Cyanobacteria Ecological Strategies and Impacts on Human Health

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algae

cyanobacteria

HABs

microcystin

saxitoxin

*paralytic shellfish poisoning (PSP)

amnesic shellfish poisoning (ASP)

cyanotoxins

*coastal & marine

Google

algae	42 million
cyanobacteria	3.4 million
HABs	467 K
microcystin	307 K
saxitoxin	218 K
paralytic	139 K
amnesic	51 K
cyanotoxins	113 K

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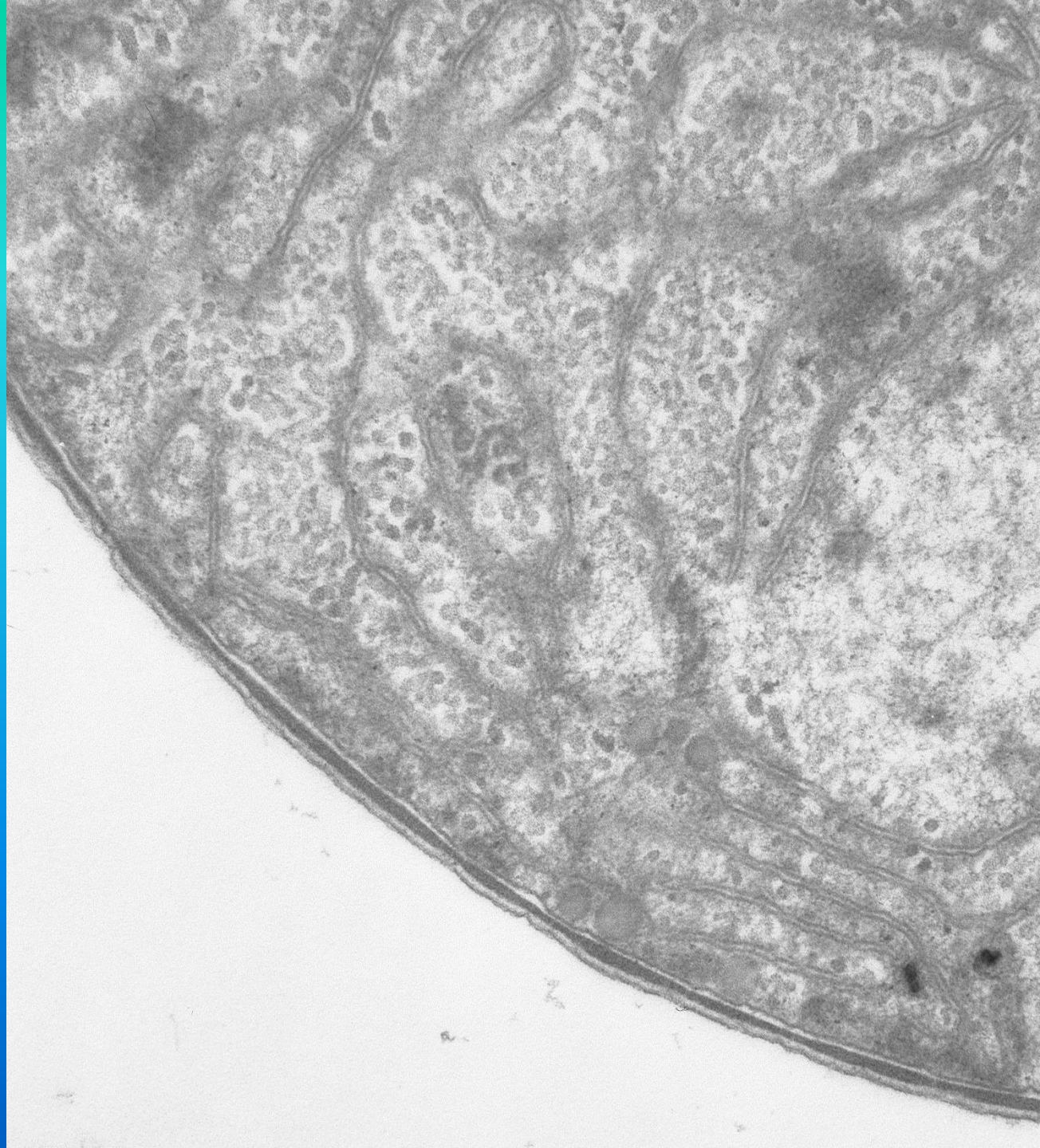
Cyanobacteria

(aka blue-green algae; cyanoHABs)

- gram negative bacteria
- pigments in thylakoids



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Where are cyanobacteria a problem?

Lakes, reservoirs, **rivers**, streams, wetlands

Estuaries and coastal systems

Marine systems

CyanoHABs

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Why are we concerned about cyanoHABs?

Toxicity

Hypoxia

Taste and odors

Aesthetics

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So why do we care about them? Some produce cyanobacteria toxins

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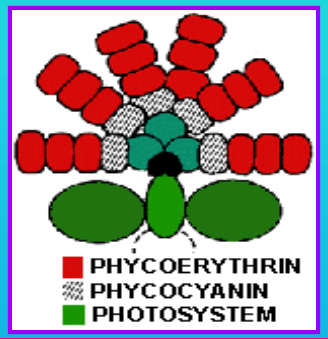
Ecological strategies for cyanobacteria: a sample

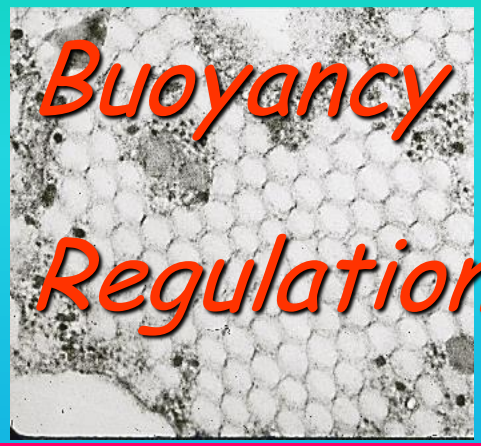
Morphology

grazing, floating

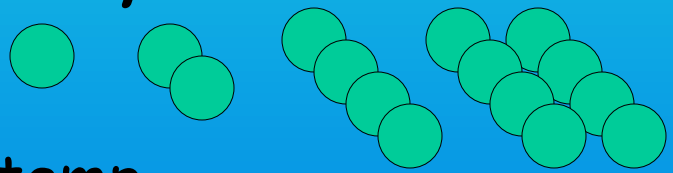
Pigments



Buoyancy Regulation

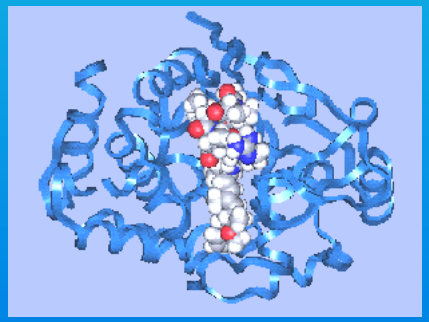


Rapid Growth



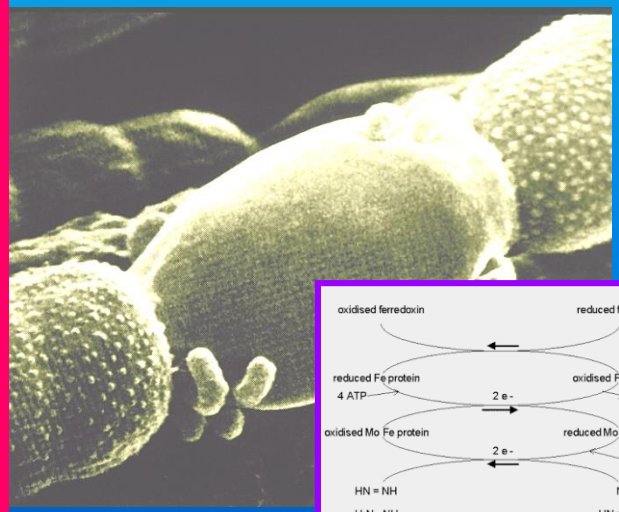
temp

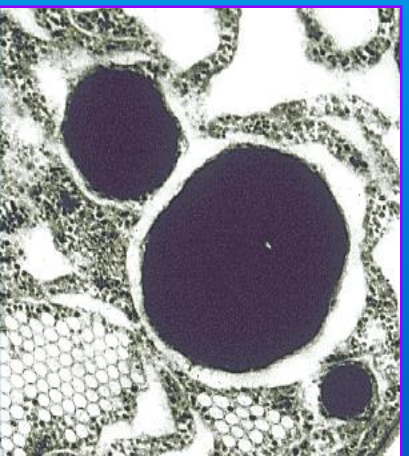
Toxicity



microcystin
LR complex

Nitrogen Fixation





trace, P,
C, N

Nutrient Storage

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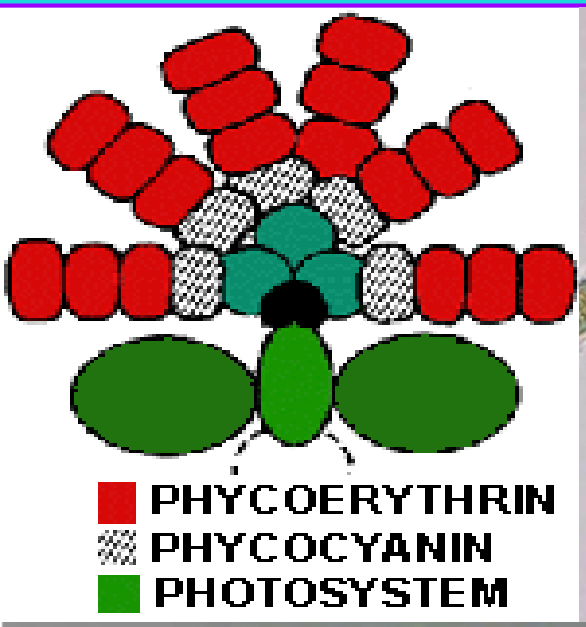
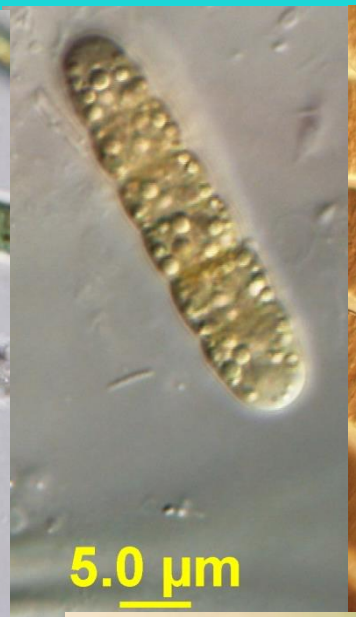
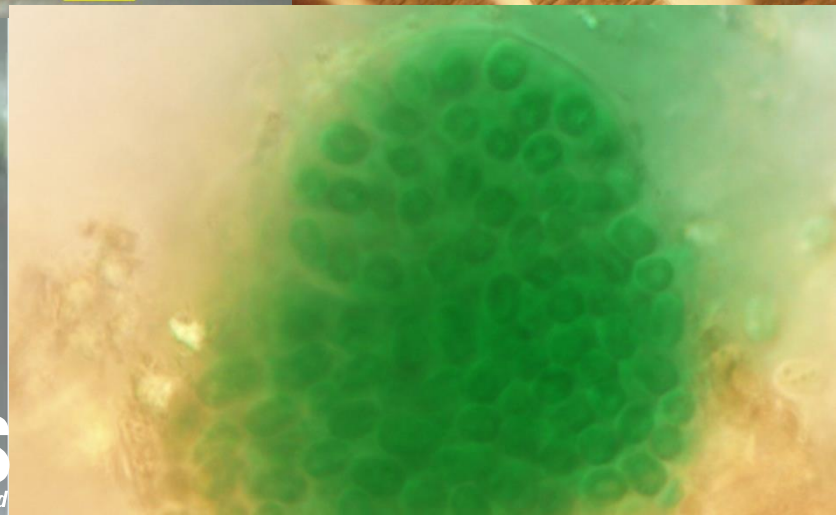
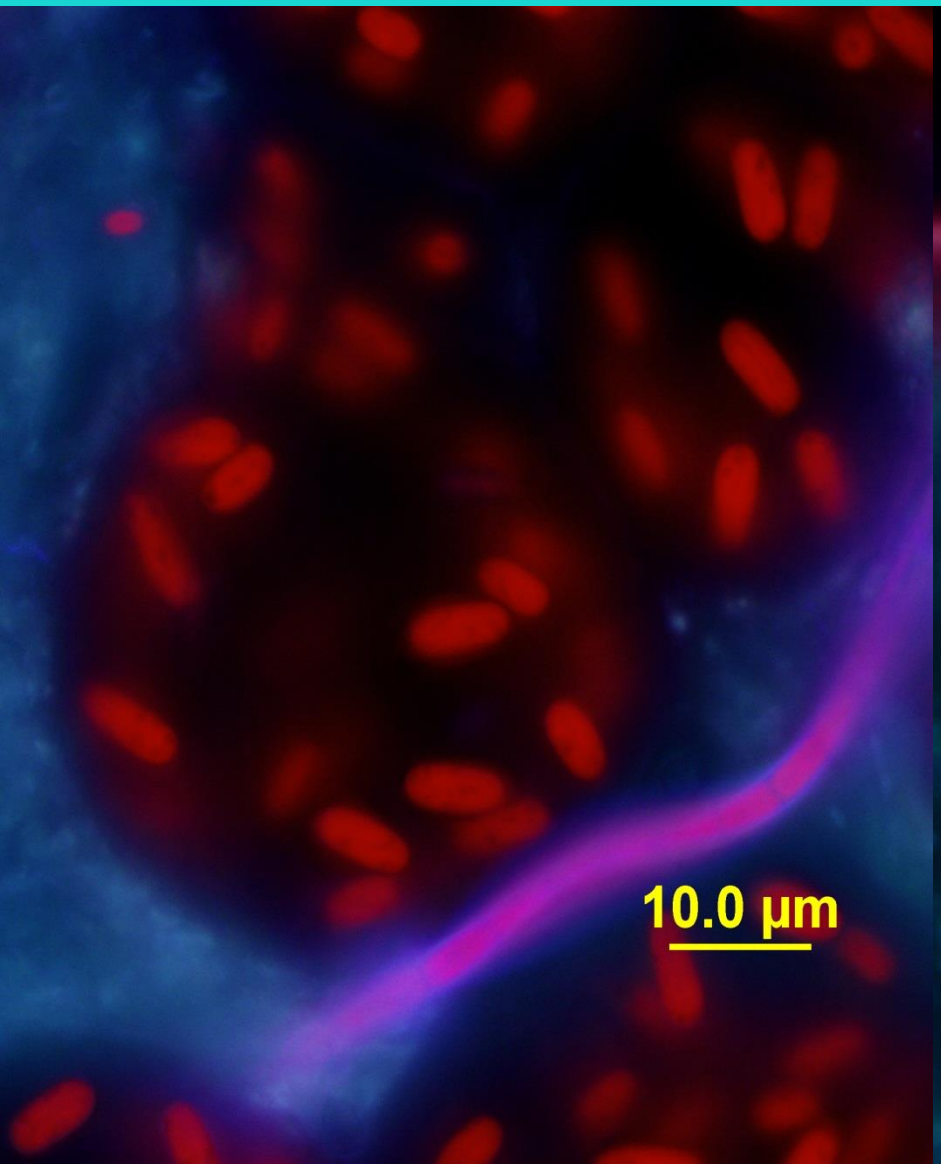
Ecological Strategies: complimentary pigments for maximizing photosynthesis

