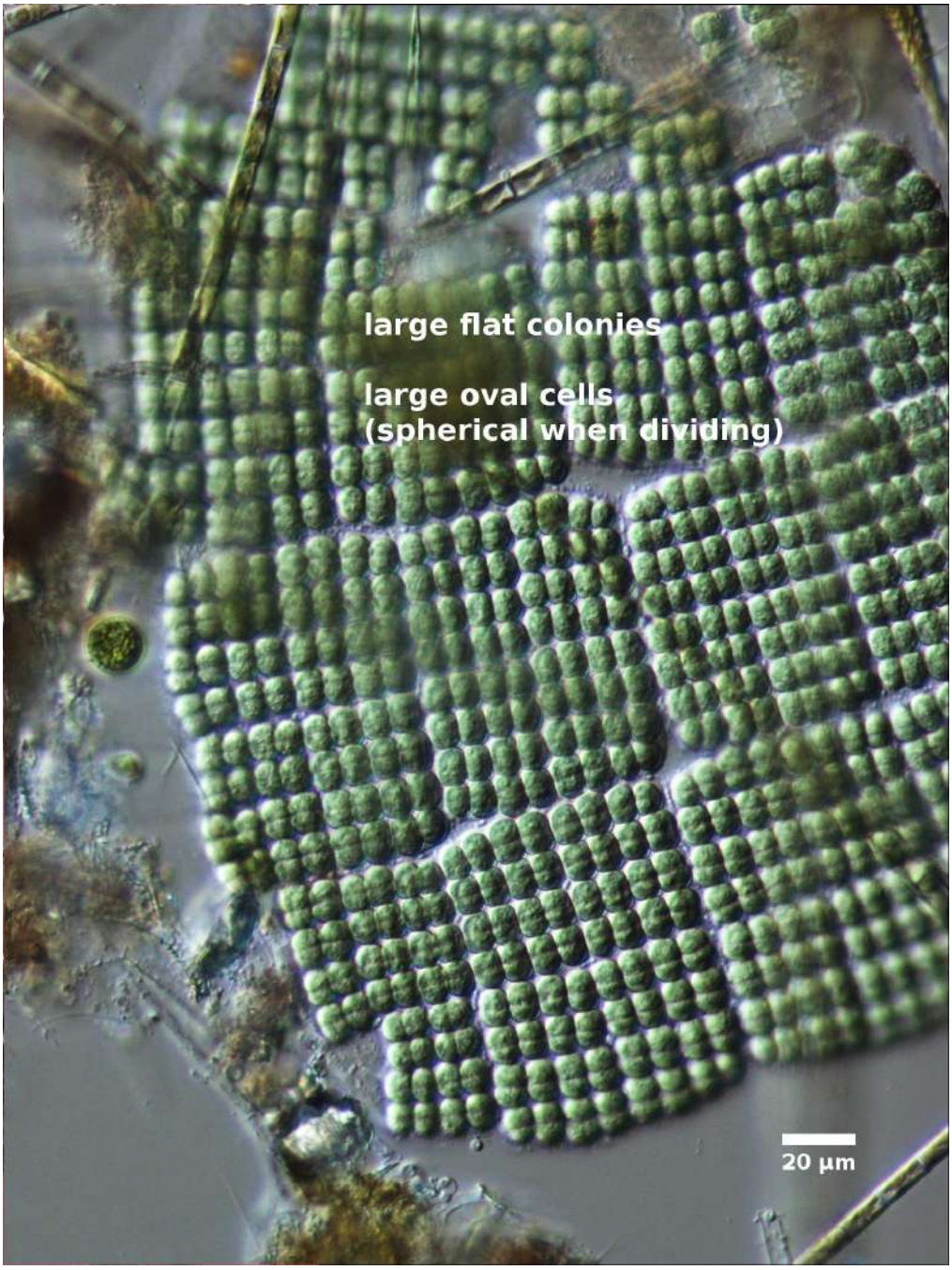


Figure 2.73: *Merismopedia elegans* (200x DIC), Cranberry Lake, IWS water quality sampling site, Island County, July 21, 2011.

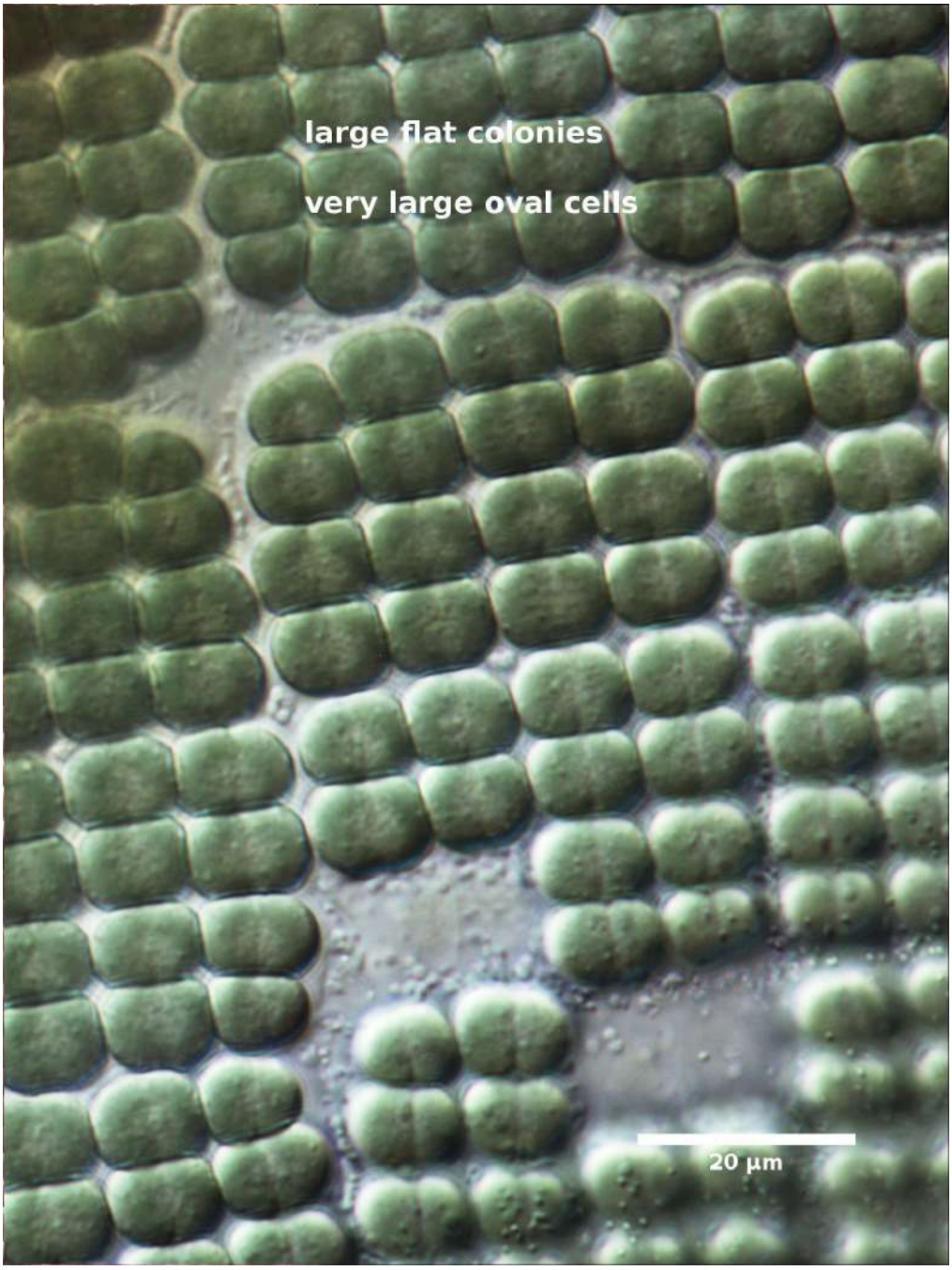


Figure 2.74: *Merismopedia elegans* (600x DIC), Cranberry Lake, IWS water quality sampling site, Island County, August 25, 2009.

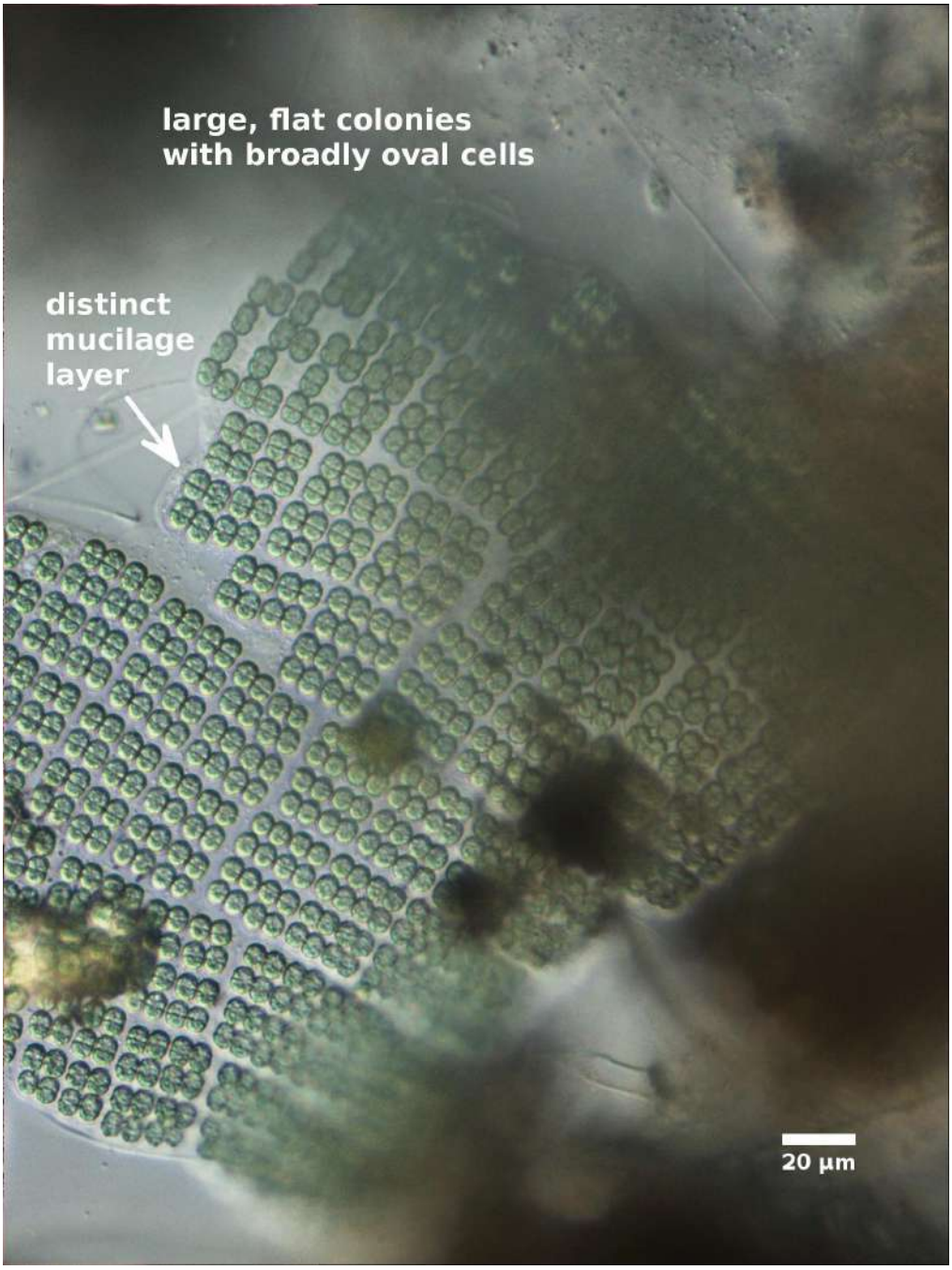


Figure 2.75: *Merismopedia elegans*? (200x DIC), Squires Lake, IWS water quality sampling site, Whatcom County, August 11, 2009.

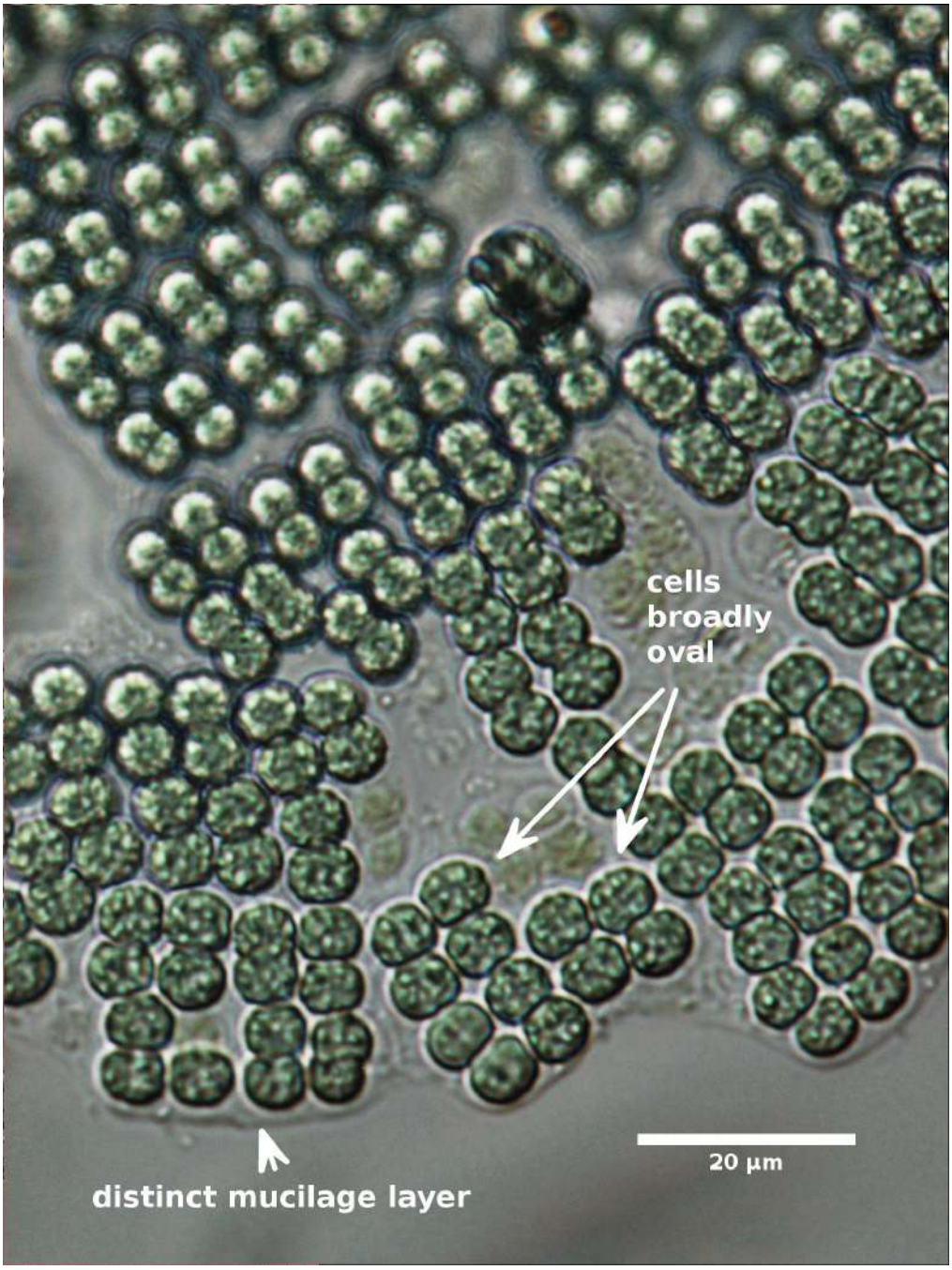


Figure 2.76: *Merismopedia elegans*? (600x DIC), Cain Lake, IWS water quality sampling site, Whatcom County, August 11, 2009.

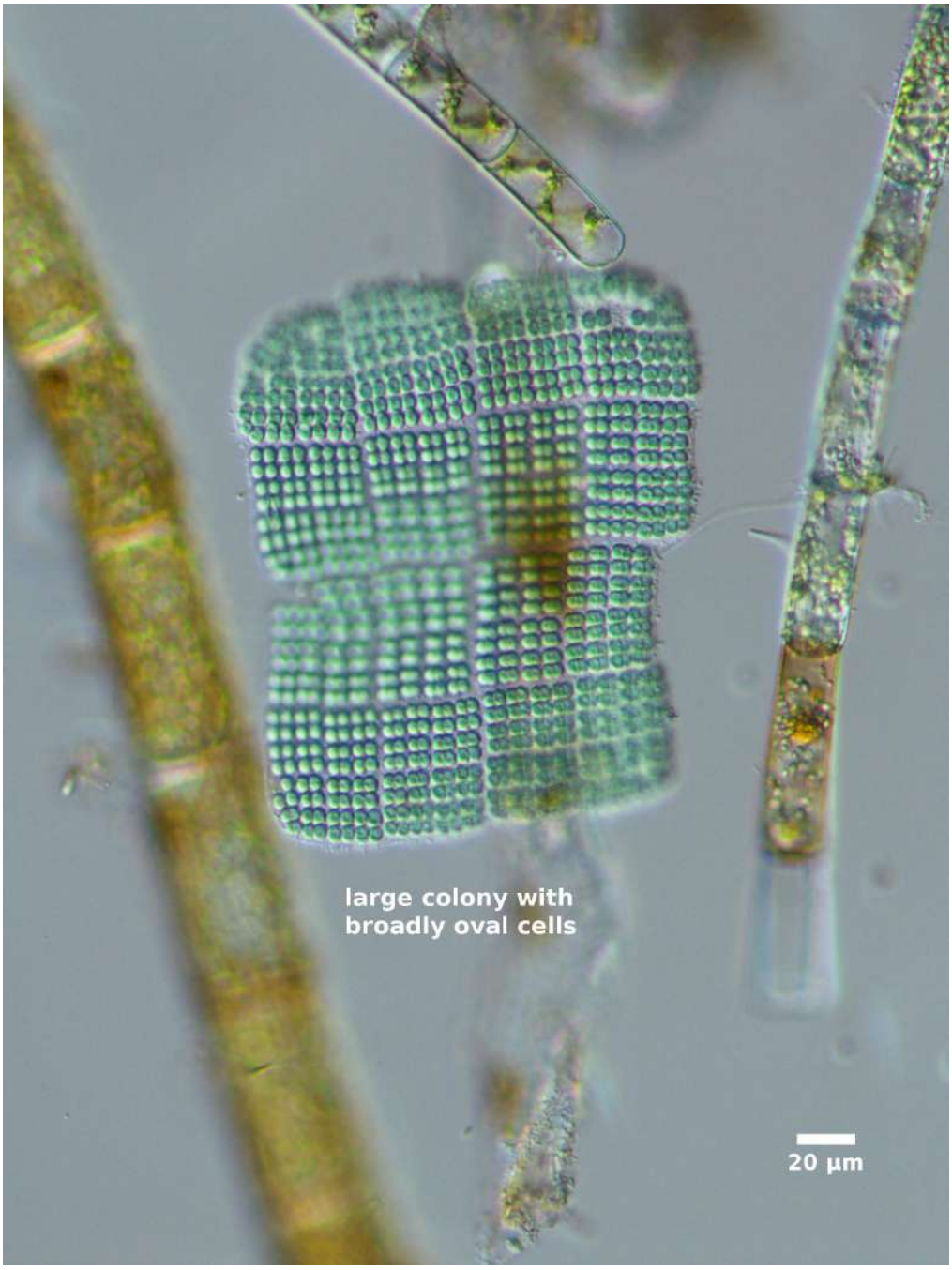


Figure 2.77: *Merismopedia elegans*? (200x DIC), Lake Terrell, IWS water quality sampling site, Whatcom County, May 29, 2015.

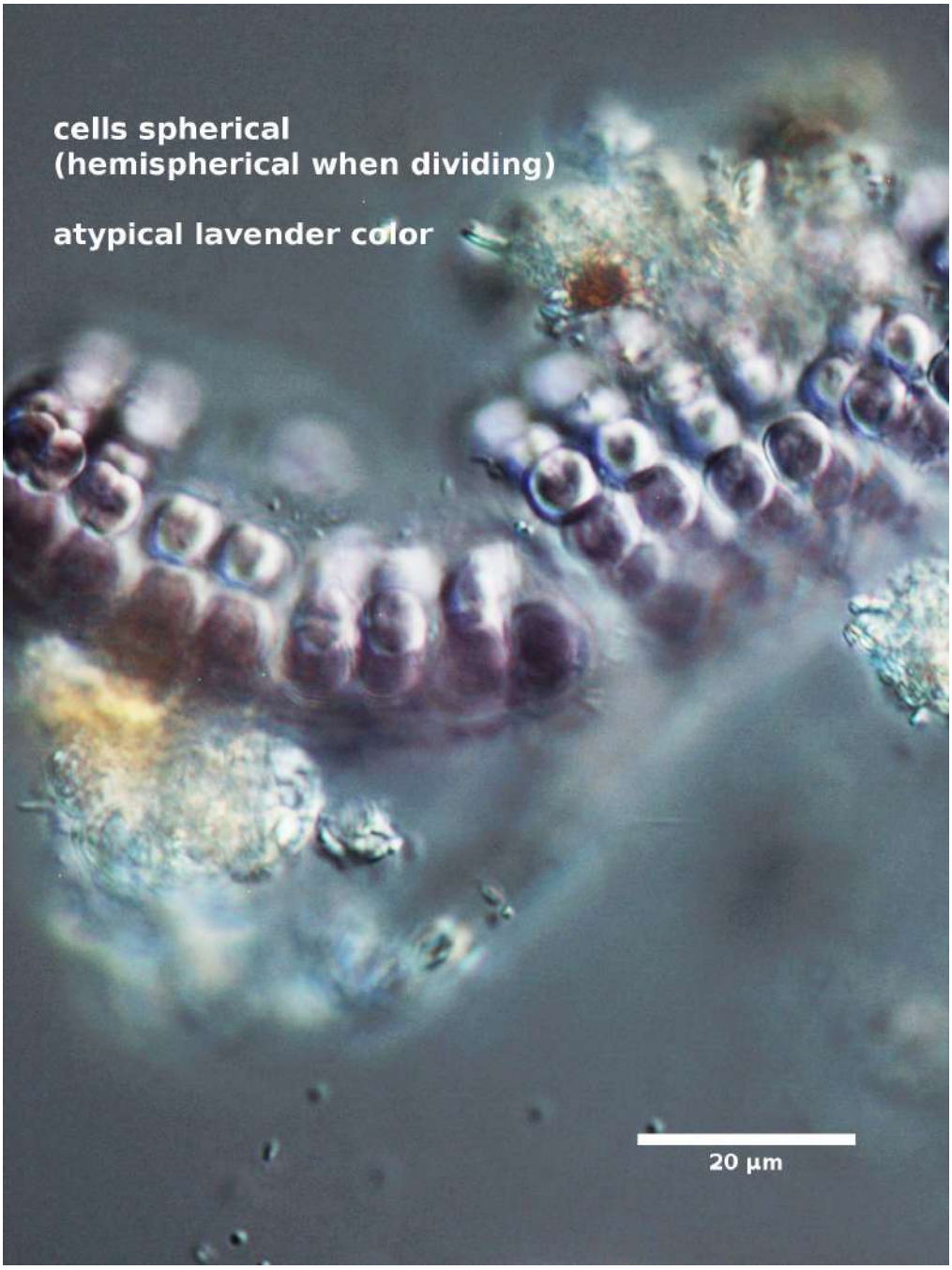


Figure 2.78: *Merismopedia glauca*? (lavender variation) (600x DIC), Lake Whatcom, IWS water quality sampling site, Whatcom County, November 13, 2013.

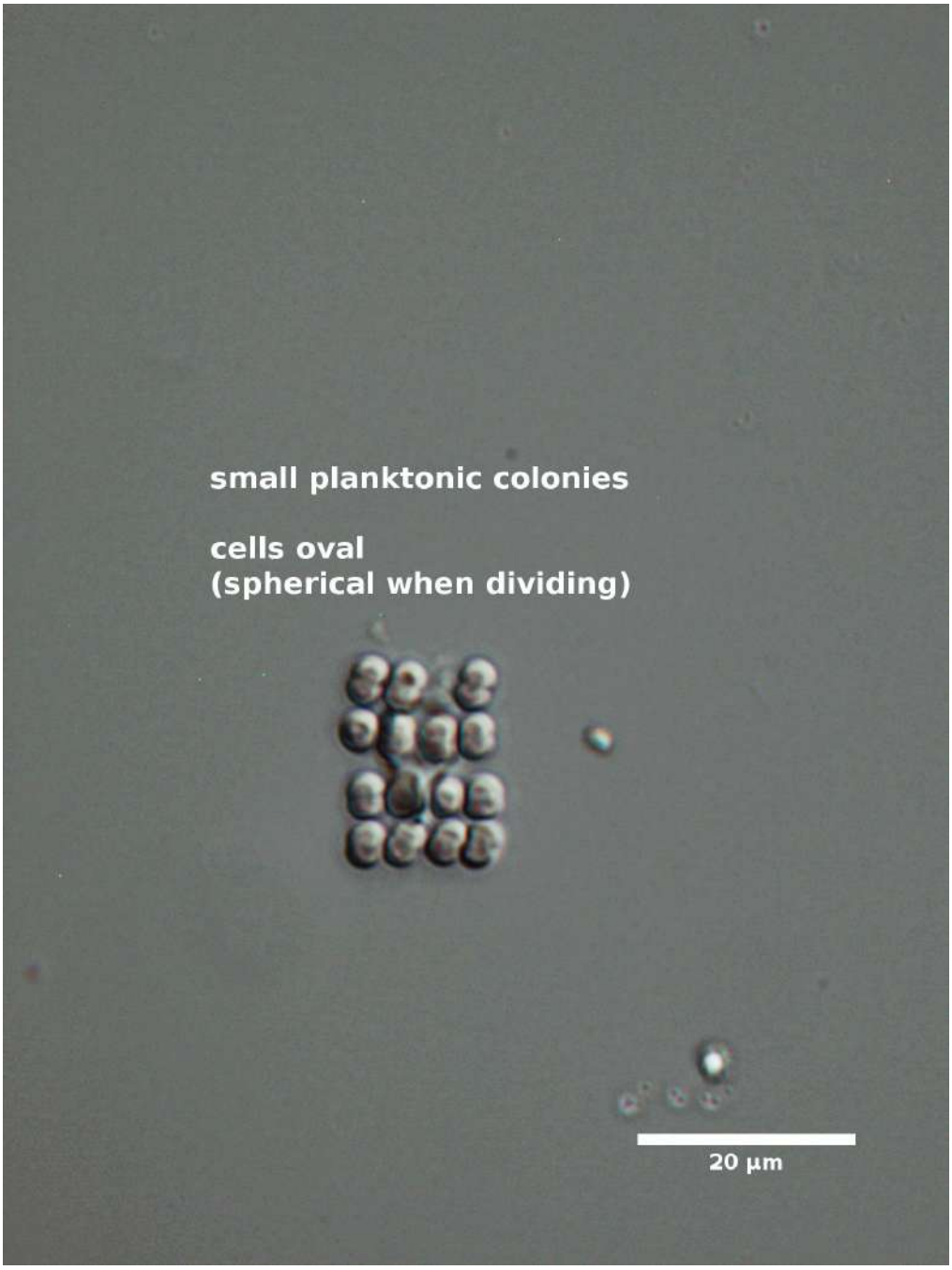


Figure 2.79: *Merismopedia punctata*? (600x DIC), Big Lake, IWS water quality sampling site, Skagit County, July 3, 2013.

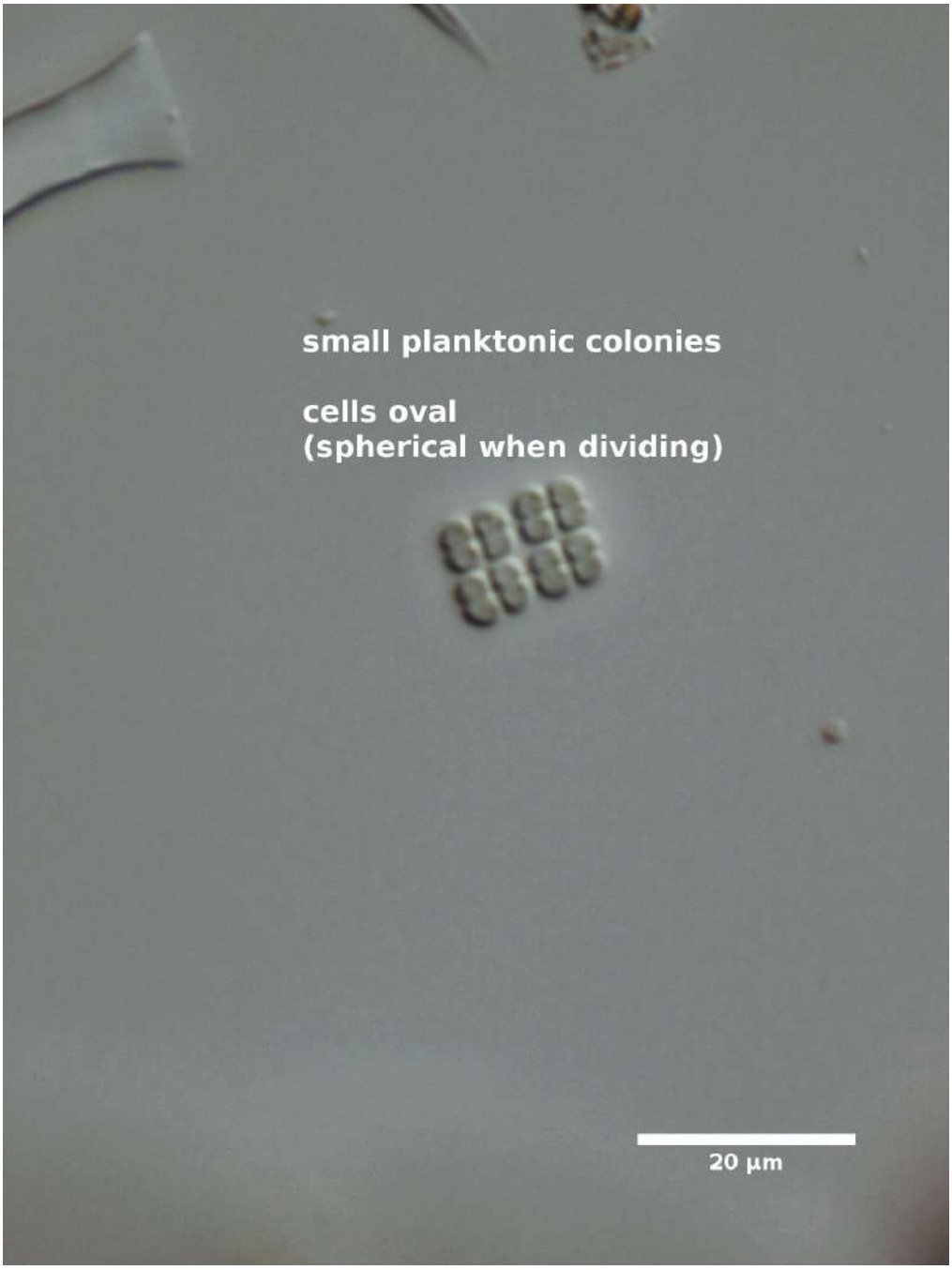


Figure 2.80: *Merismopedia punctata*? (600x DIC), Diablo Lake, Ross Lake National Recreational Area, September 21, 2012.

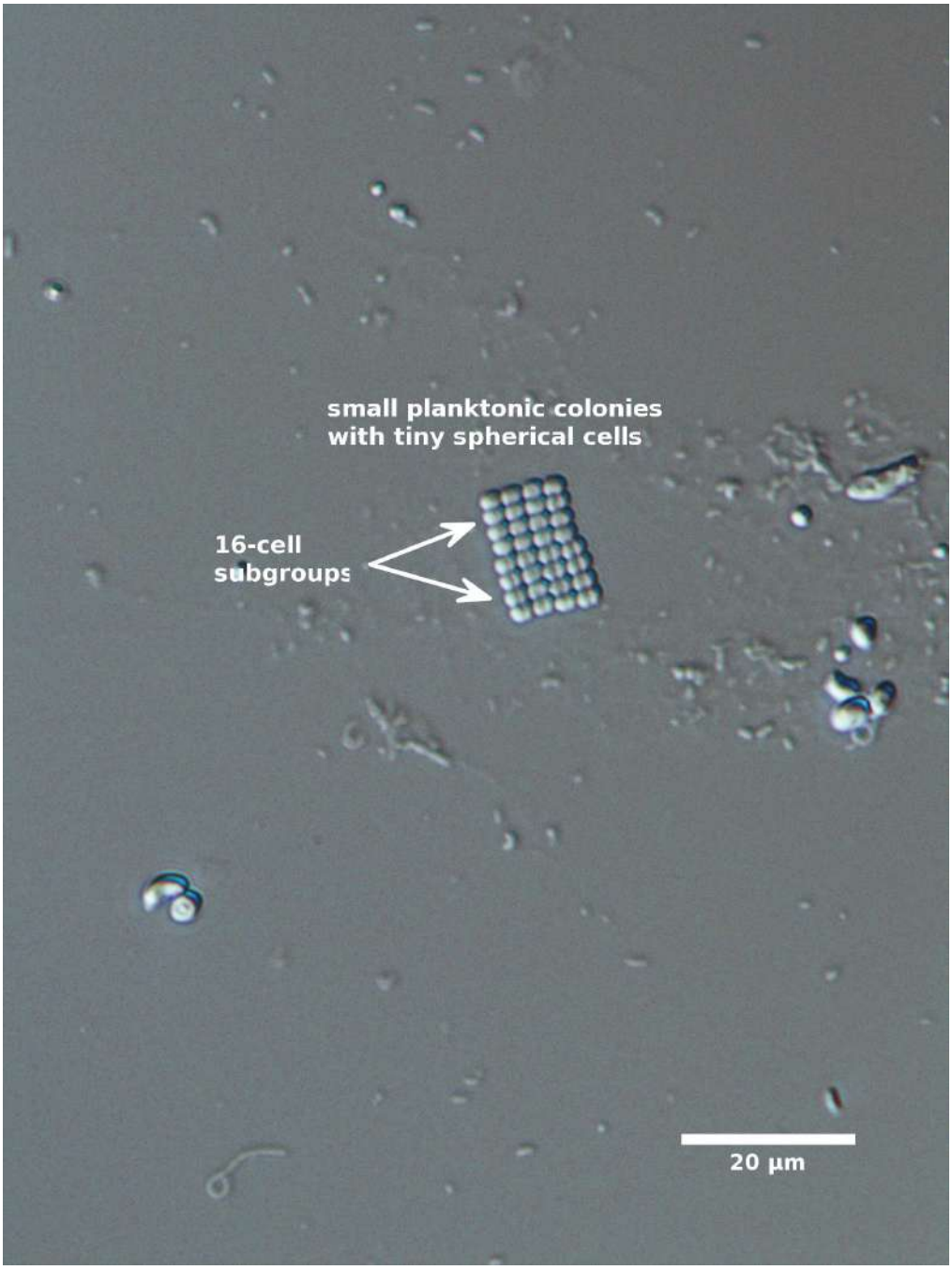


Figure 2.81: *Merismopedia tenuissima* (600x DIC), Lake Whatcom bioassay sample, IWS water quality sampling site, Whatcom County, September 8, 2014.

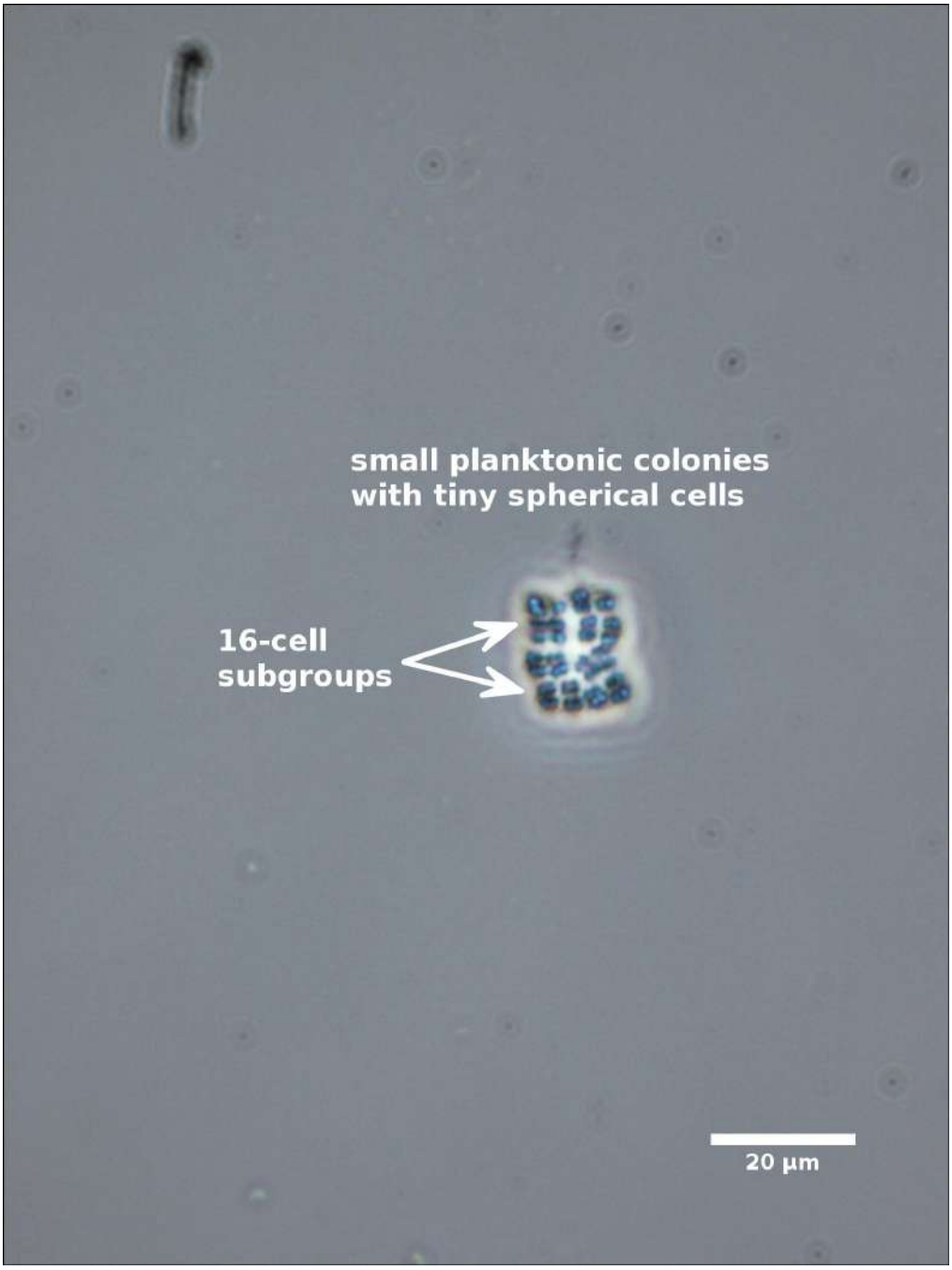


Figure 2.82: *Merismopedia tenuissima* (400x phase contrast), Squires Lake, IWS water quality sampling site, Whatcom County, November 6, 2006.



Figure 2.83: *Merismopedia tenuissima*? in Lugol's iodine solution (600x DIC), Lake Evan, IWS water quality sampling site, Snohomish County, July 31, 2014.

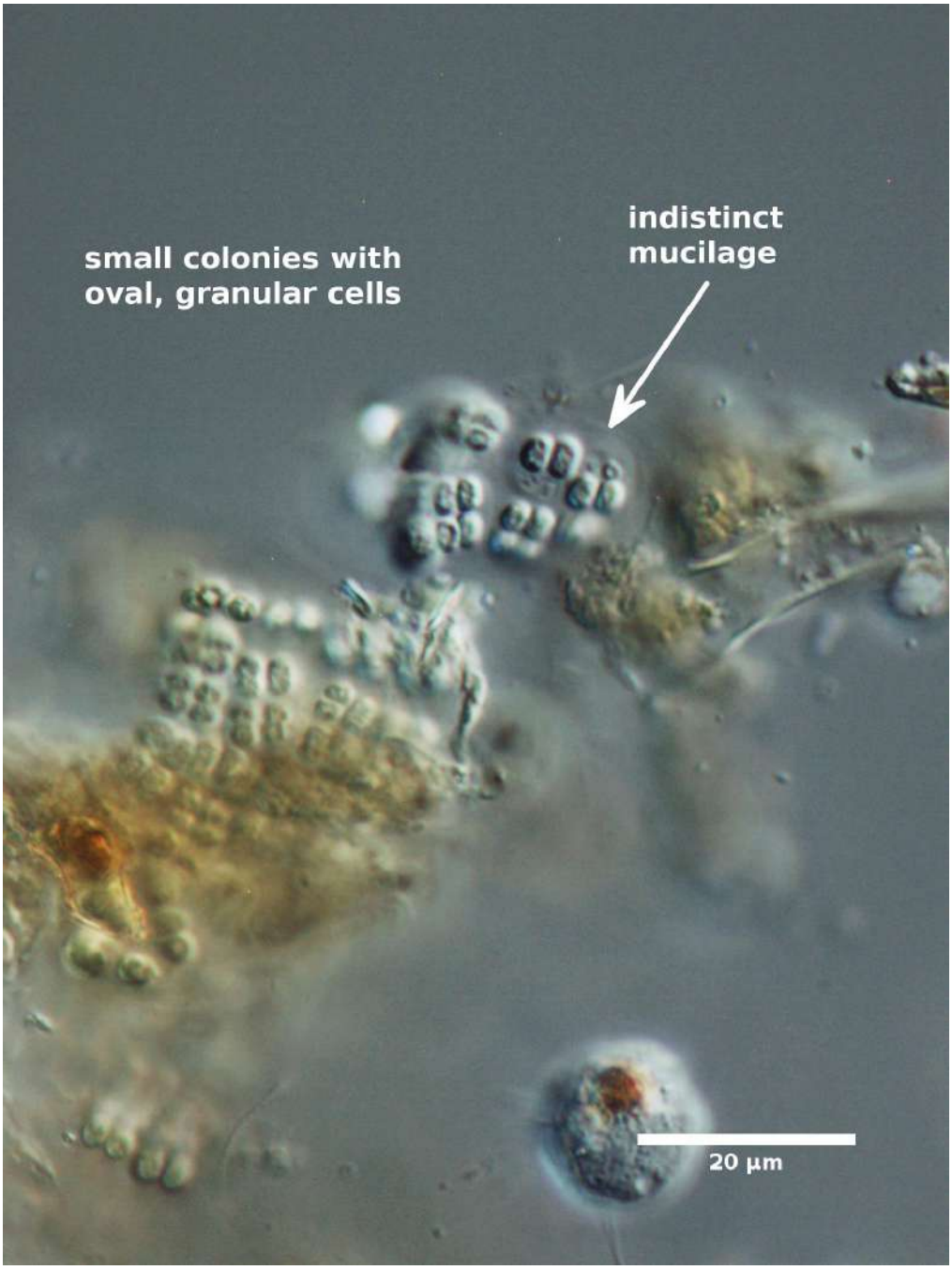


Figure 2.84: *Merismopedia* sp.1 (600x DIC), Highwood Lake, IWS water quality sampling site, Whatcom County, August 19, 2013.



Figure 2.85: *Merismopedia* sp.1 (600x DIC), Bear Lake, IWS water quality sampling site, Snohomish County, August 16, 2013.

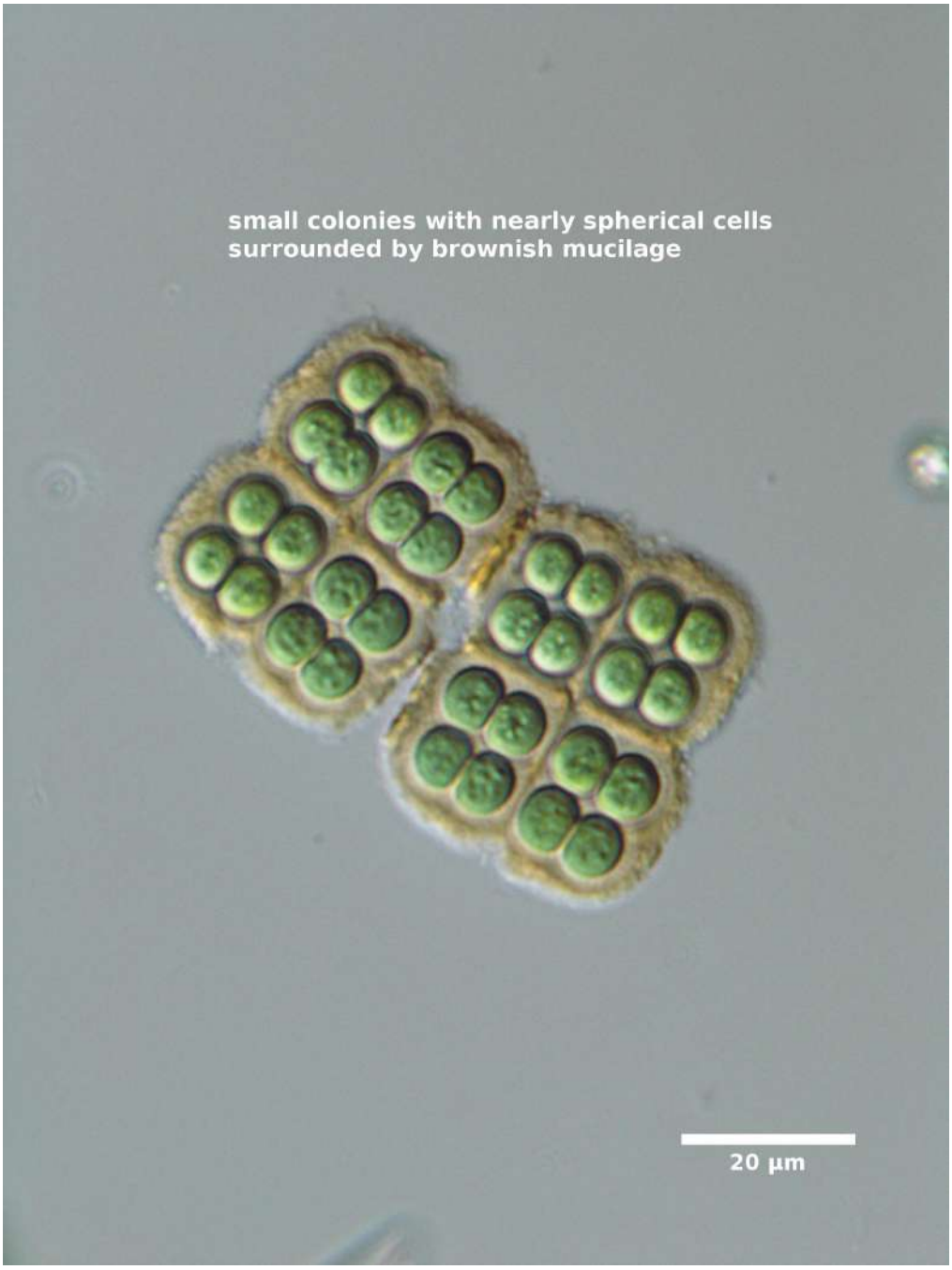


Figure 2.86: *Merismopedia* sp.2 (600x DIC), Lake Evan, IWS water quality sampling site, Snohomish County, July 22, 2015.



Figure 2.87: *Merismopedia* sp.2 (600x DIC), Lake Evan, IWS water quality sampling site, Snohomish County, August 21, 2014.



Figure 2.88: *Merismopedia* sp.3 (600x DIC), small pond on trail to Dock Butte, North Cascades along Hwy 20, July 3, 2015.

2.13 *Microcystis* Lemmermann

Local taxa
Microcystis aeruginosa (Kützing) Kützing;
Microcystis flosaquae (Wittrock) Kirchner;
Microcystis smithii Komárek & Anagnostidis?;
Microcystis wesenbergii (Komárek) Komárek ex. Komárek

Abundance
Microcystis aeruginosa is very common and may form blooms; *Microcystis wesenbergii* and *Microcystis flosaquae* are moderately common and may be present in large numbers; *Microcystis smithii* is infrequently collected.

Local measurements		Width	Length	Biovolume[†]
Microcystis aeruginosa	min	4.8 μm	5.1 μm	66.8 μm^3
cells (spheroid)	med	5.3 μm	6.1 μm	92.3 μm^3
	max	7.7 μm	7.4 μm	199 μm^3
Microcystis flosaquae	min	4.0 μm	5.0 μm	41.9 μm^3
cells (spheroid)	med	4.4 μm	5.3 μm	57.5 μm^3
	max	5.0 μm	6.2 μm	81.2 μm^3
Microcystis smithii?	min	5.0 μm	5.4 μm	70.7 μm^3
cells (spheroid)	med	5.8 μm	6.5 μm	114 μm^3
	max	6.2 μm	7.5 μm	151 μm^3
Microcystis wesenbergii	min	5.3 μm	5.7 μm	92.7 μm^3
cells (spheroid)	med	6.5 μm	7.1 μm	154 μm^3
	max	7.1 μm	7.9 μm	200 μm^3

[†]Calculated using original measurements, not summary values.

Description
Microcystis is a common water quality indicator that can form dense blooms in eutrophic lakes, often in association with *Aphanizomenon* (Section 3.3, page 250), *Dolichospermum* (Section 3.1, page 198), and *Gloeotrichia* (Section 3.9, page 293). Some strains can release toxins into the water.

Individual *Microcystis* cells are tiny, but often aggregate into large spherical or amorphous colonies (Figures 2.89–2.95). The cells are embedded in a colonial mucilage that may be diffuse or clearly visible, depending on the species and the age of the colony.

Microcystis aeruginosa is the most common local species, occasionally forming dense blooms. The colonies contain many small, closely spaced cells (Figures 2.89–2.91). The individual cells are spherical or broadly oval, dark brown, and may appear granular or mottled due to the presence of gas vacuoles. Young colonies are more or less spherical, but as the colony ages it becomes increasing irregular and clathrate (net-like). The colonies are enclosed in a diffuse mucilage layer that may not be visible without staining.

Microcystis aeruginosa is difficult to distinguish from *Microcystis flosaquae* (Figure 2.92). The primary distinctions are that *Microcystis flosaquae* colonies are consistently spherical, only rarely becoming clathrate; the cells are slightly smaller and more densely arranged compared to *M. aeruginosa*; and *M. flosaquae* is found is less nutrient rich lakes. Prescott (1962) argues against separating the species, stating that these morphological variations can be found within a single bloom. Komárek & Anagnostidis (1998) and John, et al. (2011) include detailed descriptions for both species, so the separation should be maintained. Most of the local specimens appear to be *Microcystis aeruginosa* based on cell size and the frequency of irregular and clathrate colonies. The local specimens identified as *Microcystis flosaquae* had smaller cells and dense, spherical colonies.

Microcystis smithii (Figure 2.93) forms spherical or slightly irregular colonies (never clathrate) containing loosely scattered blue-green or olive-green cells. The colony is surrounded by a clear mucilage that may be diffuse and hard to see without staining. The species identification is uncertain because only one colony has been collected and the cell dimensions exceed the range listed by Komárek & Anagnostidis (1998).

Microcystis wesenbergii colonies are large (often macroscopic) and initially spherical, but become increasingly irregular and clathrate as they age (Figures 2.94–2.95). The individual cells are about the same size or a little larger than *Microcystis aeruginosa* cells, but are less densely aggregated in the colony. The best distinguishing feature for *Microcystis wesenbergii* is the distinct colonial mucilage that extends 3–6 μm (or more) beyond the edge of the colony and is visible without staining.

Epiphytes are common on *Microcystis* colonies, especially *Pseudanabaena mucicola* (Figure 2.96), which is a specialist that grows in the mucilage surrounding Cyanobacteria colonies (see Section 4.9, page 447). *Microcystis* colonies have also been observed surrounded by what appears to be inactive *Chlamydomonas*, which is a type of single-cell green flagellate (Figures 2.97–2.99).[11] Kearns and Hunter (2001) reported that toxic strains of *Dolichospermum flosaquae* (Section 3.1, page 198) caused *Chlamydomonas* to become nonmotile. The ring of *Chlamydomonas* surrounding the *Microcystis* colonies may represent a similar phenomenon, with the *Chlamydomonas* cells inactivated by toxins released from the *Microcystis* colony.

[11] See **Freshwater Algae in Northwest Washington, Volume II. Chlorophyta and Rhodophyta**.



Figure 2.89: *Microcystis aeruginosa* (100x DIC), Pass Lake, IWS water quality sampling site, Skagit County, July 8, 2013.

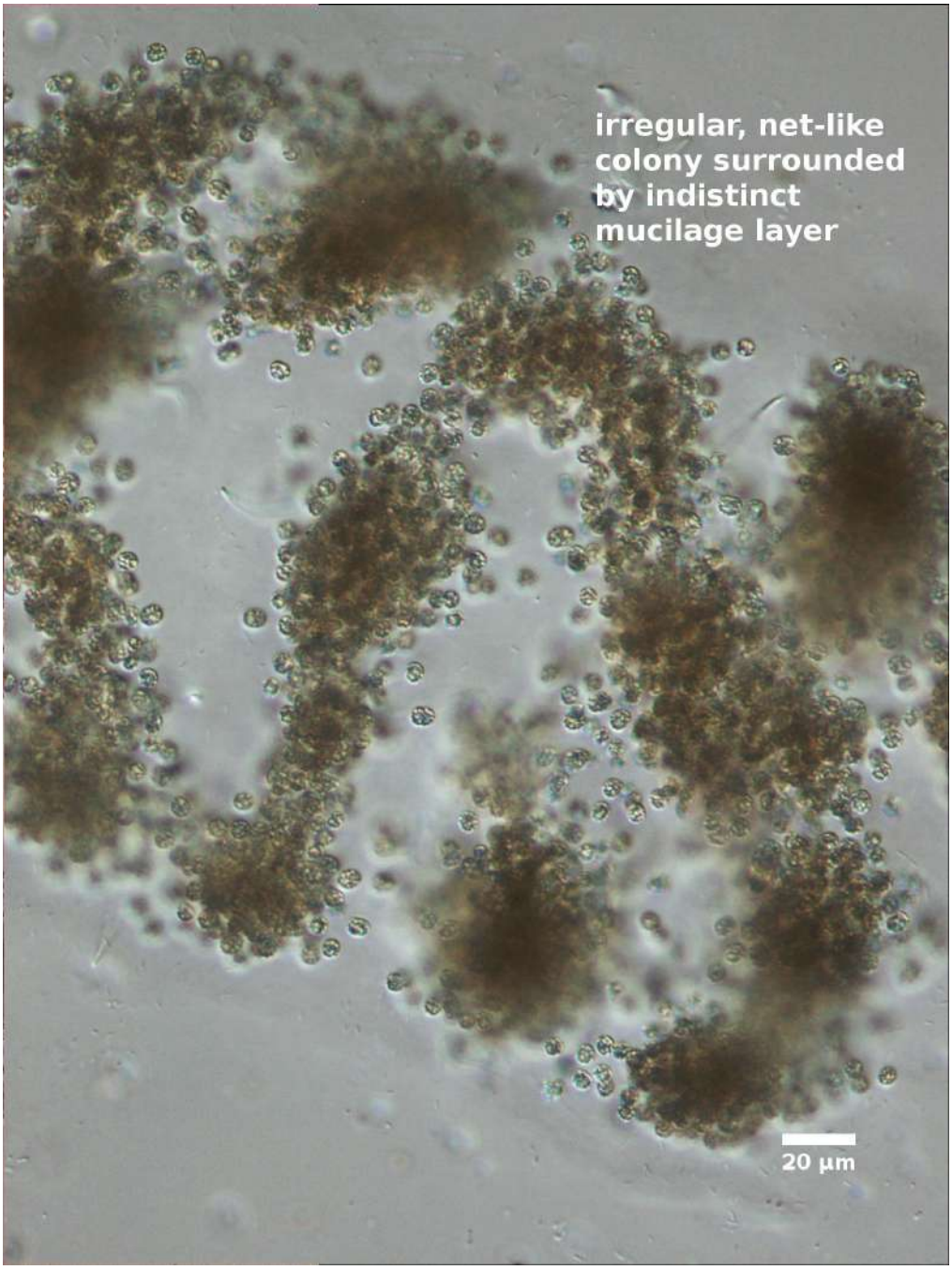


Figure 2.90: *Microcystis aeruginosa* (200x DIC), Lake Whatcom, IWS water quality sampling site, Whatcom County, September 17, 2009.

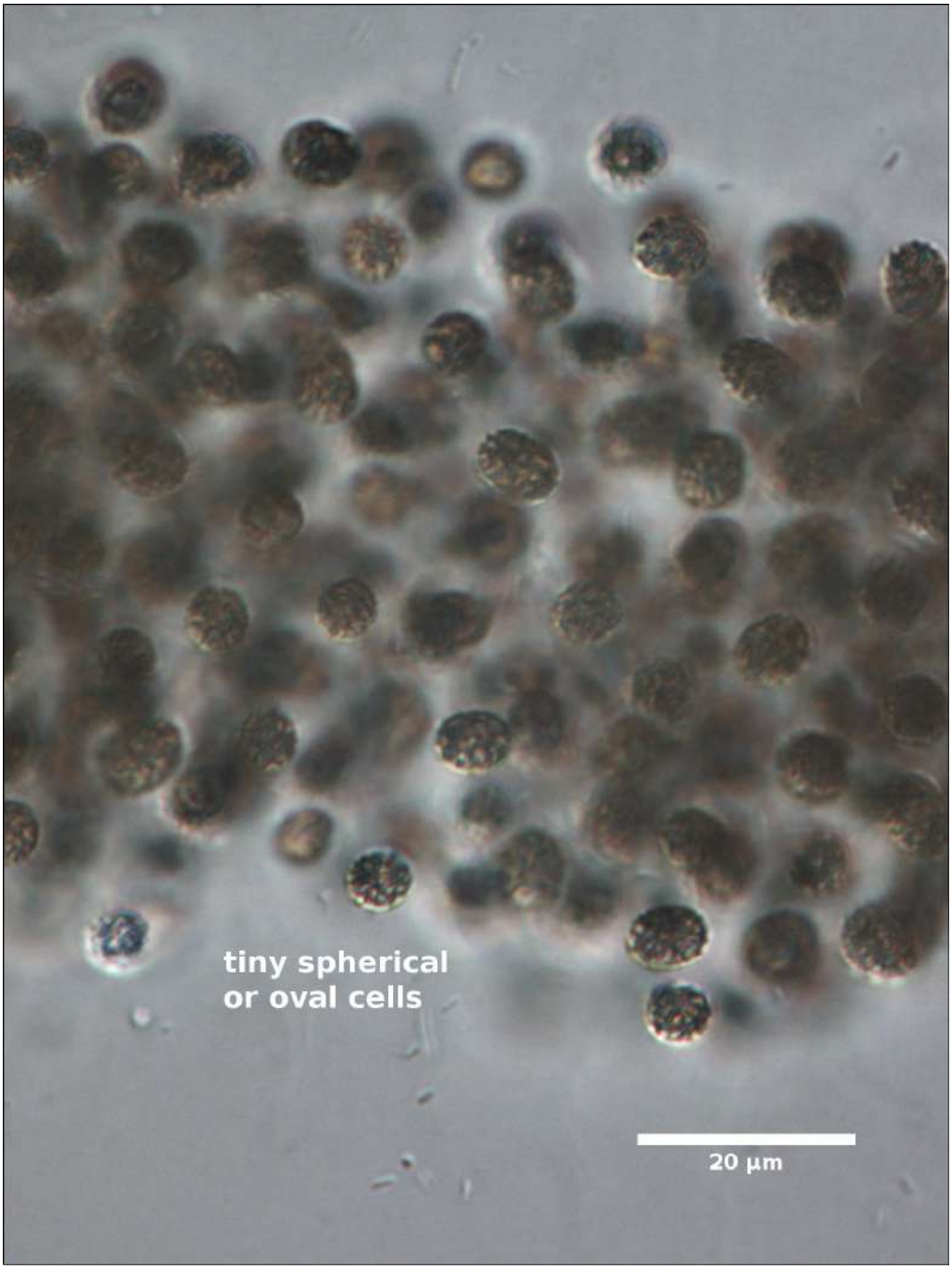


Figure 2.91: *Microcystis aeruginosa* (600x DIC), Judy Reservoir, IWS water quality sampling site, Skagit County, March 30, 2007.



Figure 2.92: *Microcystis flosaquae* (200x DIC), Lake Samish, IWS water quality sampling site, Whatcom County, August 26, 2013.

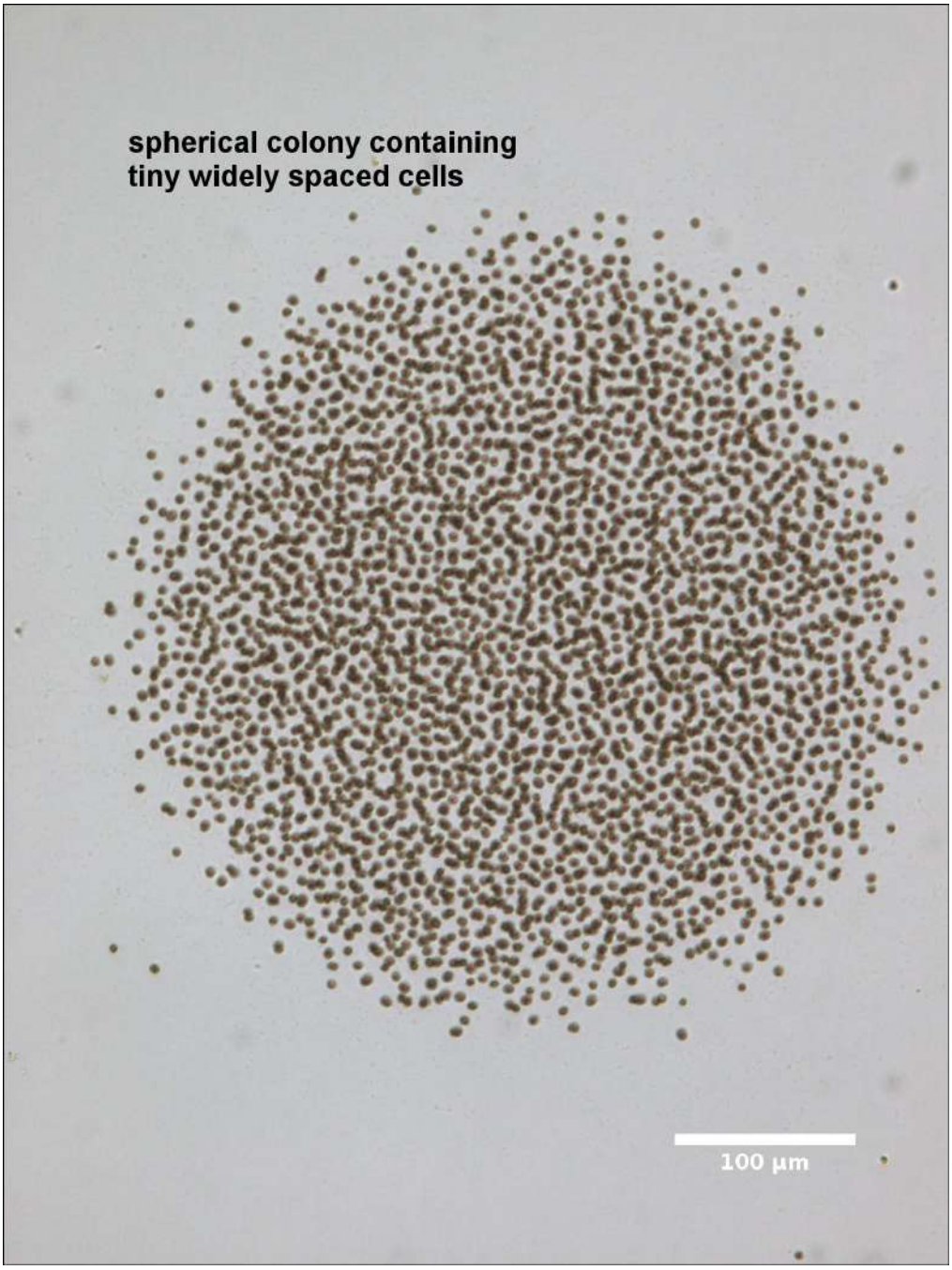


Figure 2.93: *Microcystis smithii*? (100x brightfield), Lake Samish, IWS water quality sampling site, Whatcom County, October 23, 2006.



Figure 2.94: *Microcystis wesenbergii* stained with methylene blue (200x DIC), Lake Ketchum, IWS water quality sampling site, Snohomish County, July 16, 2013.



Figure 2.95: *Microcystis wesenbergii* (200x DIC), Lake Whatcom, IWS water quality sampling site, Whatcom County, October 2, 2014.

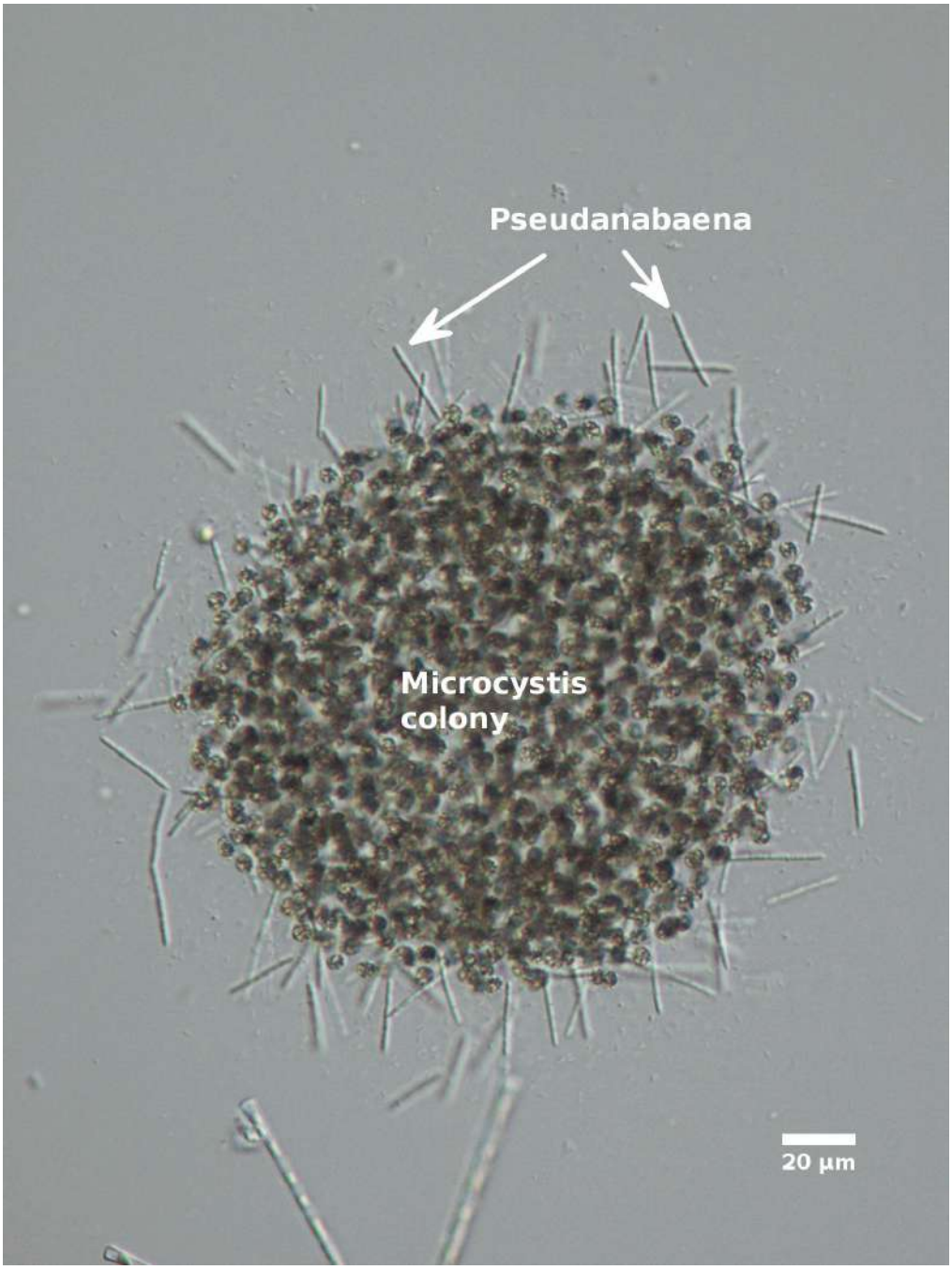


Figure 2.96: *Microcystis aeruginosa* with epiphytic *Pseudanabaena mucicola* (200x DIC), Grandy Lake, IWS water quality sampling site, Skagit County, August 6, 2013.

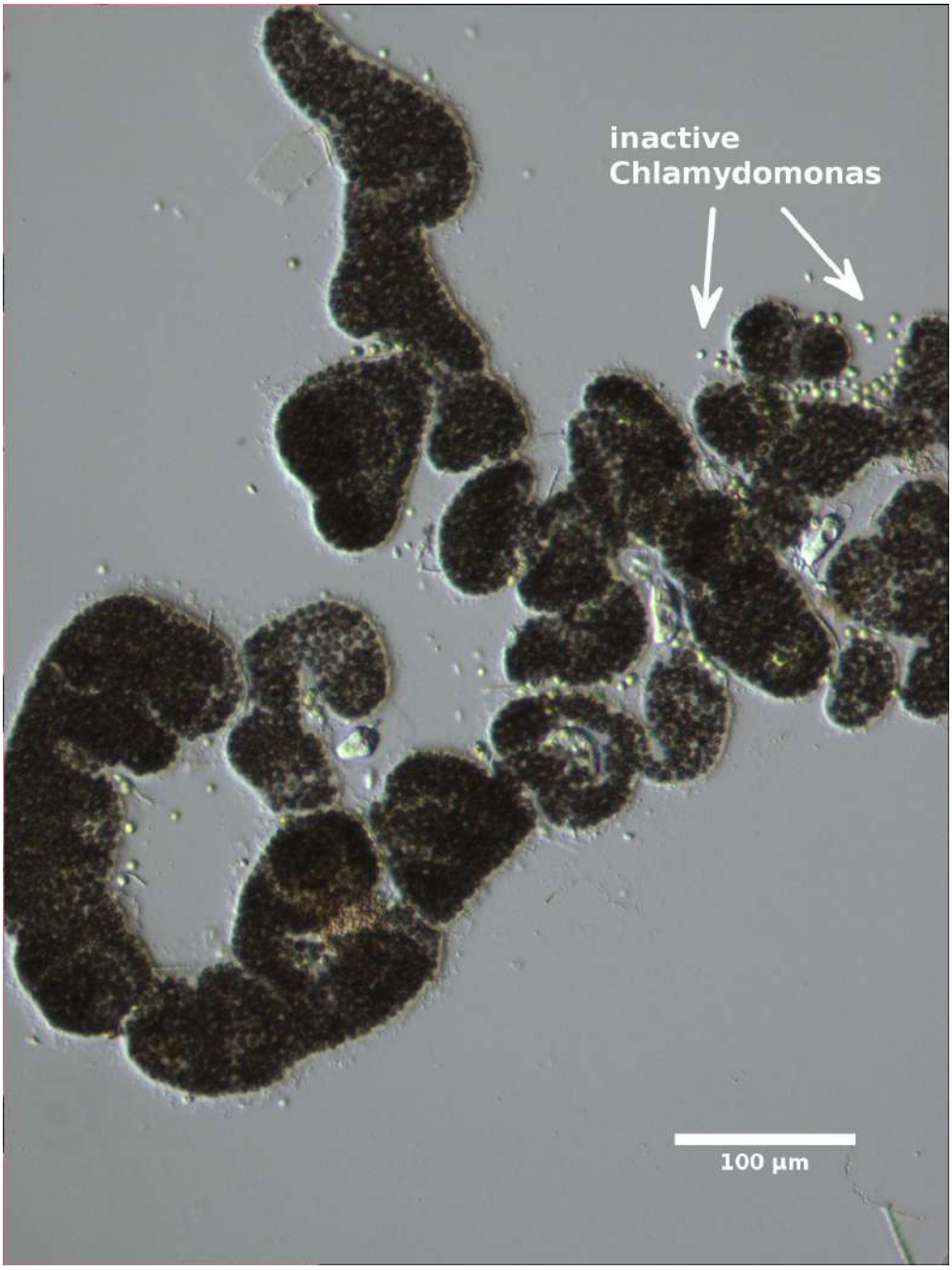


Figure 2.97: *Microcystis wesenbergii* and inactive *Chlamydomonas* (100x DIC), Lone Lake, IWS water quality sampling site, Island County, July 18, 2011.

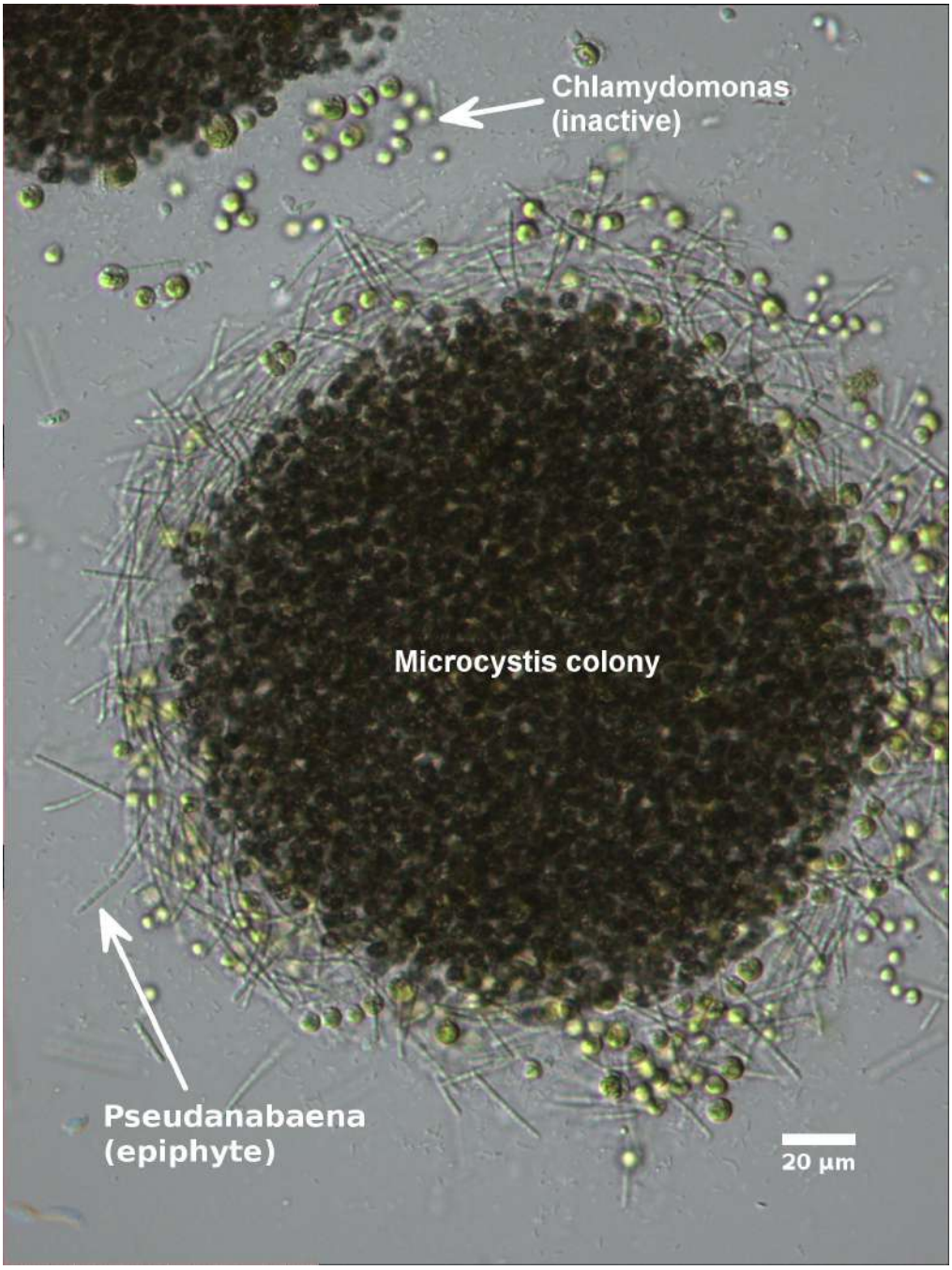


Figure 2.98: *Microcystis aeruginosa* with epiphytic *Pseudanabaena mucicola* and inactivated *Chlamydomonas* (200x DIC), Lone Lake, IWS water quality sampling site, Island County, July 19, 2011.



Figure 2.99: *Microcystis aeruginosa* and inactive *Chlamydomonas* (600x DIC), Lone Lake, IWS water quality sampling site, Island County, July 18, 2011.

2.14 *Pannus* Hickel

Local taxon
Pannus planus Hindák?

Abundance
Infrequently collected; occasionally forms blooms.

Local measurements		Width	Length	Biovolume[†]
Pannus planus?	min	2.1 μm	–	4.85 μm^3
cells (sphere)	med	2.5 μm	–	7.71 μm^3
	max	3.0 μm	–	14.1 μm^3

[†]Calculated using original measurements, not summary values.

Description
Pannus cells divide in two alternating planes, similar to *Merismopedia* (Section 2.12, page 118), but the cells don't form regular rows and columns. Instead, the cells form amorphous, flat colonies that are only one cell thick (Figures 2.100–2.102). The individual cells are spherical, pale blue-green or gray, and have a homogeneous cell content. The cells are embedded in a diffuse colonial mucilage that may be visible at the edges of the colony.

Pannus planus forms spherical, oval, or irregular colonies that are intact, not clathrate (net-like). The local specimens have a distinct mucilage layer that extends beyond the ends of the colony. The cells are slightly larger than the size range described by Komárek & Anagnostidis (1998), so the species identification is tentative. A similar species, *Pannus microcystiformis* Hindák (=*Sphaerocavum microcystiforme* [Hindák] Azededo & Sant' Anna), has larger cells (2–3 μm diameter), but *Pannus microcystiformis* cells contain distinct gas vacuoles and the colonies are irregular and clathrate (net-like). None of these features were apparent in the local *Pannus* specimens.

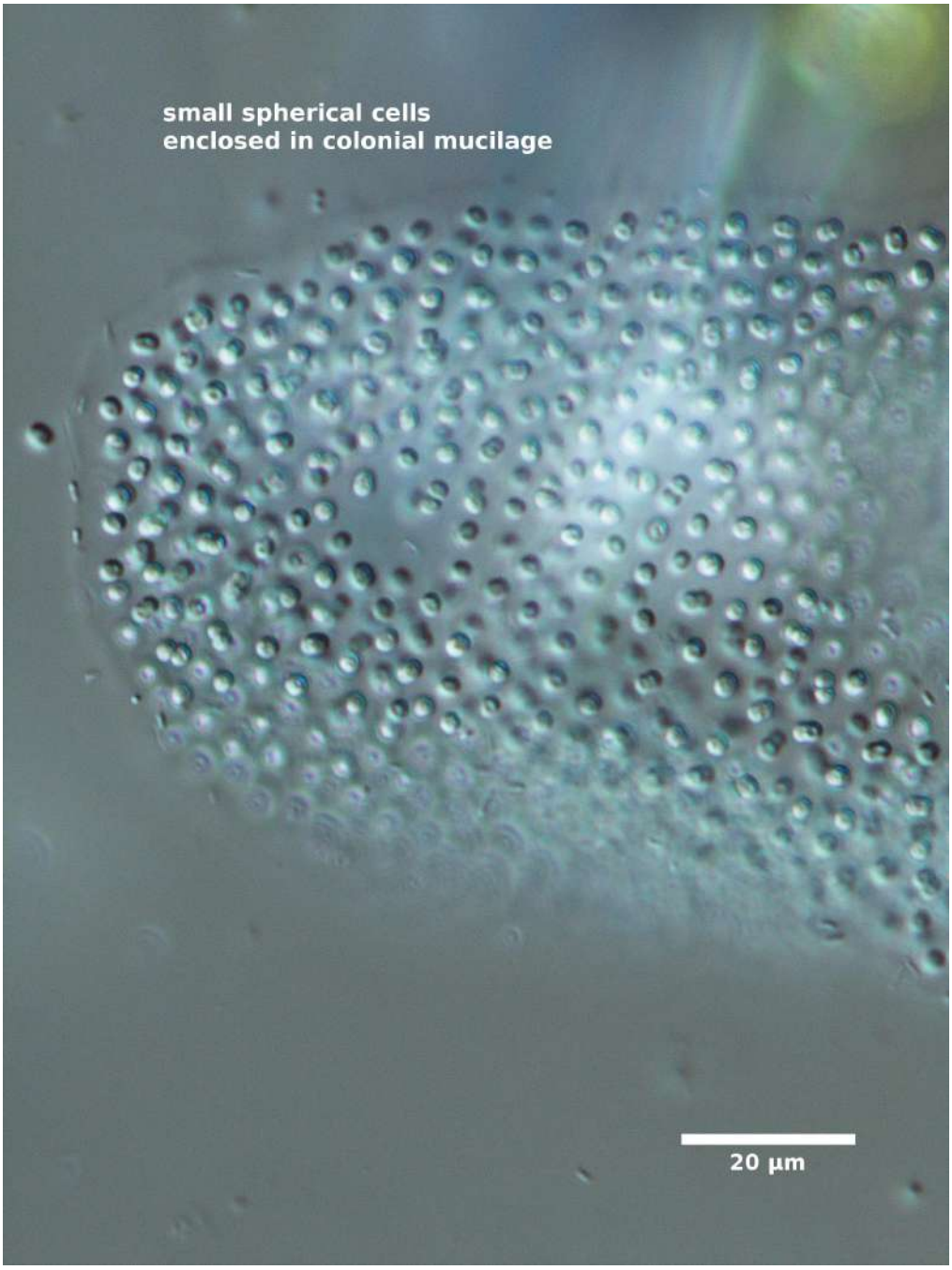


Figure 2.100: *Pannus planus*? (600x DIC), Little Twin Lake (Winthrop area), eastern Washington, June 18, 2014.

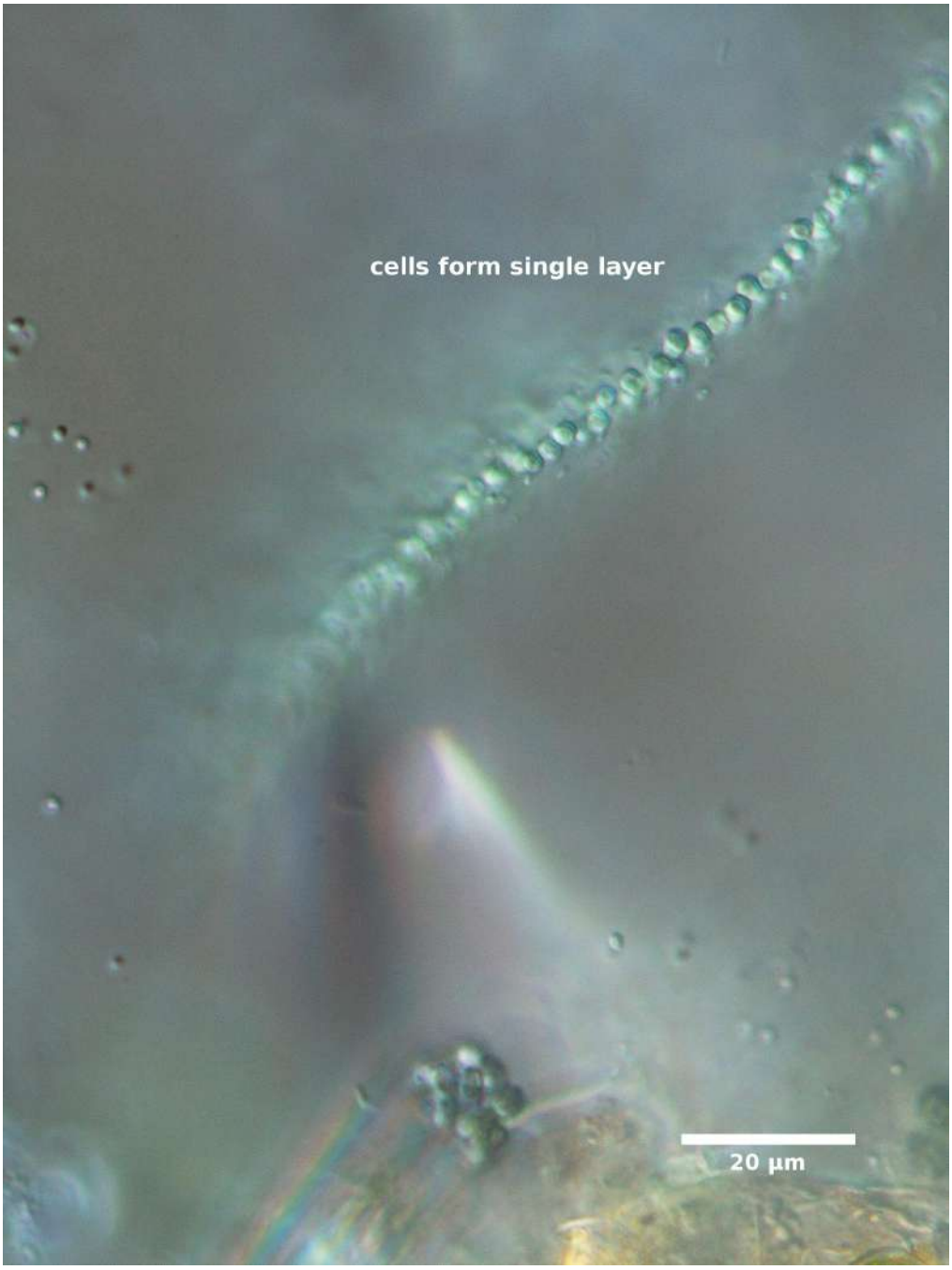


Figure 2.101: *Pannus planus*? (600x DIC), Little Twin Lake (Winthrop area), eastern Washington, June 18, 2014.

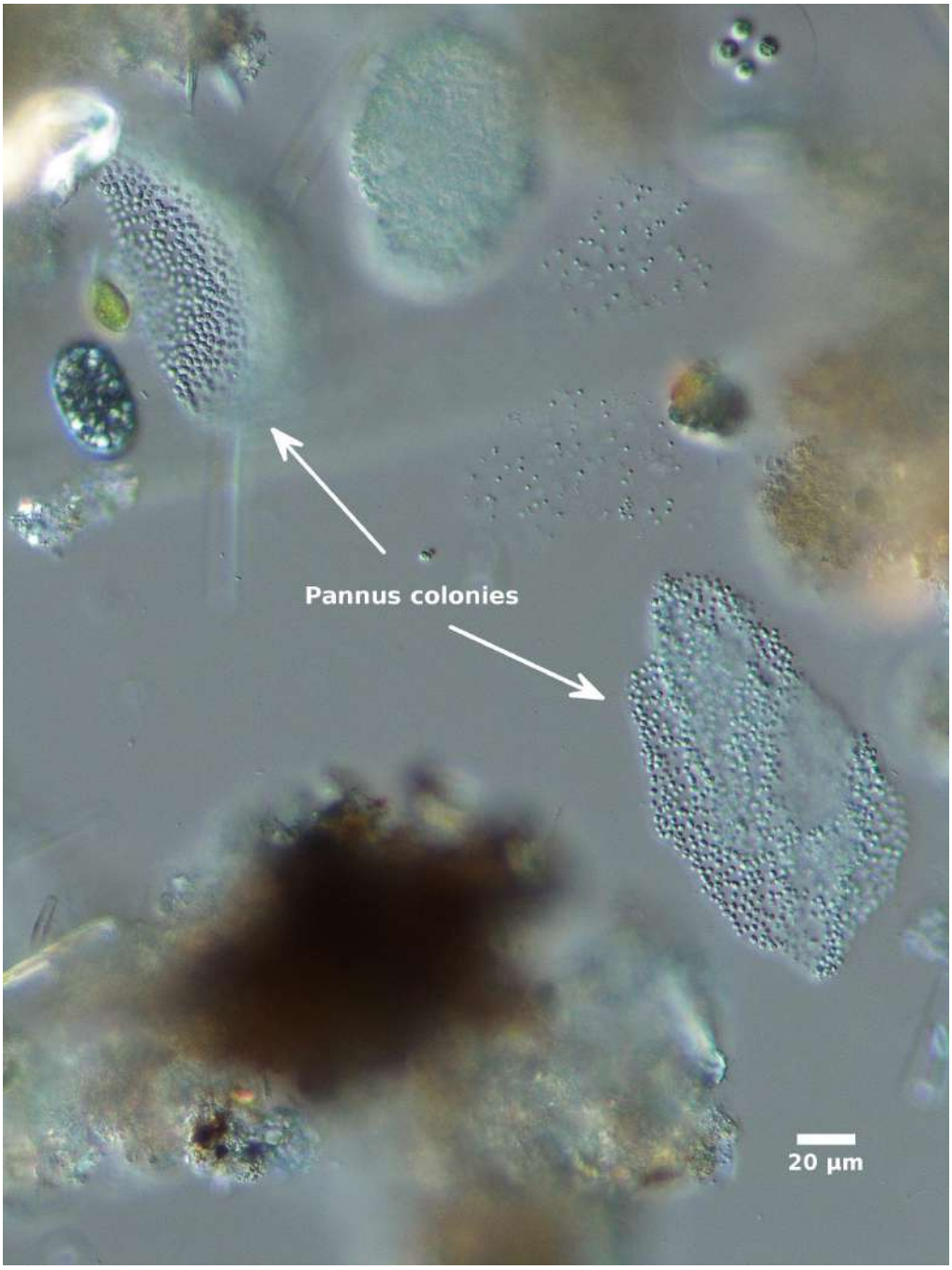


Figure 2.102: *Pannus planus*? (200x DIC), Little Twin Lake (Winthrop area), eastern Washington, June 18, 2014.

