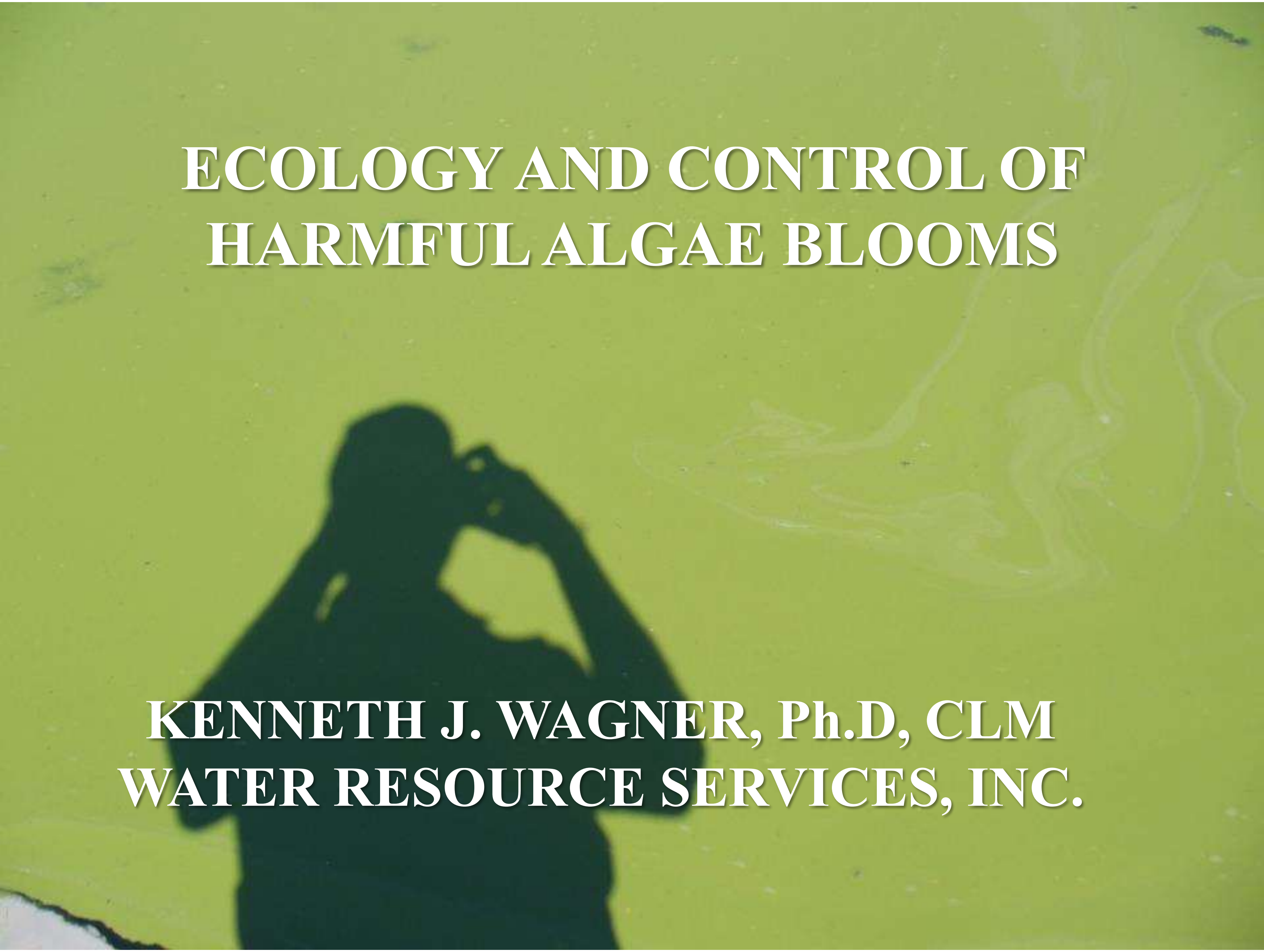
ECOLOGY AND CONTROL OF
HARMFUL ALGAE BLOOMS
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WATER RESOURCE SERVICES, INC.

Preface

What constitutes a Harmful Algae Bloom?

- Any concentration of algae that causes impacts to an aquatic system that can be documented as hazardous to human or ecological health
- Algae is a broad term, and includes cyanobacteria, members of the chlorophyta (greens), chrysophyta (goldens), and at least 5 other taxonomic divisions, depending on what system is applied
- Cyanobacteria tend to represent the greatest risk, and are therefore sometimes thought of as synonymous with HABs
- Human health impacts tend to get the most attention, but ecological effects can be quite harmful as well.

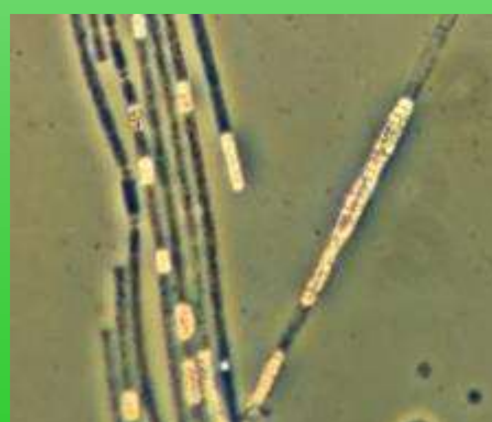
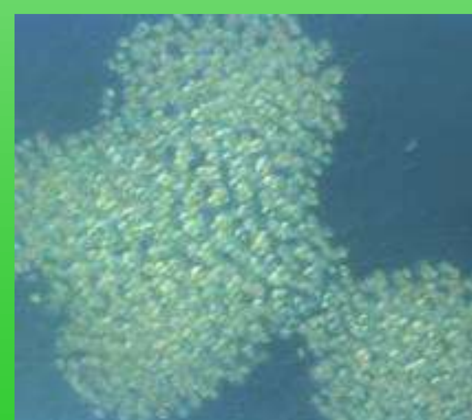




Preface

What are cyanobacteria (blue-green algae)?

- Prokaryotic cells – photosynthetic bacteria
- Have chlorophyll-a and bluish accessory pigments (phycobilins)
- Fairly weak cell wall, often with mucilage coating
- Store sugars as food reserves – better metabolized at higher temperatures
- No flagella, but many have buoyancy control through gas pockets that form in cells
- Mostly small cells in large aggregations
- Resting stages fall to sediment, germinate later


Preface

Why the increasing attention to HABs?

- Blooms are becoming more frequent and maybe more severe
- The health impacts are becoming better understood
- Management techniques have advanced to greater applicability
- The cost of bloom control is significant
- The cost of not controlling blooms may be higher
- Standard treatment is not always enough to avoid problems
- Federal and state governments have created regulations
- Media outlets have created greater “awareness”



PART 1: THE PROBLEMS

ALGAL PROBLEMS

Algal problems include:

- **Ecological imbalances**
- **Physical impacts on the aquatic system**
- **Water quality alteration**
- **Aesthetic impairment**
- **Taste and odor**
- **Toxicity**

ALGAL PROBLEMS
Ecological Imbalances

High algal densities:

- Result from overly successful growth processes and insufficient loss processes
- Represent inefficient processing of energy by higher trophic levels
- May direct energy flow to benthic/detrital pathways, tends to use up oxygen
- May actually reduce system productivity (productivity tends to be highest at intermediate biomass)

ALGAL PROBLEMS
Aesthetic Impairment

High algal densities lead to:

- High solids, low clarity
- High organic content
- Fluctuating DO and pH
- “Slimy” feel to the water
- Unaesthetic appearance
- Taste and odor
- Possible toxicity

ALGAL PROBLEMS
Taste and Odor

- At sufficient density, all algae can produce taste and odor by virtue of organic content and decay
- Geosmin and Methylisoborneol (MIB) are the two most common T&O compounds, produced by cyanobacteria in water column or on bottom
- Additional compounds produced by golden algae and can impart cucumber, violet, spicy and fishy odors

ALGAL PROBLEMS

Taste and Odor

T&O by other algae

- Green algae, diatoms, dinoflagellates and euglenoids can produce fishy or septic odors at elevated densities
- Major die-off of high density algae may produce a septic smell
- Actinomycetes bacteria can also produce geosmin and MIB
- No clear link between T&O and toxicity

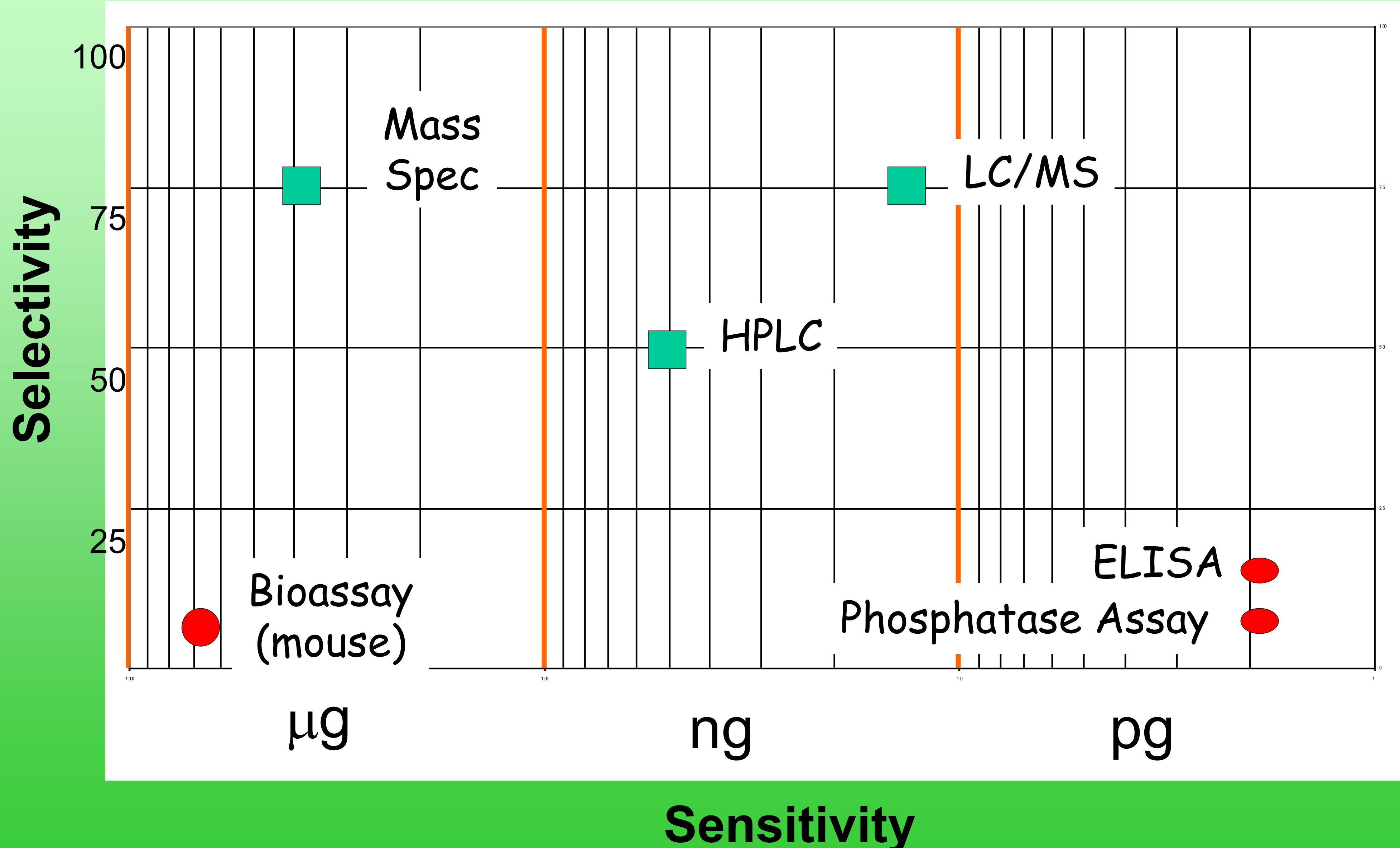
ALGAL PROBLEMS
Toxicity-Cyanotoxins

- Cyanobacteria are the primary toxin threats to people from freshwater
- Widespread occurrence of toxins but highly variable concentrations, even within lakes, usually not high
- Water treatment usually sufficient to minimize risk; greatest risk is from substandard treatment systems and direct recreational contact
- Some other algae produce toxins - Prymnesium, or golden blossom, can kill fish; marine dinoflagellates, or red tides, can be toxic to many animals and humans

ALGAL PROBLEMS
Toxicity-Cyanotoxins

- **Dermatotoxins**
  - produce rashes and other skin reactions, usually within a day (hours)
- **Hepatotoxins**
  - disrupt proteins that keep the liver functioning, may act slowly (days to weeks)
- **Neurotoxins**
  - cause rapid paralysis of skeletal and respiratory muscles (minutes)

ALGAL PROBLEMS
Toxicity-Analytical Methods



ALGAL PROBLEMS
Toxicity-Analytical Methods

Automated ELISA systems now coming out; may make toxicity testing both rapid and affordable.

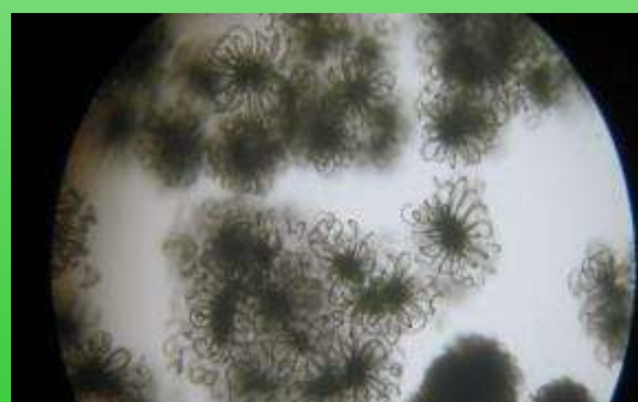
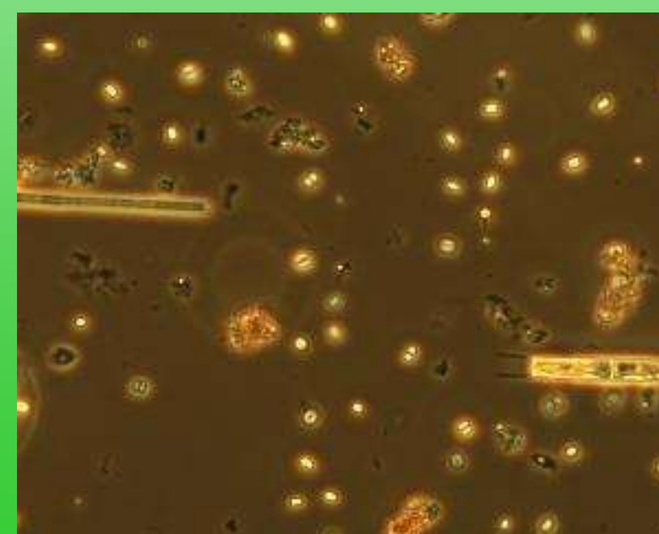
Cyanotoxin Automated Analysis System from Abraxis

ALGAL PROBLEMS
Toxicity- Key Issues

- Acute and chronic toxicity levels - how much can be tolerated?
- Synergistic effects - those with liver or nerve disorders at higher risk
- Exposure routes – ingestion or inhalation vs. skin
- Treatment options - avoid cell lysis, remove or neutralize toxins