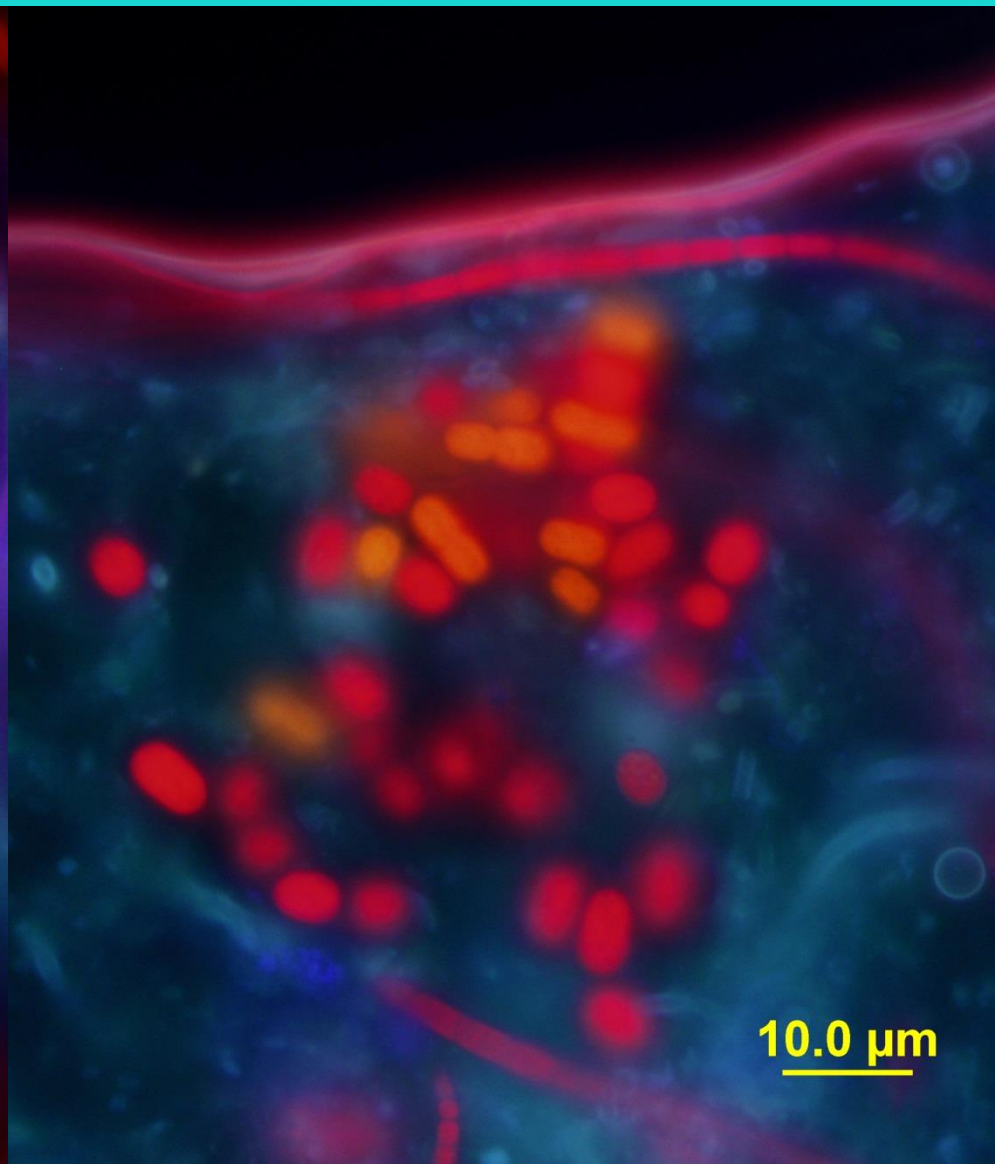






Ecological Strategies: complimentary pigments for maximizing photosynthesis





Ecological Strategies: internal structures for optimizing placement in the water column

Gas Vesicles: *Buoyancy regulation and vertical migration*

Low light

$(C_6H_{12}O_6)n$

Nutrients scavenged whilst near lake sediments or thermocline

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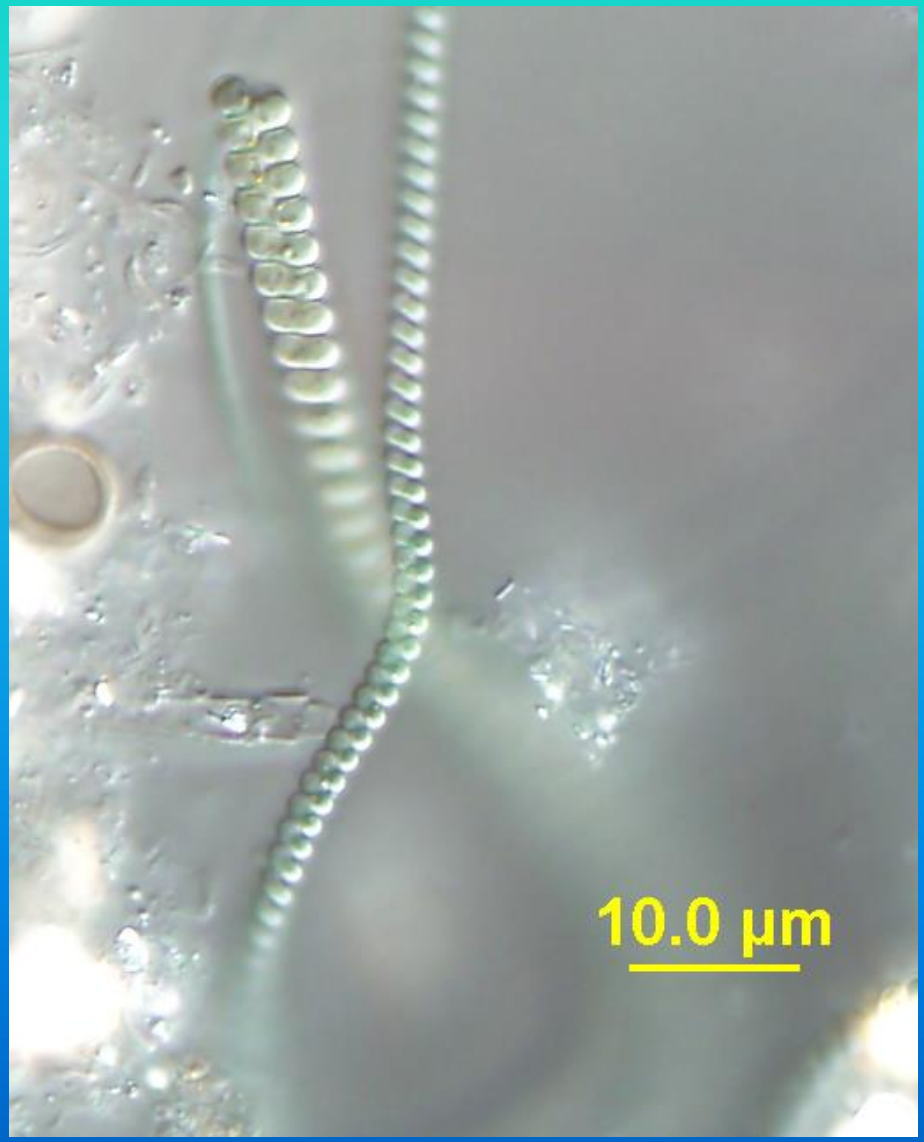
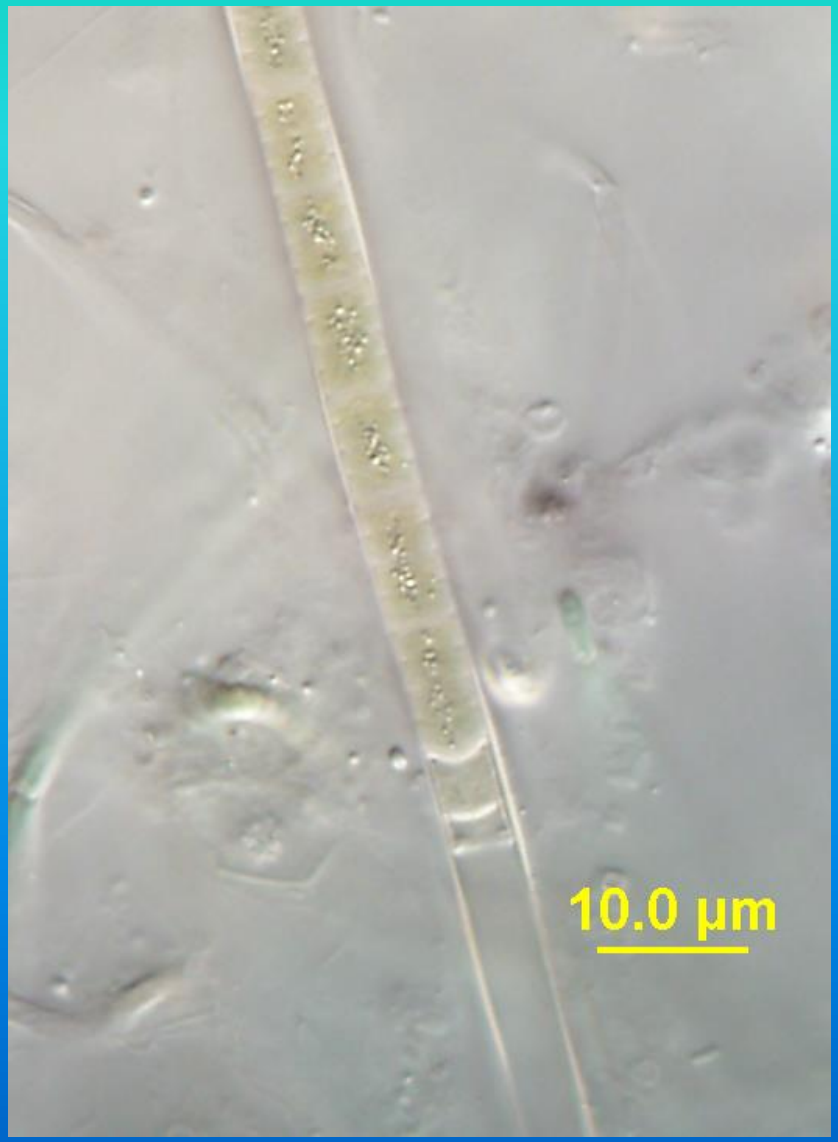
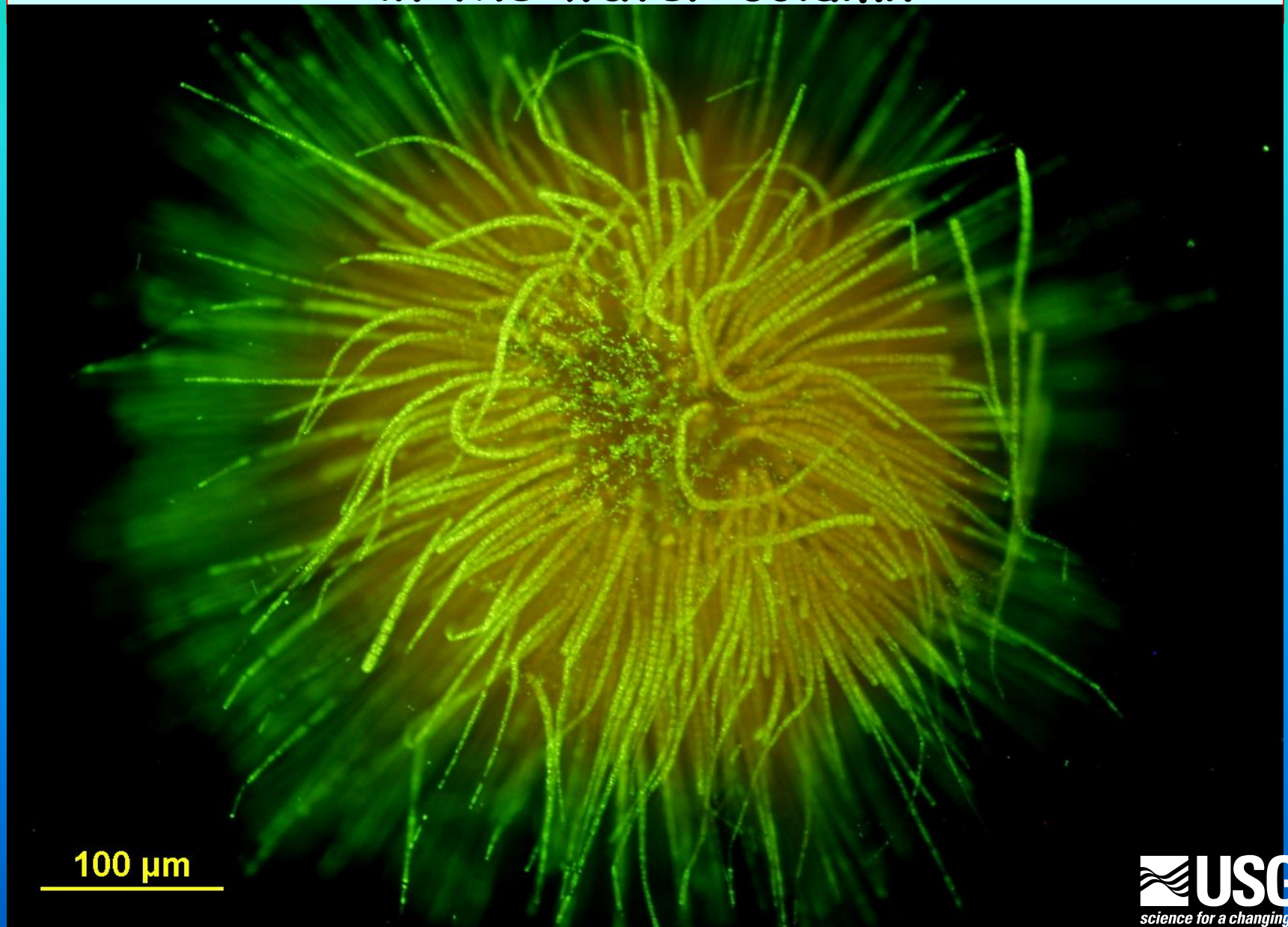
Ecological Strategies: Motility in sediments