2.15 *Rhabdoderma* Schmidle & Lauterborn and *Rhabdogloea* Schröder

Local taxa
Rhabdoderma lineare Schmidle & Lauterborn;
Rhabdogloea linearis (Geitler) Komárek;
Rhabdogloea sp.1?

Abundance
Rhabdoderma lineare is moderately common, but rarely present in large numbers; *Rhabdogloea* is infrequently collected.

Local measurements		Width	Length	Biovolume[†]
Rhabdoderma lineare	min	2.3 μm	6.8 μm	23.5 μm^3
cells (cyl + two $\frac{1}{2}$ spheres)[‡]	med	3.0 μm	12.6 μm	49.3 μm^3
	max	3.6 μm	24.4 μm	136 μm^3
Rhabdogloea linearis	min	2.2 μm	7.6 μm	20.0 μm^3
cells (cyl + two $\frac{1}{2}$ spheres)[‡]	med	2.6 μm	9.1 μm	26.4 μm^3
	max	2.8 μm	10.7 μm	34.9 μm^3
Rhabdogloea sp.1?	min	4.1 μm	11.2 μm	70.6 μm^3
cells (cyl + two $\frac{1}{2}$ spheres)[‡]	med	4.7 μm	12.9 μm	110 μm^3
	max	4.7 μm	17.1 μm	138 μm^3

[†]Calculated using original measurements, not summary values.
[‡]Biovolume based on cylinder length ($<$ cell length).

Description
Rhabdoderma and *Rhabdogloea* form pseudofilaments of long, rod-shaped cells that are enclosed in a distinct mucilage layer (Figures 2.103–2.109). Because the cells are not actually joined after division, they become displaced inside the mucilage, forming indistinct, gelatinous colonies that only reveal the pseudofilamentous structure in recently divided cells. *Rhabdoderma* pseudofilaments display a considerable amount of morphological variability, making them difficult to distinguish from *Rhabdogloea*.

Rhabdoderma lineare colonies usually contain no more than 16 elongate or rod-shaped cells enclosed in a diffuse mucilage layer that may be difficult to see without staining (Figures 2.103–2.105). The pale blue-green or gray-green cells are oriented in approximately the same direction in the colony and have a homogeneous cellular content. The cells divide perpendicular to the long axis of the cell, so recently divided cell pairs may be slightly asymmetric and flattened on their inner walls (Figures 2.104–2.105). All of the local specimens were collected in plankton samples from low elevation mesotrophic lakes

Rhabdogloea linearis (Figures 2.106–2.107) is characterized by small colonies of rod-shaped cells that are slightly granular and enclosed in a distinct mucilage layer. This species closely resembles *Rhabdoderma lineare*, but can be distinguished by the clearly visible colonial mucilage; the tendency for the cells to become displaced in the colony, losing their pseudofilamentous structure; and the collection location. This species is normally associated with peaty water (Komárek and Anagnostidis, 1998), and all of the local specimens were collected is boggy mountain lakes.

The specimens in Figures 2.108–2.109 are tentatively identified as a species of *Rhabdogloea* based on the granular cell contents and collection location (boggy mountain lake). But the cells form distinct, end-to-end pseudofilaments and are surrounded by a diffuse mucilage, which are characteristics of *Rhabdoderma*. The cell dimensions do not match any of the *Rhabdoderma* or *Rhabdogloea* species described by Komárek and Anagnostidis (1998) or John et al. (2011).

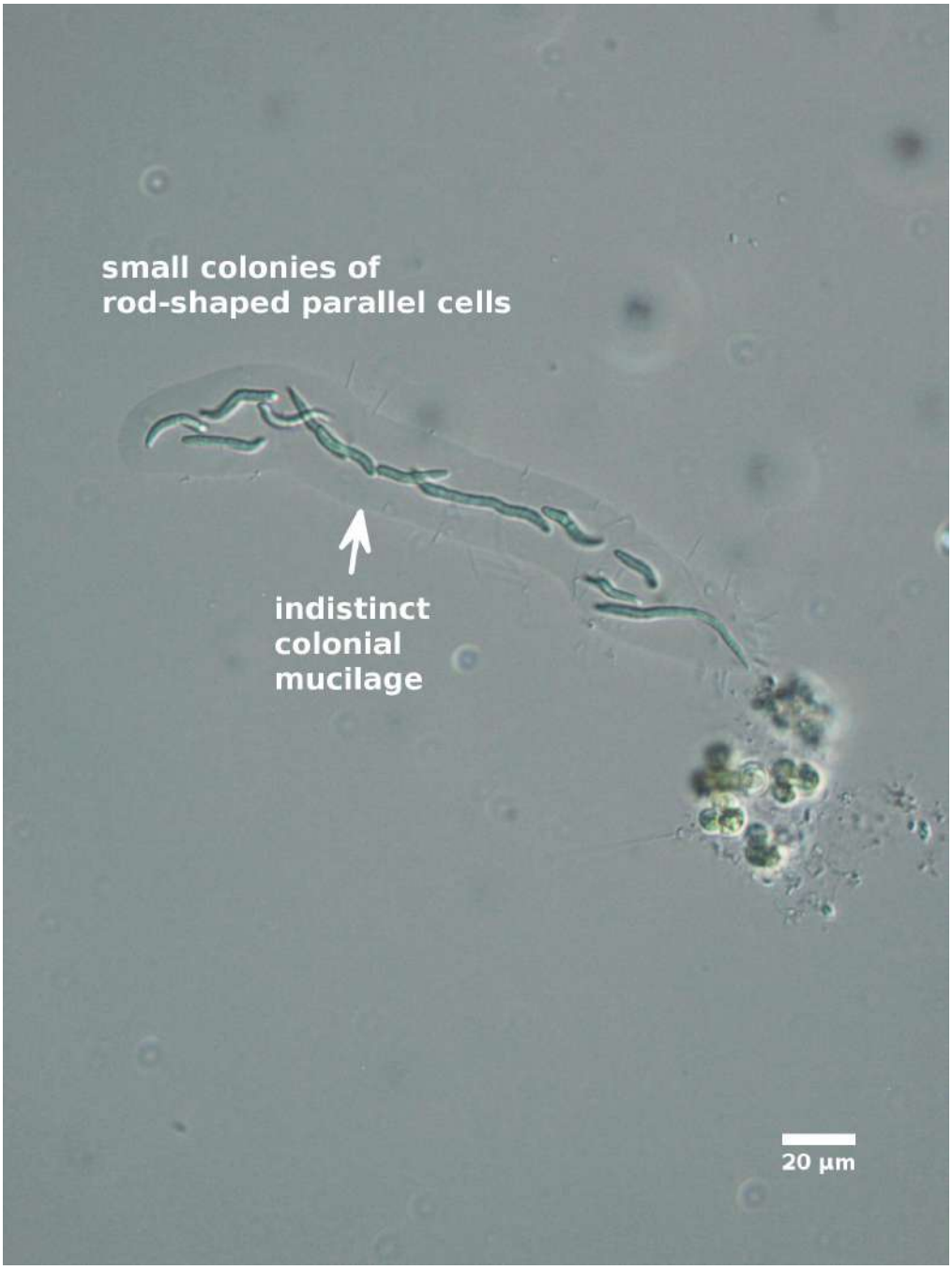


Figure 2.103: *Rhabdoderma lineare* (200x DIC), Lake Samish, IWS water quality sampling site, Whatcom County, August 26, 2013.

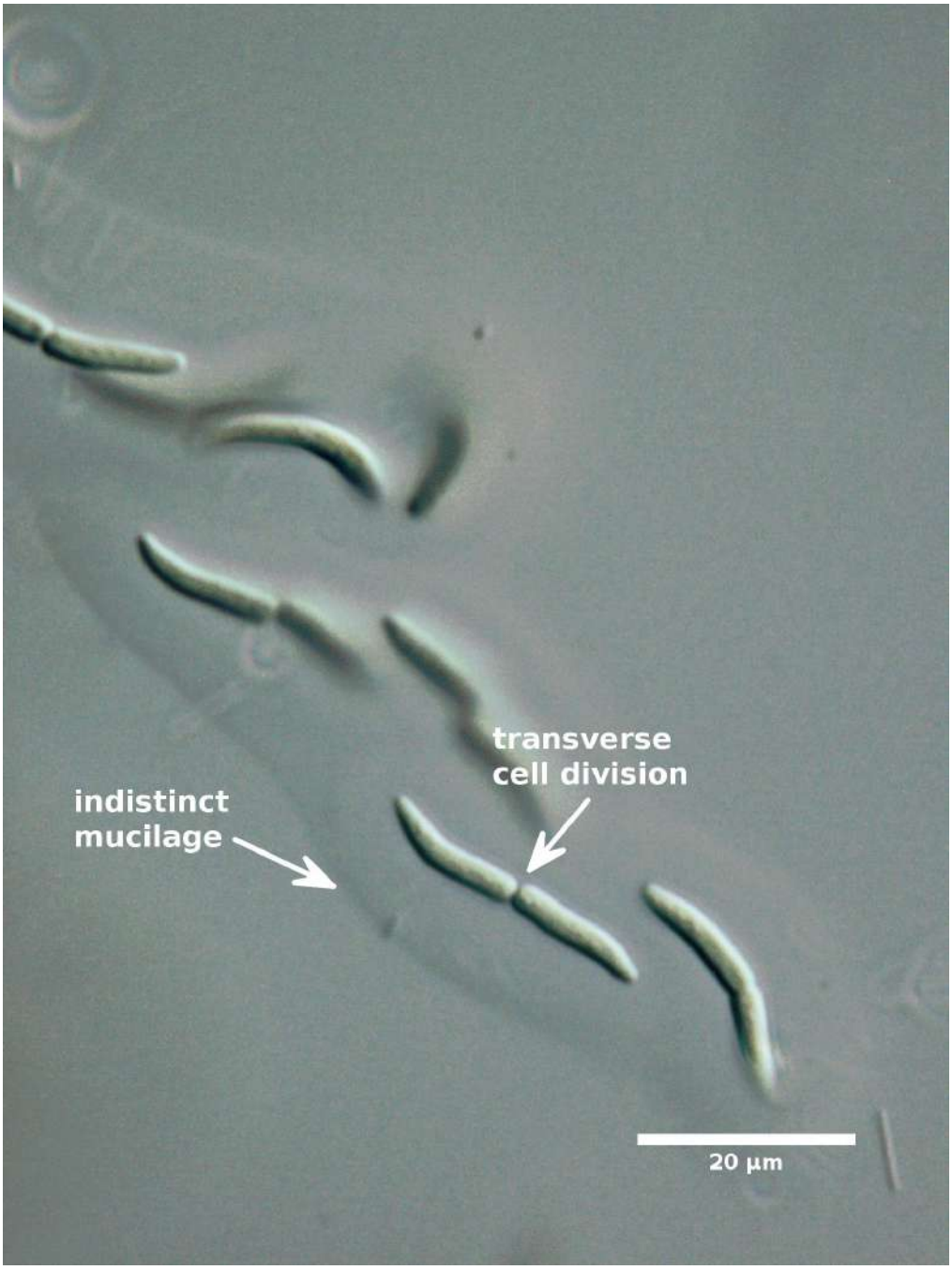


Figure 2.104: *Rhabdoderma lineare* (600x DIC), Lake Samish, IWS water quality sampling site, Whatcom County, August 26, 2013.

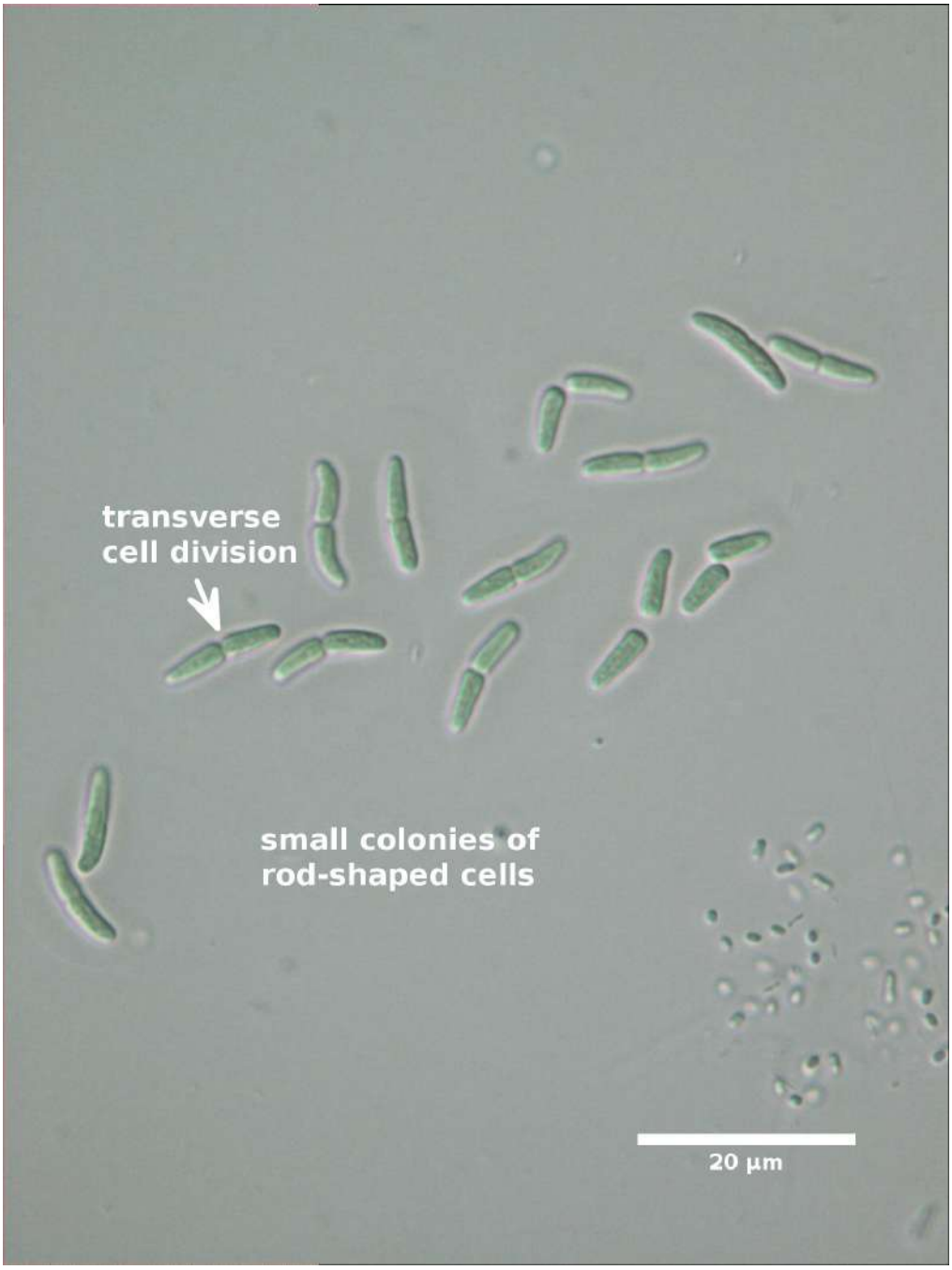


Figure 2.105: *Rhabdoderma lineare* (600x DIC), Lake Whatcom, IWS water quality sampling site, Whatcom County, October 12, 2010.



Figure 2.106: *Rhabdogloea linearis* (600x DIC), small pond on trail to Lake Ann, Mt. Baker area, September 21, 2014.

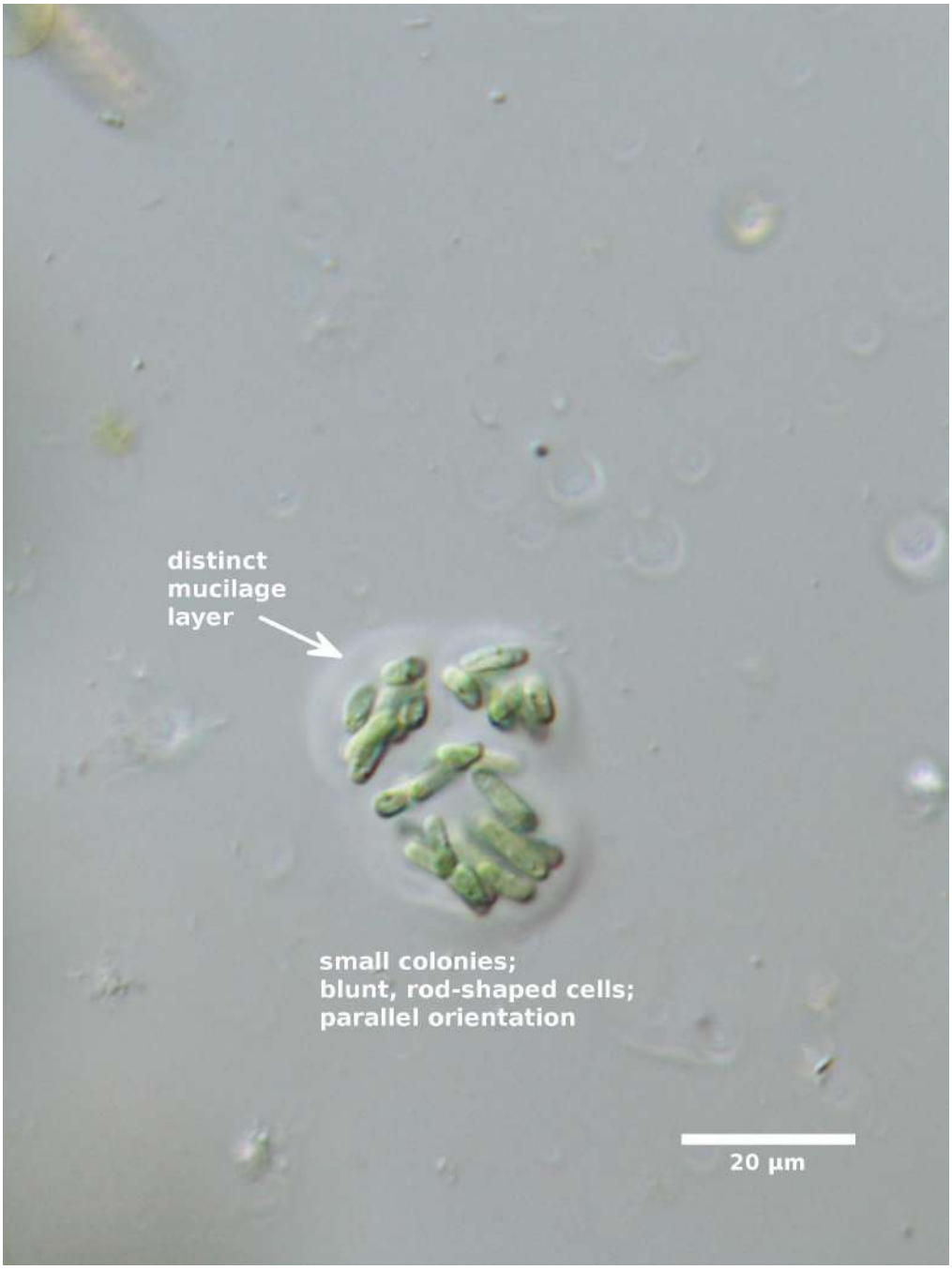


Figure 2.107: *Rhabdogloea linearis* (600x DIC), small pond on trail to Dock Butte, North Cascades along Hwy 20, July 2, 2015.

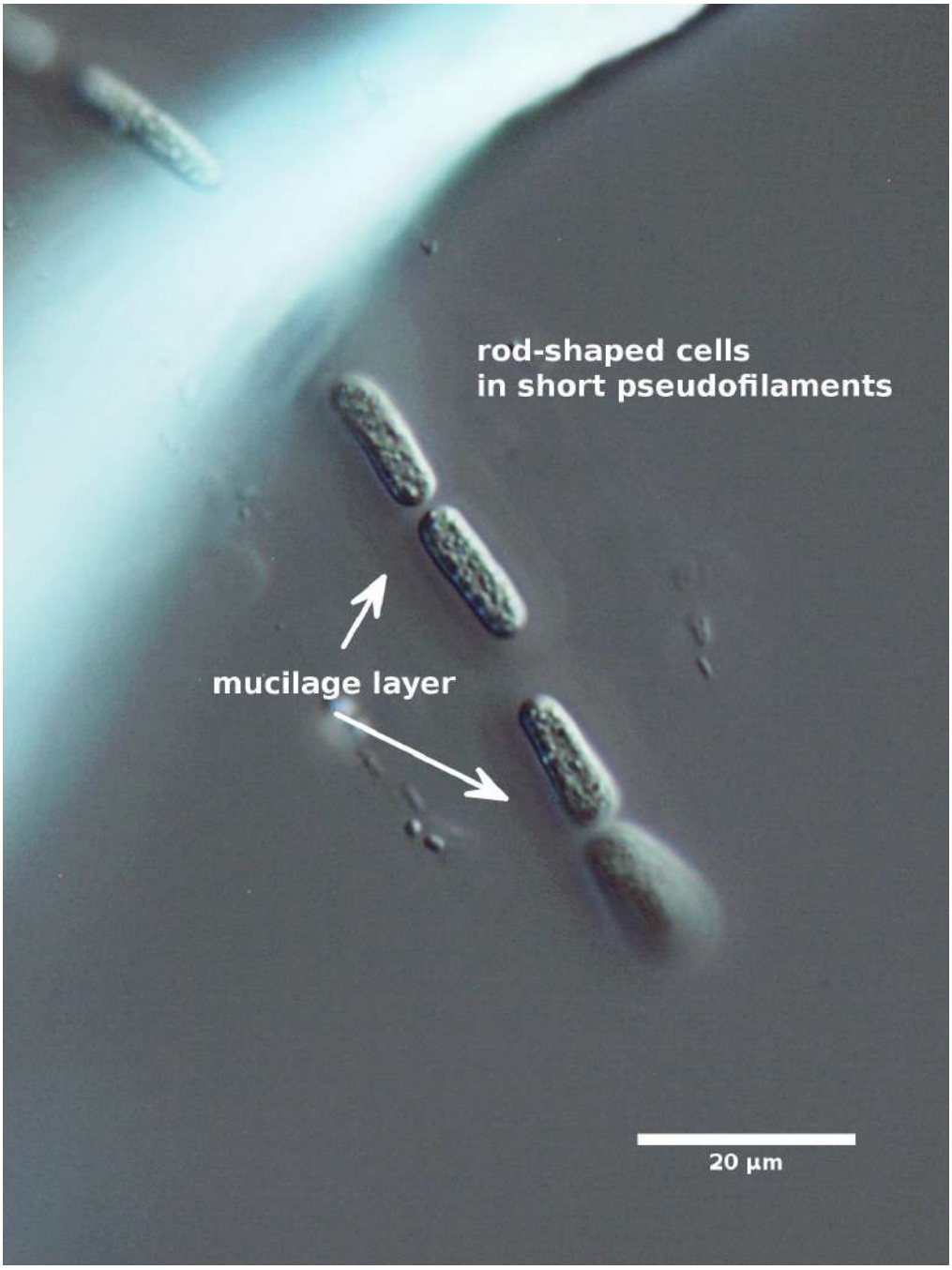


Figure 2.108: *Rhabdogloea* sp.1? (600x DIC), Bear Lake, IWS water quality sampling site, Snohomish County, August 14, 2013.



Figure 2.109: *Rhabdogloea* sp.1? (600x DIC), Bear Lake, IWS water quality sampling site, Snohomish County, August 15, 2013.

2.16 *Snowella* Elenkin

Local taxon
Snowella litoralis (Häyrén) Komárek & Hinkák

Abundance
Moderately common; may be present in large numbers but rarely forms blooms.

Local measurements		Width	Length	Biovolume[†]
Snowella litoralis	min	2.8 μm	–	11.5 μm^3
cells (sphere)	med	3.6 μm	–	24.4 μm^3
	max	4.0 μm	–	33.5 μm^3

[†]Calculated using original measurements, not summary values.

Description
Snowella colonies are spherical or oval, consisting of spherical or oval cells attached to thin, delicate mucilage strands that branch repeatedly, radiating from the colony center (Figures 2.110–2.113). The mucilage strands are not uniform in length, so the cells do not form a single peripheral layer. The cells divide in alternating planes, forming groups of 2 or 4 at the end of the strands.

Snowella colonies can be difficult to distinguish from *Coelosphaerium* (Section 2.5, page 72), which lacks radiating mucilage strands, and *Gomphosphaeria* (Section 2.11, page 111), and *Woronichinia* (Section 2.18, page 181), which have much thicker mucilage strands.

Snowella litoralis colonies are spherical or oval, and may contain multiple subcolonies. The individual cells are spherical and pale blue-green or gray. In young colonies the cells clearly form pairs or groups of four at the ends of clearly visible strands. Older colonies have denser cell clusters that may obscure the mucilage strands (Figure 2.112). *Snowella litoralis* is difficult to distinguish from *Snowella lacustris* (Chodat) Komárek & Hinkák, and some taxonomists question whether the minor differences represent true species distinctions (see Joosten, 2006). Both species have cells that are 2–4 μm wide, but *Snowella litoralis* cells are spherical, while *Snowella lacustris* cells are oval or broadly elliptical and are more densely arranged in the colony (Komárek & Anagnostidis, 1998).

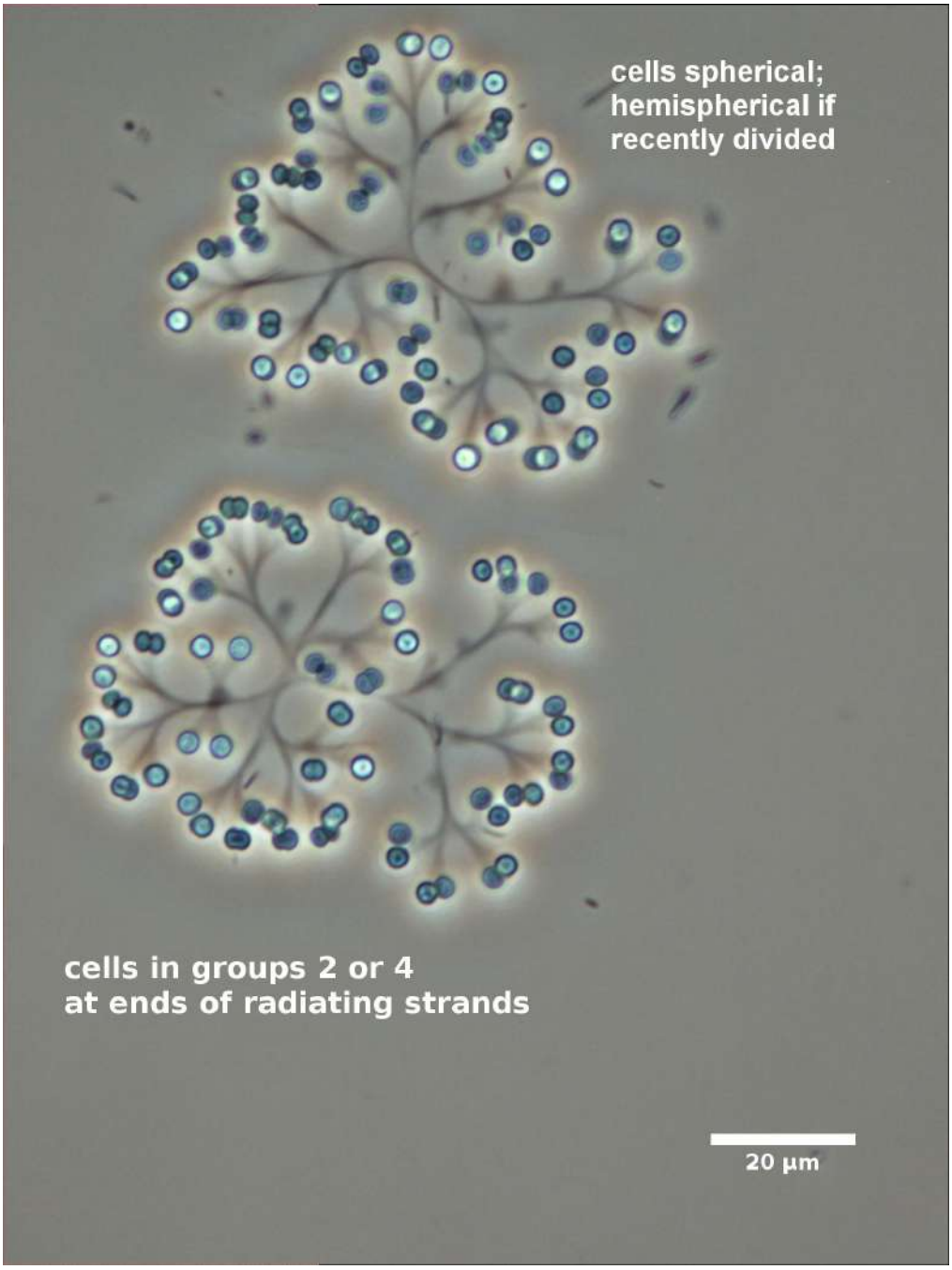


Figure 2.110: *Snowella litoralis* (400x phase contrast), Lake Whatcom, IWS water quality sampling site, Whatcom County, September 8, 2011.



Figure 2.111: *Snowella litoralis* (600x DIC), Lake Whatcom, IWS water quality sampling site, Whatcom County, October 12, 2010.

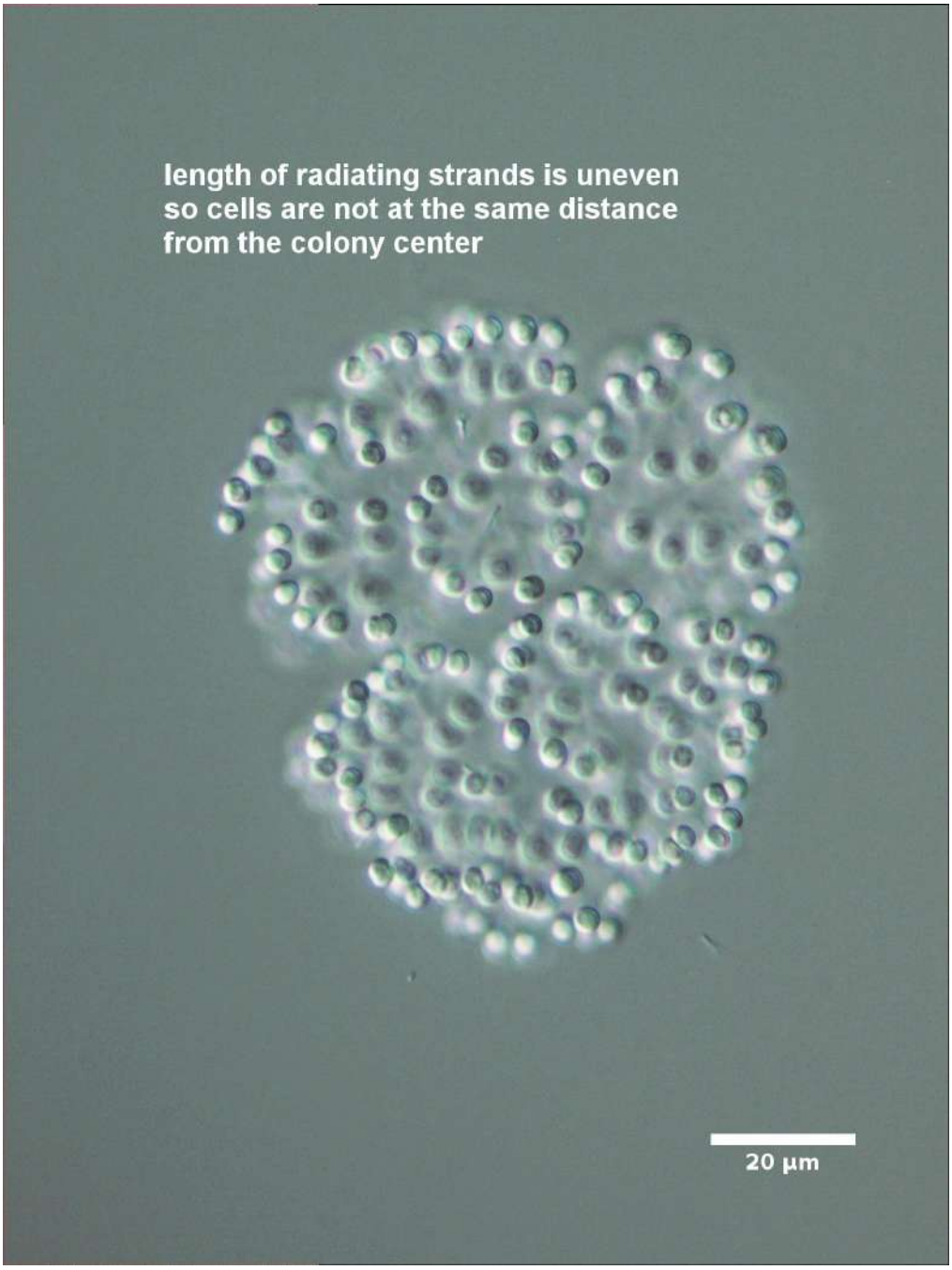


Figure 2.112: *Snowella litoralis* (400x DIC), Lake Whatcom, IWS water quality sampling site, Whatcom County, September 8, 2011.



Figure 2.113: *Snowella litoralis* (200x DIC), Lake Whatcom, IWS water quality sampling site, Whatcom County, September 5, 2013.

2.17 *Stichosiphon* Geitler

Local taxa
Stichosiphon willei (Gardner) Komárek & Anagnostidis;
Stichosiphon sp.1

Abundance
Infrequently collected in plankton samples; moderately common epiphyte.

Local measurements		Width	Length	Biovolume[†]
Stichosiphon willei	min	6.4 μm	4.6 μm	108 μm^3
cells and exocytes	med	7.3 μm	6.9 μm	197 μm^3
(spheroid)	max	8.8 μm	9.5 μm	326 μm^3
Stichosiphon sp.1	min	4.1 μm	3.3 μm	39.8 μm^3
cells and exocytes	med	5.0 μm	4.4 μm	54.8 μm^3
(spheroid)	max	5.7 μm	5.7 μm	73.2 μm^3

[†]Calculated using original measurements, not summary values.

Description
Stichosiphon is a common epiphyte on filamentous algae. The basal cells are initially solitary, oval or cylindrical, and gray, blue-green, or olive-green (Figures 2.114–2.119). The basal cell divides transversely to form exocytes (daughter cells) that are retained inside an open-ended mucilaginous sheath, forming short pseudofilaments. The exocytes are about the same size as the basal cell, which distinguishes this genus from *Chamaesiphon* (Section 2.3, page 48), which has a large basal cell and much smaller, spherical exocytes. *Stichosiphon* and *Chamaesiphon* also resemble *Cyanophanon* and *Geitleribactron* (Section 2.7, page 82), but *Cyanophanon* and *Geitleribactron* do not have the open-ended sheath surrounding the pseudofilament.

Stichosiphon willei has not been found in local lakes or streams, but was abundant in a freshwater aquarium as an epiphyte on *Vaucheria* (Figures 2.114–2.116). This species is described by Komárek and Anagnostidis (1998) as a common epiphyte on freshwater algae in warm water lakes and aquaria. The pseudofilaments may contain hundreds of exocytes, but the local aquarium specimens contained $<$20.

Stichosiphon sp.1 has slightly smaller exocytes compared to *Stichosiphon willei*. All of the local specimens were collected in cold, unpolluted, lakes, suggesting that this is a different species. The pseudofilaments initially resemble *Stichosiphon willei* (except for size), but older pseudofilaments are extremely long, containing >50 cells (Figures 2.117–2.119).



Figure 2.114: *Stichosiphon willei* (400x DIC), freshwater aquarium, April 27, 2011.

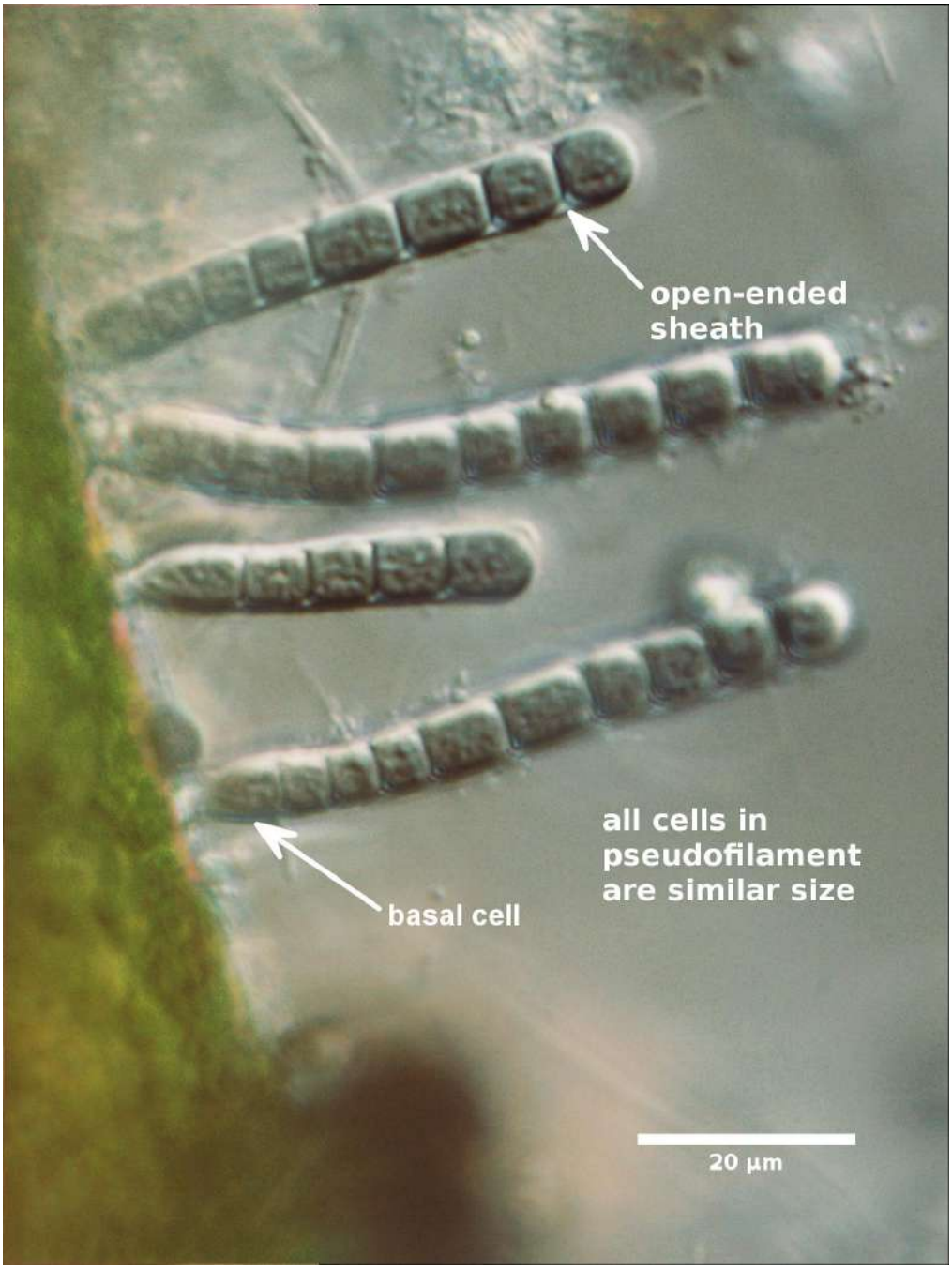


Figure 2.115: *Stichosiphon willei* (600x DIC), freshwater aquarium, April 28, 2011.



Figure 2.116: *Stichosiphon willei* (200x DIC), freshwater aquarium, April 28, 2011.

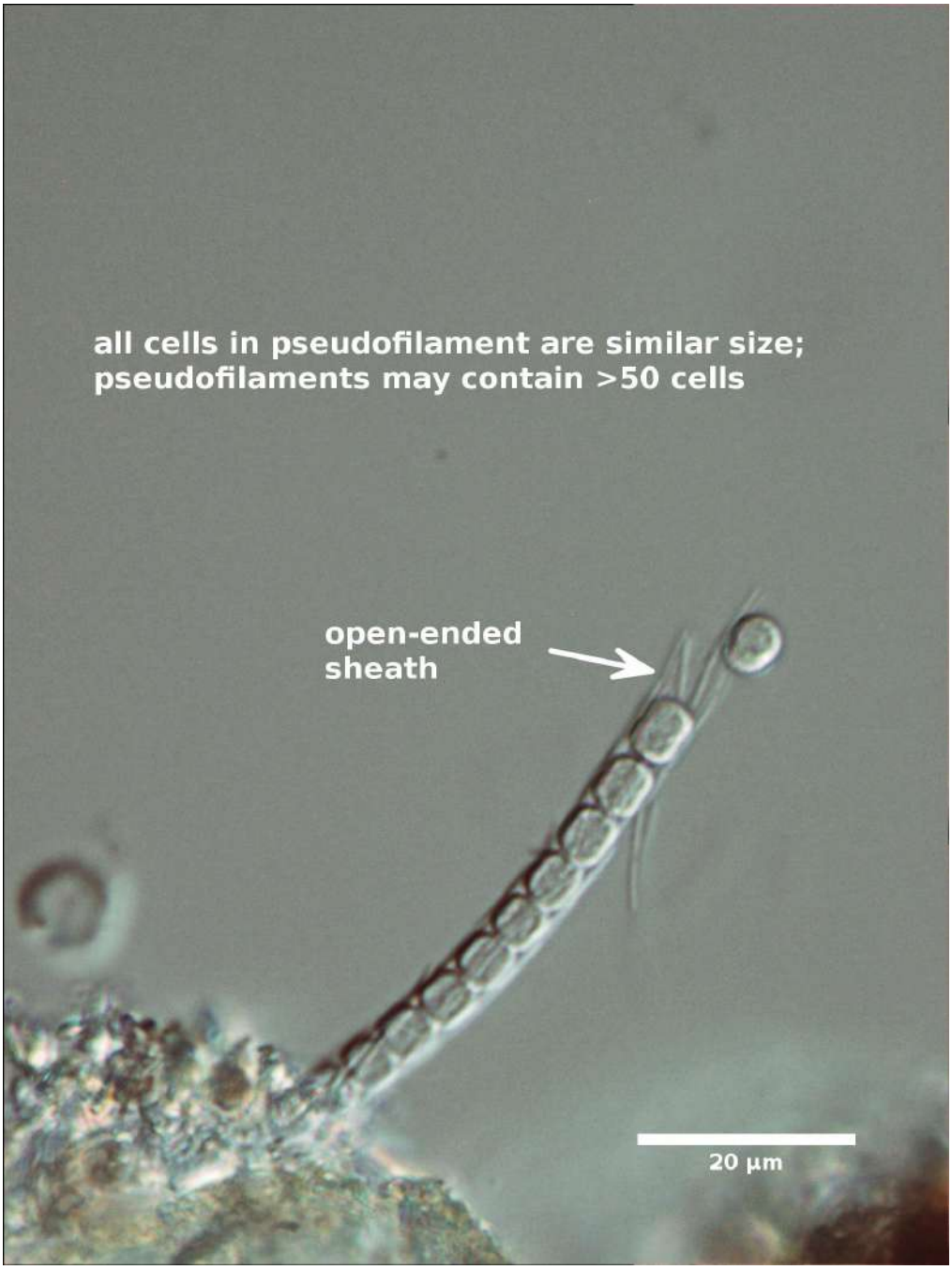


Figure 2.117: *Stichosiphon* sp.1 (600x DIC), Mirror Lake, IWS water quality sampling site, Whatcom County, July 12, 2011.

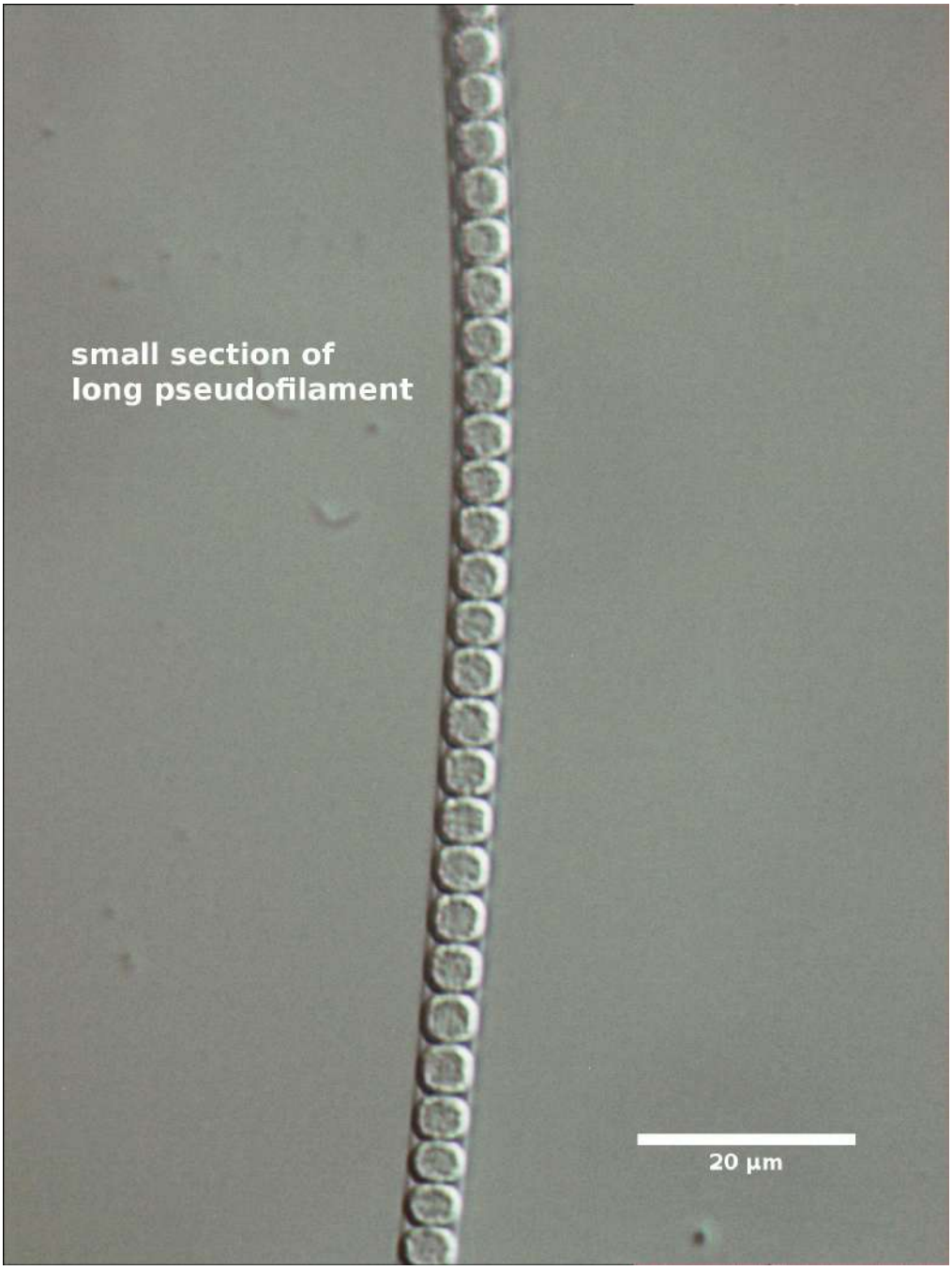


Figure 2.118: *Stichosiphon* sp.1 (600x DIC), Mirror Lake, IWS water quality sampling site, Whatcom County, July 12, 2011.

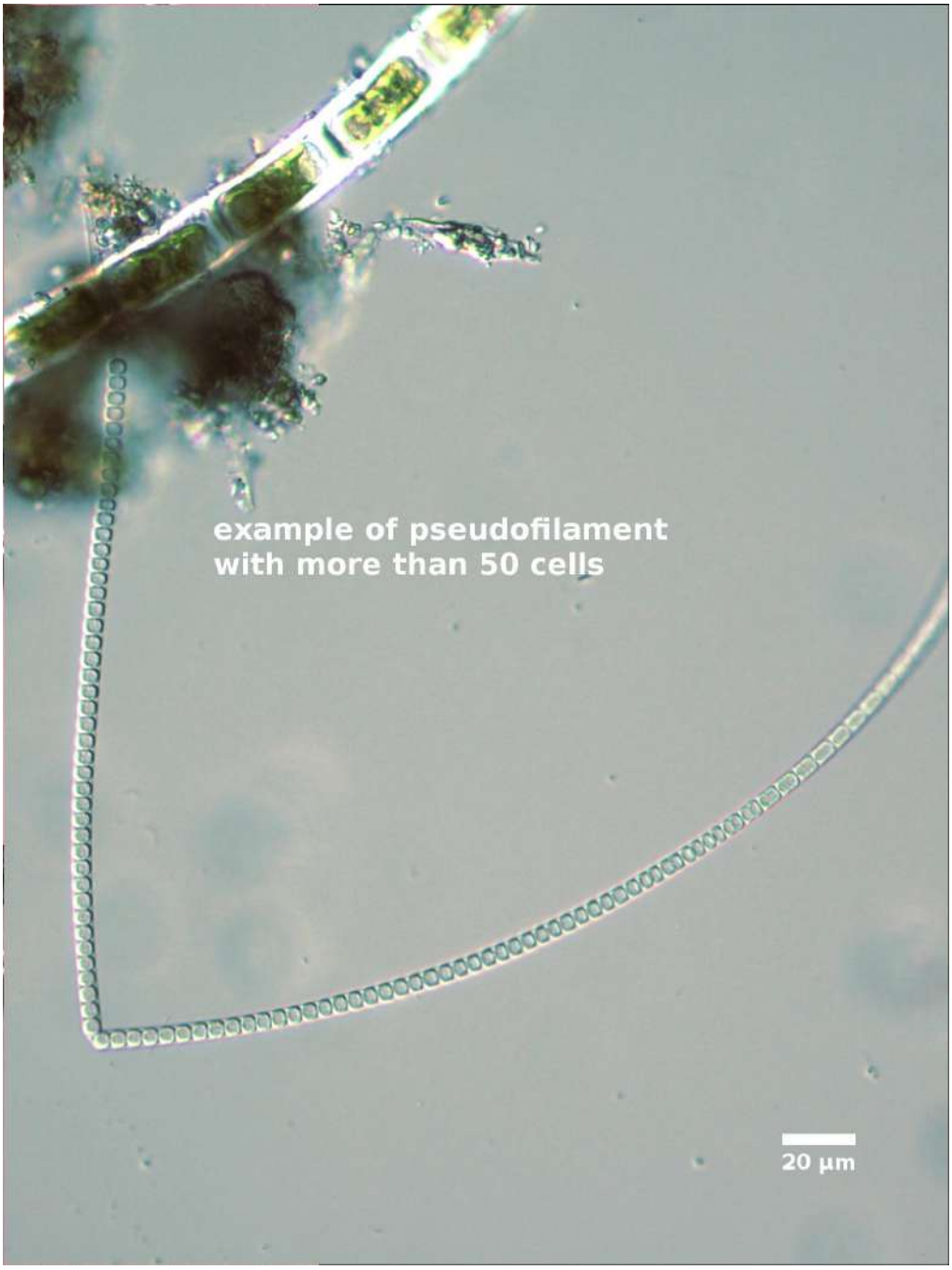


Figure 2.119: *Stichosiphon* sp.1 (200x DIC), Mirror Lake, IWS water quality sampling site, Whatcom County, July 12, 2011.

2.18 *Woronichinia* Elenkin

Local taxa
Woronichinia karelica Komárek & Komárkova-Legnerová?;
Woronichinia naegeliana (Unger) Elenkin

Abundance
Moderately common; may form blooms.

Local measurements		Width	Length	Biovolume[†]
Woronichinia karelica?	min	2.5 μm	3.5 μm	11.5 μm^3
cells (spheroid)	med	2.9 μm	4.0 μm	16.0 μm^3
	max	3.4 μm	4.6 μm	26.2 μm^3
Woronichinia karelica?	min	19.8 μm	25.1 μm	–
colonies[‡]	med	27.7 μm	30.2 μm	–
	max	35.8 μm	39.4 μm	–
Woronichinia naegeliana	min	3.5 μm	5.2 μm	33.4 μm^3
cells (spheroid)	med	4.2 μm	5.8 μm	53.0 μm^3
	max	4.7 μm	7.7 μm	85.3 μm^3
Woronichinia naegeliana	min	34.8 μm	42.2 μm	–
colonies[‡]	med	91.5 μm	101.9 μm	–
	max	114.6 μm	139.0 μm	–

[†]Calculated using original measurements, not summary values.
[‡]Colony biovolume can be estimated using a spherical or spheroid shape.

Description
Woronichinia colonies are hollow, with many densely packed oval cells arranged along the colony surface (Figures 2.120–2.129). The cells are at the end of thick mucilage stalks that radiate out from the center of the colony, but this feature may be difficult to see in dense colonies. Young colonies are typically spherical, but as the colony ages it becomes more irregular.

Woronichinia can be difficult to distinguish from *Coelosphaerium* (Section 2.5, page 72), which lacks radiating mucilage strands, and *Snowella* (Section 2.16, page 168), which has thin, delicate mucilage strands. *Woronichinia* is particularly difficult to distinguish from *Gomphosphaeria* (Section 2.11, page 111) because both genera have thick, radiating mucilage strands. But *Gomphosphaeria* forms heart-shaped cell pairs on the ends of branched mucilage strands that are narrower than the cells.

The specimens in Figures 2.120–2.121 are tentatively identified as *Woronichinia karelica*, which forms small, spherical or irregular planktonic colonies containing oval or broadly elliptical, olive-green cells. The cells form at the ends of thick, radiating mucilage strands that are approximately as wide as the attached cells. This species is much less common in local lakes than *Woronichinia naegeliana*.

Woronichinia naegeliana colonies are usually planktonic, containing densely packed, brown, blue-green, or olive-green cells (Figures 2.122–2.127). The colony is enclosed in a clear, diffuse mucilage layer that is difficult to see clearly unless stained with methylene blue (Figure 2.124). *Woronichinia* colonies often reproduce by releasing individual exocytes (daughter cells) (Figure 2.125). These exocytes should not be confused with surface epiphytes, which are very common on *Woronichinia* colonies (Figure 2.126). *Woronichinia naegeliana* can be a dominant species in late summer and early fall plankton blooms, often collected with *Dolichospermum* (Section 3.1, page 198 and other Cyanobacteria (Figure 2.127).

The specimens in Figures 2.128–2.129 have a slightly different appearance compared to most of the local *Woronichinia naegeliana* colonies. The cells are less densely aggregated, making is possible to see the thick mucilage strands radiating from the colony center. But the specimens were tentatively identified as *Woronichinia naegeliana* because the cells fit the size range described for this species by Komárek and Anagnostidis (1998) and the species exhibits considerable morphological variability.

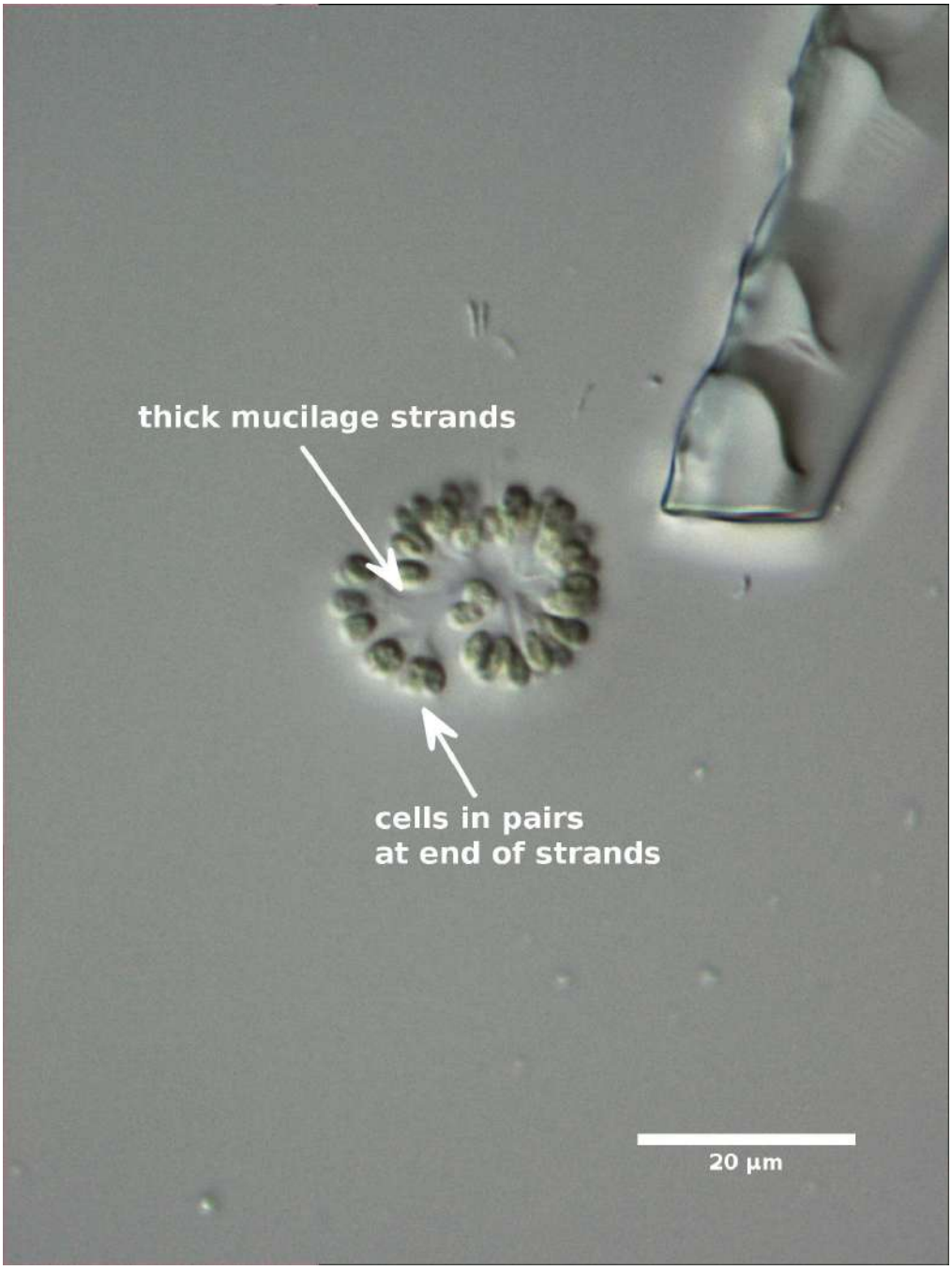


Figure 2.120: *Woronichinia karelica*? (600x DIC), Deer Lake, IWS water quality sampling site, Island County, August 14, 2008.

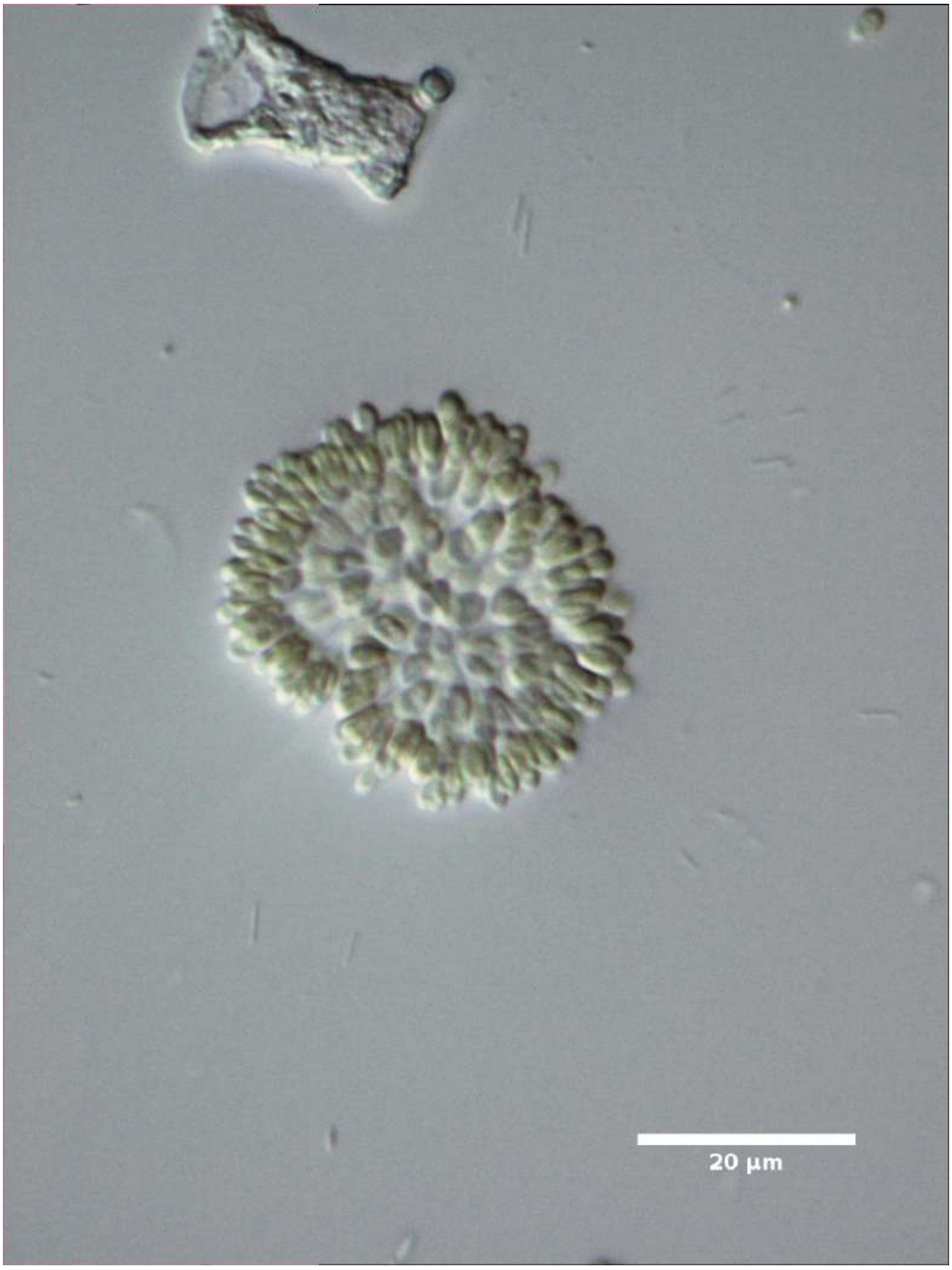


Figure 2.121: *Woronichinia karelica*? (600x DIC), Deer Lake, IWS water quality sampling site, Island County, August 14, 2008.

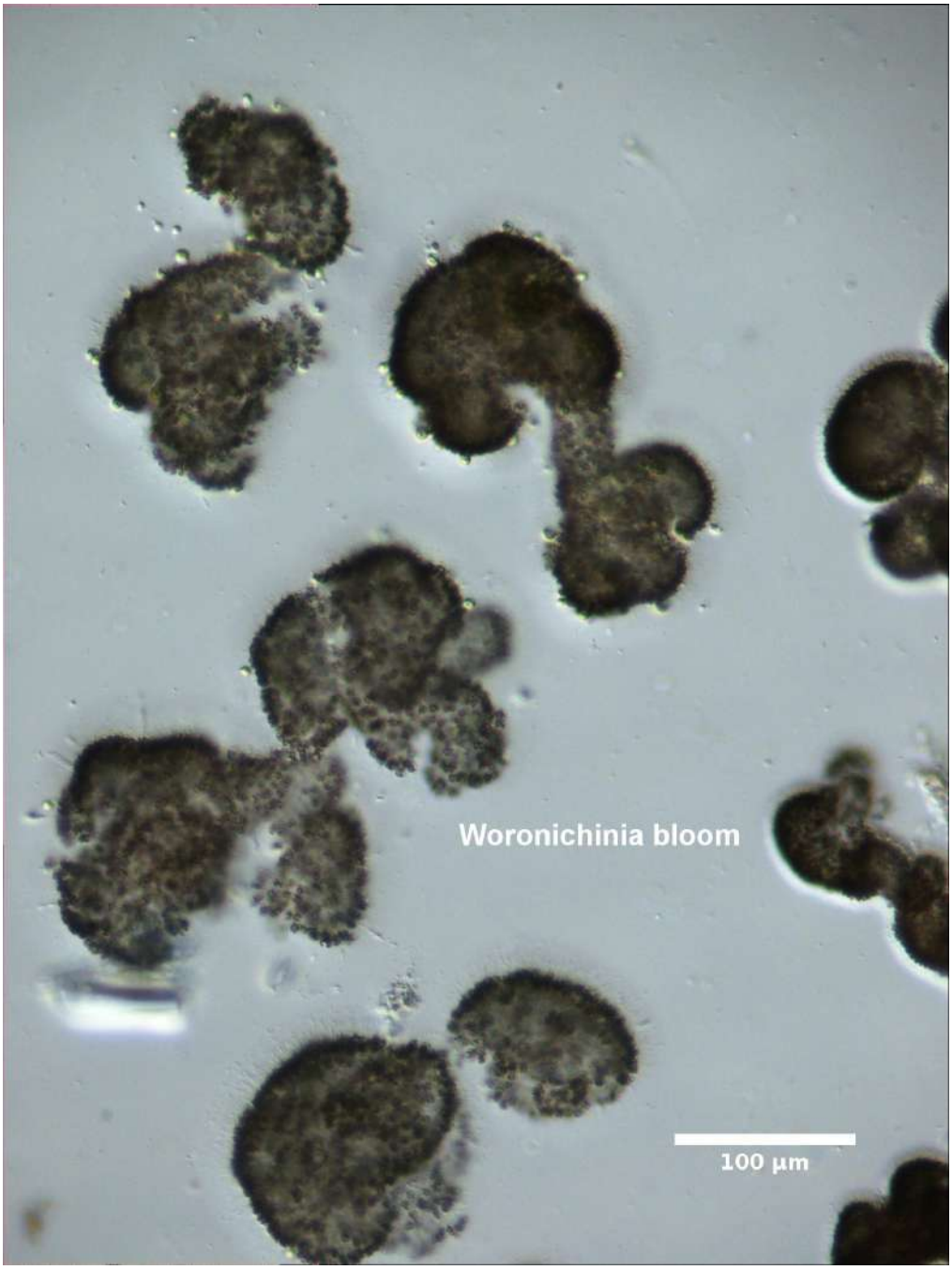


Figure 2.122: *Woronichinia naegeliana* (100x DIC), Lone Lake, IWS water quality sampling site, Island County, September 30, 2009.



Figure 2.123: *Woronichinia naegeliana* (600x DIC), Lake Campbell, IWS water quality sampling site, Skagit County, September 1, 2008.



Figure 2.124: *Woronichinia naegeliana* stained with methylene blue (200x DIC), Lone Lake, IWS water quality sampling site, Island County, October 6, 2009.

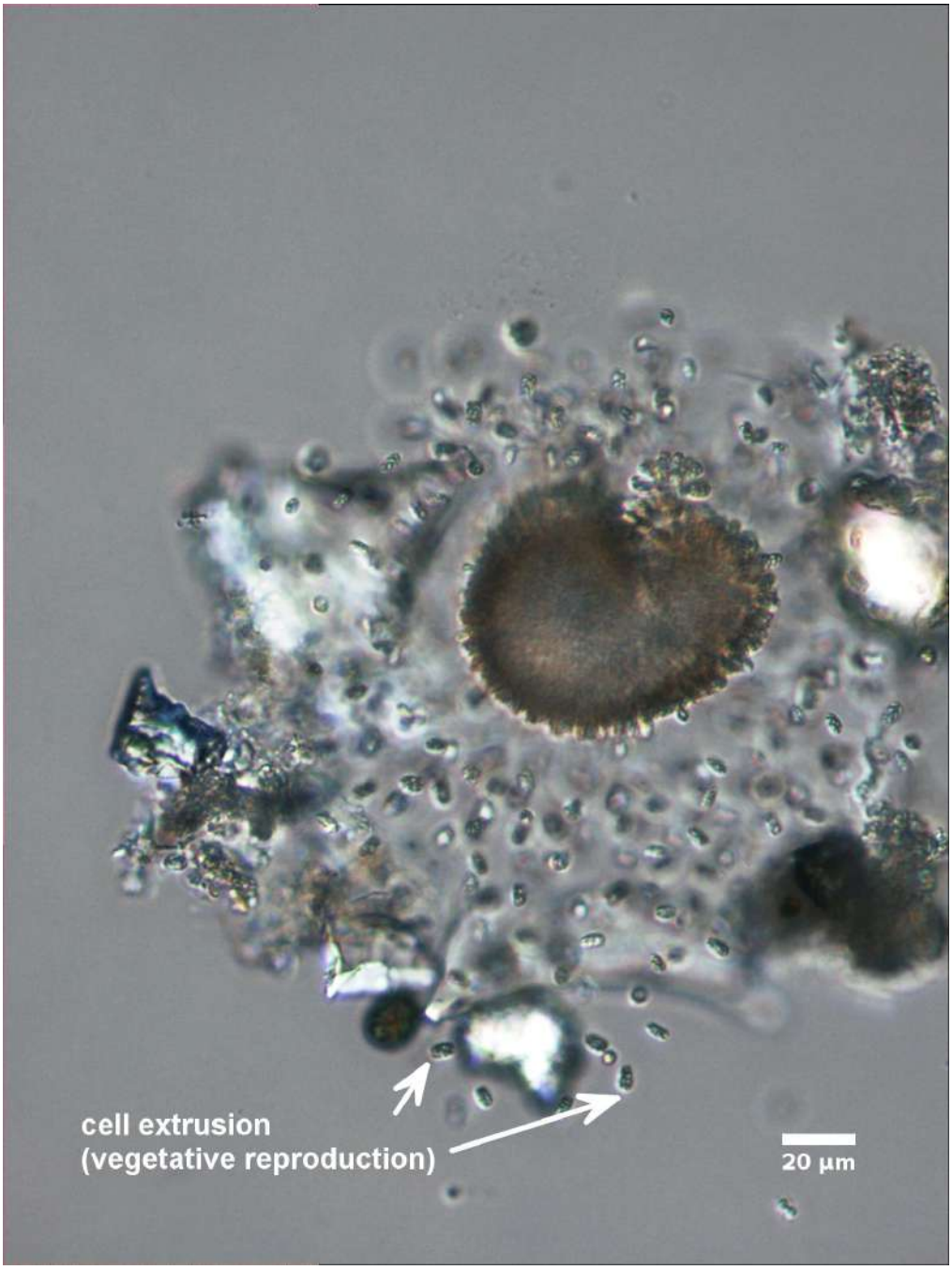


Figure 2.125: *Woronichinia naegeliana* in Lugol's iodine solution (200x DIC), Lake Howard, IWS water quality sampling site, Snohomish County, October 16, 2009.



Figure 2.126: *Woronichinia naegeliana* and epiphytes (200x DIC), Lake Terrell, IWS water quality sampling site, Whatcom County, June 29, 2010.

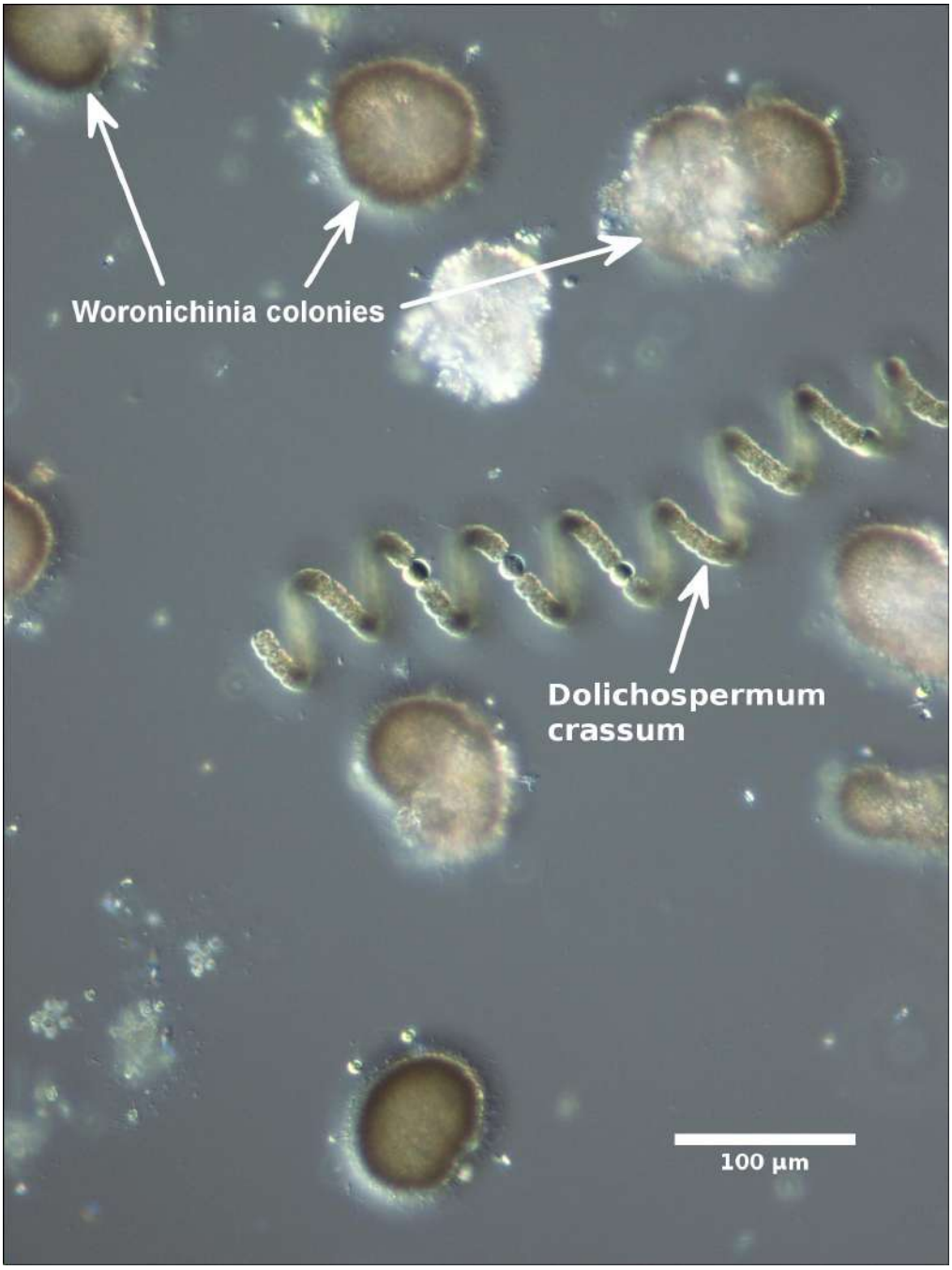


Figure 2.127: *Woronichinia naegeliana* and *Dolichospermum crassum* (100x DIC), Wiser Lake, IWS water quality sampling site, Whatcom County, August 21, 2007.



Figure 2.128: *Woronichinia naegeliana*? (400x DIC), Wiser Lake, IWS water quality sampling site, Whatcom County, May 5, 2009.



Figure 2.129: *Woronichinia naegeliana*? (200x DIC), Lake McMurray, IWS water quality sampling site, Skagit County, May 22. 2009.

Chapter 3

Filamentous Cyanobacteria With Heterocysts

The key on page 194 will help you identify filamentous Cyanobacteria that form nitrogen-fixing heterocysts (Figure 1.11, page 20). For solitary and colonial Cyanobacteria, including taxa that form pseudofilaments, go to Table 2.1 on page 24; for filamentous Cyanobacteria that do not form heterocysts, go to Table 4.1 on page 354.

Heterocyst-forming Cyanobacteria are extremely common, especially in eutrophic lakes. The ability to convert nitrogen gas (N_2) into usable forms of inorganic nitrogen allows the heterocyst-forming Cyanobacteria to thrive when other types of algae are experiencing nitrogen limitation. Heterocysts are produced when dissolved inorganic nitrogen (DIN)[12] concentrations start to drop, so the trichomes might not contain heterocysts if you sample during the winter or early spring.

Some of the heterocyst-forming filamentous Cyanobacteria taxa also form thick walled akinetes (Figure 1.12, page 21). Akinetes are produced late in the growth cycle, so their absence is more common than for heterocysts. In this guide, identifying the genus of heterocyst-forming taxa will not require the present of akinetes, but most species identifications can not be confirmed without akinetes. As with all Cyanobacteria, try to examine more than one specimen to determine whether you are trying to key representative cells and filaments.

[12]DIN = ammonium + nitrite + nitrate

Table 3.1: Key to Filamentous Cyanobacteria With Heterocysts

A	Cells not actually joined end-to-end, but loosely arranged in pseudofilaments	Go to key on page 24
B	Trichomes unbranched; untapered or very slightly tapered;	See below
C	Trichomes unbranched; distinctly tapered	Go to page 195
D	Trichomes branching at heterocyst or break in trichome (false branching)	Go to page 196
E	Trichomes with true branching caused by lateral cell division; trichomes may be multiseriate (>1 cell per row)	Go to page 196
B	Trichomes unbranched; untapered or very slightly tapered	
B.1	Heterocysts located at one end of trichome	
	B.1a Heterocyst usually adjacent to an akinete;	*Cylindrospermum* (page 273)
	B.1b Akinetes rare; trichomes straight or strongly curved/tapered; both forms usually present in sample (warm water genus - not observed locally)	*Cylindrospermopsis* (page 266)

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Table 3.1: Key to Filamentous Cyanobacteria With Heterocysts, continued

	B.2	Heterocysts located at both ends of short, coiled or twisted trichome	*Anabaenopsis* (page 248)
	B.3	Heterocysts not confined to end of trichome	
		B.3a Trichome untapered or very slightly tapered; trichomes clumped in grass-like flakes or solitary	*Aphanizomenon* (page 250)
		B.3b Trichomes straight, curved, coiled, or tangled; cells bead-like; mucilage indistinct unless stained	*Anabaena* and *Dolichospermum* Go to key on page 199
		B.3c Trichomes resemble *Anabaena* and *Dolichospermum* (see above), but enclosed inside firm colonial mucilage; colonies often macroscopic	*Nostoc* (page 309)
C		Trichomes unbranched; distinctly tapered	
	C.1	Heterocysts present at base of trichome	
		C.1a Trichomes radiate from center of spherical colony; resembles spiny sea urchin	*Gloeotrichia* (page 293)
		C.1b Mat or tuft-like colonies attached to substrate; single trichome inside sheath; unbranched or false branching	*Calothrix* (page 257)
		C.1c Mat or tuft-like colonies attached to substrate; multiple trichomes inside common sheath; unbranched or false branching	*Dichothrix* (page 280)

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Table 3.1: Key to Filamentous Cyanobacteria With Heterocysts, continued

	C.2	Heterocysts present but not basal; trichomes untapered or very slightly tapered; trichomes clumped in grass-like flakes or solitary	*Aphanizomenon* (page 250)
D		Trichomes branching at heterocyst or break in trichome (false branching)	
	D.1	Trichomes tapered	
		D.1a Mat or tuft-like colonies attached to substrate; single trichome inside sheath; unbranched or false branching	*Calothrix* (page 257)
		D.1b Mat or tuft-like colonies attached to substrate; multiple trichomes inside common sheath; unbranched or false branching	*Dichothrix* (page 280)
	D.2	Trichomes untapered	
		D.2a One or more heterocysts at base of false branch	*Tolypothrix* (page 343)
		D.2b Heterocysts present but not confined to base of false branch; trichomes surrounded by thick gelatinous sheath	*Scytonema* (page 320)
E		Trichomes with true branching caused by lateral cell division; trichomes may be multiseriate (>1 cell per row)	
	E.1	Trichome mostly uniseriate (1 cell per row); trichomes surrounded by clear or slightly yellowish mucilage	

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Table 3.1: Key to Filamentous Cyanobacteria With Heterocysts, continued

	E.1a Cells barrel-shaped or nearly spherical; main branch of trichome slightly larger than lateral branches;	*Fischerella* (page 290)
	E.1b Cells cylindrical and unconstricted; main and lateral branches of trichome about the same size	*Hapalosiphon* (page 301)
E.2	Trichome multiseriate (>1 cell per row); trichomes surrounded by firm, dark mucilage	*Stigonema* (page 329)

3.1 *Anabaena* Bory ex Bornet & Flahault and *Dolichospermum* (Ralfs ex Bornet & Flahault) Wacklin, Hoffmann & Komárek

Local taxa
Anabaena catenula Kützing ex Bornet & Flahault;
Anabaena cylindrica Lemmermann;
Anabaena echinospora Skuja;
Anabaena inaequalis Bornet & Flahault;
Anabaena oscillarioides Bory ex Bornet & Flahault;
Anabaena spp.;
Dolichospermum circinale (Nygaard) Wacklin, Hoffmann & Komárek) (=*Dolichospermum sigmoideum* [Nygaard] Wacklin, Hoffmann & Komárek);
Dolichospermum crassum (Lemmermann) Wacklin, Hoffmann & Komárek;
Dolichospermum flosaquae (Brébisson ex Bornet & Flahault) Wacklin, Hoffmann & Komárek;
Dolichospermum lemmermannii (Ricter) Wacklin, Hoffmann & Komárek;
Dolichospermum mendotae (Trelease) Wacklin, Hoffmann & Komárek;
Dolichospermum planctonicum (Brunnthaler) Wacklin, Hoffmann & Komárek;
Dolichospermum skujaelaxum (Komárek & Zapomlová) Wacklin, Hoffmann & Komárek

Abundance
There are many species of *Anabaena* and *Dolichospermum* in northwest Washington lakes and ponds. Some of the species are common, and form dense blooms, while other species are not associated with blooms.

Because of the importance of this group as water quality indicators, I included a simple key, beginning on page 199, to help identify the common local taxa. The key is followed by cell, heterocyst, and akinete measurements, beginning on page 201, which should help confirm the species identification.

Table 3.2: Key to Local *Anabaena* and *Dolichospermum* species

A		Trichomes straight or curved; akinetes cylindrical; adjacent to heterocysts	
	A.1	Akinetes spiny and solitary	*Anabaena echinospora* (Figures 3.6–3.7)
	A.2	Akinetes smooth, with multiple akinetes in a series; heterocysts spherical	*Anabaena oscillarioides* (Figures 3.10–3.13)
	A.3	Akinetes smooth and solitary; heterocysts oval	*Anabaena cylindrica* (Figures 3.4–3.5)
B		Trichomes straight or curved; akinetes oval or cylindrical; not adjacent to heterocysts	
	B.1	Akinetes cylindrical with ⇒flat ends; cells compressed (width $\geq$ length)	*Anabaena inaequalis* (Figures 3.8–3.9)
	B.2	Akinetes cylindrical with ⇒rounded ends; cells not compressed	*Anabaena catenula* group (Figures 3.2–3.3)
	B.3	Akinetes oval; ⇒planktonic	*Dolichospermum planctonicum* (Figures 3.34–3.36)
C		Trichomes tangled or spiraling; akinetes adjacent to heterocysts	
	C.1	Akinetes form very dense cluster in center of colony	*Dolichospermum lemmermannii* (Figures 3.28–3.30)

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Table 3.2: Key to the *Anabaena* and *Dolichospermum*, continued

	C.2	Akinetes scattered along trichome, not in a dense central cluster	*Dolichospermum skujaelaxum* (Figures 3.37–3.38)
D		Trichomes tangled or spiraling; akinetes not adjacent to heterocysts	
	D.1	Akinetes oval	
		D.1a Akinetes symmetric; trichomes form regular spirals resembling coiled spring; cells compressed (width $\geq$ length)	*Dolichospermum crassum* (Figures 3.24–3.25)
		D.1b Akinetes asymmetric; cells and heterocysts nearly spherical	*Dolichospermum circinale* (Figures 3.22–3.23)
	D.2	Akinetes cylindrical; trichomes tangled or forming irregular spirals	
		D.1a Akinetes curved (kidney-shaped); cells and heterocysts $\pm$spherical	*Dolichospermum flosaquae* (Figures 3.26–3.27)
		D.1b Akinetes straight; cells and heterocysts longer than wide	*Dolichospermum mendotae* (Figures 3.31–3.32)

Local measurements		Width	Length	Biovolume[†]
Anabaena catenula group	min	4.7 μm	4.7 μm	54.4 μm^3
cells (spheroid)	med	5.1 μm	5.6 μm	77.0 μm^3
	max	6.5 μm	7.7 μm	140 μm^3
Anabaena catenula group	min	5.6 μm	5.6 μm	95.2 μm^3
heterocysts (spheroid)	med	6.1 μm	6.4 μm	131 μm^3
	max	6.6 μm	7.0 μm	146 μm^3
Anabaena catenula group	min	5.6 μm	11.4 μm	117 μm^3
akinetes (cyl + two $\frac{1}{2}$ spheres)[‡]	med	6.4 μm	18.0 μm	318 μm^3
	max	7.6 μm	23.2 μm	614 μm^3
Anabaena cylindrica	min	4.9 μm	6.8 μm	96.7 μm^3
cells (spheroid)	med	5.6 μm	8.3 μm	129 μm^3
	max	6.0 μm	10.9 μm	192 μm^3
Anabaena cylindrica	min	6.3 μm	9.8 μm	210 μm^3
heterocysts (spheroid)	med	6.7 μm	11.6 μm	269 μm^3
	max	7.9 μm	12.6 μm	408 μm^3
Anabaena cylindrica	min	5.6 μm	18.4 μm	285 μm^3
akinetes (cyl + two $\frac{1}{2}$ spheres)[‡]	med	6.6 μm	25.3 μm	651 μm^3
	max	7.5 μm	41.3 μm	1,400 μm^3
Anabaena echinospora	min	7.4 μm	6.8 μm	239 μm^3
cells (spheroid)	med	8.3 μm	8.0 μm	288 μm^3
	max	11.4 μm	10.3 μm	701 μm^3
Anabaena echinospora	min	7.9 μm	6.7 μm	219 μm^3
heterocysts (spheroid)	med	9.2 μm	9.2 μm	421 μm^3
	max	11.1 μm	10.8 μm	594 μm^3
Anabaena echinospora	min	8.7 μm	16.6 μm	421 μm^3
akinetes (cyl + two $\frac{1}{2}$ spheres)[‡ §]	med	9.3 μm	20.5 μm	636 μm^3
	max	12.1 μm	37.5 μm	2,340 μm^3

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Local measurements		Width	Length	Biovolume[†]
Anabaena inaequalis	min	4.2 μm	4.0 μm	62.9 μm^3
cells (spheroid)	med	5.7 μm	5.0 μm	79.3 μm^3
	max	7.1 μm	7.7 μm	129 μm^3
Anabaena inaequalis	min	5.3 μm	5.7 μm	90.3 μm^3
heterocysts (spheroid)	med	6.7 μm	6.9 μm	157 μm^3
	max	7.7 μm	10.6 μm	329 μm^3
Anabaena inaequalis	min	5.6 μm	10.8 μm	100 μm^3
akinetes (cyl + two $\frac{1}{2}$ spheres)[‡]	med	8.3 μm	21.5 μm	762 μm^3
	max	9.2 μm	29.5 μm	1,020 μm^3
Anabaena oscillarioides	min	3.4 μm	3.2 μm	19.4 μm^3
cells (spheroid)	med	3.7 μm	3.7 μm	33.0 μm^3
	max	5.5 μm	4.6 μm	58.6 μm^3
Anabaena oscillarioides	min	4.4 μm	5.0 μm	51.7 μm^3
heterocysts (spheroid)	med	5.3 μm	5.2 μm	76.5 μm^3
	max	6.6 μm	6.6 μm	151 μm^3
Anabaena oscillarioides	min	7.4 μm	19.5 μm	519 μm^3
akinetes (cyl + two $\frac{1}{2}$ spheres)[‡]	med	7.5 μm	20.3 μm	566 μm^3
	max	8.1 μm	22.2 μm	654 μm^3
Anabaena sp.1	min	4.6 μm	5.6 μm	99.7 μm^3
cells (spheroid)	med	5.3 μm	7.3 μm	159 μm^3
	max	5.9 μm	9.8 μm	268 μm^3
Anabaena sp.1	min	5.4 μm	9.9 μm	162 μm^3
heterocysts (spheroid)	med	6.1 μm	11.1 μm	211 μm^3
	max	6.8 μm	12.5 μm	257 μm^3
Anabaena sp.1	min	6.4 μm	26.6 μm	737 μm^3
akinetes (cyl + two $\frac{1}{2}$ spheres)[‡]	med	6.9 μm	42.4 μm	1,380 μm^3
	max	10.7 μm	58.5 μm	1,620 μm^3

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Local measurements		Width	Length	Biovolume[†]
Anabaena sp.2	min	5.9 μm	5.2 μm	96.6 μm^3
cells (spheroid)	med	6.5 μm	6.2 μm	143 μm^3
	max	7.0 μm	8.9 μm	197 μm^3
Anabaena sp.2	min	5.9 μm	6.7 μm	124 μm^3
heterocysts (spheroid)	med	6.7 μm	7.1 μm	164 μm^3
	max	7.0 μm	7.5 μm	187 μm^3
Anabaena sp.2	min	7.2 μm	9.8 μm	266 μm^3
akinetes (spheroid)[§]	med	7.6 μm	12.3 μm	381 μm^3
	max	7.8 μm	13.5 μm	401 μm^3
Dolichospermum circinale	min	6.1 μm	6.1 μm	129 μm^3
cells (spheroid)	med	7.7 μm	7.0 μm	229 μm^3
	max	9.8 μm	7.8 μm	377 μm^3
Dolichospermum circinale	min	8.4 μm	7.9 μm	292 μm^3
heterocysts (spheroid)	med	9.2 μm	9.1 μm	419 μm^3
	max	9.7 μm	10.1 μm	478 μm^3
Dolichospermum circinale	min	12.2 μm	20.3 μm	1,580 μm^3
akinetes (spheroid)	med	13.6 μm	23.4 μm	2,400 μm^3
	max	15.6 μm	25.4 μm	3,050 μm^3
Dolichospermum crassum	min	8.5 μm	7.9 μm	306 μm^3
cells (spheroid)	med	11.6 μm	10.2 μm	715 μm^3
	max	14.4 μm	13.8 μm	1,340 μm^3
Dolichospermum crassum	min	9.5 μm	9.9 μm	468 μm^3
heterocysts (spheroid)	med	12.9 μm	12.8 μm	1,090 μm^3
	max	17.9 μm	22.5 μm	3,770 μm^3
Dolichospermum crassum	min	16.0 μm	22.1 μm	3,070 μm^3
akinetes (spheroid)	med	16.5 μm	28.2 μm	4,100 μm^3
	max	21.2 μm	36.6 μm	8,610 μm^3

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Local measurements		Width	Length	Biovolume[†]
Dolichospermum flosaquae	min	6.8 μm	6.3 μm	182 μm^3
cells (spheroid)	med	7.8 μm	7.8 μm	225 μm^3
	max	9.5 μm	9.9 μm	392 μm^3
Dolichospermum flosaquae	min	7.2 μm	7.1 μm	193 μm^3
heterocysts (spheroid)	med	8.3 μm	8.1 μm	289 μm^3
	max	10.1 μm	9.9 μm	529 μm^3
Dolichospermum flosaquae	min	8.5 μm	17.9 μm	677 μm^3
akinetes (spheroid)	med	10.6 μm	24.7 μm	1,460 μm^3
	max	13.9 μm	31.4 μm	2,780 μm^3
Dolichospermum lemmermannii	min	5.1 μm	7.0 μm	99.1 μm^3
cells (spheroid)	med	6.1 μm	9.0 μm	167 μm^3
	max	7.7 μm	13.1 μm	357 μm^3
Dolichospermum lemmermannii	min	6.0 μm	6.5 μm	128 μm^3
heterocysts (spheroid)	med	6.9 μm	7.5 μm	185 μm^3
	max	8.0 μm	8.3 μm	278 μm^3
Dolichospermum lemmermannii	min	7.3 μm	17.7 μm	533 μm^3
akinetes (spheroid)	med	9.4 μm	19.2 μm	835 μm^3
	max	10.6 μm	37.7 μm	2,220 μm^3
Dolichospermum mendotae	min	3.8 μm	5.3 μm	46.9 μm^3
cells (spheroid)	med	4.4 μm	7.4 μm	74.8 μm^3
	max	5.3 μm	8.7 μm	86.4 μm^3
Dolichospermum mendotae	min	5.1 μm	6.5 μm	95.6 μm^3
heterocysts (spheroid)	med	5.3 μm	7.7 μm	112 μm^3
	max	5.4 μm	7.8 μm	119 μm^3
Dolichospermum mendotae	min	5.8 μm	22.1 μm	429 μm^3
akinetes (cyl + two $\frac{1}{2}$ spheres)[‡]	med	8.6 μm	23.6 μm	763 μm^3
	max	10.3 μm	26.7 μm	1,100 μm^3

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Local measurements		Width	Length	Biovolume[†]
Dolichospermum planctonicum	min	8.8 μm	7.8 μm	316 μm^3
cells (spheroid)	med	11.4 μm	9.8 μm	685 μm^3
	max	13.4 μm	12.6 μm	1,130 μm^3
Dolichospermum planctonicum	min	10.2 μm	10.3 μm	561 μm^3
heterocysts (spheroid)	med	11.8 μm	11.8 μm	927 μm^3
	max	15.1 μm	14.1 μm	1,680 μm^3
Dolichospermum planctonicum	min	13.3 μm	11.8 μm	1,090 μm^3
akinetes (spheroid)	med	17.3 μm	23.7 μm	3,730 μm^3
	max	20.4 μm	34.0 μm	7,340 μm^3
Dolichospermum skujaelaxum	min	5.5 μm	6.2 μm	98.2 μm^3
cells (spheroid)	med	6.4 μm	7.1 μm	153 μm^3
	max	7.0 μm	8.1 μm	190 μm^3
Dolichospermum skujaelaxum	min	4.6 μm	5.3 μm	62.0 μm^3
heterocysts (spheroid)	med	5.9 μm	6.0 μm	112 μm^3
	max	6.9 μm	7.4 μm	184 μm^3
Dolichospermum skujaelaxum[‡]	min	9.2 μm	23.9 μm	935 μm^3
akinetes (cyl + two $\frac{1}{2}$ spheres)	med	10.2 μm	30.6 μm	1,400 μm^3
	max	11.0 μm	34.4 μm	1,720 μm^3

[†]Calculated using original measurements, not summary values.
[‡]Biovolume based on cylinder length ($<$ cell length).
[§]Biovolume estimates based on $<$5 cells.