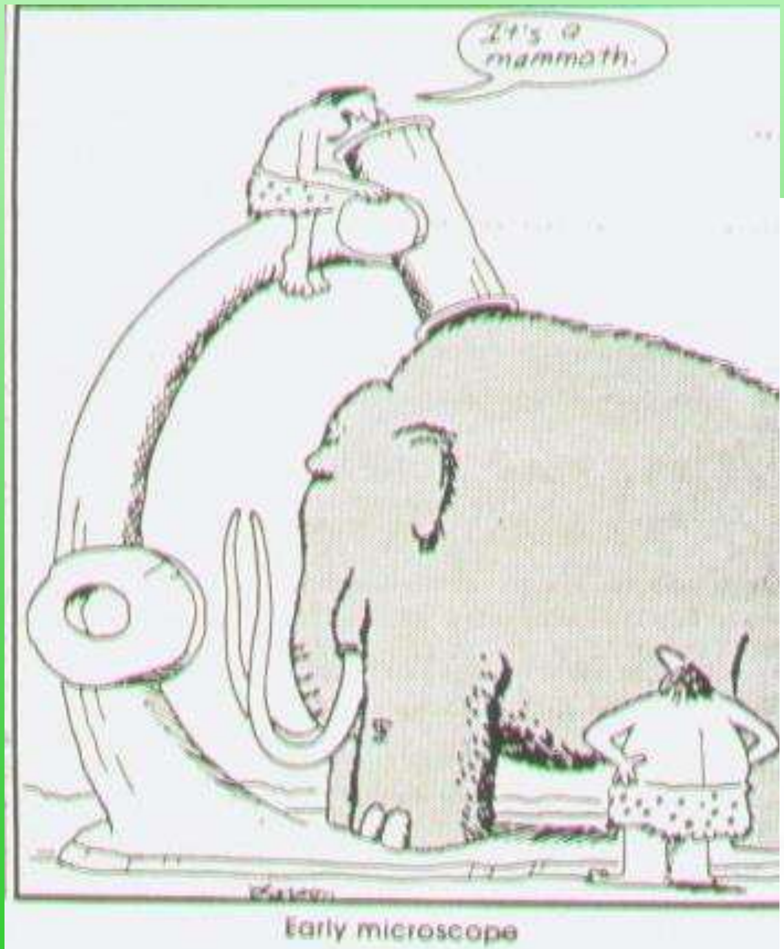
ALGAL PROBLEMS
Recommended Thresholds for Concern

- WHO: Mod/High risk thresholds at >20,000 – 100,000 cells/mL, >10 - 50 ug/L chl-a, >10 - 20 ppb microcystin-LR
- Most states use the WHO standard or some modification of it (e.g., 70,000 cells/mL).
- Some states working on more complete protocol; just knowing that there are a lot of cyanobacteria cells present is not enough, need to characterize variability and do toxin testing

ALGAL PROBLEMS
Cyanotoxin Tracking

- Microscopic viewing or fluorescence for pigment estimation
- ELISA tests for rapid quantification of toxins
- Advanced lab testing for toxins (GC/MS)



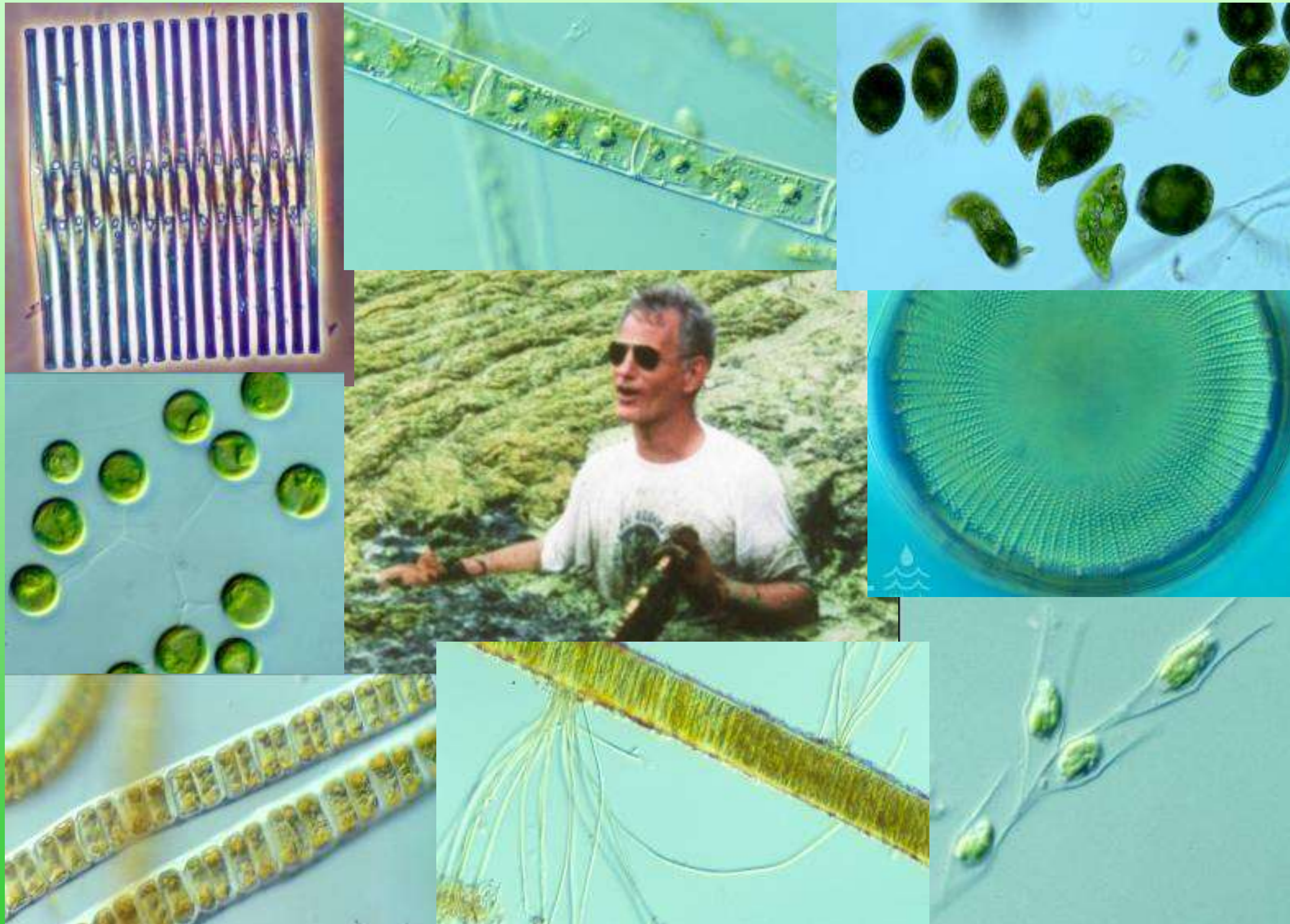
ALGAL PROBLEMS
Cyanotoxin Distribution

- **Multiple studies published in 2009 (LRM, NLA)**
- **Microcystin detected in many samples (typically about 1/3-1/2)**
- **Rare to find elevated microcystin levels in open or deep water; less rare, but not common in coves and shoreline areas**
- **Wide range of concentrations within some lakes; can’t extrapolate from single sample**
- **Microcystin at >10-20 µg/L in up to 20% of samples from “problem lakes”, <1% of samples from “random” lakes**
- **Other toxins less commonly assessed, no reliable estimate of distributional frequency, can’t assume correlation among toxins – so we don’t know as much as we should!**
- **Take home message: Recognize risk, but don’t assume toxicity**

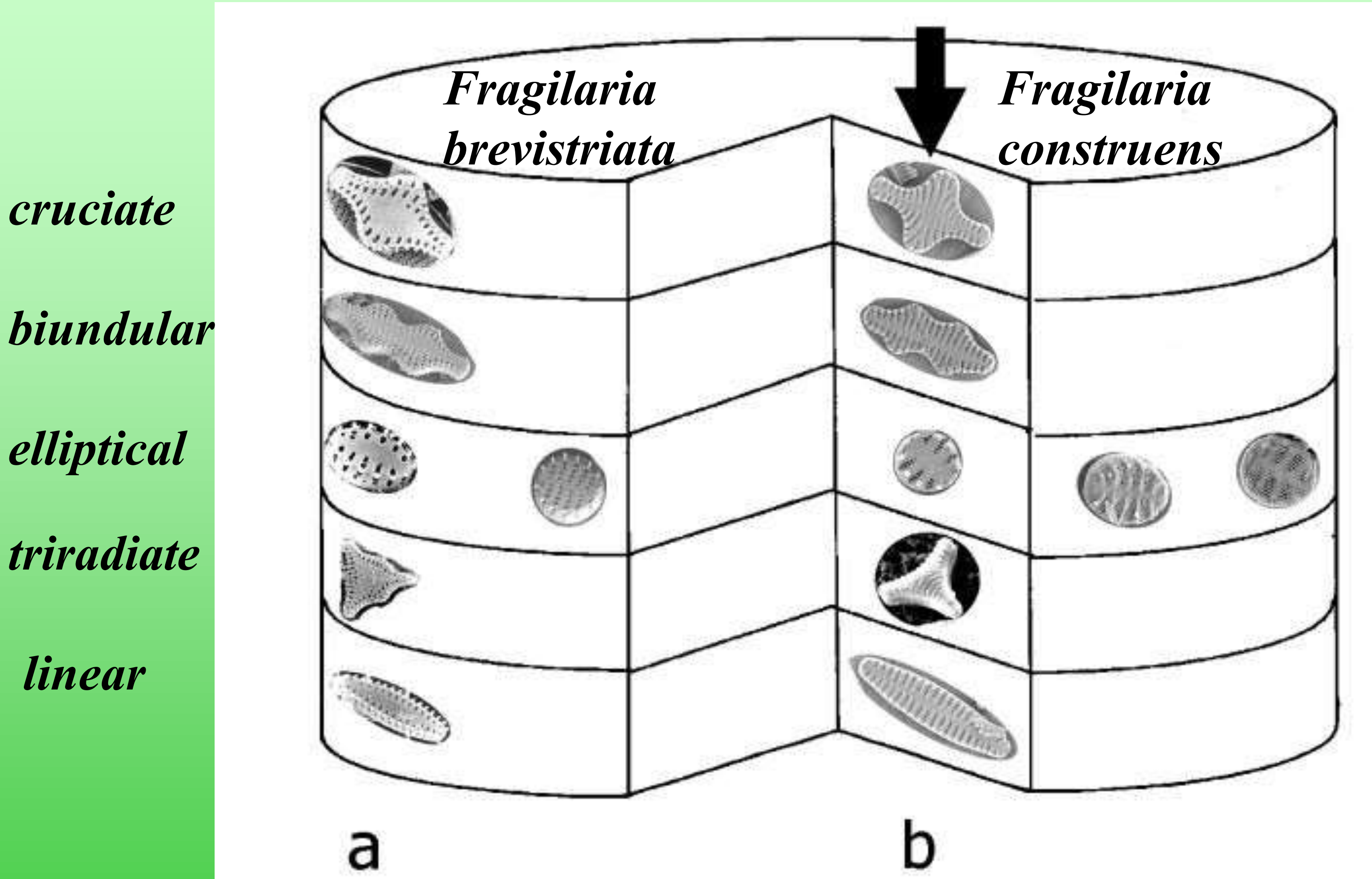
ALGAL PROBLEMS
Recommended Toxicity Precautions

- Monitor algal quantity and quality
- If potential toxin producers are detected, increase monitoring and test for toxins
- For water supplies, incorporate capability to treat for toxins (PAC or strong oxidation seem to be best)
- For recreational lakes, be prepared to warn users and/or limit contact recreation
- Avoid treatments that rupture cells after bloom is dense

PART 2: ALGAL FORMS



Algal Taxonomy



Layer cake analogy from Morales et al. 2002

Just where to make the split between species or even genera is not always obvious

Algal Taxonomy

Splitters vs. Lumpers

- Lumping limits taxa, groups by “reliable” differentiators (best if genetically based, but was not always the case)
- Splitting proliferates taxa, separates forms based on what may be genotypic or phenotypic differences
- In characterizing environmental conditions, splitting will be more useful but requires more effort

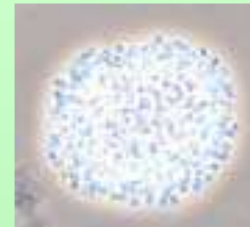
Classification Features

- Pigments
- Food storage
- Cell wall
- Flagella

- Cell structures
- Cell organization

- Reproductive mode
- Genetics
- Culture response
- Biochemistry

Algal Taxonomy




Modern Classification of Cyanobacteria

Class Synechococcineae
Order Synechococcales (e.g. *Aphanocapsa*, *Coelosphaerium*, *Synechococcus*)
Order Pseudanabaenales (e.g. *Pseudanabaena*, *Schizothrix*, *Spirulina*)


Class Oscillatoriineae
Order Chroococcales (e.g. *Chroococcus*, *Microcystis*)
Order Phormidiales (e.g. *Arthrospira*, *Phormidium*, *Planktothrix*)
Order Oscillatoriales (e.g.*Lyngbya*, *Oscillatoria*)


Class Nostocineae
Order Nostocales (e.g. *Anabaena*, *Cylindrospermopsis*, *Scytonema*, *Stigonema*)

Algal Taxonomy

- *Anabaena* and *Aphanizomenon* are closely related
- Nearly all of what we have called *Anabaena* is now *Dolichospermum*

Dolichospermum

Anabaena

Algal Taxonomy

Filaments with long attenuated end cells split from Aphanizomenon into Cuspidothrix

Separating Cyano Species

- Cell shape and Size
- Color
- Granulation
- Presence/Absence of Aerotopes
- Habitat
- Cell Arrangement
- Mucilage features
- Trichome morphology
- Presence/Absence and Nature of Sheath
- Presence/Absence of Constrictions at Cross-walls
- Shape, Size and Location of Heterocytes and Akinetes
- Motility
- End Cell Shape

Algal Forms

Algal "Blooms"

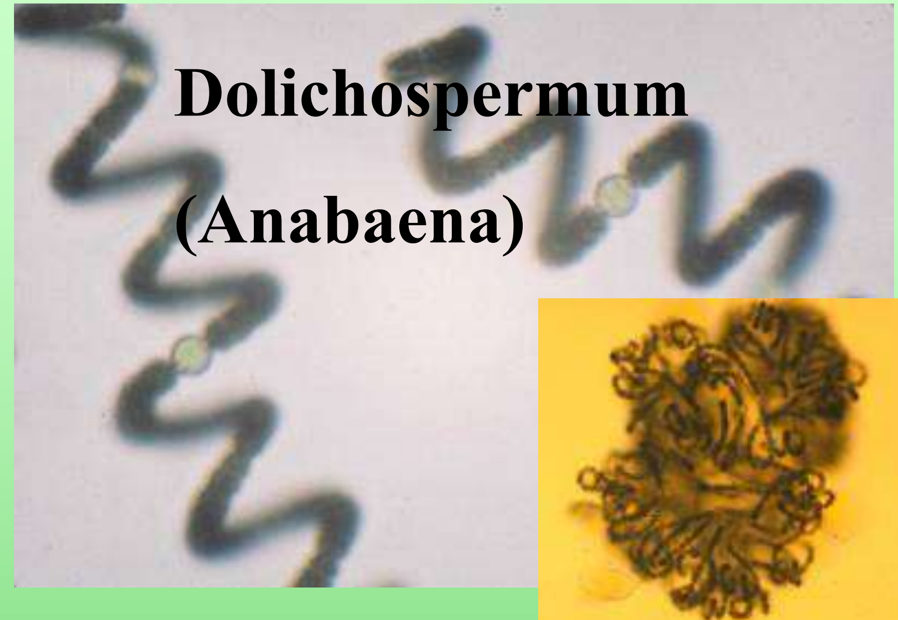
- **Water discoloration usually defines bloom conditions**
- **Many possible algal groups can "bloom"**
- **Taste and odor sources, possible toxicity**
- **Potentially severe use impairment**

Algal Forms

Algal Mats

- **Can be bottom or surface mats - surface mats often start on the bottom**
- **Usually green or blue-green algae**
- **Possible taste and odor sources**
- **Potentially severe use impairment**

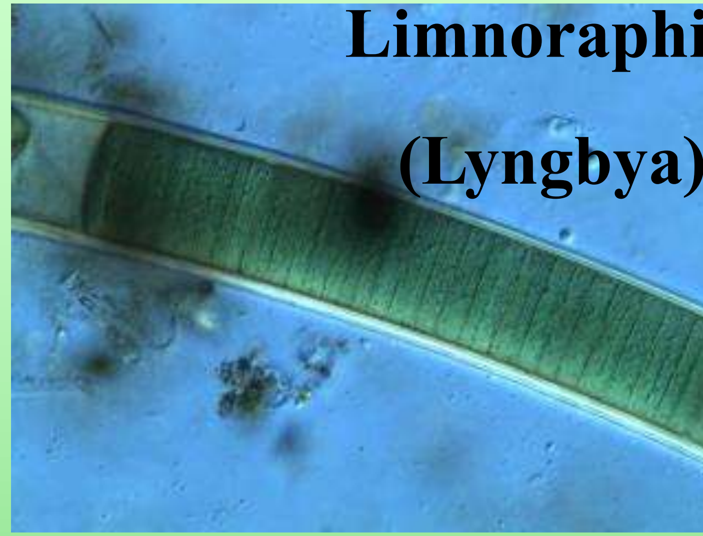
Algal Types: Planktonic Blue-greens



Algal Types: Planktonic Blue-greens

Planktolyngbya

(Lyngbya)