Ecological Strategies: morphology for staying in the water column



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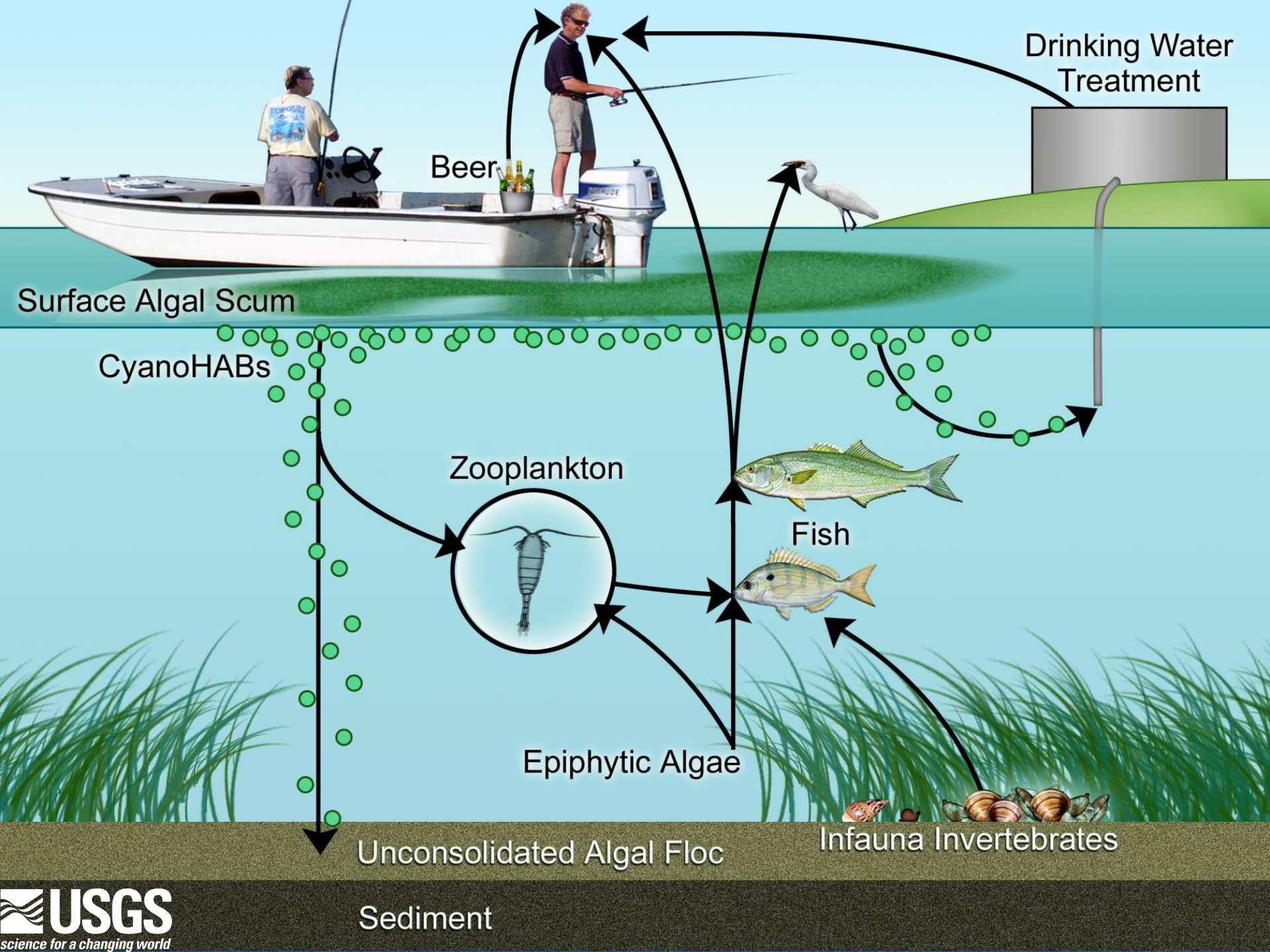
Drinking Water Treatment
Beer
Surface Algal Scum
CyanoHABs
Zooplankton
Fish
Epiphytic Algae
Infauna Invertebrates
Unconsolidated Algal Floc
Sediment
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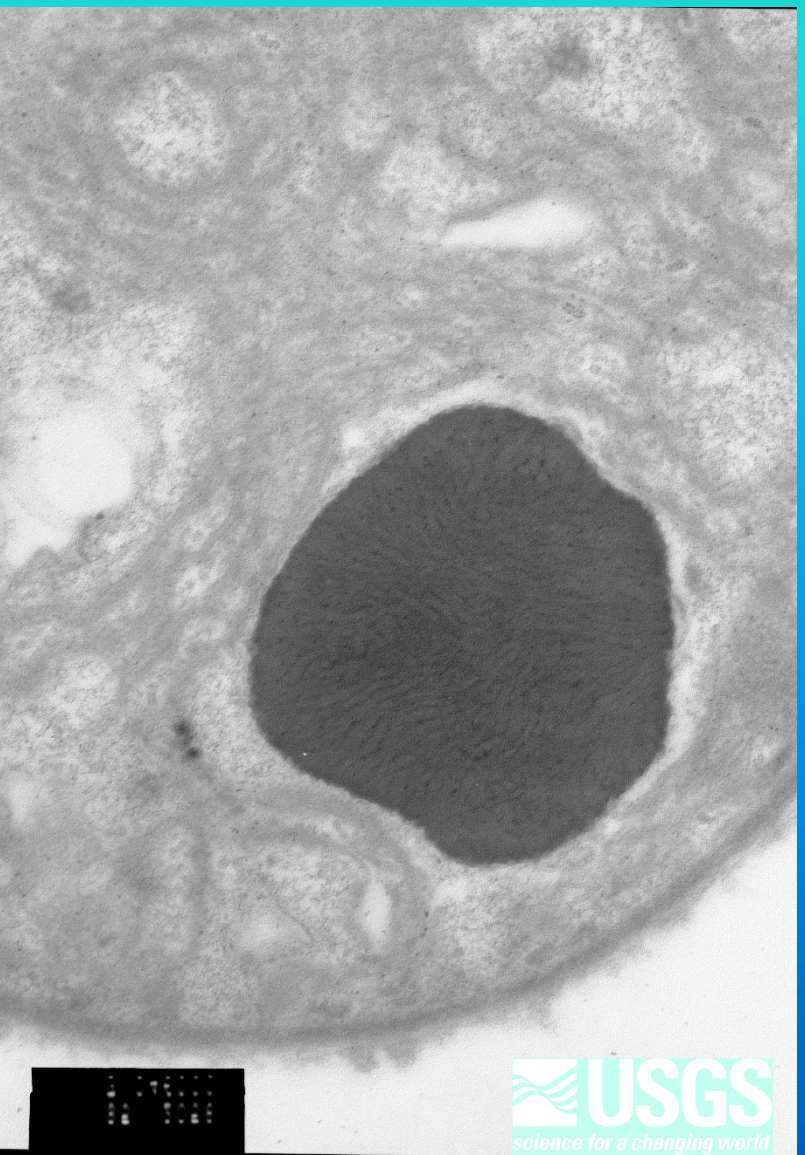
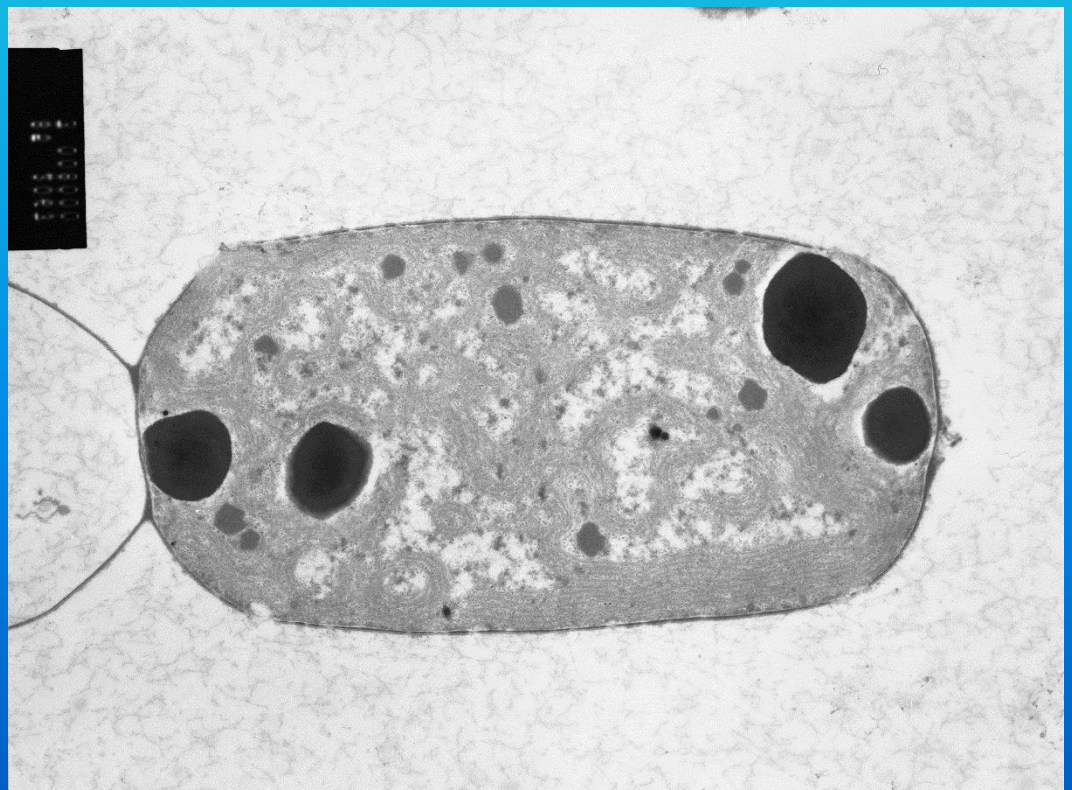
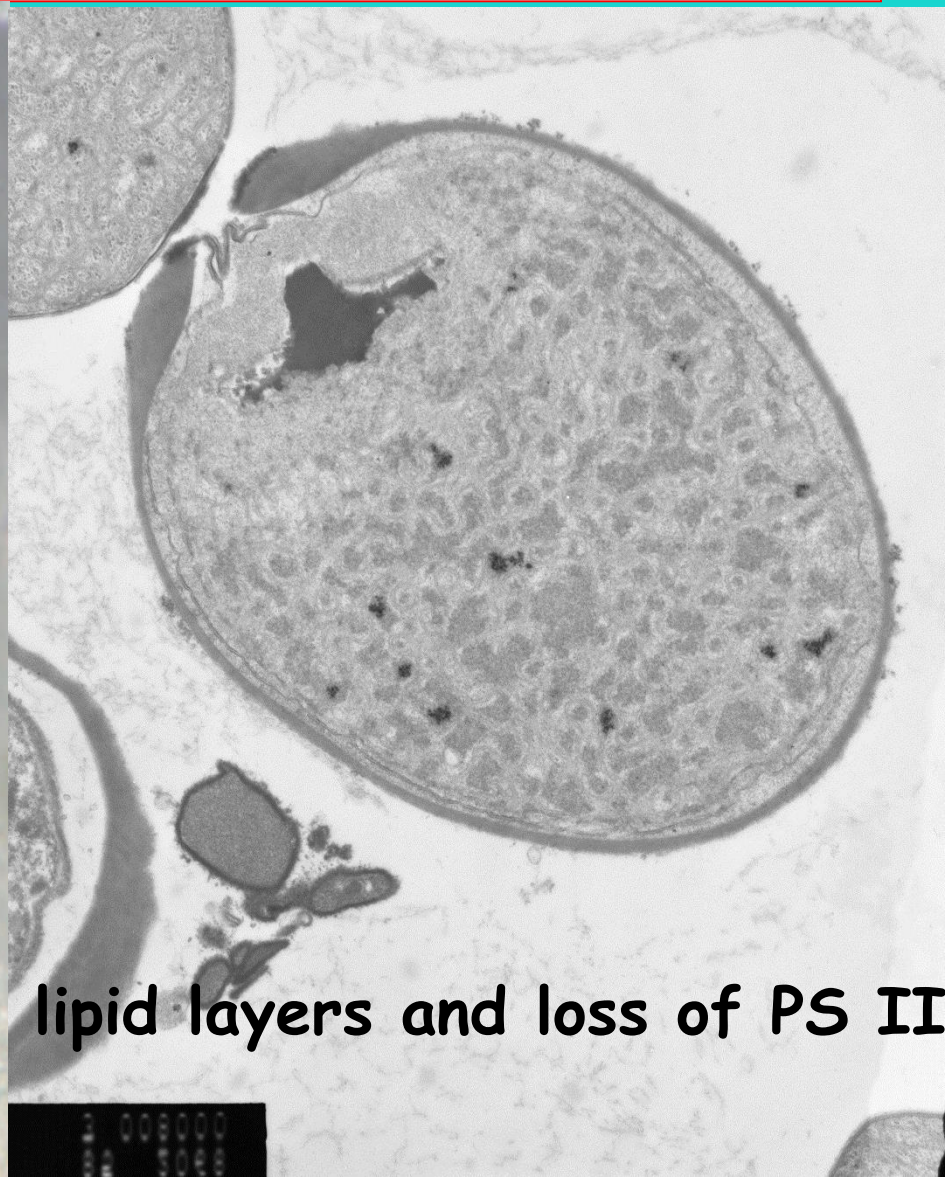
Ecological Strategies: luxuriant nutrient uptake and storage & metal sequestration