Description

Anabaena and *Dolichospermum* cells are spherical, oval, or barrel-shaped (Figures 3.1–3.38). The trichomes are unbranched and untapered, consisting of chains of bead-like vegetative cells. There is usually a mucilaginous sheath, but this can be difficult to see without staining. The trichome may be straight, bent, coiled, or irregularly twisted, and may occur as individual filaments or in tangled clumps. In addition to the vegetative cells, the trichomes often contain nitrogen-fixing heterocysts, and may contain thick-walled akinetes. Both *Anabaena* and *Dolichospermum* trichomes look similar to *Nostoc* trichomes, but

Nostoc trichomes will be enclosed in a firm, rubbery colonial mucilage (Section 3.11, page 309). *Anabaena* and *Dolichospermum* species are difficult to identify unless the sample contains vegetative cells, heterocysts, and mature akinetes.

The separation of *Anabaena* from *Dolichospermum* is fairly recent, and does not appear in older taxonomic keys. The revision is based on genetic differences that determine whether the cells can form gas vacuoles (see discussion by Wacklin, et al., 2009). All planktonic species that can form gas vacuoles have been reassigned to the genus *Dolichospermum*; this includes most of the toxin-forming species that were formerly in the genus *Anabaena*. The species that were retained in the genus *Anabaena* do not form gas vacuoles, so they should be more common in benthic mats, along shorelines, and mixed with aquatic vegetation. But wave action, wind, and other natural processes can suspend non-planktonic *Anabaena* species in the water column or cause planktonic *Dolichospermum* species to accumulate along the shoreline. As a result, separating *Anabaena* from *Dolichospermum* is challenging. Remember to use the key on page 199.

Anabaena species descriptions: *Anabaena* species lack gas vacuoles, so they do not float in the water column. Many of the species have straight or nearly straight trichomes. These taxa will be more common along shorelines, mixed with other aquatic vegetation, or in mats that form on the surface of sediments.

Anabaena catenula is a poorly described taxon that probably includes more than one species (John, et al. 2011). The distinguishing features for this group include straight or slightly curved trichomes of small, blue-green or olive-green, unconstricted, barrel-shaped vegetative cells (width $\approx$ length); spherical, oval, or broadly elliptical heterocysts; and bluntly rounded, cylindrical akinetes that are not adjacent to the heterocysts (Figures 3.2–3.3). Species in the genus *Anabaena* should not be planktonic, but according to Komárek (2013), at least some of the specimens described as *Anabaena catenula* can form gas vacuoles and should be transferred to the genus *Dolichospermum*.

Anabaena cylindrica has straight or slightly curved trichomes of blue-green, barrel-shaped vegetative cells that are longer than their width (Figures 3.4–3.5). The heterocysts are oval or elliptical and adjacent on both sides to long, narrow, cylindrical akinetes. This is a morphologically variable species that is merged with *Anabaena subcylindrica* Borge by John et al. (2011) and AlgaeBase (www.algaebase.org; downloaded October 2, 2015), but retained as a distinct species by Komárek (2013). *Anabaena cylindrica* is described as occurring in

unpolluted water (Komárek, 2013); the local specimens were collected from a clear mountain lake with extensive shoreline vegetation.

Anabaena echinospora is characterized by straight or slightly curved trichomes containing bright blue-green, spherical, vegetative cells and spherical heterocysts (Figures 3.6–3.7). The akinetes are cylindrical and adjacent on both sides to heterocysts. The mature akinetes develop a distinctive spiny covering (exospore), but immature akinetes may not show this feature, so it is important to examine more than one specimen. According to Komárek (2013), this species is found in cold ponds and marshes; all of the local specimens were collected in a boggy, high elevation lakes.

Anabaena inaequalis has straight or slightly curved trichomes of grayish-green, compressed (width $>$ length), barrel-shaped vegetative cells (Figures 3.8–3.9). The heterocysts range from approximately spherical to oval, and are not adjacent to the akinetes. The mature akinetes are long and cylindrical, with flattened ends. All of the local specimens were collected in shallow, low elevation lakes or ponds containing dense macrophyte growth.

Anabaena oscillarioides trichomes are straight or slightly curved, with small, blue-green, barrel-shaped cells, and spherical or oval heterocysts (Figures 3.10–3.13). The mature akinetes are elliptical or cylindrical and smooth (not spiny). The akinetes have heterocysts adjacent to both ends, and the trichome often contains multiple akinetes in sequence. This species usually forms mats on wet surfaces including lake or pond sediments, but can also be collected in shoreline vegetation.

The two unknown species of *Anabaena* in Figures 3.14–3.17 were collected in shoreline samples from boggy mountain lakes. *Anabaena* sp.1 has straight or slightly curved trichomes, with pale, grayish-green, barrel-shaped cells (width $<$ length), oval heterocysts, and long, cylindrical akinetes that are not adjacent to the heterocysts. This species resembles *Anabaena cylindrica* in all morphological and habitat features except the location of the heterocysts relative to the akinetes.

Anabaena sp.2 has straight trichomes, with granular, grayish-green, spherical cells. The heterocysts are spherical or broadly oval, and not adjacent to akinetes. The akinetes appear to be elliptical rather than cylindrical, but very few specimens were collected of this species, so it is difficult to tell whether the akinetes were fully developed.

Dolichospermum species descriptions: *Dolichospermum* species form gas vacuoles in their cells and are usually planktonic, but can also be found mixed with aquatic vegetation along shorelines. Many of the species have curved, tangled, or coiled trichomes, but there are also some species with straight trichomes. Many of the nuisance Cyanobacteria blooms in local lakes contain at least one species of *Dolichospermum* (Figure 3.18), as well as other types of Cyanobacteria, including *Aphanizomenon* (Section 3.3, page 250), *Gloeotrichia* (Section 3.9, page 293), and *Microcystis* (Section 2.13, page 141). Some (not all) strains can release toxins into the water. Old planktonic colonies of *Dolichospermum* may support stalked, filter-feeding protozoa or other types of epiphytes (Figures 3.19–3.20) or may show cell degradation resulting from parasitism (Figure 3.21).

Dolichospermum circinale is characterized by irregularly twisted or coiled trichomes containing approximately spherical, olive-green or brownish vegetative cells and spherical heterocysts that are slightly larger than the vegetative cells (Figures 3.22–3.23). The akinetes are solitary, oval or broadly elliptical, and may be slightly asymmetric. The akinetes are separated from heterocysts by at least a few cells. This species closely resembles *Dolichospermum flosaquae*, which has spherical cells and kidney-shaped akinetes; and *Dolichospermum mendotae*, which has barrel-shaped (not spherical) cells and approximately straight, cylindrical akinetes. *Dolichospermum circinale* also resembles *Dolichospermum lemmermannii*, which is distinguished by its central mass of cylindrical akinetes.

Dolichospermum crassum trichomes form very regular spirals of approximately spherical, olive-green or brownish vegetative cells and spherical heterocysts (Figures 3.24–3.25). The large, oval akinetes are solitary and not adjacent to the heterocysts. Several other species of *Dolichospermum* can form spiraling trichomes, but will rarely form the spring-like coils that distinguish *Dolichospermum crassum*.

Dolichospermum flosaquae (Figures 3.26–3.27) is characterized by irregularly twisted or loosely tangled trichomes of spherical, dark olive-green or brownish vegetative cells and spherical heterocysts. The akinetes are elliptical or kidney-shaped and distant from the heterocysts. This species closely resembled *Dolichospermum circinale*, which can be distinguished by its asymmetric, oval akinetes; and *Dolichospermum mendotae*, which can be distinguished by its barrel-shaped (not spherical) cells and approximately straight, cylindrical akinetes. *Dolichospermum circinale* also resembles *Dolichospermum lemmermannii*, which is distinguished by its central mass of cylindrical akinetes.

Dolichospermum lemmermannii (Figures 3.28–3.30) forms large planktonic colonies containing many densely tangled trichomes of dark olive-green or brownish, slightly elongated, barrel-shaped cells. The akinetes are usually cylindrical and slightly curved, but the shape can vary considerably, even within a single trichome. The akinetes are adjacent to spherical or oval heterocysts, and form a dense mass in the center of the colony. The colonies become so dense that it may be difficult to see the distinguishing features. Older colonies of this species often have epiphytic zooplankton (Figure 3.19). *Dolichospermum lemmermannii* resembles several other planktonic *Dolichospermum* species, but none will develop the dense central tangle of cylindrical akinetes adjacent to heterocysts.

Dolichospermum mendotae trichomes are irregularly coiled or twisted and easily fragmented, with pale blue-green or olive-green, barrel-shaped cells that are consistently longer than wide (Figures 3.31–3.32). The akinetes are large, cylindrical, solitary, and not adjacent to the heterocysts. The specimens in Figure 3.33 fit the trichome description for *Dolichospermum mendotae*, but lack akinetes and heterocysts, so the identification is uncertain. *Dolichospermum mendotae* resembles *Dolichospermum circinale*, which can by distinguished by its asymmetric, oval akinetes; and *Dolichospermum flosaquae*, which has spherical cells and kidney-shaped akinetes.

Dolichospermum planctonicum trichomes are straight or very slightly curved, not tangled or spiraled, consisting of approximately spherical, olive-green or brownish vegetative cells and spherical heterocysts (Figures 3.34–3.36). The akinetes are oval or elliptical, solitary, and distant from the heterocysts. The heterocysts often develop mucilaginous "wings" that are visible using phase contrast or DIC illumination. The akinetes may also develop mucilaginous extensions, but this feature is less common in local specimens.

Dolichospermum skujaelaxum is characterized by tangled or irregularly coiled trichomes containing olive-green or brownish, barrel-shaped cells, and oval heterocysts (Figures 3.37–3.38). The cylindrical akinetes are adjacent to heterocysts and are scattered throughout the clump, rather than forming a central mass. This species resembles *Dolichospermum circinale*, which has spherical cells and asymmetric, oval akinetes; *Dolichospermum flosaquae*, which has spherical cells and kidney-shaped akinetes; and *Dolichospermum lemmermannii*, which forms a dense, central clump of akinetes.

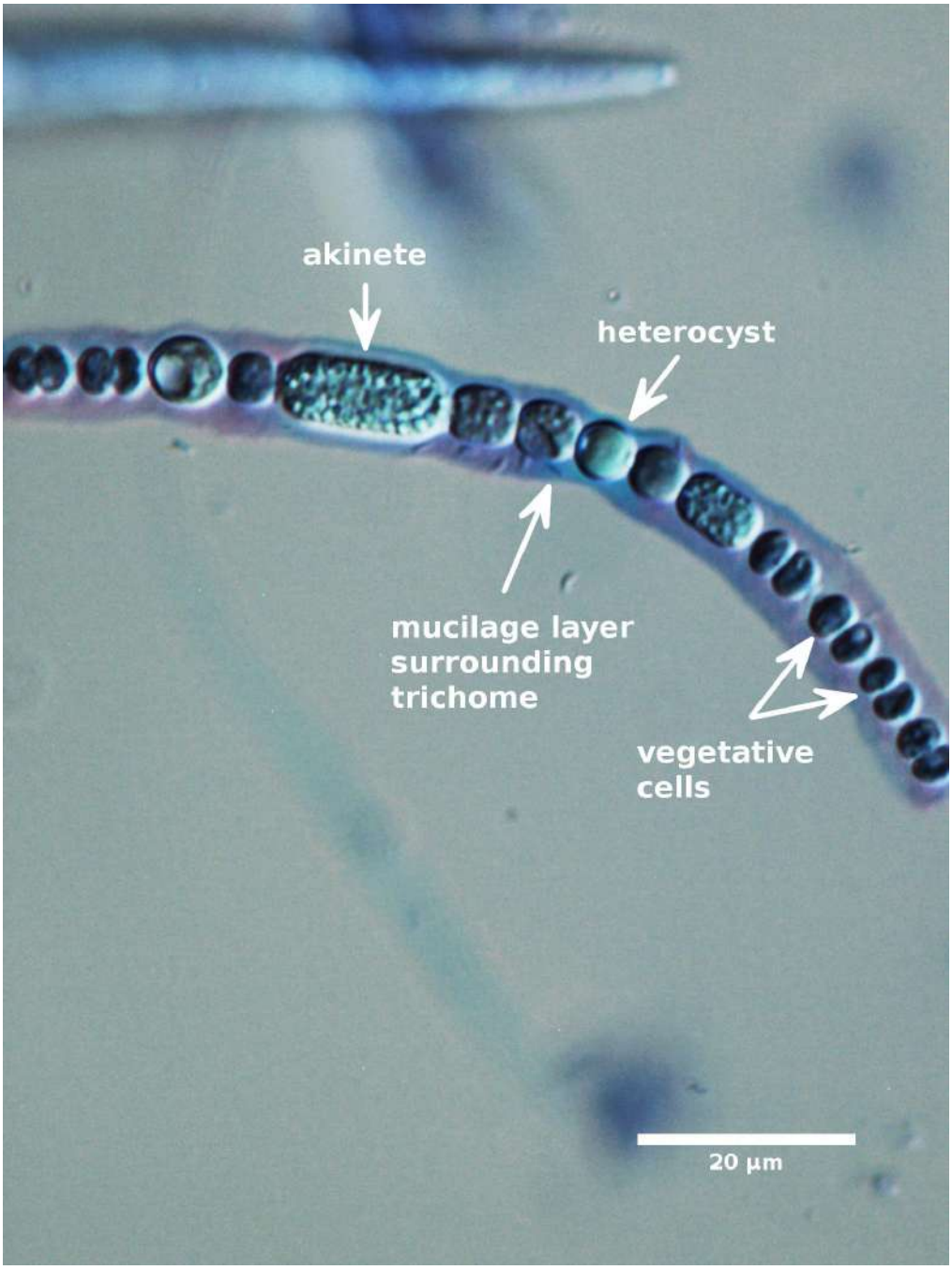


Figure 3.1: Typical *Anabaena* trichome stained with methylene blue to show mucilage layer (600x DIC), Picture Lake, IWS water quality sampling site, Whatcom County, August 6, 2013.

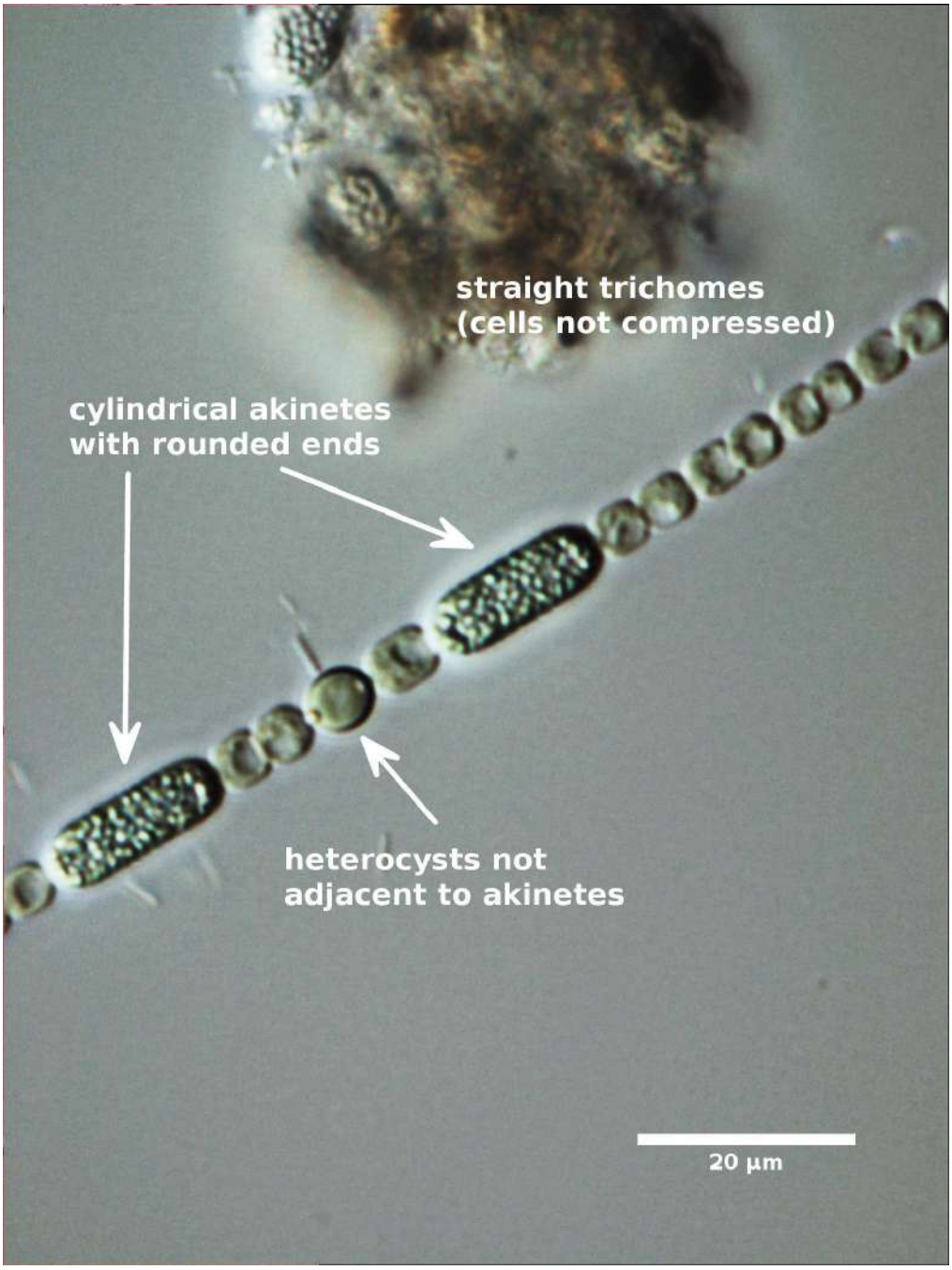


Figure 3.2: *Anabaena catenula* group (600x DIC), Picture Lake, IWS water quality sampling site, Whatcom County, August 31, 2011.

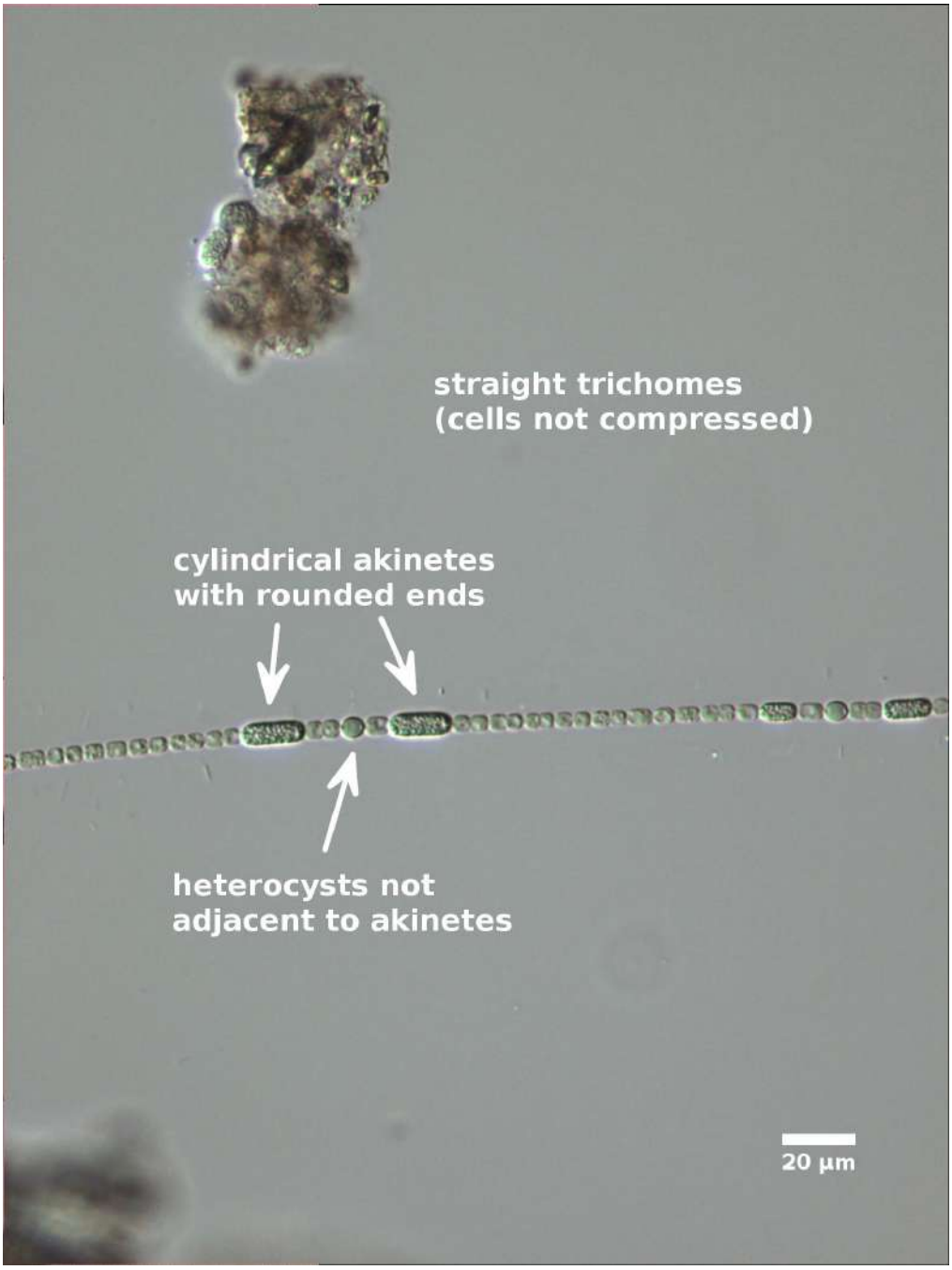


Figure 3.3: *Anabaena catenula* group (200x DIC), Picture Lake, IWS water quality sampling site, Whatcom County, August 31, 2011.

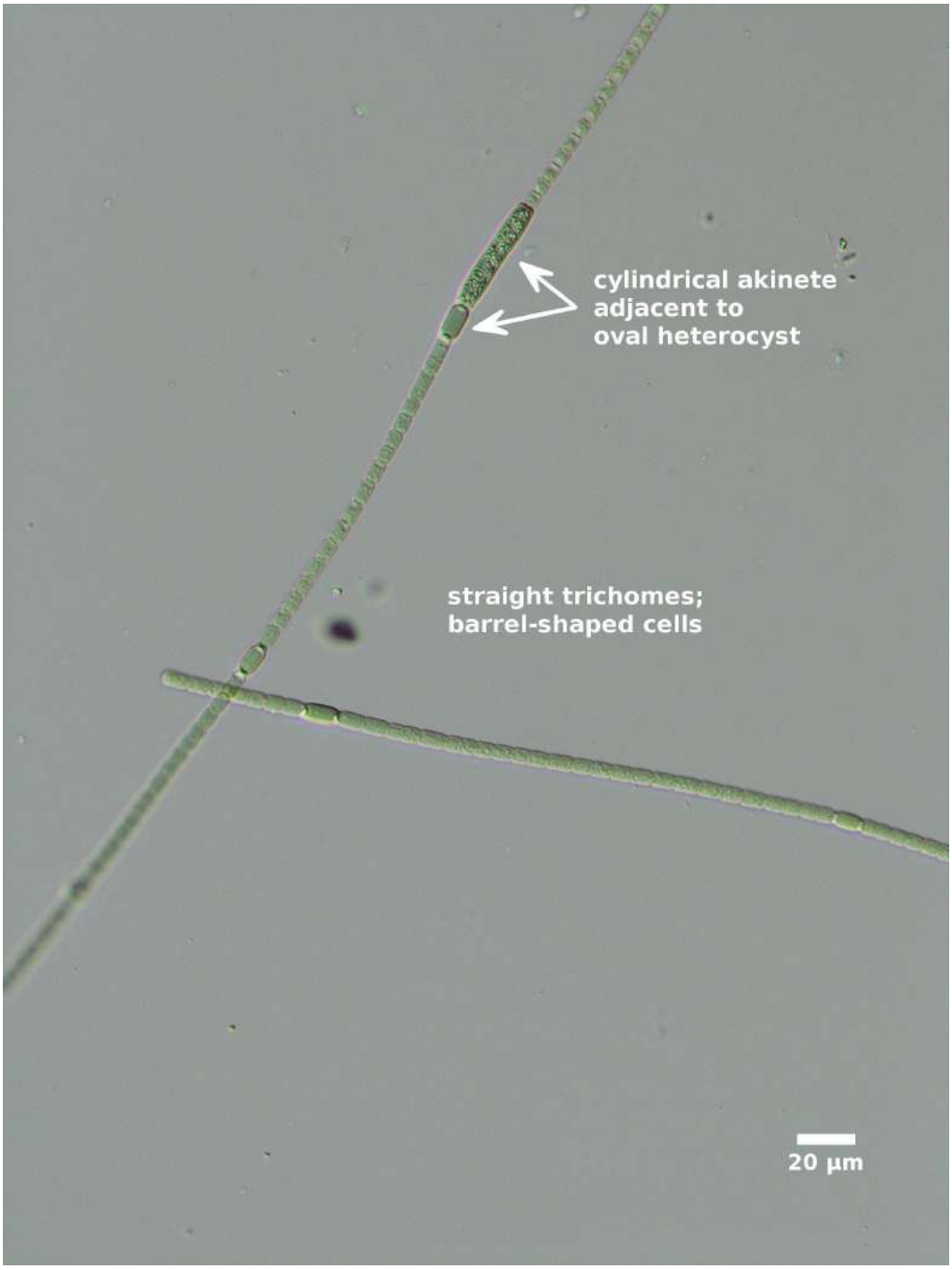


Figure 3.4: *Anabaena cylindrica* (200x DIC), Highwood Lake, IWS water quality sampling site, Whatcom County, August 11, 2015.

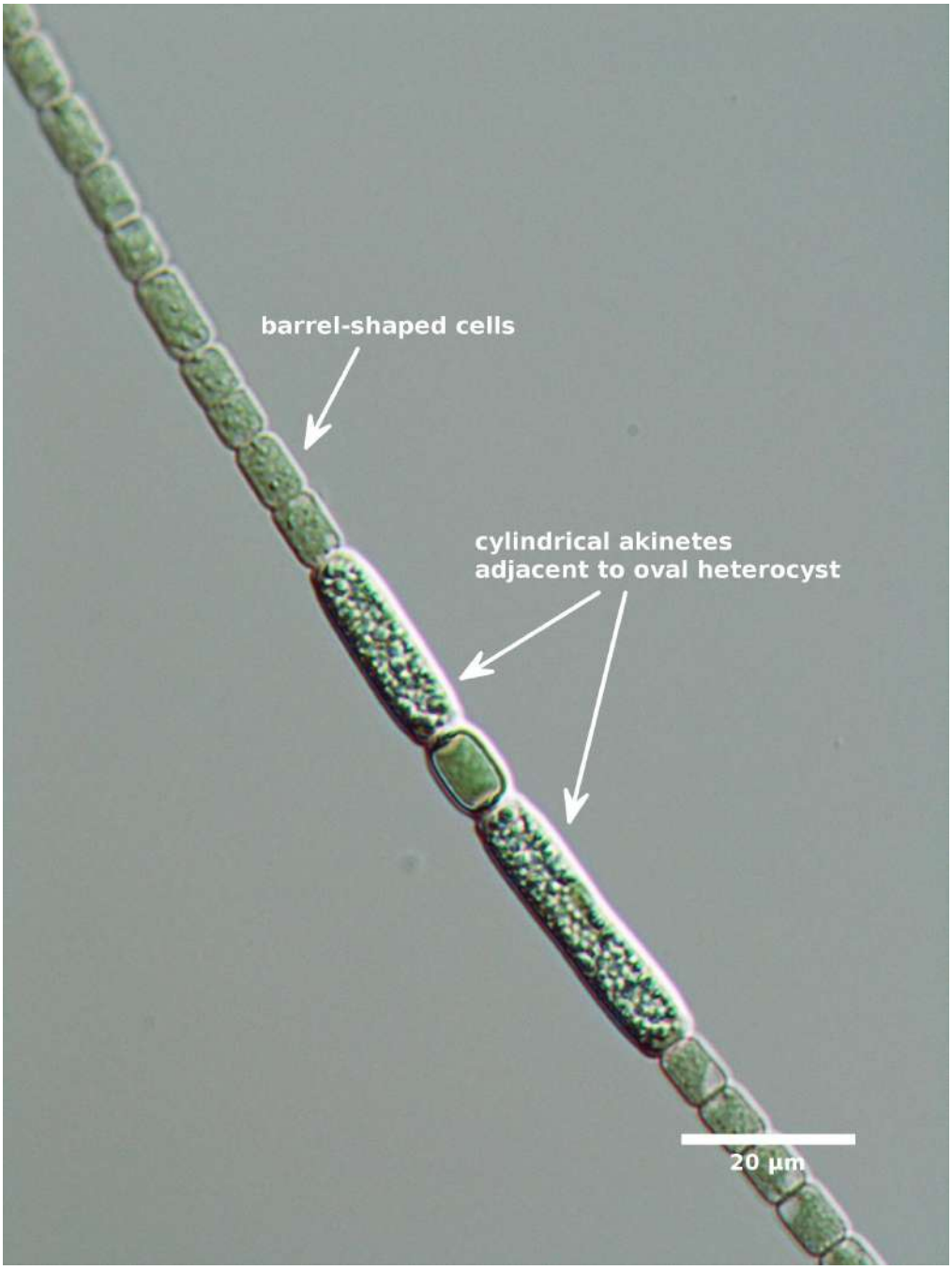


Figure 3.5: *Anabaena cylindrica* (600x DIC), Highwood Lake, IWS water quality sampling site, Whatcom County, August 11, 2015.



Figure 3.6: *Anabaena echinospora* (400x DIC), Myrtle Lake, IWS water quality sampling site, Snohomish County, September 17, 2014.

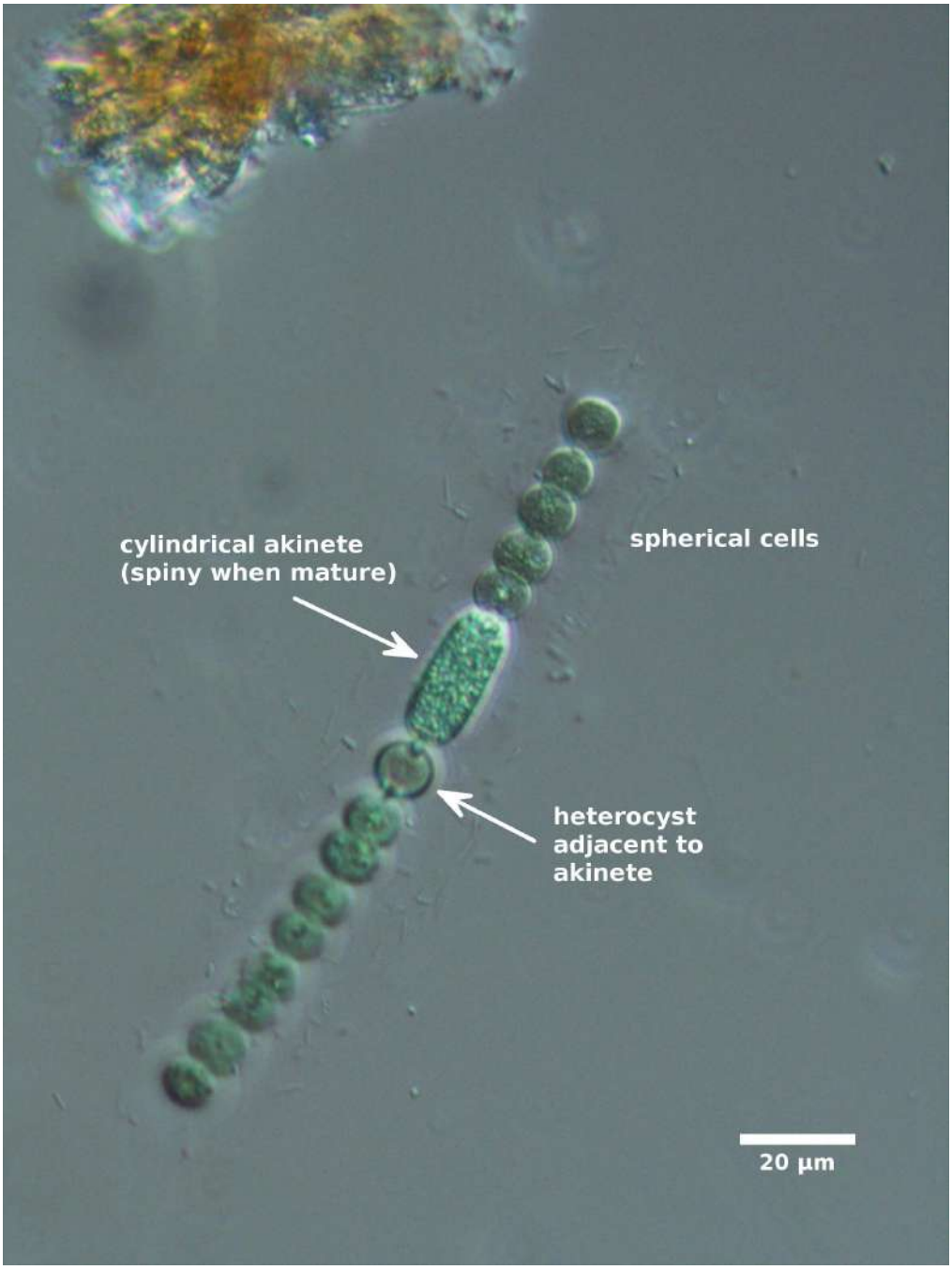


Figure 3.7: *Anabaena echinospora* (400x DIC), Myrtle Lake, IWS water quality sampling site, Snohomish County, September 17, 2014.

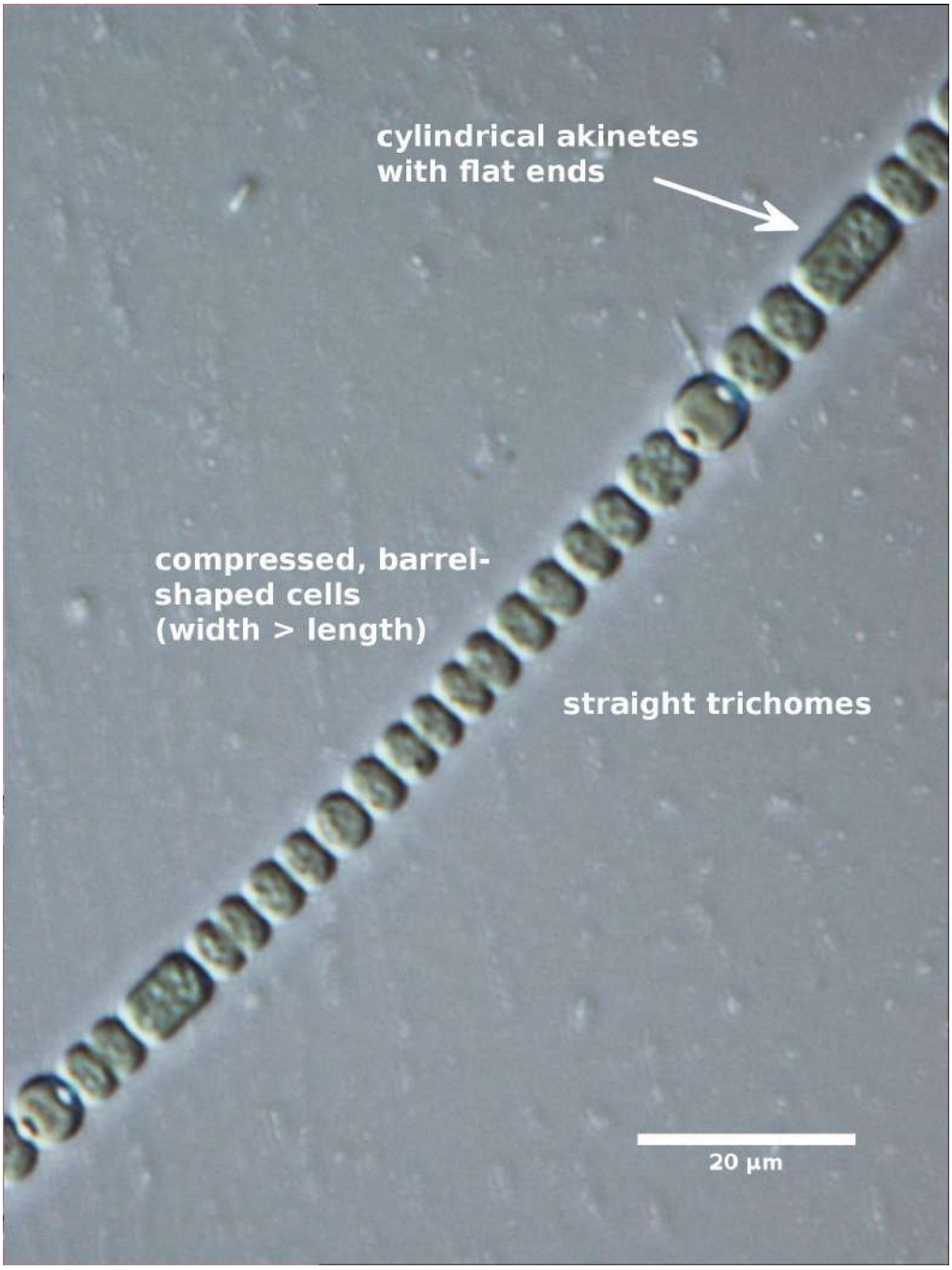


Figure 3.8: *Anabaena inaequalis* (600x DIC), small pond near Squalicum Creek, Whatcom County, May 20, 2011.

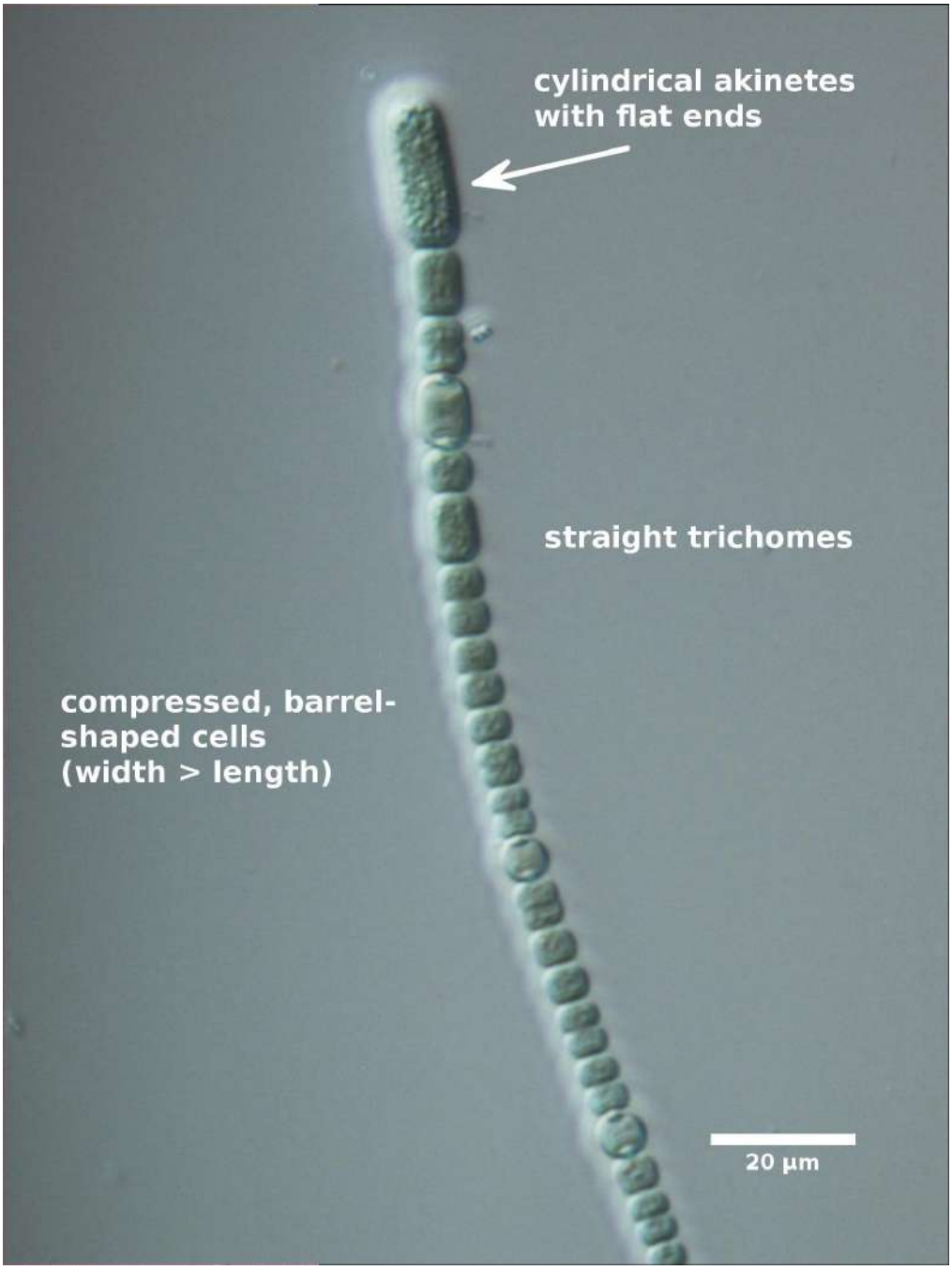


Figure 3.9: *Anabaena inaequalis* (400x DIC), small pond near Squalicum Creek, Whatcom County, May 20, 2011.

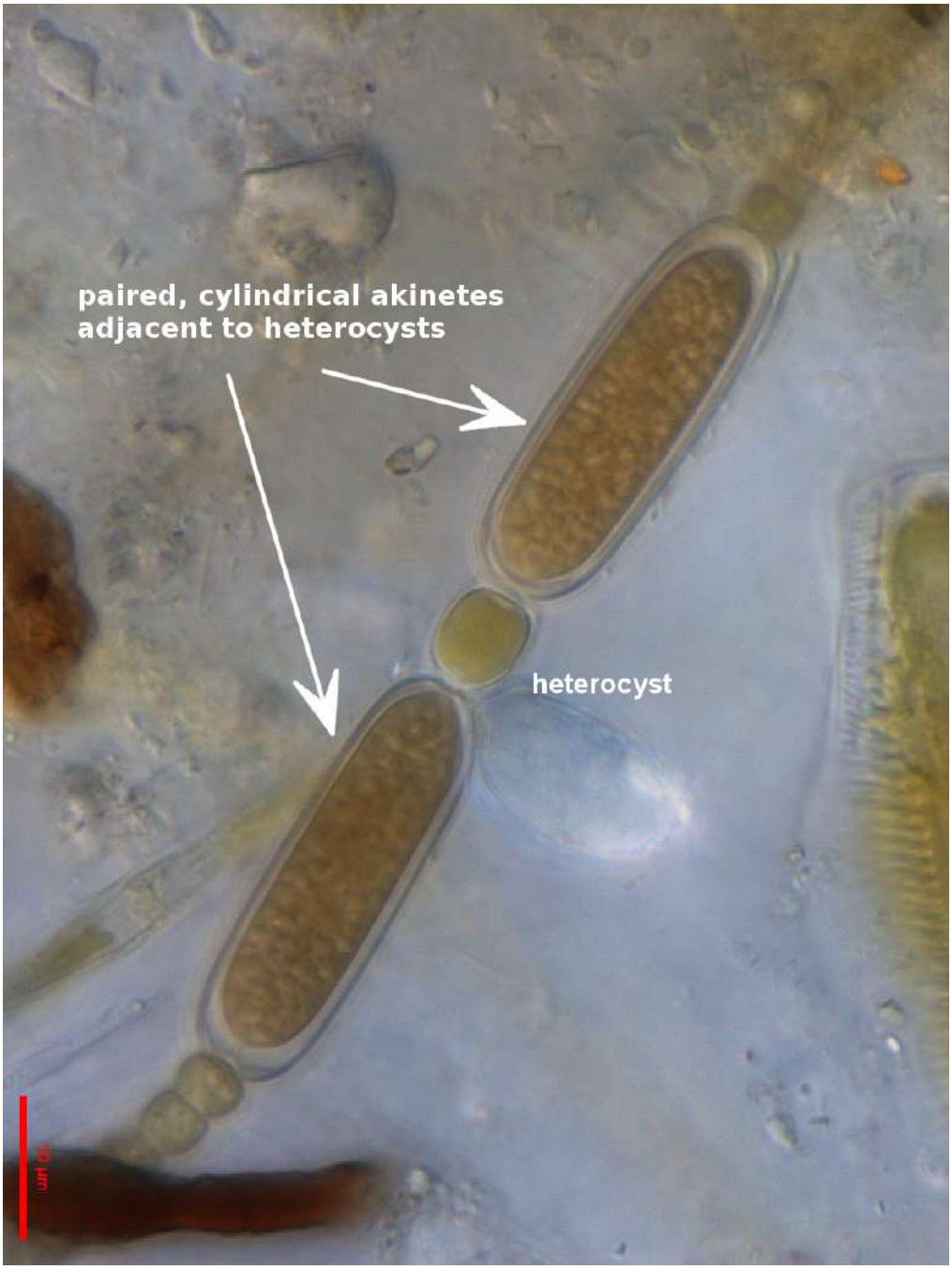


Figure 3.10: *Anabaena oscillarioides* in Lugol's iodine solution (1000x DIC), Apple Tree Golf Course, Yakima, WA, May 26, 2009. Photo provided by Karl Bruun, Nostoca Algae Laboratory, Bainbridge Island, WA.

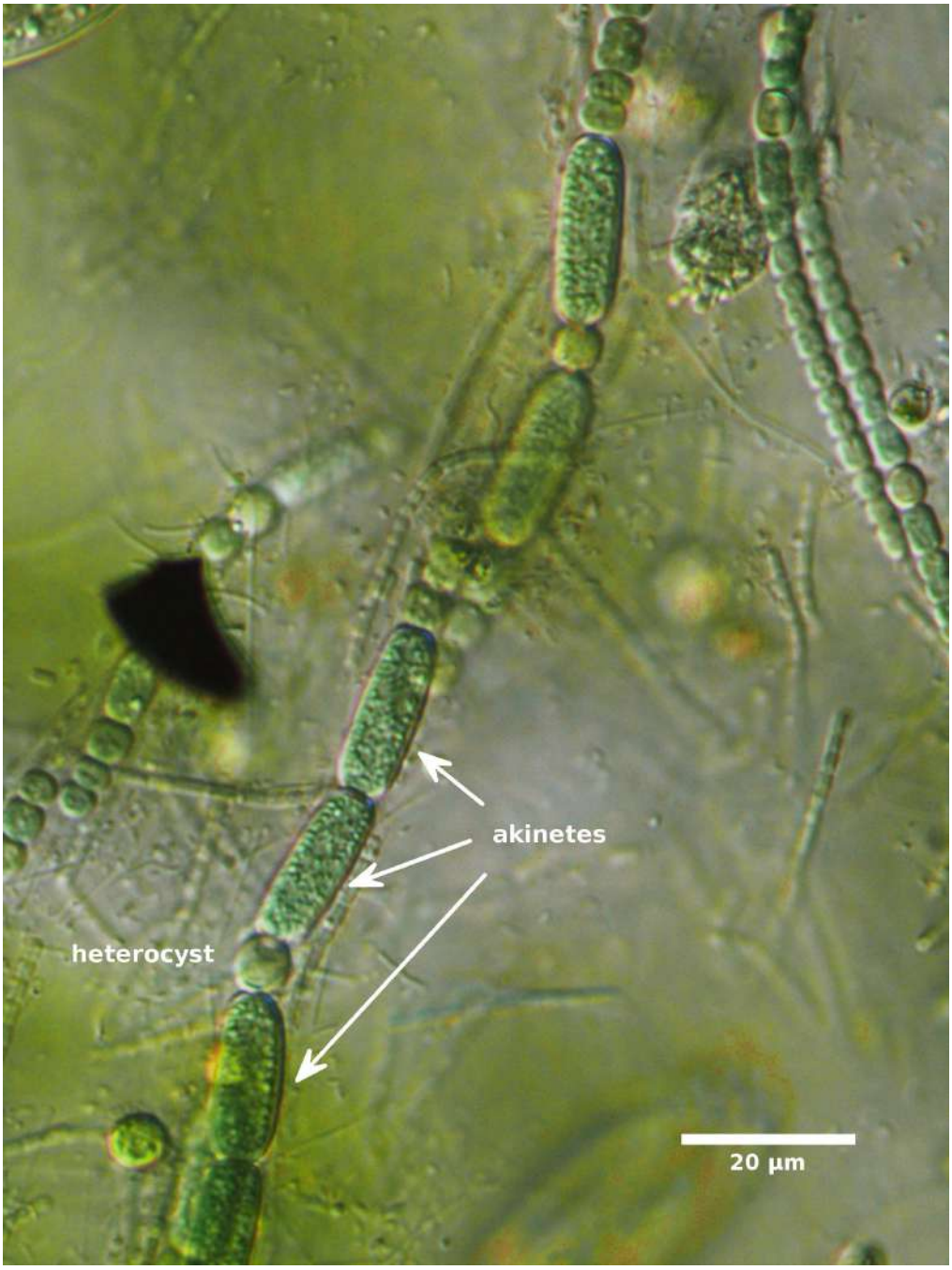


Figure 3.11: *Anabaena oscillarioides* (600x DIC), small backyard pond, Whatcom County, May 13, 2015.



Figure 3.12: *Anabaena oscillarioides* in Lugol's iodine solution (200x DIC), Apple Tree Golf Course, Yakima, WA, May 26, 2009. Photo provided by Karl Bruun, Nostoca Algae Laboratory, Bainbridge Island, WA.

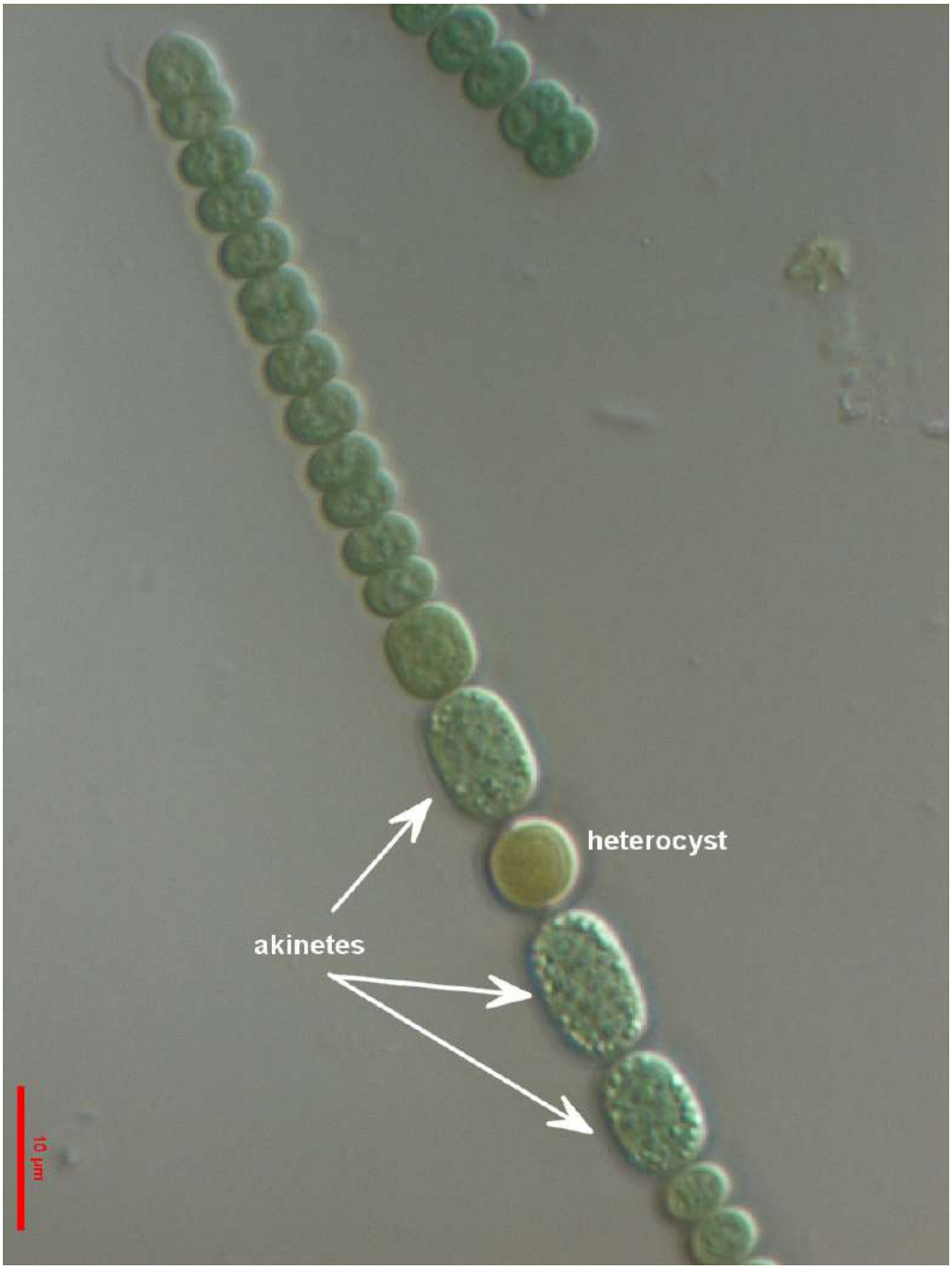


Figure 3.13: *Anabaena oscillarioides* (1000x DIC), wet sidewalk, Seattle, WA, July 12, 2009. Photo provided by Karl Bruun, Nostoca Algae Laboratory, Bainbridge Island, WA.



Figure 3.14: *Anabaena* sp.1 (200x DIC), Lower Ashland Lake, Mt. Loop Hwy, July 30, 2015.

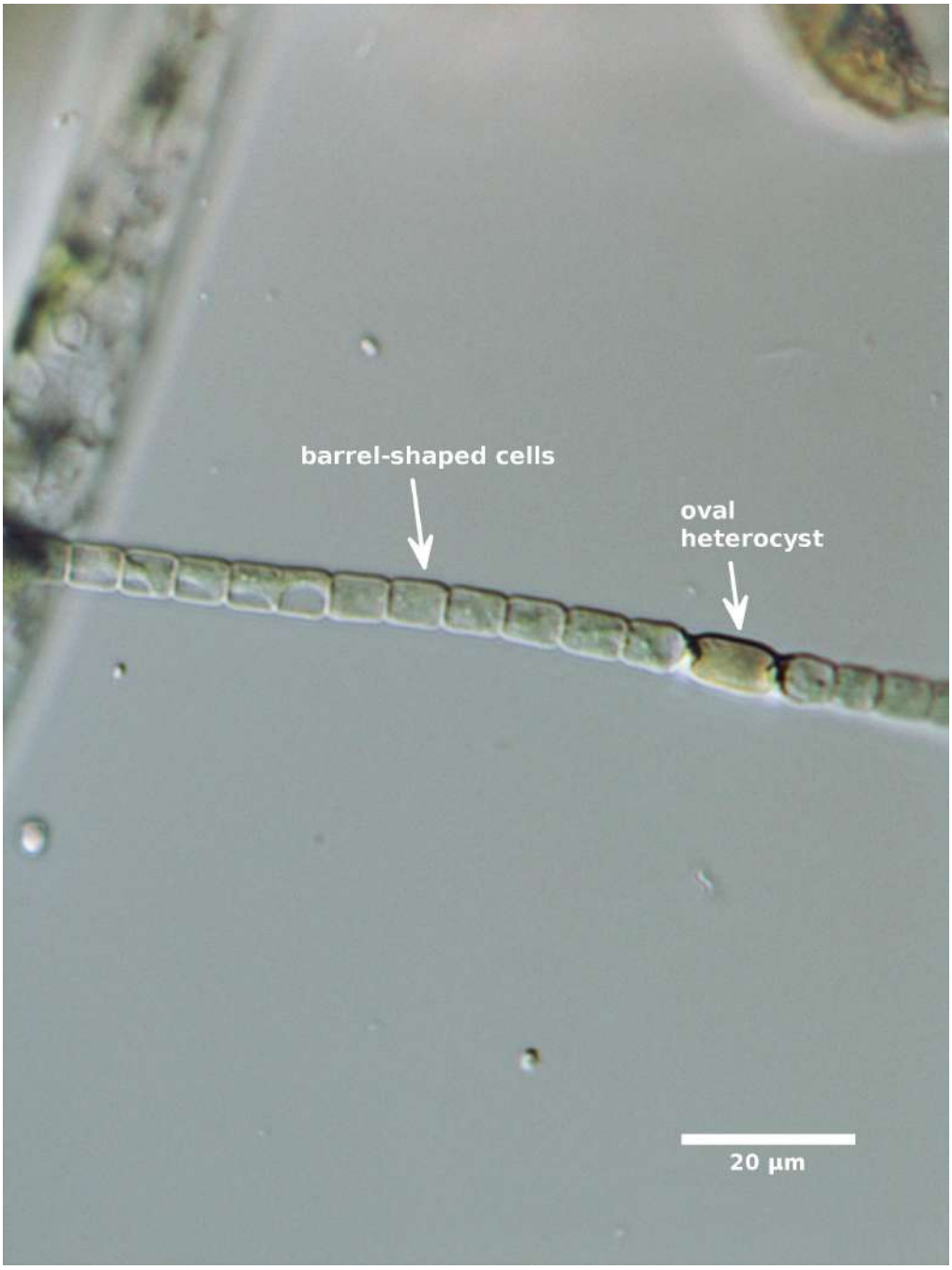


Figure 3.15: *Anabaena* sp.1 (600x DIC), Lower Ashland Lake, Mt. Loop Hwy, July 30, 2015.

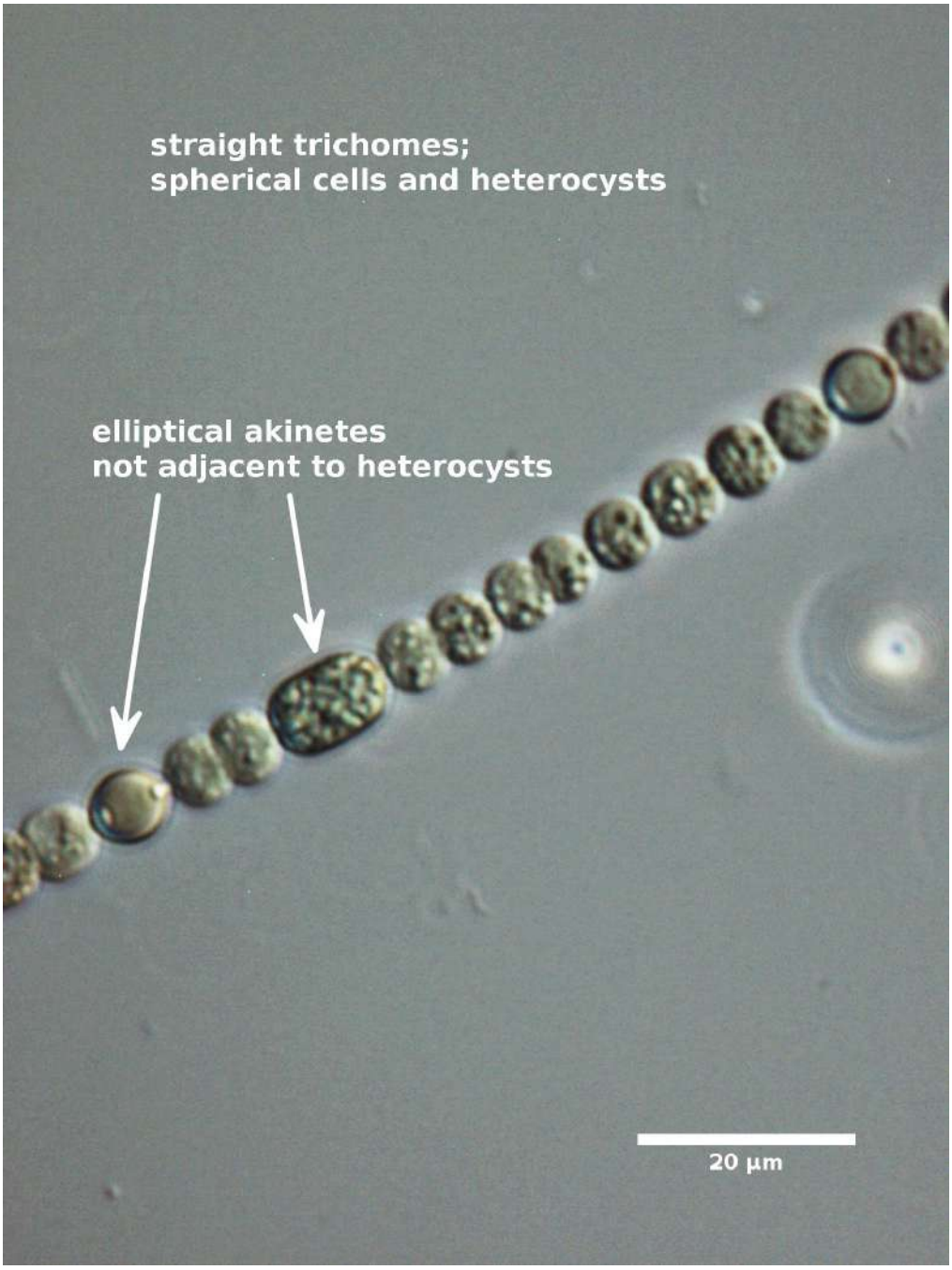


Figure 3.16: *Anabaena* sp.2 (600x DIC), Upper Watson Lake, North Cascades along Hwy 20, August 23, 2013.



Figure 3.17: *Anabaena* sp.2 (200x DIC), Coal Lake, IWS water quality sampling site, Snohomish County, August 28, 2014.

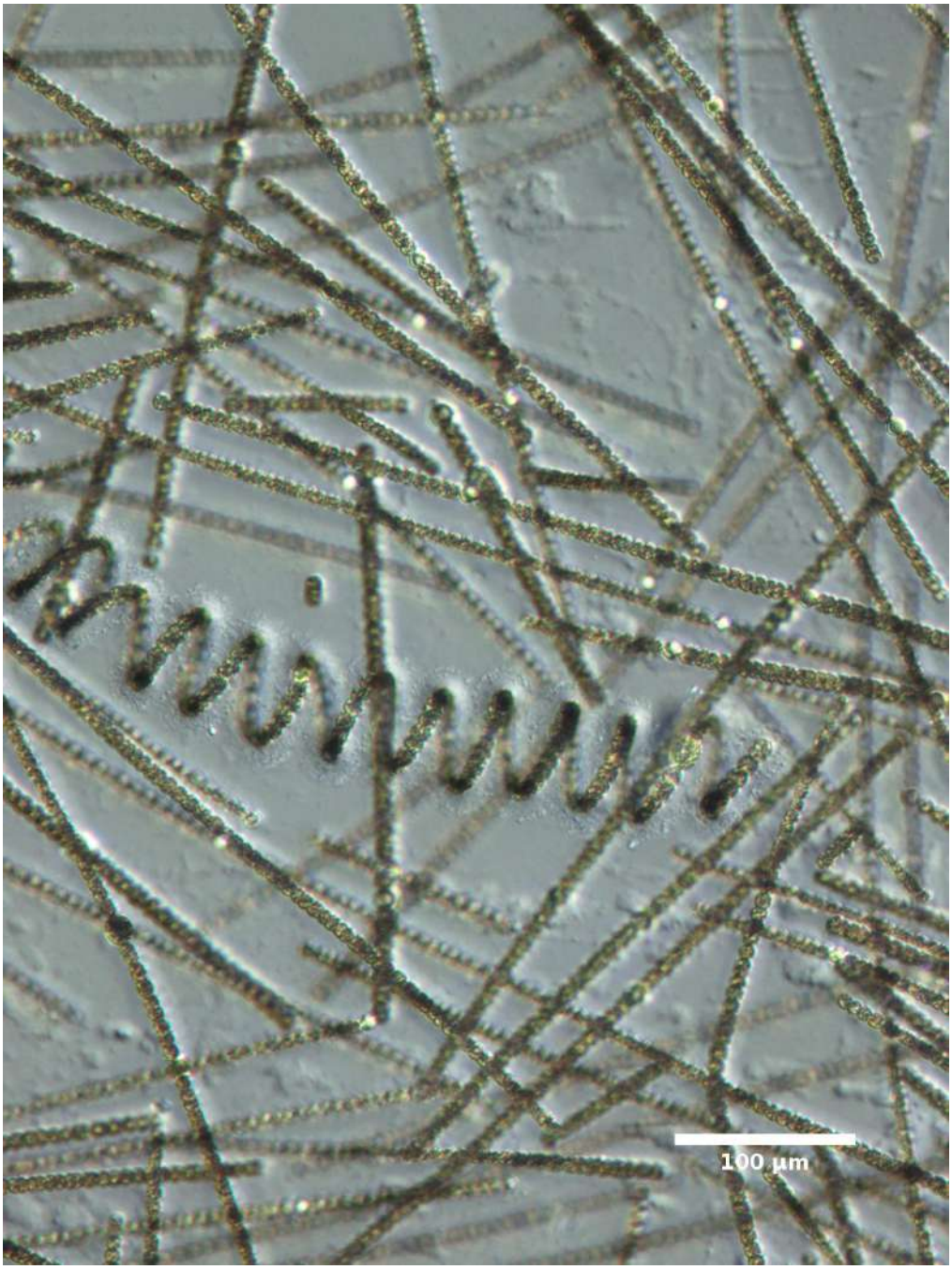


Figure 3.18: *Dolichospermum* bloom (100x DIC), Heart Lake, IWS water quality sampling site, Skagit County, August 26, 2013.

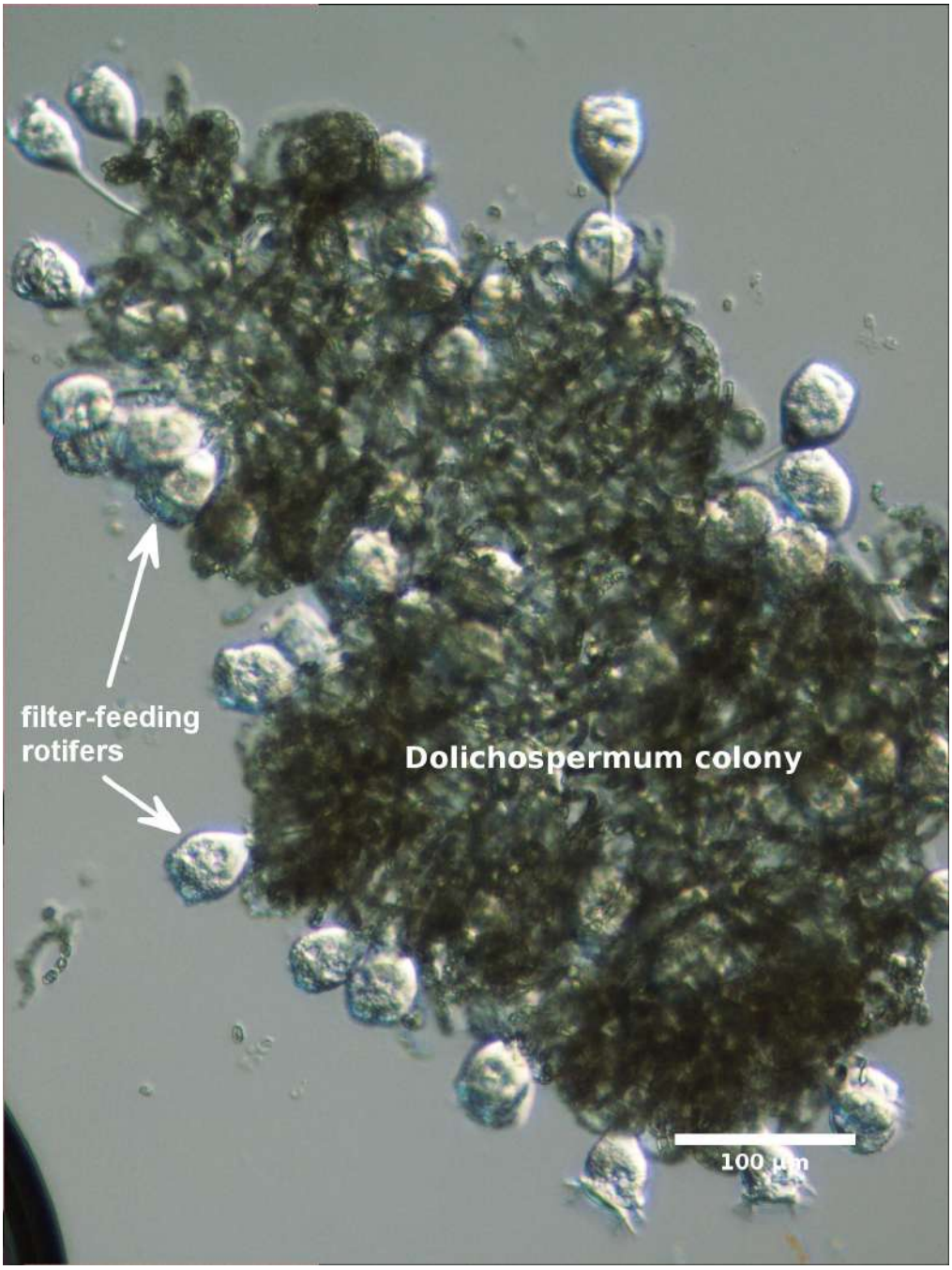


Figure 3.19: *Dolichospermum lemmermannii* colony with attached, filter-feeding rotifers (100x DIC), Deer Lake, IWS water quality sampling site, Island County, May 1, 2008.

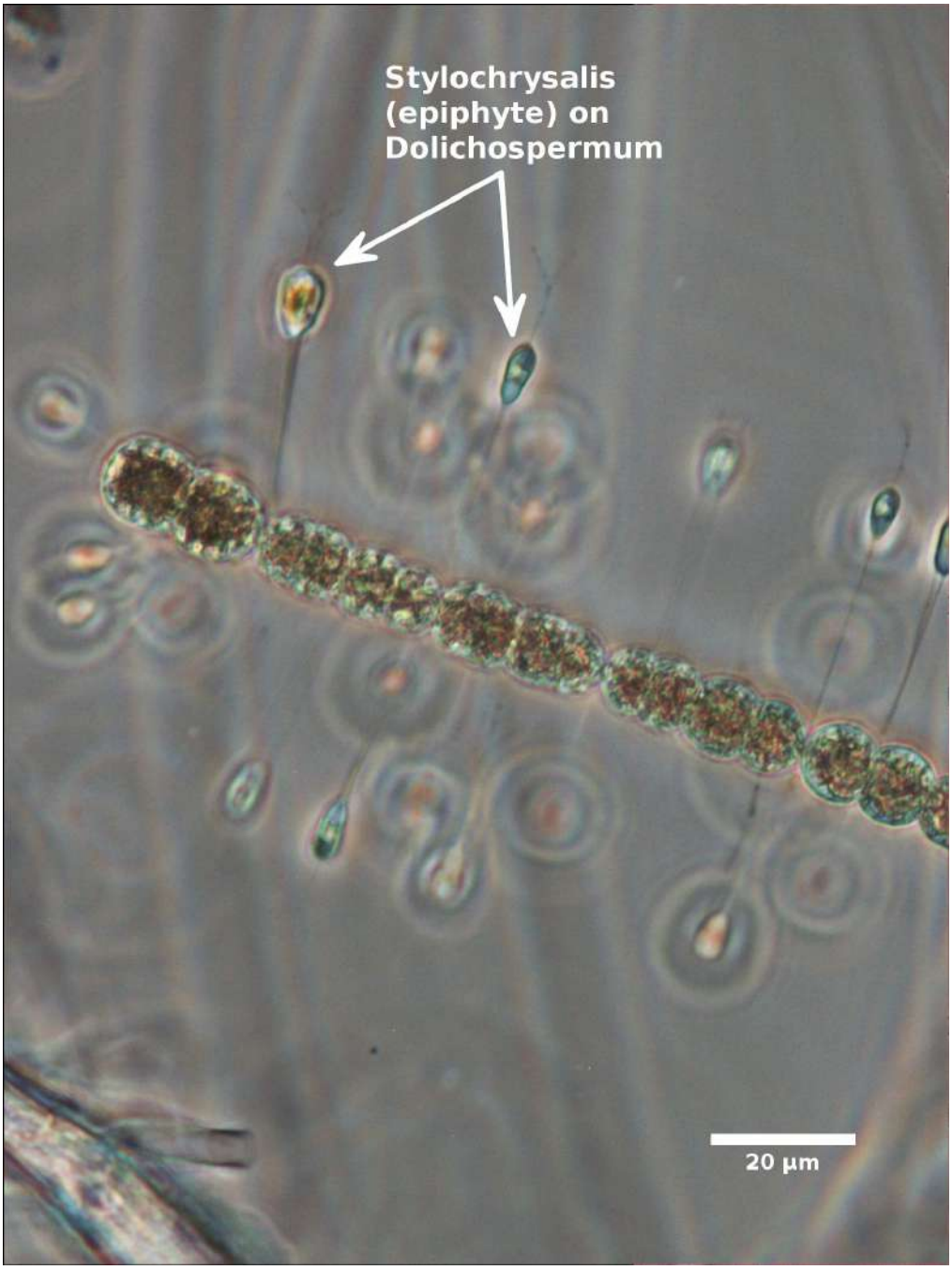


Figure 3.20: *Dolichospermum* with epiphytic *Stylochrysalis* (400x phase contrast), Crabapple Lake, IWS water quality sampling site, Snohomish County, September 21, 2009.



Figure 3.21: *Dolichospermum* parasitized by fungi (600x DIC), Heart Lake, IWS water quality sampling site, Skagit County, August 25, 2009.



Figure 3.22: *Dolichospermum circinale* (200x DIC), Lake Fazon, IWS water quality sampling site, Whatcom County, June 30, 2011.

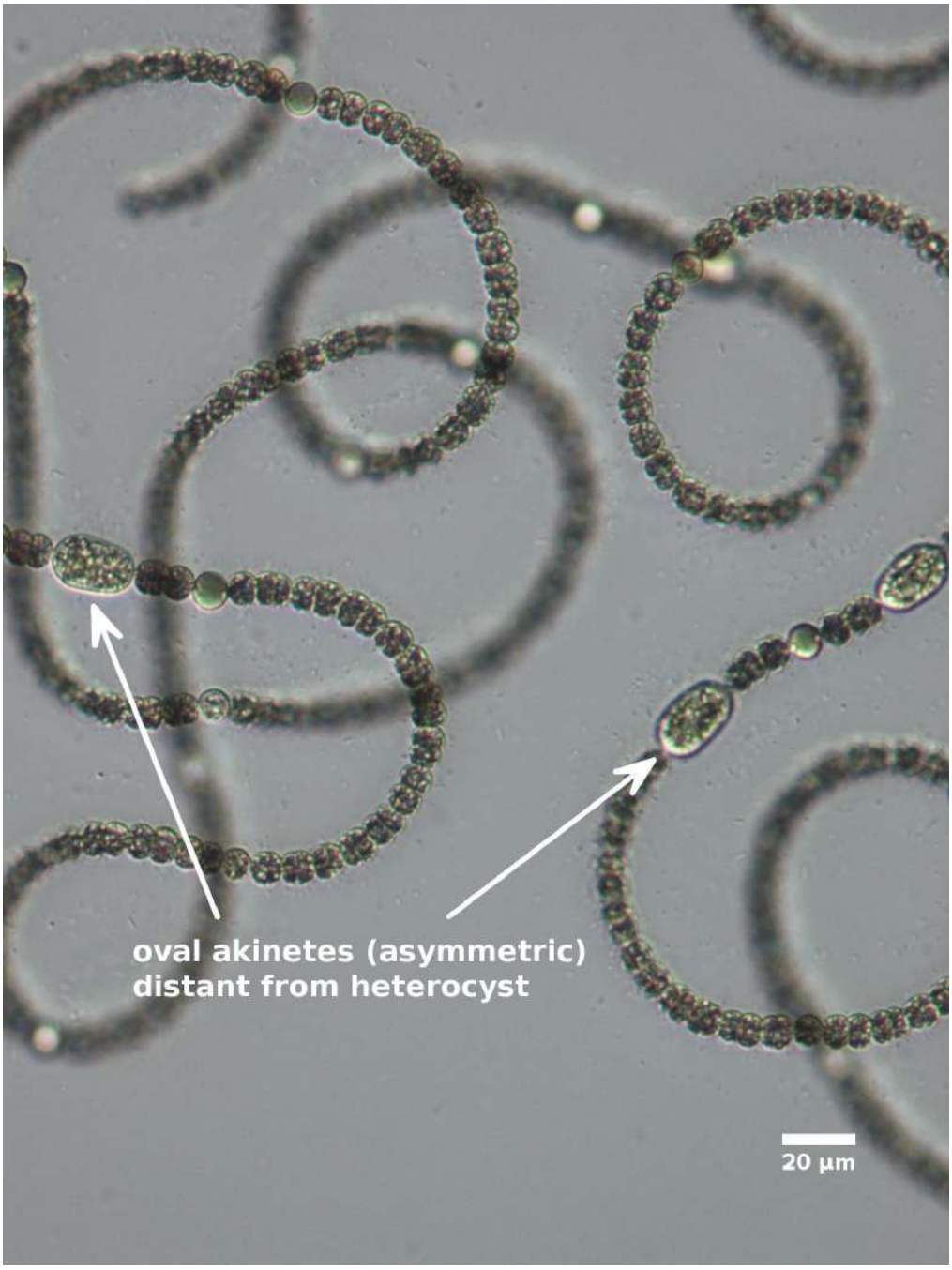


Figure 3.23: *Dolichospermum circinale* (200x DIC), Bullard Pond, IWS water quality sampling site, Whatcom County, July 22, 2013.



Figure 3.24: *Dolichospermum crassum* (200x DIC), Lone Lake, IWS water quality sampling site, Island County, August 25, 2009.



Figure 3.25: *Dolichospermum crassum* flattened trichome (200x DIC), Wiser Lake, IWS water quality sampling site, Whatcom County, June 30, 2010.

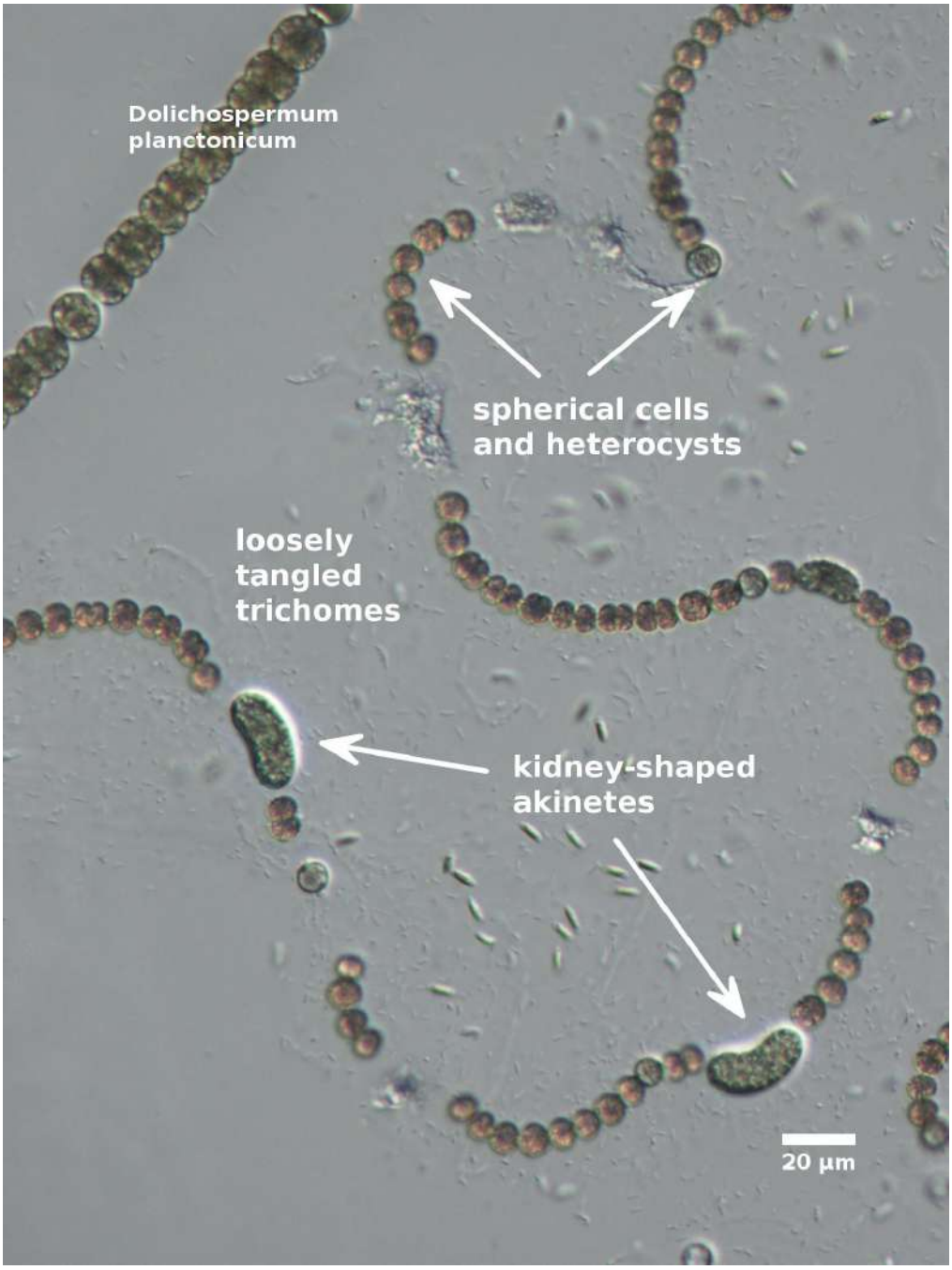


Figure 3.26: *Dolichospermum flosaquae* (200x DIC), Lake Padden, IWS water quality sampling site, September 27, 2012.



Figure 3.27: *Dolichospermum flosaquae* (200x DIC), Lake Samish, IWS water quality sampling site, Whatcom County, October 20, 2010.



Figure 3.28: *Dolichospermum lemmermannii* (100x DIC), Grandy Lake, IWS water quality sampling site, Skagit County, September 9, 2009.

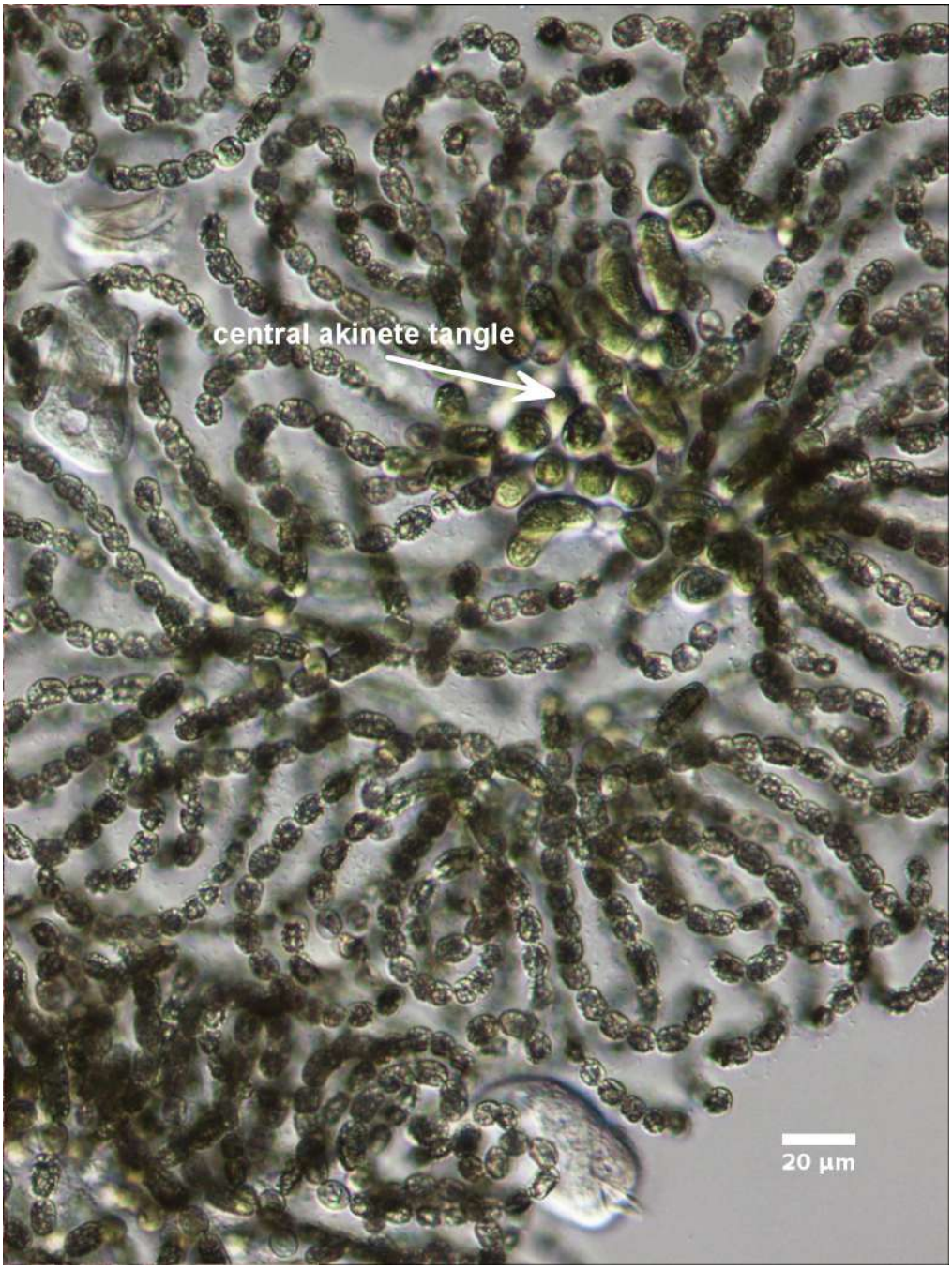


Figure 3.29: *Dolichospermum lemmermannii* (200x DIC), Grandy Lake, IWS water quality sampling site, Skagit County, September 9, 2009.