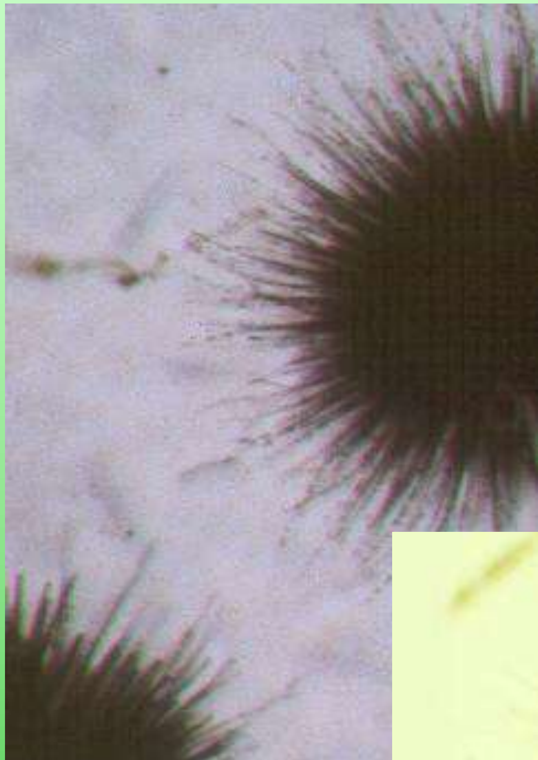
Limnoraphis

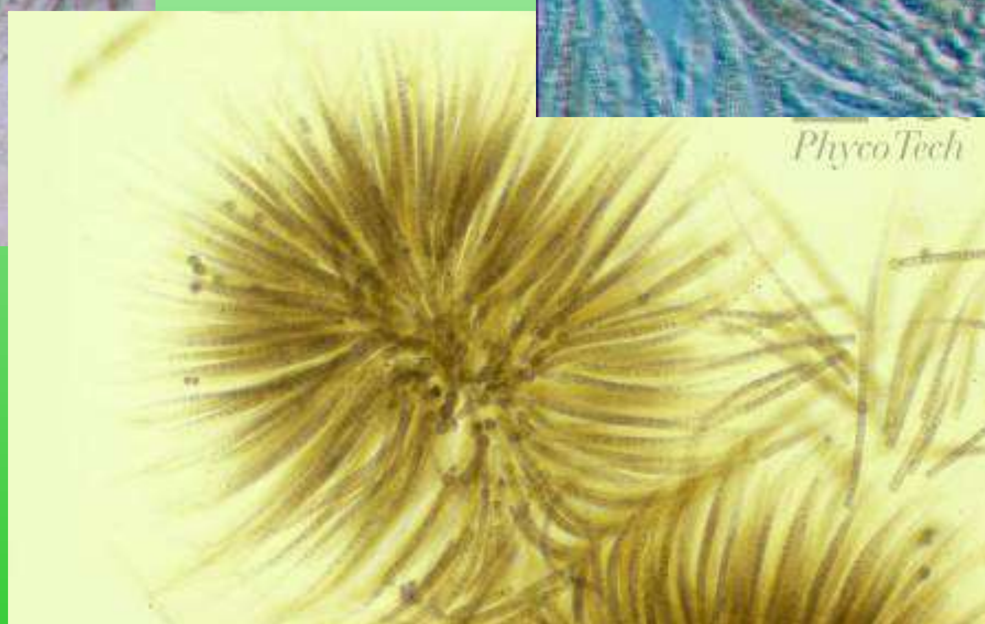
(Lyngbya)

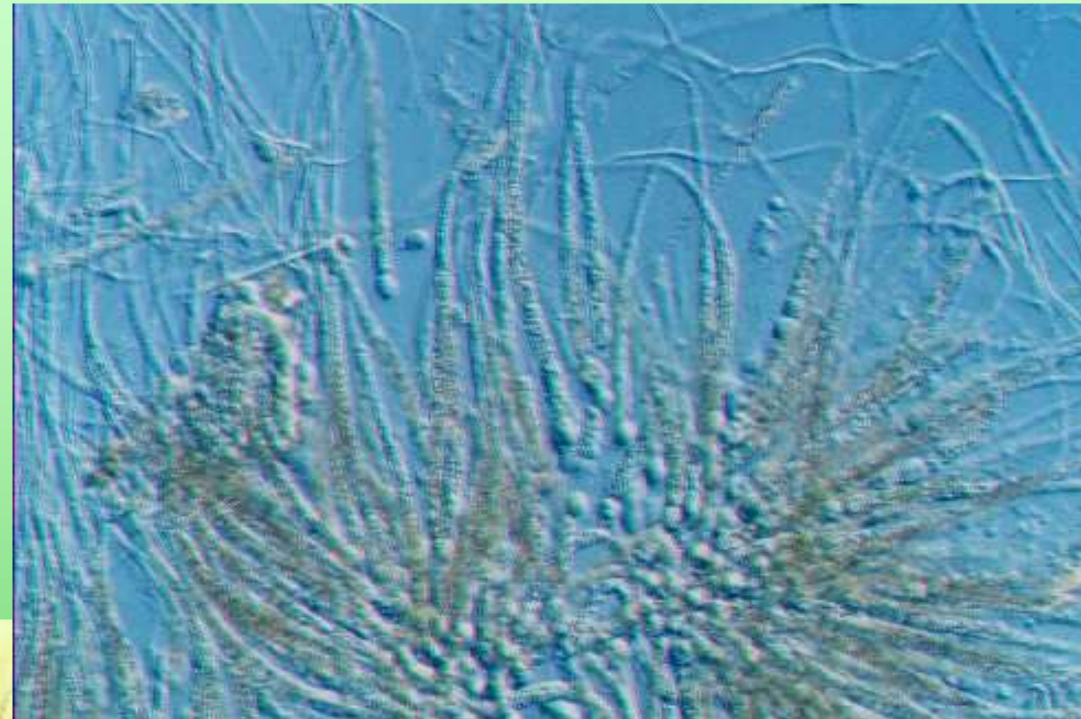
Planktothrix

(Oscillatoria)

Algal Types: Planktonic Blue-greens







Gloeotrichia

Algal Types: Planktonic Blue-greens

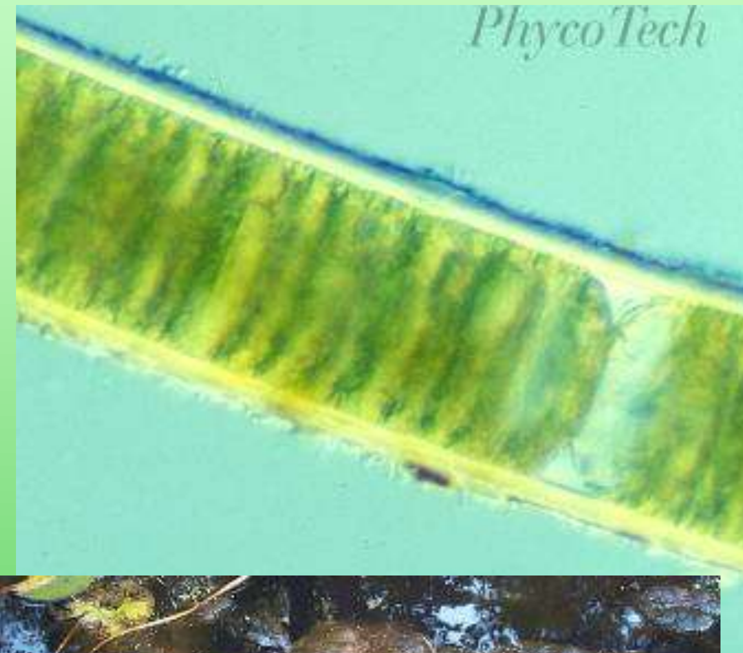
Cylindrospermopsis

- **A sub-tropical alga with toxic properties is moving north.**
- **Most often encountered in turbid reservoirs in late summer, along with a variety of other bluegreens.**

Algal Types: Mat Forming Blue-greens

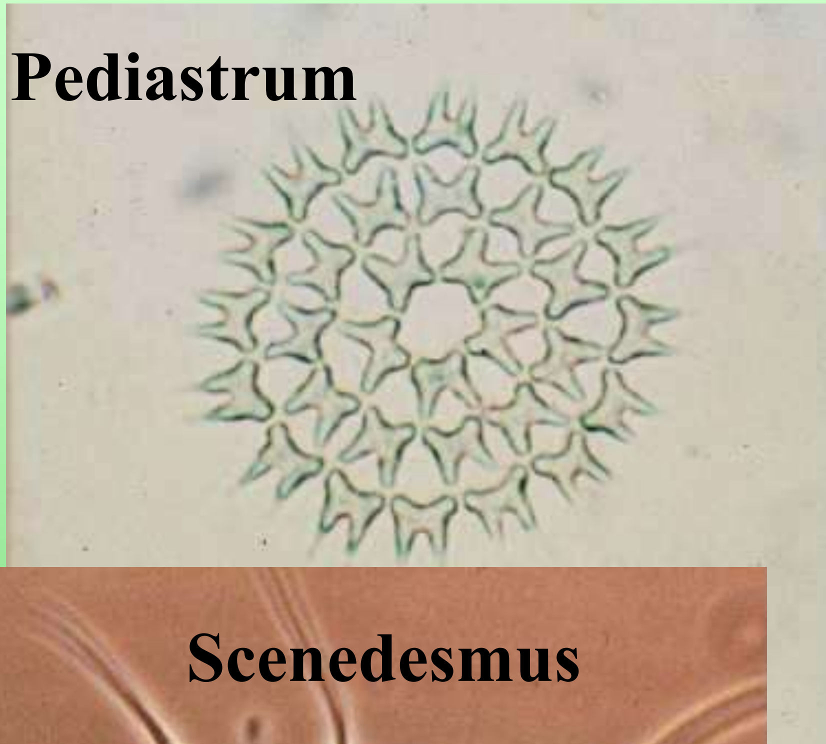
Oscillatoria

Lyngbya/Plectonema



Algal Types: Planktonic Greens

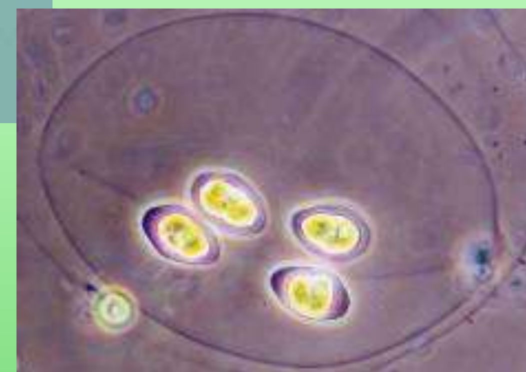
(Order Chlorococcales)

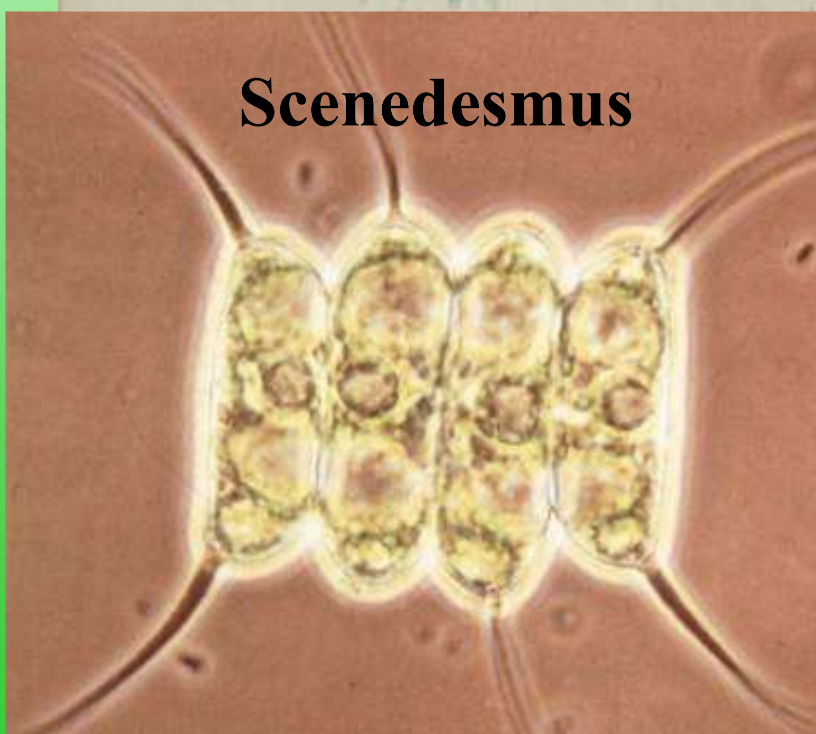


Pediastrum

Schroederia

Oocystis





Scenedesmus

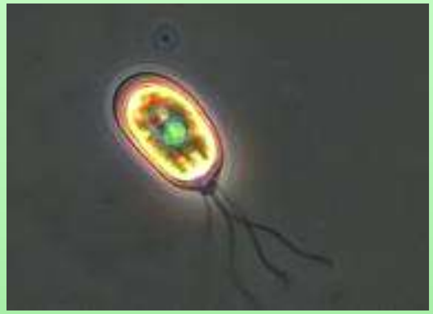
Lagerheimia Dictyosphaerium

Algal Types: Planktonic Greens

(Order Volvocales)

Pyramichlamys

Carteria



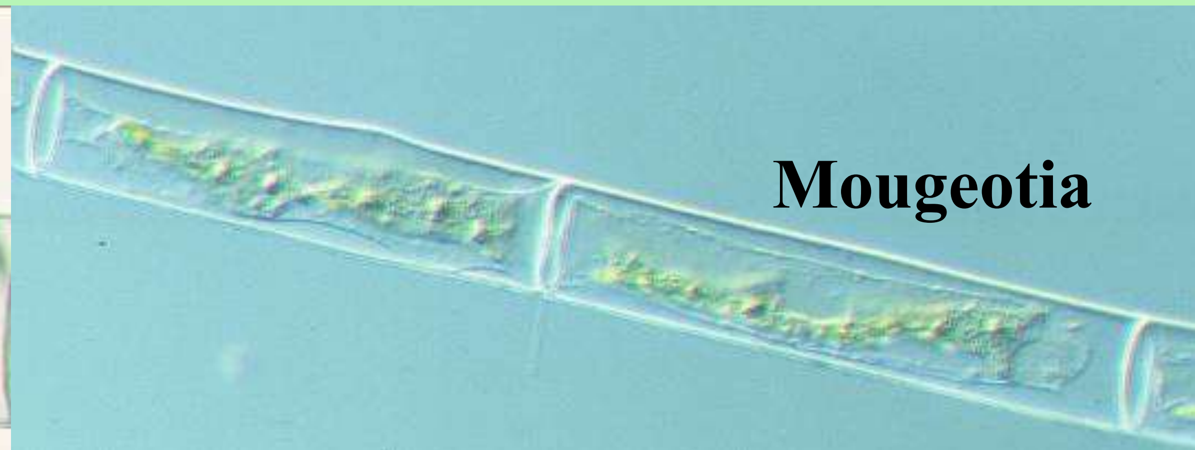
Eudorina

Volvox

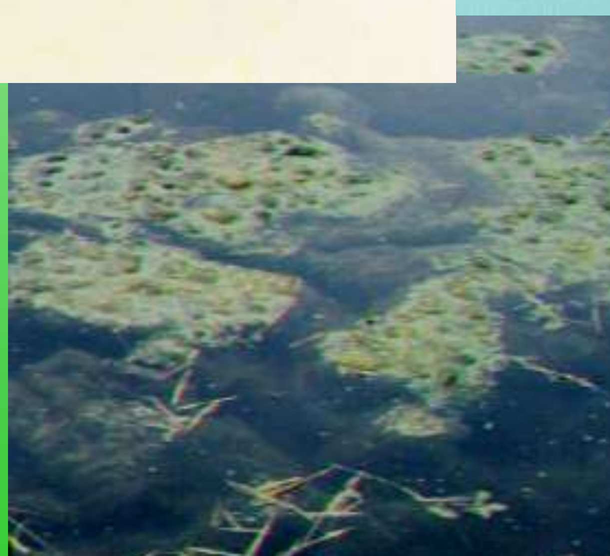
Chlamydomonas

Algal Types: Mat Forming Greens

Zygnematales - Unbranched filaments, highly gelatinous



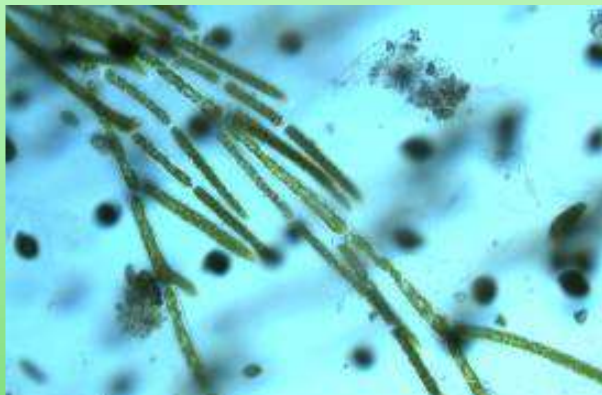
Mats trap gases and may float to surface