- Contain protein, lipids, polyP
- Na, Mg, Ca, K, Mn, Fe, Cu



Ecological Strategies: make your own nitrogen from the atmosphere



lipid layers and loss of PS II

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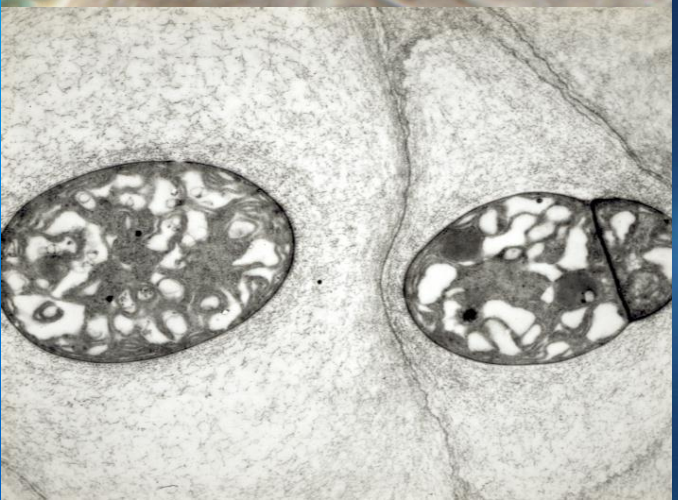
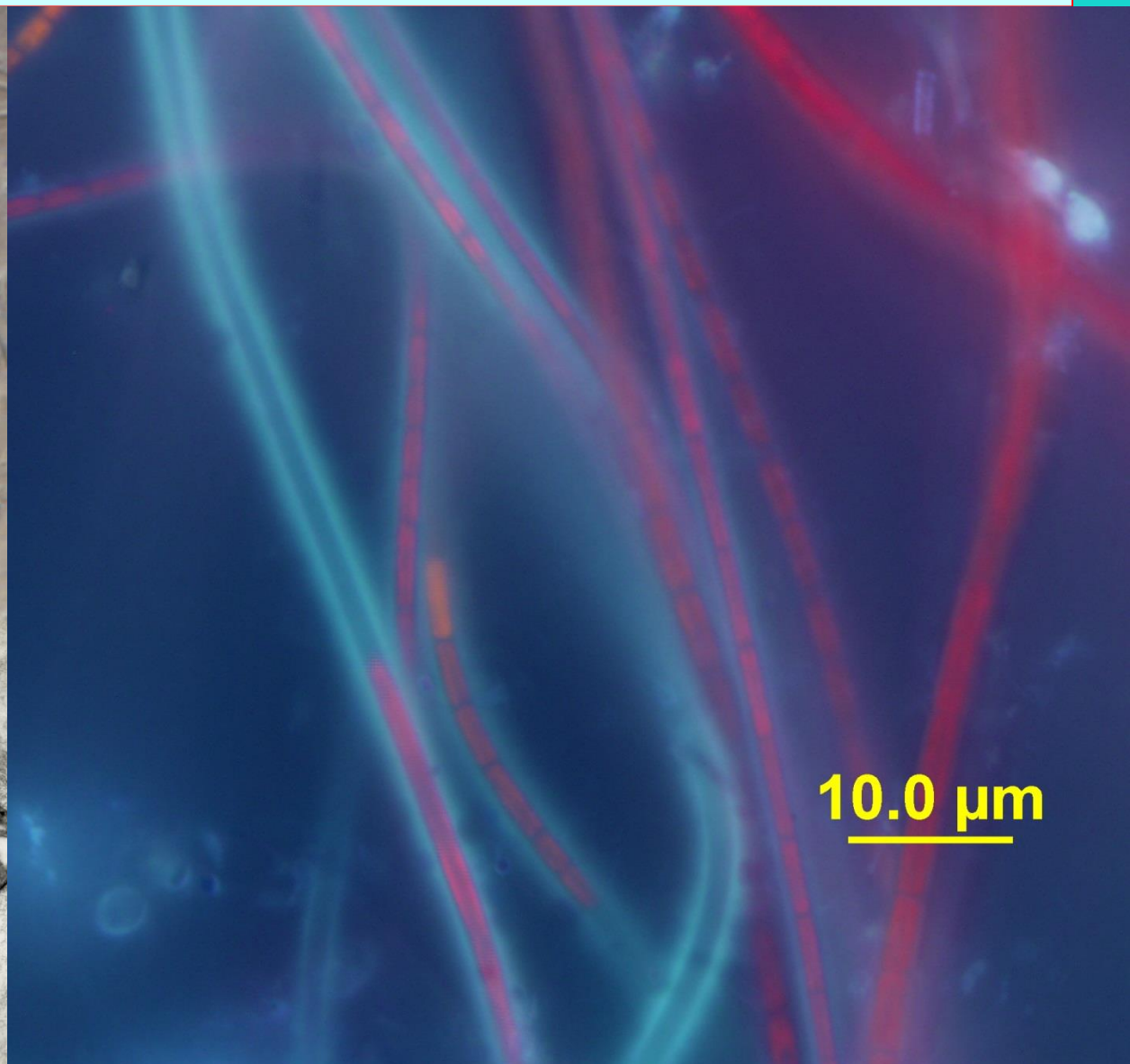
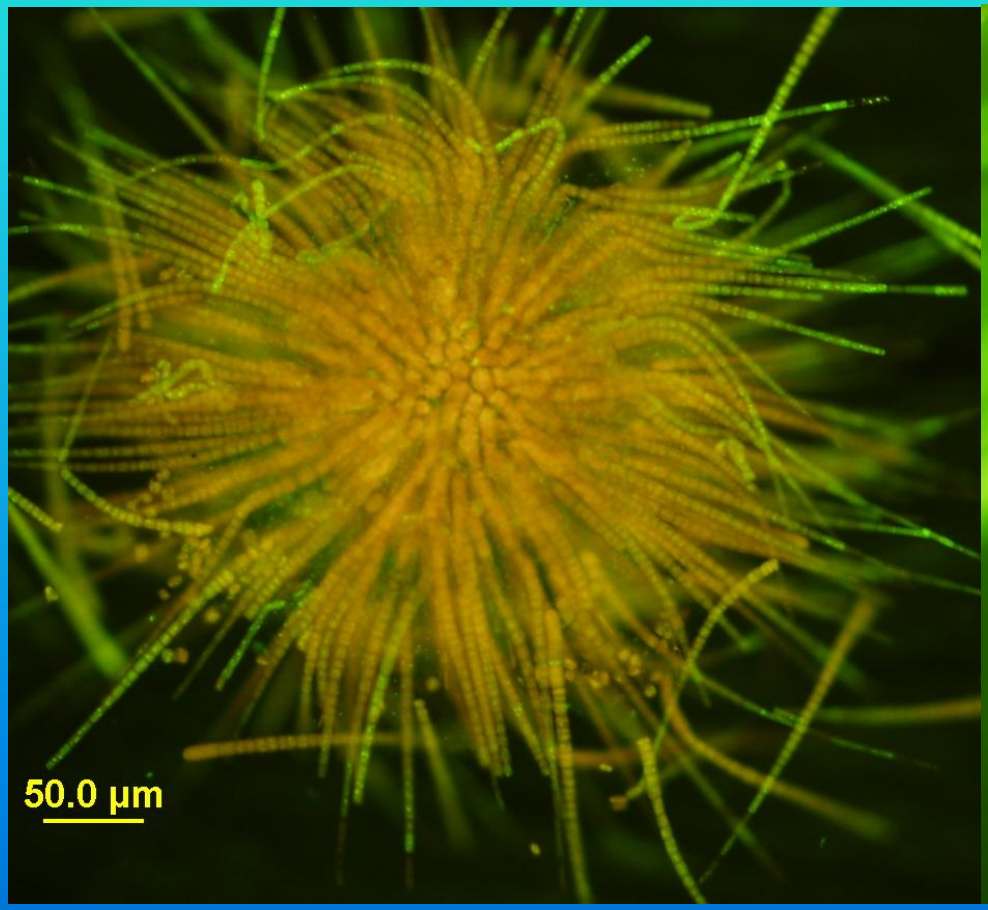
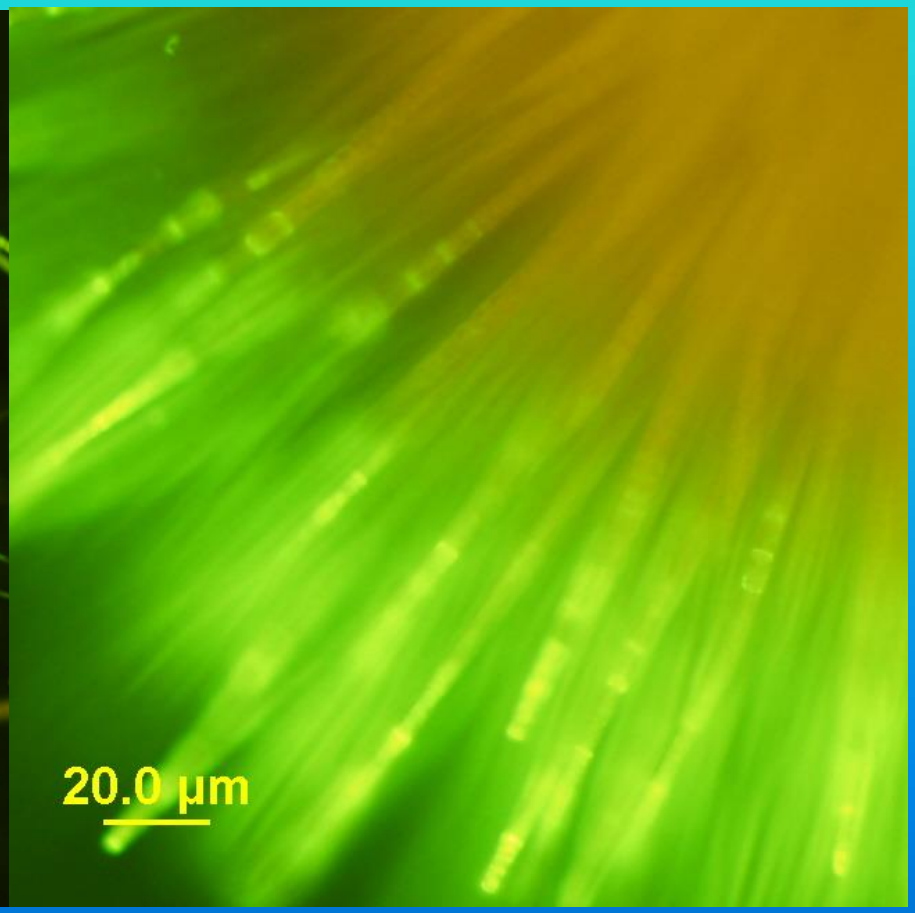
Ecological Strategies: desiccation tolerant (exopolymeric substances-often pigmented)