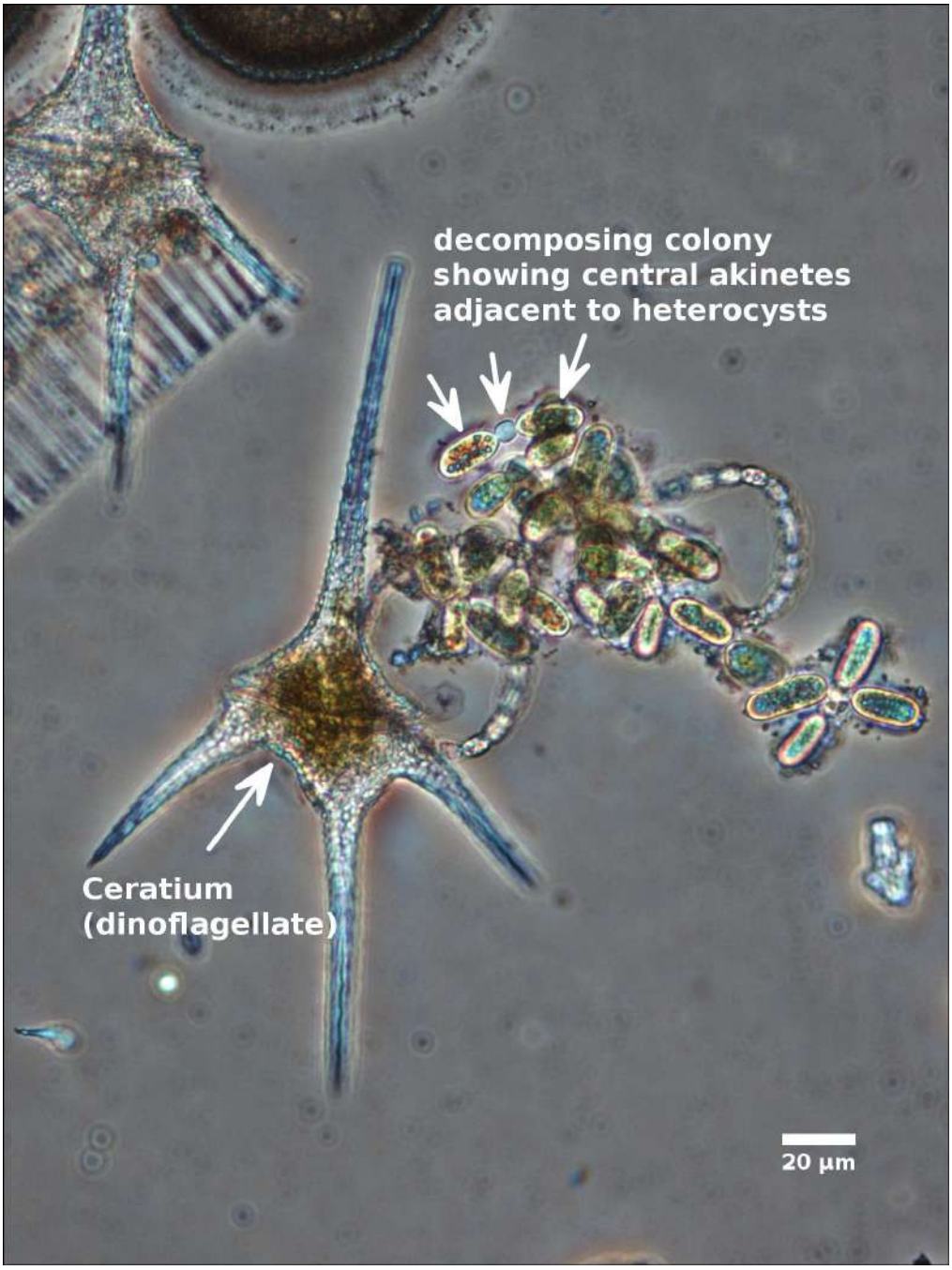


Figure 3.30: *Dolichospermum lemmermannii* (200x phase contrast), Pass Lake, IWS water quality sampling site, Skagit County, August 24, 2006.

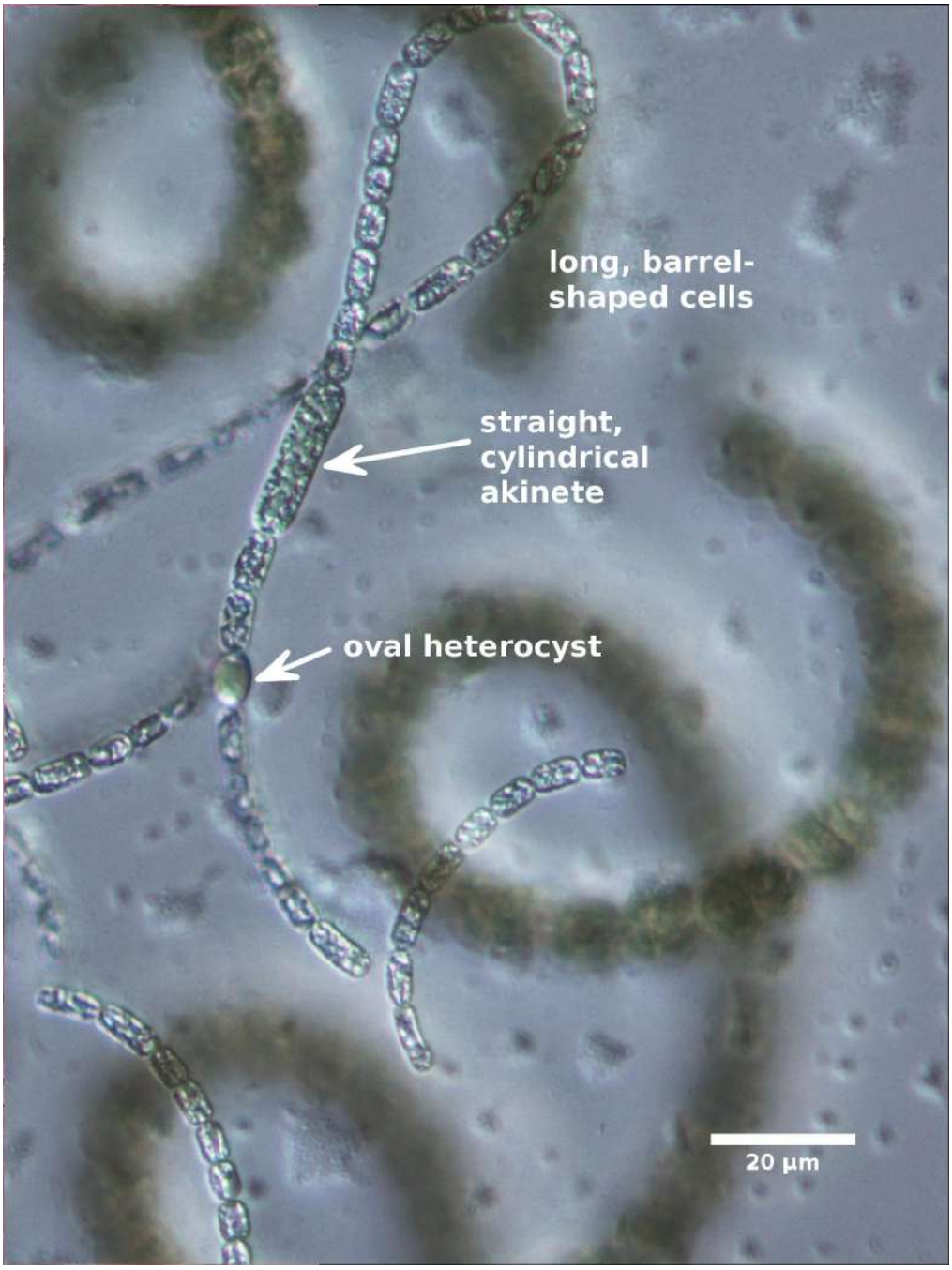


Figure 3.31: *Dolichospermum mendotae* (400x DIC), Wiser Lake, IWS water quality sampling site, Whatcom County, June 30, 2010.

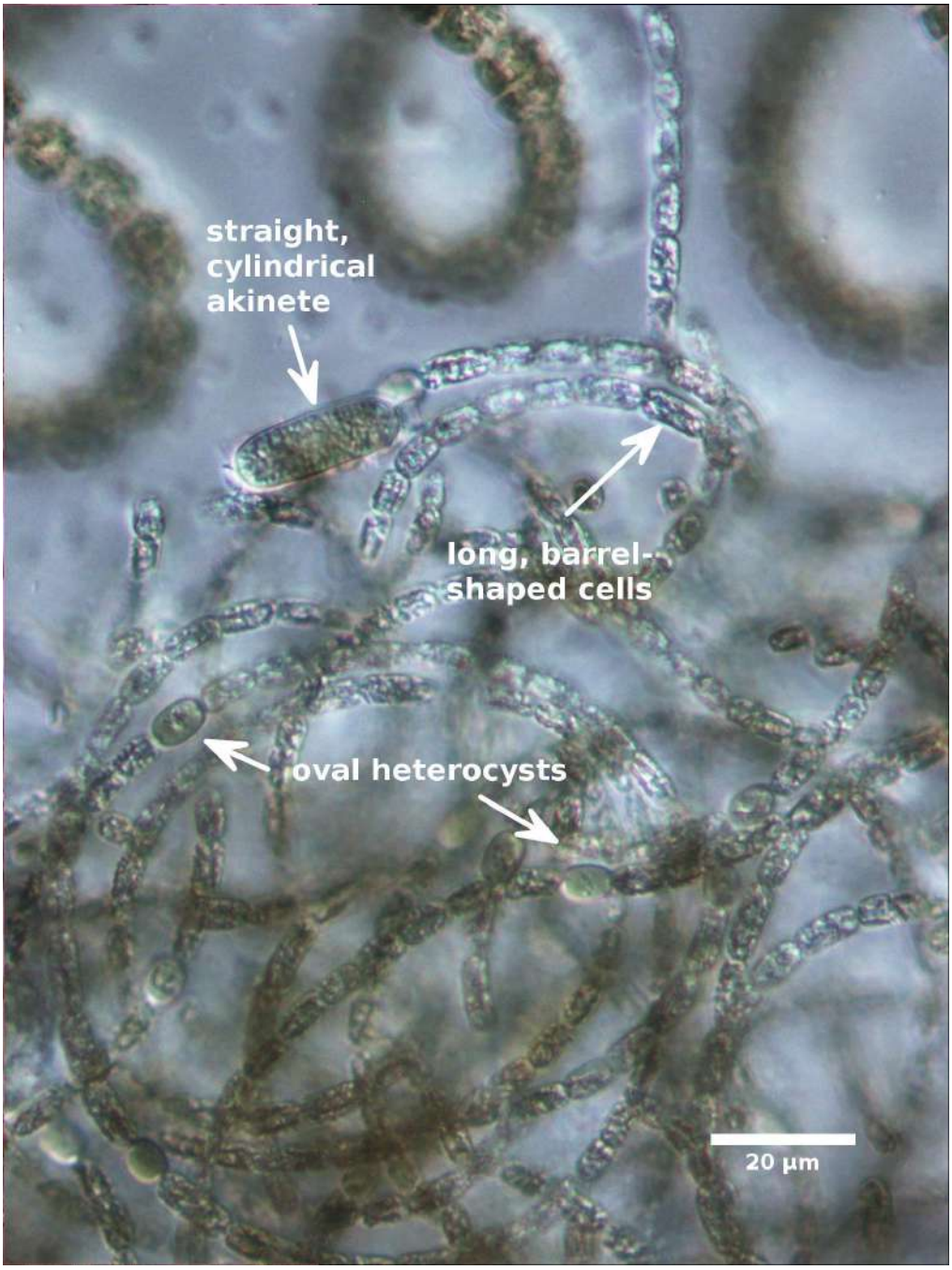


Figure 3.32: *Dolichospermum mendotae* (400x DIC), Wiser Lake, IWS water quality sampling site, Whatcom County, June 30, 2010.



Figure 3.33: *Dolichospermum mendotae*? (200x DIC), Toad Lake, IWS water quality sampling site, Whatcom County, March 24, 2010.

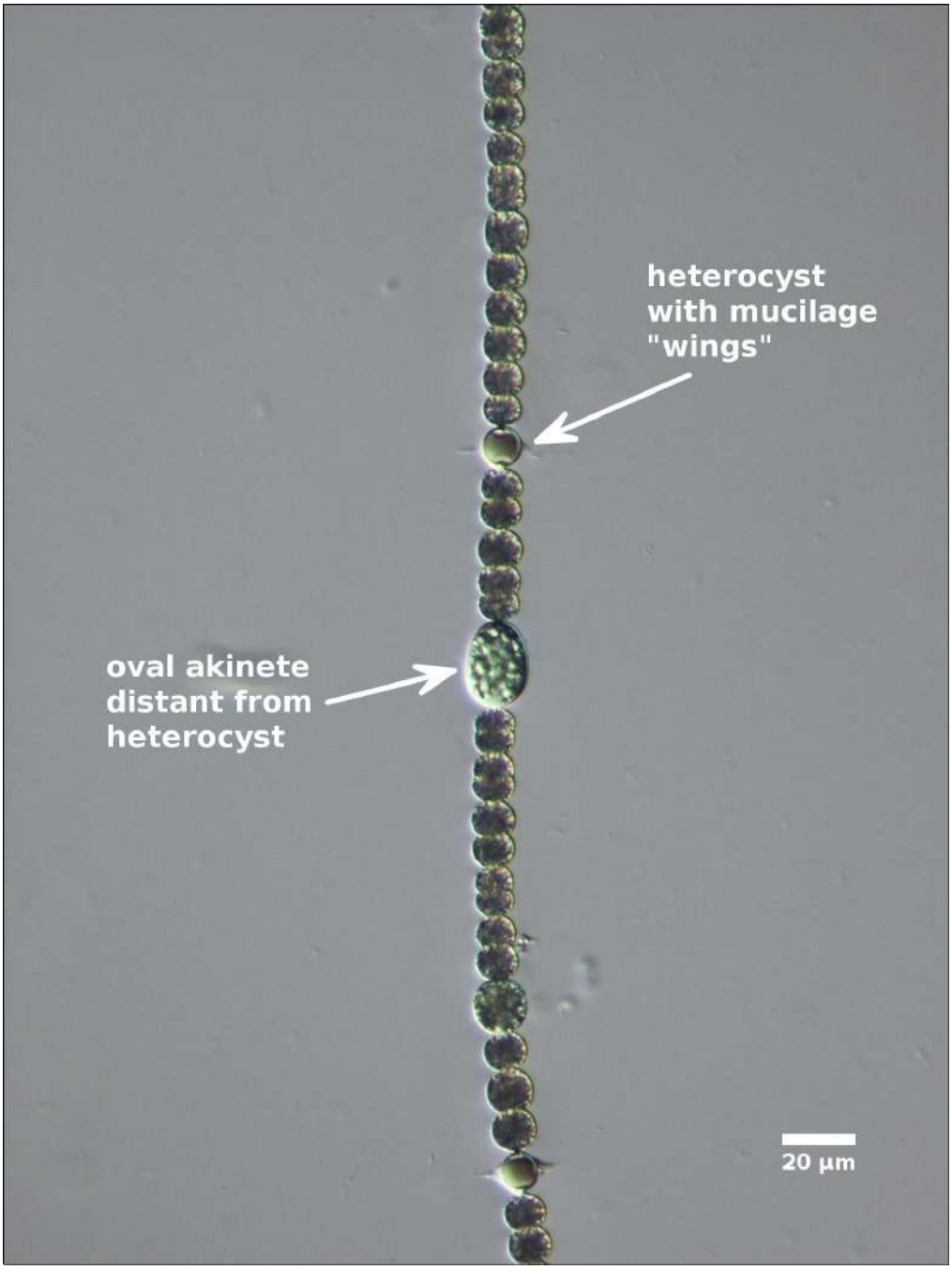


Figure 3.34: *Dolichospermum planctonicum* (200x DIC), Big Lake, IWS water quality sampling site, Skagit County, August 23, 2007.



Figure 3.35: *Dolichospermum planctonicum* winged heterocyst (600x DIC), Big Lake, IWS water quality sampling site, Skagit County, August 23, 2007.



Figure 3.36: *Dolichospermum planctonicum* in Lugol's iodine solution (600x DIC), Sunset Pond, IWS water quality sampling site, Whatcom County, August 23, 2007.

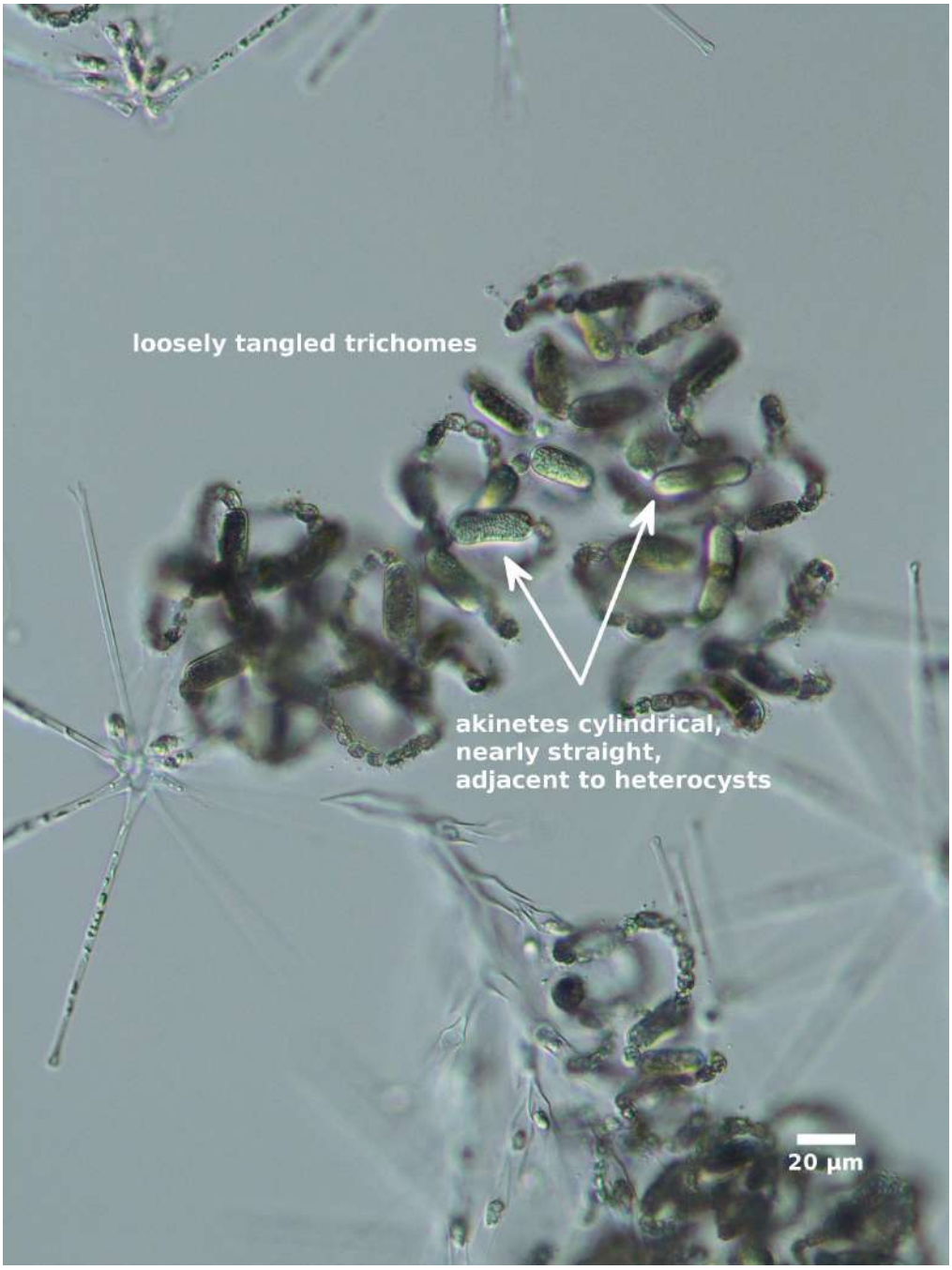


Figure 3.37: *Dolichospermum skujaelaxum* (200x DIC), Glacier Lake, Goat Rocks Wilderness Area, September 5, 2014.

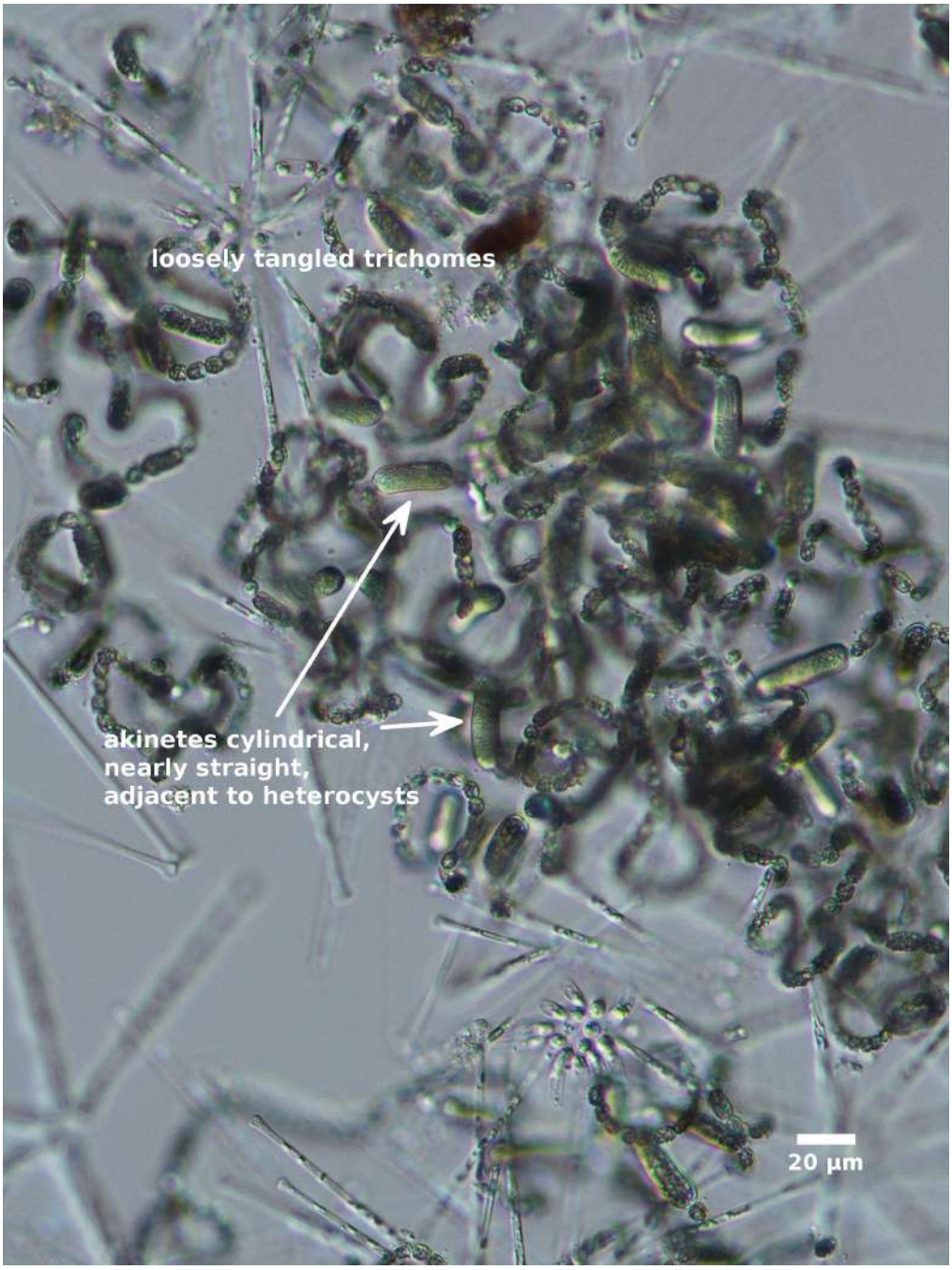


Figure 3.38: *Dolichospermum skujaelaxum* (200x DIC), Glacier Lake, Goat Rocks Wilderness Area, September 5, 2014.

3.2 *Anabaenopsis* Miller

Local taxon
Anabaenopsis elenkinii Miller

Abundance
Infrequently collected.

Local measurements		Width	Length	Biovolume[†]
Anabaenopsis elenkinii	min	5.9 μm	4.1 μm	79.9 μm^3
cells (spheroid)	med	6.2 μm	6.9 μm	165 μm^3
	max	6.9 μm	9.8 μm	212 μm^3
Anabaenopsis elenkinii	min	5.3 μm	–	78 μm^3
heterocysts (sphere)	med	5.8 μm	–	102 μm^3
	max	6.4 μm	–	137 μm^3
Anabaenopsis elenkinii[‡]	min	9.0 μm	10.8 μm	458 μm^3
akinetes (spheroid)	med	9.2 μm	10.8 μm	474 μm^3
	max	9.3 μm	10.8 μm	489 μm^3

[†]Calculated using original measurements, not summary values.
[‡]Biovolume estimates based on $<$5 cells.

Description
Anabaenopsis elenkinii trichomes are twisted into short loops or coils, with barrel-shaped vegetative cells and spherical heterocysts located at each end of the trichome (Figure 3.39). The heterocysts are initially formed in a series within the trichome, not at the ends. The trichome breaks between two heterocysts, forming short trichomes with heterocysts at each end. The akinetes are solitary or paired, not adjacent to the heterocysts, and spherical or oval.

This species is described as being slightly halophilic (tolerates salt water) and associated with eutrophic lakes (Komárek, 2013). The local specimen was collected from a small, high conductivity ($\geq$1000 μS/cm), eutrophic lake situated adjacent to the ocean in Birch Bay, WA.

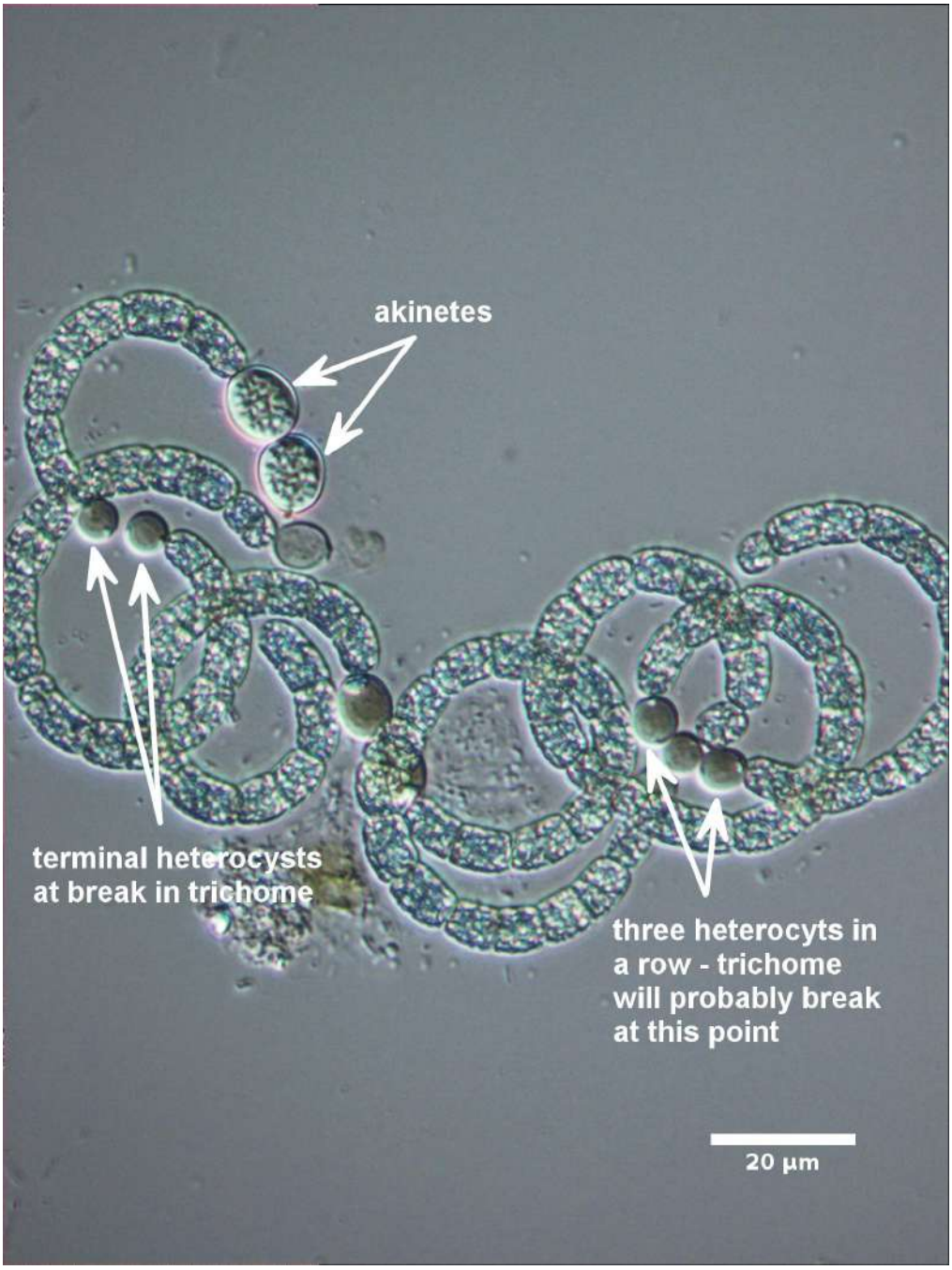


Figure 3.39: *Anabaenopsis elenkinii* (400x DIC), Kwan Lake, IWS water quality sampling site, Whatcom County, August 25, 2009.

3.3 *Aphanizomenon* Morren ex Bornet & Flahault

Local taxon
Aphanizomenon flosaquae Ralfs ex Bornet & Flahault

Abundance
Moderately common; may form very dense blooms.

Local measurements		Width	Length	Biovolume[†]
Aphanizomenon flosaquae	min	3.6 μm	4.4 μm	75.3 μm^3
cells (cylinder)	med	5.0 μm	9.4 μm	212 μm^3
	max	6.5 μm	45.1 μm	717 μm^3
Aphanizomenon flosaquae	min	4.0 μm	8.4 μm	75.4 μm^3
heterocysts (spheroid)	med	5.0 μm	11.4 μm	150 μm^3
	max	6.4 μm	13.4 μm	268 μm^3
Aphanizomenon flosaquae	min	4.4 μm	23.6 μm	412 μm^3
akinetes (cyl + two $\frac{1}{2}$ spheres)[‡]	med	8.4 μm	58.2 μm	2,780 μm^3
	max	10.3 μm	73.0 μm	4,590 μm^3

[†]Calculated using original measurements, not summary values.
[‡]Biovolume based on cylinder length ($<$ cell length).

Description
Aphanizomenon flosaquae is a common water quality indicator that can form dense blooms in eutrophic lakes (Figures 3.40–3.44). It is often associated with *Gloeotrichia* (Section 3.9, page 293), *Dolichospermum* (Section 3.1, page 198), and *Microcystis* (Section 2.13, page 141). Some strains can release toxins into the water, but other strains are non-toxic and sold as a health supplement.

Aphanizomenon flosaquae trichomes are straight or very slightly curved, and usually aggregate to form distinctive, flake-like colonies. The colonies may become so large that they are visible without magnification, resembling grass clippings (Figure 3.40). *Aphanizomenon flosaquae* is morphologically diverse, and solitary trichomes are also common, often in the same sample that contains large, flake-like colonies.

The vegetative cells are dark olive-green or brownish, and range from cylindrical (width $\approx$ length) to elongated and tapered, especially near the end of the trichome. But this feature is variable, depending on growing conditions (John, et al., 2011). The cylindrical heterocysts are located near the center of the trichome (Figure 3.41). Akinetes, when present, will be cylindrical and located near the center of the trichome, but not adjacent to the heterocysts (Figure 3.42). Decomposing blooms often release solitary akinetes, which can be difficult to identify if the trichomes are significantly degraded (Figures 3.43–3.44).



Figure 3.40: *Aphanizomenon flosaquae* (200x DIC), Big Lake, IWS water quality sampling site, Skagit County, August 21, 2008.

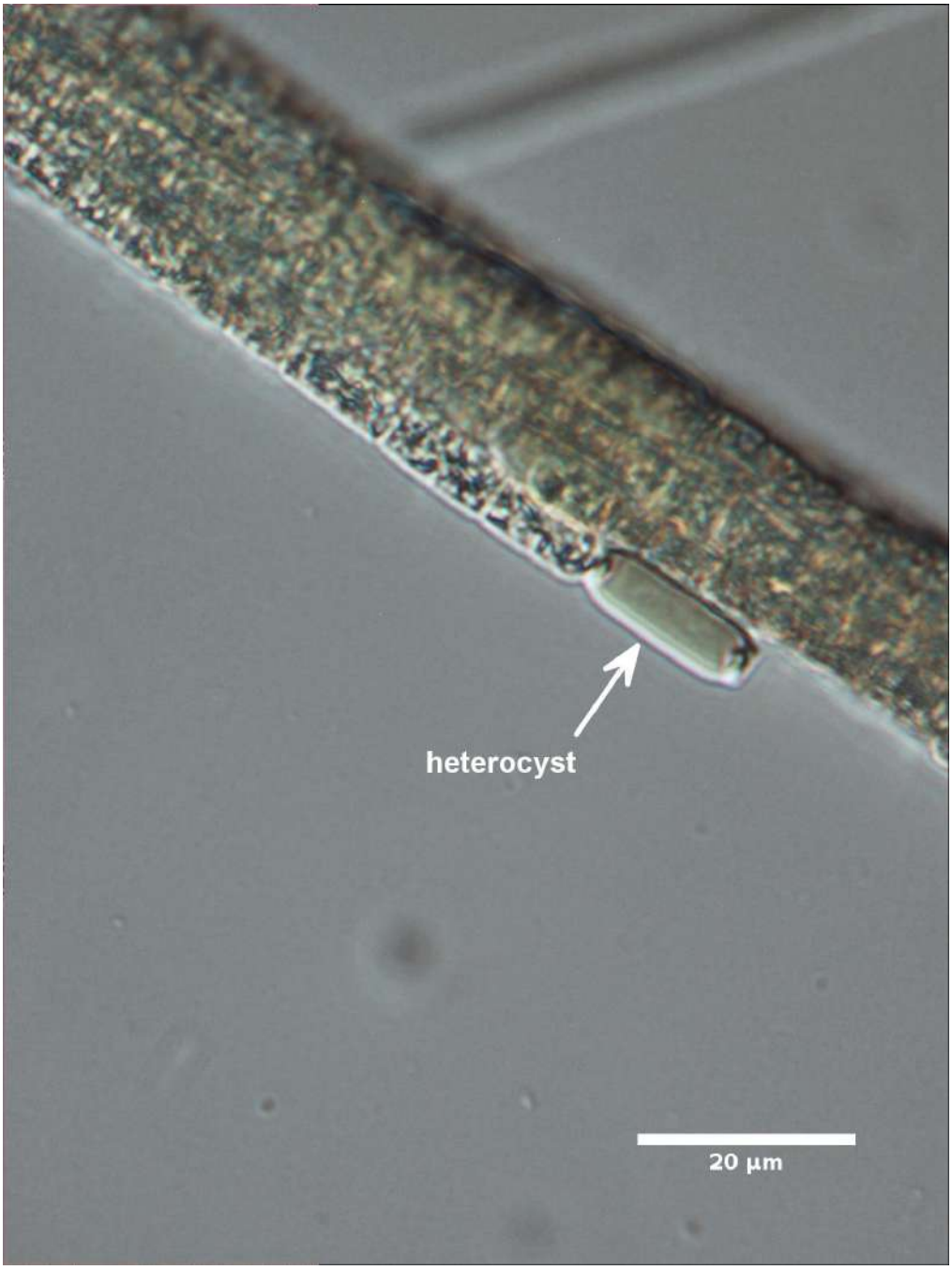


Figure 3.41: *Aphanizomenon flosaquae* heterocyst (600x DIC), Sunset Pond, IWS water quality sampling site, Whatcom County, August 19, 2009.



Figure 3.42: *Aphanizomenon flosaquae* akinete (200x DIC), Sunset Pond, IWS water quality sampling site, Whatcom County, August 19, 2009.

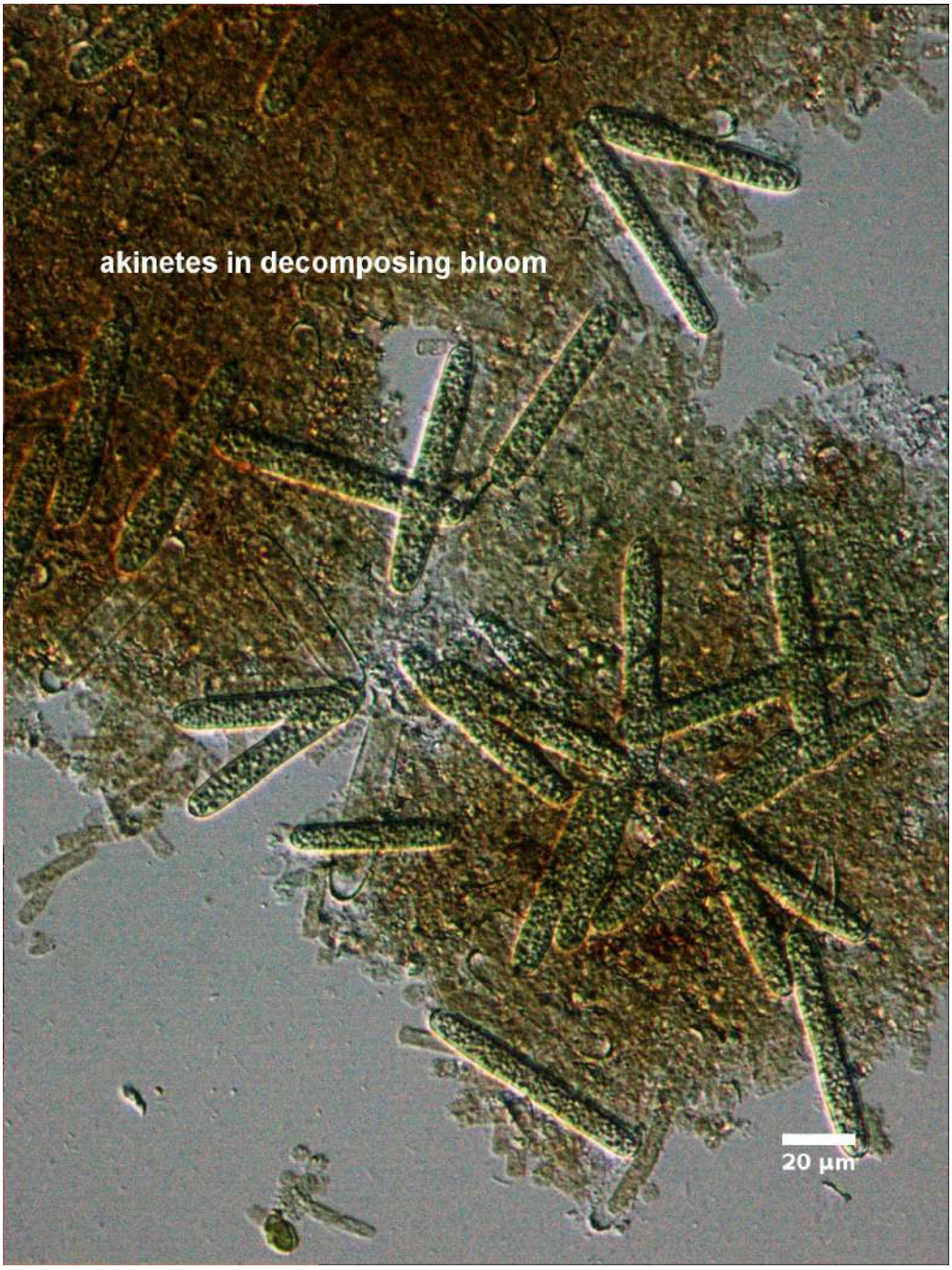


Figure 3.43: *Aphanizomenon flosaquae* akinetes in decomposing bloom (200x DIC), Thunderbird Lake, IWS water quality sampling site, Whatcom County, November 17, 2010.



Figure 3.44: *Aphanizomenon flosaquae* solitary akinete (200x DIC), Sunset Pond, IWS water quality sampling site, Whatcom County, August 19, 2009.

3.4 *Calothrix* Agardh ex Bornet & Flahault

Local taxa
Calothrix parietina Thuret ex Bornet & Flahault?;
Calothrix spp.

Abundance
Infrequently collected in plankton samples; moderately common in shoreline samples and benthic mats.

Local measurements		Width	Length	Biovolume[†]
Calothrix parietina?	min	6.0 μm	1.7 μm	59.9 μm^3
cells (cylinder)	med	8.3 μm	2.8 μm	154 μm^3
	max	11.6 μm	3.7 μm	296 μm^3
Calothrix parietina?	min	5.7 μm	3.7 μm	62.9 μm^3
heterocysts (spheroid)	med	7.1 μm	4.9 μm	132 μm^3
	max	9.6 μm	6.9 μm	333 μm^3
Calothrix sp.1	min	5.0 μm	2.8 μm	55.0 μm^3
cells (cylinder)	med	8.4 μm	3.5 μm	184 μm^3
	max	11.8 μm	6.1 μm	667 μm^3
Calothrix sp.1	min	4.8 μm	3.8 μm	47.0 μm^3
heterocysts (spheroid)	med	5.8 μm	4.5 μm	76.1 μm^3
	max	6.8 μm	6.3 μm	153 μm^3
Calothrix sp.2	min	6.8 μm	3.4 μm	149 μm^3
cells (cylinder)	med	8.9 μm	4.0 μm	272 μm^3
	max	11.2 μm	4.9 μm	464 μm^3
Calothrix sp.2	min	7.5 μm	4.0 μm	118 μm^3
heterocysts (spheroid)	med	13.4 μm	8.9 μm	921 μm^3
	max	15.4 μm	11.4 μm	1,204 μm^3

[†]Calculated using original measurements, not summary values.

Description

Calothrix trichomes are strongly tapered, originating from a spherical, oval, or hemispherical basal heterocyst (Figures 3.45–3.51). The trichomes are usually unbranched, but may form false branches at a break in the trichome. The trichome is surrounded by a distinct sheath that may be layered or smooth and is often yellowish or brown. The trichomes may be solitary or aggregated to form dense tufted mats attached to aquatic plants or other solid substrates. When in mats, the trichomes are arranged more or less parallel to each other, which helps distinguish *Calothrix* from spherical *Gloeotrichia* colonies (Section 3.9, page 293). *Calothrix* resembles *Dichothrix* (Section 3.7, page 280), but *Dichothrix* is more likely to form false branches and often has more than one trichome enclosed in a single sheath.

Calothrix is a morphologically variable genus, containing a large number of species with overlapping ranges and descriptions. Komárek (2013) states that it is likely that some of the species will be transferred into different genera as additional genetic information becomes available. Because of this, all of the local species identifications are tentative.

The specimens in Figures 3.45–3.46 are tentatively identified as *Calothrix parietina*, which is characterized by strongly tapered trichomes that end in a long, hair-like extension and are surrounded by a thick, stratified, yellowish-brown, sheath. The cells are much shorter than wide, except in the hair-like extension. According to John, et al. (2011), *Calothrix parietina* is common in residential (garden) ponds, and the local specimens were all collected in urban locations.

Both *Calothrix* sp.1 (Figures 3.47–3.49) and *Calothrix* sp.2 (Figures 3.50–3.51) were epiphytic on *Batrachospermum*, a genus of filamentous red algae.[13] Both species of *Calothrix* have short, cylindrical cells that form solitary, tapered trichomes. *Calothrix* sp.1 has small, spherical heterocysts and abruptly tapered trichomes that are surrounded by a clear or yellowish brown, stratified and flared sheath that does not extend all the way to the end of the trichome. *Calothrix* sp.2 trichomes taper gradually from a wide, hemispherical heterocyst, and have a thin, colorless sheath.

[13] See **Freshwater Algae in Northwest Washington, Volume II. Chlorophyta and Rhodophyta**.

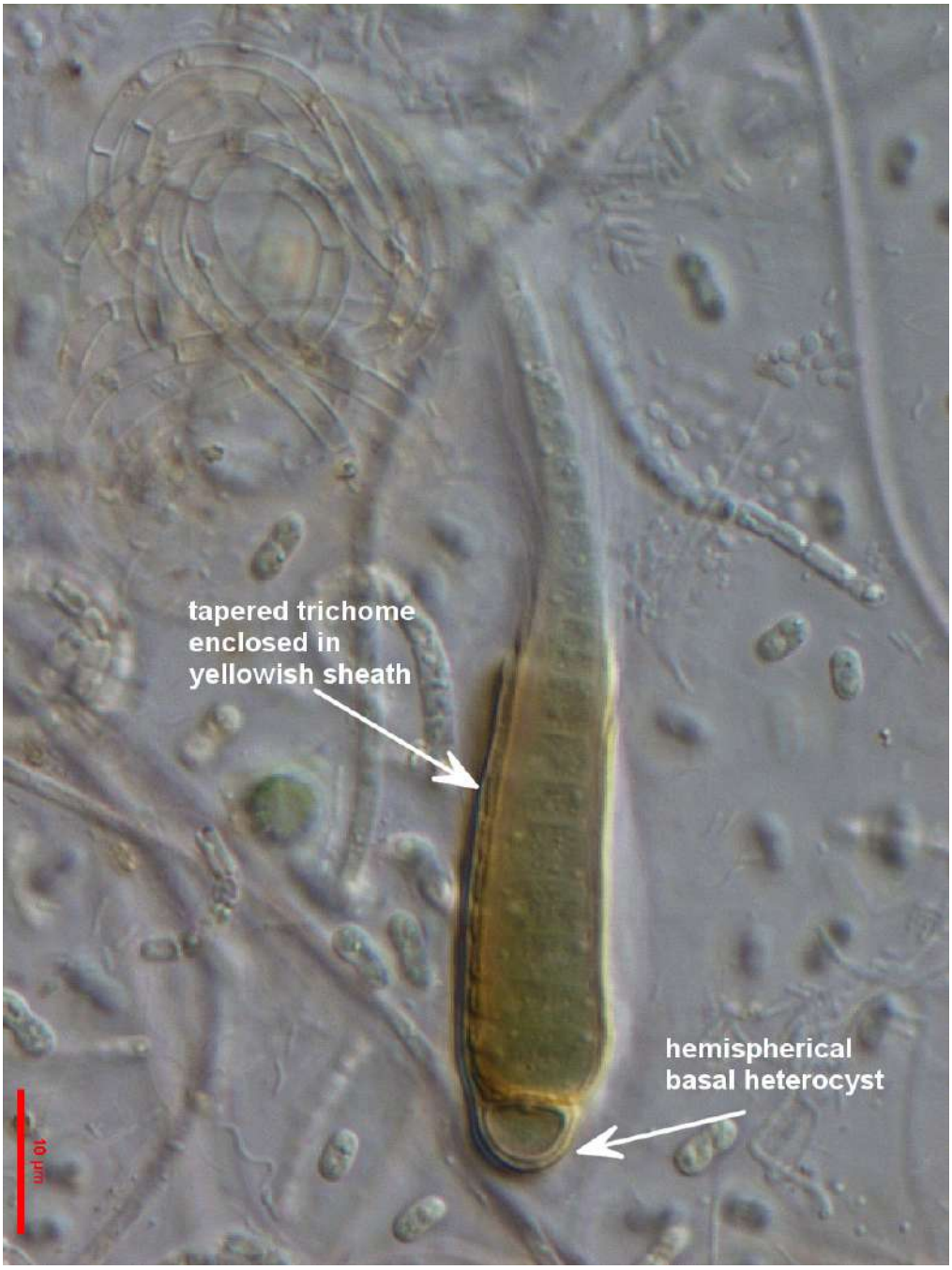


Figure 3.45: *Calothrix parietina*? (1000x DIC), Winslow Way standing water, Bainbridge Island, WA, July 5, 2009. Photo provided by Karl Bruun, Nostoca Algae Laboratory, Bainbridge Island, WA.



Figure 3.46: *Calothrix parietina*? (1000x DIC), White Horse Golf Course, Kingston, WA, May 29, 2011. Photo provided by Karl Bruun, Nostoca Algae Laboratory, Bainbridge Island, WA.



Figure 3.47: *Calothrix* sp.1 (600x DIC), Upper Ashland Lake, Mt. Loop Hwy, July 28, 2015.



Figure 3.48: *Calothrix* sp.1 (600x DIC), Upper Ashland Lake, Mt. Loop Hwy, July 28, 2015.

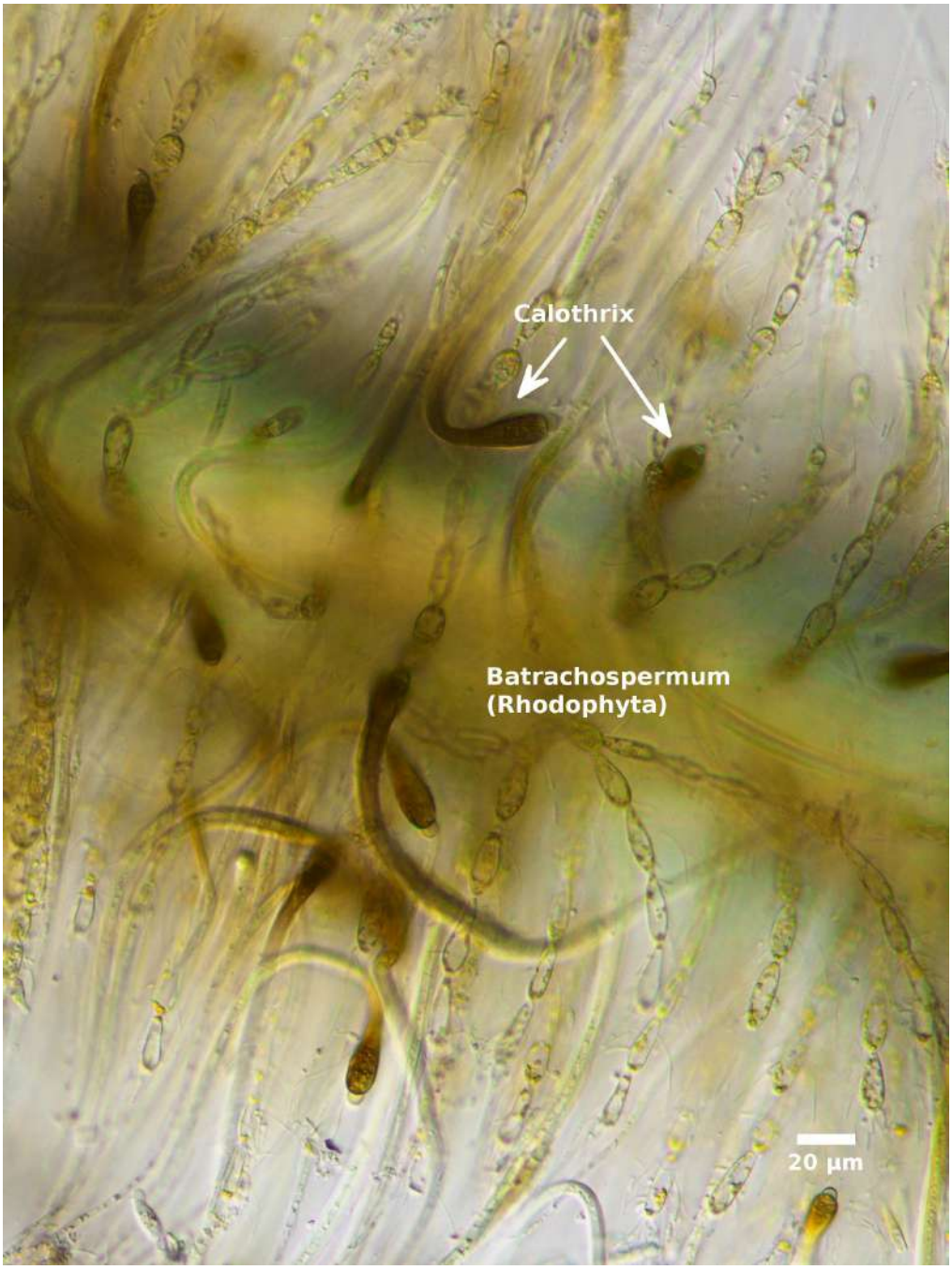
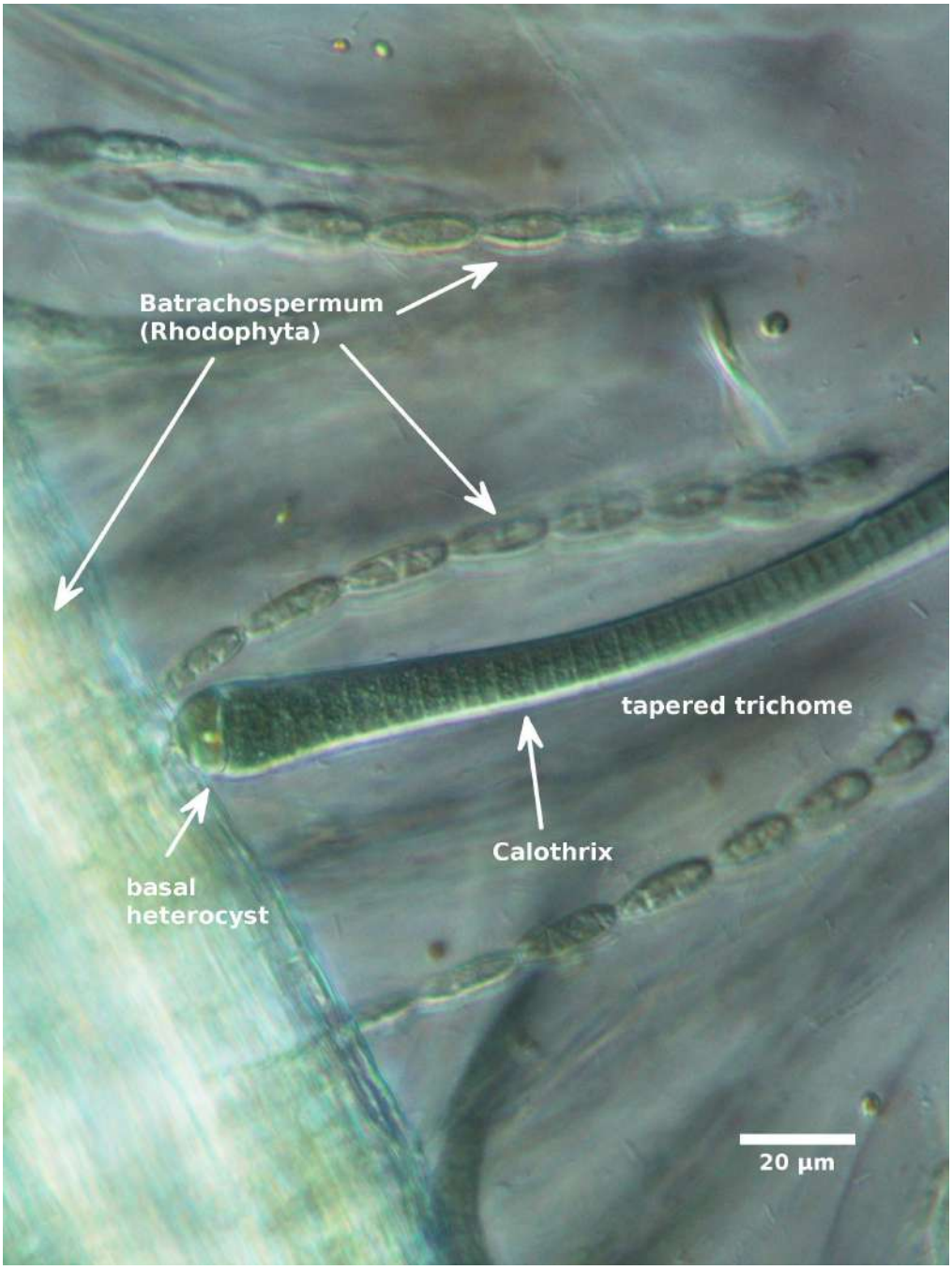


Figure 3.49: *Calothrix* sp.1 (200x DIC), Upper Ashland Lake, Mt. Loop Hwy, July 28, 2015.



A

Figure 3.50: *Calothrix* sp.2 (400x DIC), Chambers Lake, Olympia, Thurston County, May 27, 2015.



Figure 3.51: *Calothrix* sp.2 (200x DIC), Chambers Lake, Olympia, Thurston County, May 27, 2015.

3.5 *Cylindrospermopsis* Seenayya & Subba Raju

Taxon
Cylindrospermopsis raciborskii (Woloszynska) Seenayya & Subba Raju

Abundance
Not yet collected in local lakes.

Local measurements
No local samples available.

Description
Cylindrospermopsis raciborskii is normally associated with warm, eutrophic tropical lakes, but has been reported with increasing frequency in temperate lakes (Komárek and Komárková, 2003). It can form toxic blooms, but it has not yet been collected in local lakes. The specimens in Figures 3.52–3.57 are from Boyd, Texas.

Cylindrospermopsis raciborskii cells are cylindrical, usually longer than wide, with slightly constricted cross-walls. The trichomes are solitary, unbranched, lack a sheath, and often have a slightly yellowish color. Heterocysts, when present, are elliptical or conical and located at the end of the trichome. Akinetes are rarely present. The cells contain gas vacuoles, so the trichomes are planktonic.

The trichomes exhibit a surprising amount of morphological variation, ranging from straight with blunt ends to curved or sigmoid and distinctly tapered. (In most algae, this amount of variation would indicate the presence of multiple species). The strongly curved and highly tapered trichomes usually lack heterocysts.

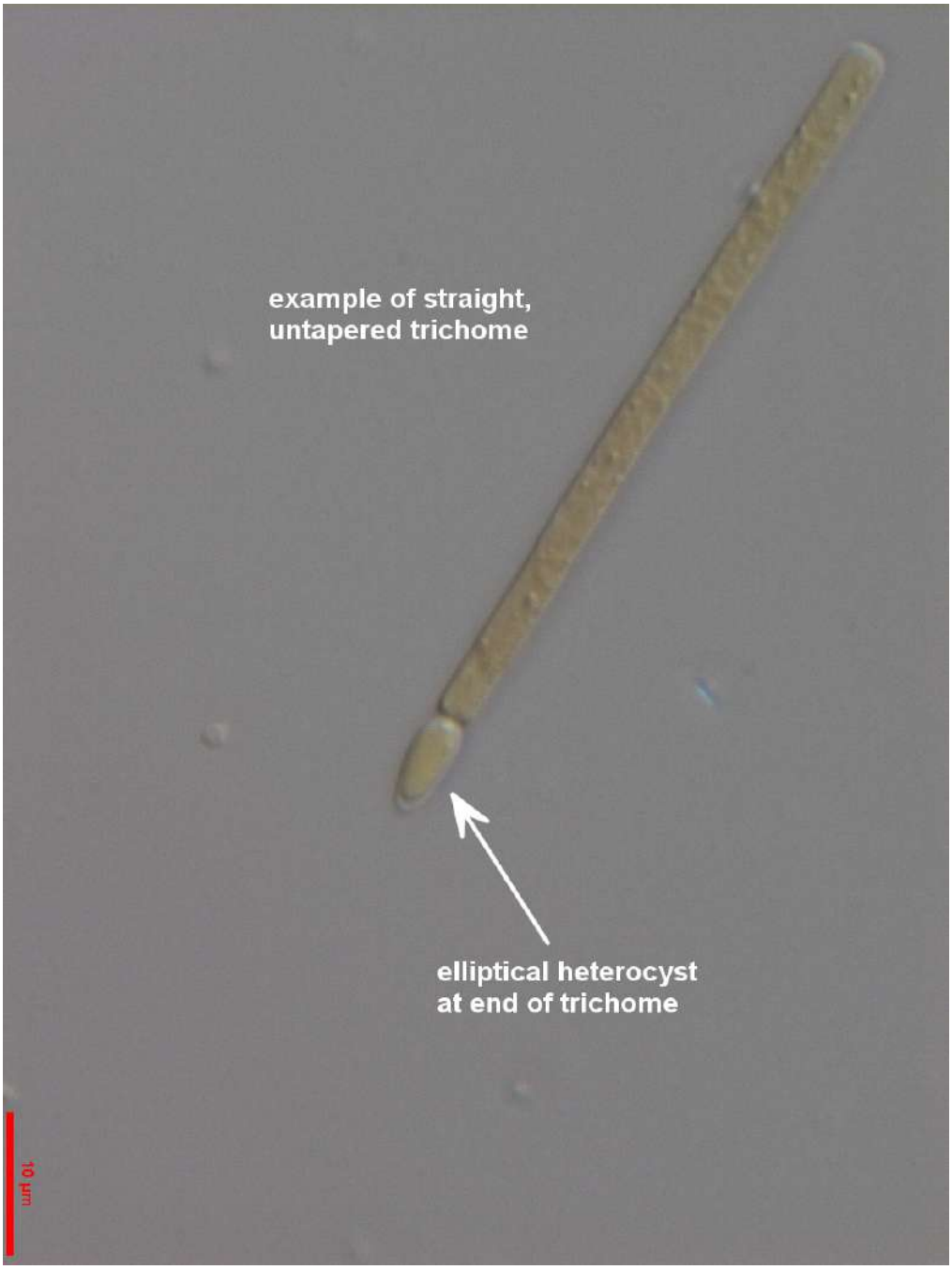


Figure 3.52: *Cylindrospermopsis raciborskii* (1000x DIC), August 13, 2011, Boyd, Texas. Sample provided by Mark Ernst, Tarrant Regional Water District, Fort Worth, TX; photo provided by Karl Bruun, Nostoca Algae Laboratory, Bainbridge Island, WA.



Figure 3.53: *Cylindrospermopsis raciborskii* (400x phase contrast), August 13, 2011, Boyd, Texas. Sample provided by Mark Ernst, Tarrant Regional Water District, Fort Worth, TX; photo provided by Karl Bruun, Nostoca Algae Laboratory, Bainbridge Island, WA.

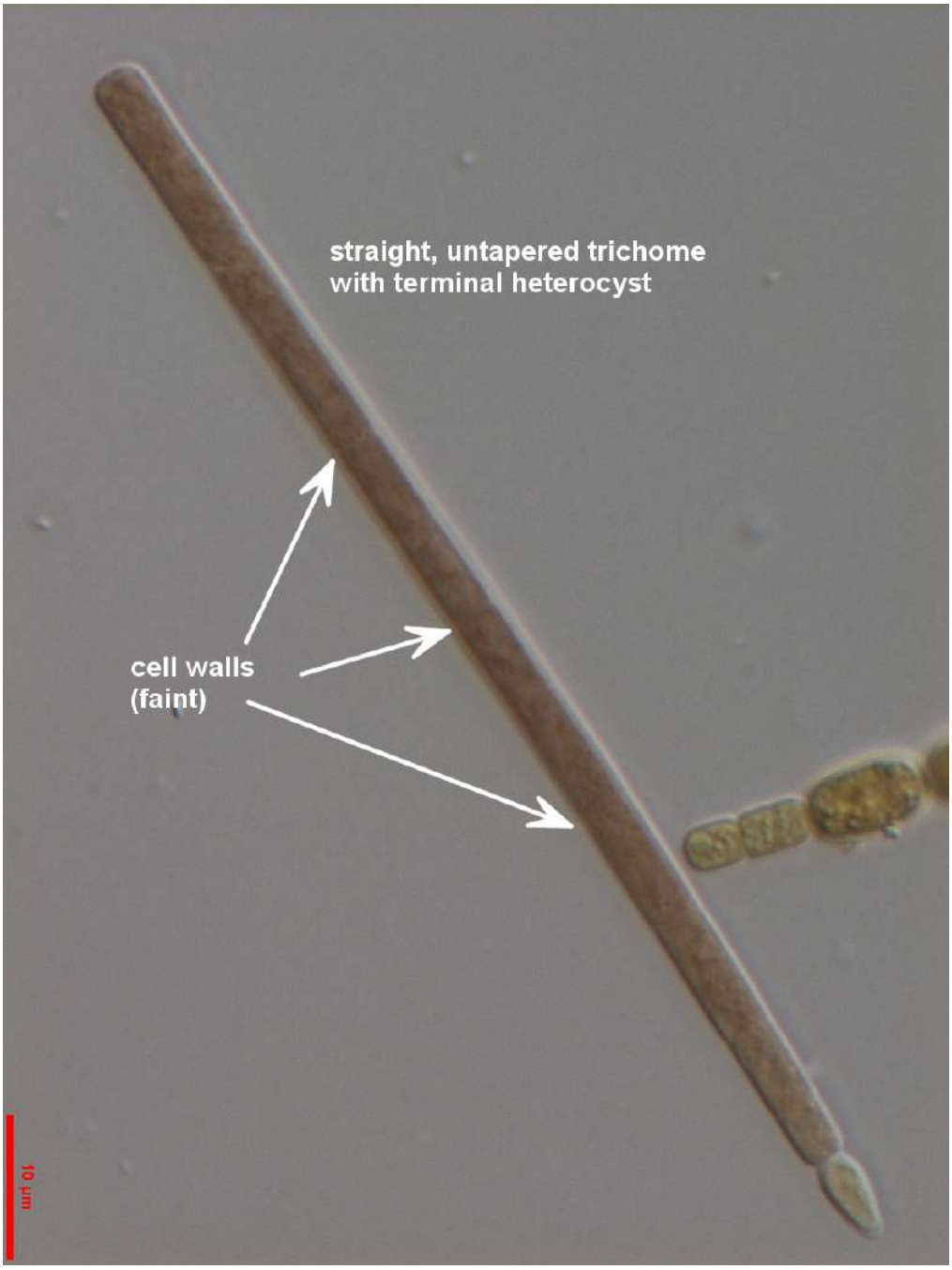


Figure 3.54: *Cylindrospermopsis raciborskii* (400x phase contrast), August 13, 2011, Boyd, Texas. Sample provided by Mark Ernst, Tarrant Regional Water District, Fort Worth, TX; photo provided by Karl Bruun, Nostoca Algae Laboratory, Bainbridge Island, WA.



Figure 3.55: *Cylindrospermopsis raciborskii* (400x DIC), August 13, 2011, Boyd, Texas. Sample provided by Mark Ernst, Tarrant Regional Water District, Fort Worth, TX; photo provided by Karl Bruun, Nostoca Algae Laboratory, Bainbridge Island, WA.



Figure 3.56: *Cylindrospermopsis raciborskii* (1000x DIC), August 13, 2011, Boyd, Texas. Sample provided by Mark Ernst, Tarrant Regional Water District, Fort Worth, TX; photo provided by Karl Bruun, Nostoca Algae Laboratory, Bainbridge Island, WA.



Figure 3.57: *Cylindrospermopsis raciborskii* (1000x DIC), August 13, 2011, Boyd, Texas. Sample provided by Mark Ernst, Tarrant Regional Water District, Fort Worth, TX; photo provided by Karl Bruun, Nostoca Algae Laboratory, Bainbridge Island, WA.

3.6 *Cylindrospermum* Kützing ex Bornet & Flahault

Local taxa
Cylindrospermum spp.

Abundance
Infrequently collected in plankton samples; moderately common in shoreline samples and benthic mats.

Local measurements		Width	Length	Biovolume[†]
Cylindrospermum sp.1	min	3.4 μm	4.3 μm	39.0 μm^3
cells (cylinder)	med	4.4 μm	6.8 μm	109 μm^3
	max	5.0 μm	10.1 μm	161 μm^3
Cylindrospermum sp.1	min	4.5 μm	7.2 μm	96.9 μm^3
heterocysts (spheroid)	med	5.6 μm	8.1 μm	137 μm^3
	max	6.7 μm	10.4 μm	195 μm^3
Cylindrospermum sp.1	min	6.6 μm	11.0 μm	226 μm^3
akinetes (cyl + two $\frac{1}{2}$ spheres)[‡]	med	8.4 μm	21.9 μm	732 μm^3
	max	11.9 μm	31.7 μm	1,360 μm^3
Cylindrospermum sp.2	min	2.9 μm	3.8 μm	34.5 μm^3
cells (cylinder)	med	3.0 μm	4.9 μm	36.8 μm^3
	max	3.4 μm	5.6 μm	41.1 μm^3
Cylindrospermum sp.2	min	3.6 μm	5.0 μm	38.0 μm^3
heterocysts (spheroid)	med	4.0 μm	5.6 μm	41.9 μm^3
	max	4.7 μm	5.8 μm	67.1 μm^3
Cylindrospermum sp.2	min	7.4 μm	11.9 μm	409 μm^3
akinetes (spheroid)	med	8.6 μm	14.0 μm	536 μm^3
	max	10.3 μm	18.7 μm	1,020 μm^3

[†]Calculated using original measurements, not summary values.
[‡]Biovolume based on cylinder length ($<$ cell length).

Description

Cylindrospermum trichomes are untapered and unbranched, originating from a single basal heterocyst that usually has at least one adjoining akinete (Figures 3.58–3.62). Most species form thick mats attached to underwater surfaces, but occasionally break free and are collected in plankton samples. Compare *Cylindrospermum* to *Gloeotrichia* (Section 3.9, page 293), which has *tapering* unbranched trichomes with a basal heterocyst and forms spherical or hemispherical colonies. The species of *Cylindrospermum* are extremely polymorphic, so the taxonomic separations described below are based primarily on habitat.

Cylindrospermum sp.1 specimens were collected in several peaty, slightly acidic, unpolluted mountain lakes. This species is characterized by straight or slightly curved trichomes of constricted, blue-green cells that are longer than wide (Figures 3.58–3.61). The heterocysts range from nearly spherical (less common) to elliptical or cylindrical (width $<$ length). The akinetes are slightly granular, and vary in shape and color from elliptical to narrowly cylindrical, and from greenish yellow to brown. Although the specimens were collected in similar habitats, the range in morphology could represent more than one species or several varieties.

Cylindrospermum sp.2 (Figure 3.62) was collected in a nutrient-rich, low elevation lake, and is probably a different species than the specimens collected in mountain lakes. This species is characterized by twisted, mucilaginous trichomes of small, cylindrical cells, cylindrical heterocysts, and small, broadly oval akinetes.



Figure 3.58: *Cylindrospermum* sp.1 (200x DIC), Upper Twin Lake, IWS water quality sampling site, Whatcom County, August 11, 2015.



Figure 3.59: *Cylindrospermum* sp.1 (600x DIC), Upper Twin Lake, IWS water quality sampling site, Whatcom County, August 11, 2015.

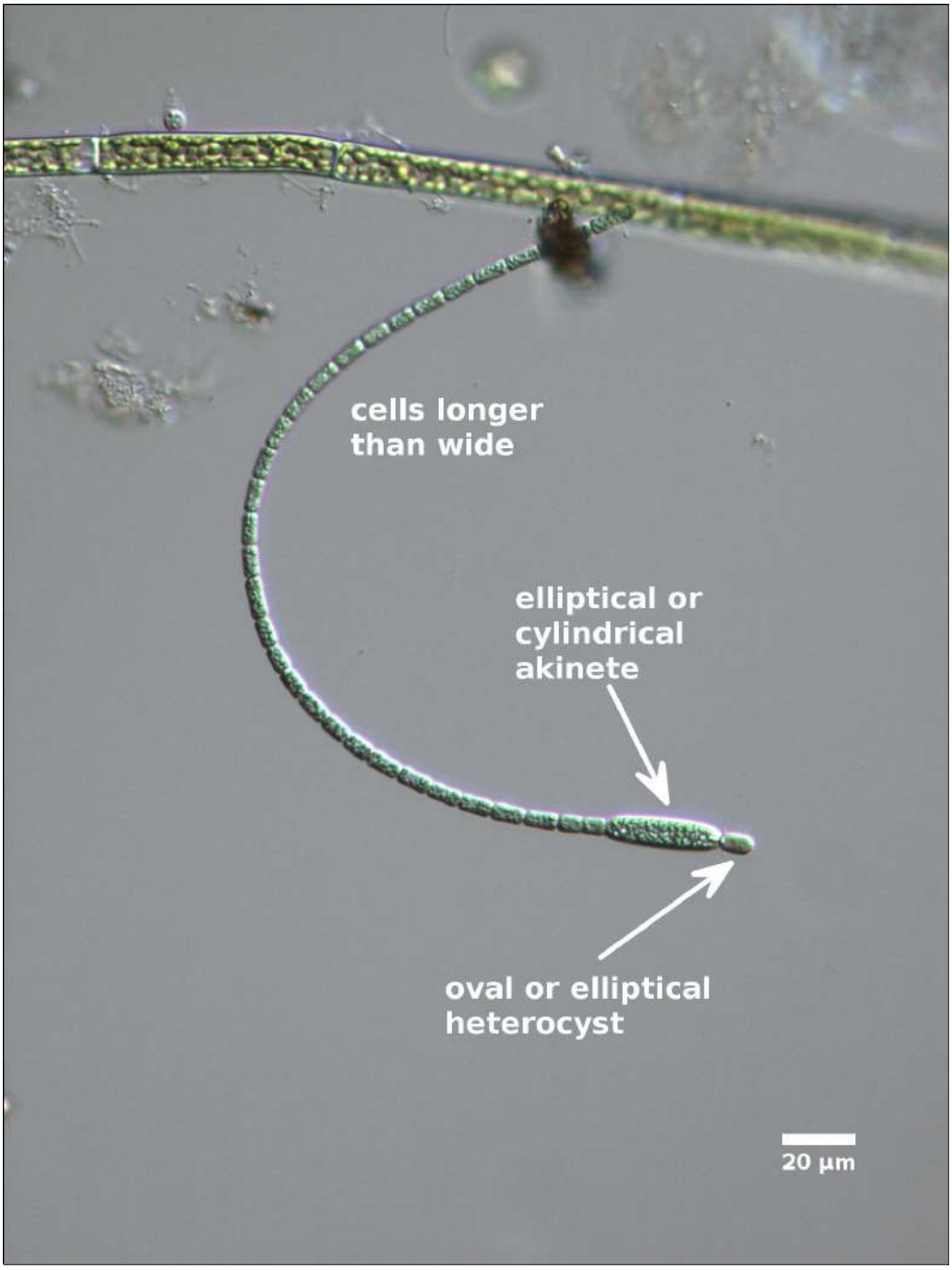


Figure 3.60: *Cylindrospermum* sp.1 (200x DIC), Picture Lake, IWS water quality sampling site, Whatcom County, October 8, 2007.

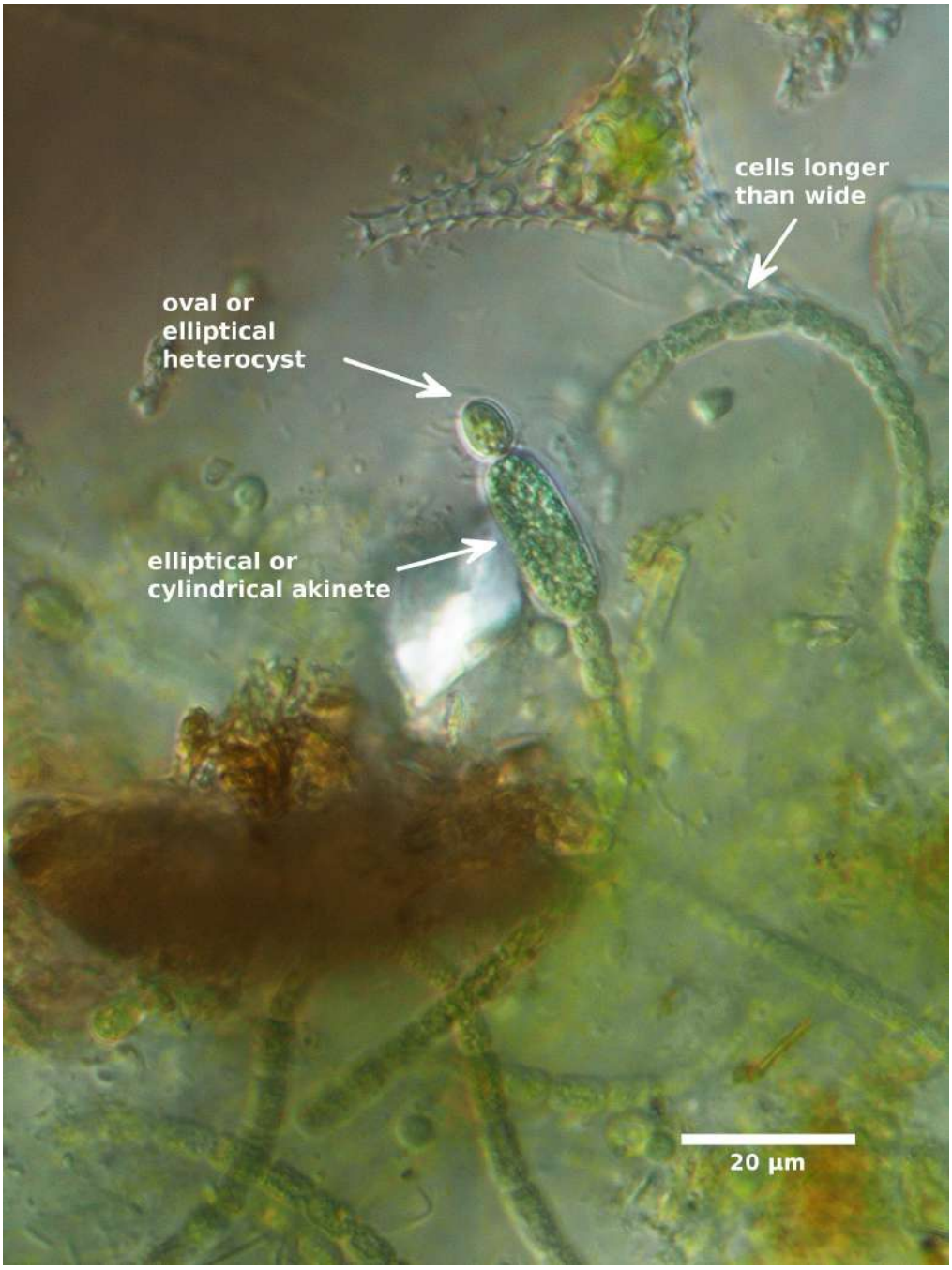


Figure 3.61: *Cylindrospermum* sp.1 (600x DIC), Myrtle Lake, IWS water quality sampling site, Snohomish County, July 31, 2014.



Figure 3.62: *Cylindrospermum* sp.2 (200x DIC), Summer Lake, IWS water quality sampling site, Skagit County, September 14, 2009.

3.7 *Dichothrix* Zanardini ex Bornet & Flahault

Local taxa
Dichothrix gypsophila Bornet et Flahault?;
Dichothrix hosfordii Bornet;
Dichothrix sp.1

Abundance
Infrequently collected in plankton samples; moderately common in shoreline samples and benthic mats.

Local measurements		Width	Length	Biovolume[†]
Dichothrix gypsophila?	min	7.2 μm	4.3 μm	190 μm^3
cells (cylinder)	med	7.8 μm	5.5 μm	262 μm^3
	max	8.5 μm	7.0 μm	334 μm^3
Dichothrix gypsophila?	min	7.9 μm	8.6 μm	320 μm^3
heterocysts (spheroid)	med	8.9 μm	9.1 μm	402 μm^3
	max	11.7 μm	9.8 μm	638 μm^3
Dichothrix hosfordii	min	11.2 μm	3.0 μm	296 μm^3
cells (cylinder)	med	12.7 μm	4.3 μm	620 μm^3
	max	18.7 μm	6.6 μm	1,430 μm^3
Dichothrix hosfordii	min	16.3 μm	7.6 μm	1,060 μm^3
heterocysts (spheroid)	med	21.2 μm	14.2 μm	3,360 μm^3
	max	24.9 μm	15.5 μm	4,740 μm^3
Dichothrix sp.1	min	6.4 μm	2.2 μm	77.2 μm^3
cells (cylinder)	med	8.8 μm	2.7 μm	153 μm^3
	max	11.4 μm	4.1 μm	329 μm^3
Dichothrix sp.1	min	5.1 μm	5.4 μm	110 μm^3
heterocysts (spheroid)	med	9.6 μm	8.5 μm	431 μm^3
	max	11.4 μm	11.2 μm	762 μm^3

[†]Calculated using original measurements, not summary values.

Description

Dichothrix trichomes originate from a basal heterocyst (false branching) and taper abruptly or gradually into long, hair-like extensions (Figures 3.63–3.70). Repeated false branching produces multiple trichomes enclosed in a common sheath; the sheath may be clear or yellowish-brown, and is often stratified. The trichomes usually aggregate to form a mat attached to solid substrates. *Dichothrix* closely resembles *Calothrix* (Section 3.4, page 257), but the *Calothrix* trichomes separate immediately above the basal heterocyst of the false branch, so multiple trichomes are not enclosed in a common sheath. *Dichothrix* is a morphologically diverse genus, so most species identifications are tentative.

The specimens identified as *Dichothrix gypsophila*? have olive-green, barrel-shaped cells with constricted cross-walls, and nearly spherical heterocysts (Figures 3.63–3.64). The trichomes are enclosed in a stratified, yellowish-brown sheath that is narrow near the base, then fans out in the middle of the trichome. The morphological features of the local specimens fit descriptions for *Dichothrix gypsophila* (John et al., 2011; Komárek, 2013), but the species is described as occurring in hard-water (calcareous) habitats. The local specimens were collected in a small, soft-water mountain lake with submerged woody debris and darkly stained water (tannins).

Dichothrix hosfordii has gradually tapered trichomes enclosed in a thick, clear or pale yellow, faintly stratified sheath (Figures 3.65–3.68). The cells are olive-green or blue-green, unconstricted, and coin-like (width $>$ length). The heterocysts are hemispherical or bluntly conical. In addition to the absence of a dark, flared, stratified sheath, this species has much wider cells and heterocysts that the other taxa, fitting the species description provided by Prescott (1962).

Dichothrix sp.1 resembles the local *Dichothrix gypsophila*? specimens, but the cells are coin-like (width $>$ length), with unconstricted cross-walls, and the heterocysts are conical or hemispherical rather than spherical (Figures 3.69–3.70). The local specimens of *Dichothrix* sp.1 were collected from a small mountain lake with a rocky shoreline and clear (unstained) water.

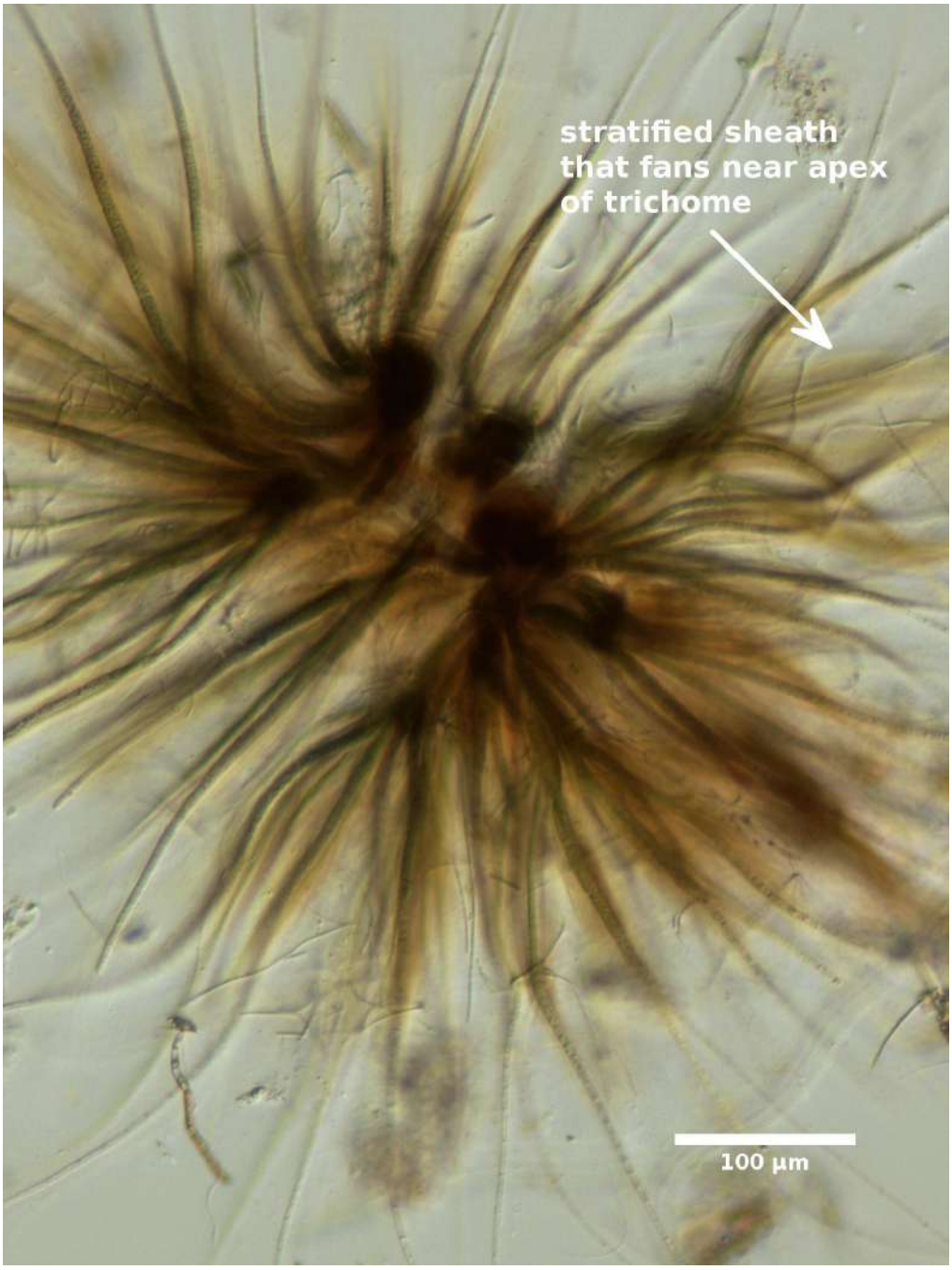


Figure 3.63: *Dichothrix gypsophila*? (100x DIC), Pyramid Lake, North Cascades along Hwy 20, September 5, 2012.

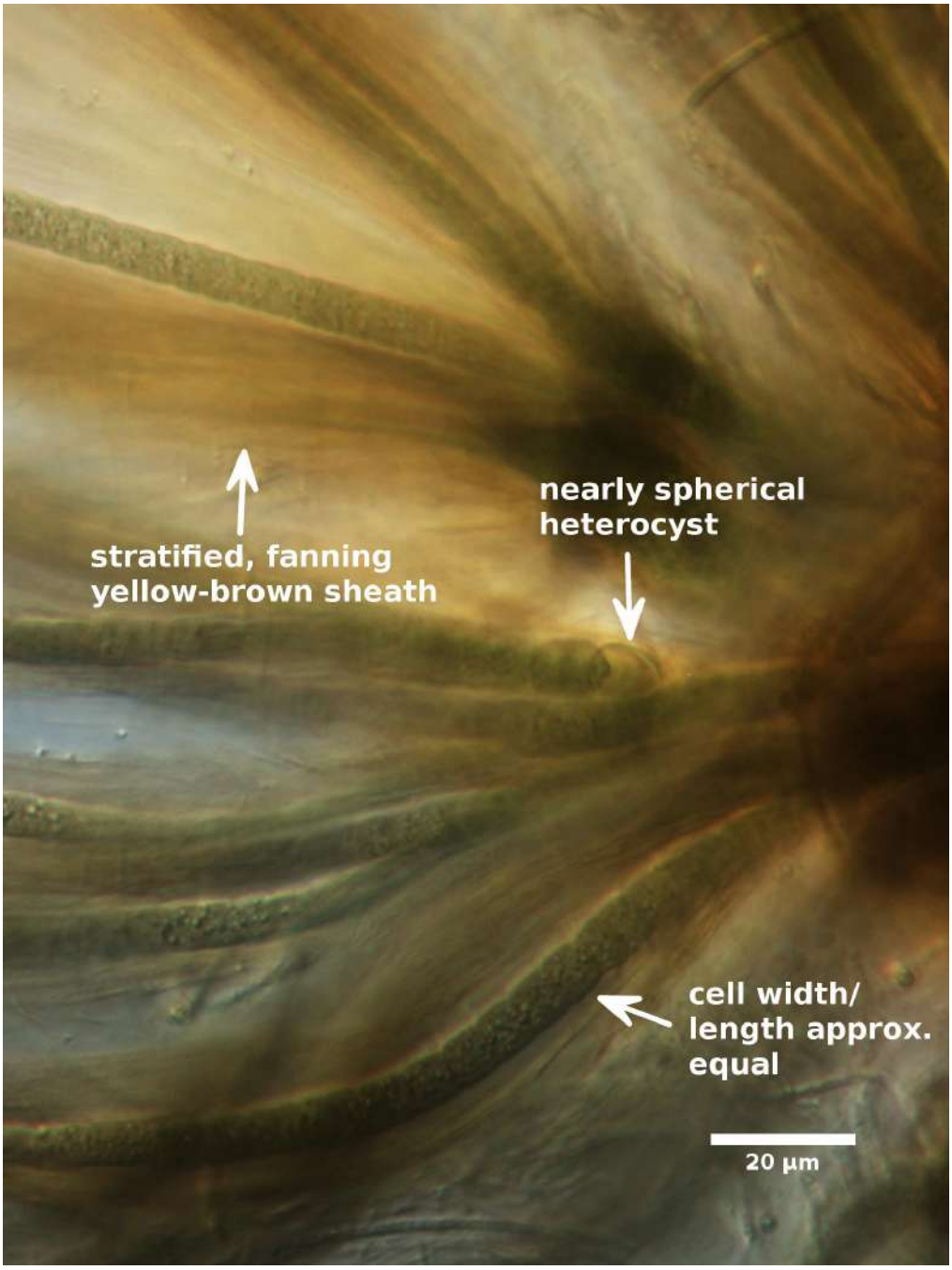


Figure 3.64: *Dichothrix gypsophila*? (400x DIC), Pyramid Lake, North Cascades along Hwy 20, September 5, 2012.