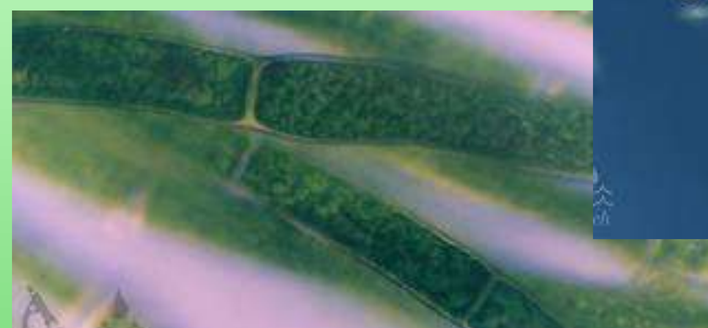
Algal Types: Mat Forming Greens

Cladophorales - Large, multinucleate cells, reticulate chromatophores, tend to be "gritty" to the touch

Cladophora

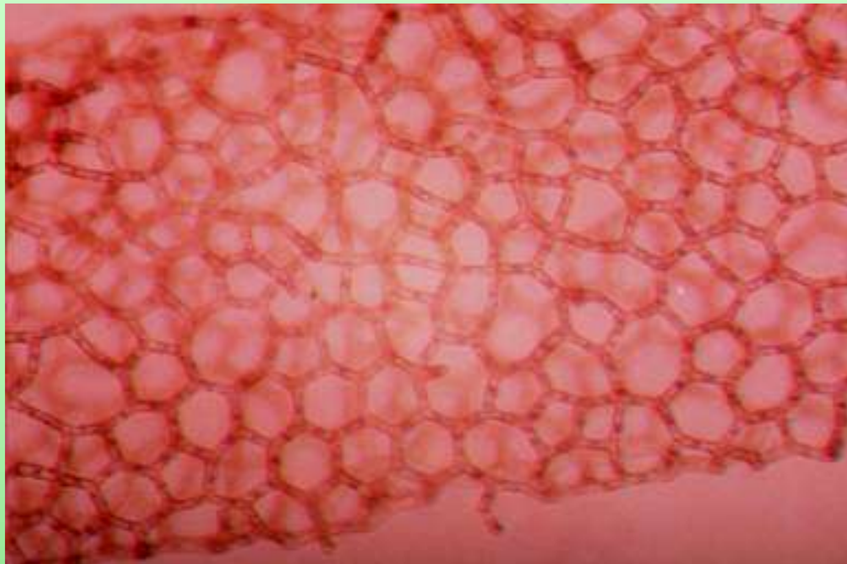


Rhizoclonium

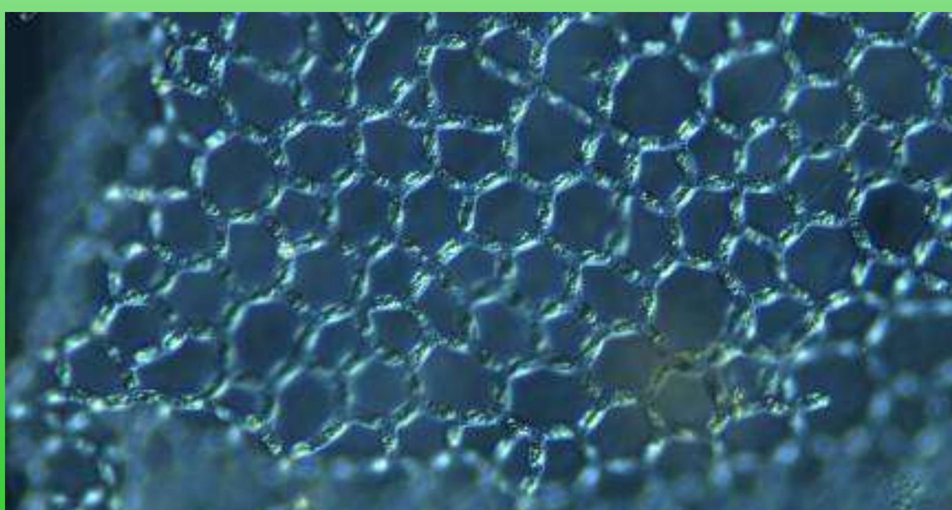


Pithophora

Algal Types: Mat Forming Greens



Hydrodictyon

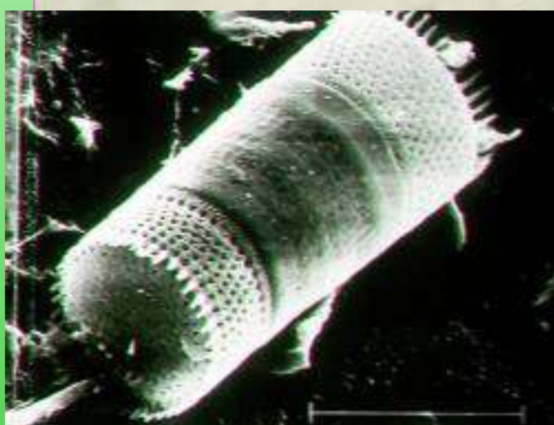


Oedogonium

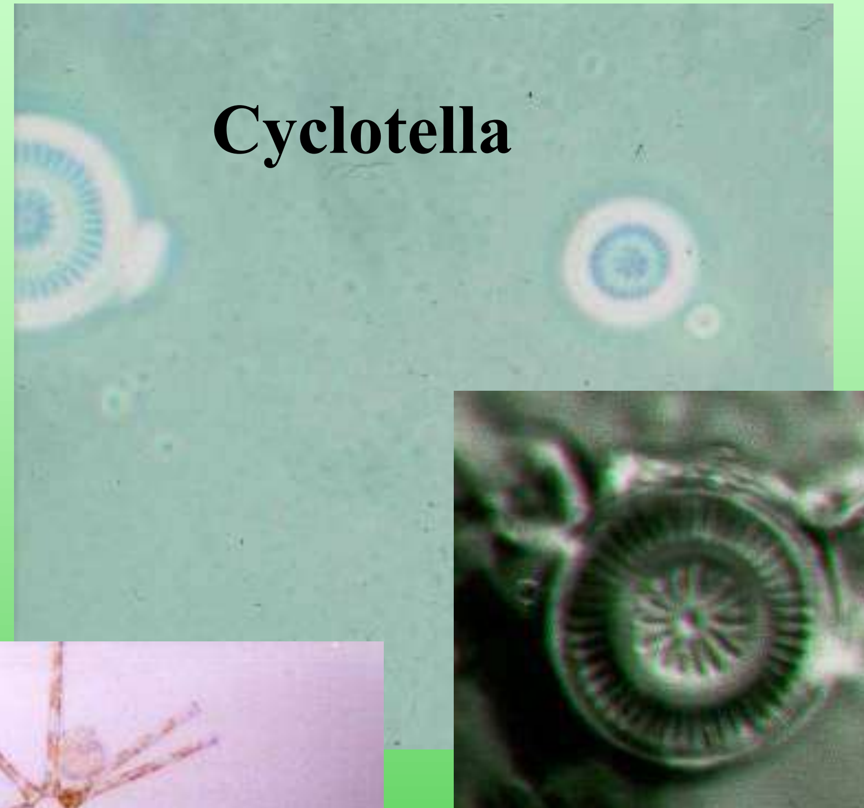
Bulbochaete

Algal Types: Planktonic Diatoms

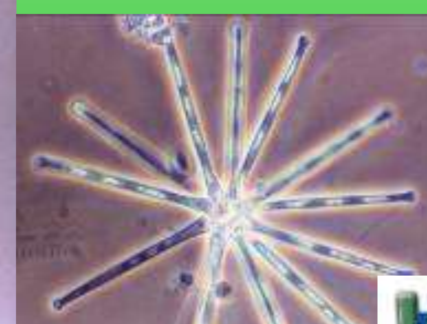
Aulacoseira



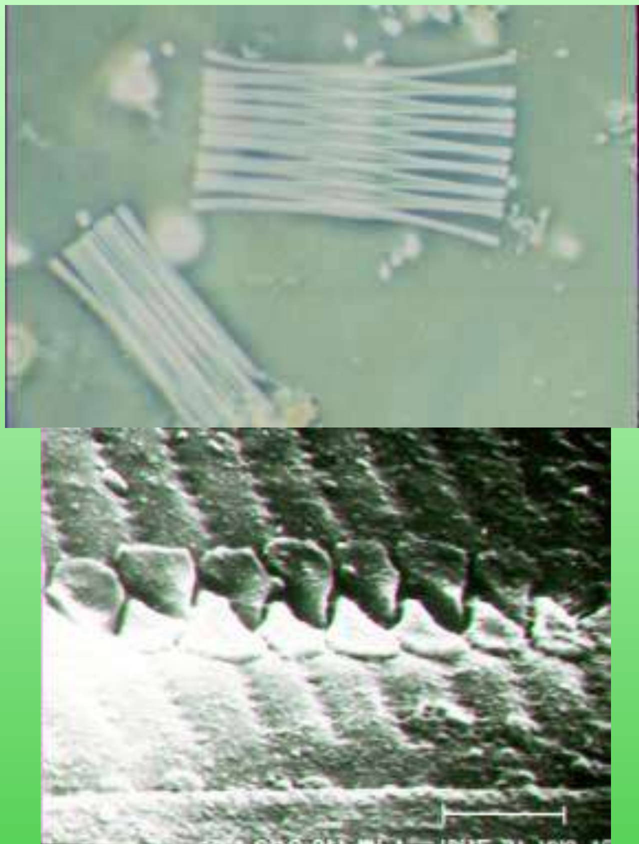
Cyclotella



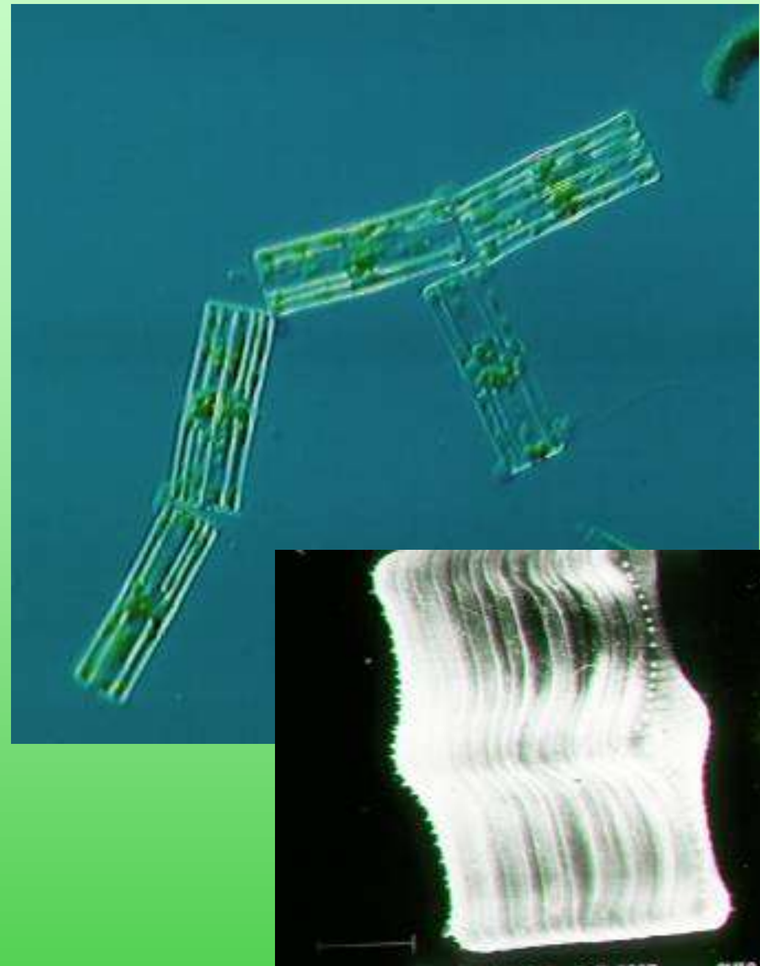
Asterionella



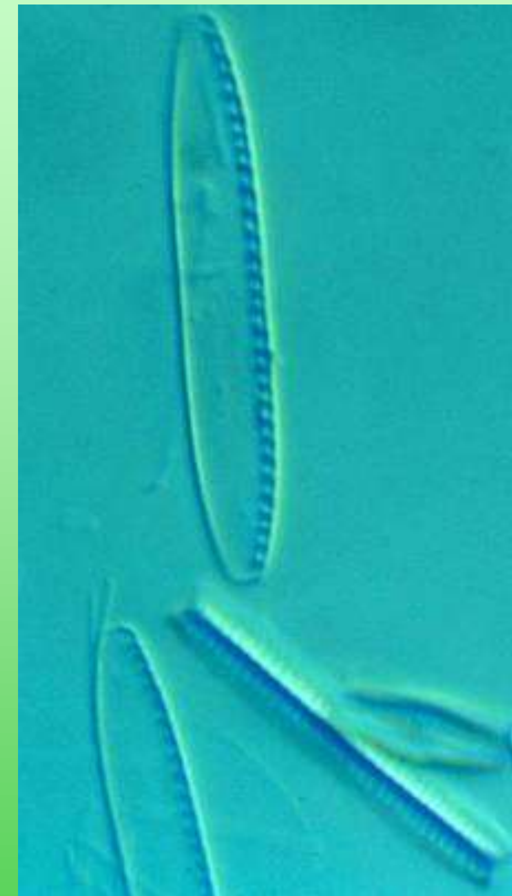
Algal Types: Planktonic Diatoms



Fragilaria

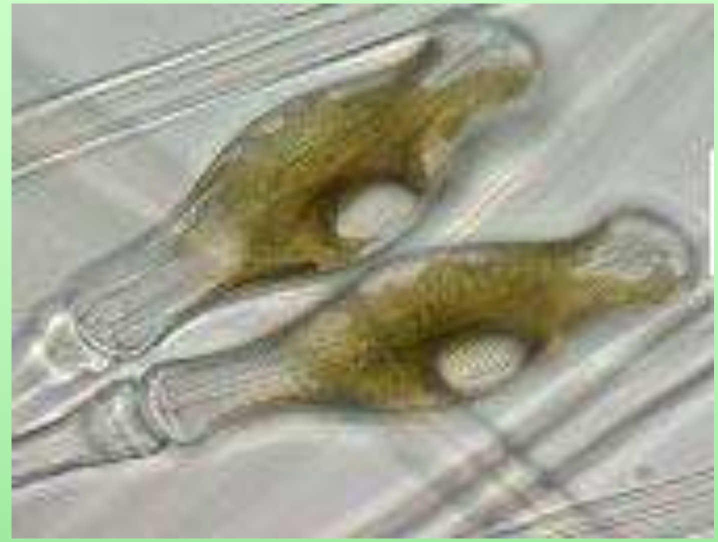


Tabellaria



Nitzschia

Algal Types: Mat Forming Diatoms



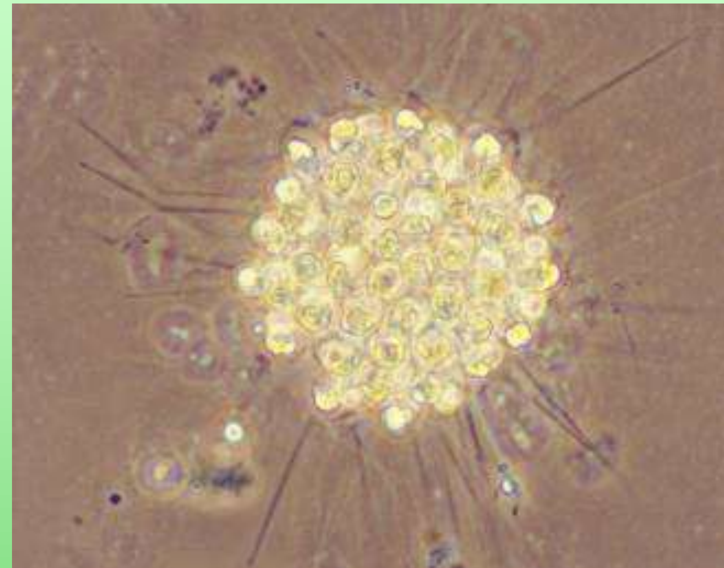
Didymosphenia ("rock snot")