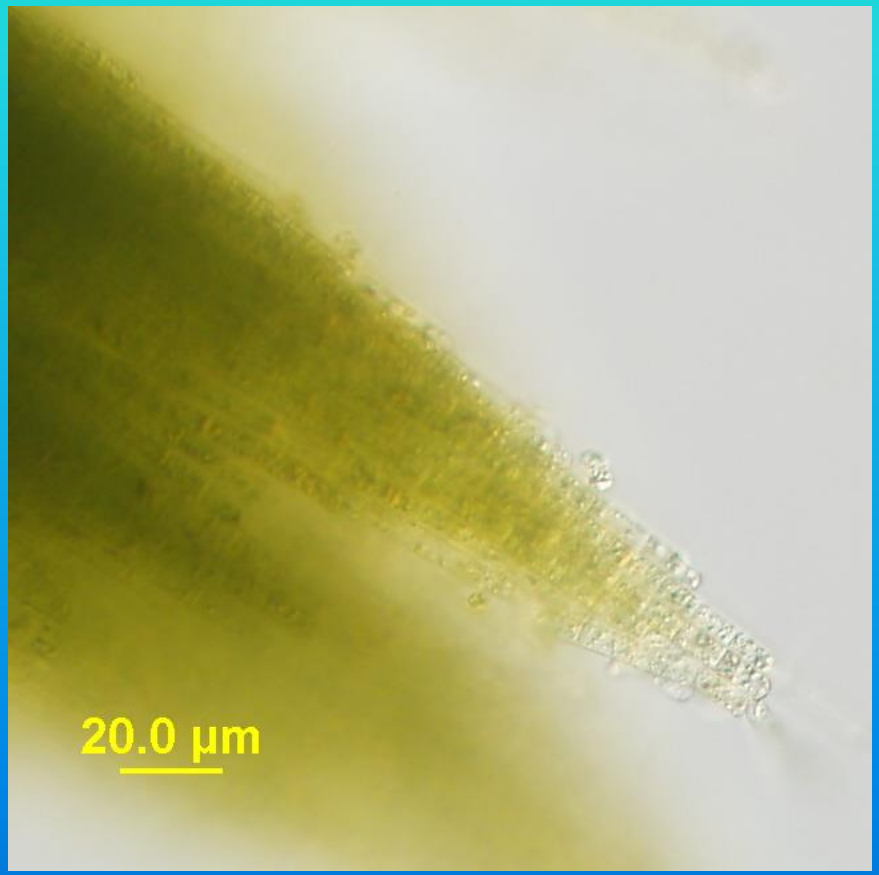


Ecological Strategies: morphology to prevent grazing



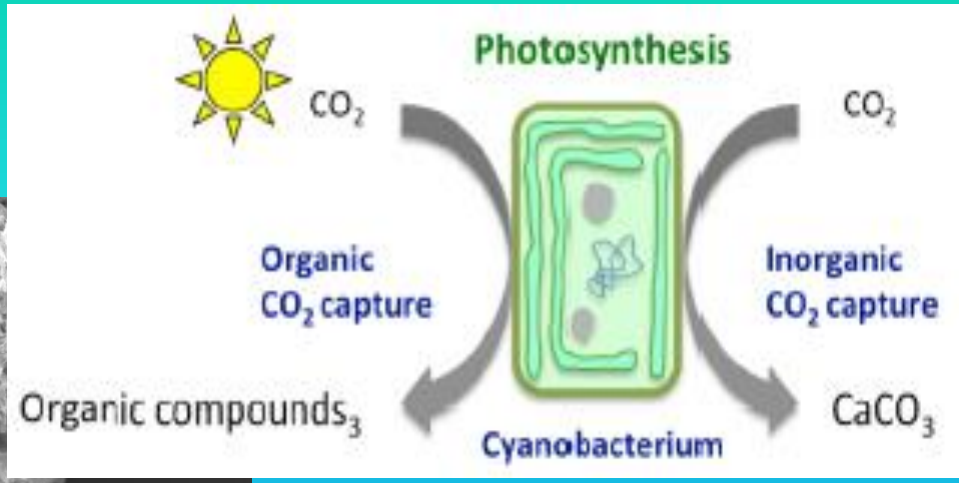


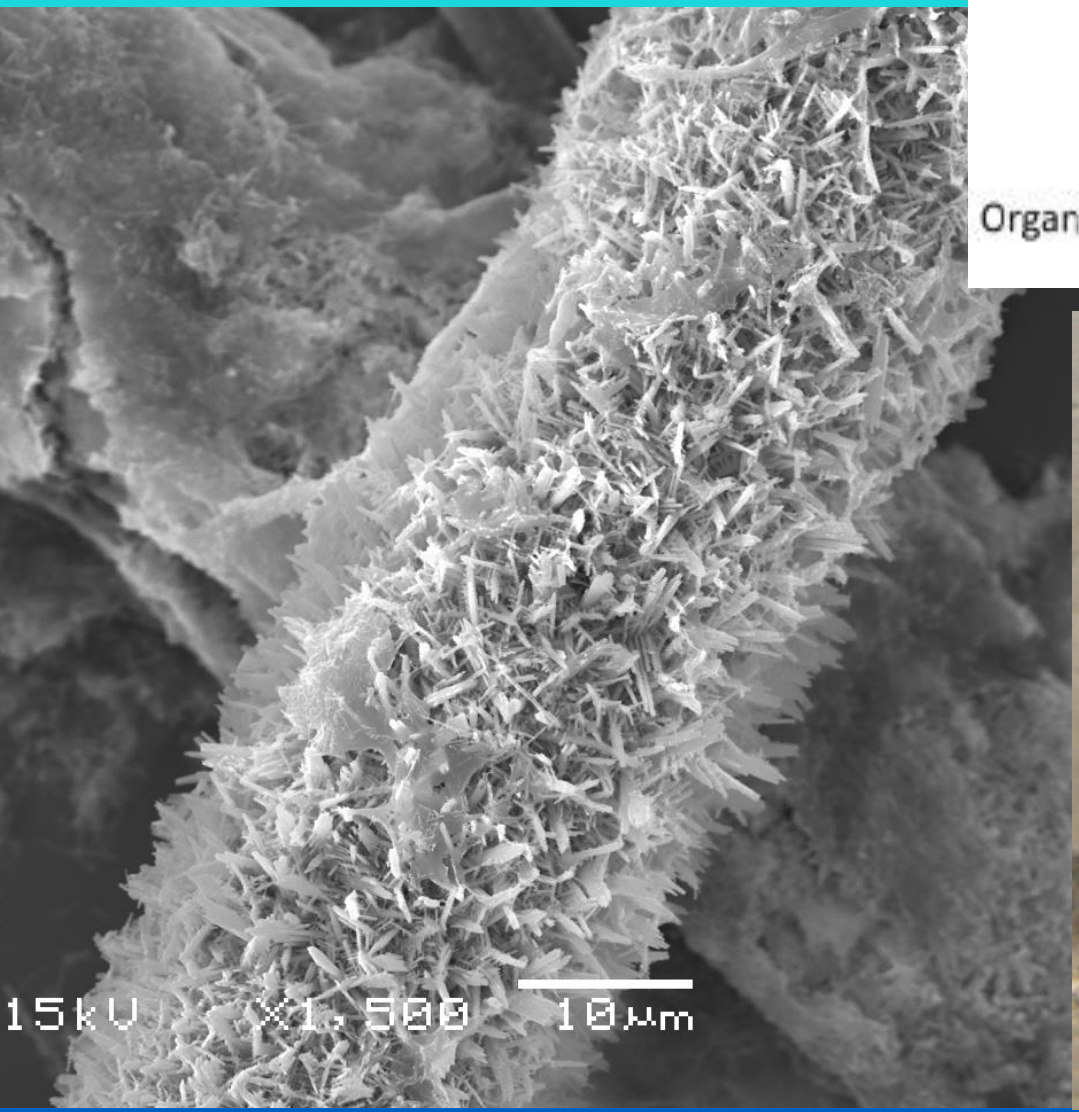
Ecological Strategies: morphology to prevent grazing

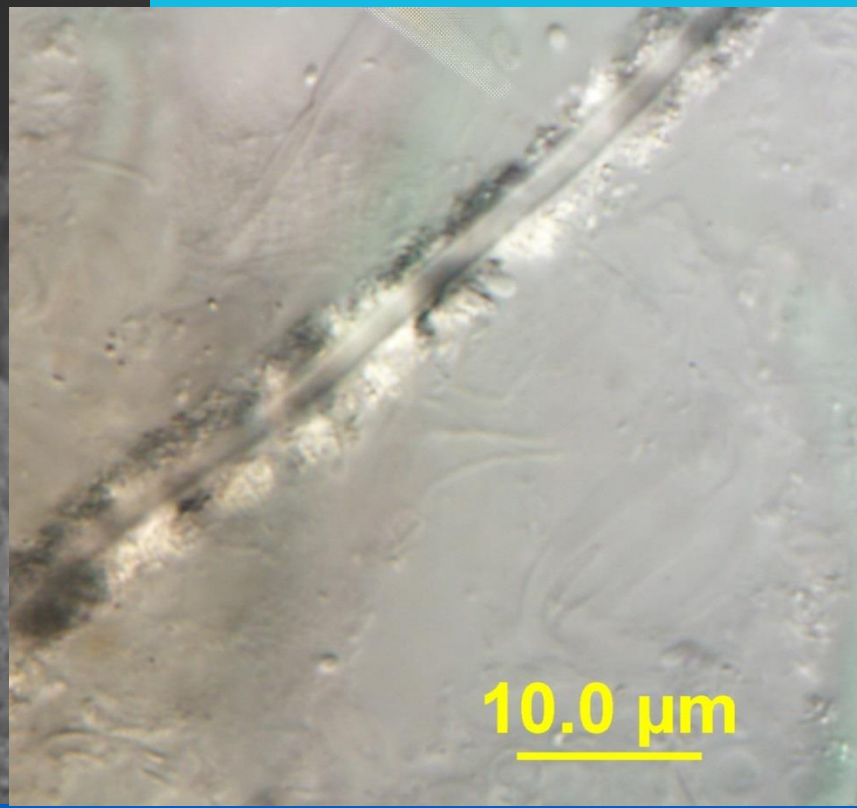


Ecological Strategies: armor to prevent grazing?