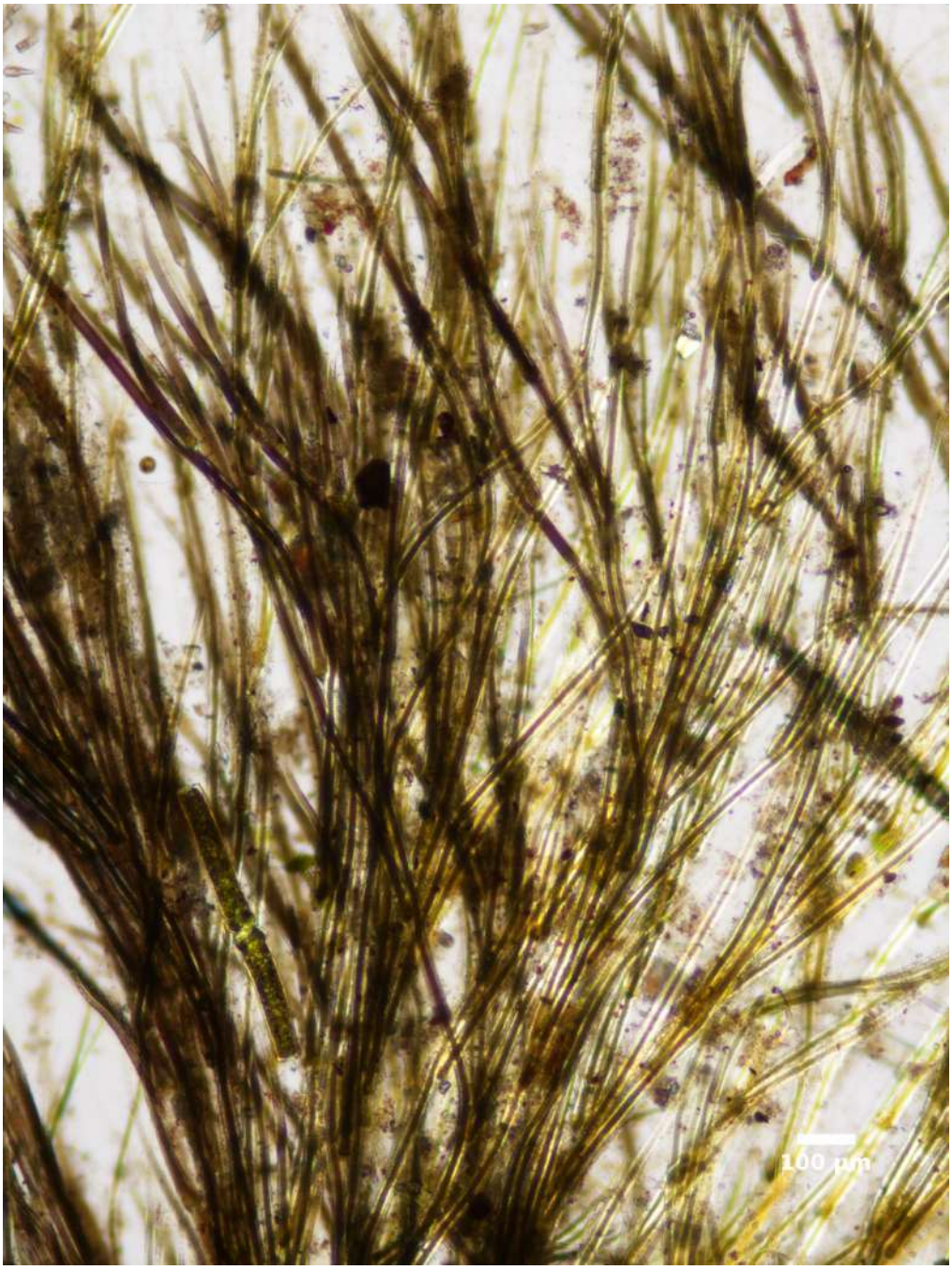


Figure 3.65: *Dichothrix hosfordii* (40x brightfield), Canyon Lake, IWS water quality sampling site, Whatcom County, August 10, 2015.



Figure 3.66: *Dichothrix hosfordii* (200x DIC), Canyon Lake, IWS water quality sampling site, Whatcom County, August 10, 2015.

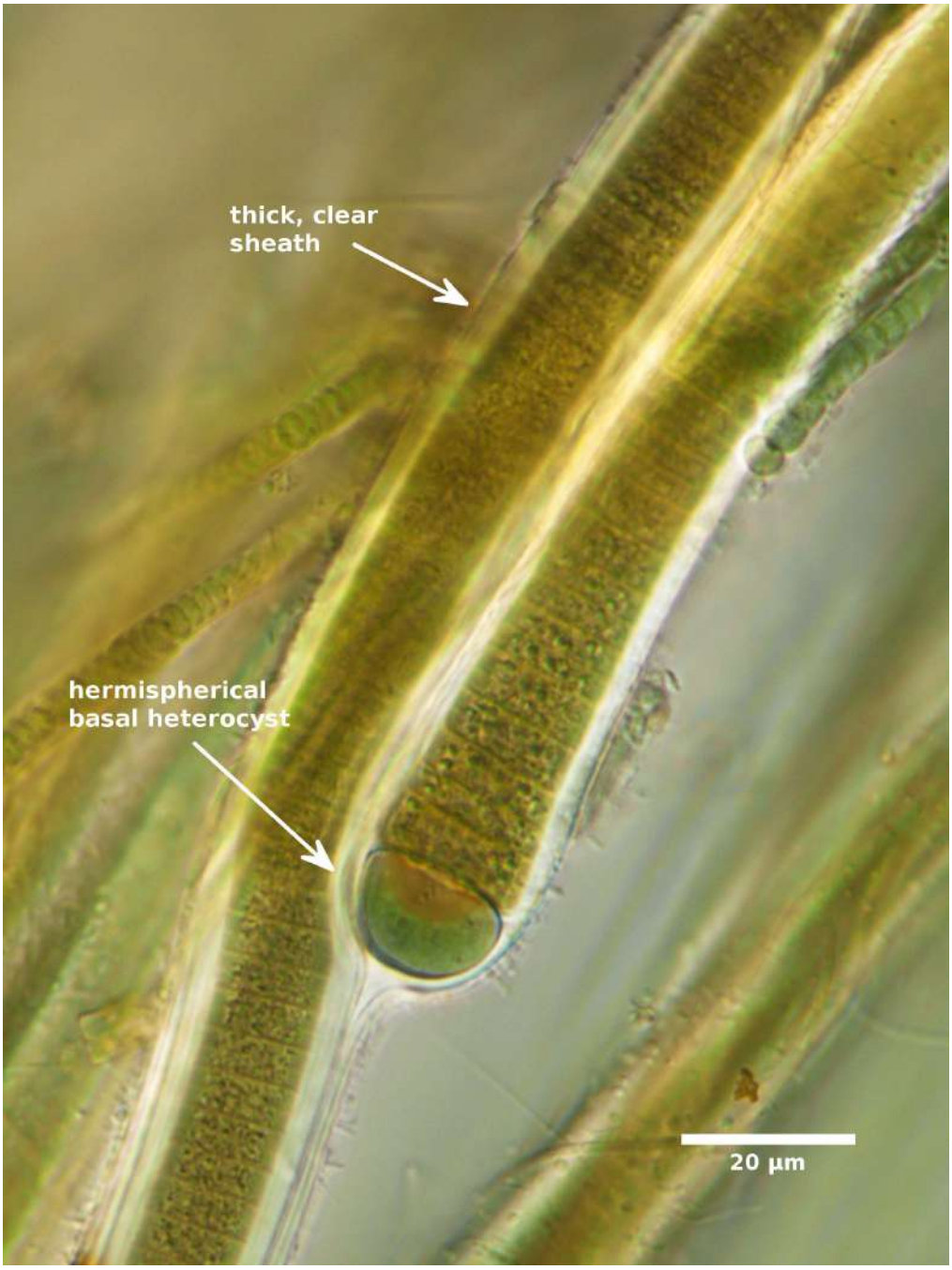


Figure 3.67: *Dichothrix hosfordii* (600x DIC), Canyon Lake, IWS water quality sampling site, Whatcom County, August 10, 2015.



Figure 3.68: *Dichothrix hosfordii* (600x DIC), small lake north of Sultan, Snohomish County, April 28, 2015.

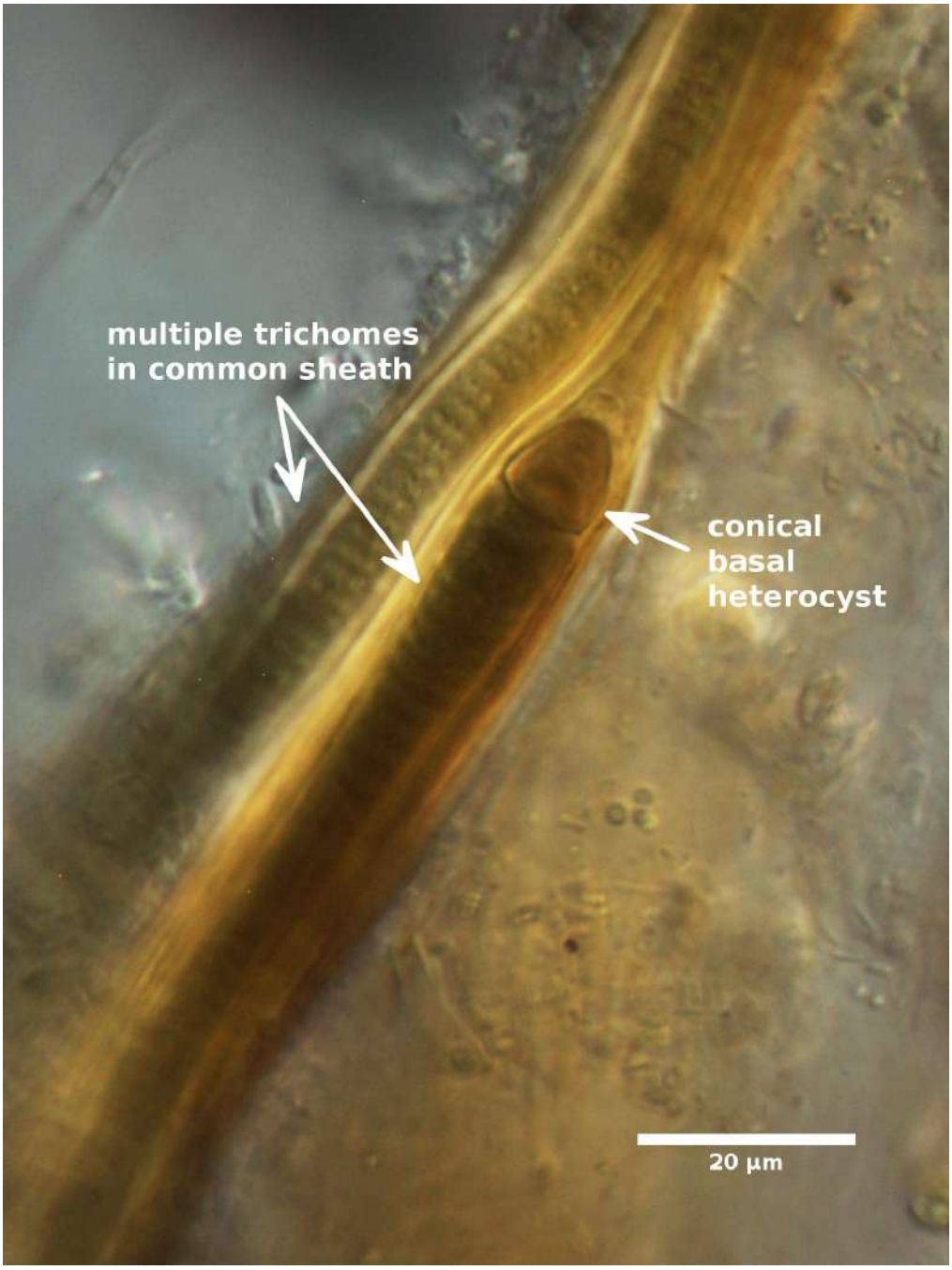


Figure 3.69: *Dichothrix* sp.1 (600x DIC), Coal Lake, IWS water quality sampling site, Snohomish County, August 20, 2013.

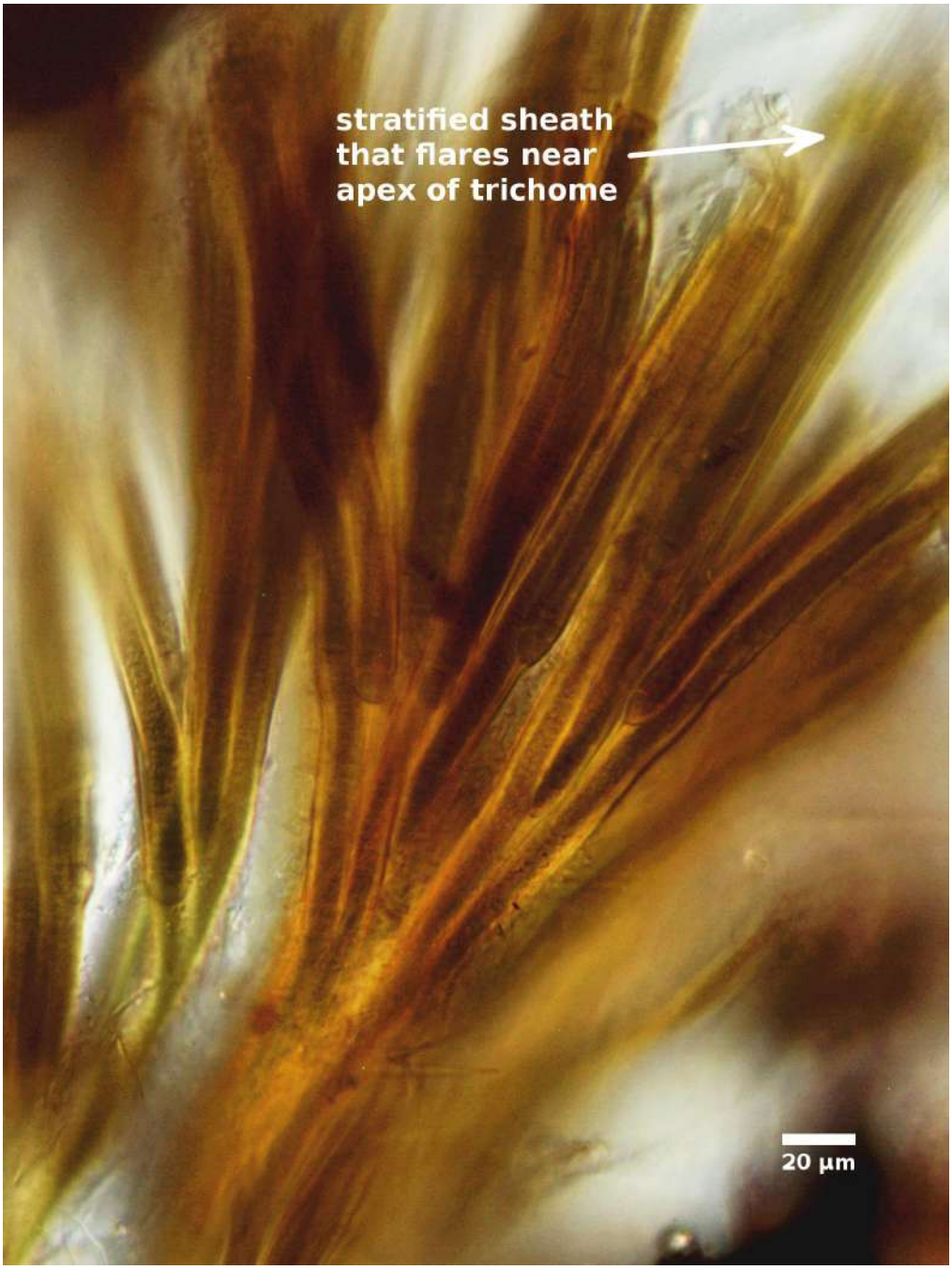


Figure 3.70: *Dichothrix* sp.1 (200x DIC), Coal Lake, IWS water quality sampling site, Snohomish County, August 19, 2013.

3.8 *Fischerella* (Bornet & Flahault) Gomont

Local taxon
Fischerella muscicola Gomont

Abundance
Infrequently collected in plankton samples; occasionally collected in shoreline samples from mountain lakes.

Local measurements		Width	Length	Biovolume[†]
Fischerella muscicola	min	6.0 μm	5.7 μm	136 μm^3
cells (spheroid)	med	7.4 μm	7.0 μm	205 μm^3
	max	10.0 μm	9.0 μm	410 μm^3
Fischerella muscicola	min	6.7 μm	5.8 μm	162 μm^3
heterocysts (spheroid)	med	7.8 μm	7.0 μm	228 μm^3
	max	9.3 μm	8.5 μm	331 μm^3

[†]Calculated using original measurements, not summary values.

Description
Fischerella trichomes form true lateral branches that diverge at 90° from the main trichome (Figures 3.71–3.72). The cells forming the main trichome may be uniseriate (1 cell in a row) or multiseriate (>1 cell in a row); the branches are mostly uniseriate and slightly smaller than the main trichome. *Fischerella* resembles *Hapalosiphon* (Section 3.10, page 301), which has similarly sized, uniseriate main and branch trichomes; and *Stigonema* (Section 3.13, page 329), which has multiseriate trichomes enclosed in thick, yellowish-brown mucilage. Most species of *Fischerella* are terrestrial or found in thermal springs, but *Fischerella muscicola* is associated with mosses, peaty water, and shallow ponds (Komárek, 2013; Prescott, 1962).

Fischerella muscicola forms creeping, highly branched trichomes of blue-green, rounded, cylindrical cells (width $\geq$ length). The heterocysts are approximately spherical and form throughout the trichome, not necessarily at the base of a branch. The trichome is surrounded by a thin, clear or yellowish sheath. All of the local specimens were collected from a mossy, high elevation pond.



Figure 3.71: *Fischerella muscicola* (600x DIC), small pond on trail to Lake Ann, Mt. Baker area, September 21, 2014.



Figure 3.72: *Fischerella muscicola* (600x DIC), small pond on trail to Lake Ann, Mt. Baker area, September 21, 2014.

3.9 *Gloeotrichia* Agardh ex Bornet & Flahault

Local taxa
Gloeotrichia echinulata Richter;
Gloeotrichia pisum Thuret ex Bornet & Flahault

Abundance
Gloeotrichia echinulata is moderately common in plankton samples; *Gloeotrichia pisum* is occasionally collected as an epiphyte in shoreline samples.

Local measurements		Width	Length	Biovolume[†]
Gloeotrichia echinulata	min	4.9 μm	5.8 μm	109 μm^3
cells (cylinder)	med	5.7 μm	6.6 μm	175 μm^3
	max	6.6 μm	9.3 μm	253 μm^3
Gloeotrichia echinulata	min	7.6 μm	8.1 μm	283 μm^3
heterocysts (spheroid)	med	8.1 μm	9.4 μm	319 μm^3
	max	9.1 μm	10.5 μm	451 μm^3
Gloeotrichia echinulata	min	384.8 μm	–	–
colonies[‡]	med	522.4 μm	–	–
	max	817.4 μm	–	–
Gloeotrichia pisum	min	6.1 μm	5.7 μm	211 μm^3
cells (cylinder)	med	7.5 μm	9.5 μm	400 μm^3
	max	9.2 μm	18.8 μm	1,060 μm^3
Gloeotrichia pisum	min	6.3 μm	5.4 μm	112 μm^3
heterocysts (spheroid)	med	9.6 μm	10.5 μm	468 μm^3
	max	13.4 μm	15.6 μm	1,450 μm^3
Gloeotrichia pisum	min	7.3 μm	26.9 μm	742 μm^3
akinetes (cyl + two $\frac{1}{2}$ spheres)[§]	med	11.1 μm	50.5 μm	3,650 μm^3
	max	12.8 μm	79.9 μm	4,950 μm^3

[†]Calculated using original measurements, not summary values.
[‡]Colony biovolume can be estimated using a spherical or spheroid shape.
[§]Biovolume based on cylinder length ($<$ cell length).

Description

Gloeotrichia forms large, dark, spherical or hemispherical colonies containing many tapered trichomes radiating from the colony center (Figures 3.73–3.78). The trichomes are embedded in clear, diffuse mucilage, but this feature can be difficult to see without staining. The cells near the base of the trichome are cylindrical, with constricted cross walls, becoming long and tapered toward the end of the trichome. Each trichome has a single basal heterocyst that is best seen when the colony is flattened (Figure 3.75). Akinetes develop adjacent to the basal heterocyst in older trichomes, but this feature can be difficult to see in dense colonies.

Gloeotrichia echinulata colonies are planktonic, comprised of densely packed, tapered trichomes radiating from a common center (Figures 3.73–3.75). The cells at the ends of the trichomes can become very long and have a distinctive banded appearance. Colonies are sometimes visible without magnification, looking like tiny green or brown specks floating at the top of the water. The colonies may start on the lake bottom, but become increasingly buoyant as the colony matures (John, et al., 2011). *Gloeotrichia echinulata* is a common water quality indicator that can form dense blooms in eutrophic lakes, often in association with *Aphanizomenon* (Section 3.3, page 250), *Dolichospermum* (Section 3.1, page 198), and *Microcystis* (Section 2.13, page 141). Some strains can release toxins into the water.

Gloeotrichia pisum is epiphytic, forming dense spherical or hemispherical colonies composed of long, tapering trichomes that radiate from the point of attached to aquatic plants (Figures 3.76–3.78). The vegetative cells are cylindrical (width $<$ length), olive-green or grayish green; the heterocysts are spherical or oval. Both the vegetative cells and heterocysts are slightly larger than *Gloeotrichia echinulata*. *Gloeotrichia pisum* have very distinctive, long, cylindrical heterocysts that form adjacent to the basal heterocyst.



Figure 3.73: *Gloeotrichia echinulata* (40x brightfield), Lake Campbell, IWS water quality sampling site, Skagit County, August 15, 2007.



Figure 3.74: *Gloeotrichia echinulata* (40x brightfield), Cranberry Lake, IWS water quality sampling site, Island County, May 28, 2008.



Figure 3.75: *Gloeotrichia echinulata* (400x DIC), Big Lake, IWS water quality sampling site, Skagit County, August 21, 2008.

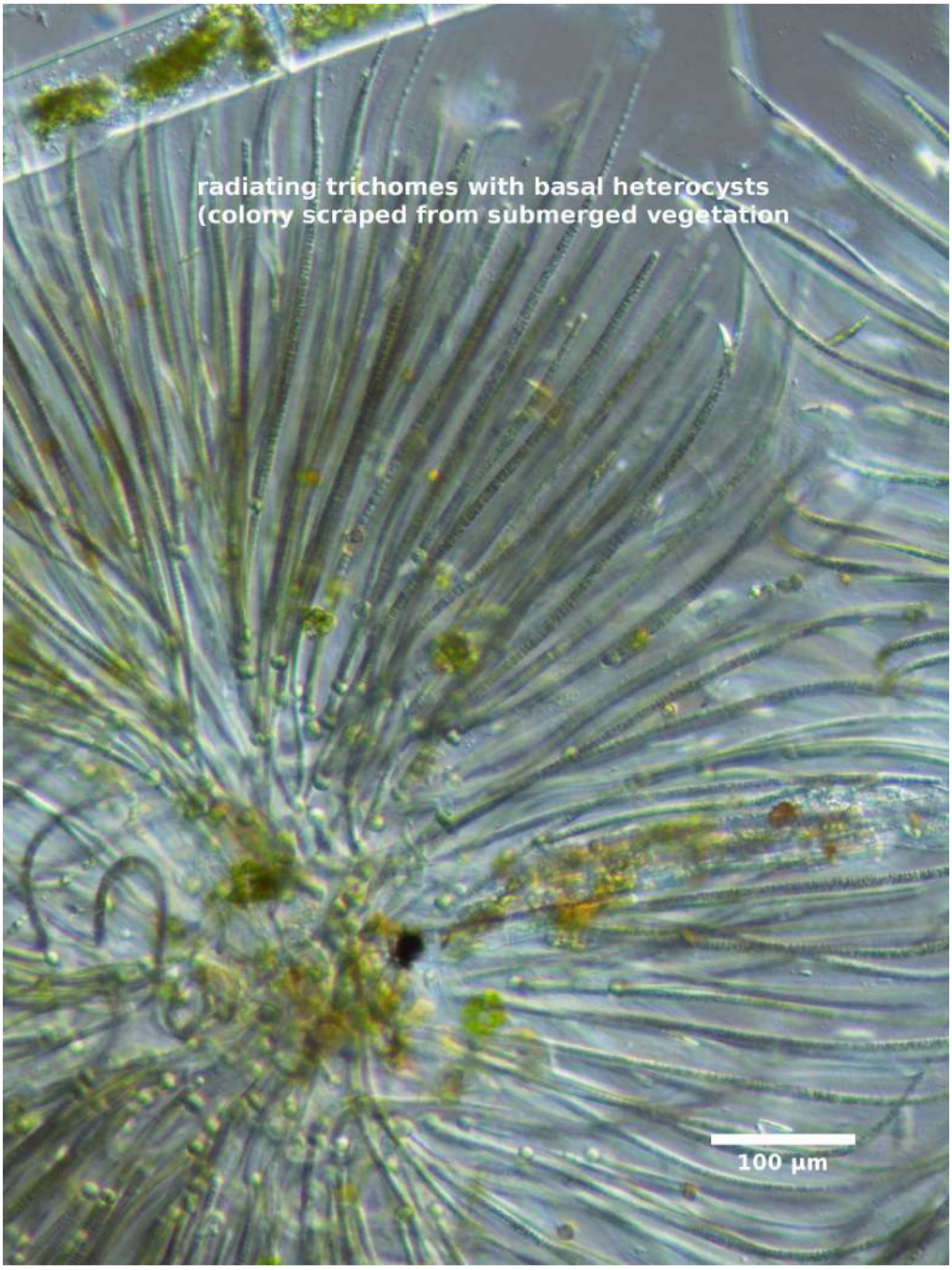


Figure 3.76: *Gloeotrichia pisum* (100x DIC), Beaver Pond Lake, IWS water quality sampling site, Whatcom County, May 7, 2015.



Figure 3.77: *Gloeotrichia pisum* (200x DIC), Beaver Pond Lake, IWS water quality sampling site, Whatcom County, May 7, 2015.



Figure 3.78: *Gloeotrichia pisum* (600x DIC), Myrtle Lake, IWS water quality sampling site, Snohomish County, July 22, 2015.

3.10 *Hapalosiphon* Nägeli ex Bornet & Flahault

Local taxa
Hapalosiphon pumilus Kirchner ex Bornet & Flahault;
Hapalosiphon sp.1

Abundance
Infrequently collected in plankton samples; occasionally collected in shoreline samples from mountain lakes.

Local measurements		Width	Length	Biovolume†
Hapalosiphon pumilus	min	9.6 μm	8.4 μm	724 μm^3
cells (cylinder)	med	13.3 μm	15.8 μm	1,770 μm^3
	max	15.0 μm	31.4 μm	4,760 μm^3
Hapalosiphon pumilus	min	9.3 μm	7.7 μm	746 μm^3
heterocysts (cylinder)	med	11.6 μm	14.0 μm	1,480 μm^3
	max	14.1 μm	19.0 μm	2,050 μm^3
Hapalosiphon sp.1	min	8.0 μm	7.31 μm	706 μm^3
cells (cylinder)	med	9.9 μm	19.3 μm	1,270 μm^3
	max	11.2 μm	34.9 μm	2,960 μm^3
Hapalosiphon sp.1	min	8.0 μm	7.3 μm	669 μm^3
heterocysts (cylinder)	med	10.2 μm	9.0 μm	808 μm^3
	max	11.0 μm	29.2 μm	2,030 μm^3

†Calculated using original measurements, not summary values.

Description
Hapalosiphon trichomes form true lateral branches that diverge at 90° from the main trichome (Figures 3.79–3.81). Both the main and branch trichomes are uniseriate (1 cell per row), comprised of unconstricted, cylindrical or slightly rounded, barrel-shaped cells surrounded by a distinct mucilage layer. Heterocysts may be present in both the main and lateral branches. *Hapalosiphon* resembles *Fischerella* (Section 3.8, page 290), which has rounded cells that are smaller in the branches than in the main trichome; and *Stigonema* (Section 3.13, page 329),

which has multiseriate (>1 cell per row) trichomes enclosed in thick, yellowish-brown mucilage.

Hapalosiphon pumilus is a highly variable species, with cells and heterocysts that range from cubical (width $\approx$ length) to cylindrical (width $<$ length). The cells may have constricted or unconstricted cell walls. The trichome is surrounded by a clear mucilage layer that turns brownish yellow in old filaments (Figures 3.79–3.81). The best distinguishing feature is the filament width (12–25 μm), which is wider than most other species of *Hapalosiphon*. This species is common in acidic (peaty) waters in the northern temperate zone (Komárek, 2013). All of the local specimens were collected in shoreline samples from boggy mountain lakes.

The *Hapalosiphon* specimens in Figures 3.82–3.84 have highly variable cells and akinetes, ranging from cubical to very long and cylindrical. But the cell and heterocyst widths are <11 μm, which may indicate that these are a different species. The trichomes share several similarities with *Hapalosiphon pumilus*, including the tendency of younger filaments to have a clear mucilage layer and older filaments to have a deep yellowish-brown mucilage layer. The specimens were collected from slightly acidic, peaty mountain lake, which matches the habitat description for *Hapalosiphon pumilus*, so these narrower specimens may just be a variation of this highly polymorphic species.

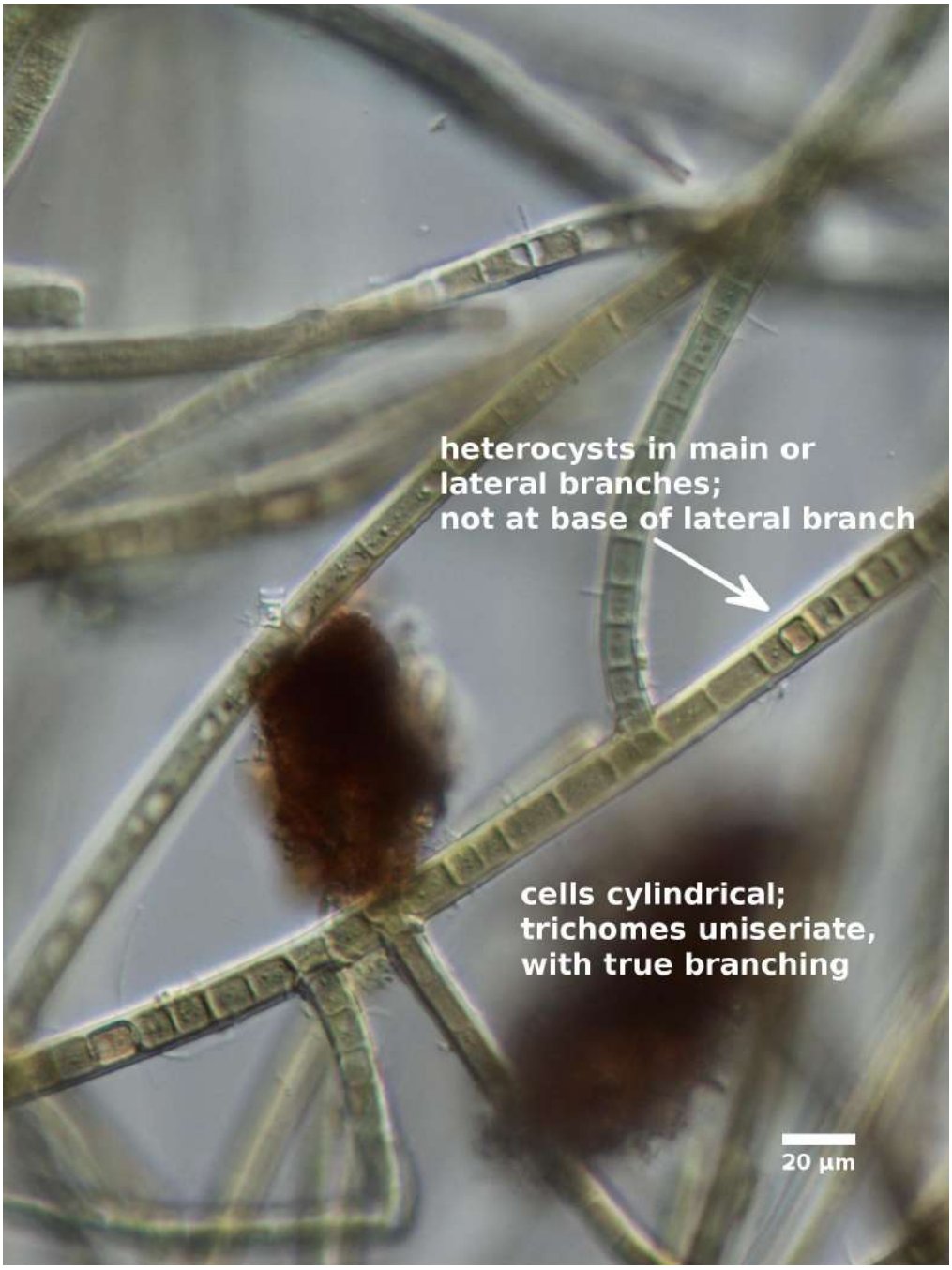


Figure 3.79: *Hapalosiphon pumilus* (200x DIC), Dorothy Lake, Alpine Lakes Wilderness Area, July 12, 2013.

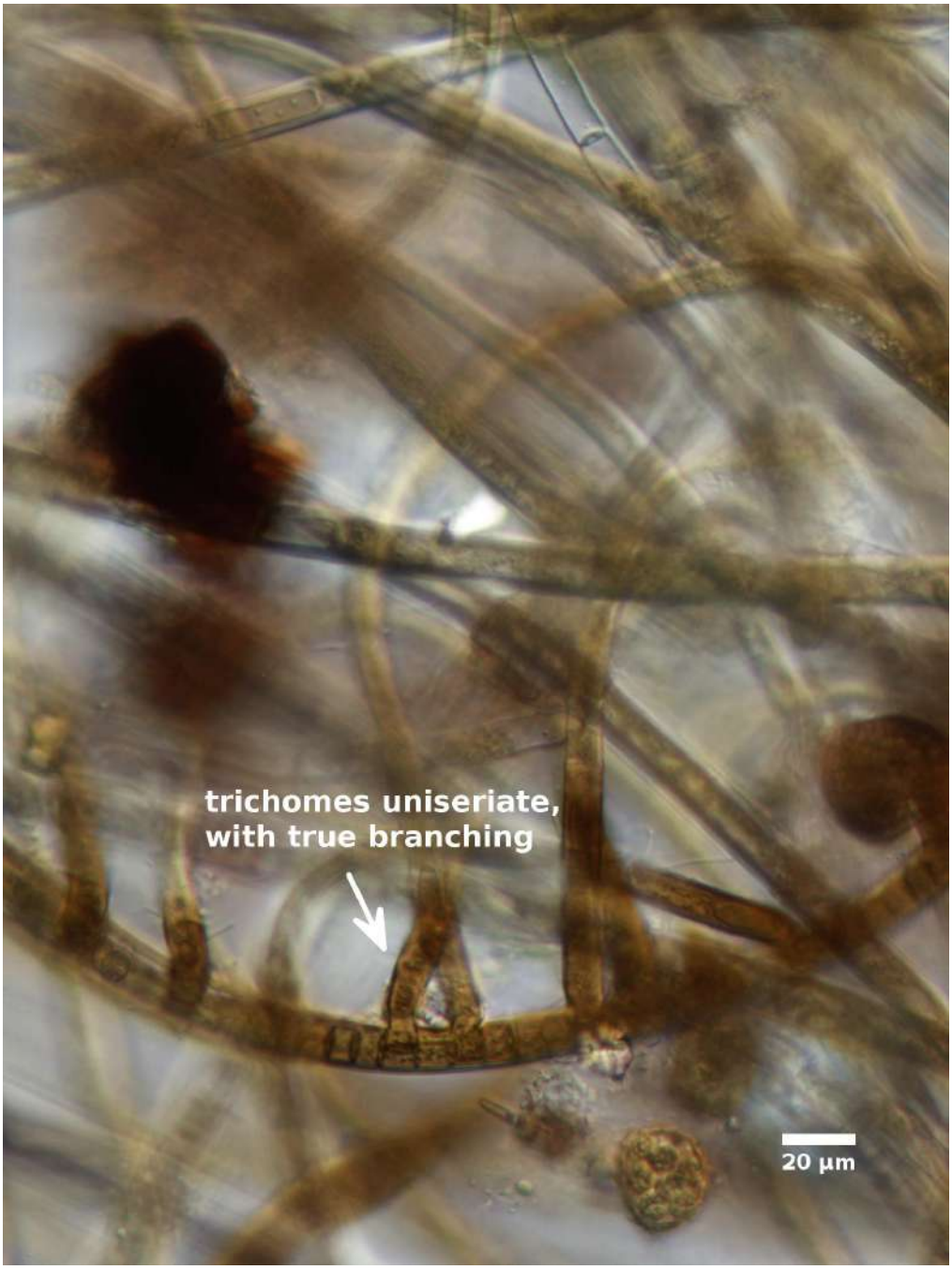


Figure 3.80: *Hapalosiphon pumilus* (200x DIC), Dorothy Lake, Alpine Lakes Wilderness Area, July 12, 2013.

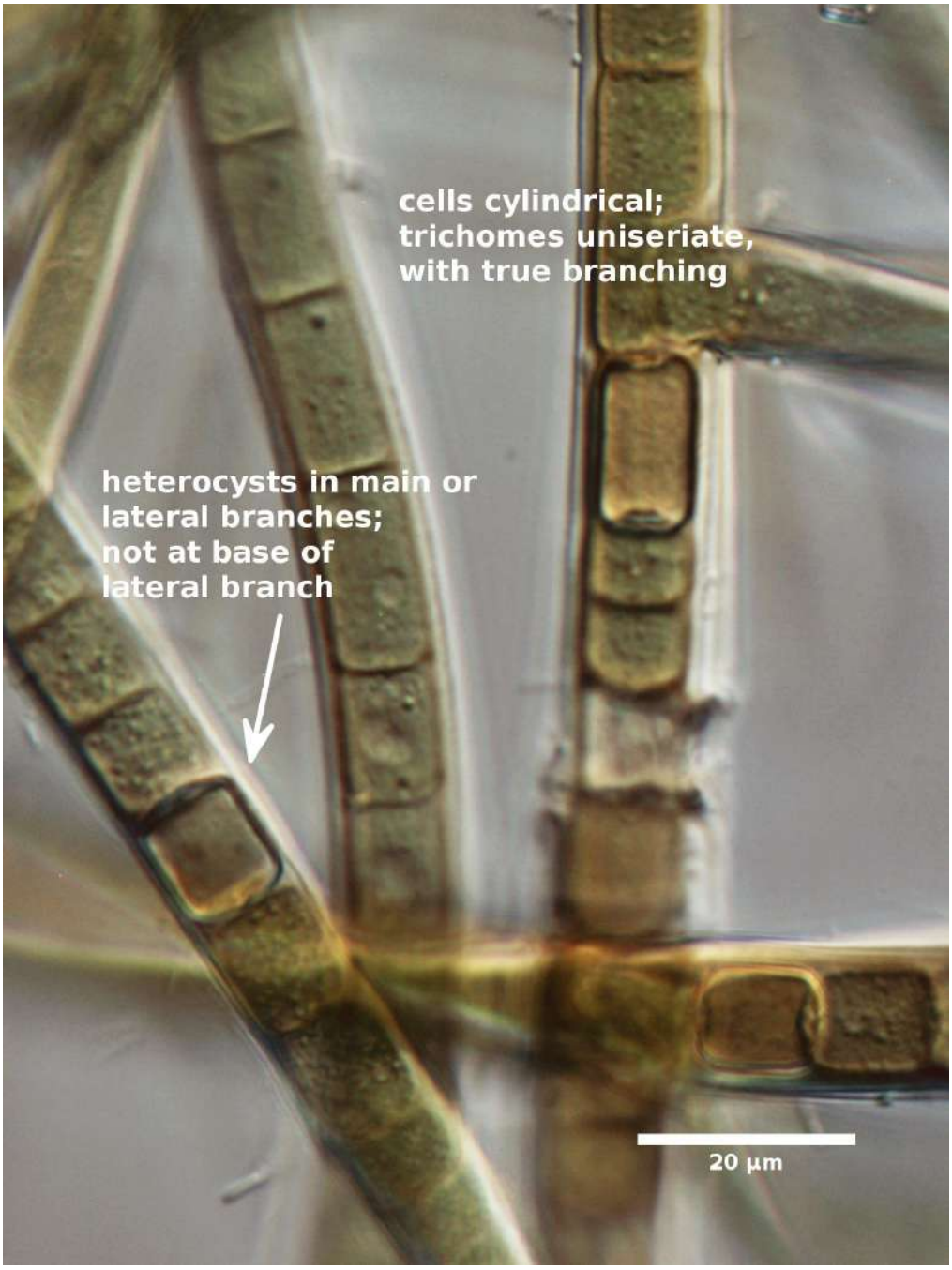


Figure 3.81: *Hapalosiphon pumilus* (600x DIC), Dorothy Lake, Alpine Lakes Wilderness Area, July 12, 2013.



Figure 3.82: *Hapalosiphon* sp.1 (200x DIC), small pond on Yellow Aster Butte trail, North Cascades near Mt. Baker, September 5, 2013.

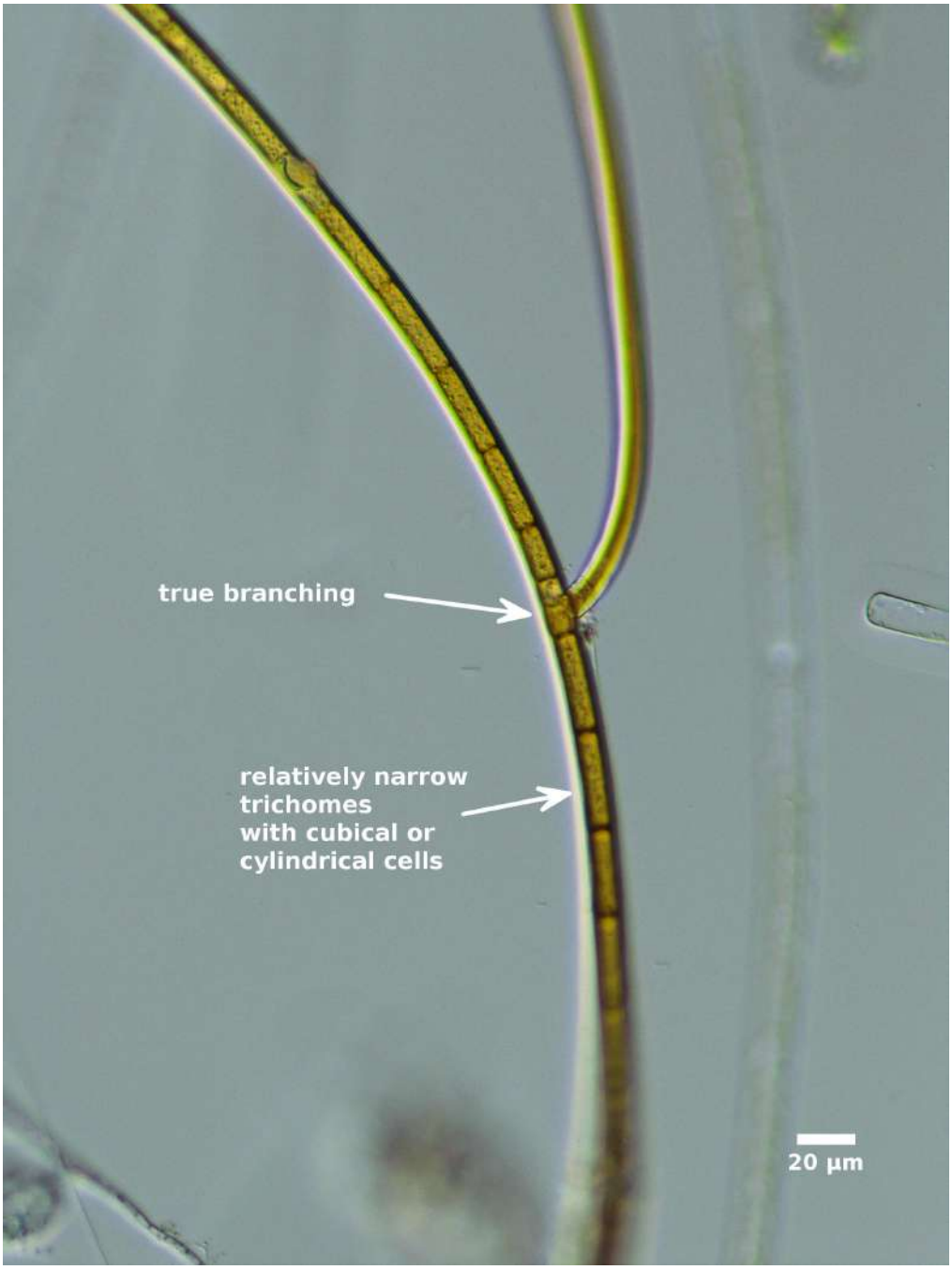


Figure 3.83: *Hapalosiphon* sp.1 (200x DIC), Bear Lake, IWS water quality sampling site, Snohomish County, August 28, 2014.

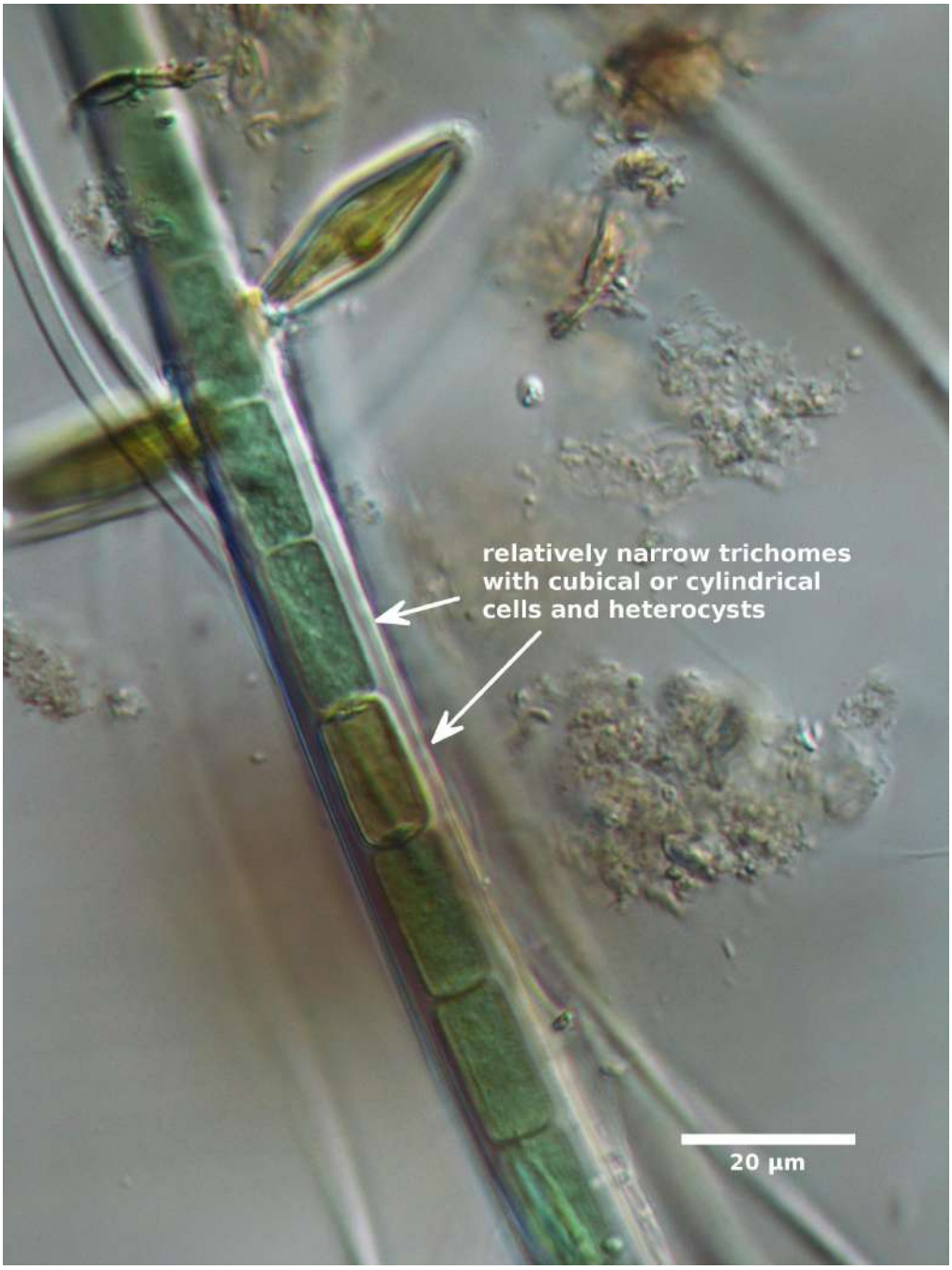


Figure 3.84: *Hapalosiphon* sp.1 (600x DIC), Bear Lake, IWS water quality sampling site, Snohomish County, August 28, 2014.

3.11 *Nostoc* Vaucher ex Bornet & Flahault

Local taxa
Nostoc caeruleum var. *planctonicum* (Poretsky & Tschernow) Whitton?;
Nostoc paludosum Kützing ex Bornet & Flahault?;
Nostoc pruniforme Agardh ex Bornet & Flahault?

Abundance
Moderately common; rarely present in large numbers, but some taxa may form large colonies.

Local measurements		Width	Length	Biovolume[†]
Nostoc caeruleum	min	4.4 μm	4.3 μm	43.6 μm^3
var. *planctonicum*?	med	5.8 μm	5.7 μm	101 μm^3
cells (spheroid)	max	6.3 μm	7.9 μm	158 μm^3
Nostoc caeruleum	min	5.3 μm	5.7 μm	83.8 μm^3
var. *planctonicum*?	med	7.2 μm	7.8 μm	207 μm^3
heterocysts (spheroid)	max	8.4 μm	9.1 μm	336 μm^3
Nostoc paludosum?	min	3.5 μm	3.9 μm	25.0 μm^3
cells (spheroid)	med	5.3 μm	4.7 μm	71.8 μm^3
	max	6.1 μm	6.0 μm	115 μm^3
Nostoc paludosum?	min	4.9 μm	5.9 μm	79.2μm^3
heterocysts (spheroid)	med	5.9 μm	6.3 μm	113 μm^3
	max	6.7 μm	7.6 μm	179 μm^3
Nostoc pruniforme?	min	4.9 μm	–	61.6 μm^3
cells (sphere)	med	5.2 μm	–	75.8 μm^3
	max	5.8 μm	–	102 μm^3
Nostoc pruniforme?	min	5.9 μm	5.8 μm	117 μm^3
heterocysts (spheroid)	med	7.0 μm	7.0 μm	176 μm^3
	max	8.2 μm	8.0 μm	282 μm^3

[†]Calculated using original measurements, not summary values.

Description

Nostoc trichomes are comprised of spherical or bead-like cells that resemble *Anabaena* and *Dolichospermum* cells (Section 3.1, page 198), but the trichomes are enclosed in gelatinous or rubbery mucilage to form spherical or irregularly shaped colonies (Figures 3.85–3.93). *Nostoc* is a morphologically diverse genus, especially with respect to colony size and appearance. Most species eventually form large, macroscopic colonies, but reproduce by creating small, microscopic subcolonies (buds). The major diagnostic characteristics separating the species is exceedingly difficult, so all of the identifications for local taxa are tentative.

Nostoc caeruleum var. *planctonicum* is a planktonic species with spherical, microscopic (<4 mm diameter) colonies (Figures 3.85–3.88). The colonial mucilage is firm, smooth, and colorless. The individual trichomes are not surrounded by a visible sheath (see *Nostoc paludosum* description below) and the heterocysts and vegetative cells are slightly larger than other local *Nostoc* taxa. This species will key to *Nostoc planctonicum* in most older taxonomic keys.

Nostoc paludosum can be distinguished by the presence of a visible, yellowish sheath around individual trichomes, the irregular shape of the colony, and the yellowish-brown colonial mucilage (Figures 3.89–3.91). This species is associated with acidic water (Komárek, 2013); all of the local specimens were collected in acidic mountain lakes and ponds.

The specimens in Figures 3.92–3.93 are tentatively identified as *Nostoc pruniforme*. *Nostoc pruniforme* colonies are macroscopic, often reaching several centimeters in diameter, ranging from olive-green to dark brown. The trichomes are loosely twisted and comprised of barrel-shaped vegetative cells and larger spherical heterocysts.



Figure 3.85: *Nostoc caeruleum* var. *planctonicum*? (100x DIC), Upper Bagley Lake, IWS water quality sampling site, Whatcom County, August 30, 2011.



Figure 3.86: *Nostoc caeruleum* var. *planctonicum*? (600x DIC), Upper Bagley Lake, IWS water quality sampling site, Whatcom County, August 30, 2011.

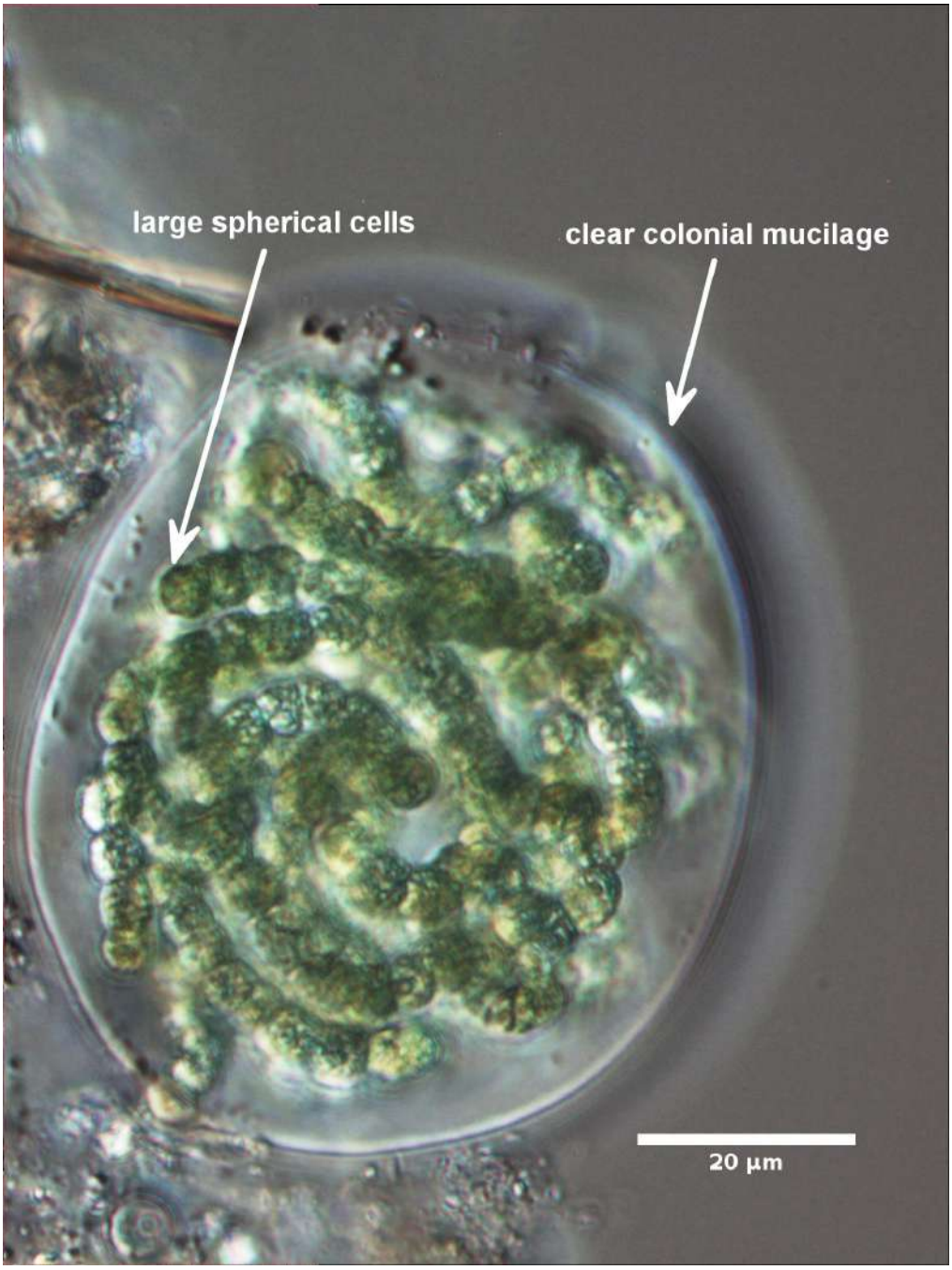


Figure 3.87: *Nostoc caeruleum* var. *planctonicum*? (600x DIC), Highwood Lake, IWS water quality sampling site, Whatcom County, August 30, 2011.

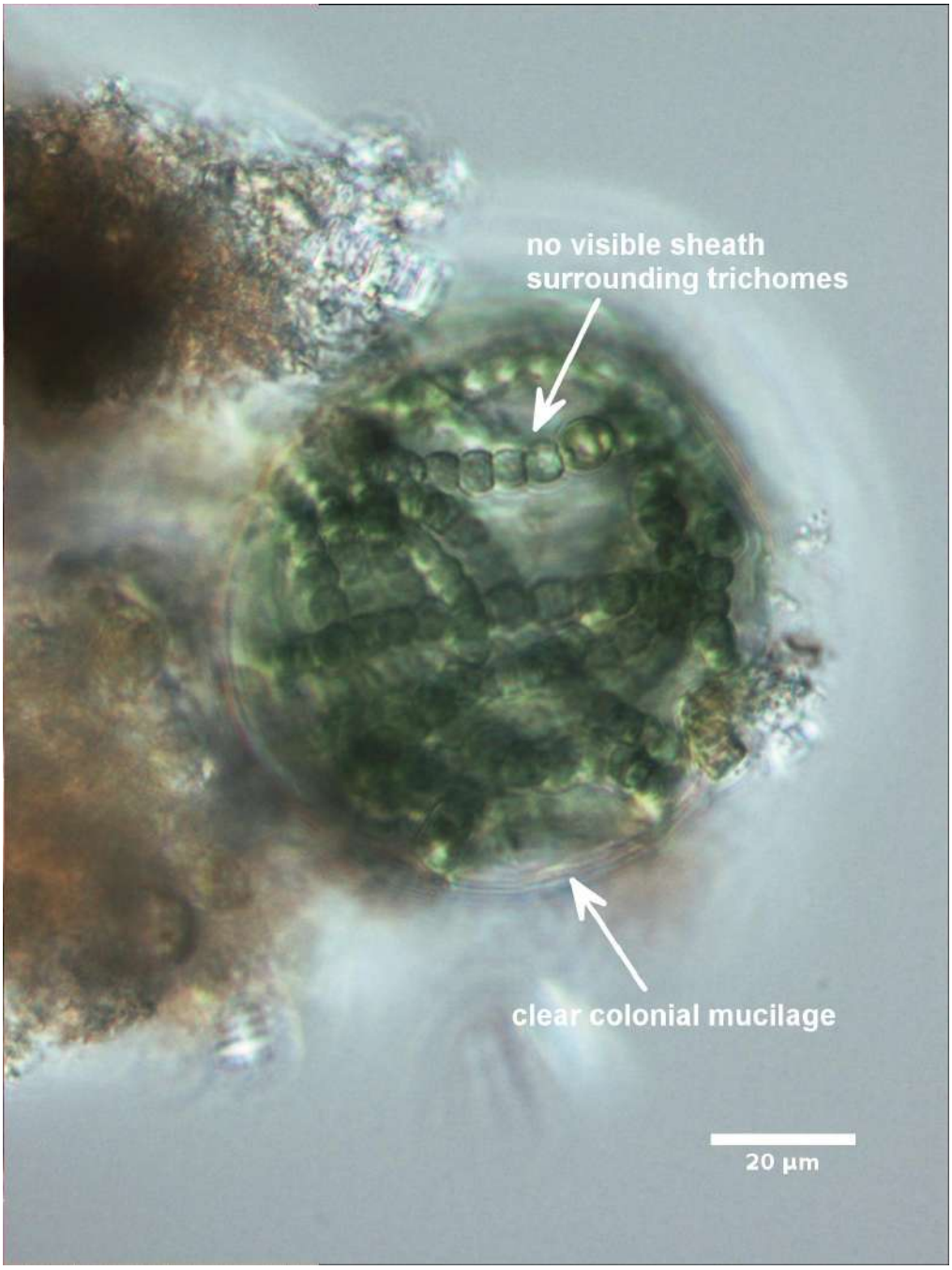


Figure 3.88: *Nostoc caeruleum* var. *planctonicum*? (400x DIC), Lower Bagley Lake, IWS water quality sampling site, Whatcom County, September 30, 2010.



Figure 3.89: *Nostoc paludosum*? (100x DIC), Upper Bagley Lake, IWS water quality sampling site, Whatcom County, August 29, 2011.

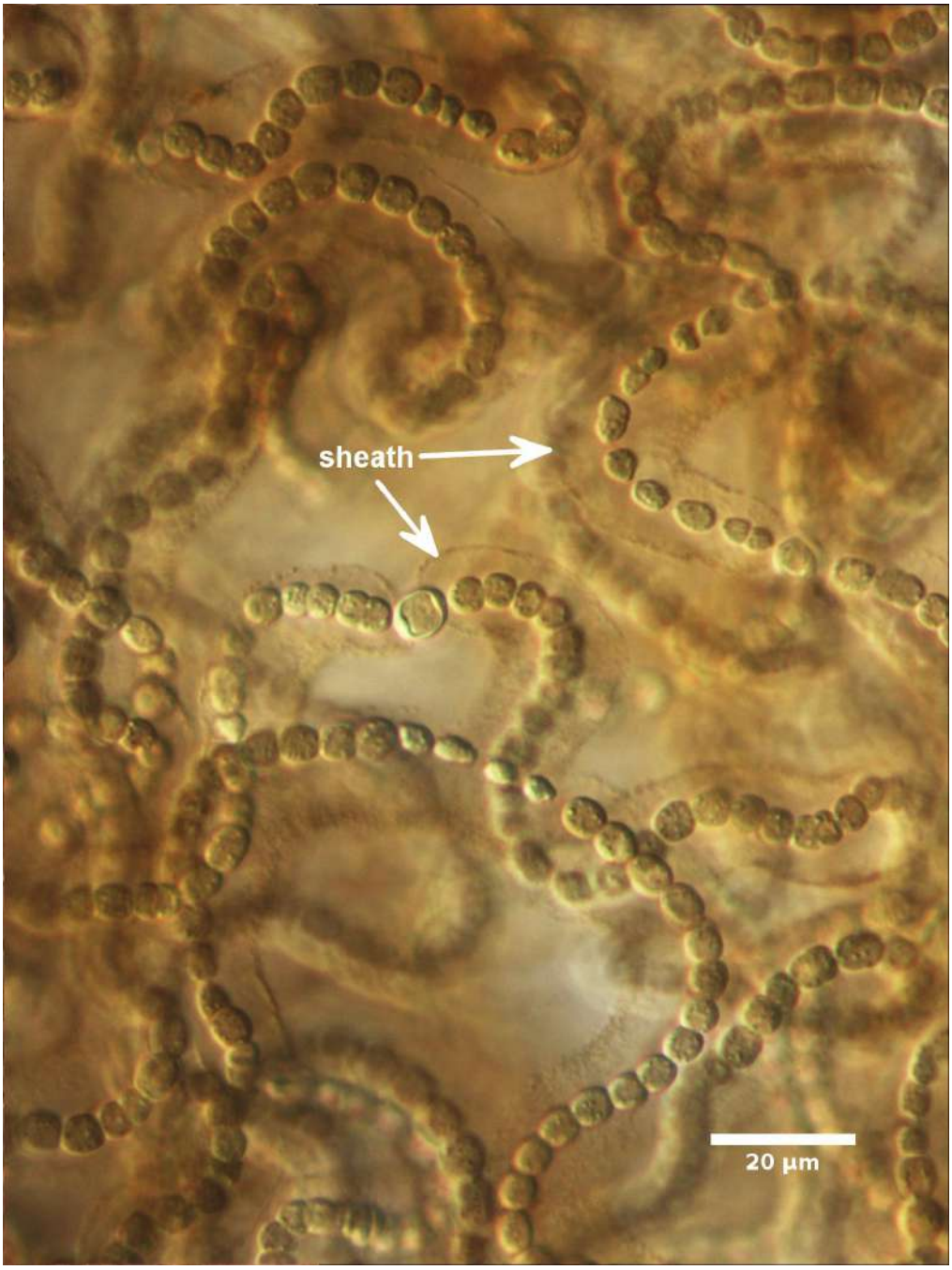


Figure 3.90: *Nostoc paludosum*? (400x DIC), Upper Bagley Lake, IWS water quality sampling site, Whatcom County, August 29, 2011.



Figure 3.91: *Nostoc paludosum*? (200x DIC), Mirror Lake, IWS water quality sampling site, Whatcom County, August 12, 2009.



Figure 3.92: *Nostoc pruniforme*? (63x brightfield), Ross Lake, Ross Lake National Recreation Area, November 7, 2009. Macroscopic colonies are ≈1–4 cm in diameter.



Figure 3.93: *Nostoc pruniforme*? (200x DIC), Ross Lake, Ross Lake National Recreation Area, November 7, 2009.

3.12 *Scytonema* Agardh ex Bornet & Flahault

Local taxa
Scytonema spp.

Abundance
Infrequently collected in plankton samples; occasionally collected in shoreline samples and benthic mats.

Local measurements		Width	Length	Biovolume[†]
Scytonema sp.1	min	6.9 μm	6.0 μm	401 μm^3
cells (cylinder)	med	8.9 μm	12.2 μm	688 μm^3
	max	11.7 μm	20.5 μm	2,200 μm^3
Scytonema sp.1	min	8.3 μm	9.0 μm	487 μm^3
heterocysts (cylinder)	med	9.3 μm	19.3 μm	1,200 μm^3
	max	10.3 μm	34.6 μm	2,340 μm^3
Scytonema sp.2	min	8.5 μm	4.3 μm	274 μm^3
cells (cylinder)	med	11.0 μm	6.1 μm	570 μm^3
	max	13.4 μm	8.5 μm	1,120 μm^3
Scytonema sp.2	min	9.5 μm	7.0 μm	714 μm^3
heterocysts (cylinder)	med	12.2 μm	9.7 μm	1,180 μm^3
	max	14.7 μm	12.7 μm	1,780 μm^3
Scytonema sp.3	min	8.7 μm	5.4 μm	336 μm^3
cells (cylinder)	med	10.3 μm	9.6 μm	810 μm^3
	max	11.4 μm	11.8 μm	1,200 μm^3
Scytonema sp.3	min	8.5 μm	9.8 μm	556 μm^3
heterocysts (cylinder)[‡]	med	9.3 μm	12.1 μm	931 μm^3
	max	9.9 μm	14.5 μm	985 μm^3

[†]Calculated using original measurements, not summary values.
[‡]Biovolume estimates based on $<$5 cells.

Description

Scytonema trichomes are untapered and form false branches where the trichome continues to grow in both directions on either side of breaks in the trichome (Figures 3.94–3.100). The individual cells are cylindrical, blue-green, usually granular, and may be slightly constricted at the cross-walls. The heterocysts are described as solitary, only occasionally occurring in a series (Komárek, 2013), but several local taxa were observed to have multiple adjacent heterocysts in the trichome (e.g., Figures 3.96–3.97). *Scytonema* resembles *Tolypothrix* (Section 3.14, page 343), which also forms false branches, but *Tolypothrix* branches originate at a heterocyst. *Scytonema* is a highly polymorphic genus, so species identifications are beyond the scope of this guide.

Scytonema sp.1 has narrow trichomes (usually $\leq$10 μm wide) enclosed in a moderately thick, colorless mucilage layer (Figures 3.94–3.96). The cells are cylindrical, and range from approximately equal in length and width to much longer than wide. The heterocysts are rounded, ranging from oval to very long and cylindrical. The heterocysts are usually solitary, but occasionally form a series (Figure 3.96). All of the local specimens were collected in peaty, slightly acidic mountain lakes.

Scytonema sp.2 trichomes are slightly wider ($\geq$10 μm) compared to *Scytonema* sp.1. The individual cells are consistently shorter than their width (Figures 3.97–3.98). The heterocysts are rounded, slightly shorter than their width, and occasionally form a series (Figure 3.97). The trichome is enclosed in a thick, yellowish-brown mucilage layer. Most of the local specimens were collected in peaty, slightly acidic mountain lakes.

The specimens identified as *Scytonema* sp.3 share some morphological features with both of the other local *Scytonema* taxa, but were collected from a marshy, low elevation lake (different habitat). The trichomes are fairly narrow (usually $\leq$10 μm), comprised of cylindrical cells that range from slightly shorter to slightly longer than wide (Figures 3.99–3.100). The heterocysts are rounded and longer than wide. The trichomes are enclosed in a thin, yellowish-brown mucilage layer.



Figure 3.94: *Scytonema* sp.1 (200x DIC), Vogler Lake, IWS water quality sampling site, Skagit County, August 26, 2013.



Figure 3.95: *Scytonema* sp.1 (200x DIC), Pyramid Lake, North Cascades along Hwy 20, September 14, 2012.

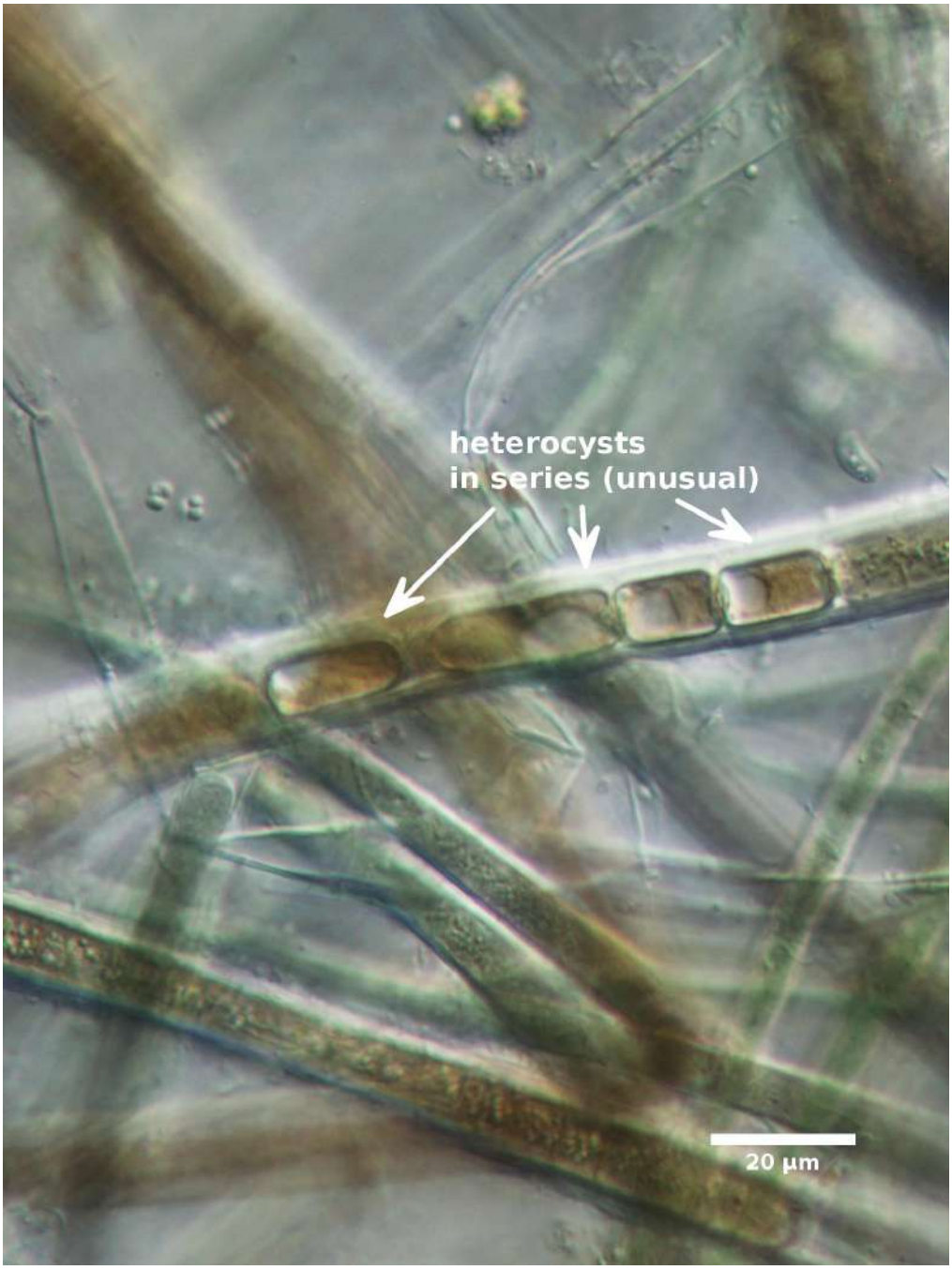


Figure 3.96: *Scytonema* sp.1 (400x DIC), Pyramid Lake, North Cascades along Hwy 20, September 14, 2012.

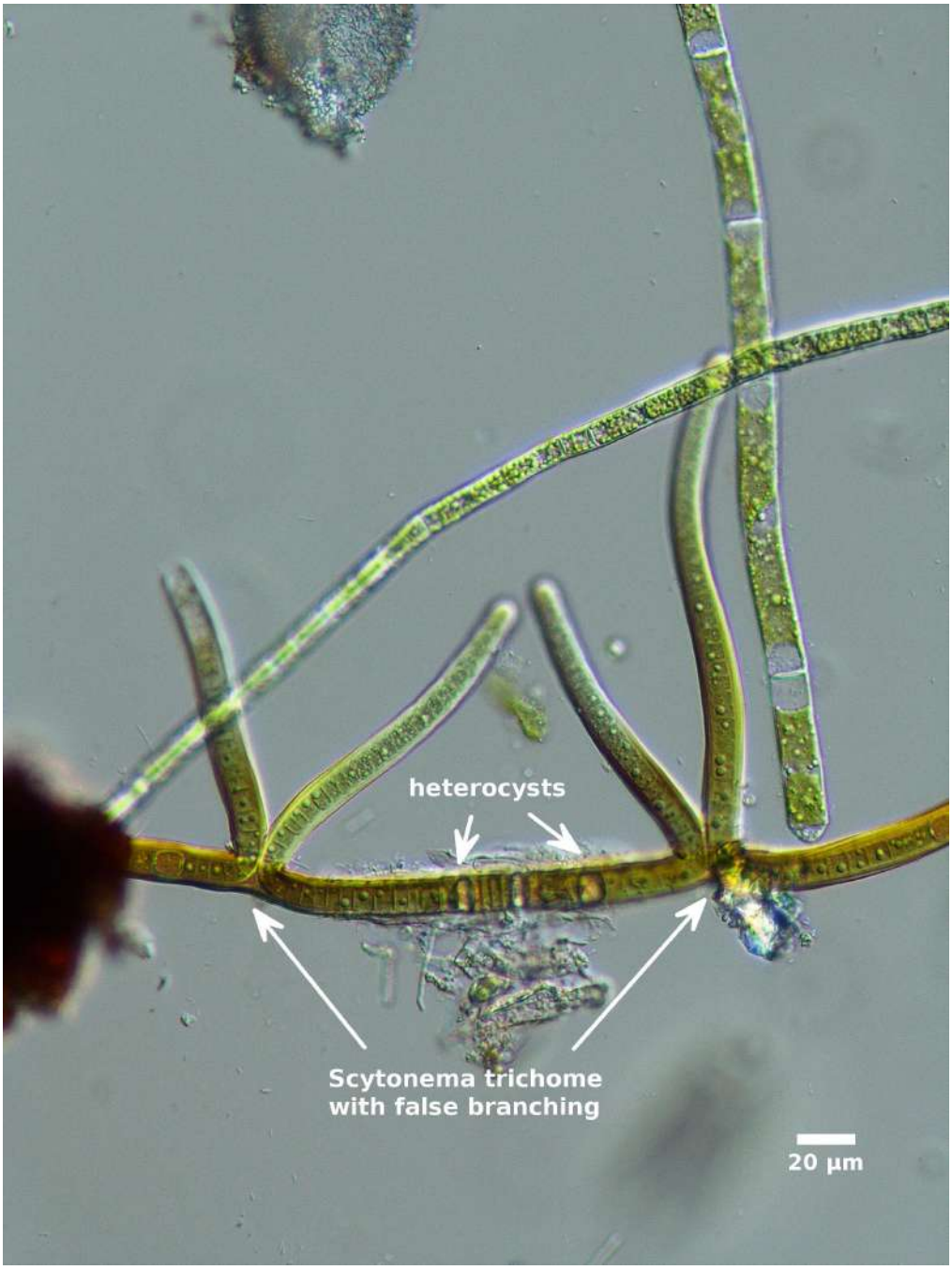


Figure 3.97: *Scytonema* sp.2 (200x DIC), Lake Twenty-two, Mt. Loop Hwy, July 24, 2014.



Figure 3.98: *Scytonema* sp.2 (200x DIC), Lake Twenty-two, Mt. Loop Hwy, July 24, 2014.



Figure 3.99: *Scytonema* sp.3 (200x DIC), Beaver Pond Lake, IWS water quality sampling site, Whatcom County, May 8, 2013.



Figure 3.100: *Scytonema* sp.3 (600x DIC), Beaver Pond Lake, IWS water quality sampling site, Whatcom County, May 8, 2013.

3.13 *Stigonema* Agardh ex Bornet & Flahault

Local taxa
Stigonema mamillosum Agardh ex Bornet & Flahault;
Stigonema ocellatum Thuret ex Bornet & Flahault;
Stigonema spp.

Abundance
Infrequently collected in plankton samples; moderately common in shoreline samples from mountain lakes and streams.

Local measurements		Width	Length	Biovolume[†]
Stigonema mamillosum	min	13.8 μm	12.4 μm	1,510 μm^3
cells (spheroid)	med	16.2 μm	15.1 μm	2,000 μm^3
	max	26.0 μm	21.4 μm	6,300 μm^3
Stigonema mamillosum	min	8.3 μm	5.2 μm	188 μm^3
heterocysts (spheroid)	med	16.2 μm	10.0 μm	1,370 μm^3
	max	21.1 μm	12.3 μm	2,870 μm^3
Stigonema ocellatum	min	13.0 μm	6.9 μm	639 μm^3
cells (spheroid)	med	17.5 μm	12.8 μm	2,040 μm^3
	max	25.5 μm	19.7 μm	5,500 μm^3
Stigonema ocellatum	min	12.9 μm	11.6 μm	1,040 μm^3
heterocysts (spheroid)	med	17.4 μm	13.3 μm	2,190 μm^3
	max	24.0 μm	14.4 μm	3,500 μm^3
Stigonema sp.1	min	6.5 μm	6.5 μm	223 μm^3
cells (spheroid)	med	10.7 μm	9.9 μm	544 μm^3
	max	12.3 μm	12.6 μm	998 μm^3
Stigonema sp.2	min	7.0 μm	4.2 μm	131 μm^3
cells (spheroid)	med	13.9 μm	5.4 μm	561 μm^3
	max	15.3 μm	8.8 μm	968 μm^3

continued on next page

Local measurements		Width	Length	Biovolume[†]
Stigonema sp.2	min	10.4 μm	6.2 μm	379 μm^3
heterocysts (spheroid)	med	14.6 μm	6.7 μm	745 μm^3
	max	15.8 μm	11.3 μm	1,440 μm^3

[†]Calculated using original measurements, not summary values.

Description

Stigonema trichomes form dense, dark benthic mats, usually attached to rocky or woody substrates in streams. The trichomes are twisted or coiled, highly branched (true branching), comprised of densely packed rows of cells (Figures 3.101–3.111). The individual cells are approximately spherical, but are often compressed by adjacent cells. The cells are embedded in a dense mucilaginous sheath that ranges from yellowish to dark brown. The heterocysts form within the trichome, not at the base of a false branch, but due to the dark coloration, it may be difficult to see the trichome features.

Stigonema mamillosum cells are spherical, oval, or elliptical, and usually highly compressed (Figures 3.101–3.103). The trichomes are repeatedly branched, with multiple rows of cells in the main and auxiliary branches, and occasional single rows in the short auxiliary branches. The trichome is surrounded by a thick, dense, brown mucilage that can obscure the cell features.

Stigonema ocellatum cells are spherical, oval, or cylindrical and slightly compressed (Figures 3.104–3.106). The trichomes often contain only one row of cells, especially in the side branches. The filament is surrounded by a thick, clear or yellowish mucilage, but unlike *Stigonema mamillosum*, the trichome features are clearly visible.

The *Stigonema* sp.1 specimens in Figures 3.107–3.108 were collected in melting snow near the Big Four Ice Caves, along with the bright red cysts of *Chlamydomonas nivalis* or "watermelon snow" algae.[14] The trichome sheath is unusually thick, and the individual cells are small and highly compressed, especially near the ends of the side branches. The specimens resemble *Stigonema mamillosum*, but are probably a different species due to the unusual habitat and other morphological differences.

[14]See **Freshwater Algae in Northwest Washington, Volume II. Chlorophyta and Rhodophyta**.

Stigonema sp.2 specimens were collected from the wet rocks adjacent to a large waterfall, mixed in with mosses and bright orange mats of *Trentepohelia*, a type of semi-aquatic, filamentous green algae.[15] The main axis of this species of *Stigonema* forms a thick, cushion-like filament containing many rows of spherical or slightly compressed oval cells enclosed in a firm, clear or yellowish-brown mucilage (Figures 3.109–3.111). The lateral branches are narrow, usually with a single rows of cells. The main branch and lateral trichomes are enclosed in clear or orange mucilage.

[15] See **Freshwater Algae in Northwest Washington, Volume II. Chlorophyta and Rhodophyta**.



Figure 3.101: *Stigonema mamillosum* (600x DIC), Lake Twenty-two, Mt. Loop Hwy, May 29, 2015.

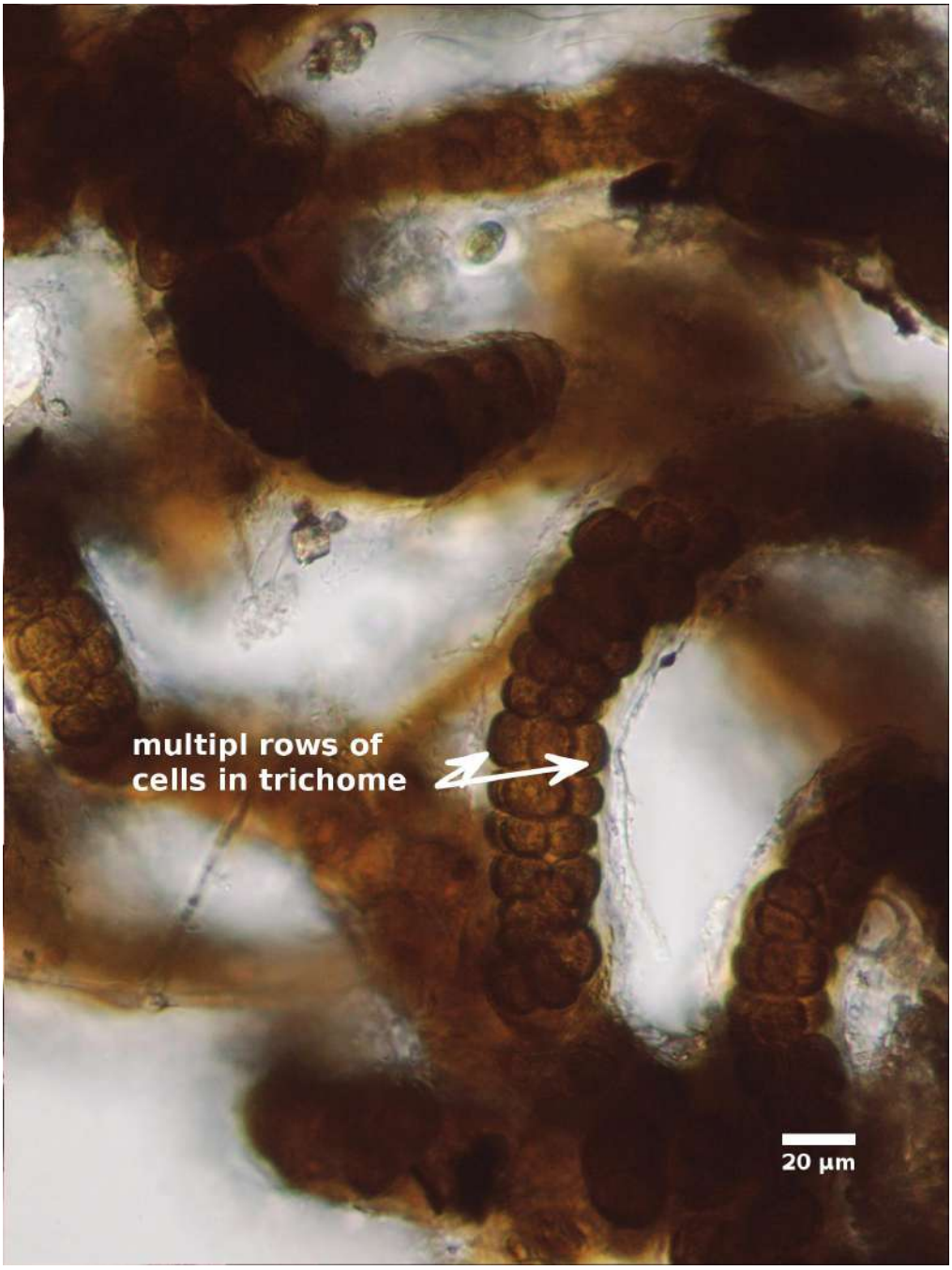


Figure 3.102: *Stigonema mamillosum* (200x DIC), Silver Creek, tributary to Ross Lake, Ross Lake National Recreation Area, September 28, 2010.



Figure 3.103: *Stigonema mamillosum* (400x DIC), Silver Creek, tributary to Ross Lake, Ross Lake National Recreation Area, September 28, 2010.



Figure 3.104: *Stigonema ocellatum* (200x DIC), Myrtle Lake, IWS water quality sampling site, Snohomish County, August 20, 2013.



Figure 3.105: *Stigonema ocellatum* (200x DIC), boggy seep on trail to Lake Anderson, North Cascades along Hwy 20, August 23, 2013.



Figure 3.106: *Stigonema ocellatum* (600x DIC), Myrtle Lake, IWS water quality sampling site, Snohomish County, July 22, 2015.



Figure 3.107: *Stigonema* sp.1 (200x DIC), Big Four Ice Caves melt water sample, Mt. Loop Hwy, July 18, 2011.



Figure 3.108: *Stigonema* sp.1 (400x DIC), Big Four Ice Caves melt water sample, Mt. Loop Hwy, July 18, 2011.