In flowing waters, more northern, recent ecological "event"

Algal Types: Plankton Goldens

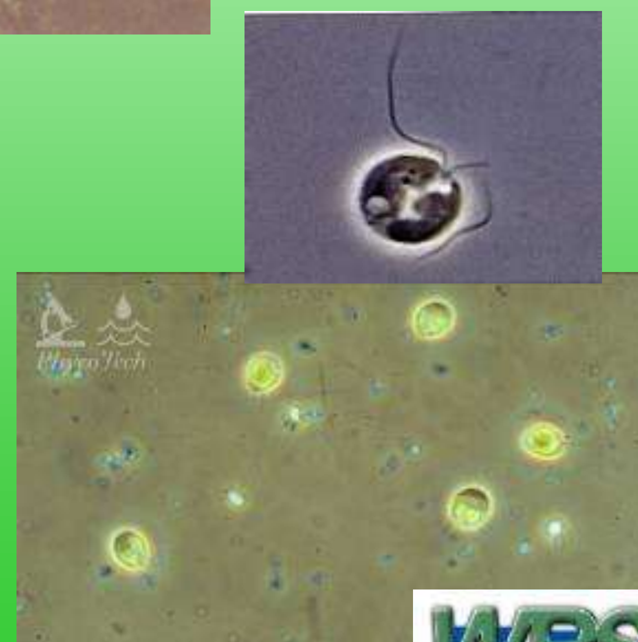
Synura

Chrysosphaerella



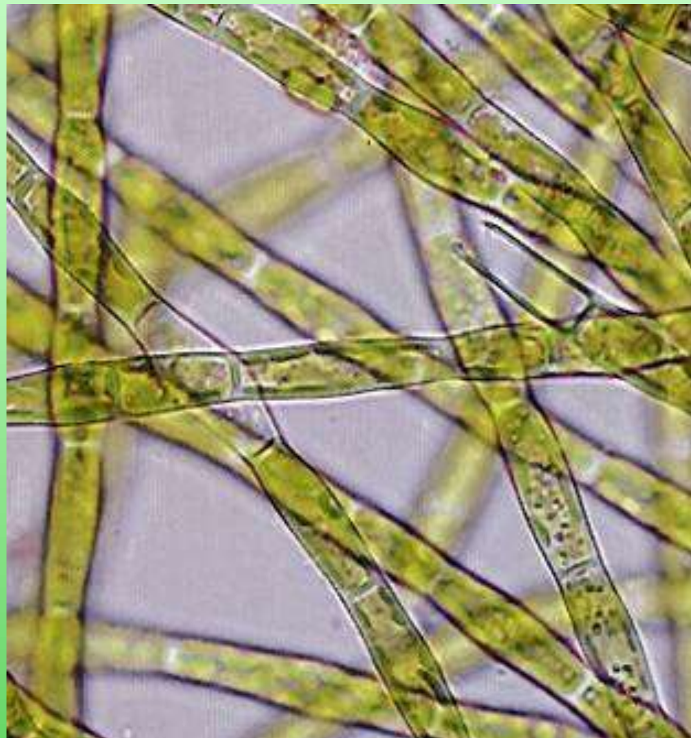
Dinobryon

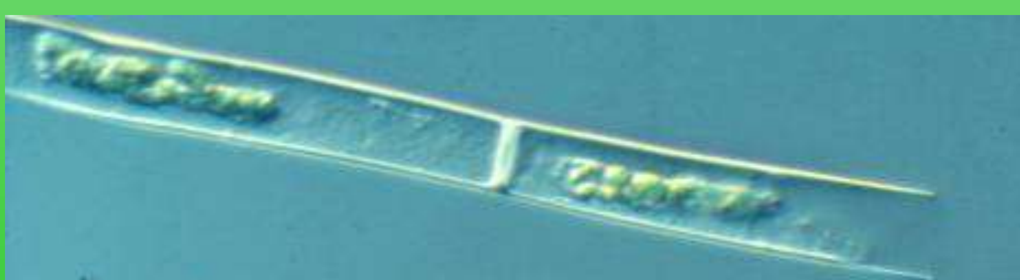
Prymnesium



Algal Types: Mat Forming Goldens

Tribonema





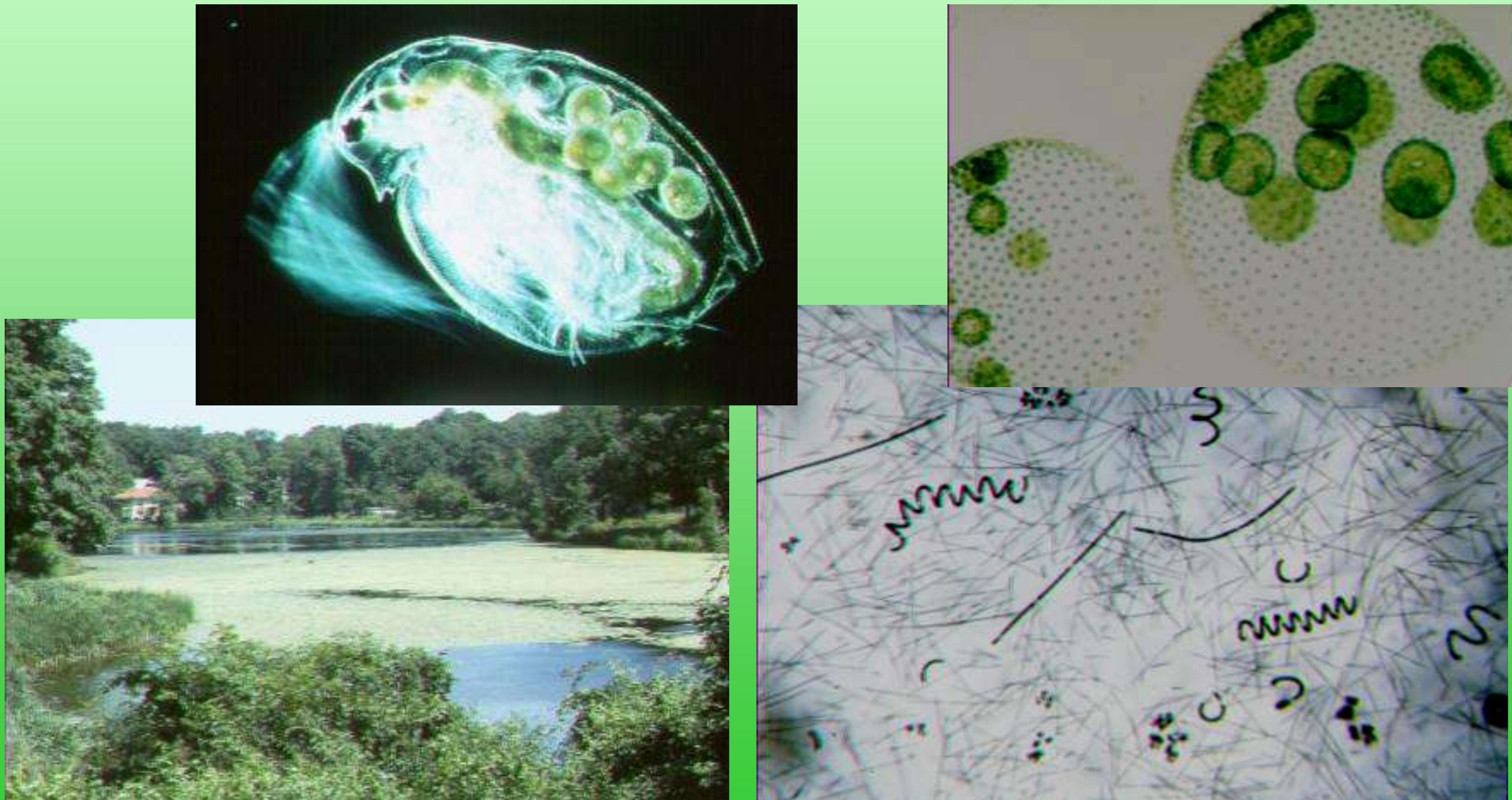
Vaucheria

Algal Types: Other Plankton

(Euglenoids)

(Dinoflagellates)

PART 3: THE ECOLOGICAL BASIS FOR ALGAL CONTROL



ALGAL ECOLOGY
Key Processes Affecting Abundance
Growth Processes

- Primary production – controlled by light and nutrients, algal physiology
- Heterotrophy – augments primary production, dependent upon physiology and environmental conditions
- Release from sediment – recruitment from resting stages, related to turbulence, life strategies

ALGAL ECOLOGY
Key Processes Affecting Abundance

Loss Processes

- Physiological mortality – inevitable but highly variable timing – many influences
- Grazing – complex algae-grazer interactions
- Sedimentation/burial – function of turbulence, sediment load, algal strategies
- Hydraulic washout/scouring – function of flow, velocity, circulation, and algal strategy

ALGAL ECOLOGY
Key Processes Affecting Abundance

Annual variability in growth/loss factors

- Winter –
  - Lower light and temperature affect production
  - Variable but generally moderate nutrient availability
  - Possibly high organic content
  - Grazer density below average

ALGAL ECOLOGY
Key Processes Affecting Abundance

Annual variability in growth/loss factors

- Spring/fall –
  - Isothermal and well-mixed
  - Relatively high nutrient availability
  - Light increases in spring, decreases in fall
  - Temperature changing, spring increase, fall decline
  - Stratification setting (spring) or breaking down (fall)
  - Grazer density in transition (low to high in spring, high to low in fall)

ALGAL ECOLOGY
Key Processes Affecting Abundance

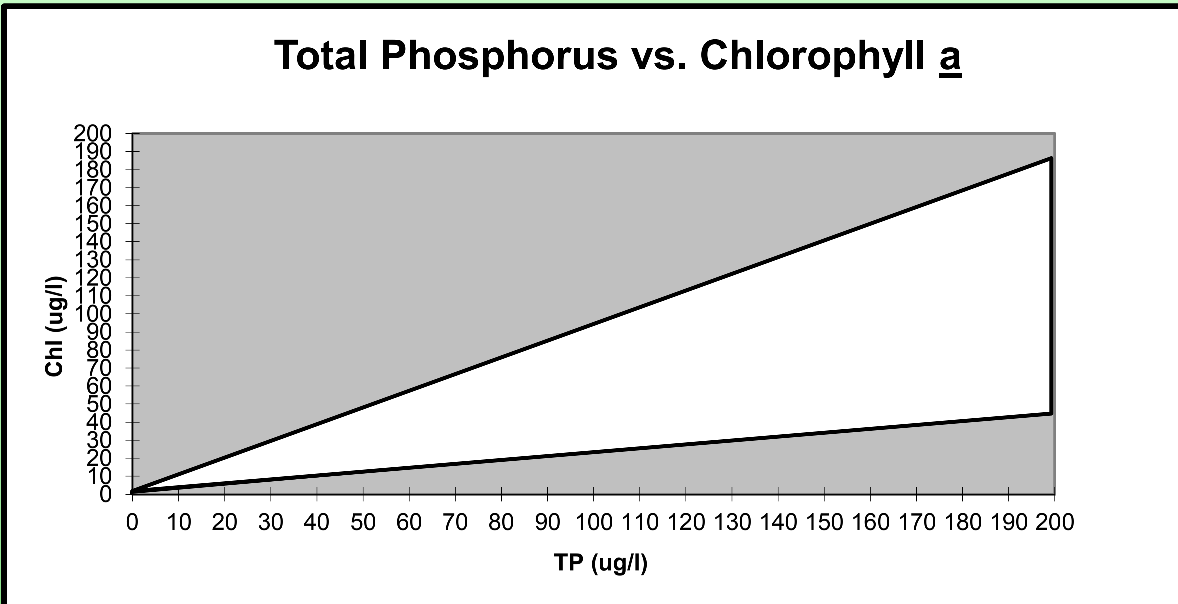
Annual variability in growth/loss factors

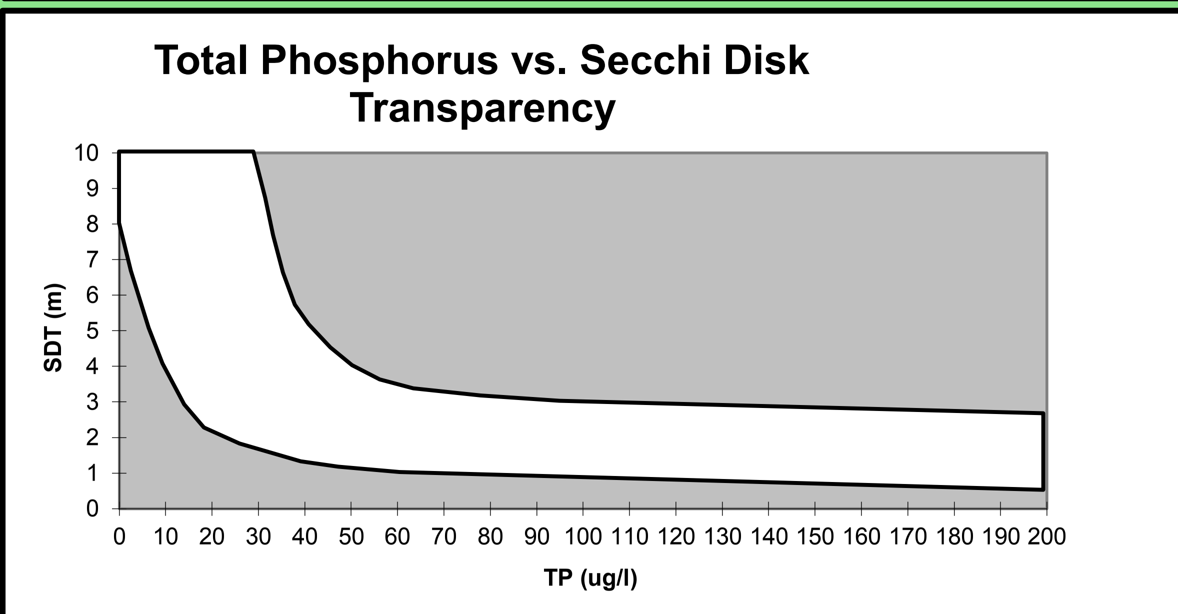
- Summer –
  - Potential stratification, even in shallow lakes
  - Often have low nutrient availability
  - Light limiting only with high algae or sediment levels
  - Temperature vertically variable – highest near surface
  - Vertical gradients of abiotic conditions and algae
  - Grazer densities variable, often high unless fish predation is a major factor

ALGAL ECOLOGY
Phytoplankton Succession - Notes

- Biomass can vary greatly over seasons
- Primary productivity and biomass may not correlate due to time lags, cell size and nutrient or light limitations
- Highest productivity normally at intermediate biomass (Chl a = 10 ug/L)
- Phosphorus tends to determine how abundant algae are, while nitrogen tends to determine types of algae present