cyanobacteria nucleate $CaCO_3$ precipitation

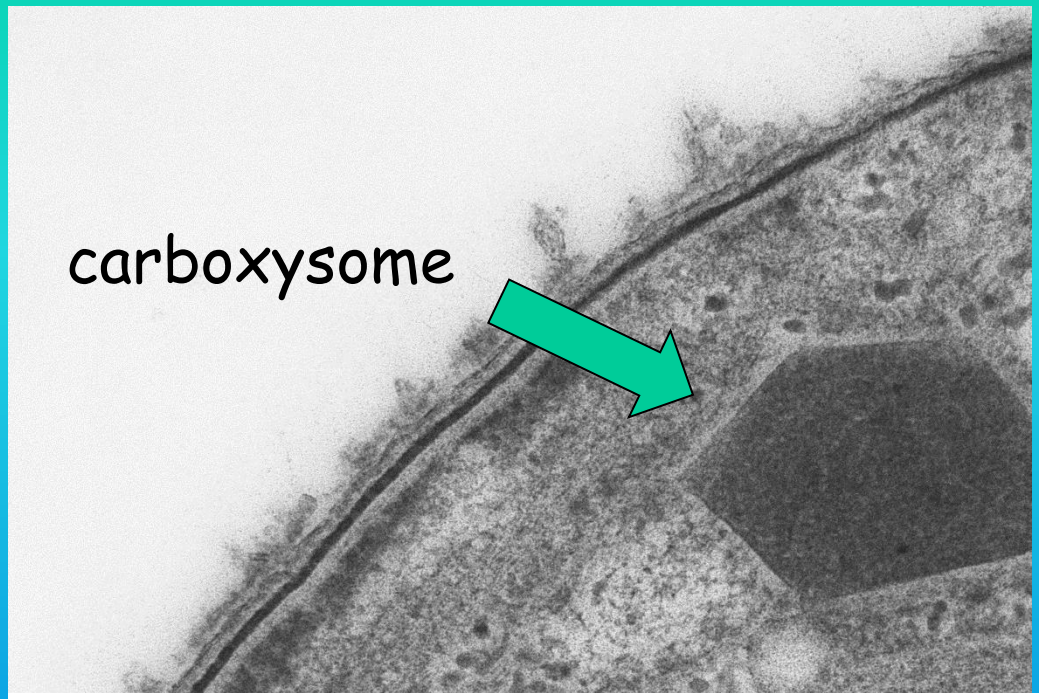


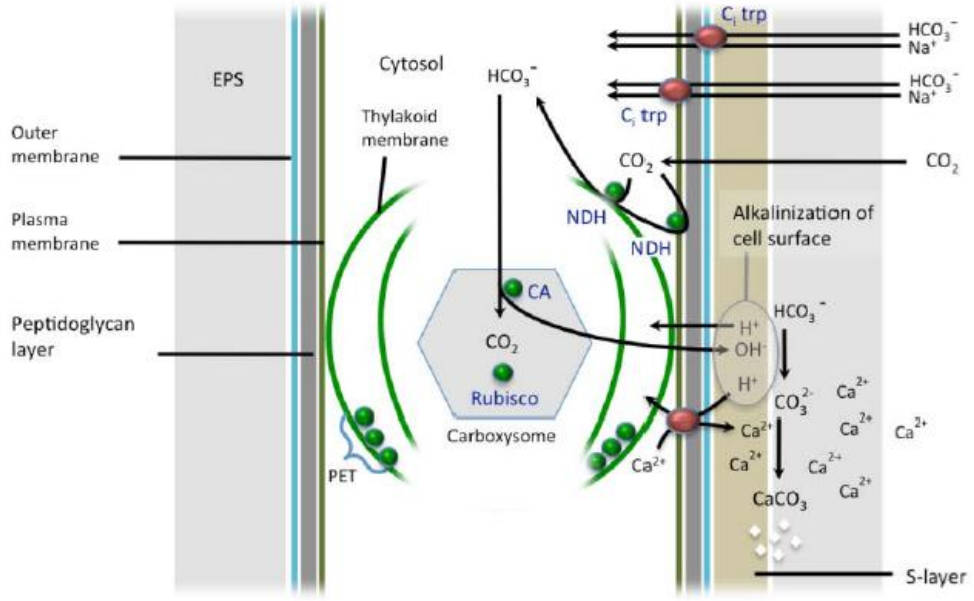




Ecological Strategies: carbon dioxide concentrating mechanism

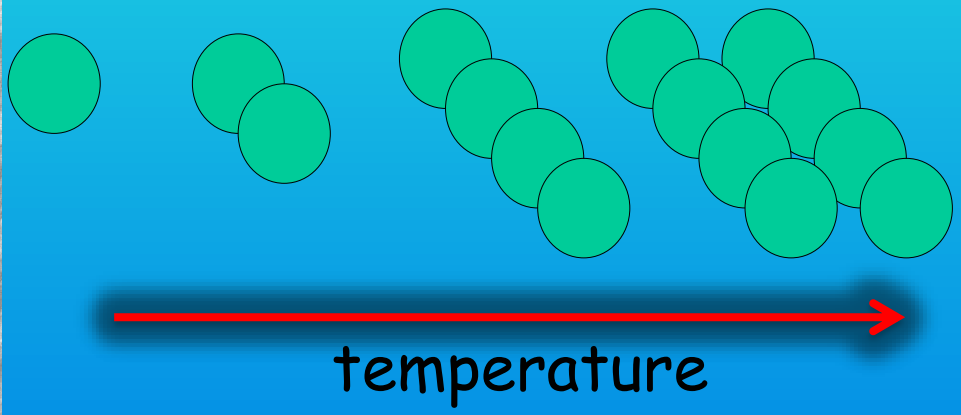
When bicarboante is limiting, raises the CO_2 using a bio-chemical system that allows the cells to raise the concen-tration at the site of the Rubisco up to **1000-fold** over that in the surrounding medium.





Ecological Strategies: thermophiles grow fast and will be worse as the climate warms

Rapid Growth



3 “doublings” or divisions every day

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Why are we concerned about cyanoHABs?

Toxicity

Hypoxia

Taste and odors

Aesthetics

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Cyanotoxins

- **Hepatotoxins**
  - Disrupt proteins that keep the liver functioning, may act slowly (days to weeks)

microcystin (120+ variants)
nodularin
cylindrospermopsin

- **Neurotoxins**
  - Cause rapid paralysis of skeletal and respiratory muscles (minutes)

anatoxin -a
anatoxin -a (s)
saxitoxin
neosaxitoxin

- **Dermatotoxins**
  - Produce rashes and other skin reactions, usually within a day (hours)

lyngbyatoxin

- **b-*N*-methylamino-L-alanine**
  - Neurological: linked to ALS

BMAA

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Cyanotoxins are highly potent

Compounds & LD_{50} (ug/kg)

Saxitoxin	9	Ricin	0.02
Anatoxin-a(s)	20	Cobra toxin	20
Microcystin LR	50	Curare	500
Anatoxin-a	200-250	Strychnine	2000
Nodularin	50		
Cylindrospermopsins	200		

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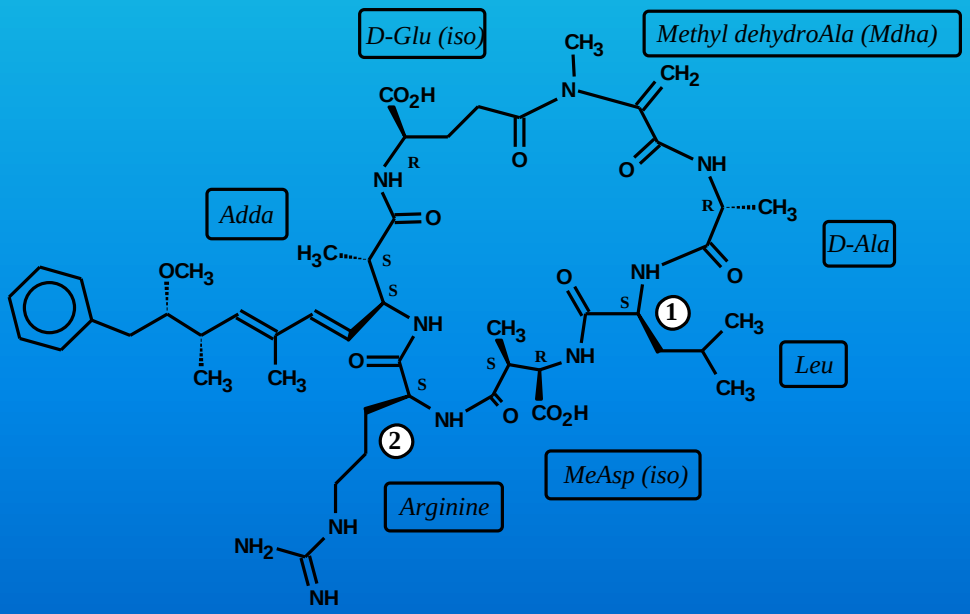
Microcystins

- Mostly *Microcystis aeruginosa* (very common)
  - also produced by a number of other species.
- Potent hepatotoxin
  LD-50: 25-60 µg kg^{-1}
- Called "fast death factor"
- Potent carcinogen
- Guide line values in water:
  - 0.3 micrograms per liter drinking water (10 days, younger than school age; 1.6 for other ages
  - Soon- recreational contact
- **Peptide Toxins:**
  120+ structural variants



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Drinking Water Guidelines

EPA Issues Health Advisories for Algal Toxins in Drinking Water Release Date: 05/06/2015

The health advisory values for algal toxins recommend 0.3 micrograms per liter for microcystin and 0.7 micrograms per liter for cylindrospermopsin at levels not to be exceeded in drinking water for children younger than school age.

For all other ages, the health advisory values for drinking water are 1.6 micrograms per liter for microcystin and 3.0 micrograms per liter for cylindrospermopsin.

Potential health effects from longer exposure to higher levels of algal toxins in drinking water include gastroenteritis and liver and kidney damage. The health advisory values are based on exposure for 10 days.

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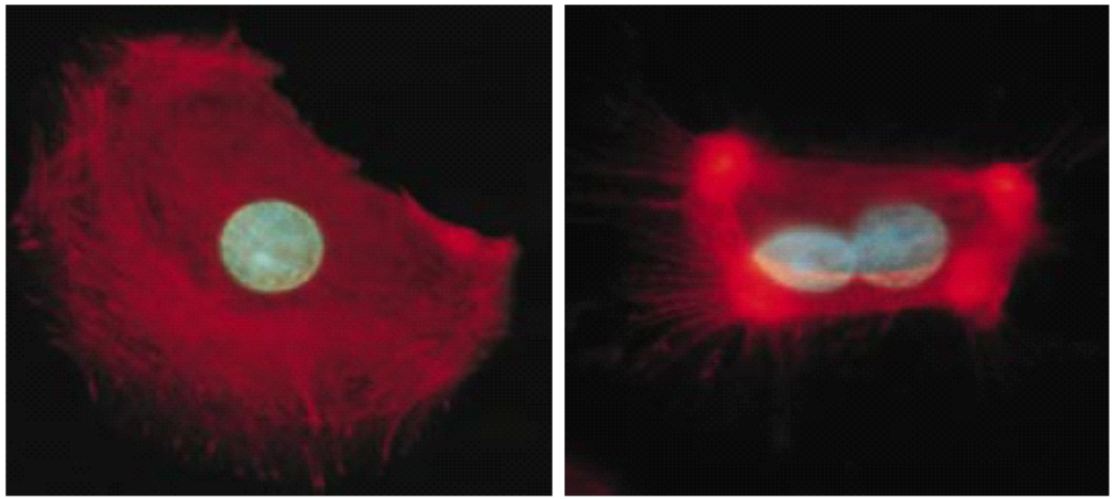
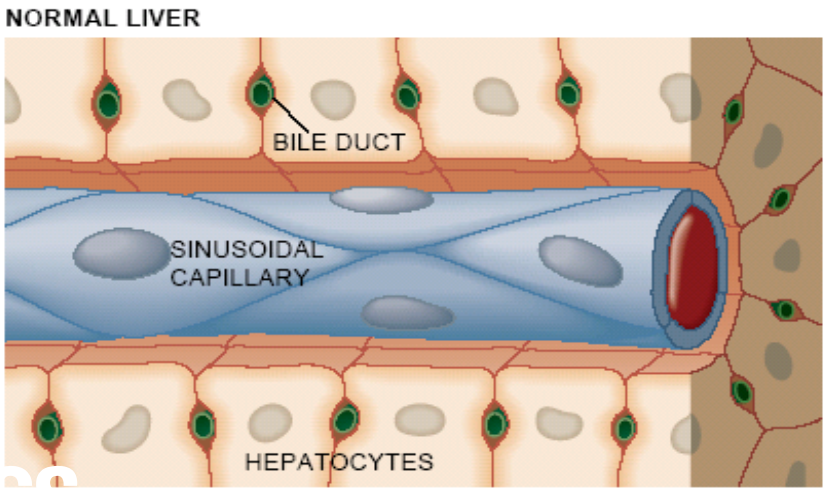
Microcystin exposure: response