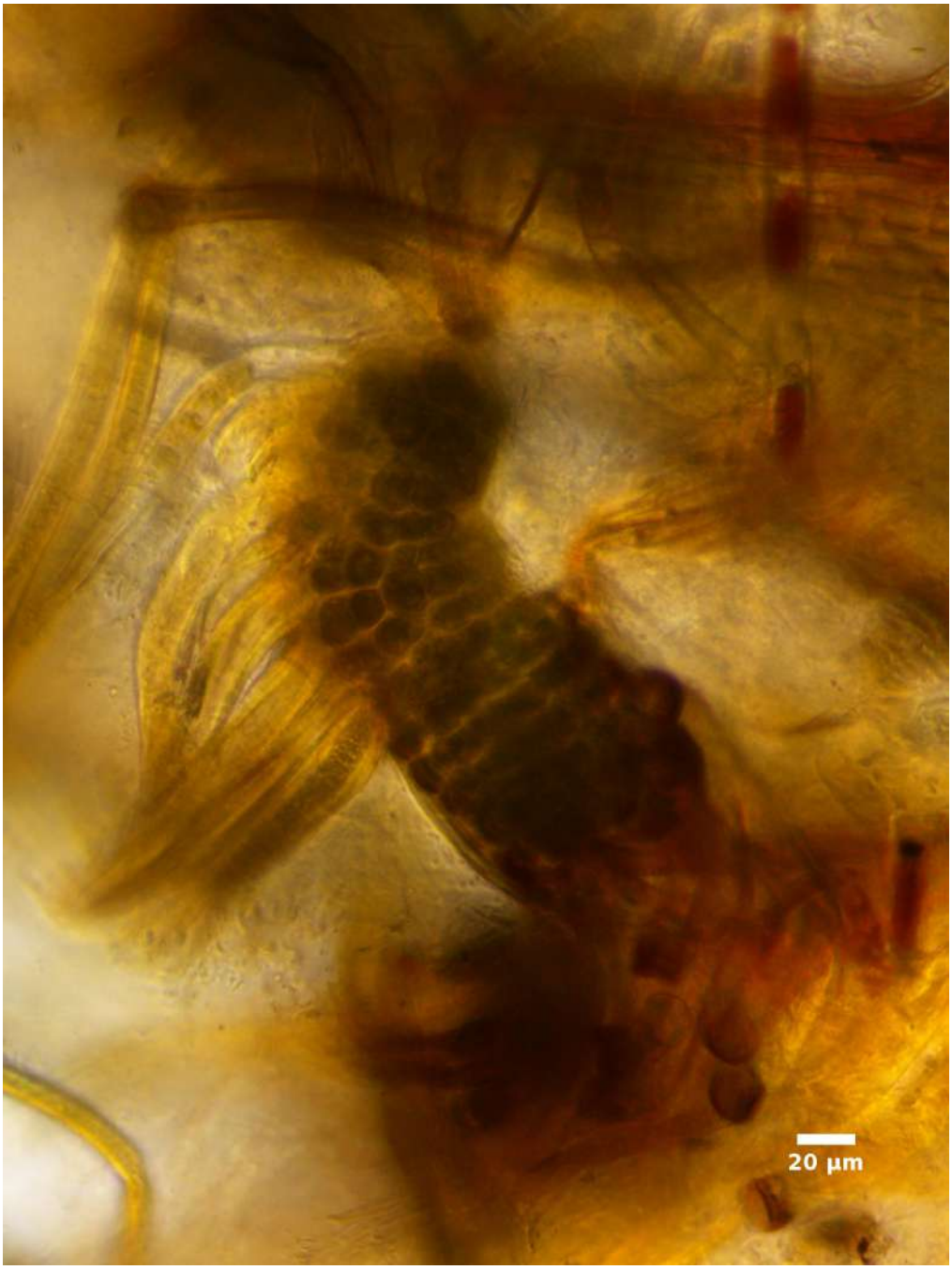


Figure 3.109: *Stigonema* sp.2 (200x DIC), spray zone in waterfall near Rainy Pass, North Cascades along Hwy 20, July 9, 2015.



Figure 3.110: *Stigonema* sp.2 (600x DIC), spray zone in waterfall near Rainy Pass, North Cascades along Hwy 20, July 9, 2015.



Figure 3.111: *Stigonema* sp.2 (600x DIC), spray zone in waterfall near Rainy Pass, North Cascades along Hwy 20, July 9, 2015.

3.14 *Tolypothrix* Kützing ex Bornet & Flahault

Local taxa
Tolypothrix lanata Wartmann ex Bornet & Flahault;
Tolypothrix penicillata Thuret ex Bornet & Flahault?;
Tolypothrix tenuis Kützing ex Bornet & Flahault?

Abundance
Infrequently collected in plankton samples; moderately common in shoreline samples and benthic mats.

Local measurements		Width	Length	Biovolume[†]
Tolypothrix lanata	min	9.6 μm	4.7 μm	409 μm^3
cells (cylinder)	med	11.8 μm	7.8 μm	833 μm^3
	max	15.4 μm	12.9 μm	2,400 μm^3
Tolypothrix lanata	min	9.1 μm	8.2 μm	399 μm^3
heterocysts (spheroid)	med	13.4 μm	12.1 μm	1,250 μm^3
	max	15.7 μm	17.6 μm	1,890 μm^3
Tolypothrix penicillata?	min	9.6 μm	4.4 μm	362 μm^3
cells (cylinder)	med	10.6 μm	5.3 μm	454 μm^3
	max	15.8 μm	8.2 μm	1,590 μm^3
Tolypothrix penicillata?	min	10.0 μm	10.4 μm	571 μm^3
heterocysts (spheroid)	med	11.7 μm	12.2 μm	935 μm^3
	max	13.5 μm	16.5 μm	1,470 μm^3
Tolypothrix tenuis?	min	6.4 μm	4.6 μm	185 μm^3
cells (cylinder)	med	7.2 μm	6.0 μm	217 μm^3
	max	7.7 μm	8.4 μm	391 μm^3
Tolypothrix tenuis?	min	7.6 μm	9.1 μm	403 μm^3
heterocysts (spheroid)[‡]	med	9.0 μm	12.2 μm	417 μm^3
	max	9.2 μm	13.8 μm	517 μm^3

[†]Calculated using original measurements, not summary values.
[‡]Biovolume estimates based on $<$5 cells.

Description

Tolypothrix trichomes are untapered, surrounded by a distinct mucilage layer, and form false branches where the new trichome originates from one or more basal heterocysts (Figures 3.112–3.119). The individual cells are cylindrical, blue-green or olive-green, and may be slightly constricted at the cross-walls. *Tolypothrix* resembles *Calothrix* and *Dichothrix* (Sections 3.4 and 3.7, pages 257 and 3.7), which can be distinguished by their distinctly tapered trichomes.

Tolypothrix lanata is characterized by highly branched, widely divergent trichomes (Figures 3.112–3.115). The individual cells can be shorter, longer, or equal to their width, and are unconstricted or very slightly constricted at the cross-walls. The basal heterocyst may be solitary or form a series of 2–4 oval or cylindrical heterocysts. The sheath is colorless or slightly yellowish, but not darkly colored. Most of the *Tolypothrix* samples collected in local lakes and their tributaries fit this general description. John et al. (2011) lists this species as a synonym for *Tolypothrix tenuis* Kützing. Komárek (2013) separates the two species based on trichome width (4–8 μm for *Tolypothrix tenuis*; 8–10 μm for *Tolypothrix lanata*). Both species are described as polymorphic and common in the littoral zone of soft-water lakes.

The specimens collected from Upper Bagley Lake have been tentatively identified as *Tolypothrix penicillata*, which is distinguished by branches that are nearly parallel to the main branch, and the thin, unstratified, yellow-brown sheath (Figures 3.116–3.117). This species is described as occurring in clear streams and mountain lakes in limestone regions (Komárek, 2013); the local specimens were collected in a clear, soft-water mountain lake, which only fits part of the description, so the species identification is uncertain.

Based on the trichome width distinction described above, the specimens in Figures 3.118–3.119 are listed as *Tolypothrix tenuis*, which resembles *Tolypothrix lanata*, but has narrower trichomes. The local specimens were collected in a slightly acidic mountain lake with extensive shoreline vegetation.



Figure 3.112: *Tolypothrix lanata* (200x DIC), Cranberry Lake, IWS water quality sampling site, Island County, August 25, 2009.



Figure 3.113: *Tolypothrix lanata* (200x DIC), Myrtle Lake, IWS water quality sampling site, Snohomish County, May 21, 2014.



Figure 3.114: *Tolypothrix lanata* (200x DIC), Lake Terrell, IWS water quality sampling site, Whatcom County, September 12, 2012.



Figure 3.115: *Tolypothrix lanata* (600x DIC), Lake Terrell, IWS water quality sampling site, Whatcom County, September 12, 2012.



Figure 3.116: *Tolypothrix penicillata*? (100x DIC), Upper Bagley Lake, IWS water quality sampling site, Whatcom County, September 16, 2010.

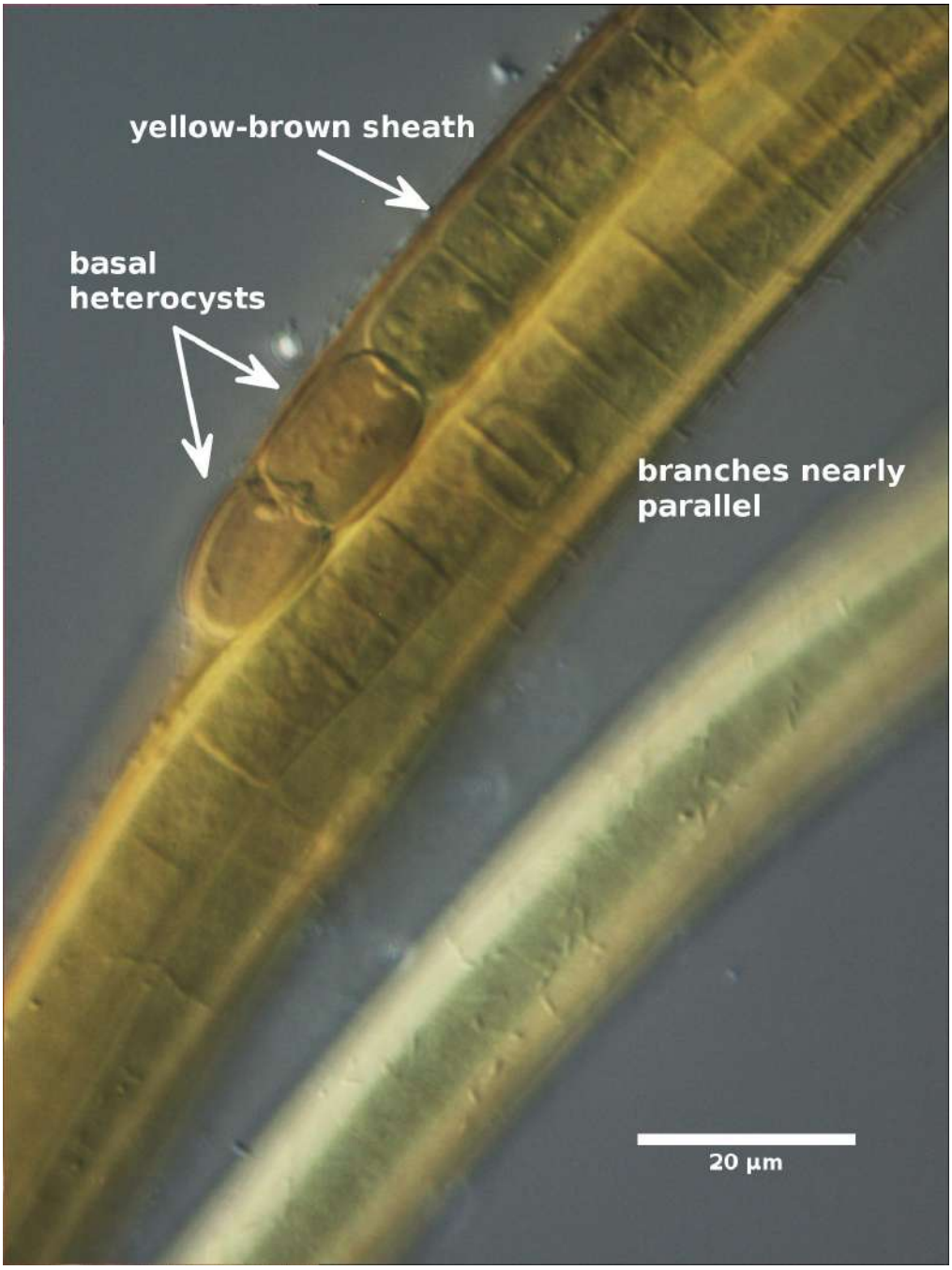


Figure 3.117: *Tolypothrix penicillata*? (600x DIC), Upper Bagley Lake, IWS water quality sampling site, Whatcom County, September 16, 2010.

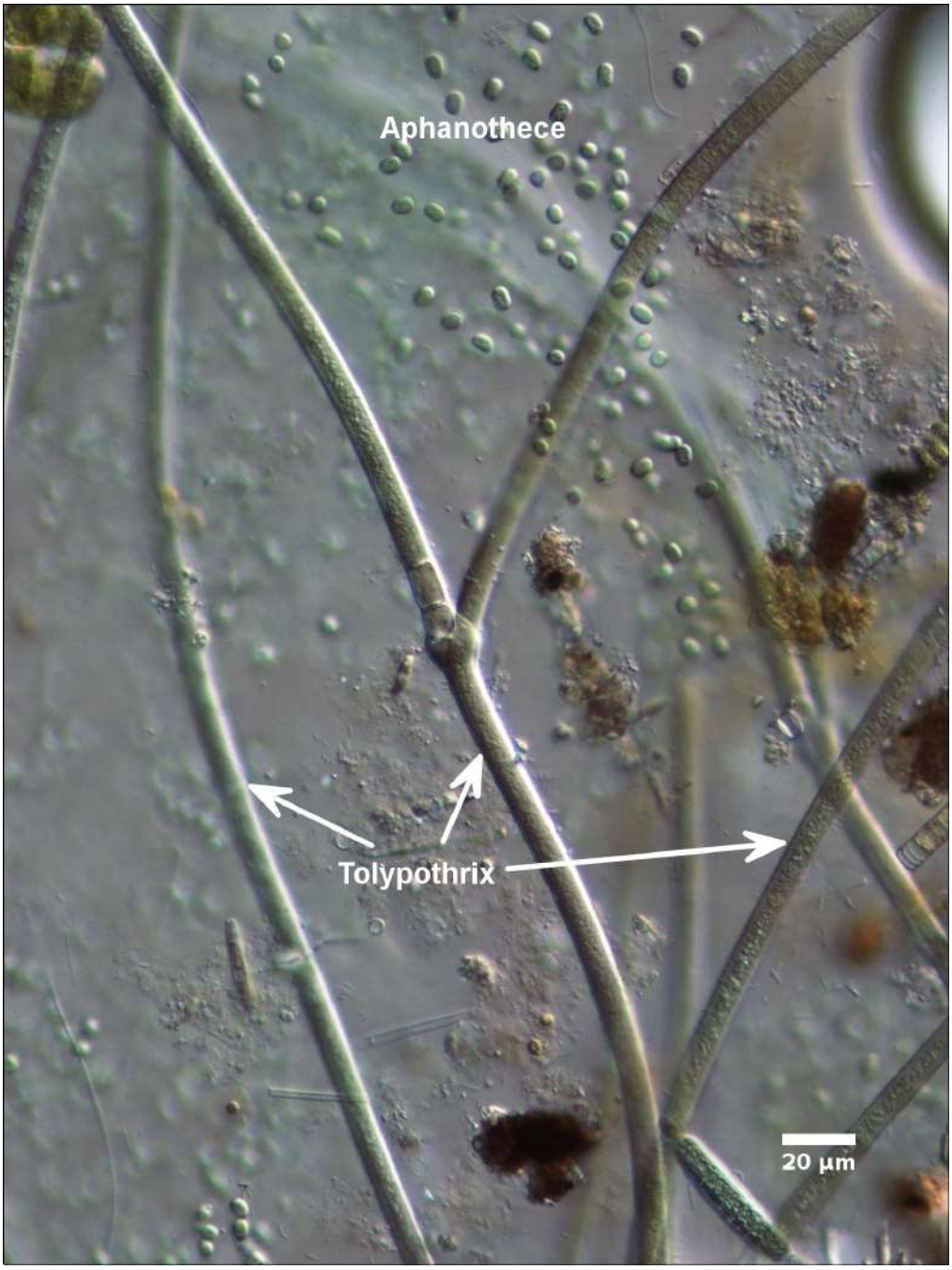


Figure 3.118: *Tolypothrix tenuis*? (200x DIC), Picture Lake, IWS water quality sampling site, Whatcom County, October 8, 2007.

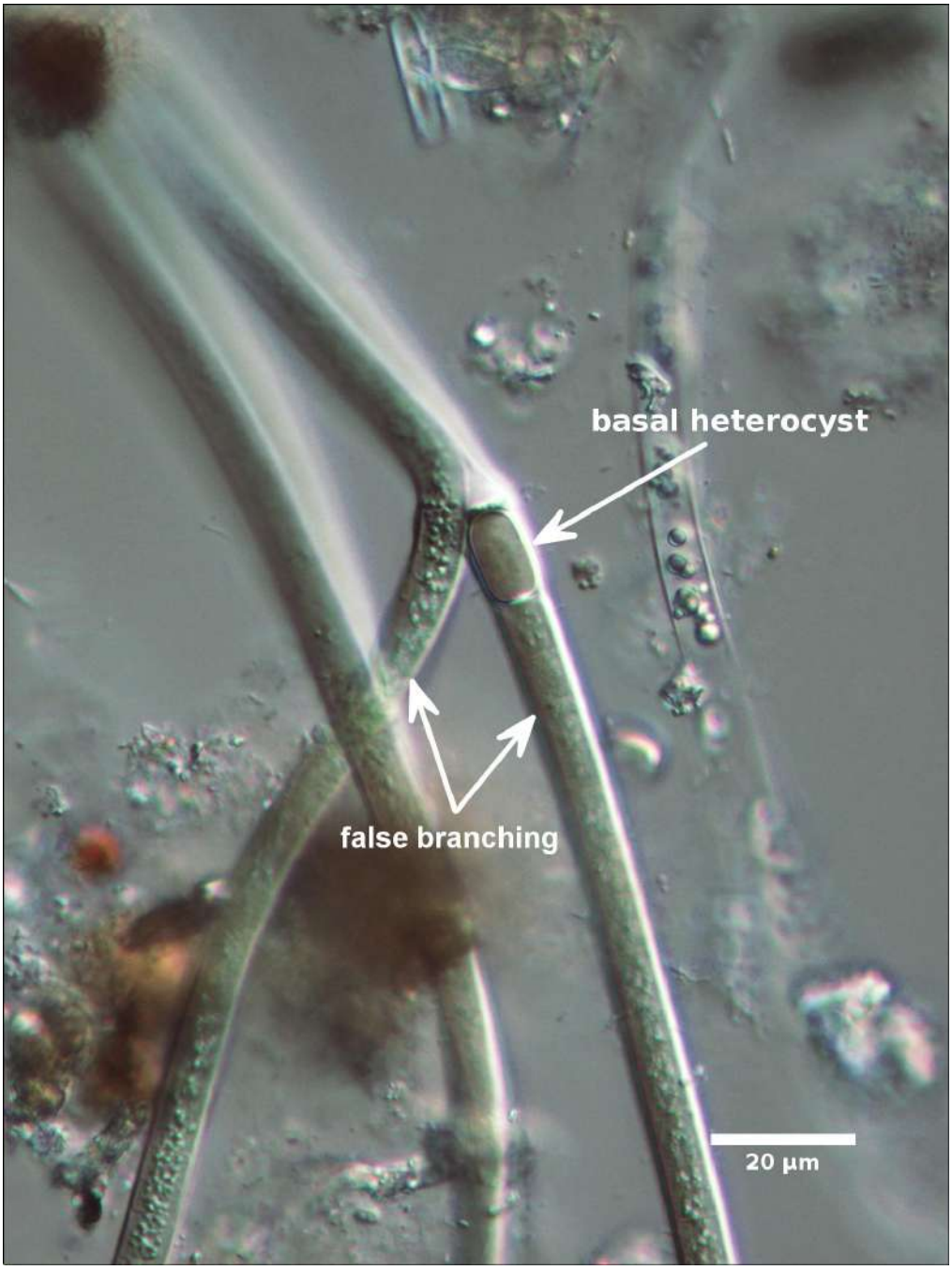


Figure 3.119: *Tolypothrix tenuis*? (400x DIC), Picture Lake, IWS water quality sampling site, Whatcom County, October 8, 2007.

Chapter 4

Filamentous Cyanobacteria Without Heterocysts

The key on page 354 will help you identify filamentous Cyanobacteria that do not form nitrogen-fixing heterocysts. For solitary and colonial Cyanobacteria, including taxa that produce pseudofilaments, go to Table 2.1 on page 24; for filamentous Cyanobacteria that form heterocysts, go to Table 3.1 on page 194. Remember that heterocyst formation occurs when inorganic nitrogen concentrations are low, so specimens collected during winter and early spring may not contain heterocysts, even if the trichome is capable of producing heterocysts.

Many of the filamentous Cyanobacteria that do not form heterocysts are very difficult to identify, even at the genus level. Most of the taxa form simple, unbranched trichomes of cylindrical cells, which can look very similar when you are trying to separate the taxa. The presence of a sheath or mucilage layer surrounding the trichome may help with some genus identifications, but the sheath may not be visible without staining, and environmental conditions can influence whether the trichome develops a sheath. Another important identification feature is the ratio of cell length to width, but this can be influenced by the rate of cell division. As with all Cyanobacteria, try to examine more than one specimen to determine whether you are trying to key representative cells and colonies.

Table 4.1: Key to Filamentous Cyanobacteria Without Heterocysts

A		Cells not actually joined end-to-end, but loosely arranged in pseudofilaments	Go to key on page 24
B		Cells joined end-to-end in ⇒very short, unbranched, untapered trichomes, often with ≤8 cells; cell walls constricted	
	B.1	Trichomes relatively wide (≥7 μm); often with 1–3 cells; cell walls slightly constricted	*Borzia* (page 368)
	B.2	Trichomes narrow (≤4 μm); consisting of more than 3 cells; cell walls deeply constricted; often associated with algal or zooplankton mucilage	*Pseudanabaena* (page 447)
C		Cells joined end-to-end in unbranched, but distinctly tapered trichomes	
	C.1	Trichomes narrow (≤4 μm), with hooked or bent apical cell; sheath not visible	*Geitlerinema* (page 372)
	C.2	Trichomes narrow (≤4 μm); enclosed in thick sheath	*Schizothrix* (page 462)
	C.3	Trichomes *usually* wider than 4 μm; sheath absent or indistinct (difficult group)	*Phormidium* and similar taxa, in part (page 414)
D		Cells joined end-to-end in unbranched, untapered (or very slightly tapered) trichomes containing >5 cells ⇒ This is a large group - check other key choices before proceeding!	Go to page 355

continued on next page

Table 4.1: Key to Filamentous Cyanobacteria Without Heterocysts, continued

D	Cells joined end-to-end in unbranched, untapered (or very slightly tapered) trichomes containing >5 cells	
D.1	Trichomes form loose or tightly coiled spirals	*Arthrospira* and *Spirulina* (page 356)
D.2	Trichomes straight or gently curved, but not coiled; cells cylindrical (width $\leq$ length)	
	D.2a Filament contains many parallel trichomes enclosed in common sheath	*Microcoleus* (page 390)
	D.2b Cells in trichome appear empty and colorless (highly vacuolated)	*Tychonema* (page 465)
	D.2c Cells do not appear empty; trichomes not in common sheath; sheath absent or indistinct (difficult group)	*Phormidium* and similar taxa, in part (page 414)
D.3	Trichomes straight or gently curved, but not coiled; cells short cylindrical or coin-like (width > length)	
	D.3a Trichomes relatively wide (usually $\geq$10–12 μm); without visible sheath	*Oscillatoria* (page 394)
	D.3b Trichomes relatively wide (usually $\geq$10–12 μm); with a clearly visible sheath	*Lyngbya* (page 378)
	D.3c Trichomes narrow ($\leq$10–12 μm); cross-walls slightly constricted; planktonic	*Planktothrix* (page 442)

4.1 *Arthrospira* Stitzenberger ex Gomont and *Spirulina* Turpin ex Gomont

Local taxa
Arthrospira jenneri Stitzenberger ex Gomont;
Arthrospira sp.1;
Spirulina major Kützing ex Gomont;
Spirulina sp.1

Abundance
Infrequently collected in plankton samples; moderately common in shoreline and benthic samples.

Local measurements		Width	Length	Biovolume[†]
Arthrospira jenneri	min	5.5 μm	2.4 μm	72.5 μm^3
cells (cylinder)	med	6.5 μm	4.9 μm	167 μm^3
	max	7.7 μm	7.7 μm	257 μm^3
Arthrospira jenneri	min	11.5 μm	18.6 μm	–
spirals	med	14.5 μm	21.4 μm	–
	max	15.3 μm	23.7 μm	–
Arthrospira sp.1?	min	3.0 μm	2.5 μm	20.1 μm^3
cells (cylinder)	med	3.3 μm	3.5 μm	30.7 μm^3
	max	3.6 μm	4.7 μm	42.7 μm^3
Arthrospira sp.1?	min	5.5 μm	34.4 μm	–
spirals	med	12.0 μm	48.8 μm	–
	max	13.5 μm	51.7 μm	–
Spirulina major	min	1.8 μm	(cell length not visible)	
cells (cylinder)	med	2.0 μm	(cell length not visible)	
	max	2.2 μm	(cell length not visible)	

continued on next page

Local measurements		Width	Length	Biovolume[†]
Spirulina major	min	3.8 μm	2.4 μm	–
spirals	med	4.1 μm	2.6 μm	–
	max	4.3 μm	2.7 μm	–
Spirulina sp.1?	min	2.8 μm	17.4 μm	107 μm^3
cells (cylinder)	med	2.9 μm	22.2 μm	145 μm^3
	max	3.1 μm	25.0 μm	189 μm^3
Spirulina sp.1?	min	9.9 μm	10.8 μm	–
spirals	med	10.8 μm	11.9 μm	–
	max	11.6 μm	12.7 μm	–

[†]Calculated using original measurements, not summary values.

Description

Arthrospira is difficult to separate from *Spirulina* based on strictly on features visible using light microscopy. Both genera are characterized by motile, spiraling, unbranched trichomes that lack sheaths, heterocysts, or akinetes (Figures 4.1–4.9). The individual cells are cylindrical, and may be shorter, longer, or equal in length and width, but not coin-like. The cell cross-walls may be very difficult to see without staining.

Arthrospira trichomes are usually slightly wider than *Spirulina*, and typically wavy or loosely spiraled. The cells are slightly shorter than wide, or about equal in width and length, and the cell cross-walls should be faint, but visible without staining. *Spirulina* trichomes are often more tightly coiled (not always), and comprised of long, cylindrical cells (width $<$ length) with indistinct cross-walls.

Arthrospira jenneri trichomes are loosely spiraled and bright blue-green (Figures 4.1–4.3). The individual cells are cylindrical, wider than long, unconstricted at the cross-walls, and do not taper near the end of the trichome. The cell contents is slightly granular. The species is usually associated with macrophytes or other substrates, so the trichomes are often tangled in plant matter.

The specimen from Sunset Pond is tentatively identified as a species of *Arthrospira* (Figure 4.4). The trichomes are very loosely spiraled, consisting of small, barrel-shaped cells that are approximately equal in length and width. The cell content is slightly granular, and the cell cross-walls are visible.

Spirulina major (Figures 4.5–4.7) is characterized by tightly coiled trichomes of small, cylindrical, blue-gray cells with a homogeneous cell content. The individual cells are difficult to distinguish because the cross-walls are indistinct.

The specimens from Beaver Pond Lake are tentatively identified as a species of *Spirulina*. The trichomes are loosely coiled, brownish, and comprised of very long, narrow, cylindrical cells (Figures 4.8–4.9). The individual cells appear to form one full spiral in the trichome.

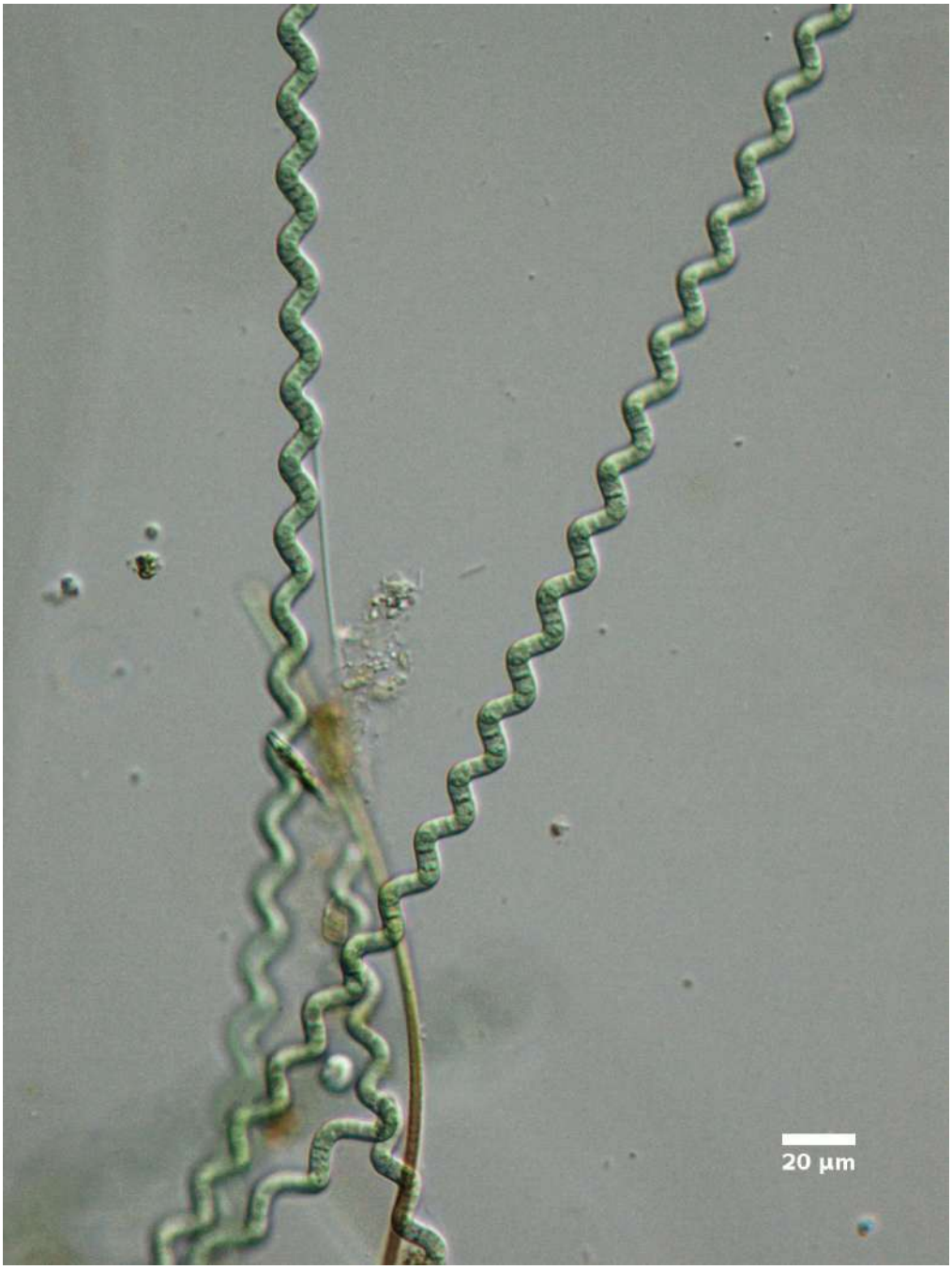


Figure 4.1: *Arthrospira jenneri* (200x DIC), Tennant Lake, IWS water quality sampling site, Whatcom County, April 26, 2013.



Figure 4.2: *Arthrospira jenneri* (100x DIC), Sunset Pond, IWS water quality sampling site, Whatcom County, August 19, 2009.

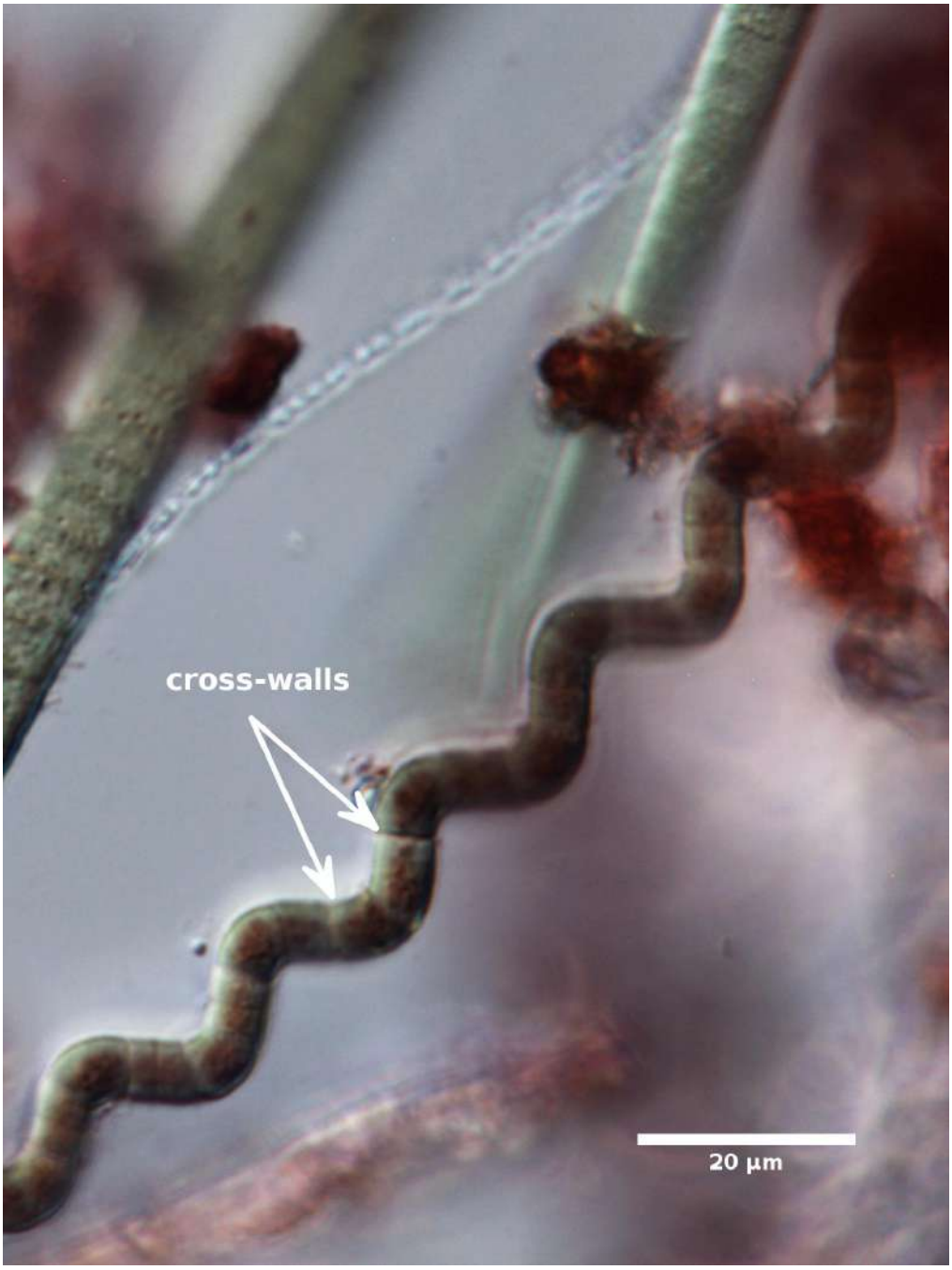


Figure 4.3: *Arthrospira jenneri* cell cross-walls stained with neutral red (600x DIC), Tennant Lake, IWS water quality sampling site, Whatcom County, April 17, 2013.



Figure 4.4: *Arthrospira* sp.1? (600x DIC), Sunset Pond, IWS water quality sampling site, Whatcom County, August 19, 2009.



Figure 4.5: *Spirulina major* (1000x DIC), Waterfront Park, Bainbridge Island, WA, July 3, 2009. Photo provided by Karl Bruun, Nostoca Algae Laboratory, Bainbridge Island, WA.



Figure 4.6: *Spirulina major* (400x DIC) Little Twin Lake (Winthrop area), eastern Washington, June 19, 2014.



Figure 4.7: *Spirulina major* (600x DIC) Little Twin Lake (Winthrop area), eastern Washington, June 19, 2014.



Figure 4.8: *Spirulina* sp.1? (200x DIC), Beaver Pond Lake, IWS water quality sampling site, Whatcom County, October 24, 2011.



Figure 4.9: *Spirulina* sp.1? (600x DIC), Beaver Pond Lake, IWS water quality sampling site, Whatcom County, October 24, 2011.

4.2 *Borzia* Cohn ex Gomont

Local taxa
Borzia trilocularis Cohn ex Gomont;

Abundance
Infrequently collected, but easily overlooked.

Local measurements		Width	Length	Biovolume[†]
Borzia trilocularis	min	7.3 μm	3.0 μm	140 μm^3
cells (cylinder)	med	7.7 μm	4.8 μm	225 μm^3
	max	7.9 μm	6.2 μm	304 μm^3
Borzia sp.1?	min	9.9 μm	2.4 μm	196 μm^3
heterocysts (spheroid)	med	10.4 μm	3.5 μm	298 μm^3
	max	11.4 μm	5.2 μm	531 μm^3

[†]Calculated using original measurements, not summary values.

Description
Borzia trichomes are small and inconspicuous, consisting of just a few cells (Figures 4.10–4.12). The trichomes are unbranched, lack heterocysts and akinetes, and usually lack a sheath or mucilage layer. The individual cells have constricted cross-walls, are shorter than wide, and have cylindrical interior cells and hemispherical apical cells. *Borzia trilocularis* trichomes usually contain no more than 3–4 cells. The cells are olive-green or orangish-green and have conspicuous cytoplasmic granules. The local specimens were actively motile (twitching/creeping). *Borzia* filaments are easily mistaken for hormogonia,[16] but can be distinguished by the regular, 3-cell filaments that divide to form new 3-cell filaments (Figure 4.11).

[16]Hormogonia are short, fragmented filaments that are formed by some filamentous Cyanobacteria as a means of asexual reproduction.



Figure 4.10: *Borzia trilocularis* (600x DIC), Lake Everett, IWS water quality sampling site, Skagit County, August 5, 2015.



Figure 4.11: *Borzia trilocularis* (600x DIC), Lake Everett, IWS water quality sampling site, Skagit County, August 5, 2015.



Figure 4.12: *Borzia trilocularis* (600x DIC), Lake Everett, IWS water quality sampling site, Skagit County, August 5, 2015.

4.3 *Geitlerinema* (Anagnostidis & Komárek) Anagnostidis

Local taxa

Geitlerinema splendidum (Greville ex Gomont) Anagnostidis;
Geitlerinema sp.1

Abundance

Infrequently collected in plankton samples; moderately common in shoreline samples and benthic mats.

Local measurements		Width	Length	Biovolume[†]
Geitlerinema splendidum	min	2.1 μm	4.6 μm	17.3 μm^3
cells (cylinder)	med	2.8 μm	6.0 μm	36.9 μm^3
	max	3.2 μm	8.2 μm	65.9 μm^3
Geitlerinema sp.1	min	2.8 μm	4.9 μm	33.7 μm^3
cells (cylinder)	med	3.0 μm	6.9 μm	45.7 μm^3
	max	3.3 μm	9.0 μm	74.4 μm^3

[†]Calculated using original measurements, not summary values.

Description

Geitlerinema trichomes are very narrow ($\leq$4 μm) and actively motile, containing cylindrical cells that are consistently longer than wide (Figures 4.13–4.16). The trichomes are usually tapered, with a hooked or bent apex. Many of the species are from thermal springs. *Geitlerinema* is very similar to *Phormidium* (Section 4.7, page 414). Both genera have simple, unbranched trichomes that lack heterocysts and akinetes and are comprised of cylindrical cells that are usually longer than wide or about equal in length and width. The cylindrical cells help distinguish both genera from the short, coin-like cells found in *Lyngbya* (Section 4.4, page 378) and *Oscillatoria* (Section 4.6, page 394).

Geitlerinema splendidum is characterized by straight or slightly curved trichomes with no apparent sheath (Figures 4.13–4.15). The cells are consistently longer than their width, and the last few cells in the trichome are tapered, ending in a hooked, knobbed (capitate) apical cell. The individual trichomes are highly

motile. This species is found in nonthermal, freshwater locations, often mixed in with other aquatic plants (Komárek and Anagnostidis, 2005).

The trichomes in Figure 4.16 fit the morphological description for *Geitlerinema splendidum*, but were collected from the muddy banks surrounding a sulfur hot springs. Komarek and Anagnostidis (2005) indicate that thermal springs specimens that resemble *Geitlerinema splendidum* should be evaluated using genetic analysis and are probably a different species.



Figure 4.13: *Geitlerinema splendidum* (600x DIC), Lake Armstrong, Snohomish County, July 23, 2015.



Figure 4.14: *Geitlerinema splendidum* (600x DIC), small pond near Lynwood, Snohomish County, May 1, 2015.



Figure 4.15: *Geitlerinema splendidum* (200x DIC), small pond near Lynwood, Snohomish County, May 1, 2015.

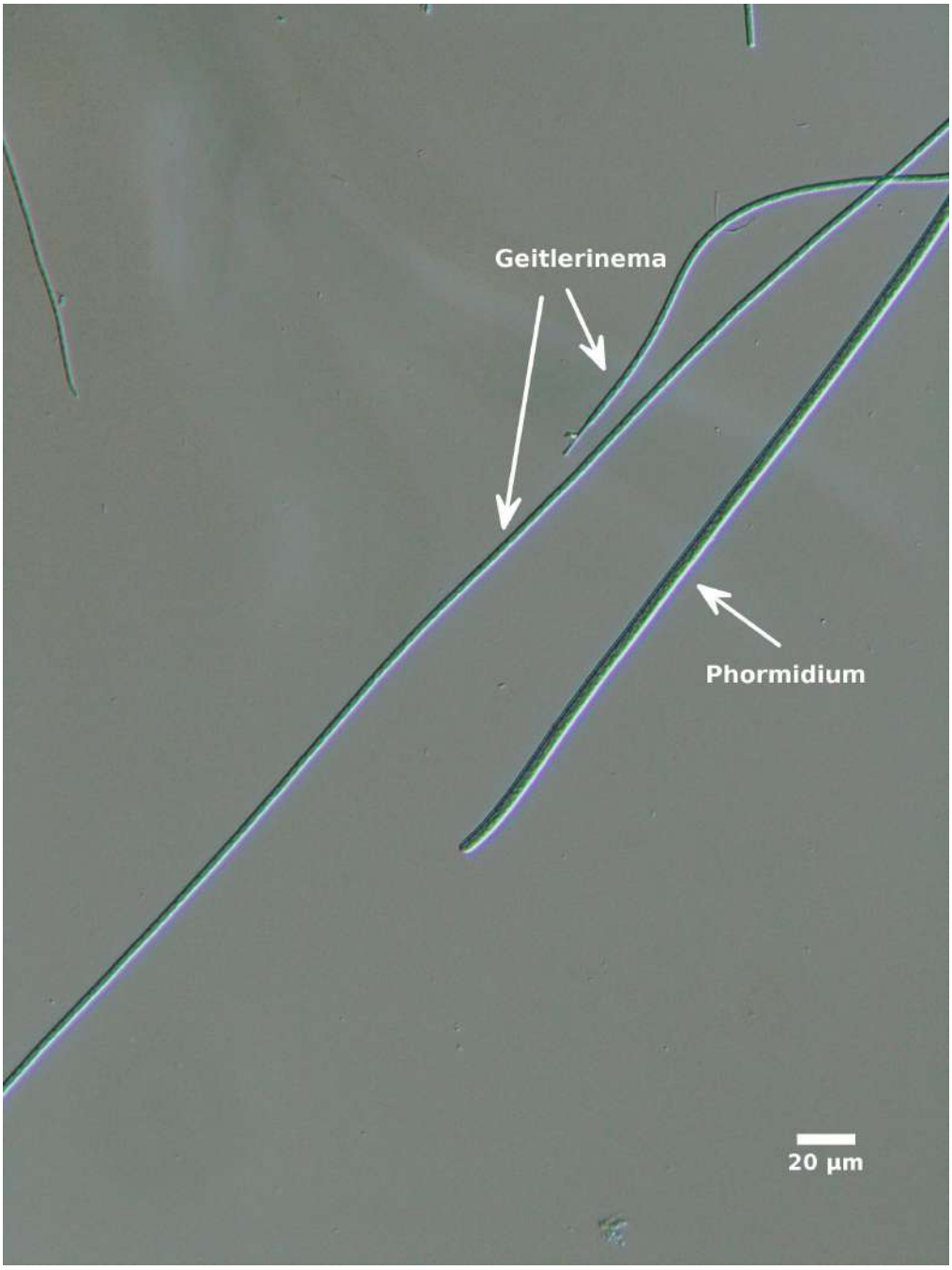


Figure 4.16: *Geitlerinema* sp.1 (200x DIC), Mt. Baker hot springs, Whatcom County, May 5, 2014.

4.4 *Lyngbya* Agardh ex Gomont

Local taxa

Lyngbya birgei G. M. Smith
(=*Limnoraphis birgei* [G. M. Smith] Komárek, Zapomelová, Smarda, Kopecky, Rejmánková, Woodhouse, Neilan & Komárková);
Lyngbya hieronymusii Lemmermann?
(=*Limnoraphis hieronymusii* [Lemmermann] Komárek, Zapomelová, Smarda, Kopecky, Rejmánková, Woodhouse, Neilan & Komárková);
Lyngbya nigra Agardh ex Gomont?;
Lyngbya sp.1

Abundance

Moderately common; may be present in large numbers but rarely forms blooms; occasionally forms dense benthic mats.

Local measurements		Width	Length	Biovolume[†]
Lyngbya birgei	min	18.3 μm	1.8 μm	571 μm^3
cells (cylinder)	med	21.1 μm	2.7 μm	855 μm^3
	max	23.3 μm	3.6 μm	1,280 μm^3
Lyngbya hieronymusii?	min	11.0 μm	1.8 μm	214 μm^3
cells (cylinder)	med	12.4 μm	3.1 μm	333 μm^3
	max	13.3 μm	4.2 μm	566 μm^3
Lyngbya nigra?	min	6.6 μm	2.4 μm	103 μm^3
cells (cylinder)	med	7.0 μm	2.8 μm	111 μm^3
	max	7.4 μm	3.2 μm	116 μm^3
Lyngbya sp.1	min	15.3 μm	2.9 μm	533 μm^3
cells (cylinder)	med	17.2 μm	4.2 μm	953 μm^3
	max	20.8 μm	6.9 μm	2,240 μm^3

[†]Calculated using original measurements, not summary values.

Description

Lyngbya trichomes are simple and unbranched, with short, cylindrical or coin-like cells (width > length) enclosed in a firm sheath (Figures 4.17–4.26). The trichomes lack akinetes and heterocysts. The presence of the sheath distinguishes *Lyngbya* from *Oscillatoria* (Section 4.6, page 394) and *Planktothrix* (Section 4.8, page 442), which usually lack a sheath. *Lyngbya* cells are shorter than wide, and most species are wider than 6 μm, which distinguished *Lyngbya* from *Geitlerinema* (Section 4.3, page 372) and *Phormidium* (Section 4.7, page 414).

Lyngbya birgei trichomes are solitary, planktonic, and surrounded by a firm, unstratified sheath that may extend beyond the end of the trichome (Figures 4.17–4.20). The individual cells are coin-like, much wider than their length, with smooth, unconstricted cross-walls. Although the filaments may not appear especially active, the entire trichome can creep out of its sheath, especially when stressed. As a result, the sheath may be visible at only one end of the trichome, or may be entirely missing. Old samples may contain sheathless trichomes that resemble *Oscillatoria* and abandoned sheaths (Figure 4.21). This species is not particularly common, but is found in most plankton samples from Pass Lake.

The *Lyngbya hieronymusii*? specimens are characterized by narrow trichomes (compared to *Lyngbya birgei*), with slightly granular cells that have unconstricted, slightly granular cross-walls (Figures 4.22–4.23). The trichome is surrounded by a clear, rough, striated sheath. Like *Lyngbya birgei*, *Lyngbya hieronymusii* is a planktonic species (Komárek and Anagnostidis, 2005); the local specimens were collected in near-shore samples from moderately productive low elevation lakes.

The *Lyngbya nigra*? specimens have relatively narrow, cylindrical cells that are shorter than wide, but not coin-like, slightly granular, with smooth, unconstricted cross-walls (Figure 4.24). The trichomes are surrounded by a thin, clear, unstriated sheath, and are slightly narrowed near the apex, ending in a rounded, conical calyptra. This species is associated with flowing water (Komárek and Anagnostidis, 2005); the local specimens were collected from the wetted surface of a small waterfall.

Lyngbya sp.1 trichomes are nearly as wide as *Lyngbya birgei*, but the cells have distinctive raised, granular cross-walls (Figures 4.25–4.26). The trichome is surrounded by a smooth, clear sheath that appears to be slightly layered. All of the specimens were collected from benthic habitats or in association with shoreline vegetation, suggesting that this species is not planktonic.

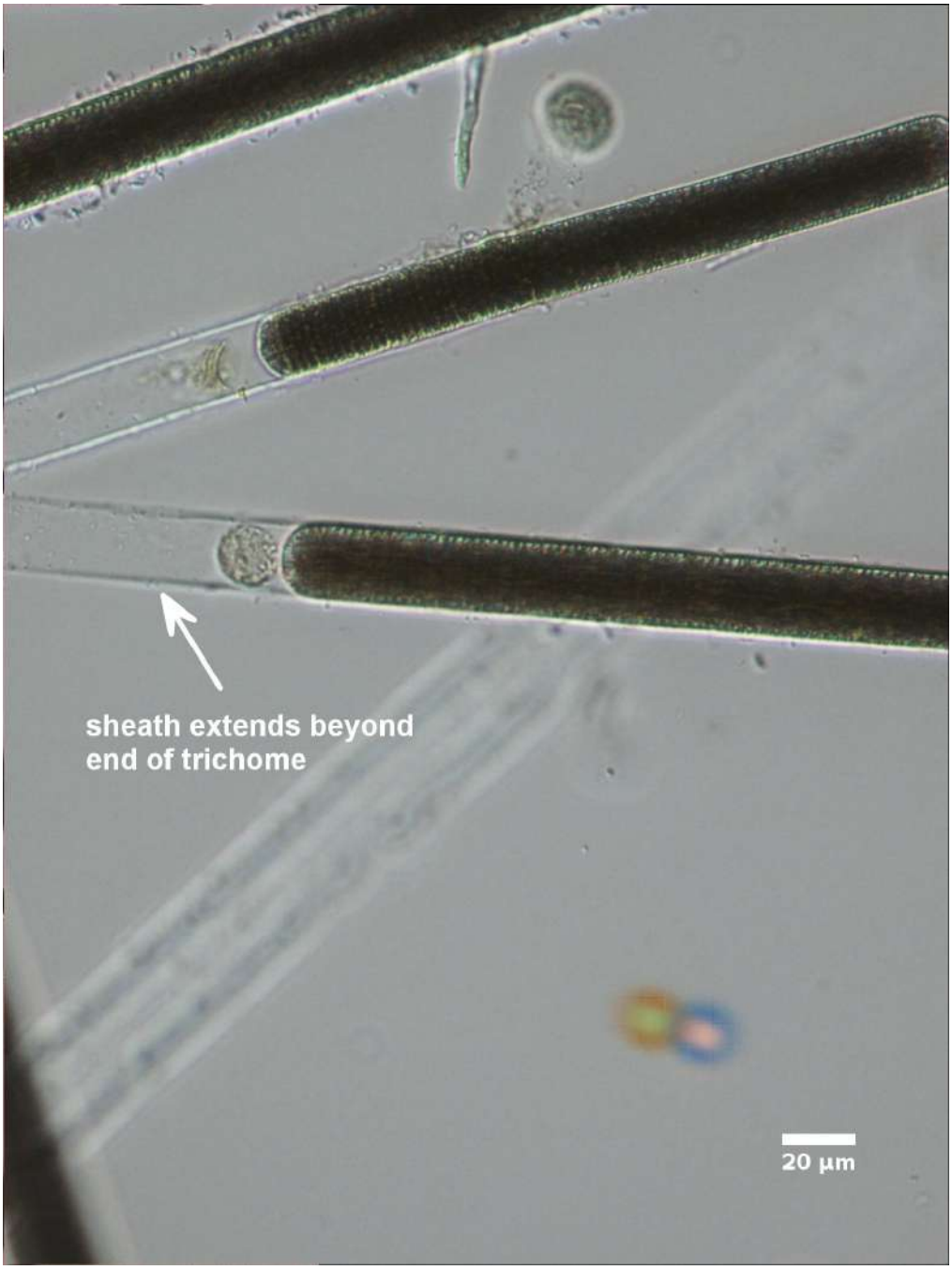


Figure 4.17: *Lyngbya birgei* (200x DIC), Lone Lake, IWS water quality sampling site, Island County, August 28, 2008.



Figure 4.18: *Lyngbya birgei* bloom (100x DIC), Pass Lake, IWS water quality sampling site, Skagit County, July 8, 2013.

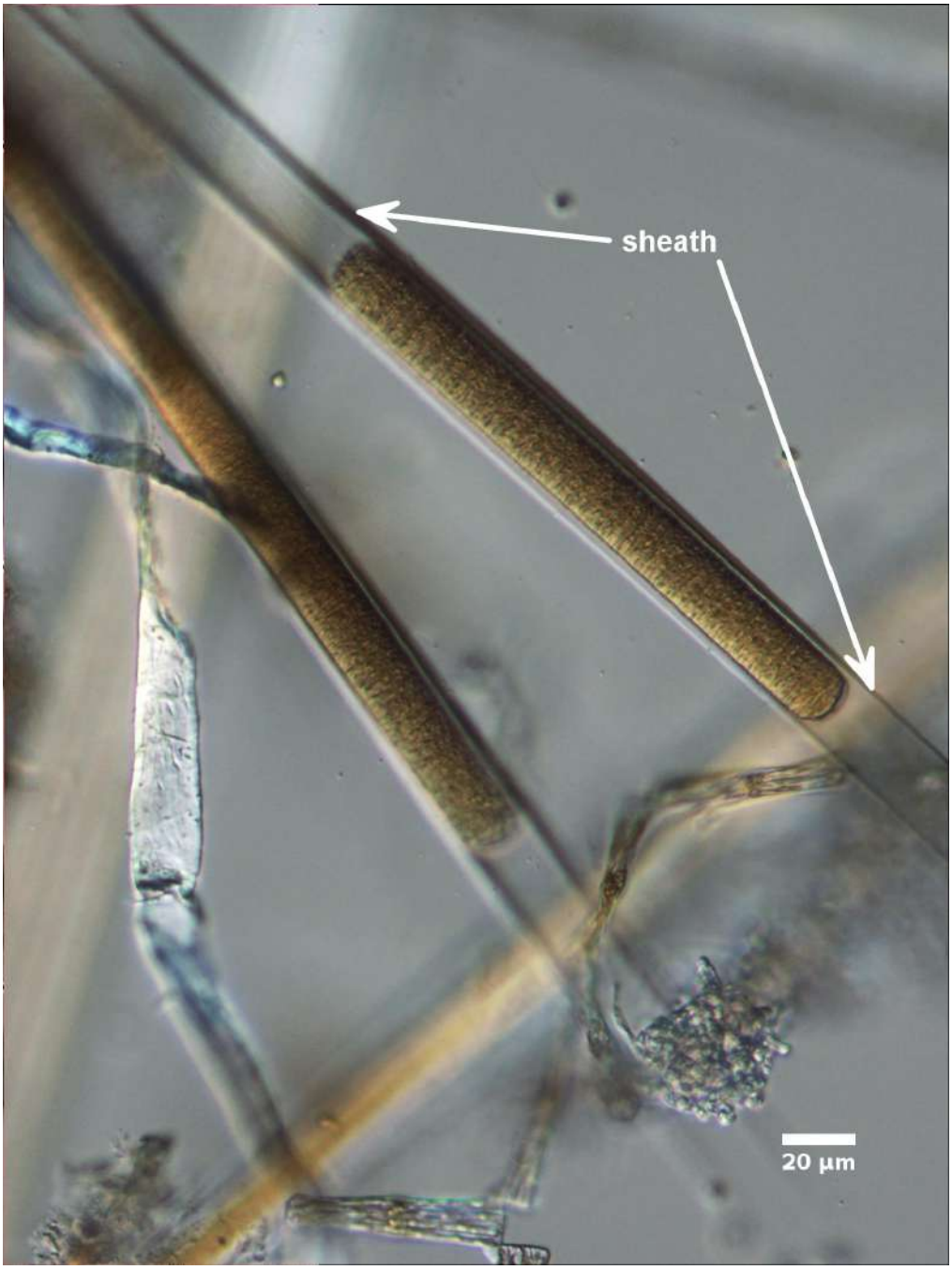


Figure 4.19: *Lyngbya birgei* in Lugol's iodine solution (200x DIC), Pass Lake, IWS water quality sampling site, Skagit County, September 3, 2009.

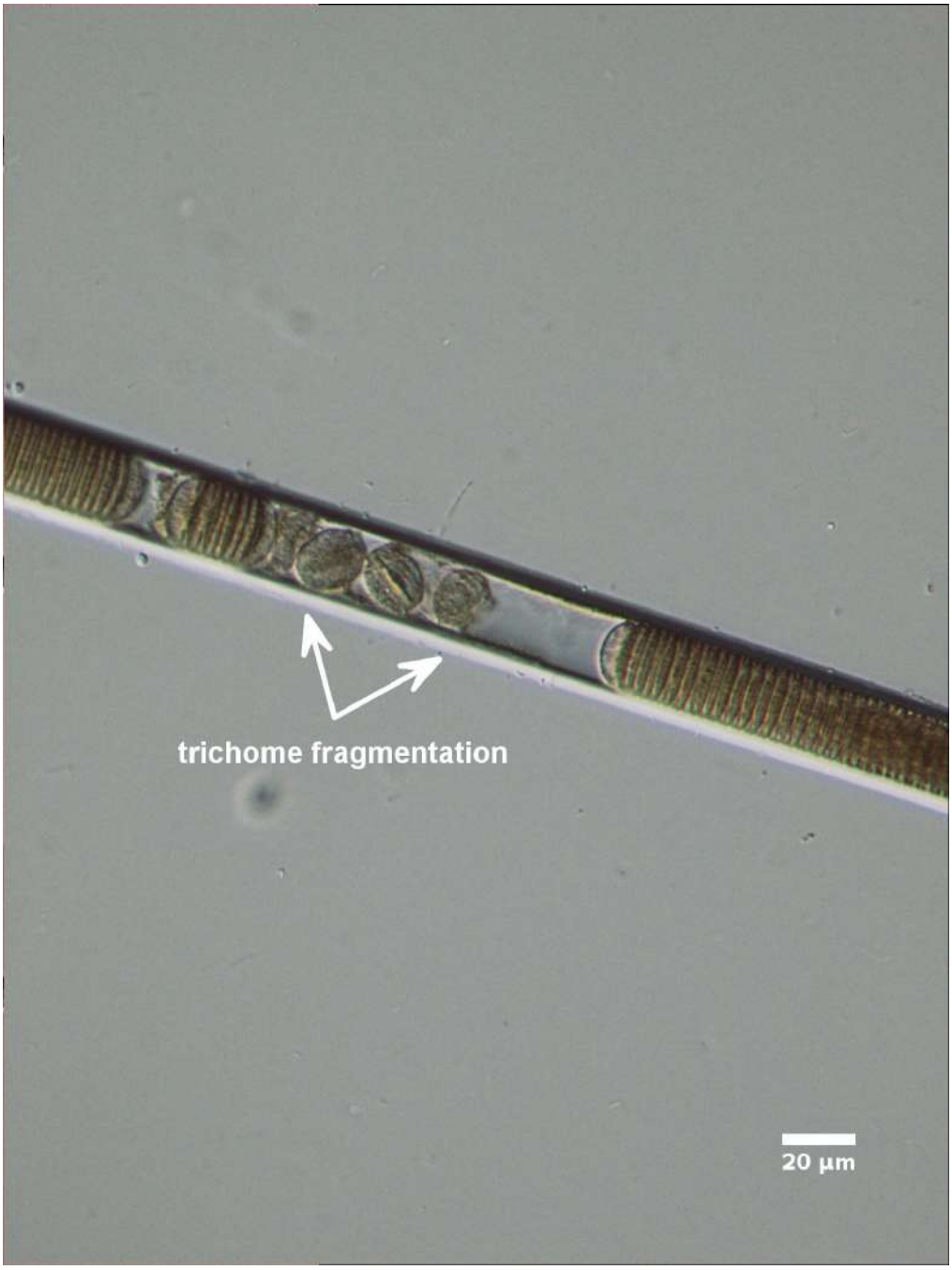


Figure 4.20: *Lyngbya birgei* trichome fragmentation (200x DIC), Pass Lake, IWS water quality sampling site, Skagit County, July 9, 2010.



Figure 4.21: *Lyngbya birgei* empty sheath (200x DIC), Lone Lake, IWS water quality sampling site, Island County, September 30, 2009.

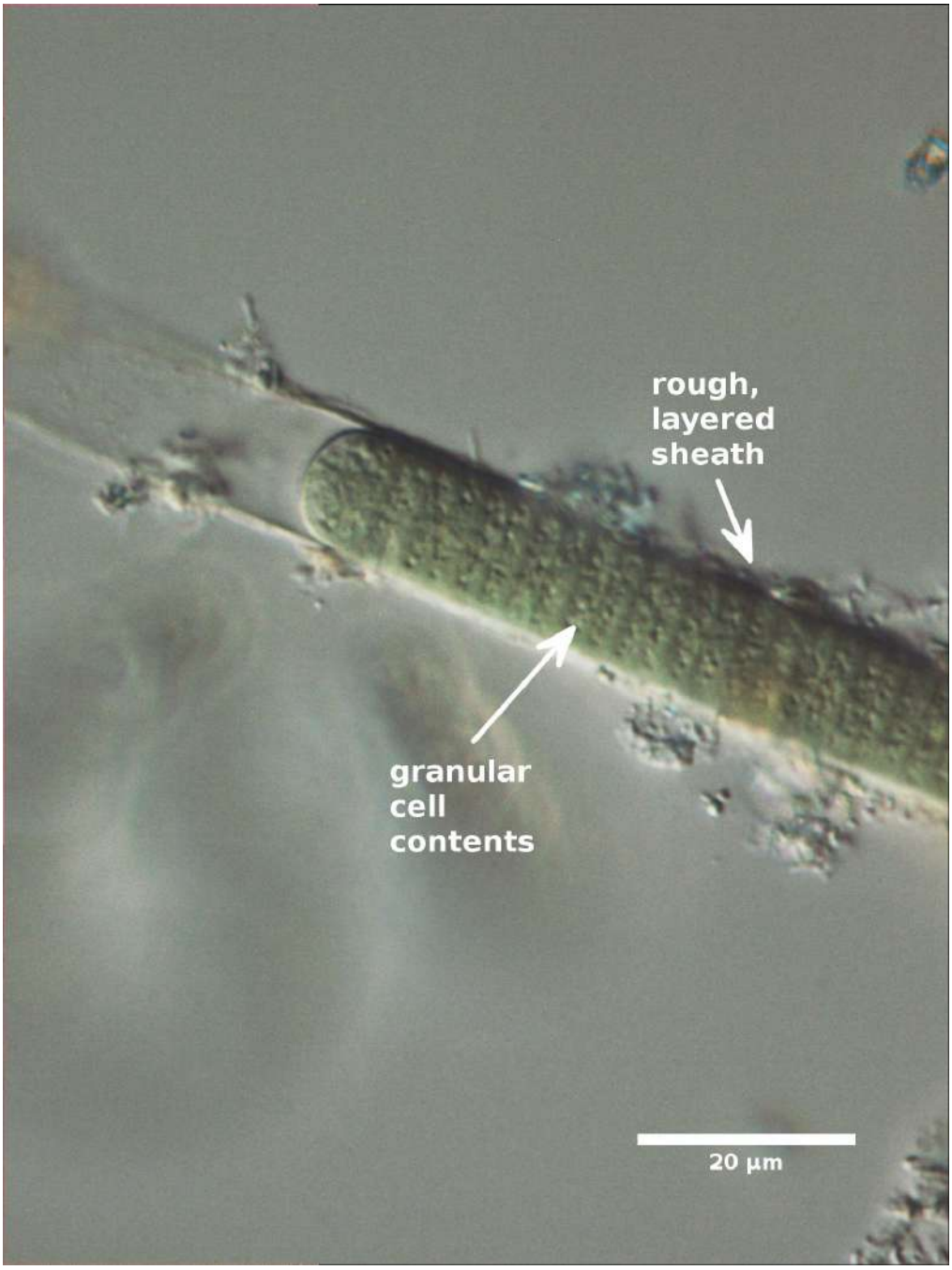


Figure 4.22: *Lyngbya hieronymusii*? (600x DIC), Heart Lake, IWS water quality sampling site, Skagit County, July 9, 2010.

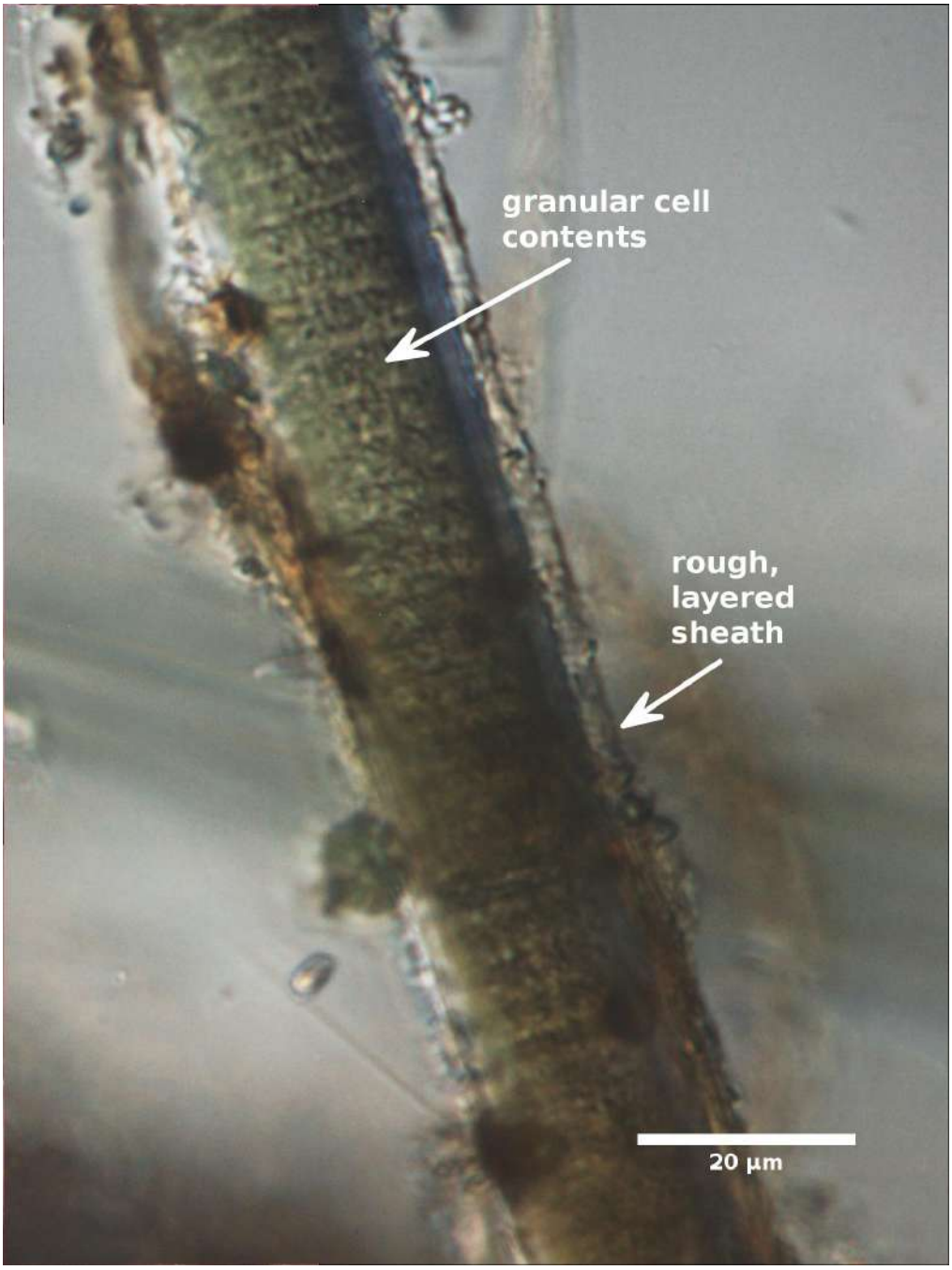


Figure 4.23: *Lyngbya hieronymusii*? (600x DIC), Heart Lake, IWS water quality sampling site, Skagit County, July 9, 2010.



Figure 4.24: *Lyngbya nigra*? (200x DIC), waterfall on Fragrance Lake trail, Whatcom County, April 12, 2014.



Figure 4.25: *Lyngbya* sp.1 (600x DIC), Tennant Lake, IWS water quality sampling site, Whatcom County, April 17, 2013.

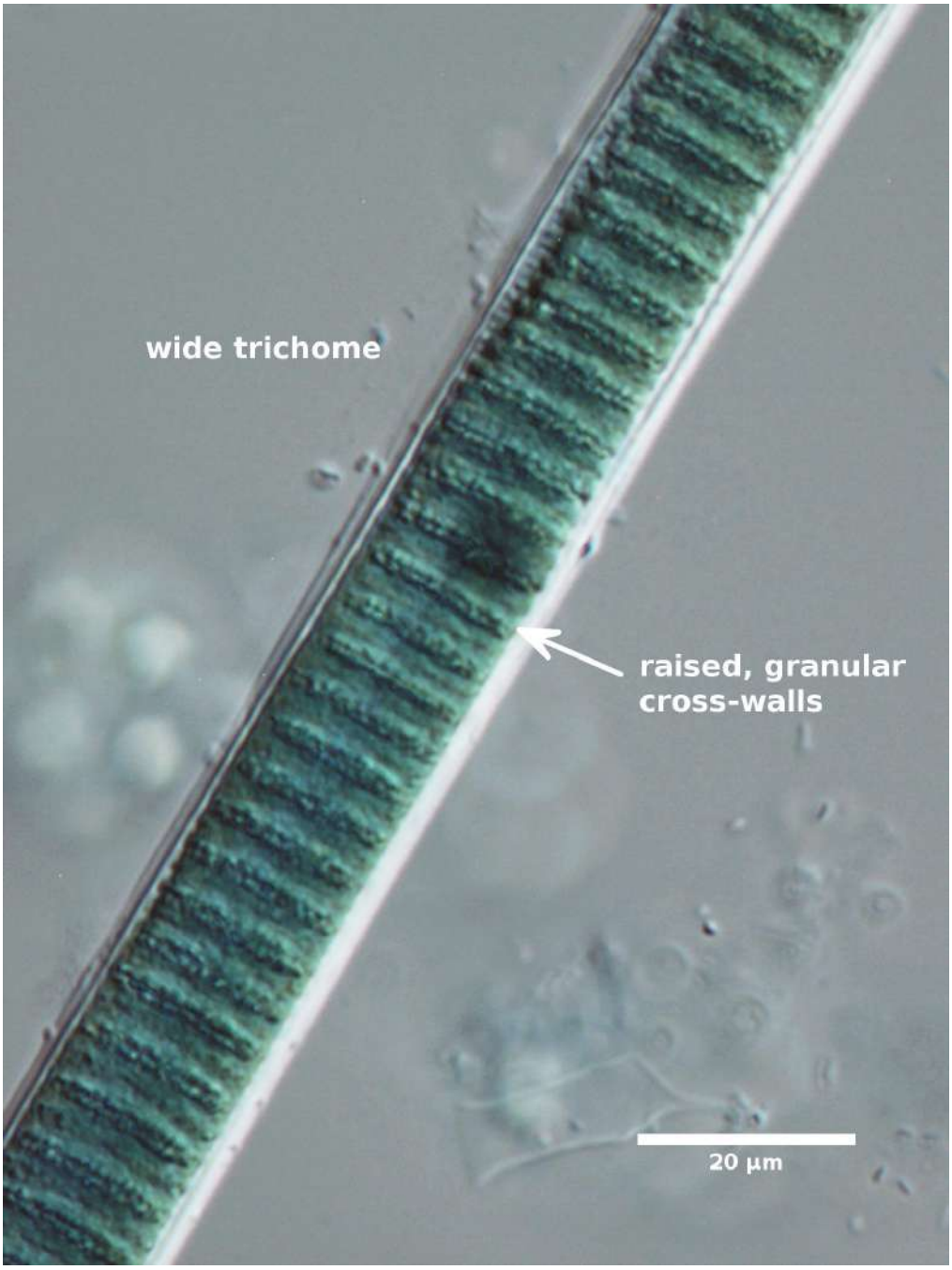


Figure 4.26: *Lyngbya* sp.1 stained with methylene blue (600x DIC), Picture Lake, IWS water quality sampling site, Whatcom County, August 5, 2013.

4.5 *Microcoleus* Desmaziéres ex Gomont

Local taxon
Microcoleus lacustris Farlow ex Gomont

Abundance
Infrequently collected in plankton samples; occasionally collected in shoreline samples and benthic mats.

Local measurements		Width	Length	Biovolume[†]
Microcoleus lacustris	min	2.9 μm	6.2 μm	49.8 μm^3
cells (cylinder)	med	3.2 μm	7.3 μm	60.3 μm^3
	max	4.1 μm	8.8 μm	97.7 μm^3

[†]Calculated using original measurements, not summary values.

Description
Microcoleus forms bundles of parallel, unbranched trichomes enclosed in a clear, wide, mucilaginous sheath (Figures 4.27–4.29). The sheath is often wrinkled, with scalloped edges. The individual cells are cylindrical (width $\leq$ length) except for the apical cell, which is bluntly conical.

Microcoleus lacustris has relatively narrow, cylindrical cells, with a bluntly conical apical cell. The cells have a granular appearance and are constricted at the cross-walls. The trichomes are very closely bundled inside the clear, wrinkled mucilage layer, forming a long, rope-like filament. The trichomes are highly motile in live samples, and individual trichomes can be observed gliding past each other inside the mucilage layer.

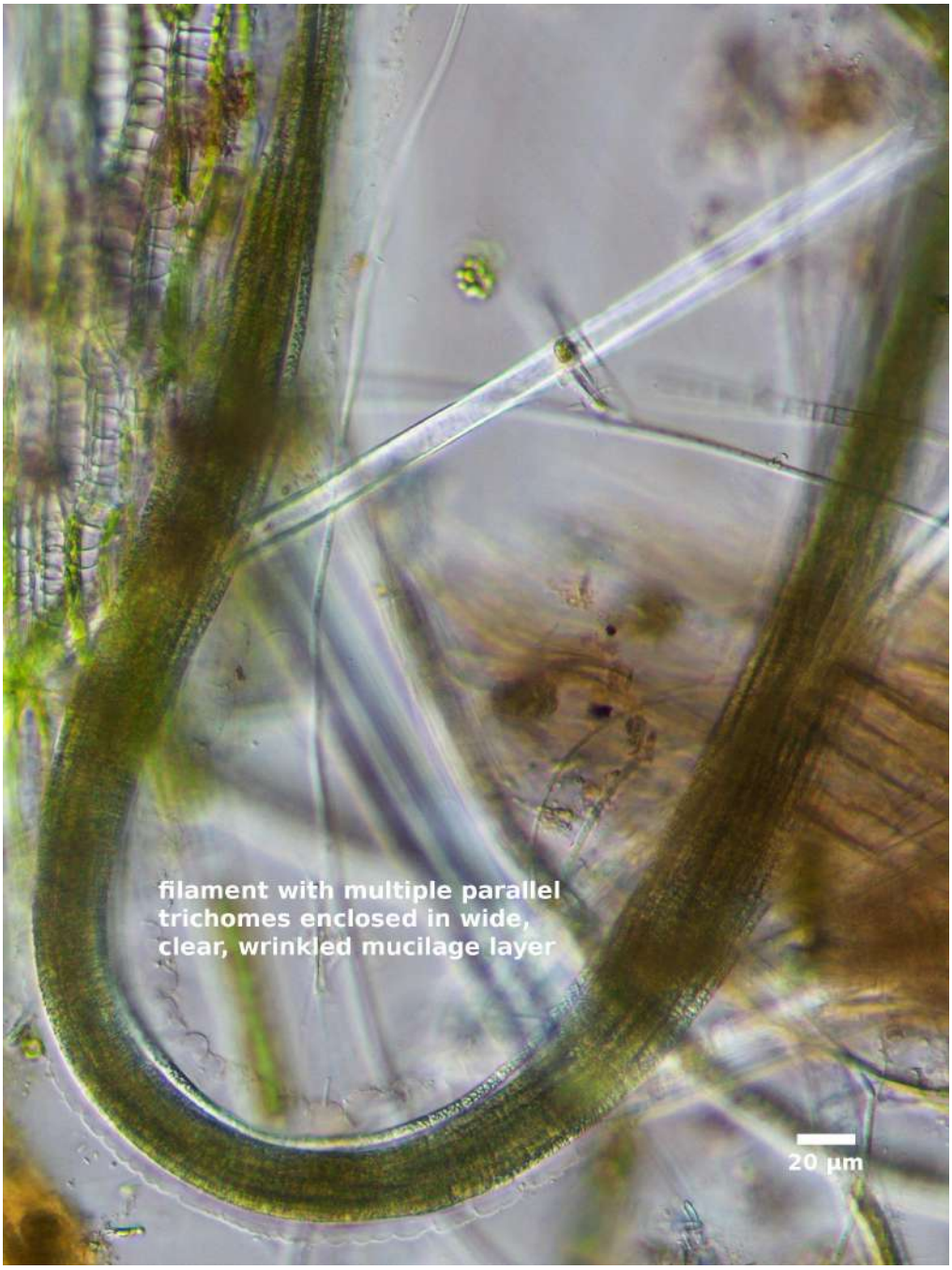


Figure 4.27: *Microcoleus lacustris* (200x DIC), Bear Lake, IWS water quality sampling site, Snohomish County, August 28, 2014.



Figure 4.28: *Microcoleus lacustris* (400x DIC), Bear Lake, IWS water quality sampling site, Snohomish County, August 28, 2014.

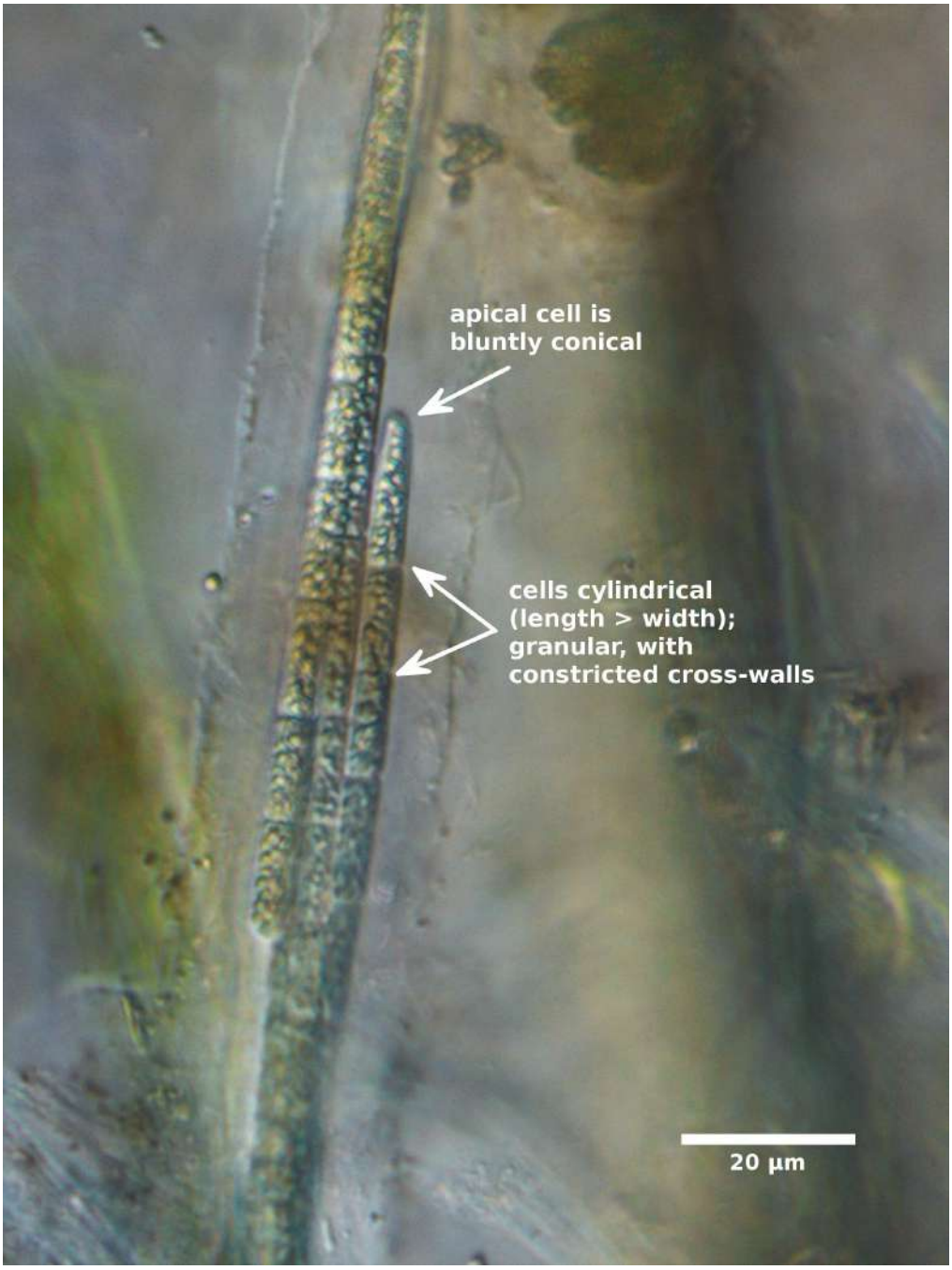


Figure 4.29: *Microcoleus lacustris* (600x DIC), Bear Lake, IWS water quality sampling site, Snohomish County, August 28, 2014.

4.6 *Oscillatoria* Vaucher ex Gomont

Local taxa
Oscillatoria curviceps Agardh ex Gomont;
Oscillatoria limosa Agardh ex Gomont
Oscillatoria princeps Vaucher ex Gomont;
Oscillatoria tenuis Vaucher ex Gomont;
Oscillatoria spp.

Abundance
Moderately common; may be present in large numbers but rarely forms blooms; occasionally forms dense benthic mats.

Local measurements		Width	Length	Biovolume[†]
Oscillatoria curviceps	min	12.6 μm	3.0 μm	380 μm^3
cells (cylinder)	med	14.3 μm	6.2 μm	1,060 μm^3
	max	15.7 μm	9.3 μm	1,720 μm^3
Oscillatoria limosa	min	13.9 μm	2.0 μm	321 μm^3
cells (cylinder)	med	16.0 μm	3.7 μm	742 μm^3
	max	19.2 μm	6.6 μm	1,850 μm^3
Oscillatoria princeps	min	39.8 μm	5.9 μm	7,650 μm^3
cells (cylinder)	med	41.0 μm	7.5 μm	9,860 μm^3
	max	49.6 μm	8.8 μm	15,000 μm^3
Oscillatoria tenuis	min	8.3 μm	2.5 μm	139 μm^3
cells (cylinder)	med	9.4 μm	3.8 μm	278 μm^3
	max	10.6 μm	4.9 μm	383 μm^3
Oscillatoria sp.1	min	12.4 μm	5.5 μm	776 μm^3
cells (cylinder)	med	13.8 μm	7.3 μm	1,080 μm^3
	max	14.2 μm	10.8 μm	1,710 μm^3

continued on next page

Local measurements		Width	Length	Biovolume[†]
Oscillatoria sp.2	min	13.3 μm	2.7 μm	410 μm^3
cells (cylinder)	med	13.7 μm	3.4 μm	501 μm^3
	max	14.0 μm	4.4 μm	649 μm^3
Oscillatoria sp.3	min	15.5 μm	4.7 μm	887 μm^3
cells (cylinder)	med	16.2 μm	6.7 μm	1,470 μm^3
	max	17.1 μm	8.6 μm	1,820 μm^3

[†]Calculated using original measurements, not summary values.

Description

Oscillatoria trichomes are unbranched, straight or slightly curved, and do not form akinetes or heterocysts (Figures 4.30–4.46). The trichomes lack a sheath under normal conditions; although, sheaths may be formed when the cells are stressed (Komárek and Anagnostidis, 2005). The cells are always shorter than wide (short cylindrical or coin-like). The trichomes usually grow as benthic mats or tangles, but may become dislodged and planktonic.

Oscillatoria can be very difficult to distinguish from *Geitlerinema* (Section 4.3, page 372), *Lyngbya* (Section 4.4, page 378), *Phormidium* (Section 4.7, page 414, and *Planktothrix* (Section 4.8, page 442). In general, *Oscillatoria* trichomes will be wider and shorter than *Geitlerinema* and *Phormidium*, and are more likely to be associated with benthic mats or shoreline vegetation than *Planktothrix*, which is usually planktonic. The absence of a sheath distinguishes *Oscillatoria* from typical specimens of *Lyngbya* (Section 4.4, page 378), but not from stressed *Lyngbya* trichomes that have exited their sheath (see Figure 4.20, page 383).

Oscillatoria curviceps trichomes are slightly wavy and often hooked or bent near the apex, ending in a rounded, hemispherical apical cell (Figures 4.30–4.32 and 4.43). The short, cylindrical cells are dark gray-blue, with unconstricted, raised, smooth or slightly granular cross-walls. Most of the local specimens were collected in a benthic mat containing other other types of filamentous Cyanobacteria.

Oscillatoria limosa is characterized by long, untapered, olive-green or brownish trichomes (Figures 4.33–4.35). The individual cells have distinctly raised, granulated cross-walls; the apical cell is hemispherical and may be thickened, but will not form a calyptra. The cells have raised, granulated cross-walls. This

species superficially resembles *Oscillatoria princeps*, but the trichomes are about half as wide. *Oscillatoria limosa* forms benthic mats in stagnant water (Komárek and Anagnostidis, 2005). The local specimens were collected in several nutrient-rich, low elevation lakes and ponds, usually in association with benthic mats or shoreline vegetation.

Oscillatoria princeps (Figures 4.36–4.38) has extremely large blue-green, olive-green or reddish-green trichomes. The cells do not have the distinctly granular cross-walls that characterize *Oscillatoria limosa*, but may appear slightly raised or faintly granular at high magnification. The apical cell is hemispherical and thickened, not capitate, with a clear, vacuolated region (Figure 4.36).

Oscillatoria tenuis forms benthic mats of straight or slightly curved trichomes containing small, actively motile cells (Figures 4.39–4.40). The cells are narrower and more cylindrical than *Oscillatoria princeps* or *Oscillatoria limosa*. The cell walls are slightly raised, and may or may not appear granular; the apical is rounded, but not thickened.

Oscillatoria sp.1 has straight or gently curved trichomes, ending in a rounded, hemispherical apical cell (Figures 4.41–4.43). The short, cylindrical cells are bright blue-green, with unconstricted, raised, slightly granular cross-walls. The trichomes resemble *Oscillatoria curviceps*, and were collected concurrently with local specimens of *Oscillatoria curviceps*, but side-by-side comparisons suggest that *Oscillatoria* sp.1 is either a different species or a smaller variety of *Oscillatoria curviceps* (Figure 4.43).

Oscillatoria sp.2 was collected from a small, diverse, boggy lake on the Mt. Loop Highway in the North Cascades (Myrtle Lake). This species has short, coin-like, blue-green or olive-green cells with raised, slightly granular, unconstricted cross-walls (Figures 4.44–4.45). The trichomes are slightly tapered near the apex, ending in a knob-shaped apical cell.

Oscillatoria sp.3 forms tapered, hooked trichomes, with short cylindrical cells that are slightly constricted at the cross-walls (Figure 4.46). The cell are bright green, with a granular cell content. The width of the cells suggest that this is a species of *Oscillatoria*, but the hooked, tapered trichome and cylindrical cells resemble *Phormidium*. This is a good example of the morphological similarity between these two genera, and illustrates some of the difficulty in separating the taxa based strictly on appearance.



Figure 4.30: *Oscillatoria curviceps* (600x DIC), Myrtle Lake, IWS water quality sampling site, Snohomish County, July 29, 2014.