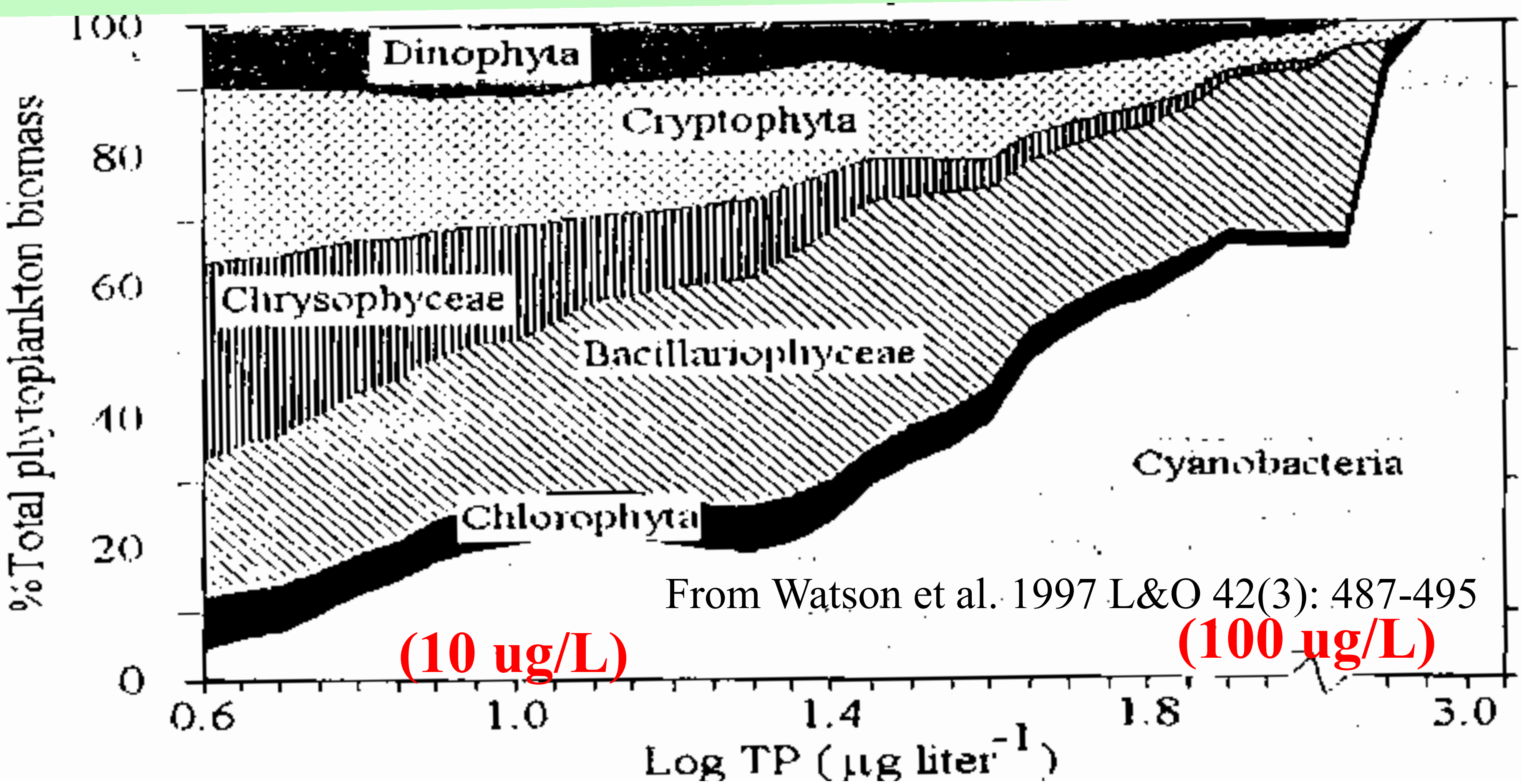
ALGAL ECOLOGY
Trophic Gradients





- Based on decades of study, more P leads to more algae
- More algae leads to lower water clarity, but in a non-linear pattern
- Fertile systems will have more algae and more cyanobacteria with lower clarity

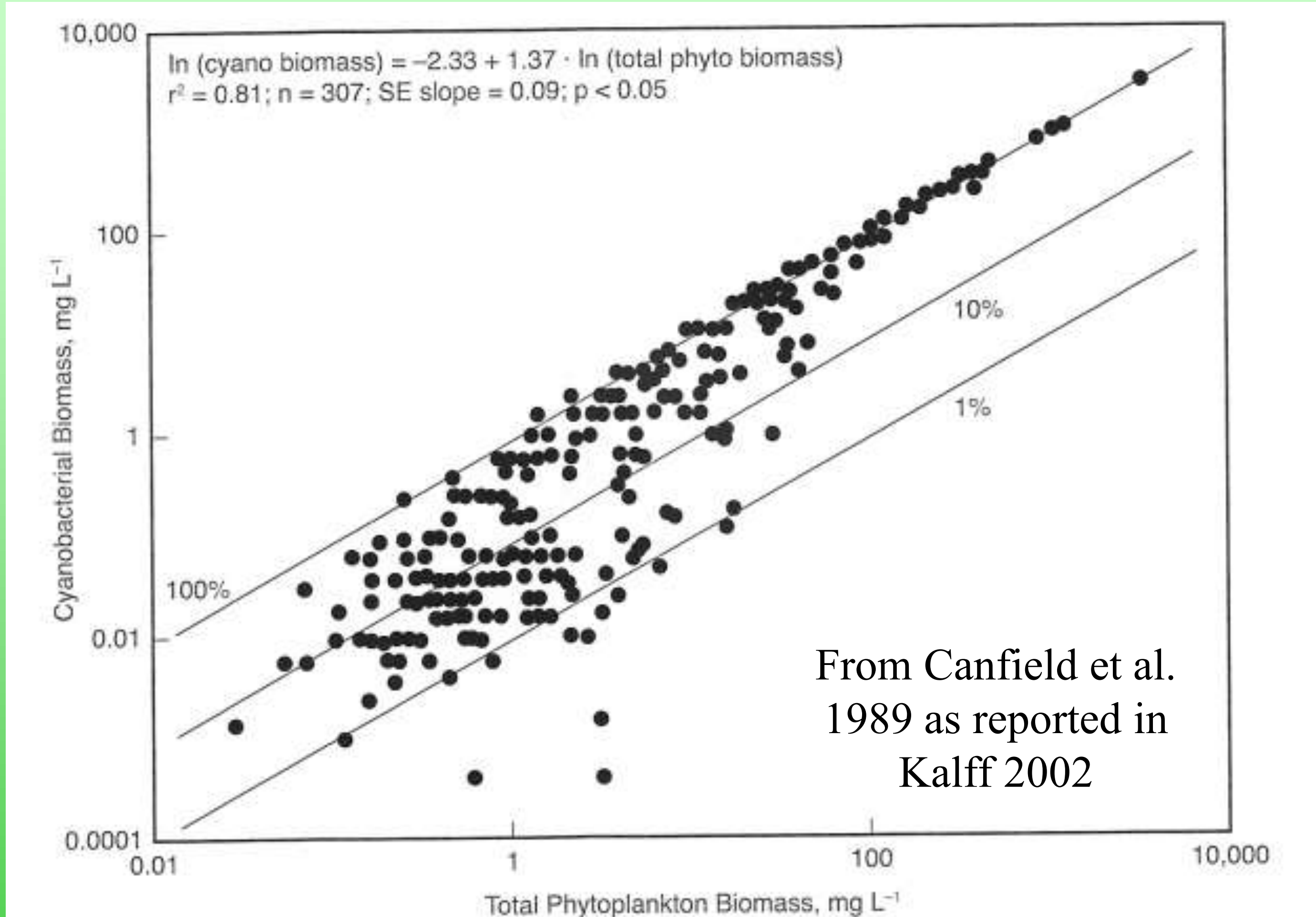
ALGAL ECOLOGY
Trophic Gradients



From Watson et al. 1997 L&O 42(3): 487-495

- High P also leads to more cyanobacteria, from considerable empirical research. Key transition range is between 10 and 100 ug/L

ALGAL ECOLOGY
Trophic Gradients



From Canfield et al. 1989 as reported in Kalff 2002

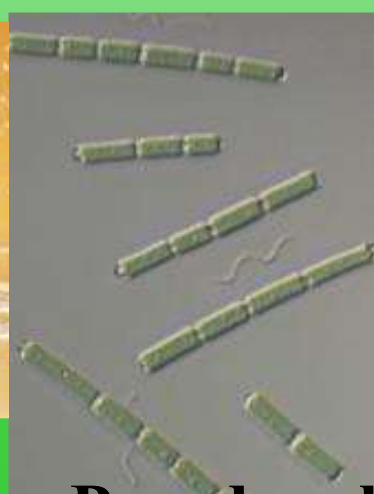
- As algal biomass rises, a greater % of that biomass is cyanobacteria. So more P = more algae + more cyanos.

ALGAL ECOLOGY: Bloom Formation

Organic growth in upper water layer using sunlight and nutrients:

- **Starter population still has to come from somewhere, either upstream or sediment.**
- **But population starts small, grows into bloom over 3-4 weeks**
- **Water column nutrients/light control bloom severity**

Aphanizomenon



Pseudanabaena

Planktolyngbya

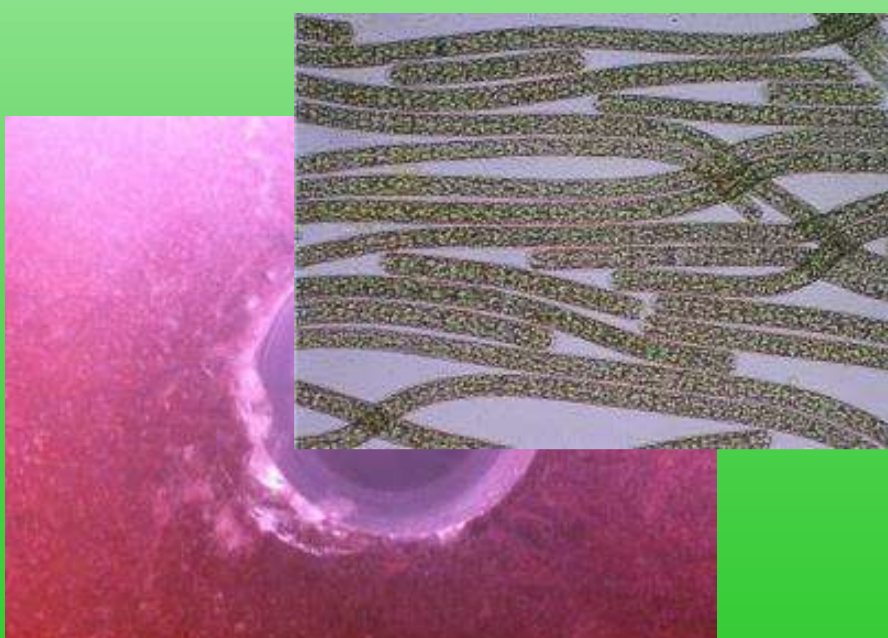
Chlorococcales

ALGAL ECOLOGY: Bloom Formation

Formation at mid-depth with movement into upper water layer:

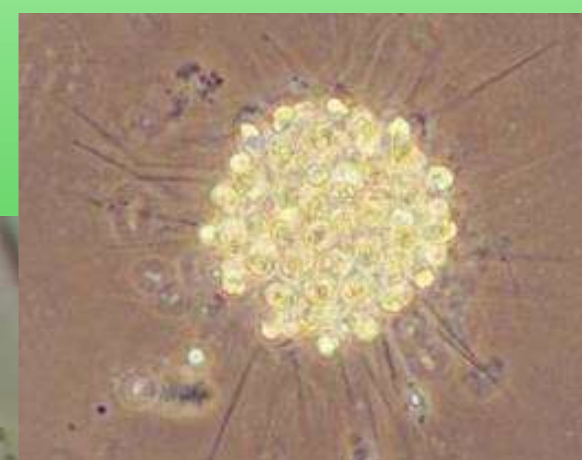
- Starter population normally from sediment, rises to near thermocline
- Growth at depth depends on high efficiency of light use but capitalizes on generally higher nutrient levels

Planktothrix



Synura

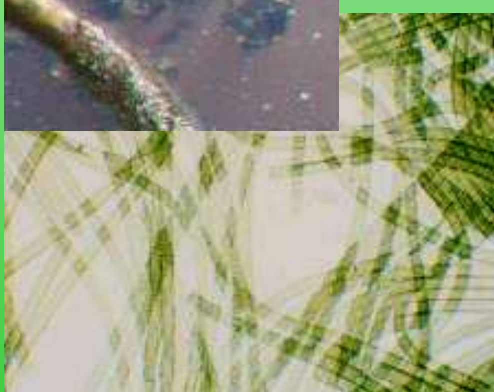
Chrysosphaerella



ALGAL ECOLOGY: Bloom Formation

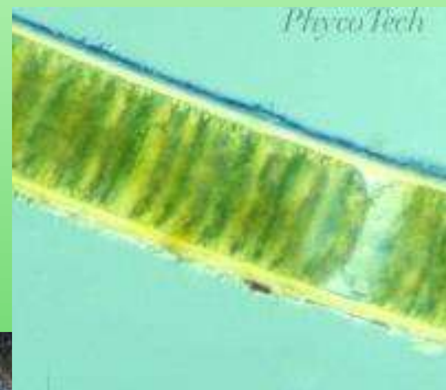
Bottom growth by filamentous blue-greens and green algae well documented:

- **Filamentous mats form, trap gases, float to surface as mats or “chunks”**



Oscillatoria

Plectonema



Rhizoclonium

ALGAL ECOLOGY: Bloom Formation

Bottom growth of planktonic forms followed by synchronized rise into the upper water layer:

- **Resting stages germinate on sediment surface, grow in place to fully formed colonies.**
- **Gas vesicles form synchronously and create buoyancy; colonies float to surface quickly**

Dolichospermum

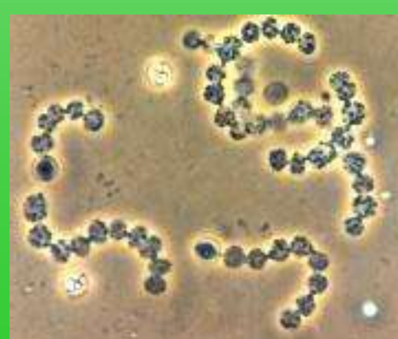
ALGAL ECOLOGY: Bloom Trends

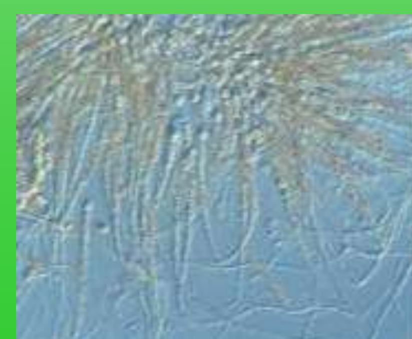
Cyano blooms are increasing:

- Phosphorus rising; decreased N:P ratios favor cyanos
- Temperatures rising; 30 C in 2012, also favors cyanos

Bottom growth/quick rise blooms seem to be increasing in particular:

- Long-term accumulation of nutrients in sediment fosters such growths
- Light and sediment mixing are key triggers; shallow zone implicated as bigger contributor than deep zone



ALGAL ECOLOGY: Climate Change

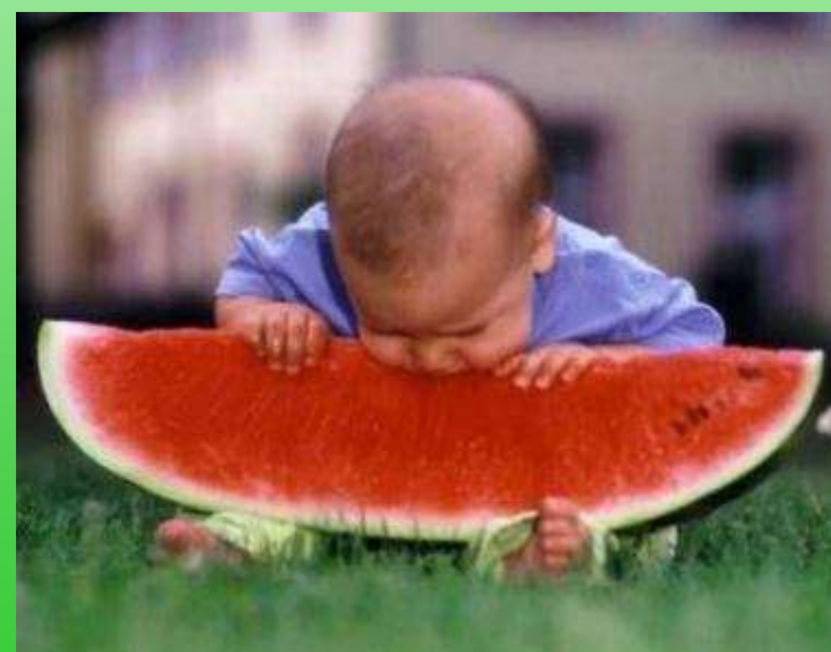
Warmer water increases growth rates and favors cyanobacteria. Temperatures are rising.