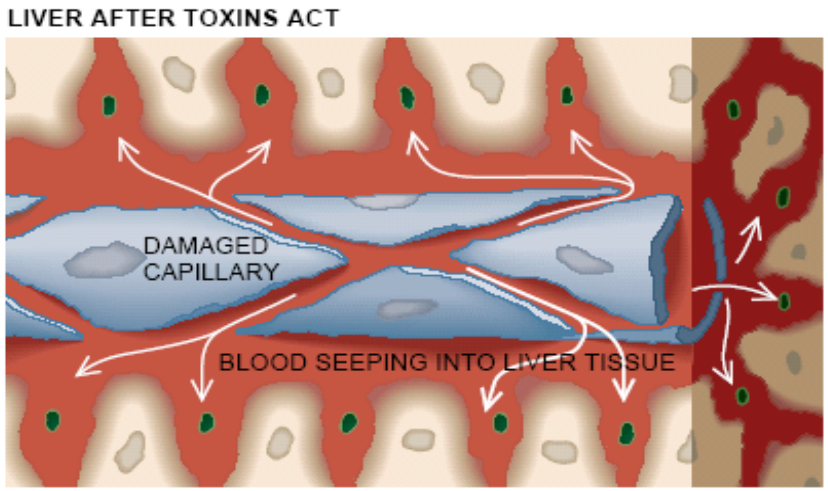
- Uptake by bile acid transporter
- Inhibit protein phosphatases 1 and 2A
- Affects cytoskeleton, cell cycle, general metabolism, apoptosis

Hepatotoxicity

MICROFILAMENTS (*red threads in micrographs*), structural components of cells, are usually quite long, as in the rat hepatocyte at the left. But after exposure to microcystins (*right*), microfilaments collapse toward the nucleus (*blue*). (This cell, like many healthy hepatocytes, happens to have two nuclei.) Such collapse helps to shrink hepatocytes—which normally touch one another and touch sinusoidal capillaries (*left drawing*). Then the shrunken cells separate from one another and from the sinusoids (*right drawing*). The cells of the sinusoids separate as well, causing blood to spill into liver tissue. This bleeding can lead swiftly to death.







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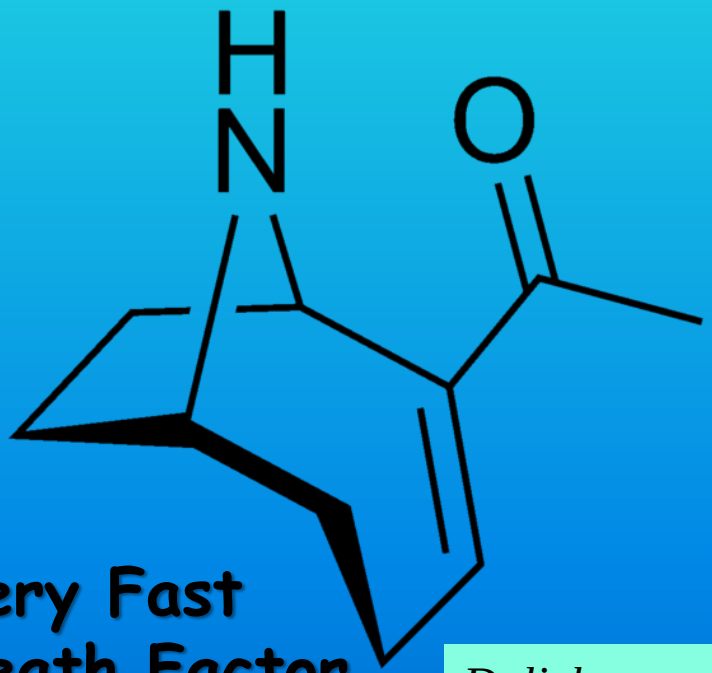
Wayne Carmichael ISOC-HAB Ch. 4, Scientific American, January, 1994

Anatoxins

Anatoxin-a

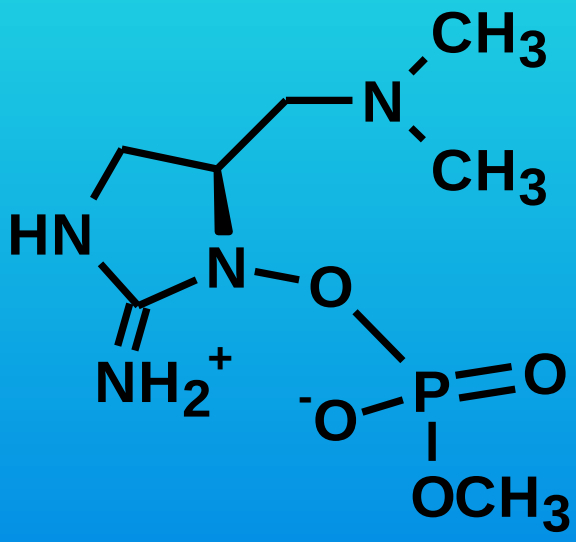
actylcholine agonist



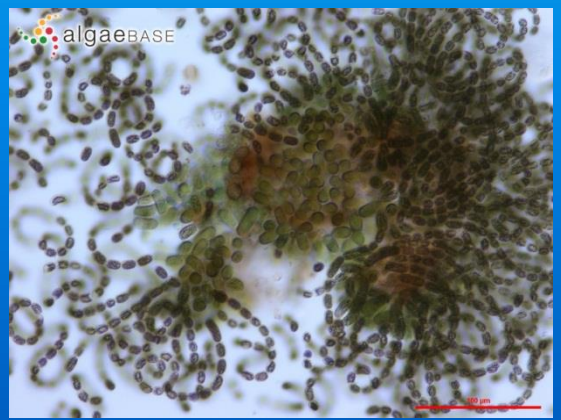
Very Fast Death Factor

Anatoxin-a(S)

acetylcholinesterase inhibitor



Dolichospermum flos-aquae
&
lemmermannii



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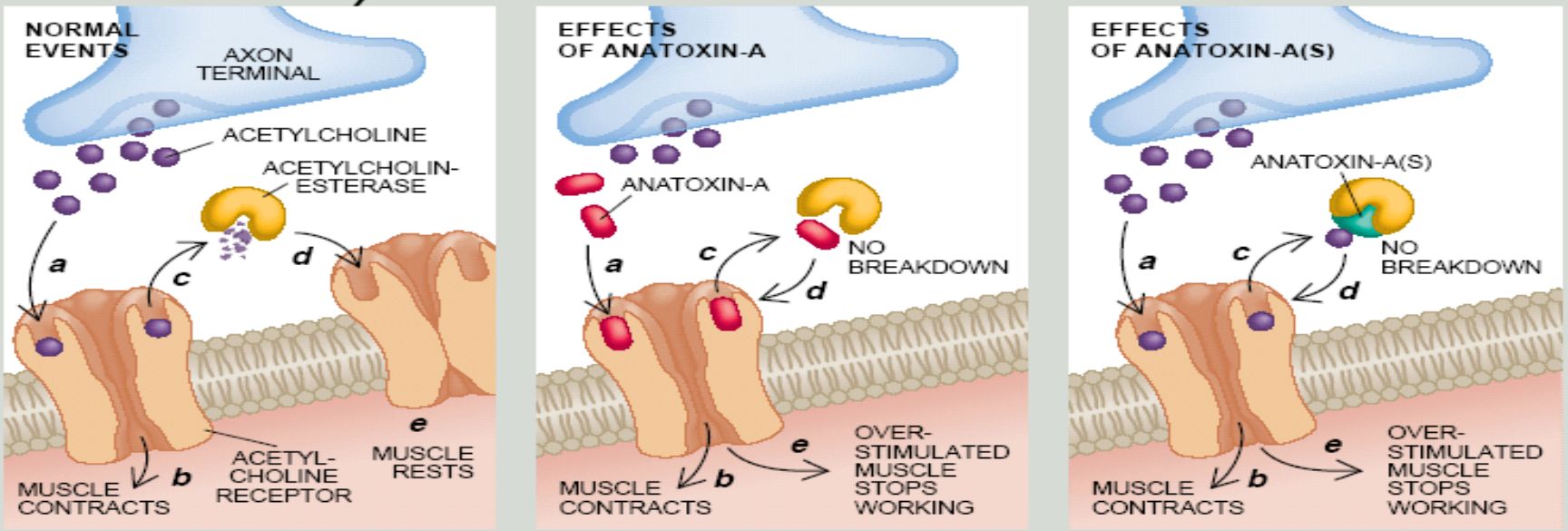
Anatoxin-a and a(s)

Anabaena

Anatoxin-a: Acetylcholine receptor agonist
Anatoxin-a(s): Acetylcholinesterase inhibitor

Neurotoxicity



Anatoxin-a and anatoxin-a(s) (*center and right panels*) overexcite muscle cells by disrupting the functioning of the neurotransmitter acetylcholine. Normally, acetylcholine molecules (*purple*) bind to acetylcholine receptors on muscle cells (*a in left panel*), thereby inducing the cells to contract (*b*). Then the enzyme acetylcholinesterase (*yellow*) degrades acetylcholine (*c*), allowing its receptors and hence the muscle cells to return to their resting state (*d* and *e*). Anatoxin-a (*red in center panel*) is a mimic of acetylcholine. It, too, binds to acetylcholine receptors (*a*), triggering contraction (*b*), but it cannot be degraded by acetylcholinesterase (*c*). Consequently, it continues to act on muscle cells (*d*). The cells then become so exhausted from contracting that they stop operating (*e*). Anatoxin-a(s) (*green in right panel*) acts more indirectly. It allows acetylcholine to bind to its receptors and induce contraction as usual (*a* and *b*), but it blocks acetylcholinesterase from degrading acetylcholine (*c*). As a result, the neurotransmitter persists and overstimulates respiratory muscles (*d*), which once again eventually become too fatigued to operate (*e*).

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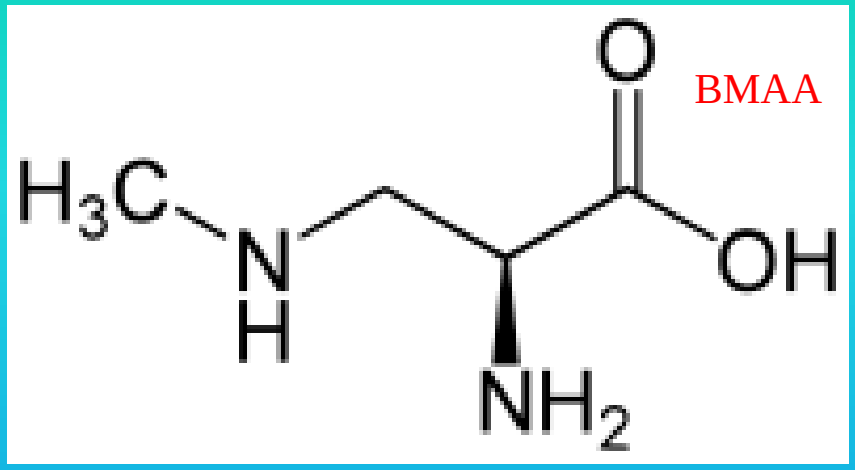
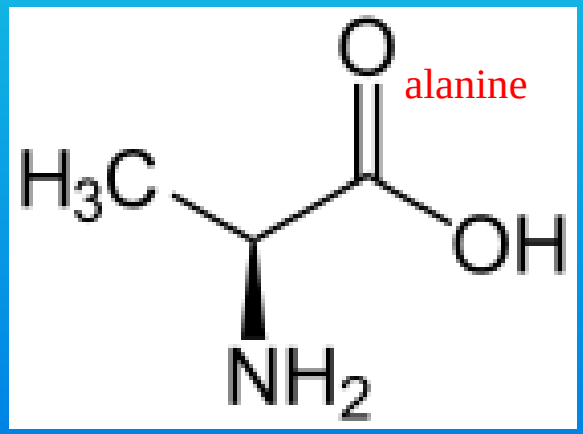
Wayne Carmichael ISOC-HAB Ch. 4, Scientific American, January, 1994

β-methyl amino alanine (BMAA)

- Non-proteinogenic amino acid
- Made by almost all cyanobacteria



(Cox, Banack, Murch, Rasmussen, Tien, Bidigare, Metcalf, Morrison, Codd, and Bergman. PNAS 2005)



REVIEW ARTICLE

Is exposure to cyanobacteria an environmental risk factor for amyotrophic lateral sclerosis and other neurodegenerative diseases?