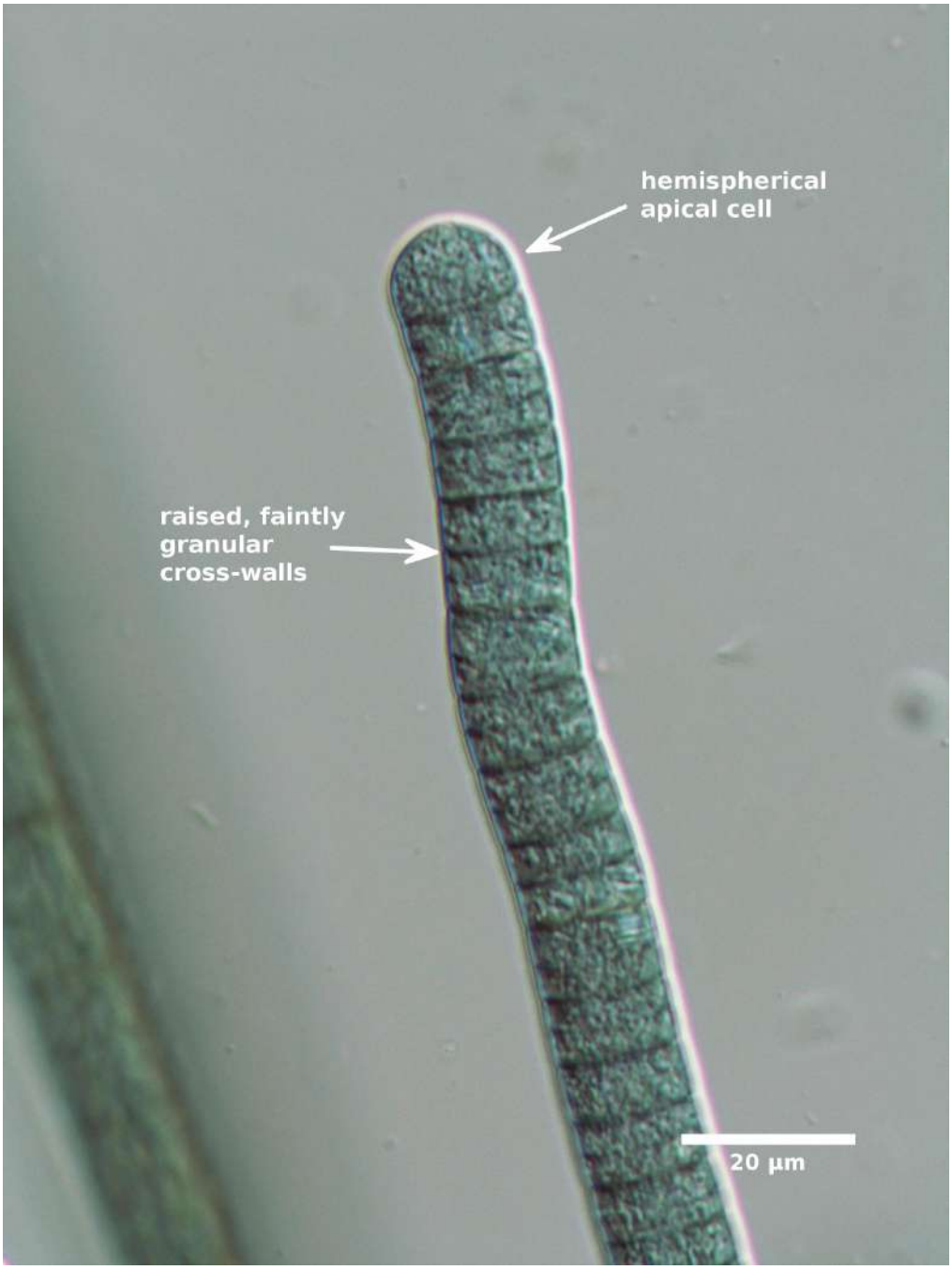


Figure 4.31: *Oscillatoria curviceps* (600x DIC), Canyon Lake, IWS water quality sampling site, Whatcom County, August 10, 2015.



Figure 4.32: *Oscillatoria curviceps* (200x DIC), Myrtle Lake, IWS water quality sampling site, Snohomish County, July 29, 2014.

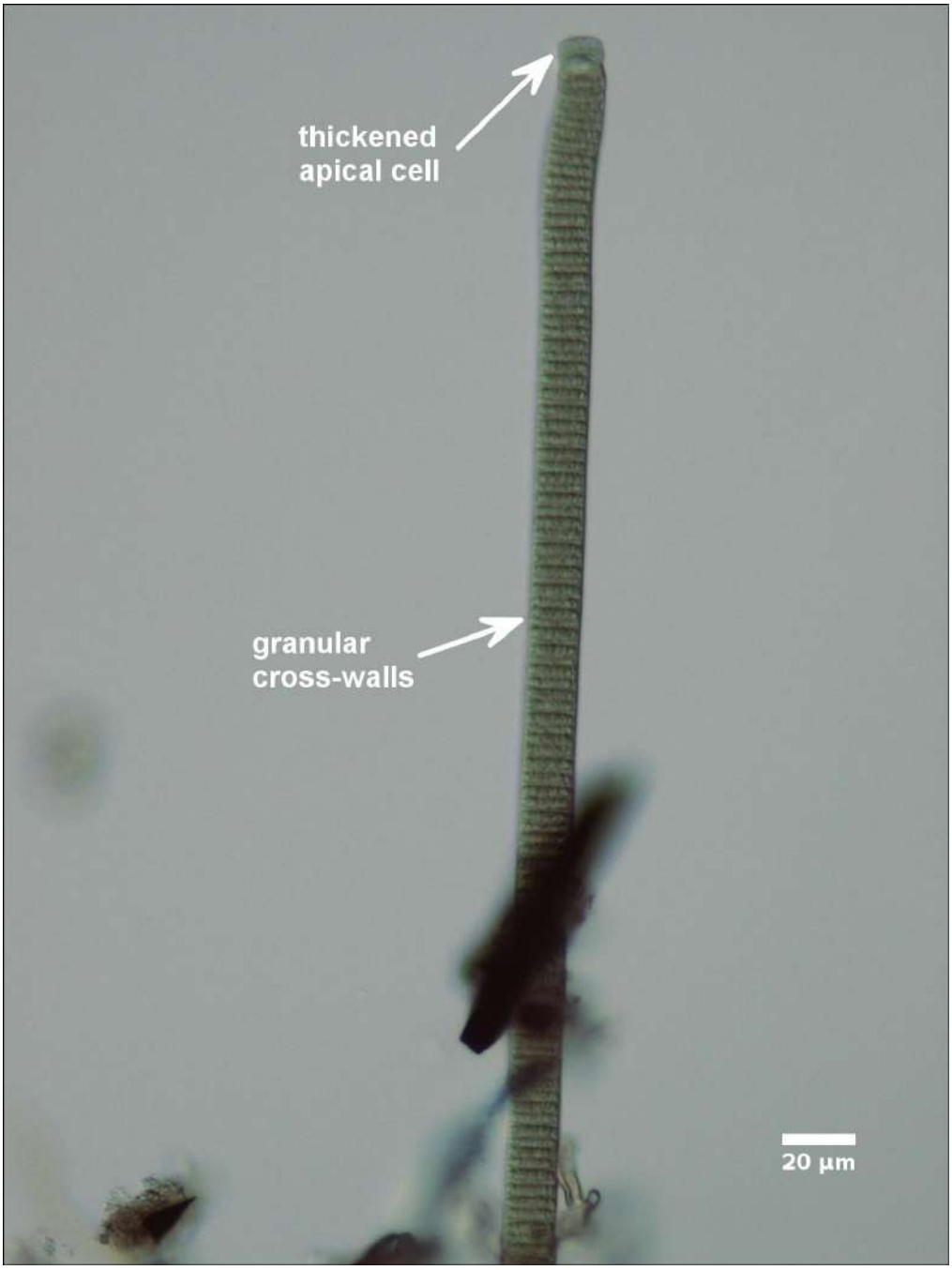


Figure 4.33: *Oscillatoria limosa* (200x DIC), Squires Lake, IWS water quality sampling site, Whatcom County, April 20, 2007.



Figure 4.34: *Oscillatoria limosa* (200x DIC), Capitol Lake, Olympia, Thurston County, May 27, 2015.

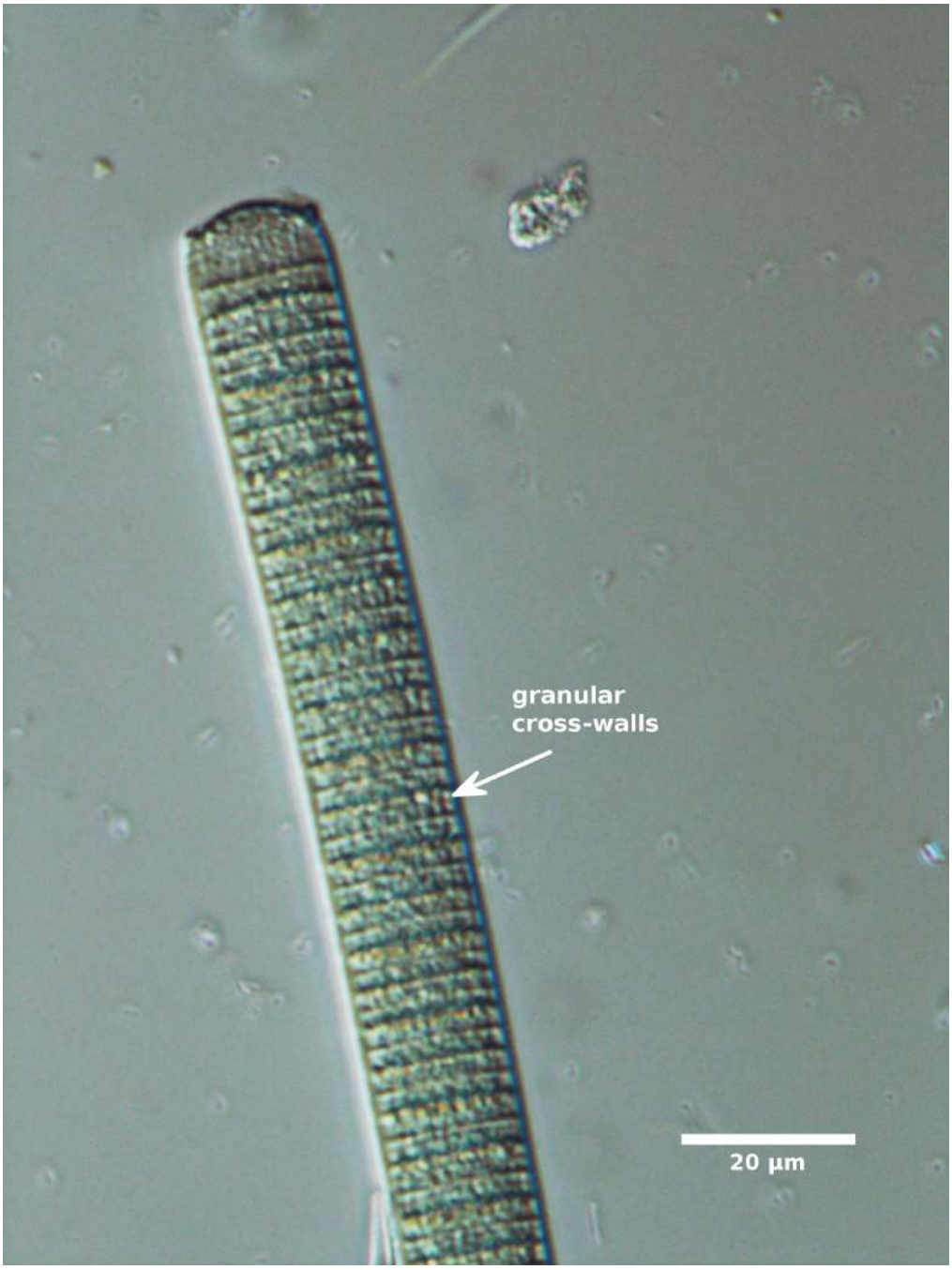


Figure 4.35: *Oscillatoria limosa* (600x DIC), Capitol Lake, Olympia, Thurston County, May 27, 2015.

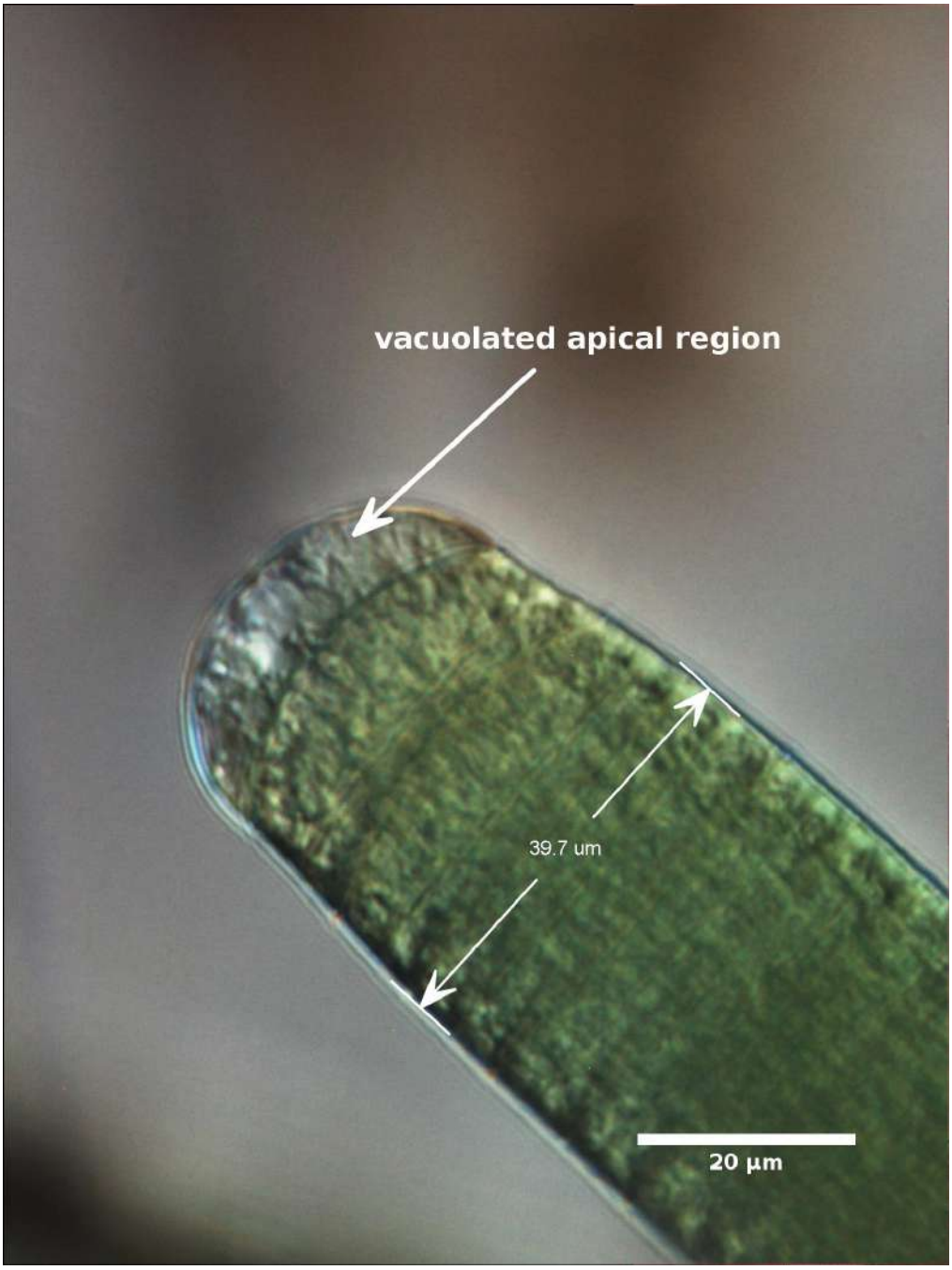


Figure 4.36: *Oscillatoria princeps* (600x DIC), Heart Lake, IWS water quality sampling site, Skagit County, July 21, 2011.



Figure 4.37: *Oscillatoria princeps* (200x DIC), Tennant Lake, IWS water quality sampling site, Whatcom County, June 10, 2015.



Figure 4.38: *Oscillatoria princeps* (200x DIC), Heart Lake, IWS water quality sampling site, Skagit County, September 21, 2010.

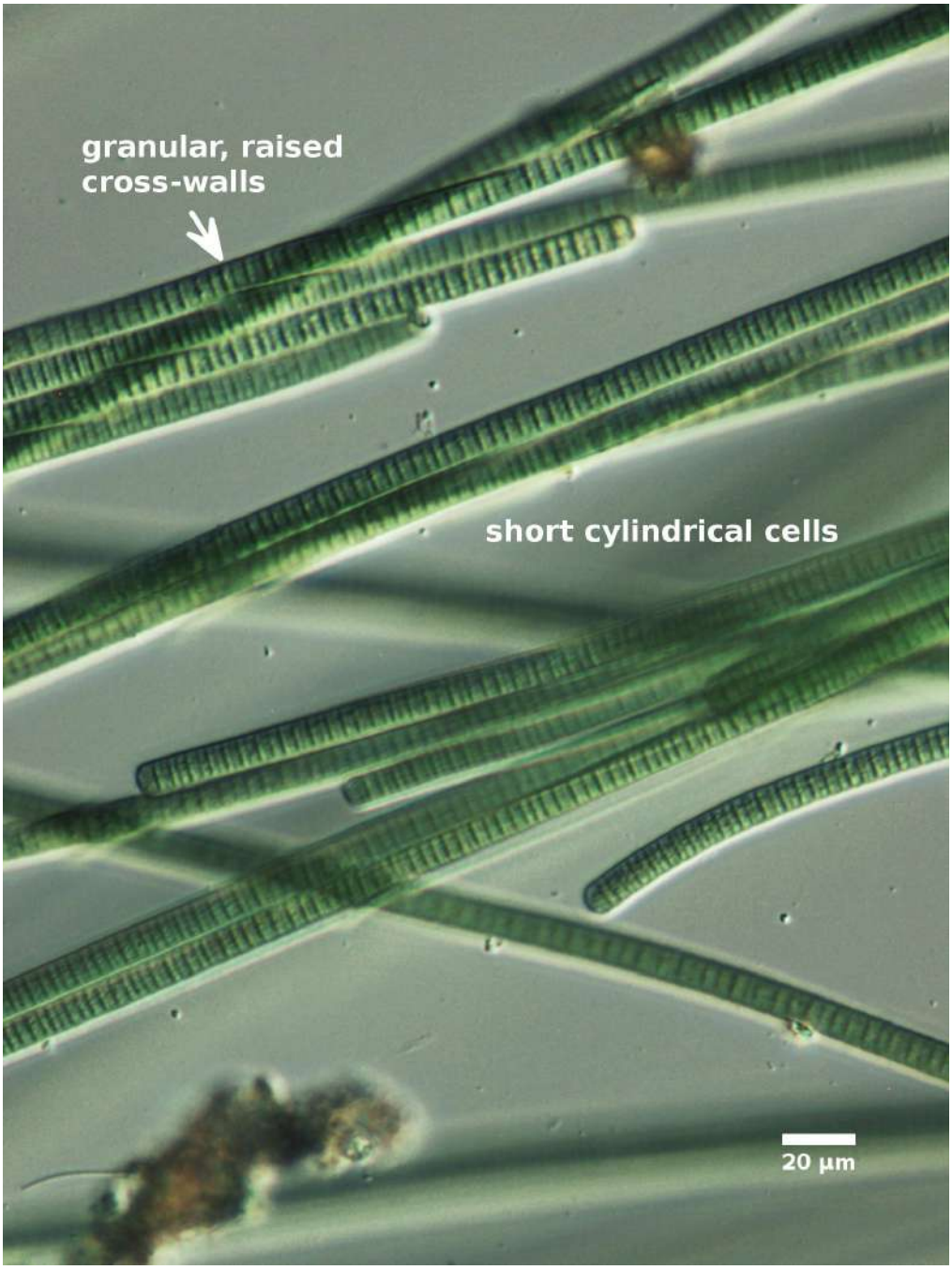


Figure 4.39: *Oscillatoria tenuis* (200x DIC), Monte Cristo Lake, IWS water quality sampling site, Snohomish County, August 20, 2013.



Figure 4.40: *Oscillatoria tenuis* (200x DIC), Tennant Lake, IWS water quality sampling site, Whatcom County, April 17, 2013.



Figure 4.41: *Oscillatoria* sp.1 (200x DIC), Canyon Lake, IWS water quality sampling site, Whatcom County, August 10, 2015.

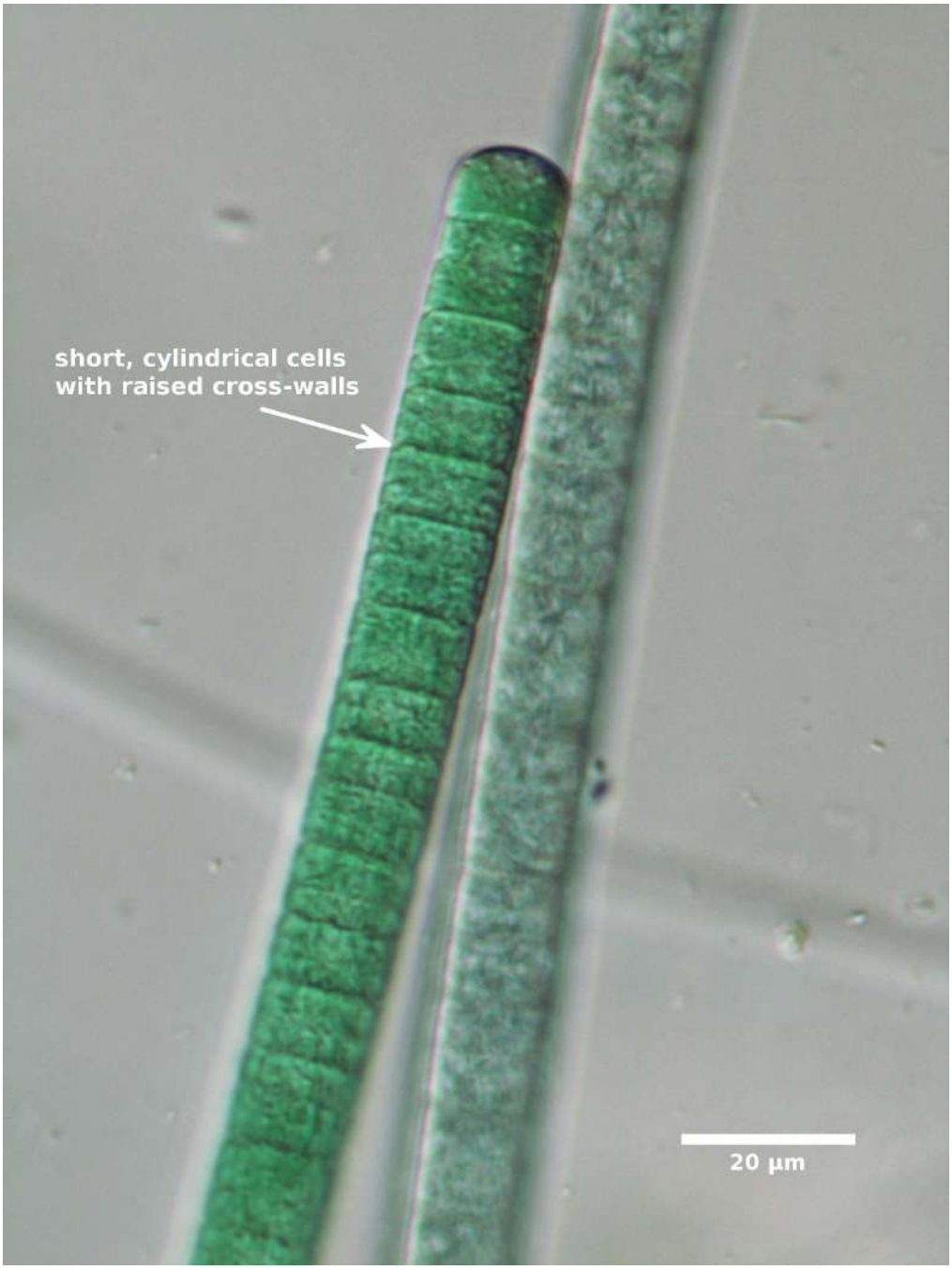


Figure 4.42: *Oscillatoria* sp.1 (600x DIC), Canyon Lake, IWS water quality sampling site, Whatcom County, August 10, 2015.

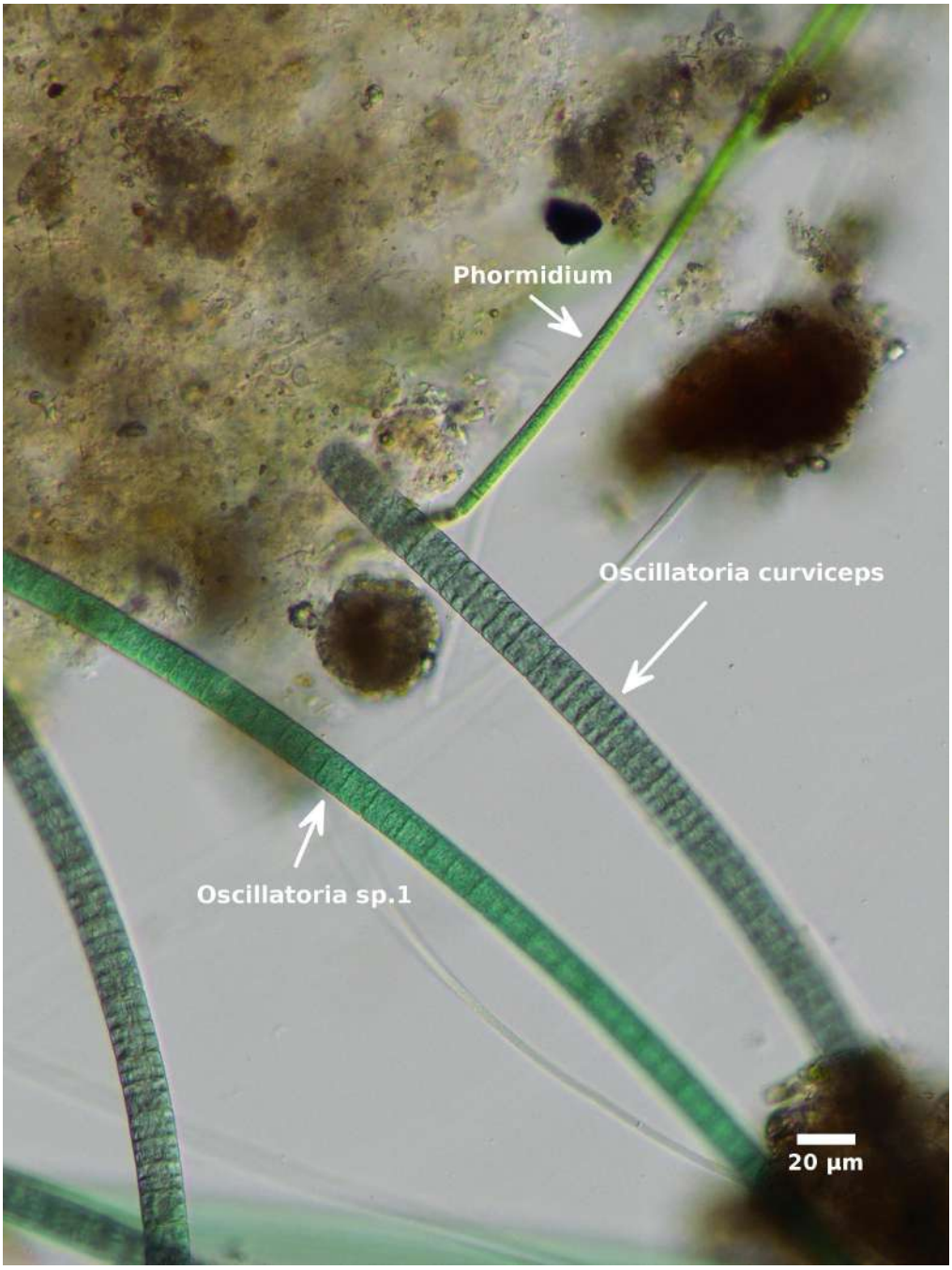


Figure 4.43: *Oscillatoria curviceps* and *Oscillatoria* sp.1 (600x DIC), Canyon Lake, IWS water quality sampling site, Whatcom County, August 10, 2015.

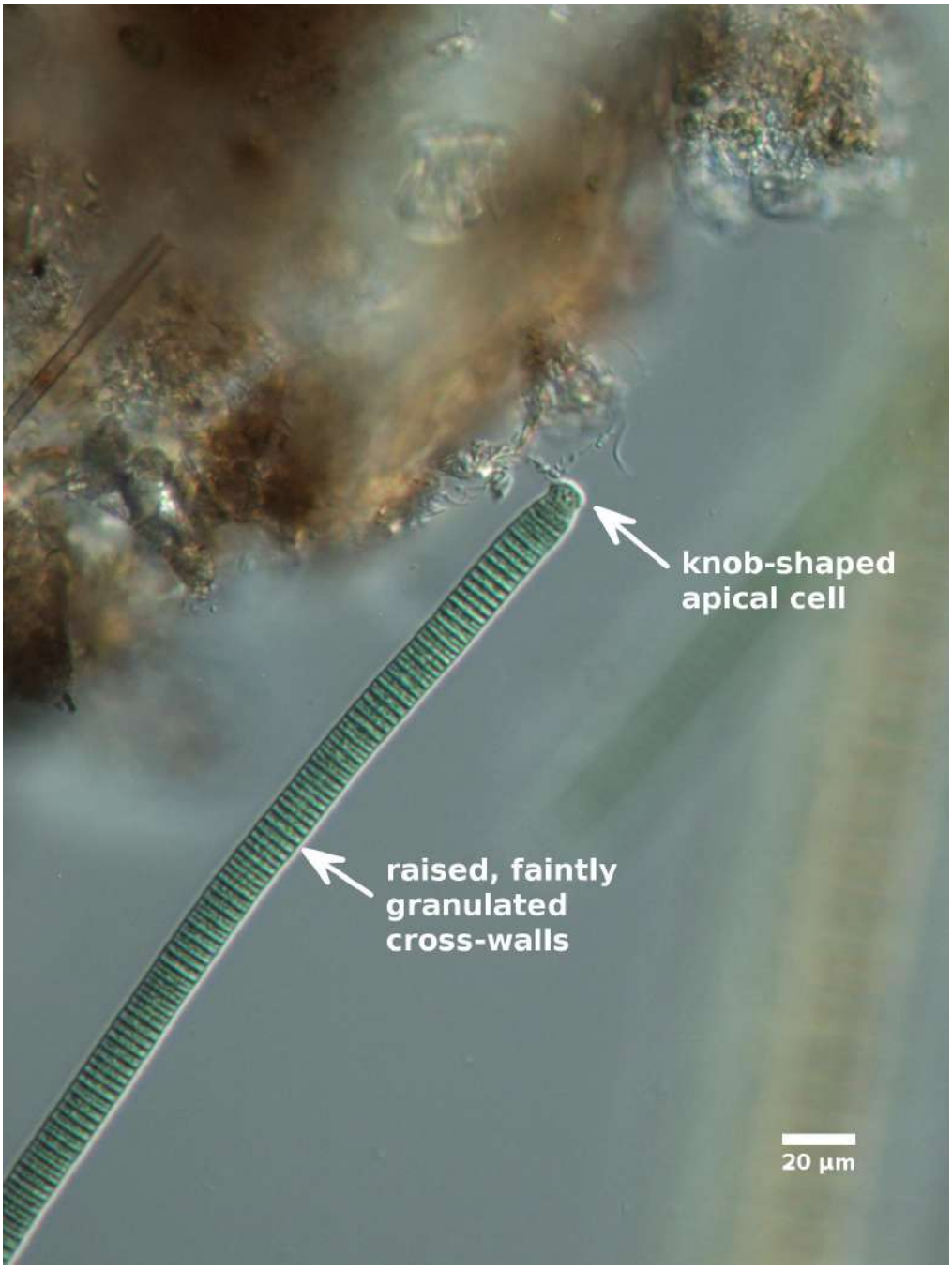


Figure 4.44: *Oscillatoria* sp.2 (200x DIC), Myrtle Lake, IWS water quality sampling site, Snohomish County, August 19, 2013.

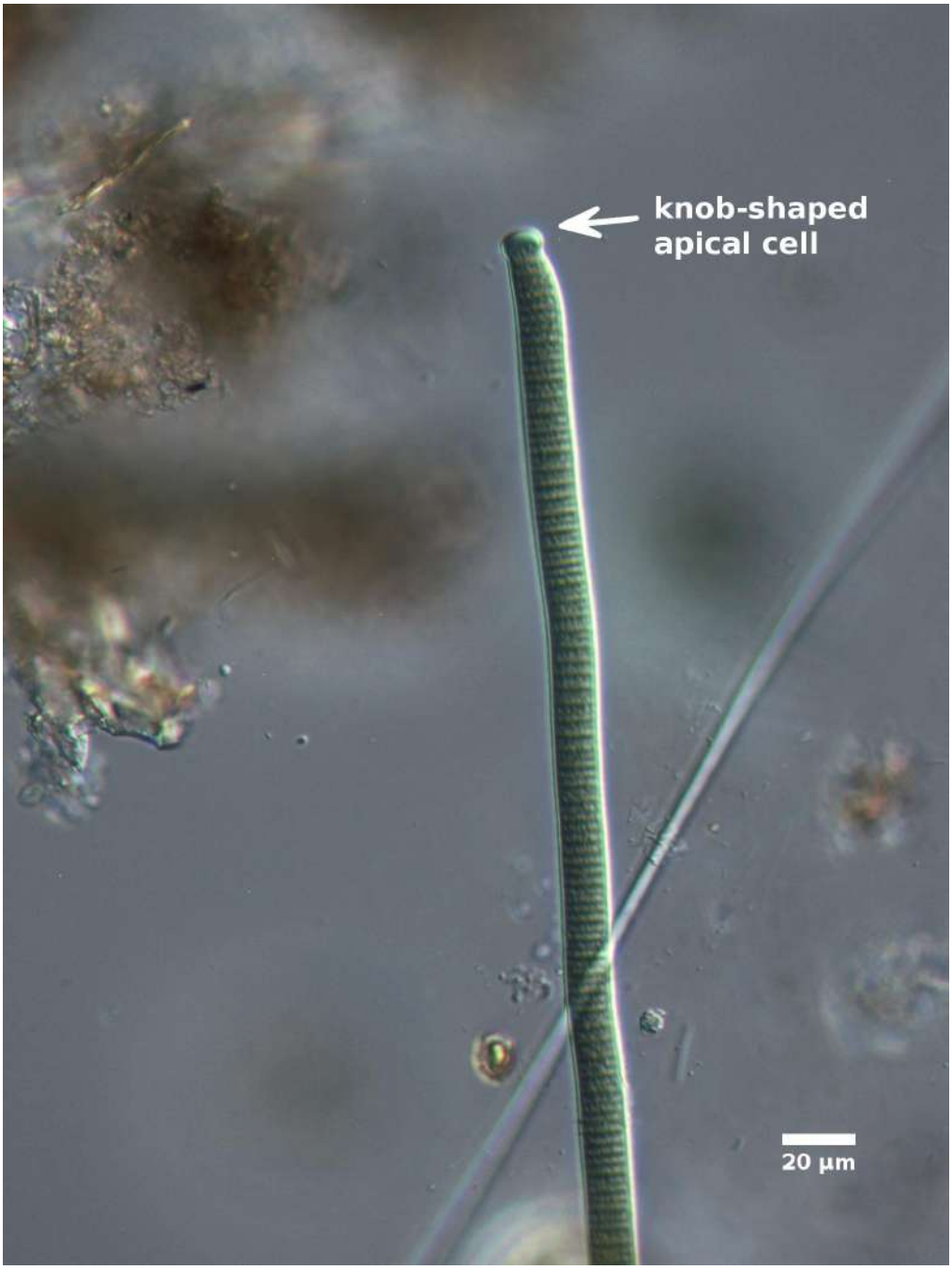


Figure 4.45: *Oscillatoria* sp.2 (200x DIC), Myrtle Lake, IWS water quality sampling site, Snohomish County, August 19, 2013.



Figure 4.46: *Oscillatoria* sp.3 (200x DIC), Little Twin Lake (Winthrop area), eastern Washington, June 18, 2014,

4.7 *Phormidium* Kützing ex Gomont and similar taxa

Local taxa
Phormidium spp.

Abundance
Moderately common; may be present in large numbers but rarely forms blooms; occasionally forms dense benthic mats.

Local measurements		Width	Length	Biovolume†
Group II (see page 417)				
Phormidium II.1	min	3.5 μm	6.8 μm	73.1 μm^3
cells (cylinder)	med	4.3 μm	10.6 μm	149 μm^3
	max	4.7 μm	13.3 μm	221 μm^3
Phormidium II.2	min	6.2 μm	10.9 μm	347 μm^3
cells (cylinder)	med	6.3 μm	11.9 μm	388 μm^3
	max	6.9 μm	12.9 μm	415 μm^3
Phormidium II.3	min	4.9 μm	7.4 μm	173 μm^3
cells (cylinder)	med	5.5 μm	9.5 μm	216 μm^3
	max	6.0 μm	11.7 μm	331 μm^3
Phormidium II.4	min	5.2 μm	5.4 μm	115 μm^3
cells (cylinder)	med	5.3 μm	7.2 μm	158 μm^3
	max	5.5 μm	9.8 μm	233 μm^3
Phormidium II.5	min	3.2 μm	2.4 μm	20.9 μm^3
cells (cylinder)	med	3.9 μm	2.8 μm	33.1 μm^3
	max	4.4 μm	5.3 μm	80.6 μm^3

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Local measurements		Width	Length	Biovolume†
Group III (see description on page 417)				
Phormidium III.1	min	4.4 μm	3.4 μm	61.5 μm^3
cells (cylinder)	med	4.7 μm	4.6 μm	78.8 μm^3
	max	5.0 μm	7.0 μm	121 μm^3
Phormidium III.2	min	6.3 μm	2.4 μm	77.2 μm^3
cells (cylinder)	med	7.2 μm	4.1 μm	174 μm^3
	max	7.9 μm	5.5 μm	270 μm^3
Phormidium III.3	min	5.3 μm	3.2 μm	79.4 μm^3
cells (cylinder)	med	5.8 μm	4.3 μm	106 μm^3
	max	6.2 μm	5.3 μm	155 μm^3
Group IV (see description on page 417)				
Phormidium IV.1	min	7.0 μm	8.2 μm	343 μm^3
cells (cylinder)	med	7.3 μm	11.8 μm	484 μm^3
	max	7.9 μm	16.3 μm	720 μm^3
Group V (see description on page 418)				
Phormidium V.1	min	6.0 μm	5.1 μm	169 μm^3
cells (cylinder)	med	6.7 μm	6.2 μm	230 μm^3
	max	7.3 μm	8.1 μm	273 μm^3
Phormidium V.2	min	9.8 μm	3.1 μm	283 μm^3
cells (cylinder)	med	10.8 μm	3.7 μm	334 μm^3
	max	11.1 μm	6.4 μm	483 μm^3
Phormidium V.3	min	9.3 μm	2.7 μm	183 μm^3
cells (cylinder)	med	9.7 μm	3.3 μm	247 μm^3
	max	10.1 μm	4.4 μm	325 μm^3
Phormidium V.4	min	7.8 μm	3.3 μm	174 μm^3
cells (cylinder)	med	8.3 μm	4.2 μm	240 μm^3
	max	9.5 μm	4.7 μm	298 μm^3

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Local measurements		Width	Length	Biovolume[†]
Phormidium V.5	min	5.8 μm	3.4 μm	96.1 μm^3
cells (cylinder)	med	6.3 μm	4.5 μm	143 μm^3
	max	6.5 μm	5.5 μm	156 μm^3
Phormidium V.6	min	8.0 μm	4.1 μm	222 μm^3
cells (cylinder)	med	8.4 μm	5.2 μm	281 μm^3
	max	9.1 μm	5.9 μm	384 μm^3
Phormidium V.7	min	10.4 μm	3.4 μm	294 μm^3
cells (cylinder)	med	10.6 μm	4.1 μm	357 μm^3
	max	10.9 μm	4.9 μm	457 μm^3
Phormidium V.8	min	5.2 μm	3.7 μm	84.7 μm^3
cells (cylinder)	med	5.4 μm	5.7 μm	124 μm^3
	max	5.7 μm	7.7 μm	180 μm^3

[†]Calculated using original measurements, not summary values.

Description

Phormidium trichomes are narrow ($\leq$10–12 μm), unbranched, and lack heterocysts or akinetes (Figures 4.47–4.69). The individual cells are cylindrical, and can be slightly longer, shorter, or equal in length and width, but not coin-like. The trichomes may be surrounded by a sticky sheath, but this feature can be influenced by environmental conditions.

Komárek and Anagnostidis (2005) describe *Phormidium* as an exceptionally difficult genus, with many poorly-described taxa and highly variable morphological characteristics. Recent genetic analyses have resulted in major revisions to the genus, making morphologically-based identifications an exercise in futility. *Phormidium* trichomes resemble *Geitlerinema* (Section 4.3, page 372), *Lyngbya* (Section 4.4, page 378), *Oscillatoria* (Section 4.6, page 394), *Planktothrix* (Section 4.8, page 442), and *Tychonema* (Section 4.11, page 465). Because *Phormidium* identification is so difficult, this section will be limited to a few local taxa that illustrate four of the eight major subgroups[17] used by Komárek and Anagnostidis (2005) in their key to species of *Phormidium*.

[17]Local specimens were collected from **Groups II–V**, but not from **Group I** or **Groups VI–VIII**.

***Phormidium* Group II** trichomes taper very gradually, ending in a narrow, rounded apical cell (Figures 4.47–4.55). *Phormidium* II.1–II.3 are very similar in appearance, with long, gray, tapered trichomes that appeared "sparkly" due to the presence of clusters of refractive granules (Figures 4.47–4.51). The cells have unconstricted, or very slightly constricted, cross-walls. *Phormidium* II.1 and II.2 were both collected in shoreline samples from high elevation lakes, but the *Phormidium* II.1 trichomes are half the width of the *Phormidium* II.2 trichomes. *Phormidium* II.3 trichomes were collected in shaded, low elevation streams.

Phormidium II.4 was collected from benthic mats in a very cold, clear stream flowing from a large ice cave. The trichomes taper gradually into a curved, reflexed apex (Figures 4.52–4.53). The individual cells have raised, granular, unconstricted cross-walls and a distinctly orangish tint.

Phormidium II.5 was collected from in a shoreline plankton sample from a high elevation lake. The bright blue-green trichomes contain unconstricted cells with slightly raised (not granular) cross-walls (Figures 4.54–4.55). The trichomes are surrounded by a visible sheath and the filaments formed sticky mats.

***Phormidium* Group III** trichomes taper abruptly, ending in a blunt, conical or hemispherical apical cell (Figures 4.56–4.59). The *Phormidium* III.1 trichomes formed sticky orange mats covering the rocks and soil in wet seeps along a high elevation trail. The individual cells are granular, with unconstricted, raised cross-walls; the apical cell is hooked, conical, and slightly thickened (Figures 4.56–4.57).

Phormidium III.2 was collected from a benthic mat in a nutrient-rich, shaded, low elevation stream. The trichomes taper very abruptly into a hooked, hemispherical apical cell. The individual cells are gray-green, with unconstricted, slightly granular, raised cross-walls (Figure 4.58). *Phormidium* III.3 also has unconstricted, slightly granular, raised cross-walls, but the trichomes are narrower relative to the cell width (Figure 4.59).

***Phormidium* Group IV** trichomes are untapered except for the final cell (apical), which is conical (Figure 4.60). The local specimen from Goss Lake was solitary, with no apparent sheath, and was collected in a nearshore plankton sample. The individual cells are slightly granular, olive-green, consistently longer than wide, and slightly constricted at the cross-walls.

***Phormidium* Group V** trichomes are untapered, with a rounded apical cell (Figures 4.61–4.69). This group is virtually indistinguishable from narrow species of *Oscillatoria* unless the trichome is enclosed in a visible sheath. Taxa that I included in this section have relatively narrow ($\leq$10–12 μm) cylindrical cell (not coin-like). But given the uncertainty surrounding the genus, it is possible that some of these are not species of *Phormidium*, but rather a narrow species of *Oscillatoria* or similar genus.

Phormidium V.1–V.3 are common in nearshore plankton samples from nutrient-rich, low elevation lakes (Figures 4.61–4.63). All three types have solitary, planktonic trichomes. The individual cells are similar in width (5.5–7.9 μm), and have a homogeneous cell content and smooth, unconstricted or slightly constricted cross-walls. The primary distinctly was in the degree to which the cross-walls are constricted and the ratio of width to length, but these differences could easily occur within a single species.

Phormidium V.4–V.7 were collected from mountain lakes or the wet surfaced near a waterfall. All of these taxa have cylindrical cells with raised cross-walls, but are otherwise quite distinct from each other. *Phormidium* V.4 has granular cross-walls (Figure 4.64); *Phormidium* V.5 and *Phormidium* V.6 have smooth cross-walls, but different widths (Figures 4.65–4.66). *Phormidium* V.7 has relatively wide, short cells, with slightly granular cross-walls (Figure 4.67).

Phormidium V.8 was part of a benthic mat containing other types of filamentous Cyanobacteria that was collected from a small mountain lake with a large amount of submerged woody debris. The trichomes are very narrow, consisting of cells that are approximately equal in length and width (Figures 4.68–4.69). The cells are bright golden or yellow-green in color, with slightly constricted cell walls.



Figure 4.47: *Phormidium* II.1 (200x DIC), Myrtle Lake, IWS water quality sampling site, Snohomish County, May 19, 2014.

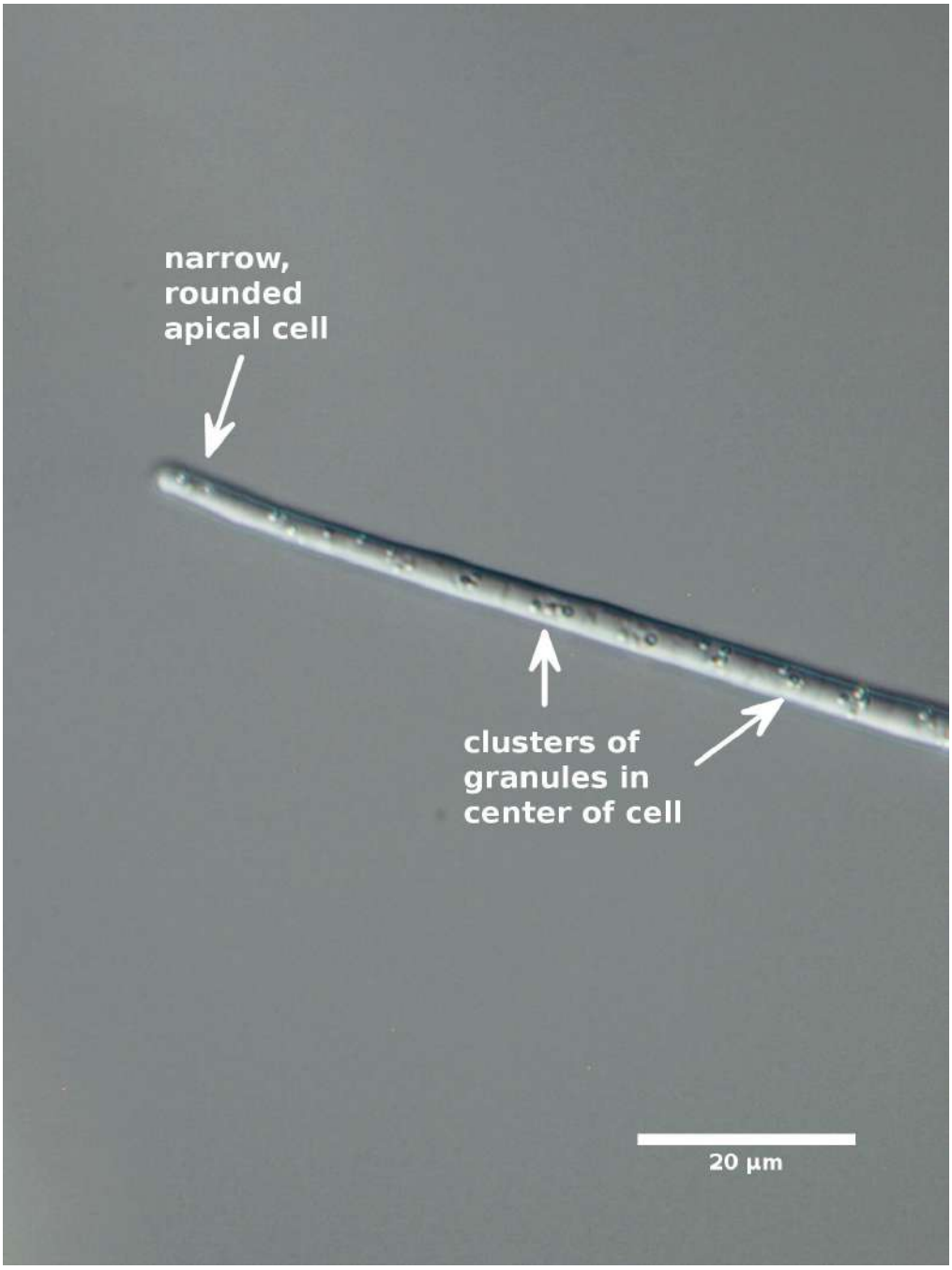


Figure 4.48: *Phormidium* II.1 (600x DIC), Highwood Lake, IWS water quality sampling site, Whatcom County, September 28, 2012.

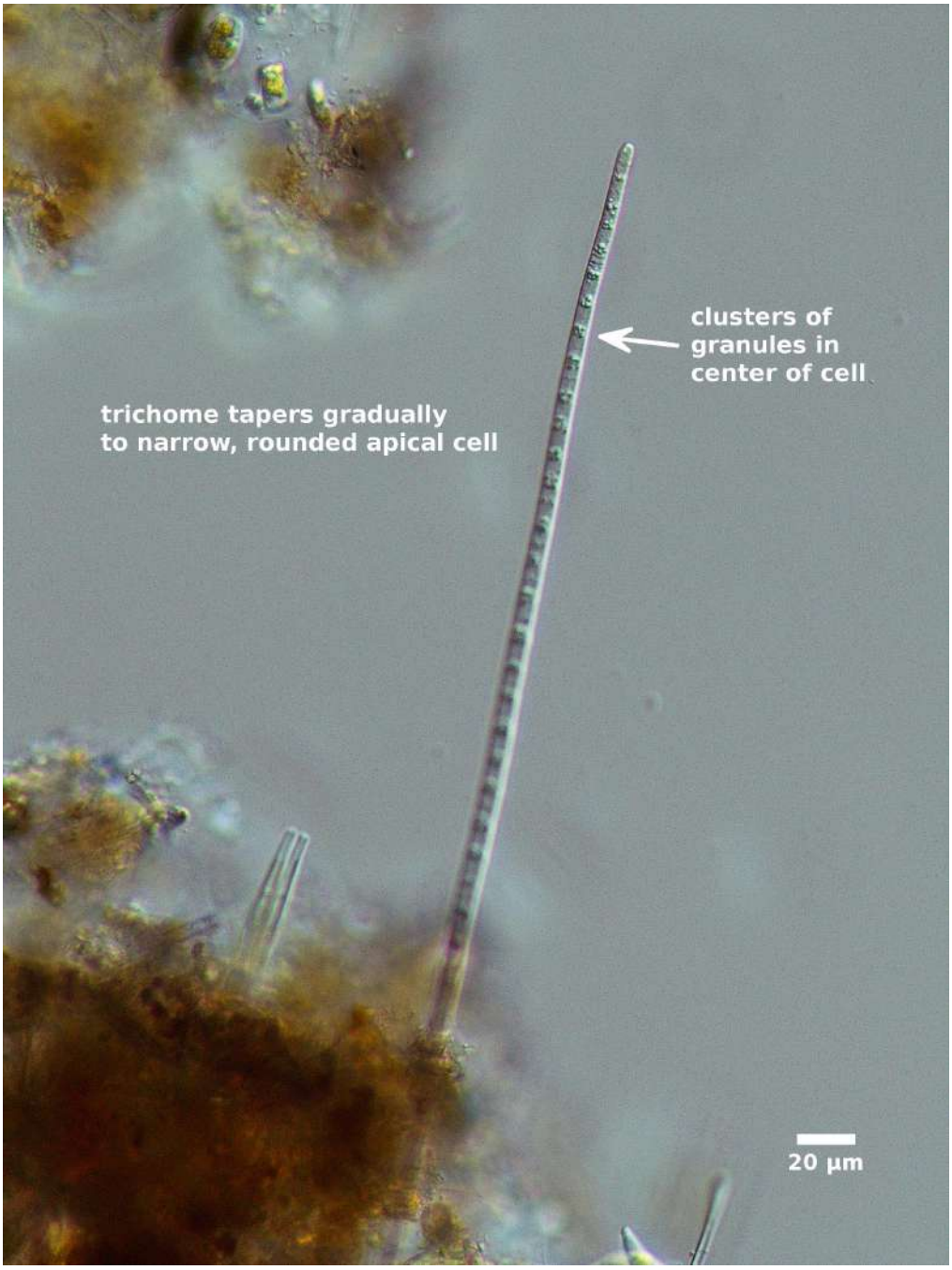


Figure 4.49: *Phormidium* II.2 (200x DIC), Goat Lake, Mt. Loop Hwy, June 2, 2014.



Figure 4.50: *Phormidium* II.3 (200x DIC), stream along Klipsun trail, Whatcom County, April 15, 2014.

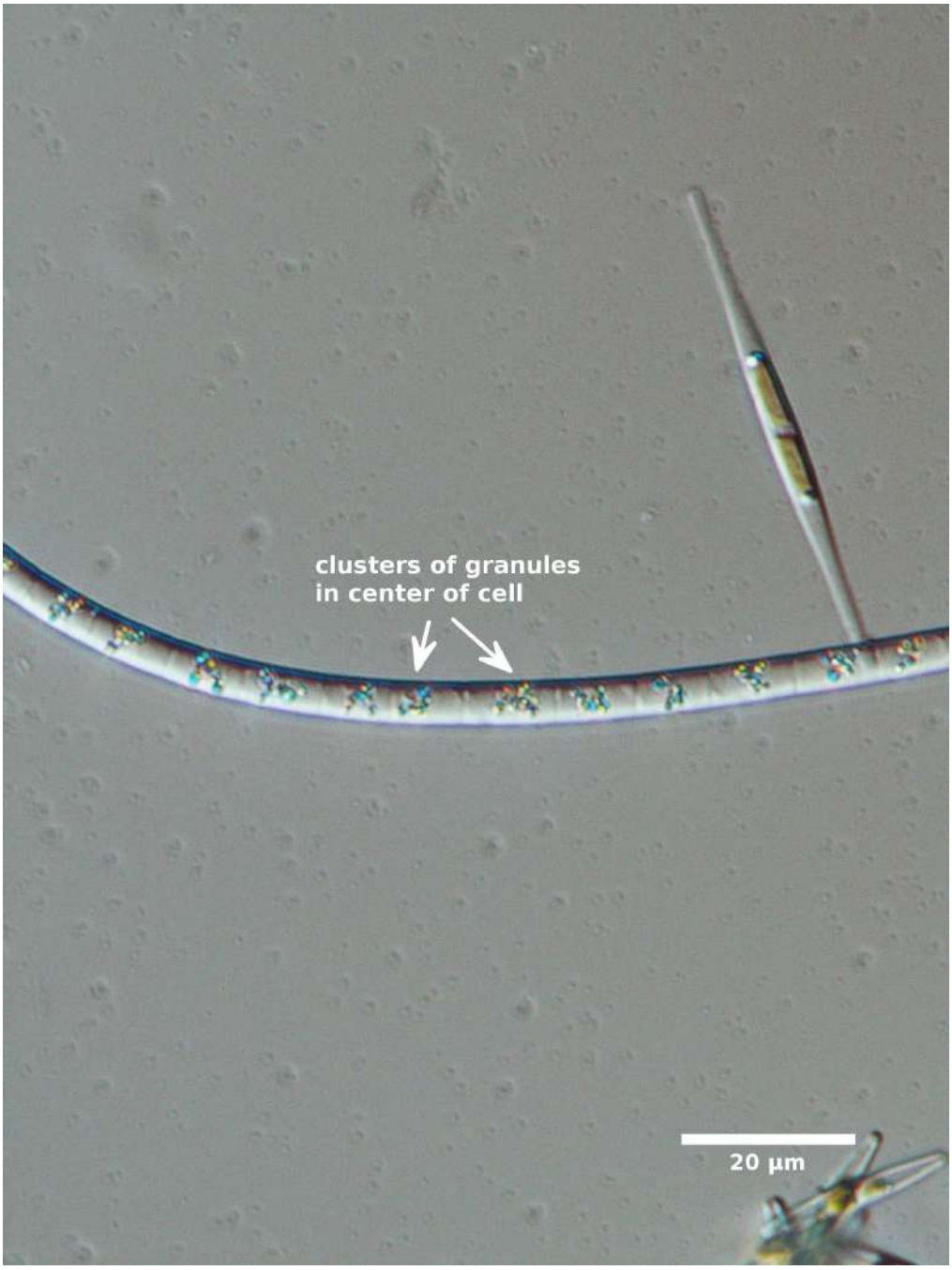


Figure 4.51: *Phormidium* II.3 (600x DIC), stream along Klipsun trail, Whatcom County, April 15, 2014.

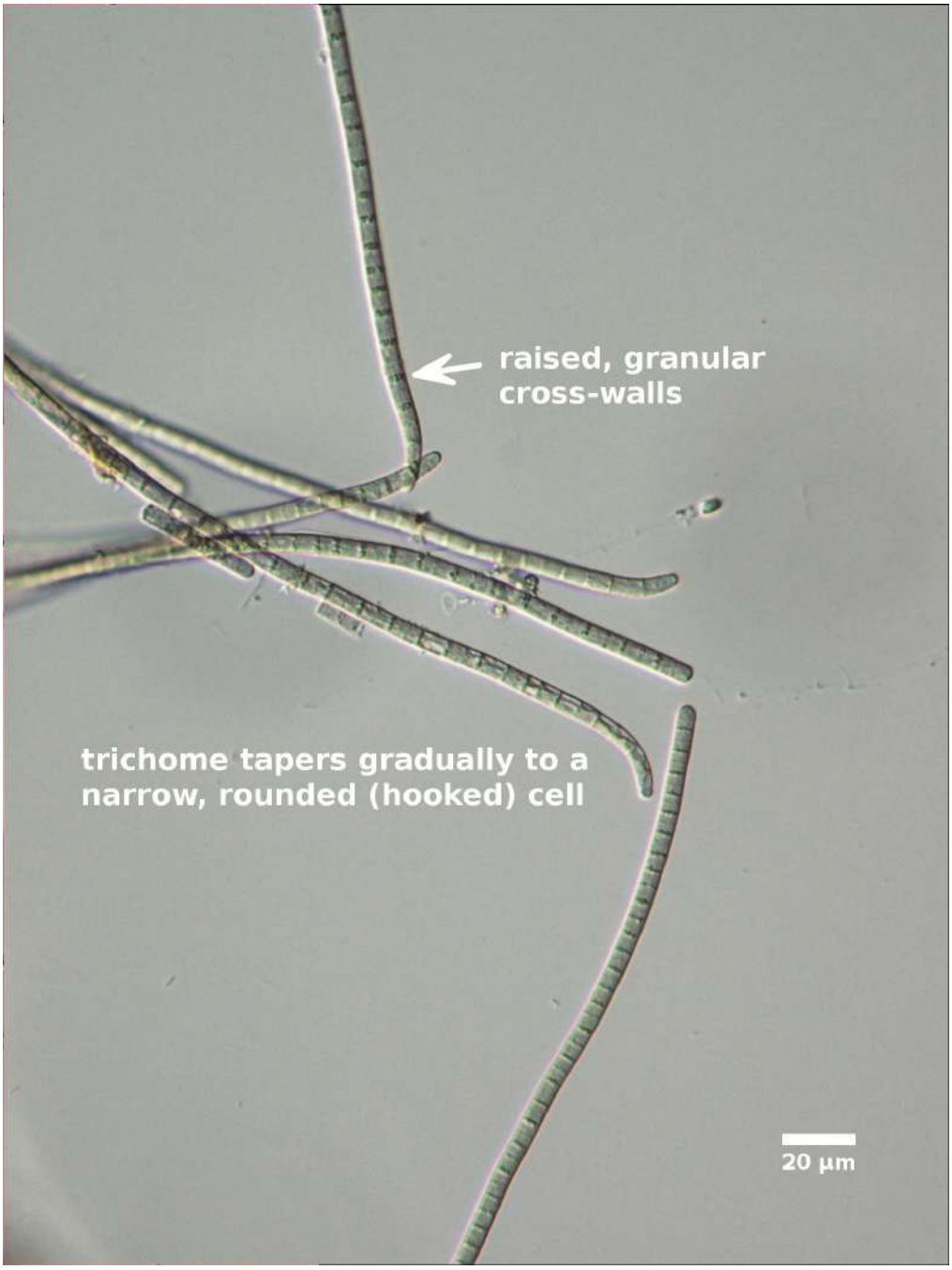


Figure 4.52: *Phormidium* II.4 (200x DIC), stream outlet from Big Four Ice Caves, Mt. Loop Hwy, July 18, 2011.

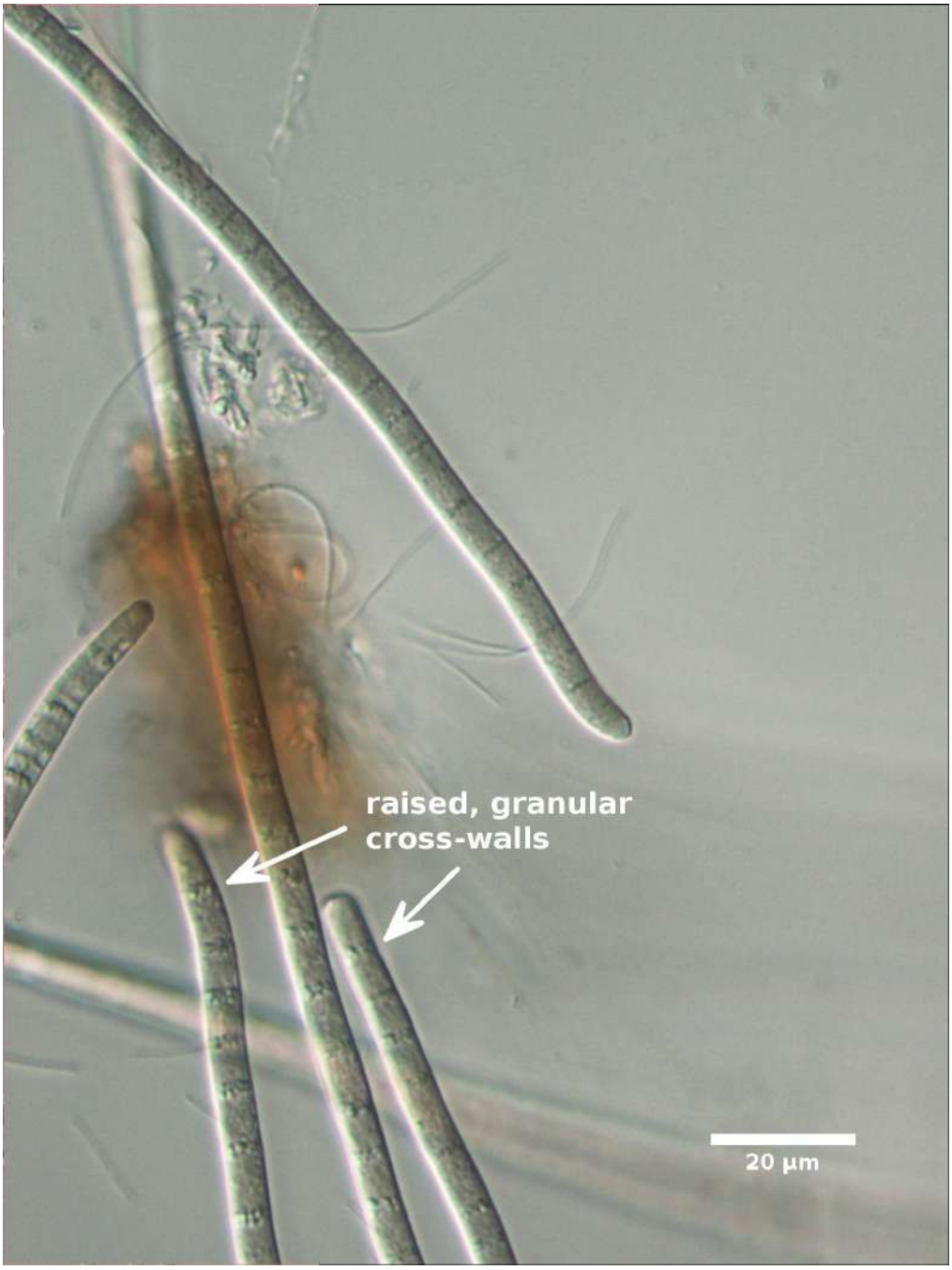


Figure 4.53: *Phormidium* II.4 (400x DIC), stream outlet from Big Four Ice Caves, Mt. Loop Hwy, July 18, 2011.



Figure 4.54: *Phormidium* II.5 (600x DIC), Coal Lake, IWS water quality sampling site, Snohomish County, July 31, 2014.



Figure 4.55: *Phormidium* II.5 (200x DIC), Coal Lake, IWS water quality sampling site, Snohomish County, July 31, 2014.

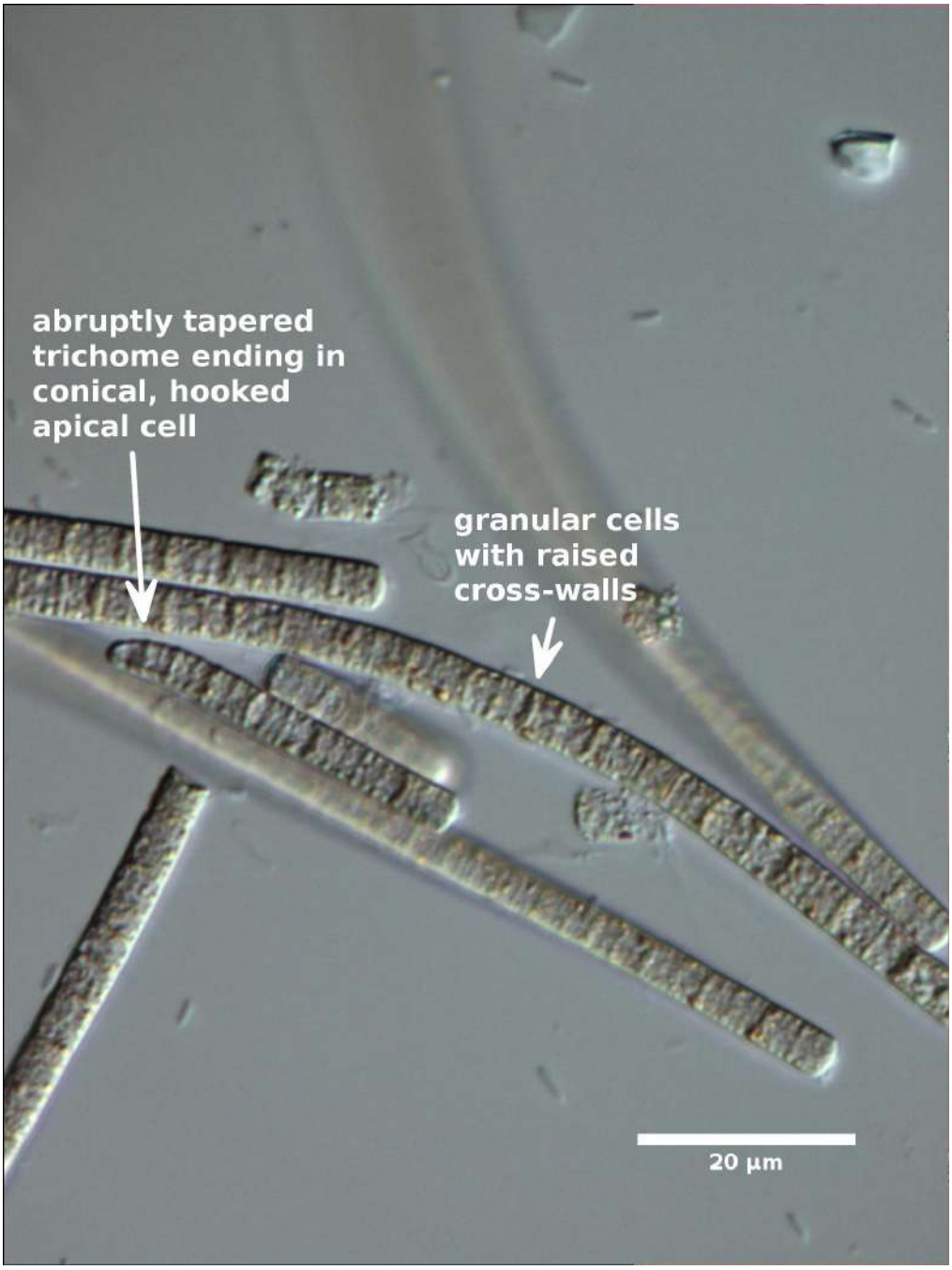


Figure 4.56: *Phormidium* III.1 (600x DIC), wet seep on Ptarmigan Ridge trail, Whatcom County, September 18, 2008.



Figure 4.57: *Phormidium* III.1 (200x DIC), wet seep on Ptarmigan Ridge trail, Whatcom County, September 18, 2008.



Figure 4.58: *Phormidium* III.2 (600x DIC), stream along Klipsun trail, Whatcom County, April 15, 2014.

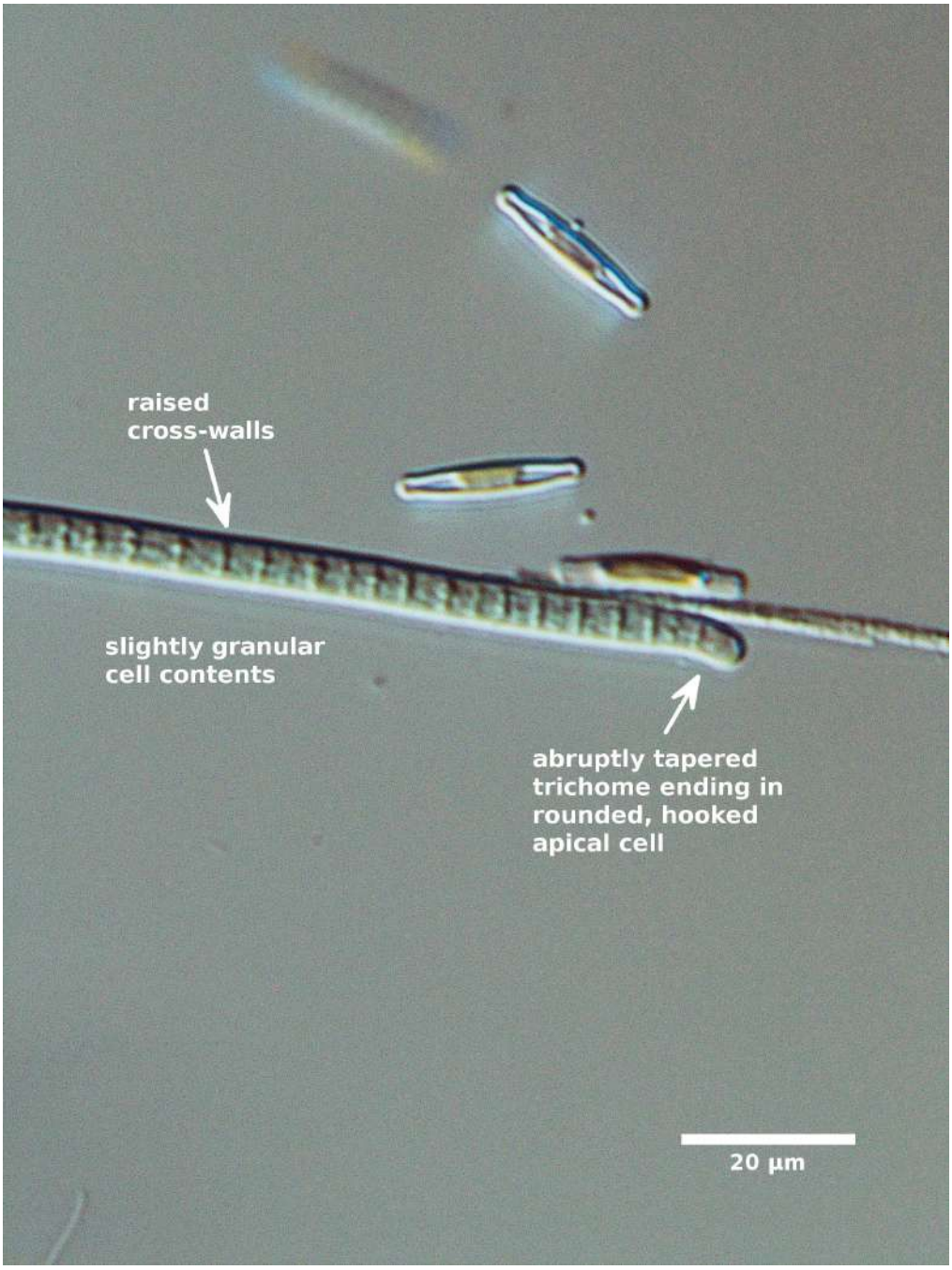


Figure 4.59: *Phormidium* III.3 (600x DIC), Goat Lake, Mt. Loop Hwy, June 2, 2014.

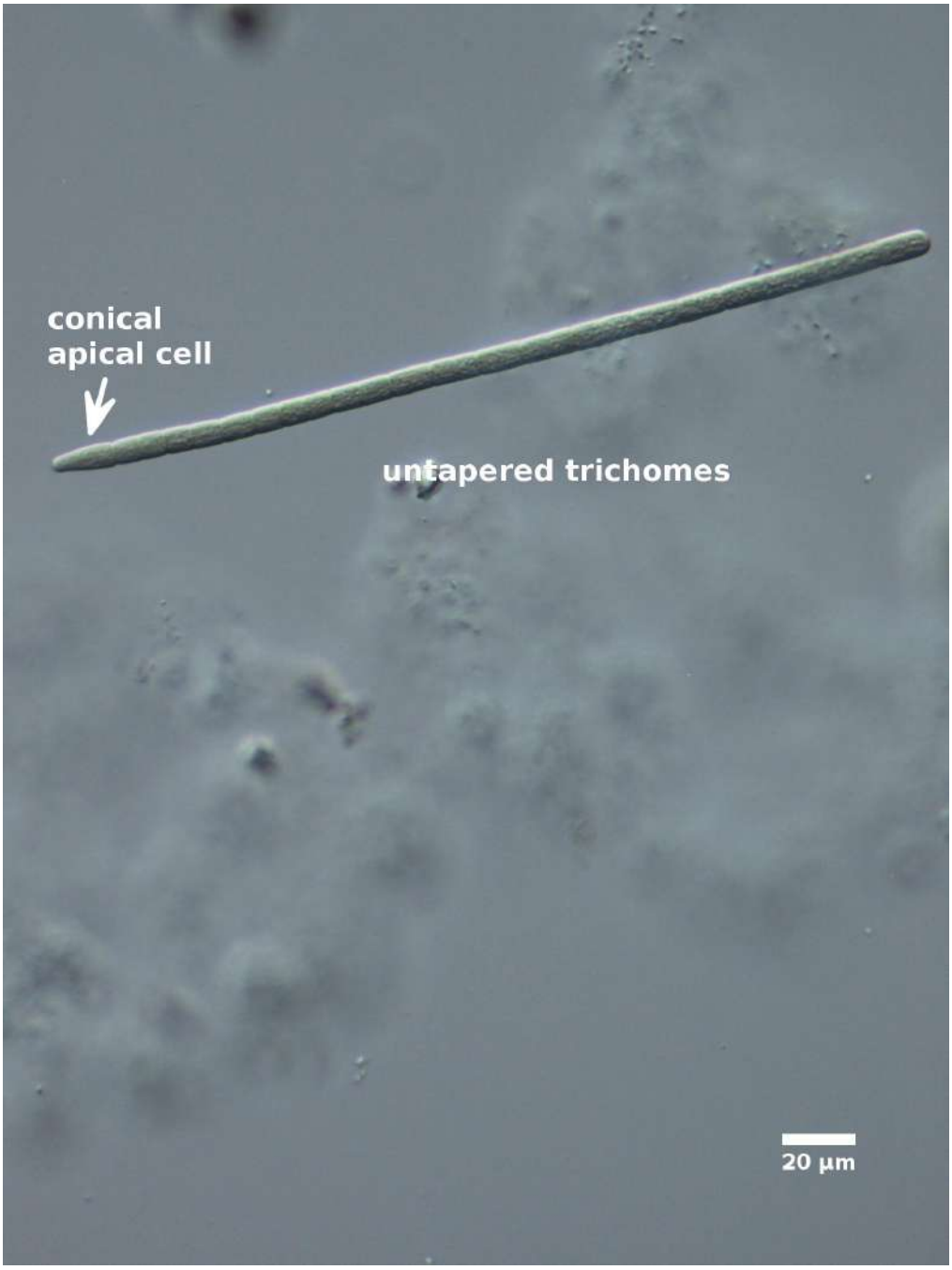


Figure 4.60: *Phormidium* IV.1 (200x DIC), Goss Lake, IWS water quality sampling site, Island County, July 22, 2013.



Figure 4.61: *Phormidium* V.1 (600x DIC), Lake Geneva, IWS water quality sampling site, Whatcom County, November 15, 2012.



Figure 4.62: *Phormidium* V.2 (400x DIC), Lake Campbell, IWS water quality sampling site, Skagit County, July 31, 2013.

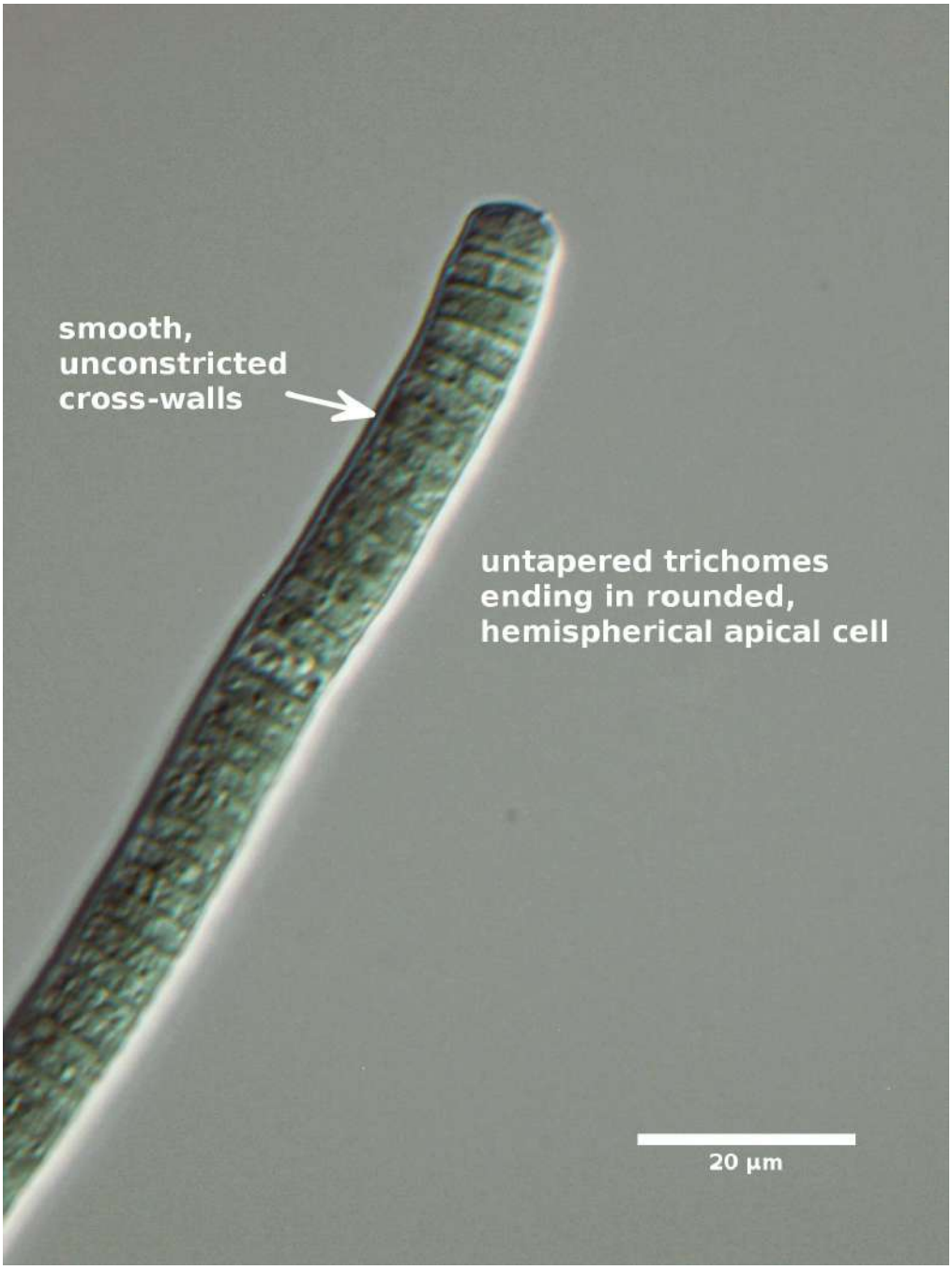


Figure 4.63: *Phormidium* V.3 (600x DIC), Lake Padden, IWS water quality sampling site, Whatcom County, October 26, 2012.

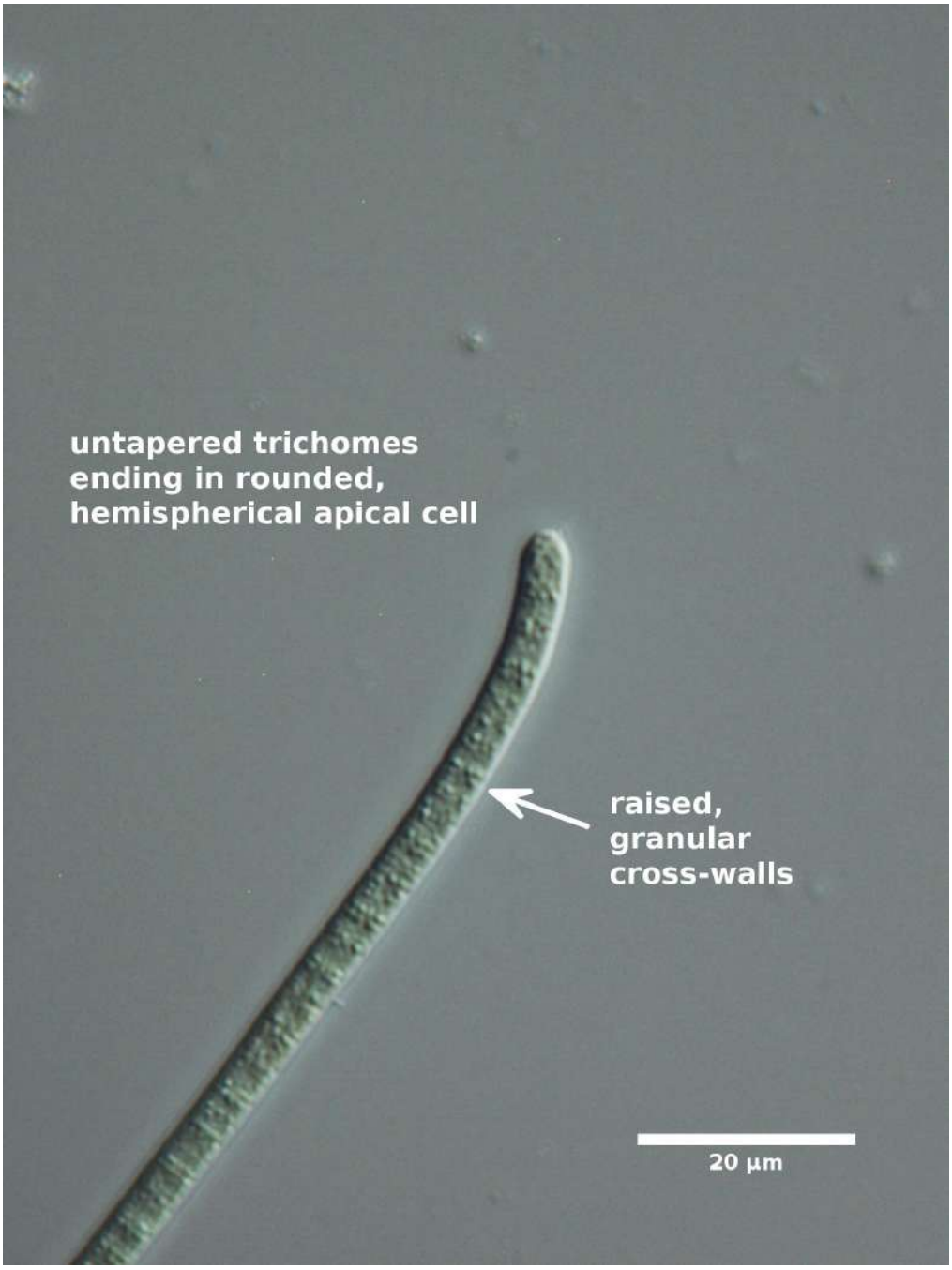


Figure 4.64: *Phormidium* V.4 (600x DIC), Monte Cristo Lake, IWS water quality sampling site, Snohomish County, August 20, 2013.

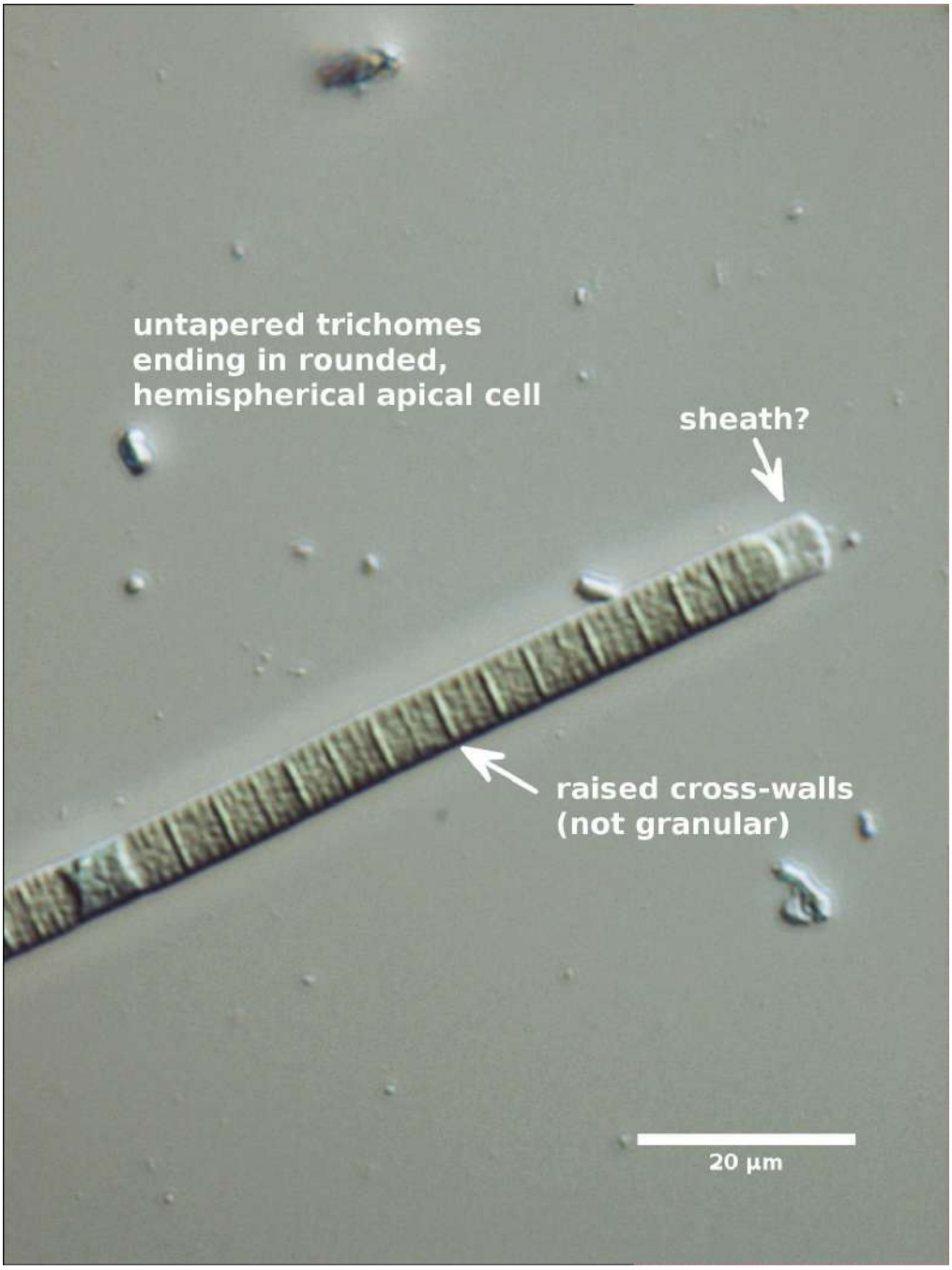


Figure 4.65: *Phormidium* V.5 (600x DIC), Lower Bagley Lake, IWS water quality sampling site, Whatcom County, August 26, 2008.



Figure 4.66: *Phormidium* V.6 (200x DIC), Heather Lake, Mt. Loop Hwy, August 19, 2014.