Data from many sources, but Hans Paerl's illustration may be the most "elegant"

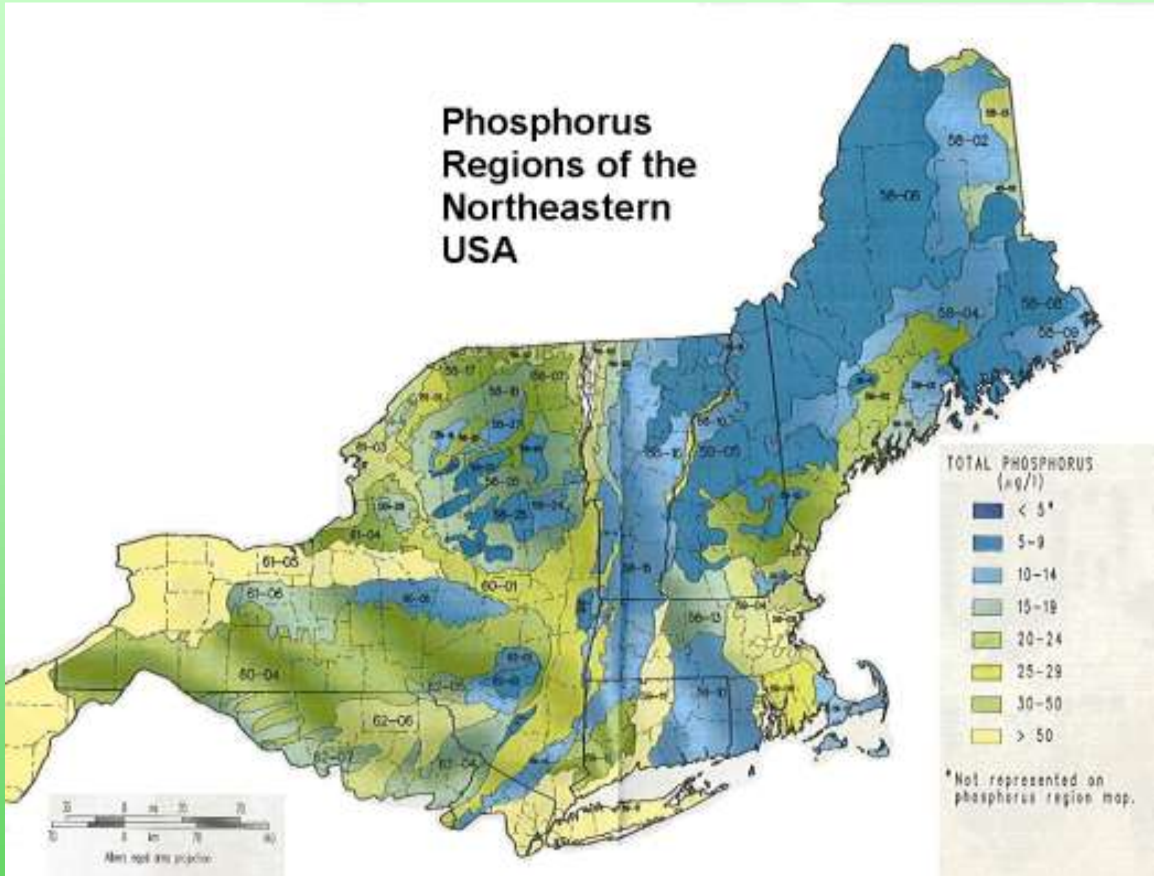
PART 4: METHODS OF ALGAL CONTROL

Three step process:

- Don't lose your head
- Get ducks in a row
- Don't bite off more than you can chew



Algal Control: Watershed Management



Understand the watershed and manage it!

Algal Control: Watershed Management

- ♦ **Source controls**
  - Banning certain high-impact actions
  - Best Management Practices for minimizing risk of release
- ♦ **Pollutant trapping**
  - Detention
  - Infiltration
  - Uptake/treatment
  - Maintenance of facilities

Watershed management should be included in any successful long-term algal management plan, but may not be sufficient by itself.



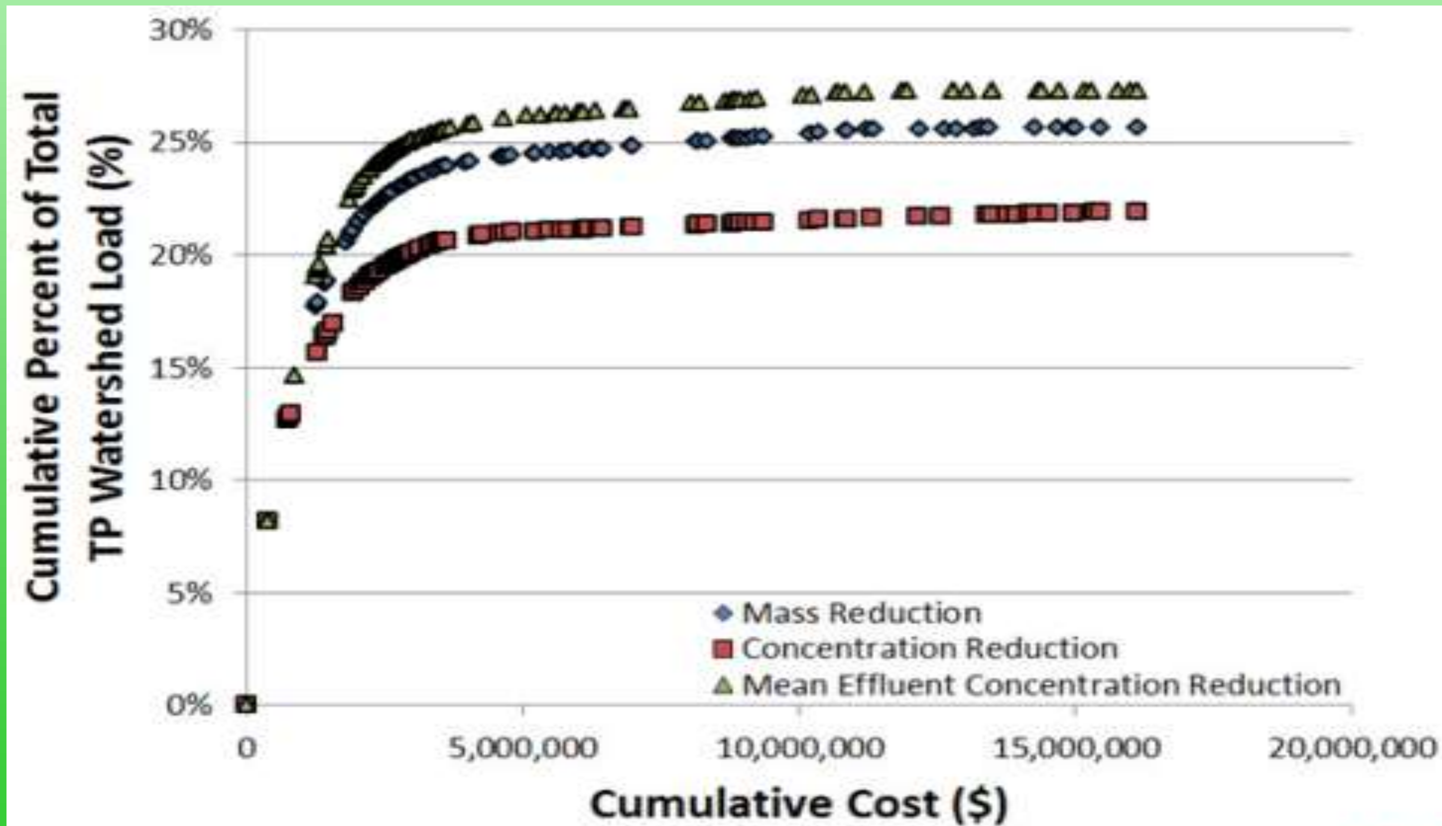


Algal Control: Watershed Management

- Developed land typically increases phosphorus loading by >10X
- Common BMPs rarely reduce phosphorus by <50%; unless all runoff can be infiltrated, we are unable to make developed land behave like undeveloped land
- Agricultural impacts are at least as great as urban impacts
- With more than about 20% of the watershed in urban or agricultural use, water quality in the receiving lake is strongly impacted
- Watershed management alone is rarely sufficient to restore lakes

Algal Control: Watershed Management

- Reduced P is first choice, but not always achievable or affordable with just watershed actions
- Adequately reducing P inputs from urban or agricultural areas is a big challenge (>$5M/sq. mi. needed for <30% reduction)



From K. Debusk 2012 NALMS presentation

Algal Control: In-Lake Management

Data needs include:

- Algal types and quantity (planktonic and benthic)
- Water quality (nutrients, pH, temperature, oxygen, conductivity, and clarity over space and time)
- Inflow and outflow sources and amounts, with water quality assessment
- Lake bathymetry (area, depth, volume)
- Sediment features
- Zooplankton and fish communities
- Vascular plant assemblage

All of which facilitate a hydrologic and nutrient loading analysis and biological assessment essential to evaluating algal control options

Algal Control: In-Lake Management

In-lake detention and wetland systems to limit nutrient inputs

Fulfilling a watershed function in the lake

Algal Control: In-Lake Management

Dredging

- **Dry (conventional)**
- **Wet (bucket/dragline)**
- **Hydraulic (piped)**

- **Removes nutrient reserves**
- **Removes "seed" bank**
- **Potential mat control**

Algal Control: In-Lake Management

Harvesting

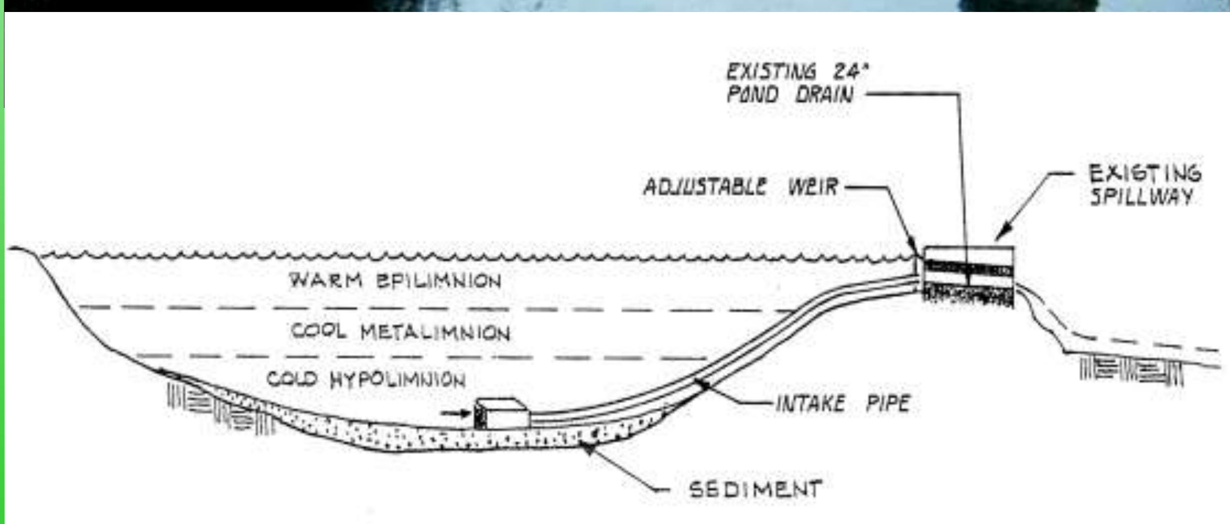
- Not feasible for many algal nuisances
- Possible to collect surface algal mats

Algal Control: In-Lake Management

Dilution and Flushing

- Add enough clean water to lower nutrient levels
- Add enough water of any quality to flush the lake fast enough to prevent blooms

Algal Control: In-Lake Management



Selective withdrawal

- Often coupled with drawdown
- May require treatment of discharge
- Best if discharge prevents hypolimnetic anoxia

Algal Control: In-Lake Management

Dye addition

- Light limitation - not an algaecide
- May cause stratification in shallow lakes
- Will not prevent all growths, but colors water in an appealing manner

Algal Control: In-Lake Management

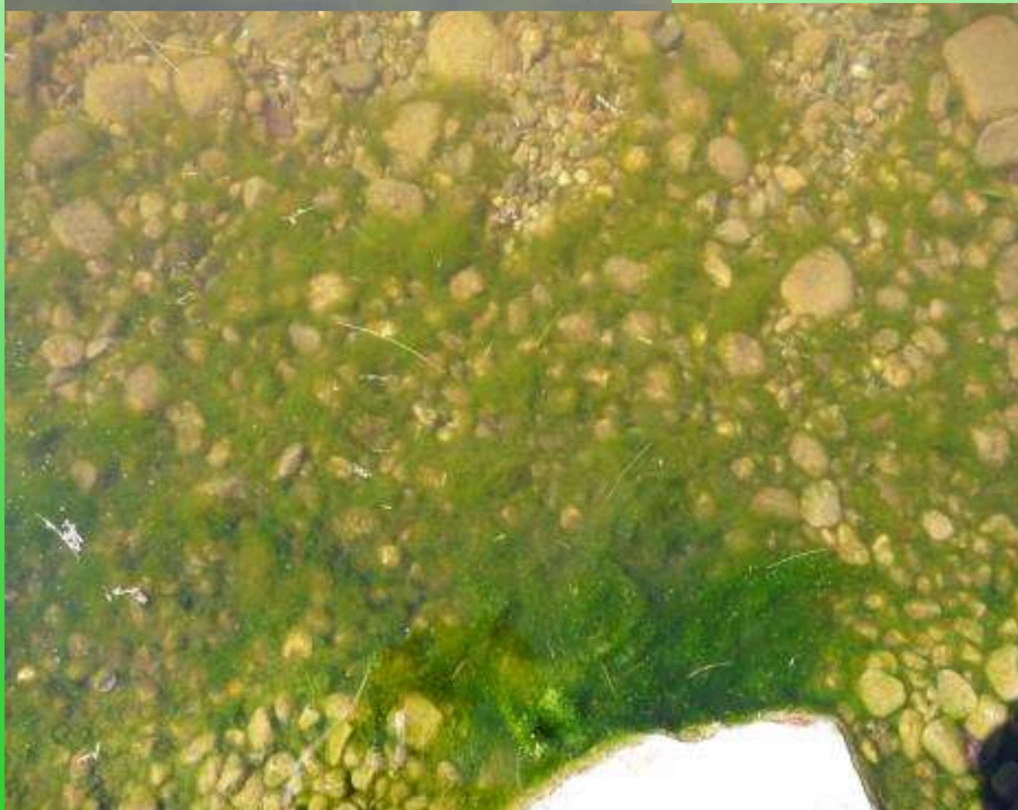
Sonication

- Disruption of cells with sound waves – may break cell wall or just dissociate plasma from wall
- Used in the lab to break up algal clumps
- Won't eliminate nutrients, but may keep algae from growing where running all the time
- Varied algal susceptibility

Algal Control: In-Lake Management

Sonication

- Units require clear “line of sight” to be effective
- Particularly good at keeping growths off of exposed substrates



Algal Control: In-Lake Management

Algaecides

- Relatively few active ingredients available
- Copper-based compounds are by far the most widely applied algaecides
- Peroxides also commonly used
- Some use of endothall and flumioxazin
- Effectiveness and longevity are issues