WALTER G. BRADLEY[1], AMY R. BORENSTEIN[2], LORENE M. NELSON[3], GEOFFREY A. CODD[4], BARRY H. ROSEN[5], ELIJAH W. STOMMEL[6] & PAUL ALAN COX[7]

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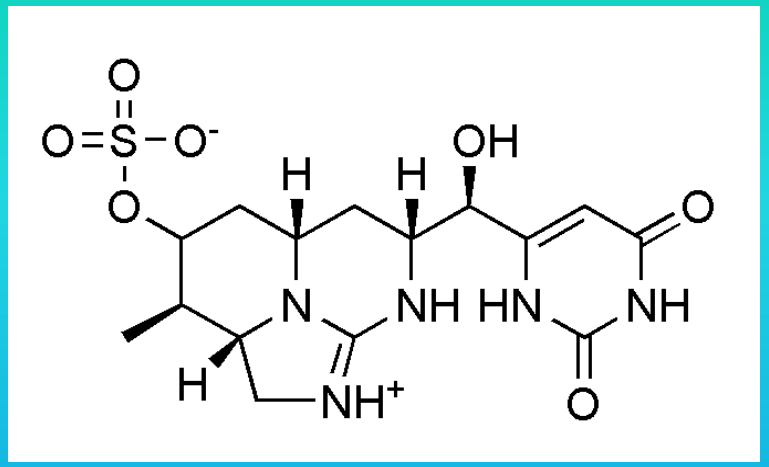
Cylindrospermopsin

Cylindrospermopsis



Alkaloid Toxin

- Gastrointestinal effects
- Hepatotoxicity
- Liver necrosis
- Kidney effects
- Inhibition of protein synthesis

- Covalently modify DNA and/or RNA
- Resistant to degradation by pH and temp-persistent

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Has anyone ever died from these toxins?

Not in the US. Most affects are with animals:

……associated with the *Anabaena flos-aquae* bloom were estimated deaths of 5000-7000 gulls, 560 ducks, 400 coots, 200 pheasants, 50 squirrels, 18 muskrats, 15 dogs, 4 cats, 2 hogs, 2 hawks, 1 skunk, 1 mink, plus numerous song birds."

Storm Lake, Iowa, 1952

Documented human mortality

1996: Caruaru Brazil

- 1996 outbreak in water supply for a hemodialysis center in Caruaru, Brazil.
- 117 of 136 patients (86%) had symptoms.
- 75 of 136 died (55%) over several month period.
- Microcystins identified in blood and liver tissues.
- Pretreatment (sand, carbon, resin and microfiltration) of the incoming water.
- WHO set limit of 1 $\mu g\ L^{-1}$

Sea Otters in CA and Chesapeake Bay

"Twenty one sea otter **(***Enhydra lutris kenyoni*) deaths reported in California during the period 1999-2008, showed that cause of death was due to exposure to microcystins (Miller et al. 2010)"

"During the period 2001-2004 Great Blue Heron (*Ardea herodias*) mortalities in the Chesapeake Bay region were associated with microcystin exposure at a small island freshwater pond (Driscoll et al. 2002)"

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How we are exposed

Poison	Causative organism	Vector	Onset
Anatoxin-a	*Anabaena* spp. *Aphanizomenon* spp. *Planktothrix* spp.	Contaminated fresh water	minutes to hours
Anatoxin-a(s)	*Anabaena flos-aquae*	Contaminated fresh water	minutes to hours
Azaspiracid	*Protoperidinium*	Shellfish: clams, scallops, mussels, oysters	<24 hours
Brevetoxin	Dinoflagellates *Karenia brevis* Other *Karenia* spp.	Contaminated marine waters and shellfish	<24 hours
Ciguatoxins	Dinoflagellates *Gambierdiscus* toxicus *Gambierdiscus* spp	Many fish species: eel, grouper, mackerel, snapper…	<24 hours
Cylindrospermopsin	*Cylindrospermopsis raciborskii,* *Aphanizomenon ovalisporum*	Contaminated fresh water and possibly fish	hours to days
Domoic acid	*Pseudo-nitzschia* spp. *Nitzschia pungens*	Shellfish: crab, clams, scallops, mussels, oysters	<24 hours
Lyngbyatoxin	*Lyngbya sp.*	Contaminated fresh or marine waters	<24 hours
Microcystins	*M. Aeruginosa* *Anabaena* spp. *Planktothrix* spp.	Contaminated fresh water	hours to days
Okadaic acid	*Dinophysis* sp.	Shellfish: crab, clams, scallops, mussels, crabs	minutes to hours
Saxitoxins	Dinoflagellates and Cyanobacteria *(Aphanizomenon* sp. *Anabaena circinalis)*	Shellfish (clams, cockles, mussels, oysters, whelks) or puffer fish Contaminated fresh water	<24 hours Unknown

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Taxonomy: Initial ID and some of the major players

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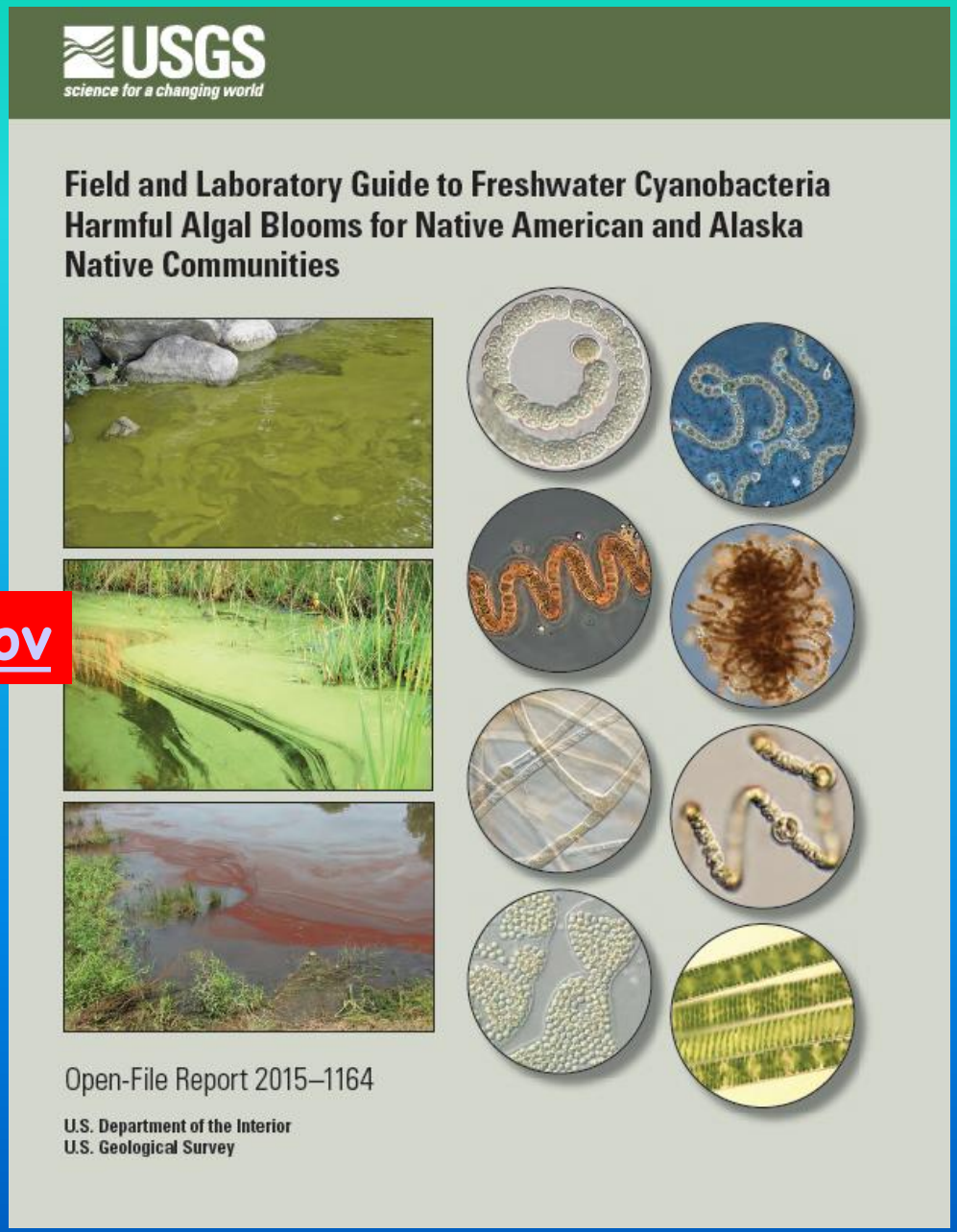

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Common Filamentous Cyanobacteria

Lake Mattamuskeet, NC (East and West)
July 22, 2015

Cylindrospermopsis raciborskii **(CYN)**

Chrysosporum ovalisporum **(CYN)**

Komvophoron (Pseudanabaena)

Planktolyngbya contorta **(MYC)**

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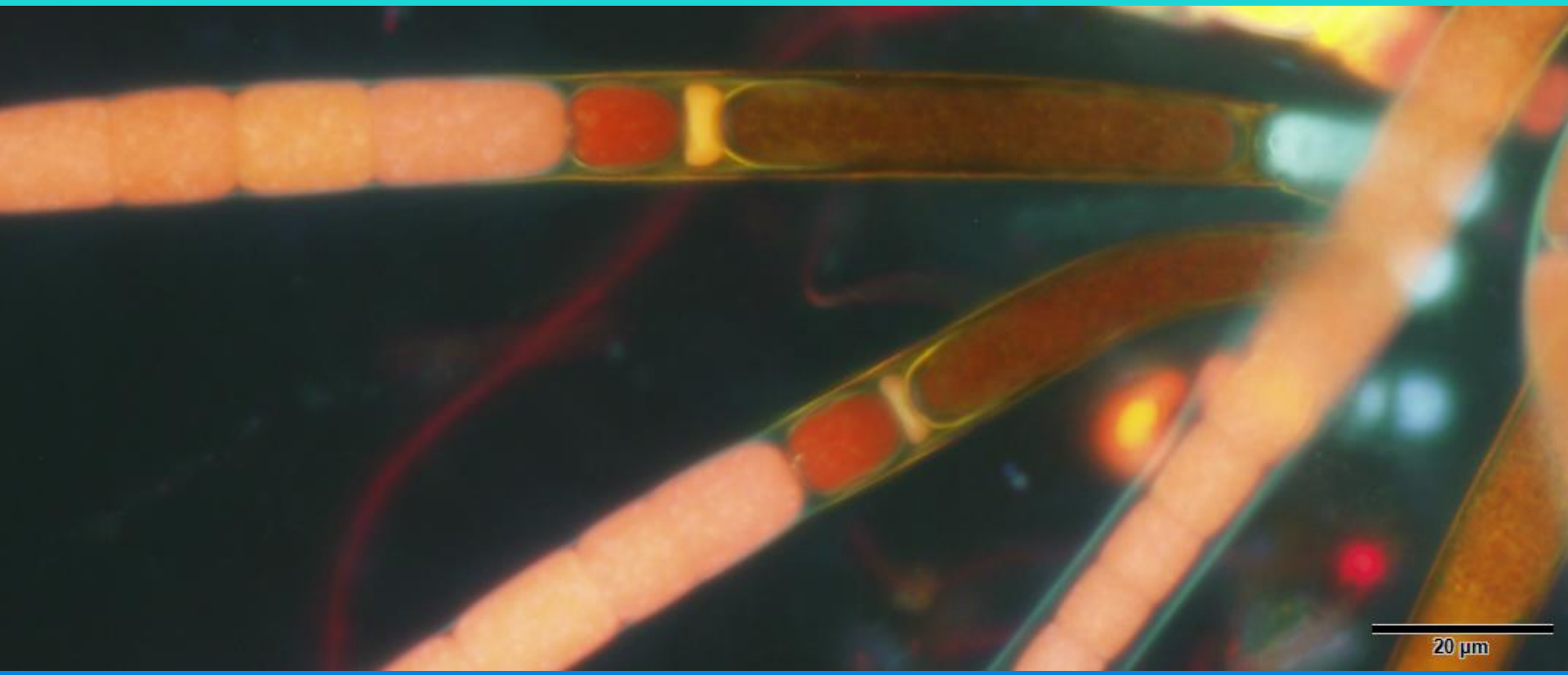
WARNING
LIFEGUARD, BACTERIOLOGIST, MICROBIOLOGIST, & TOXICOLOGIST NOT ON DUTY
SWIM AT YOUR OWN RISK

Thank You!



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