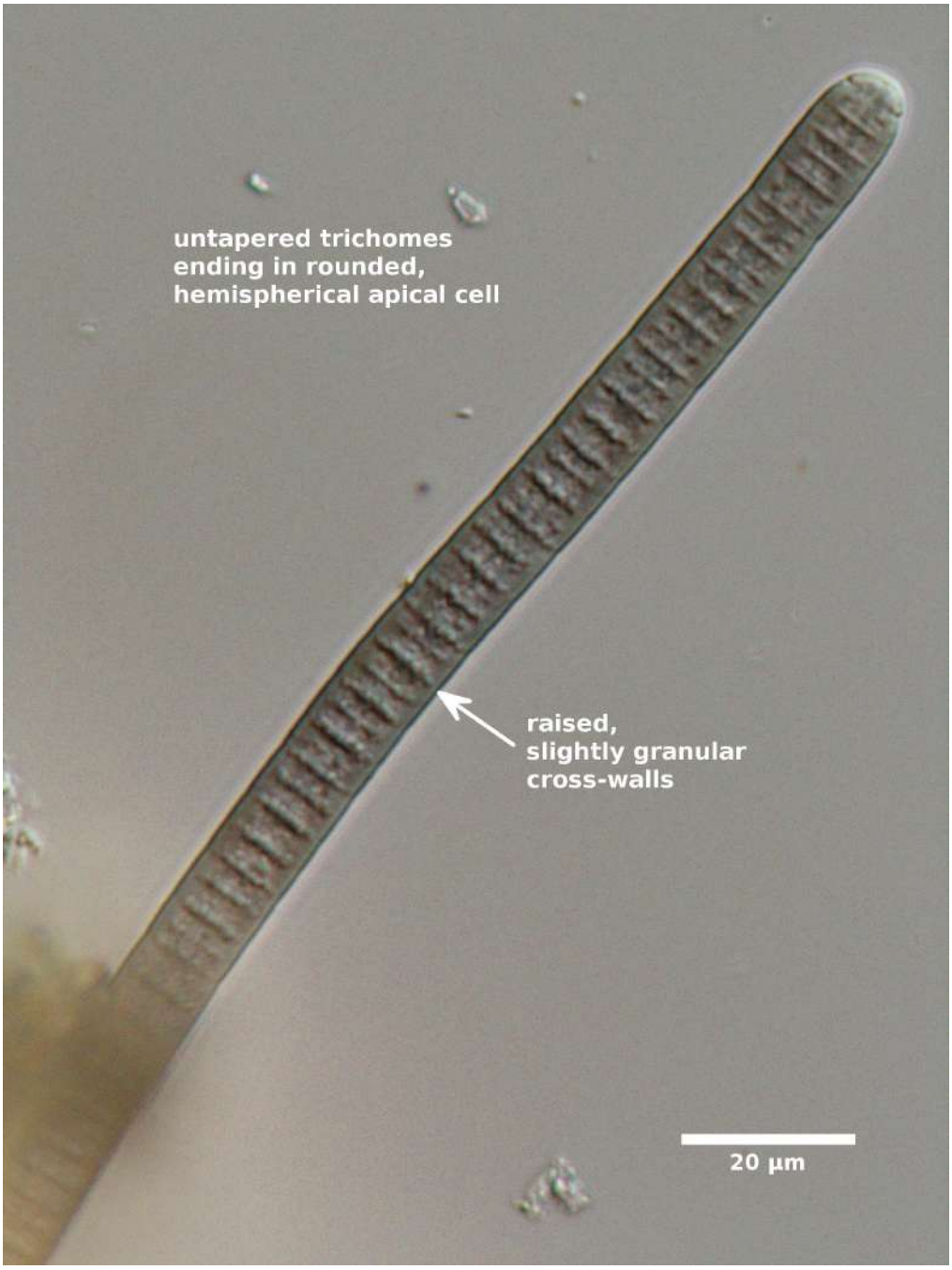


Figure 4.67: *Phormidium* V.7 (600x DIC), waterfall on Fragrance Lake trail, Whatcom County, April 12, 2014.

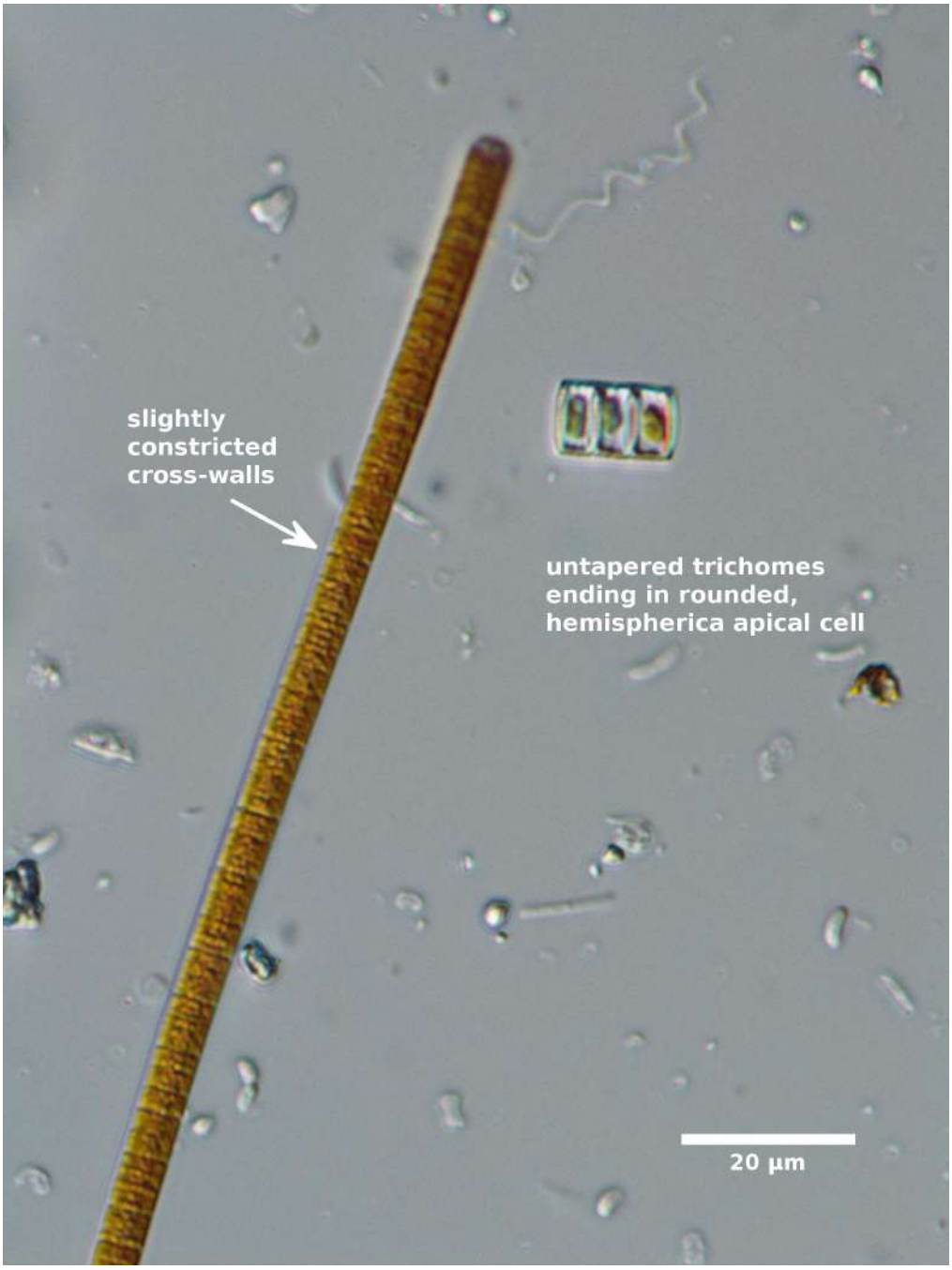


Figure 4.68: *Phormidium* V.8 (600x DIC), Canyon Lake, IWS water quality sampling site, Whatcom County, August 10, 2015.



Figure 4.69: *Phormidium* V.8 (200x DIC), Canyon Lake, IWS water quality sampling site, Whatcom County, August 10, 2015.

4.8 *Planktothrix* Anagnostidis & Komárek

Local taxon
Planktothrix isothrix (Skuja) Komárek & Komárková

Abundance
Infrequently collected; occasionally forms blooms.

Local measurements		Width	Length	Biovolume[†]
Planktothrix isothrix	min	5.9 μm	2.8 μm	105 μm^3
cells (cylinder)	med	7.0 μm	3.7 μm	144 μm^3
	max	8.0 μm	5.1 μm	181 μm^3

[†]Calculated using original measurements, not summary values.

Description
Planktothrix trichomes are simple, unbranched, and lack heterocysts, akinetes, or a sheath. The cylindrical cells are slightly shorter than wide and contain numerous gas vacuoles (Figures 4.70–4.73). The trichomes are usually planktonic and often motile. *Planktothrix isothrix* is characterized by bright green or greenish-blue cells containing numerous gas vacuoles. The trichomes are very actively motile. *Planktothrix isothrix* is often found in eutrophic waters, and can be associated with toxic blooms.

Planktothrix can be difficult to distinguish from other unbranched filamentous Cyanobacteria. The cylindrical cells help distinguish *Planktothrix* from the short, coin-like cells found in *Oscillatoria* (Section 4.6, page 394), and *Planktothrix* trichomes are not enclosed in a sheath, which distinguishes it from *Lyngbya* (Section 4.4, page 378). But *Planktothrix* closely resembles some species of *Phormidium* (Section 4.7, page 414), and there is no single morphological feature that reliably separates these two genera. *Planktothrix* trichomes lack a sheath, so they will not form sticky mats or clumps. Also, as indicated above, *Planktothrix* is more common in plankton samples from nutrient-rich lakes than *Phormidium*, although plankton samples may contained clumps of *Phormidium* that presumably dislodged from benthic mats. Finally, fresh, unpreserved *Planktothrix isothrix* cells contain gas vacuoles, which give the trichomes a distinctive mottled appearance.



Figure 4.70: *Planktothrix isothrix* (1000x DIC), Stillwaters Environmental Center pond, Kingston, WA, June 18, 2011. Photo provided by Karl Bruun, Nostoca Algae Laboratory, Bainbridge Island, WA.



Figure 4.71: *Planktothrix isothrix* (1000x DIC), Stillwaters Environmental Center pond, Kingston, WA, June 18, 2011. Photo provided by Karl Bruun, Nostoca Algae Laboratory, Bainbridge Island, WA.

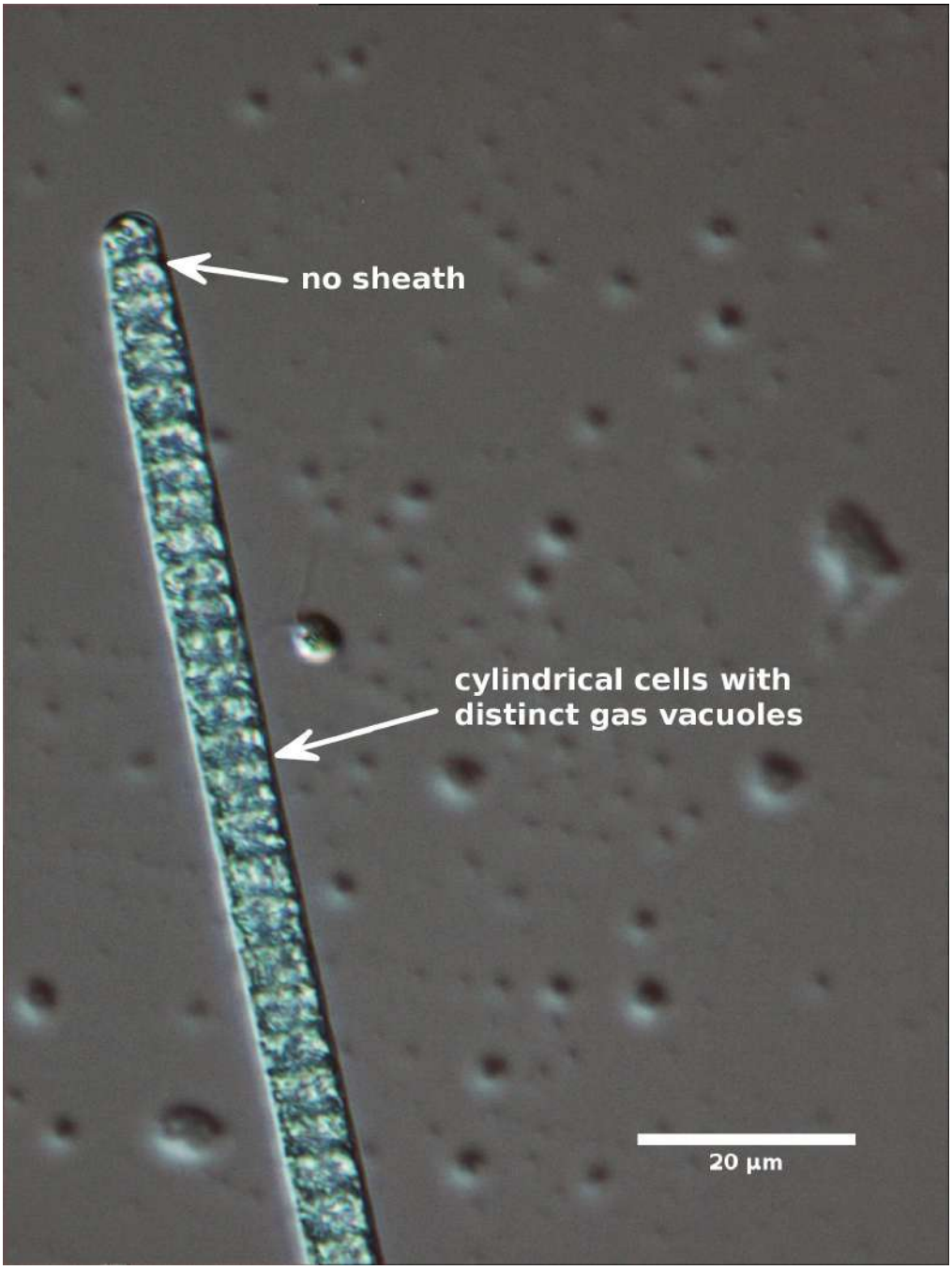


Figure 4.72: *Planktothrix isothrix* (600x DIC), Lake Ketchum, IWS water quality sampling site, Snohomish County, September 2, 2009.



Figure 4.73: *Planktothrix isothrix* (200x DIC), Lake Ketchum, IWS water quality sampling site, Snohomish County, September 2, 2009.

4.9 *Pseudanabaena* Lauterborn

Local taxa
Pseudanabaena arcuata (Skuja) Anagnostidis & Komárek?;
Pseudanabaena catenata Lauterborn;
Pseudanabaena constricta (Szafer) Lauterborn
(=*Johanseninema constrictum* [Szafer] Hasler, Dvorák & Poulícková);
Pseudanabaena limnetica (Lemmermann) Komárek;
Pseudanabaena mucicola (Naumann & Huber-Pestalozzi) Schwabe;
Pseudanabaena spp.

Abundance
Moderately common, but easily overlooked; common epiphyte in mucilage of other algae or zooplankton.

Local measurements		Width	Length	Biovolume†
Pseudanabaena arcuata?	min	1.3 μm	4.0 μm	6.24 μm^3
cells (cylinder)	med	1.6 μm	4.8 μm	9.45 μm^3
	max	1.8 μm	6.6 μm	16.8 μm^3
Pseudanabaena catenata	min	1.6 μm	2.8 μm	10.7 μm^3
cells (cylinder)	med	2.2 μm	4.5 μm	18.4 μm^3
	max	3.1 μm	9.6 μm	40.0 μm^3
Pseudanabaena constricta	min	3.8 μm	5.5 μm	42.3 μm^3
cells (spheroid)	med	4.1 μm	6.0 μm	54.5 μm^3
	max	4.5 μm	7.2 μm	76.3 μm^3
Pseudanabaena limnetica	min	1.5 μm	6.9 μm	19.6 μm^3
cells (cylinder)	med	1.8 μm	16.6 μm	37.3 μm^3
	max	2.1 μm	30.5 μm	75.2 μm^3
Pseudanabaena mucicola	min	1.4 μm	2.9 μm	5.12 μm^3
cells (cylinder)	med	1.7 μm	4.3 μm	9.43 μm^3
	max	2.4 μm	6.5 μm	16.3 μm^3

continued on next page

Local measurements		Width	Length	Biovolume[†]
Pseudanabaena sp.1	min	1.7 μm	2.4 μm	5.67 μm^3
cells (cylinder)	med	2.0 μm	3.2 μm	9.83 μm^3
	max	2.3 μm	4.0 μm	15.0 μm^3
Pseudanabaena sp.2?	min	2.4 μm	2.5 μm	19.1 μm^3
cells (cylinder)	med	2.9 μm	4.0 μm	27.6 μm^3
	max	3.2 μm	5.8 μm	35.0 μm^3

[†]Calculated using original measurements, not summary values.

Description

Most *Pseudanabaena* trichomes are tiny, pale blue-gray, and very easy to overlook. The individual cells may be cylindrical, barrel-shaped, or nearly spherical, and are usually deeply constricted at the cross-walls (Figures 4.74–4.85). Some species have very short trichomes, often consisting of only a few cells, and many are associated with the mucilage layer of other aquatic organisms.

Pseudanabaena arcuata is a specialist that grows in rotifer mucilage, especially in association with *Conochilus* (Figures 4.74–4.75). *Pseudanabaena arcuata* has short, straight trichomes that contain approximately 5–7 cylindrical cells, ending in a conical apical cell. The cells are pale blue-gray or blue-green, with constricted end-walls. The species identification is tentatively because the local specimens of *Pseudanabaena arcuata* are virtually indistinguishable from *Pseudanabaena mucicola* (Figures 4.81–4.82), which is commonly found in the mucilage surrounding planktonic Cyanobacteria. Komárek and Anagnostidis (2005) suggest that specimens listed as *Pseudanabaena mucicola*, but associated with rotifer mucilage, are probably incorrectly identified.

Pseudanabaena catenata is characterized by long (>10–20 cells), straight, solitary trichomes that are usually planktonic (Figures 4.76–4.77). The individual cells are cylindrical, with abruptly indented cross-walls that give the cells a rectangular appearance. The cells range from pale gray to olive-green and have a slightly granular cell content. This group is morphologically variable, especially with regard to the cell length, and probably includes more than one species.

Pseudanabaena constricta trichomes are solitary, straight or slightly curved, and relatively long (>10–20 cells). The individual cells are deeply constricted (bead-like), grayish, with a slightly granular cell content (Figures 4.78–4.79). The genus

of this taxon has been revised repeatedly, reflecting a lack of genetic similarity to other species of *Pseudanabaena*. Komárek and Anagnostidis (2005) included this taxon as *Komvophoron constrictum* (Szafer) Anagnostidis & Komárek, and AlgaeBase lists it as *Johanseninema constrictum* (Szafer) Hasler, Dvorák & Poulicková (AlgaeBase, downloaded October 22, 2015).

Pseudanabaena limnetica trichomes are long (>10–20 cells), straight, and solitary. The cells are pale gray, cylindrical, and have abruptly constricted cross-walls (Figure 4.80). *Pseudanabaena limnetica* resembles *Pseudanabaena catenata*, but has slightly narrower and much longer cells.

Pseudanabaena mucicola is a specialist that grows in the mucilage layer surrounding many species of Cyanobacteria (Figures 4.81–4.82). The species forms short 3–6 cell trichomes of pale blue-gray, cylindrical cells that are constricted at the cross-walls. The apical cell is bluntly pointed.

Pseudanabaena sp.1 trichomes are short, straight, and extremely motile (Figures 4.83–4.84). The individual cells are cylindrical, abruptly constricted, and pale blue-gray or slightly pinkish; the apical cells are rounded, not pointed or conical.

Figure 4.85 shows several epiphytic trichomes that are tentatively identified as a species of *Pseudanabaena*. The trichomes are relatively long (>10–20 cells), consisting of short, cylindrical cells with constricted cross-walls. The local specimens were all collected as epiphytes on *Tolypothrix* (Section 3.14, page 343) in a nutrient-rich, low elevation lake.



Figure 4.74: *Pseudanabaena arcuata*? (100x phase contrast), Lake Whatcom, IWS water quality sampling site, Whatcom County, November 2, 2011.

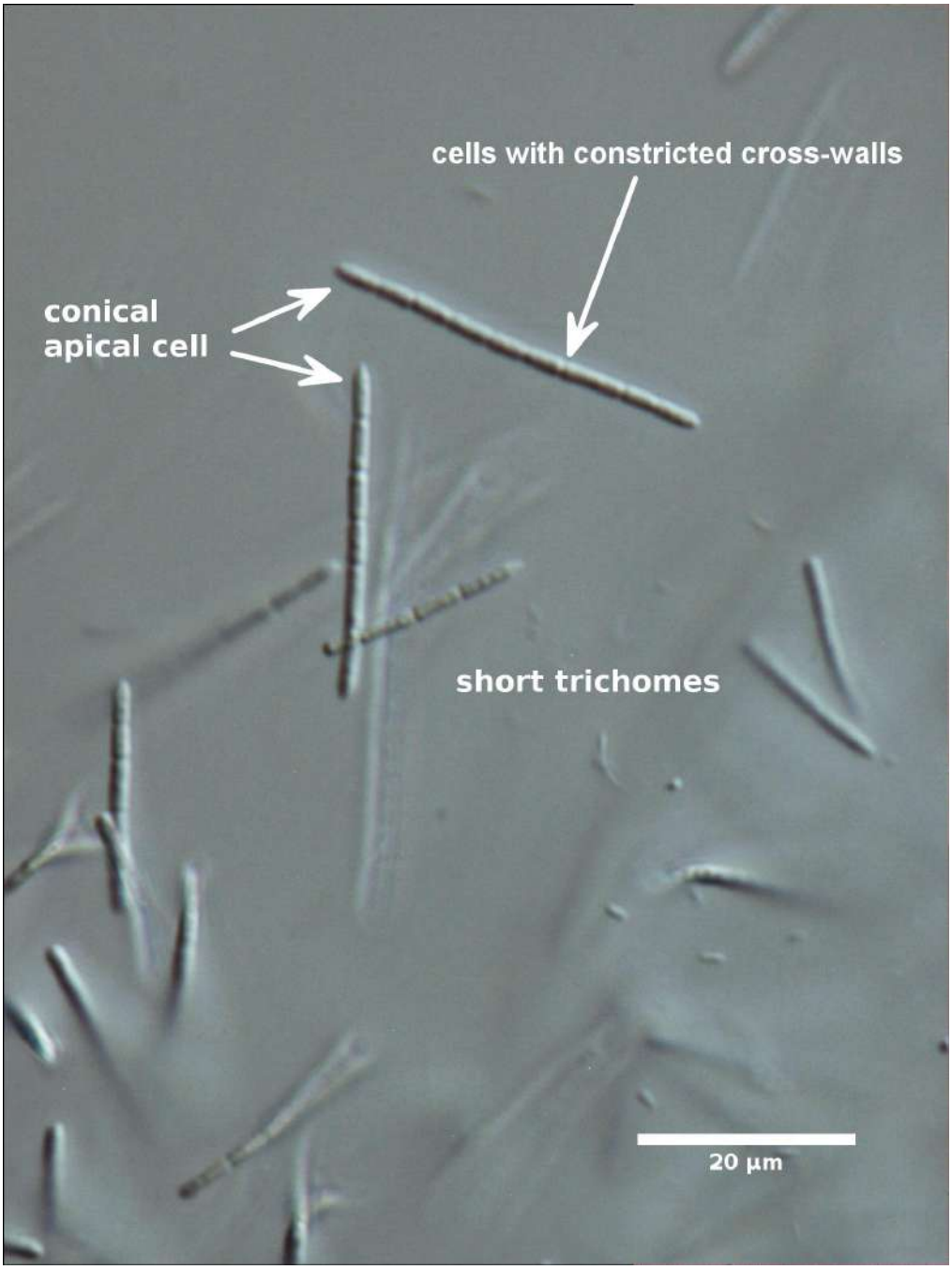


Figure 4.75: *Pseudanabaena arcuata*? (600x DIC), Lake Whatcom, IWS water quality sampling site, Whatcom County, November 2, 2011.

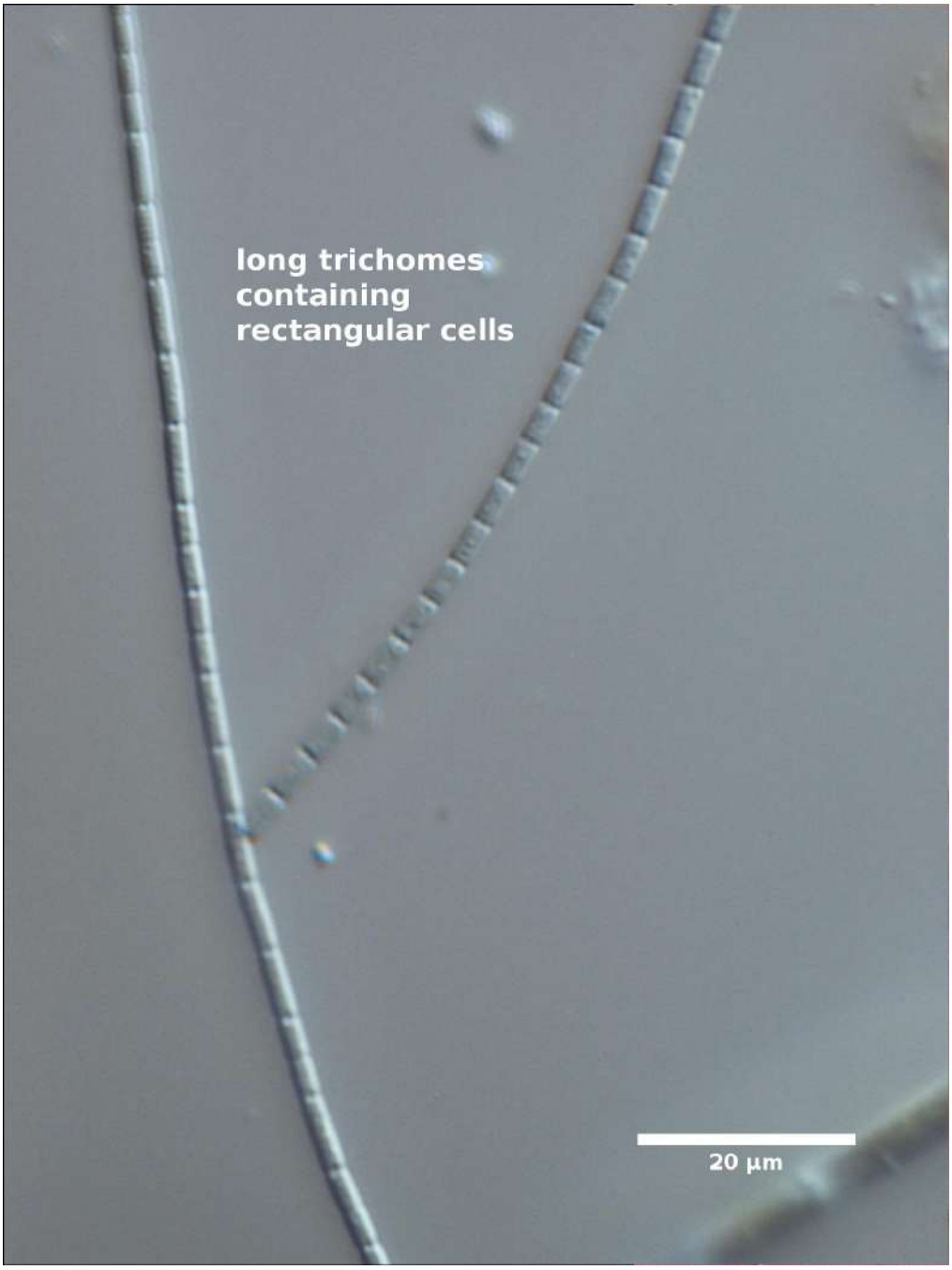


Figure 4.76: *Pseudanabaena catenata* (600x DIC), Lake Fazon, IWS water quality sampling site, Whatcom County, September 23, 2008.



Figure 4.77: *Pseudanabaena catenata* (600x DIC), Lake Fazon, IWS water quality sampling site, Whatcom County, August 17, 2009.

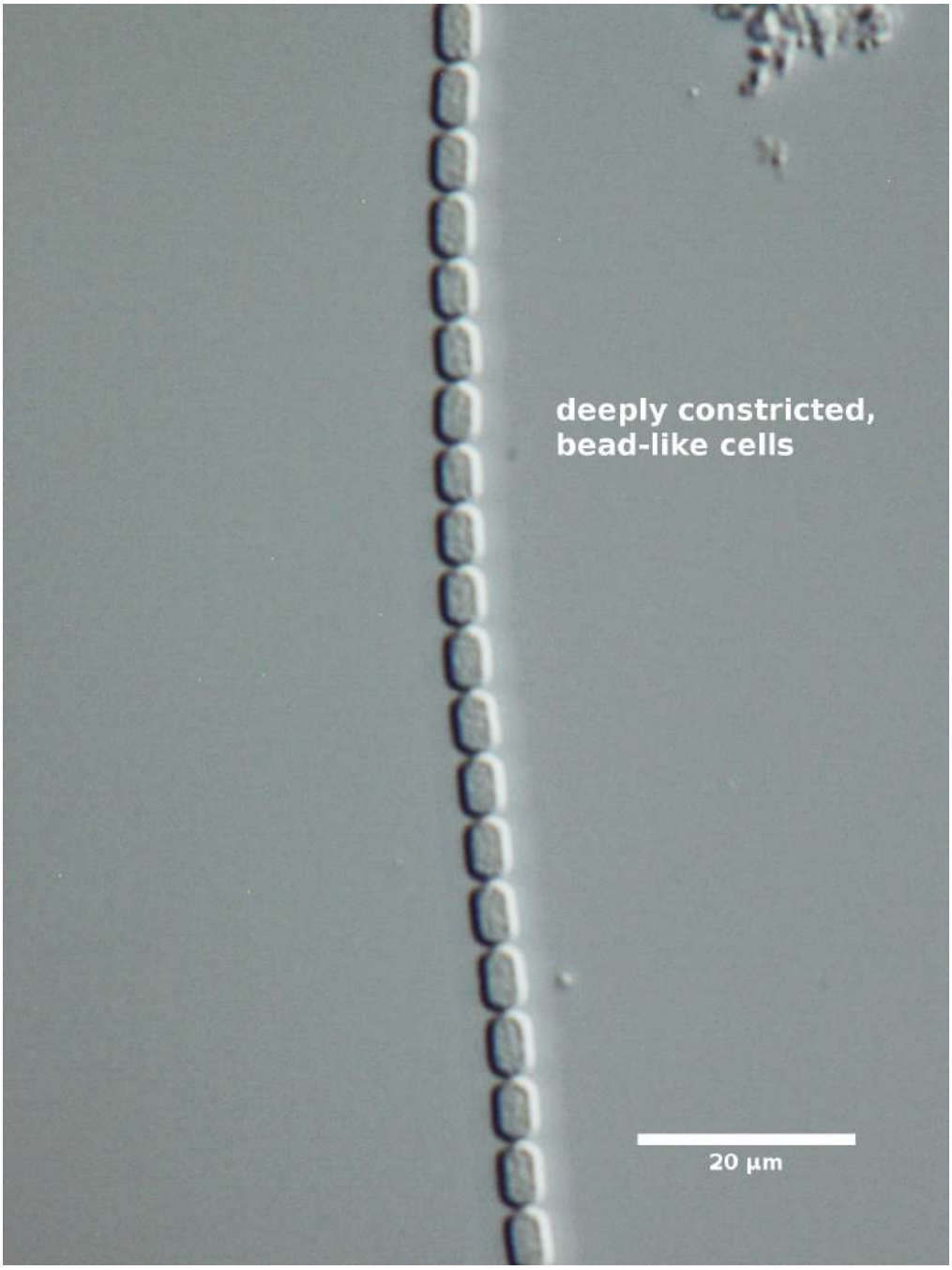


Figure 4.78: *Pseudanabaena constricta* (600x DIC), Coal Lake, IWS water quality sampling site, Snohomish County, August 20, 2013.

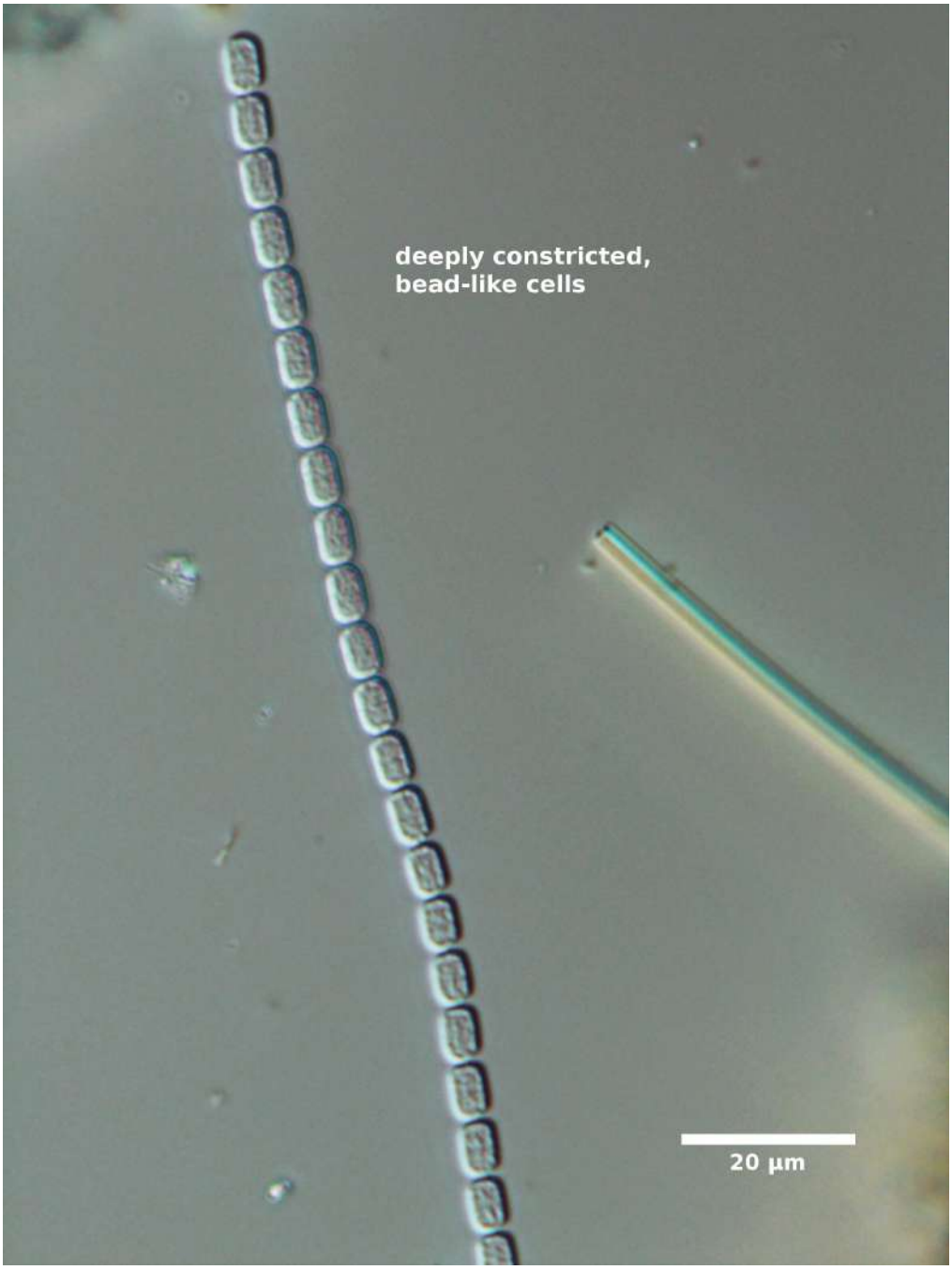


Figure 4.79: *Pseudanabaena constricta* (600x DIC), stream along Klipsun trail, Whatcom County, May 7, 2015.

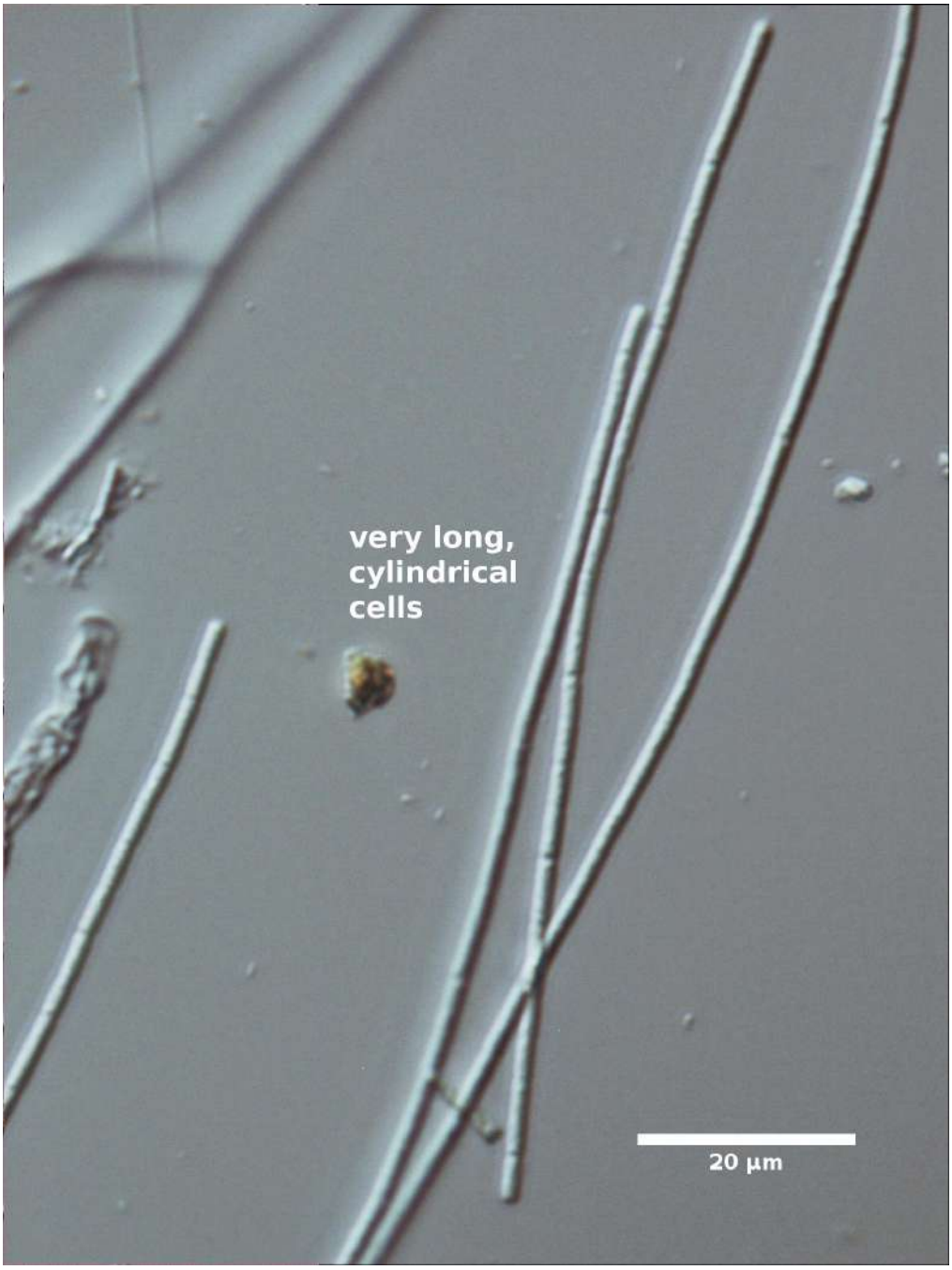


Figure 4.80: *Pseudanabaena limnetica* (600x DIC), Lake Fazon, IWS water quality sampling site, Whatcom County, August 20, 2009.

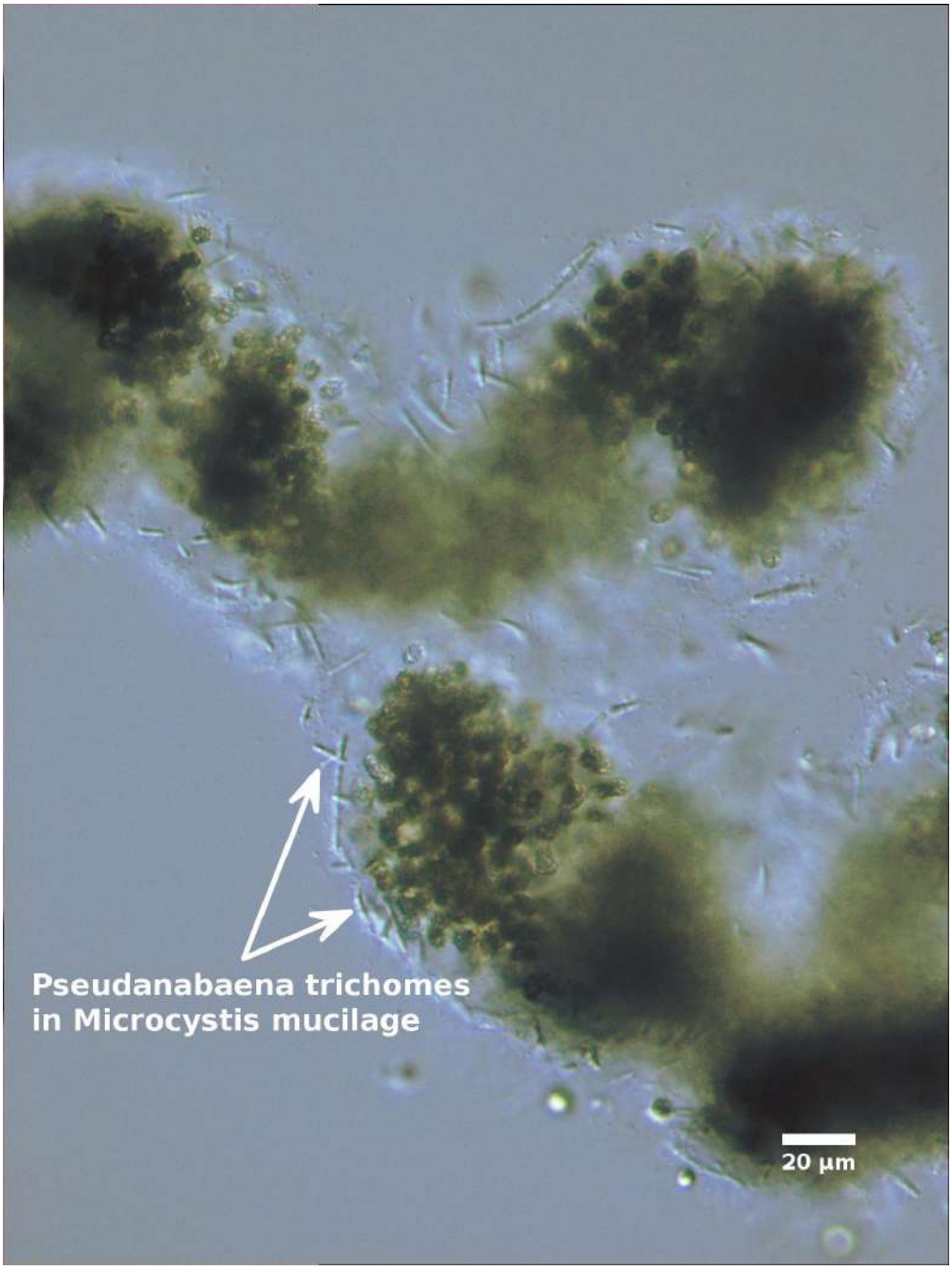


Figure 4.81: *Pseudanabaena mucicola* (200x DIC), Lone Lake, IWS water quality sampling site, Island County, July 14, 2010.

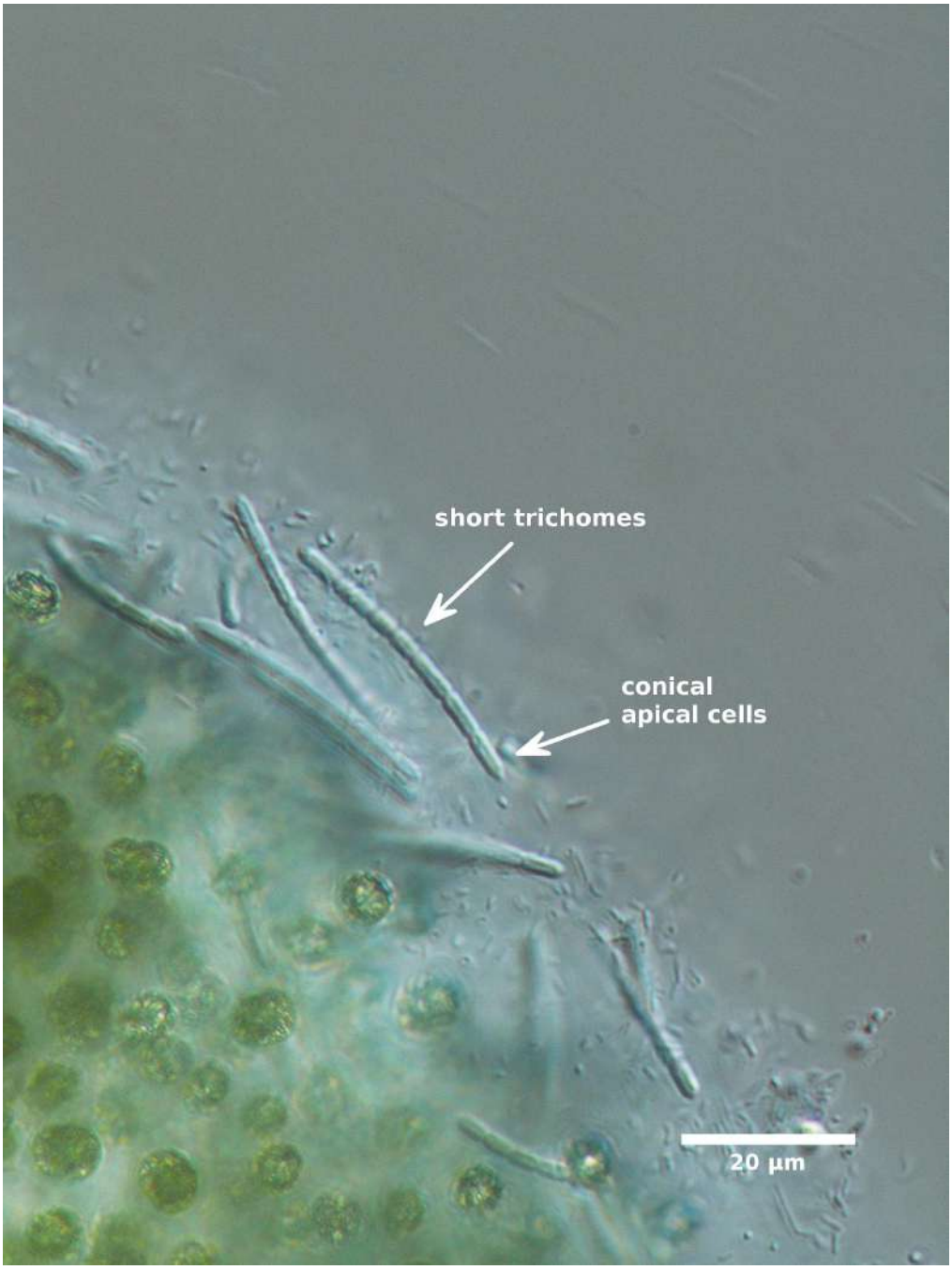


Figure 4.82: *Pseudanabaena mucicola* (600x DIC), Lone Lake, IWS water quality sampling site, Island County, August 4, 2014.

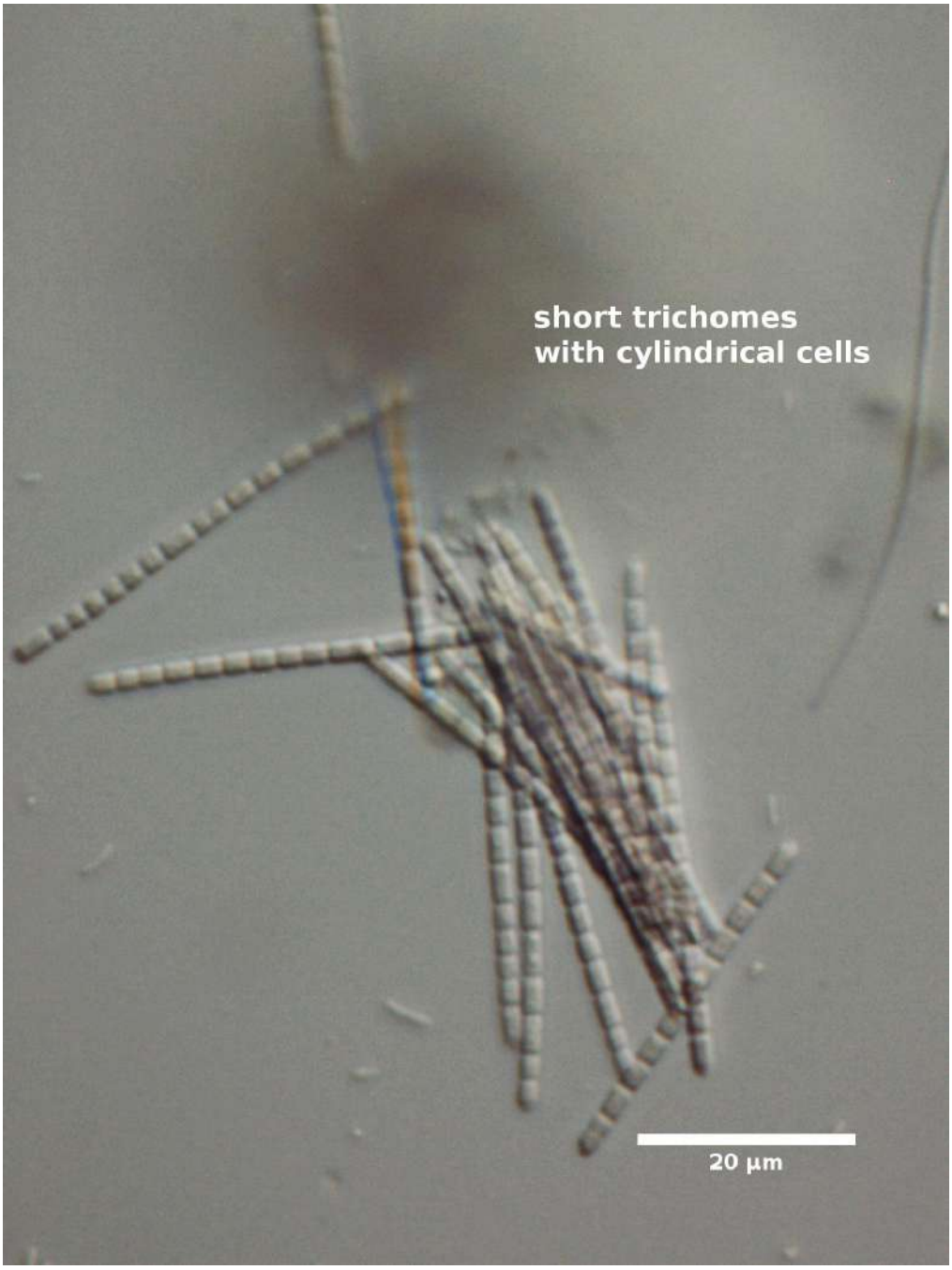


Figure 4.83: *Pseudanabaena* sp.1 (600x DIC), Lake Padden, IWS water quality sampling site, Whatcom County, October 26, 2012.



Figure 4.84: *Pseudanabaena* sp.1 (200x DIC), Lake Padden, IWS water quality sampling site, Whatcom County, October 26, 2012.

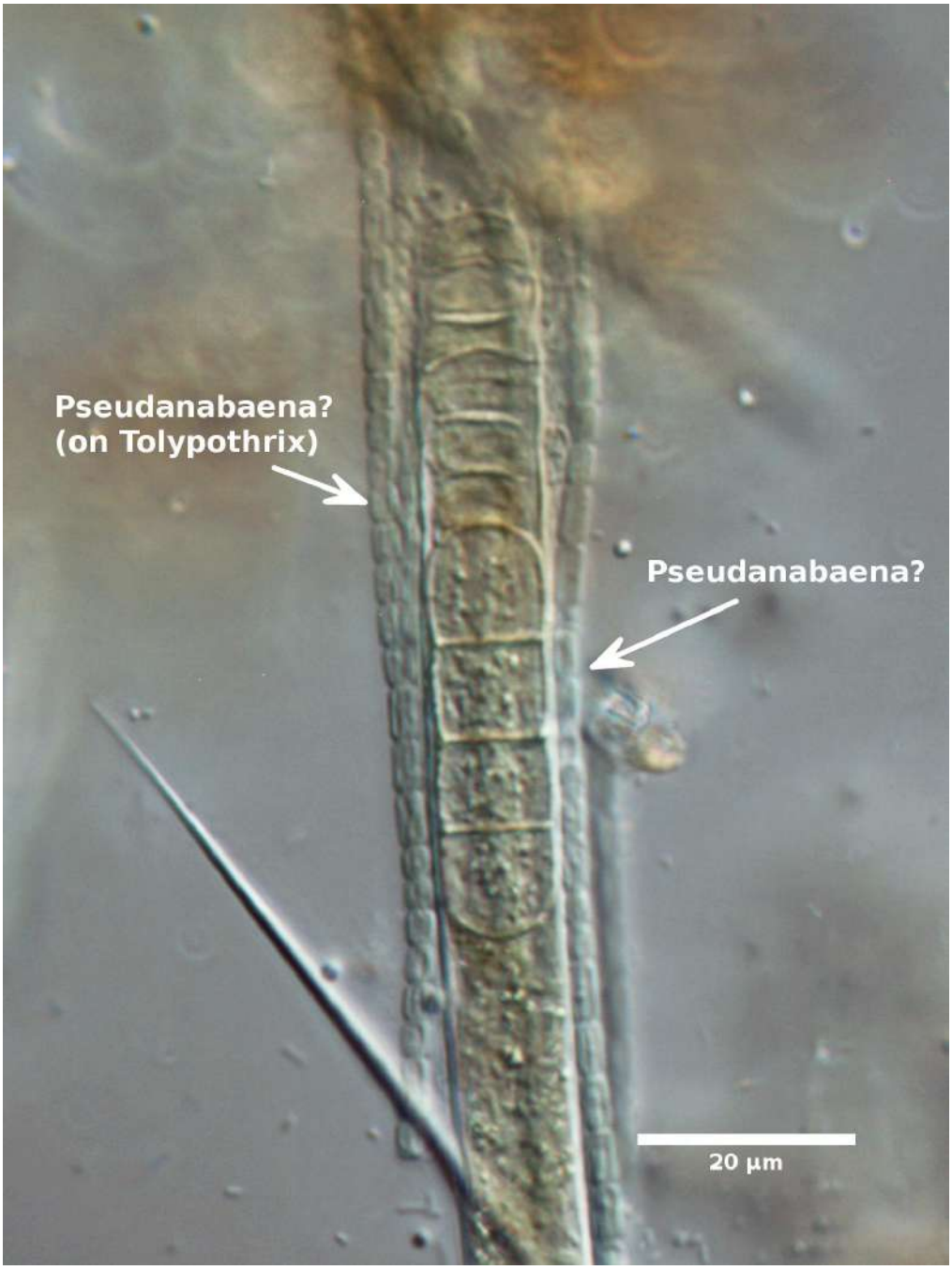


Figure 4.85: *Pseudanabaena* sp.2? (600x DIC), Lake Terrell, IWS water quality sampling site, Whatcom County, September 21, 2012.

4.10 *Schizothrix* Kützing ex Gomont

Local taxon
Schizothrix facilis (Skuja) Anagnostidis?

Abundance
Infrequently collected in plankton samples; may form mats on wet, rocky surfaces.

Local measurements		Width	Length	Biovolume[†]
Schizothrix facilis?	min	2.4 μm	2.1 μm	9.50 μm^3
cells (cylinder)	med	2.6 μm	2.7 μm	15.4 μm^3
	max	4.5 μm	4.1 μm	63.6 μm^3

[†]Calculated using original measurements, not summary values.

Description
Schizothrix facilis trichomes are unbranched and surrounded by a thick mucilage that often extends beyond the end of the trichome (Figures 4.86–4.87). The individual cells are cylindrical and approximately equal in width and length or slightly longer than wide. The filaments usually form dense sticky mats attached to a solid substrate, and are often yellowish, orange, red, brown, or violet. The taxonomy of this genus is very complex (Komárek and Anagnostidis, 2005), so both the genus and species identifications are tentative.

The specimens in Figures 4.86–4.87 were collected from a cold, clear seep near a waterfall in the North Cascades. The trichomes were firmly attached to wet stones in the seep, forming a sticky orange mat.

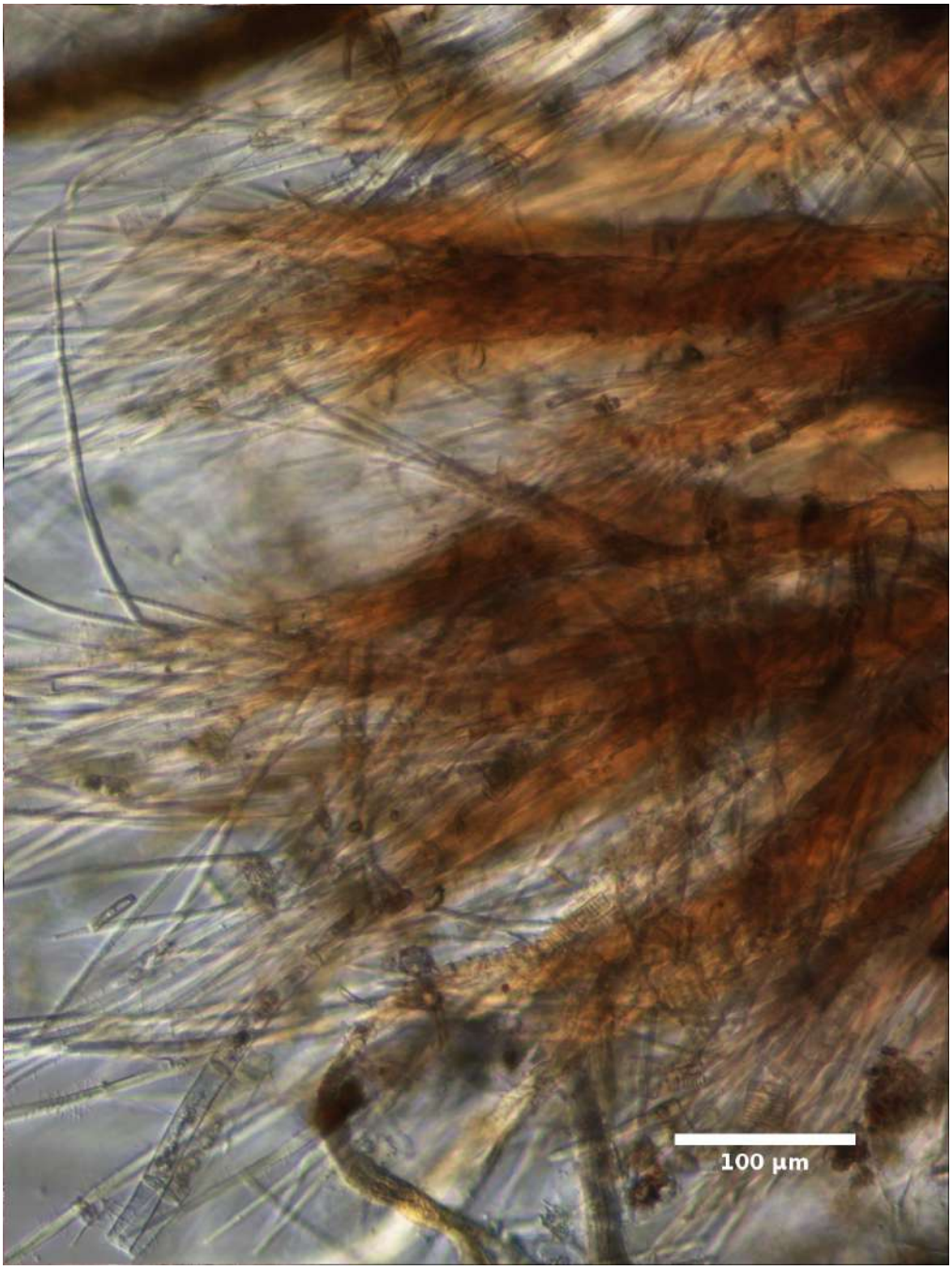


Figure 4.86: *Schizothrix facilis*? (100x DIC), seep on trail to Lake Serene near Bridal Veil Falls, Mt. Loop Hwy, August 15, 2011.



Figure 4.87: *Schizothrix facilis*? (600x DIC), seep on trail to Lake Serene near Bridal Veil Falls, Mt. Loop Hwy, August 15, 2011.

4.11 *Tychonema* Anagnostidis & Komárek

Local taxa
Tychonema bornetti (Zukal) Anagnostidis & Komárek?;
Tychonema tenue (Skuja) Anagnostidis & Komárek?

Abundance
Moderately common, but easily overlooked.

Local measurements		Width	Length	Biovolume[†]
Tychonema bornetti?	min	9.5 μm	4.7 μm	416 μm^3
cells (cylinder)	med	10.9 μm	6.0 μm	551 μm^3
	max	15.1 μm	7.9 μm	1,340 μm^3
Tychonema tenue?	min	7.0 μm	4.3 μm	175 μm^3
cells (cylinder)	med	7.3 μm	5.5 μm	242 μm^3
	max	7.8 μm	8.6 μm	400 μm^3

[†]Calculated using original measurements, not summary values.

Description
Tychonema trichomes are unbranched, untapered, and lack heterocysts, akinetes, or a visible sheath (Figures 4.88–4.94). The individual cells are cylindrical (not coin-like) and usually only slightly shorter than wide. The most distinctive feature of this genus is the intensely vacuolated cell contents (keritomized), which makes the individual cells appear to be empty. Most taxa are solitary, planktonic, and nonmotile, or at least lacking the active twisting, twitching, or gliding motility that characterizes *Oscillatoria* (Section 4.6, page 394), *Geitlerinema* (Section 4.3, page 372), *Phormidium* (Section 4.7, page 414), and other similar taxa.

Tychonema bornetii has wide cells ($\geq$10 μm) that are nearly colorless, but may have a slight reddish tint (Figures 4.88–4.91). The cell walls are unconstricted, but the cross-walls may be granulated (or not!). The local specimens appear to have two morphological forms: a blue-gray variation with distinctly granulated cross-walls (Figures 4.88–4.89) and a reddish variation with smooth cross-walls (Figure 4.90–4.91). The published descriptions for this species are inconsistent; John, et al. (2011) attribute some of the species variation to morphological responses to

environmental conditions. Due to the uncertainty in the species description, all specimens $\geq$10 μm wide are tentatively listed as *Tychonema bornetti*.

Tychonema tenue has narrower cells ($\leq$7 μm) that are pale blue-gray or nearly colorless (Figures 4.92–4.94). The cell walls are unconstricted, but should be distinctly granulated. This species is described as being associated with cold, acidic water (Komárek and Anagnostidis, 2005), and all of the local specimens were collected from cold, slightly acidic, high elevation lakes. The specimen from Boardman Lake (Figure 4.92) has granulated cross-walls, but the specimens from Bear Lake (Figures 4.93–4.94) appear to have smooth cross-walls. Given the similarities in habitat and trichome width, along with the general uncertainty for species separations in this genus, both variations are listed as *Tychonema tenue*.



Figure 4.88: *Tychonema bornetti*? (200x DIC), Big Twin Lake (Winthrop area), eastern Washington, June 18, 2014.



Figure 4.89: *Tychonema bornetti*? (200x DIC), Big Twin Lake (Winthrop area), eastern Washington, June 18, 2014.

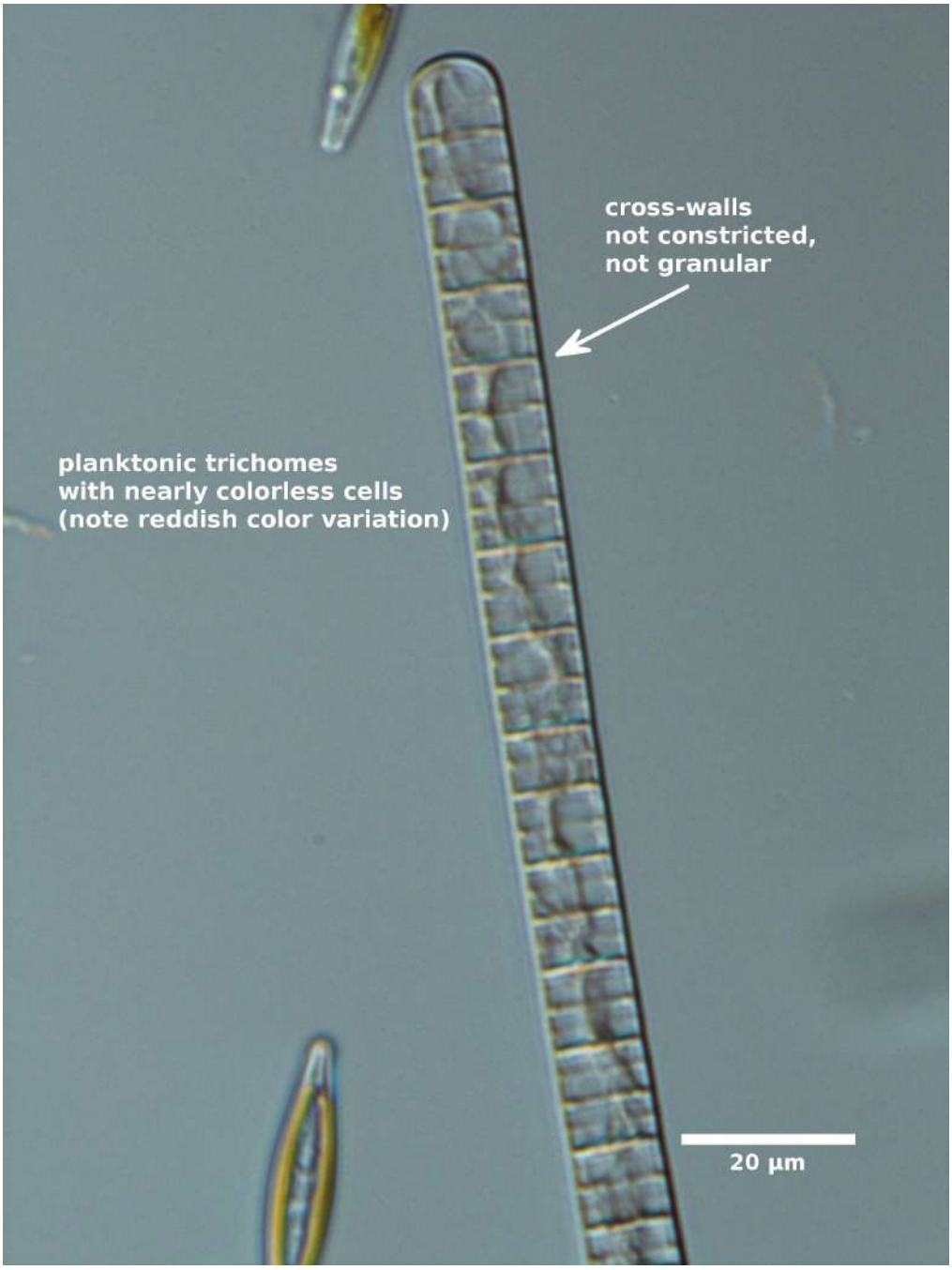


Figure 4.90: *Tychonema bornetti*? (600x DIC), Lake Ames, King County, May 11, 2015.



Figure 4.91: *Tychonema bornetti*? (600x DIC), Lake Everett, IWS water quality sampling site, Skagit County, August 5, 2015.

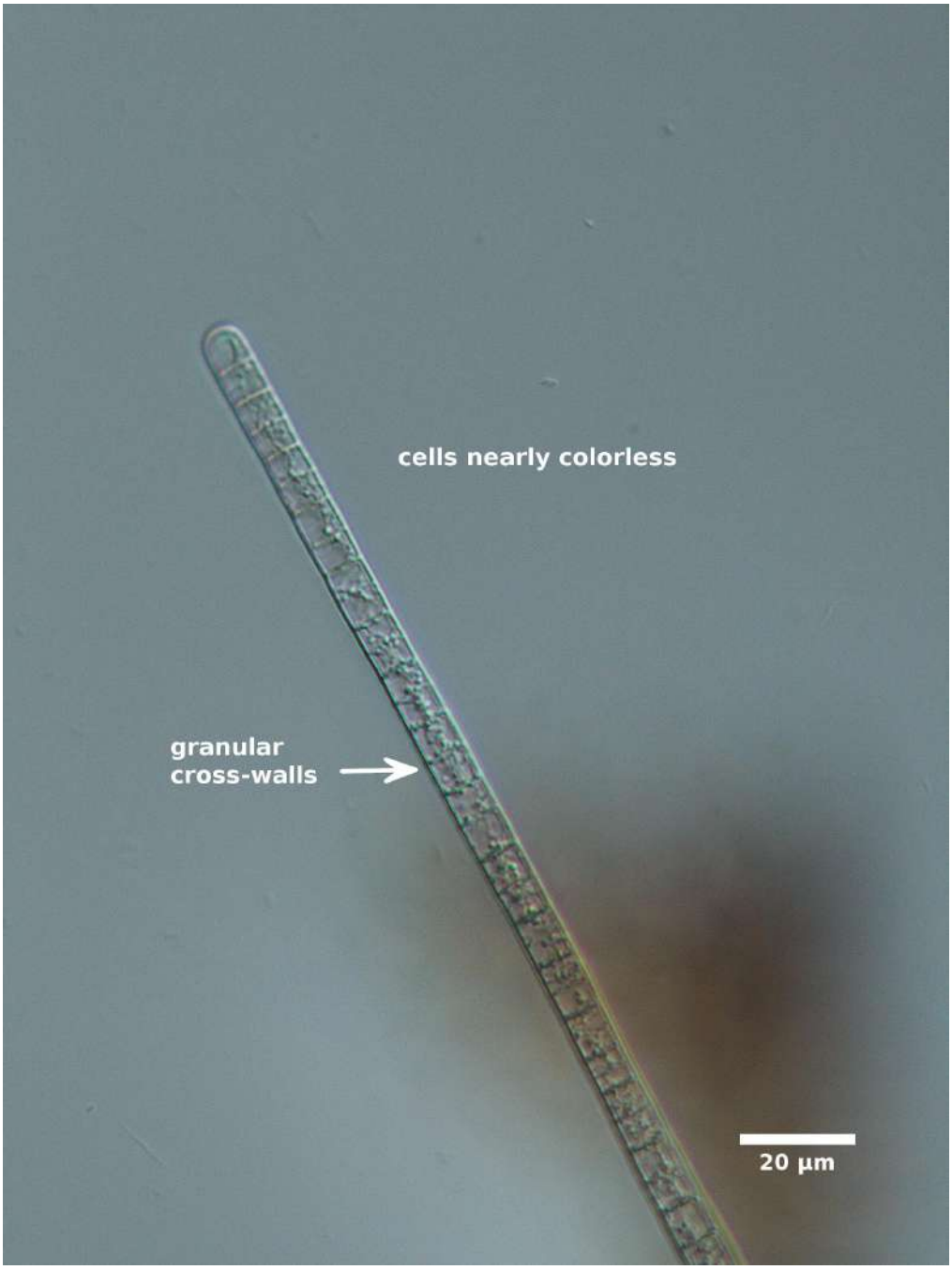
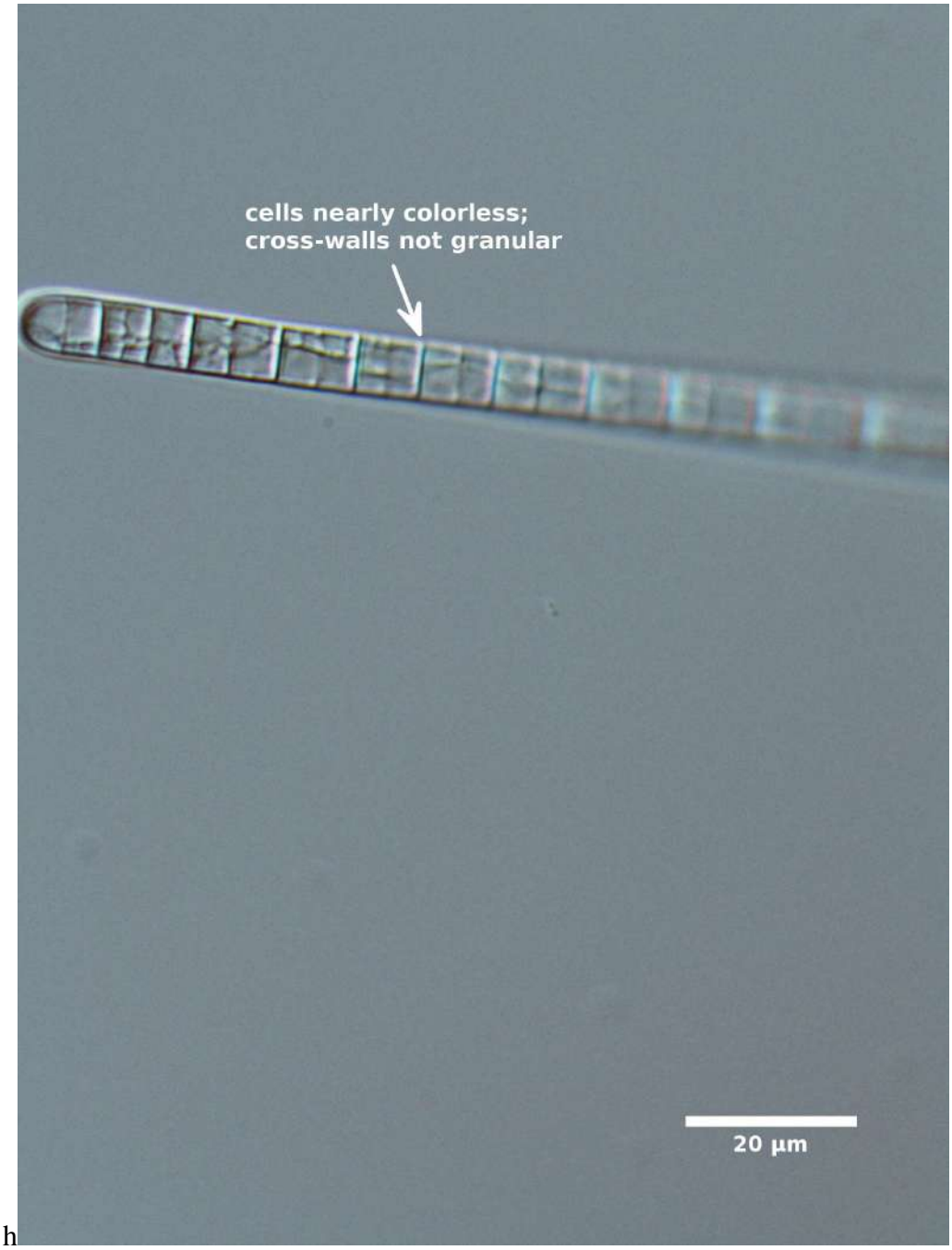


Figure 4.92: *Tychonema tenue*? (400x DIC), Boardman Lake, Mt. Loop Hwy, August 28, 2014.



Figure 4.93: *Tychonema tenue*? (200x DIC), Bear Lake, IWS water quality sampling site, Snohomish County, August 28, 2014.



h

Figure 4.94: *Tychonema tenue*? (600x DIC), Bear Lake, IWS water quality sampling site, Snohomish County, August 28, 2014.

Chapter 5

Biovolume Calculations

Algal counts can be misleading because the cells vary in size from very tiny (<2 μm diameter) to nearly macroscopic (>1 mm diameter). In addition, some cells are too tiny or indistinct to count accurately, so the algae are counted as colonies. Algal biovolume is often used to adjust for variations in size by estimating the total volume occupied by each type of algae.

Algal biovolume is estimated by collecting cell or colony measurements from a representative number of algae, then the biovolume is estimated using a similar geometric shape. Cell biovolume estimates are included for many of the species in this volume using the equations listed in Table 5.1 (page 476). Examples of each shape and solved biovolume calculations are illustrated in Figures 5.1–5.4.

The biovolume approach used in this manual is based on personal observations and recommendations by EPA (2010), Hillebrand, et al., (1999), Olenina, et al., (2006), and Sun & Liu (2003); all equations in Table 5.1 are from Hillebrand, et al. (1999) or EPA (2010). My approach was to use the simplest geometric approximation because the accuracy that is saved by using a "better" geometric shape is rarely worth the extra time required to make complex measurements.

Where possible, the biovolume summary statistics were based on at least 5–10 cells collected from different sites. Estimates based on fewer than 5 cells were flagged in the cell dimension tables. The biovolume summary statistics (minimum, median, maximum) were generated from original cell measurements, not averages, and were rounded to three significant figures. Colony biovolume estimates were not included because they are too variable.

Shape	**Measurements**[†]	**Equation**
Sphere: spherical cells; circular in cross-section (Figure 5.1)	width (W)	$\frac{\pi}{6} \times \mathrm{W}^3$
Spheroid: oval or bluntly elliptical cells; circular in cross-section (Figure 5.2)	width (W); length (L)	$\frac{\pi}{6} \times \mathrm{W}^2 \times \mathrm{L}$
Cylinder: cylindrical cells with flat ends; circular in cross-section (Figure 5.3)	width (W); length (L)	$\frac{\pi}{4} \times \mathrm{W}^2 \times \mathrm{L}$
Cylinder+2 half-spheres: bluntly rounded cylindrical cells; circular in cross-section (Figure 5.4)	length (L); width (W)	$\pi \times \mathrm{W}^2 \times \left(\frac{\mathrm{L}}{4} - \frac{\mathrm{W}}{6}\right)$

[†]Width is equivalent to diameter; length is equivalent to height.

Table 5.1: Biovolume equations (adapted from EPA, 2010; Hillebrand, et al., 1999; Olenina, et al., 2006; Sun & Liu, 2003).



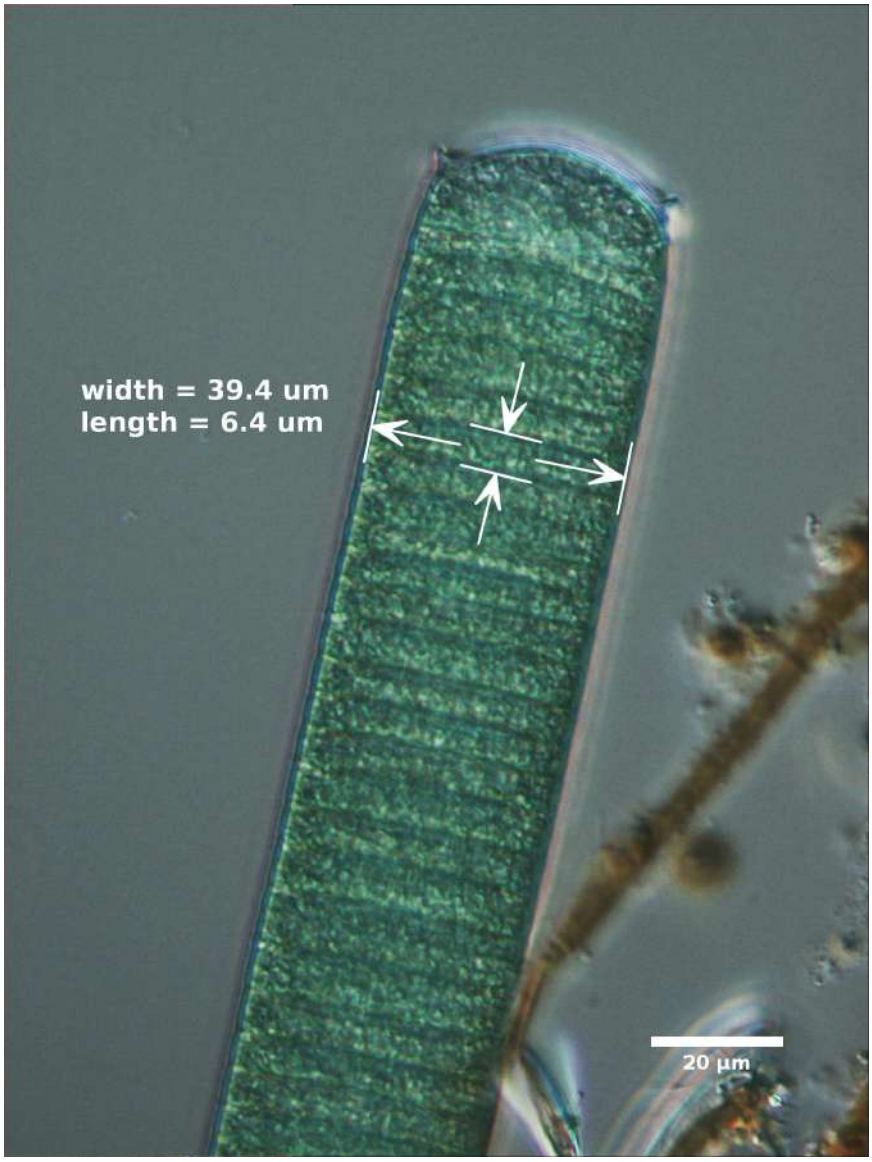
$$\begin{aligned} \text{Sphere} &= \frac{\pi}{6} \times \mathrm{W}^3 \\ &= \frac{\pi}{6} \times 10.2^3 = 556\,\mu\mathrm{m}^3\,(3\,\text{sig. figs}) \end{aligned}$$

Figure 5.1: Biovolume example - sphere (*Chroococcus*).



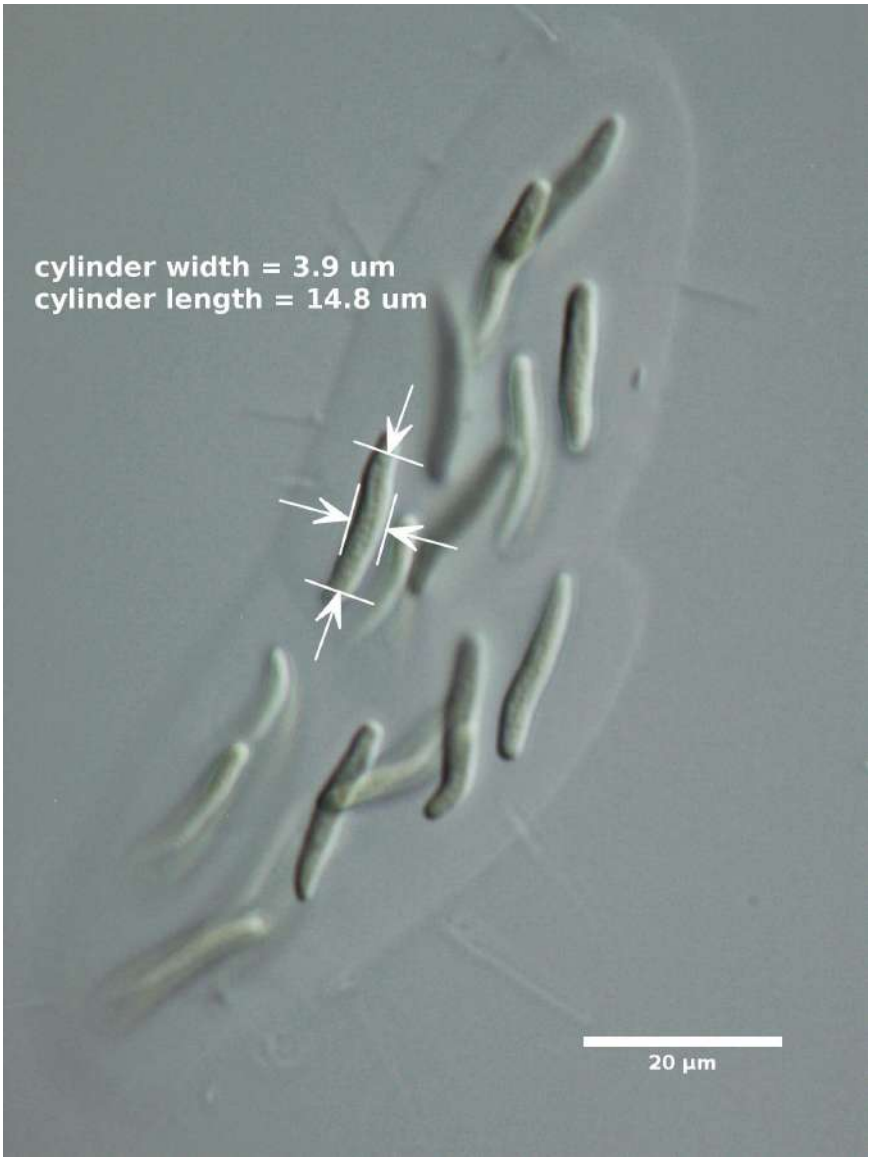
$$\begin{aligned}
\text{Spheroid} &= \frac{\pi}{6} \times \mathrm{W}^2 \times \mathrm{L} \\
&= \frac{\pi}{6} \times 23.1^2 \times 46.2 = 12,908\,\mu\mathrm{m}^3 \\
&= 12,900\,\mu\mathrm{m}^3\,(3\,\text{sig. figs})
\end{aligned}$$

Figure 5.2: Biovolume example - spheroid (*Cyanothece*).



$$\begin{aligned}
\text{Cylinder} &= \frac{\pi}{4} \times \mathrm{W}^2 \times \mathrm{L} \\
&= \frac{\pi}{4} \times 39.4^2 \times 6.4 = 7,803\,\mu\mathrm{m}^3 \\
&= 7,800\,\mu\mathrm{m}^3\,(3\,\text{sig. figs})
\end{aligned}$$

Figure 5.3: Biovolume example - cylinder (*Oscillatoria*).



$$\begin{aligned} \text{Cylinder} + 2\,\text{half spheres} &= \pi \times \mathrm{W}^2 \times \left(\frac{\mathrm{L}}{4} - \frac{\mathrm{W}}{6}\right) \\ &= \pi \times 3.9^2 \times \left(\frac{14.8}{4} - \frac{3.9}{6}\right) = 146\,\mu\mathrm{m}^3 \end{aligned}$$

Figure 5.4: Biovolume example - cylinder+2 half-spheres (*Rhabdoderma*).

Chapter 6

References

Bellinger, E. G. and D. C. Sigee. 2015. Freshwater Algae, Second Edition. Identification, Enumeration, and Use as Bioindicators. John Wiley & Sons, LTD., West Sussex, UK.

Brodie, J. and J. Lewis. 2007. Unravelling the Algae; the Past, Present, and Future of Algal Systematics. The Systematics Association Special Volume Series #75, CRC Press, New York, NY.

Dillard, G. E. 2008. Common Freshwater Algae of the United States. An Illustrated Key to the Genera (Excluding the Diatoms). J. Cramer Publishers, Berlin, GE.

EPA. 2010. Standard Operating Procedure for Phytoplankton Analysis, LG401, Revision 05, February 2010. U. S. Environmental Protection Agency, Washington, D. C.

Guiry, M. D. and Guiry, G. M. 2016. AlgaeBase. World-wide electronic publication, National University of Ireland, Galway. www.algaebase.org.

Hillebrand, H., C-D. Dürselen, D. Kirschtel, U. Pollingher, and T. Zohary. 1999. Biovolume calculations for pelagic and benthic microalgae. J. Phycology 35: 403–424.

John, D. M., B. A. Whitton, and A. J. Brook. 2011. The Freshwater Algal Flora of the British Isles: An Identification Guide to Freshwater and Terrestrial Algae, Second Edition. Cambridge University Press, Cambridge UK.

Joosten, A. M. T. 2006. Flora of the blue-green algae of the Netherlands I. The non-filamentous species of inland waters. KNNV Publishing, Utrecht, The Netherlands.

Kearns, K. D. and M. D. Hunter. 2001. Toxin-producing *Anabaena flos-aquae* induces settling of *Chlamydomonas reinhardtii*, a competing motile alga. Microbial Ecology 42:80–86.

Komárek, J. 2013. Cyanoprokaryota, Part 3: Heterocystous Genera. Süßwasserflora von Mitteleuropa, Vol. 19/3, B. Büdel, G. Gärtner, L. Krienitz, M. Schagerl (Eds). Springer Spektrum, Heidelberg, GE.

Komárek, J. and K. Anagnostidis. 1998. Cyanoprokaryota, Part 1: Chroococcales. Süßwasserflora von Mitteleuropa, Vol. 19/1, H. Ettl, J. Gerloff, H. Heynit, D. Mollenhauer (Eds). Spektrum Academic Press, Heidelberg, GE.

Komárek, J. and K. Anagnostidis. 2005. Cyanoprokaryota, Part 2: Oscillatoriales. Süßwasserflora von Mitteleuropa, Vol. 19/2, B. Büdel, G. Gärtner, L. Krienitz, M. Schagerl (Eds). Spektrum Academic Press, Heidelberg, GE.

Komárek, J. and Komáreková. 2003. Phenotype diversity of the cyanoprokaryotic genus *Cylindrospermopsis* (Nostocales); review 2002. Czech Phycology 3: 1 - 30.

Lee, R. E. 2008. Phycology, Fourth Edition. Cambridge University Press, New York, NY.

Olenina, I., S. Hajdu, L. Edler, A. Andersson, N. Wasmund, S. Busch, J. Göbel, S. Gromisz, S. Huseby, M. Huttunen, A. Jaanus, P. Kokkonen, I. Ledaine, and E. Niemkiewicz. 2006. Biovolumes and Size-Classes of Phytoplankton in the Baltic Sea. Baltic Sea Environment Proceeding No. 106, Baltic Marine Environment Protection Commission, Helsinki, Finland.

Prescott, G. W. 1962. Algae of the Western Great Lakes Area, Revised Edition. WM. C. Brown Company Publishers, Dubuque, IO.

Sun, J. and D. Liu. 2003. Geometric models for calculating cell biovolume and surface area for phytoplankton. J. Plankton Research 25: 1331–1346.

Van den Hoek, C., D. G. Mann, and H. M. Jahns. 1995. Algae: An Introduction to Phycology. Cambridge University Press, New York, NY.

Wacklin, P., L. Hoffman, and J. Komárek. 2009. Nomenclatural validation of the genetically revised cyanobacterial genus *Dolichospermum* (Ralfs ex Bornet et Flahault) comb. nova. Fottea 9: 59–64.

Wehr, J. D., R. G. Sheath, and J. P. Kociolek. 2015. Freshwater Algae of North America: Ecology and Classification, Second Edition. Academic Press, London.

WHO. 1999. Toxic Cyanobacteria in Water: A Guide to their Public Health Consequences, Monitoring and Management. Ed. I. Chorus and J. Bartram, World Health Organization, St. Edmundsbury Press, Suffolk, Great Britain.