Algal Control: In-Lake Management

About copper

- Lyses cells, releases contents into water
- Formulation affects time in solution and effectiveness for certain types of algae
- Possible toxicity to other aquatic organisms
- Long term build up in sediment a concern, but no proven major negative impacts
- Resistance noted in multiple nuisance blue-greens and greens
- Usually applied to surface, but can be injected deeper by hose
- Less effective at colder temperatures

Algal Control: In-Lake Management

About peroxide

- Lyses cells, but more effective on thin walled forms; less impact on most diatoms and greens
- Degrades to non-toxic components; adds oxygen to the water, may oxidize some of the compounds released during lysis
- Typically applied to surface, but may reach greater depth with adequate activity (slower release/reaction rate)
- No accumulation of unwanted contaminants in water or sediment
- Considerably more expensive than copper

Algal Control: In-Lake Management

Proper Use of Algaecides

- Prevents a bloom, not removes one
- Must know when algal growth is accelerating
- Must know enough about water chemistry to determine most appropriate form of algaecide
- May involve surface or shallow treatment where nutrients are fueling expansion of small population
- May require targeted treatment where major migration from sediment is occurring
- May require repeated application, but at an appropriate frequency - if too often, look for ways to control nutrients or adjust treatment

Algal Control: In-Lake Management

Phosphorus inactivation
- anti-fertilizer treatments

Algal Control: In-Lake Management

- Iron is the most common natural binder, but does not hold P under anoxia
- Aluminum is the most common applied binder, multiple forms, permanent results, toxicity issues
- Calcium used in some high pH systems
- Lanthanum more recently applied
- Used for water column or sediment P

Algal Control: In-Lake Management

Factors in Planning Lake Treatments:

- Existing P load, internal vs. external
- Sources and inactivation needs – field and lab tests
- System bathymetry and hydrology
- Potential water chemistry alteration - pH, metals levels, oxygen concentration
- Potentially sensitive receptors - fish, zooplankton, macroinvertebrates, reptiles, amphibians, waterfowl
- Accumulated residues - quantity and quality

Algal Control: In-Lake Management

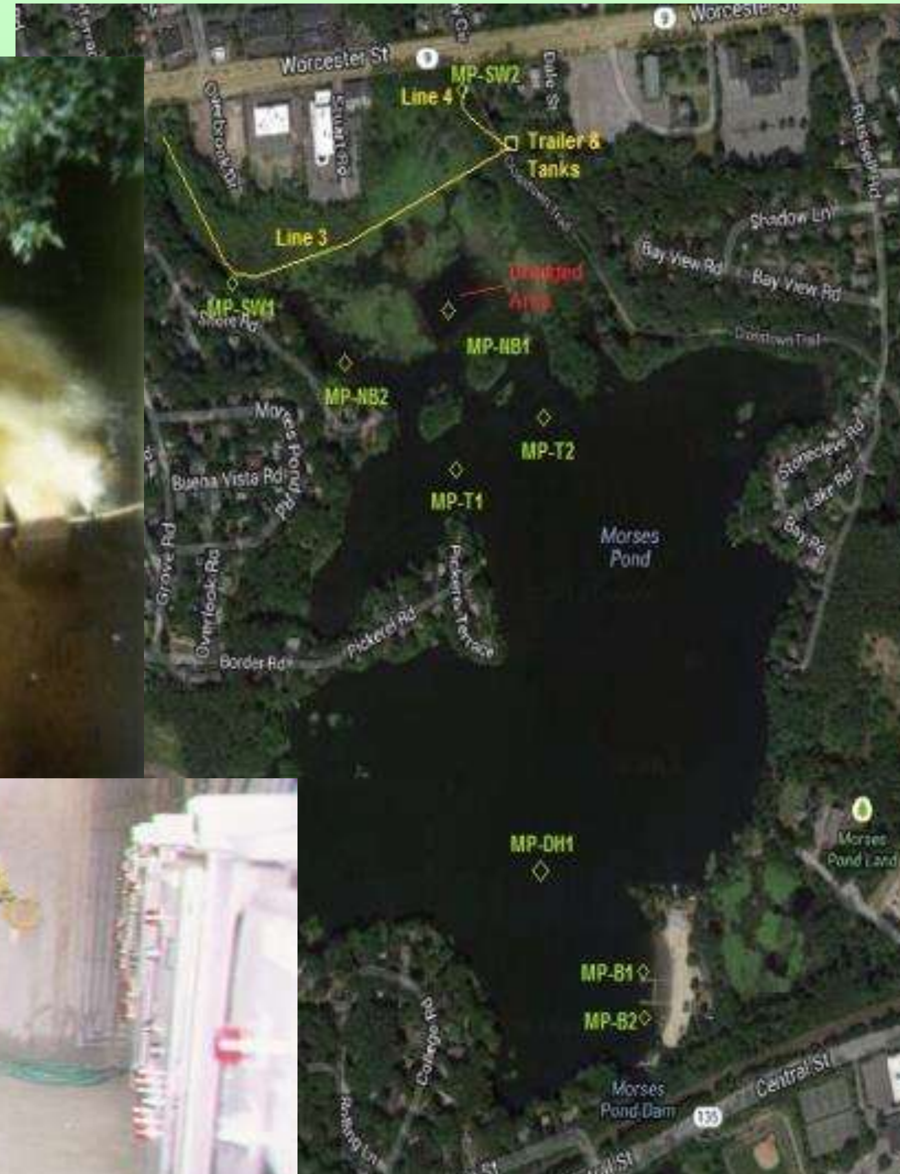
Lake Water Column Treatment:

- Doses vary - need 5-20 times TP conc.
- Can achieve >90% P removal, 60-80% more common
- Effects diminish over 3-5 flushings of the lake

Algal Control: In-Lake Management

Tributary Injection Treatment:

- 1-10 mg/L dose
- Treating mostly storm water
- Limiting available P entering the lake
- Longest track record in FL, great example in MA



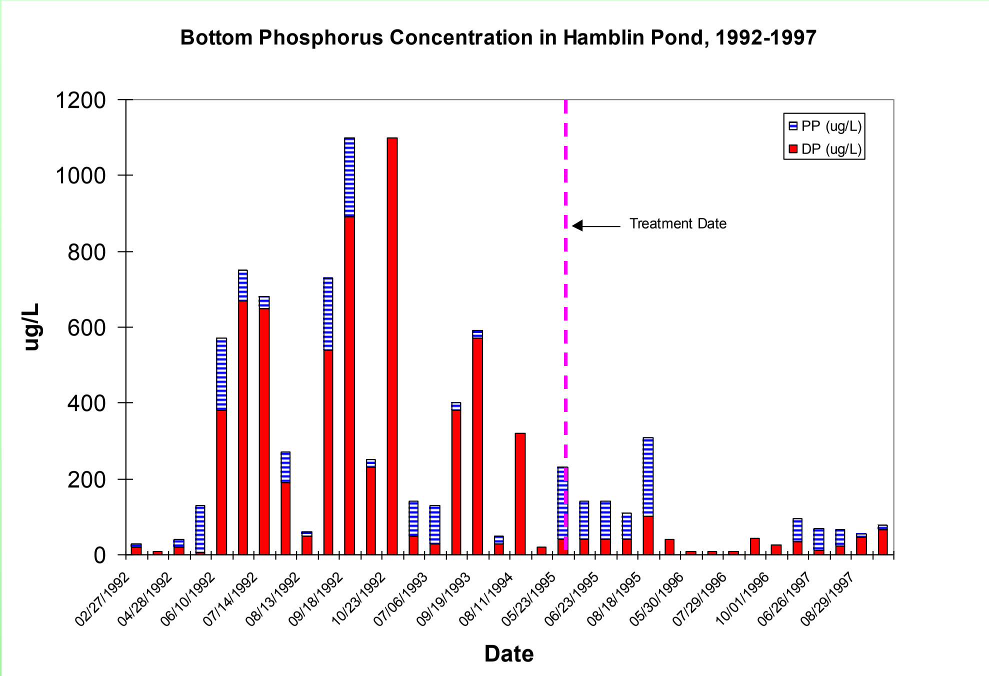
Algal Control: In-Lake Management

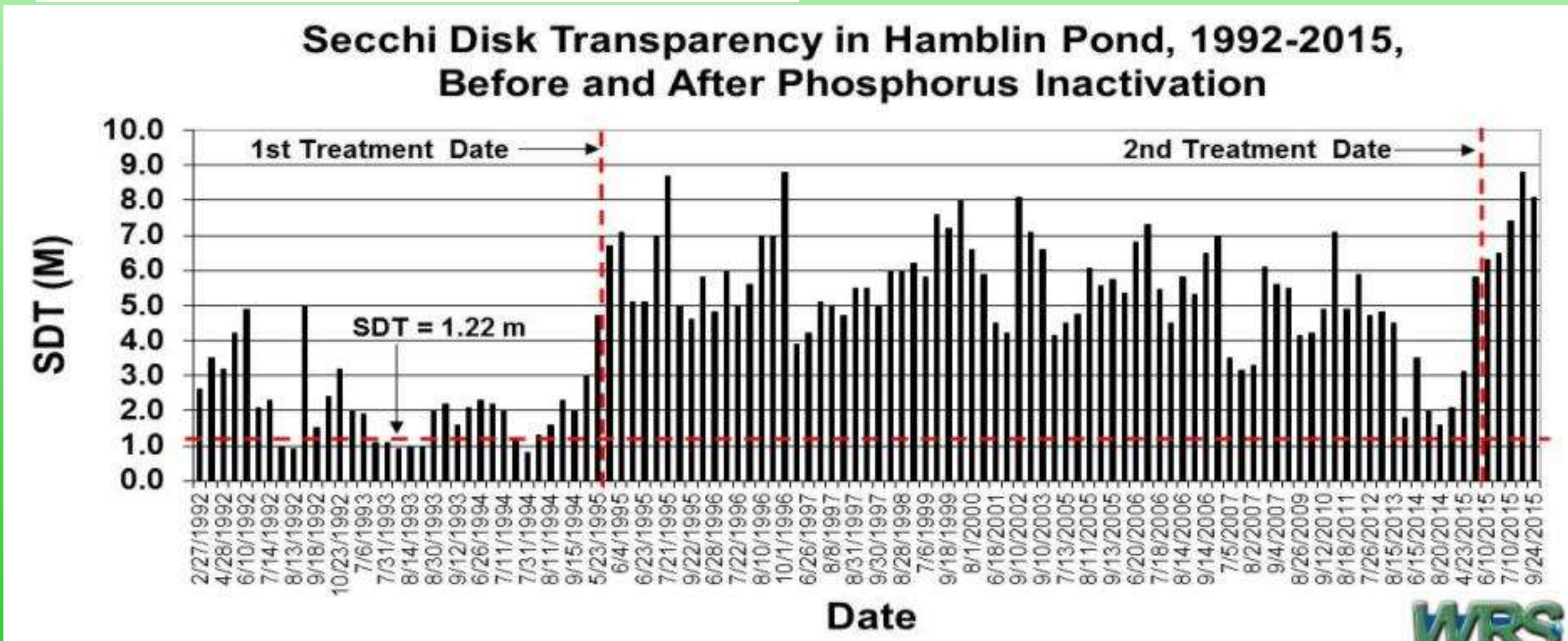
Lake Sediment Treatment:

- Can reduce longer-term P release
- Normally reacts with upper 2-4 inches of sediment
- Dose usually 25-100 g/m2 with Al - should depend upon form in which P is bound in sediment

Hamblin Pond Example Cape Cod, MA.

P levels dramatically reduced with Al treatment, water clarity substantially increased until 2013-2014, retreated in 2015





Algal Control: In-Lake Management

Aluminum treatment longevity is a function of:

- **External P load**
- **Release of P from organic matter by decomposition**
- **Upward migration of sediment P through treated zone**



Algal Control: In-Lake Management

Lanthanum modified bentonite clay (Phoslock®)

- Developed by Australian national science agency (CSIRO) for surface waters
- Used globally though relatively new to the USA
- No direct pH change, so no buffer required
- Specific to binding free phosphorus
- Stable mineral formed
- Positive environmental profile
- Marketed by SePRO

WRS

Lake Lorene, WA

8 ac, 12 ft max depth, cyano blooms
Treated June 2012
Lanthanum/Bentonite Application
Reduced P by about 75%
Eliminated cyano blooms

Courtesy of : AquaTechnex SePRO

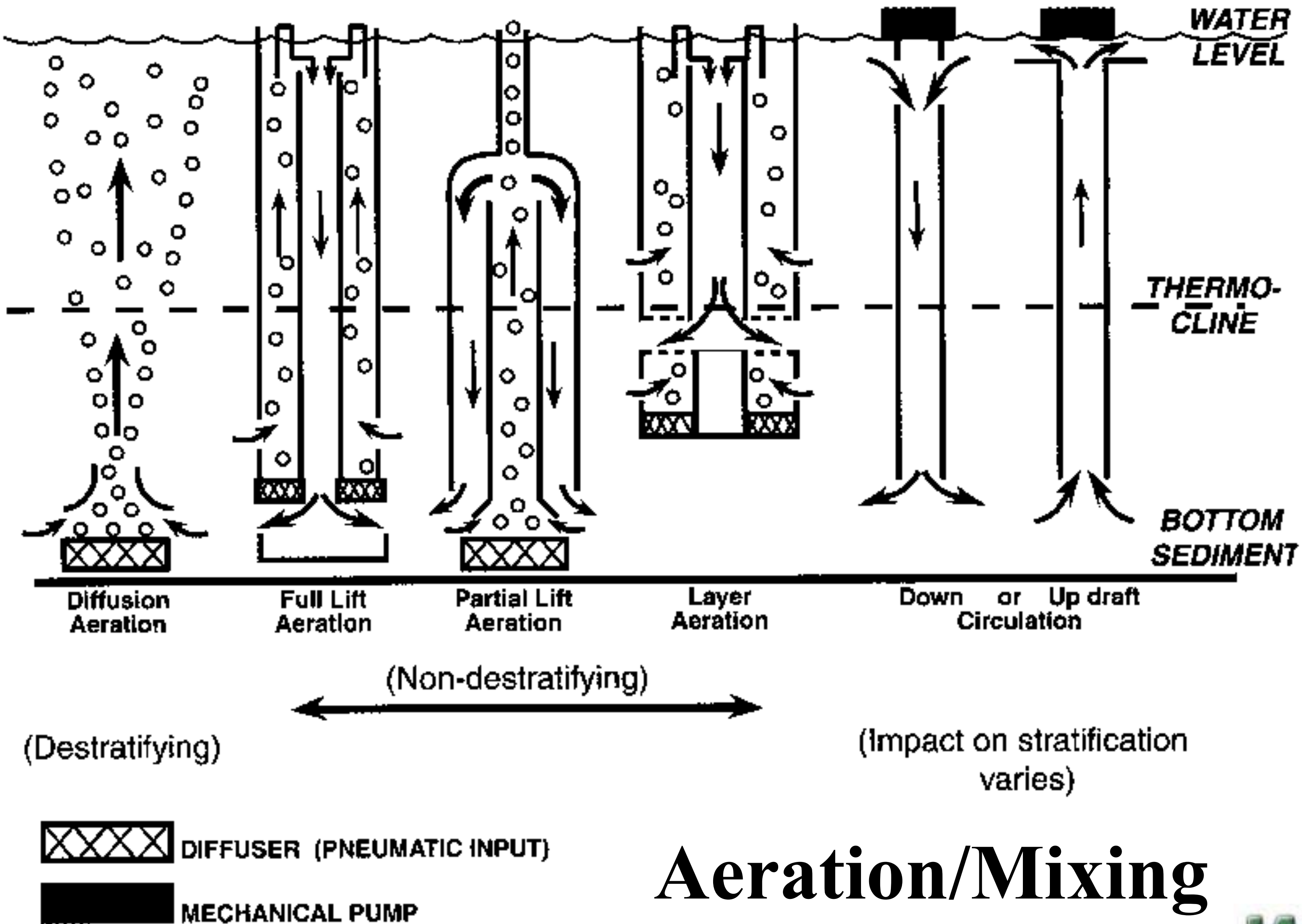
WRS

Algal Control: In-Lake Management

Selective nutrient addition

- Addition of nutrients (most often N or Si) to shift ratios to favor more desirable algae
- Used in fertilization for fish production
- Recent evidence that nitrate addition can prevent cyanoblooms
- Recent product to promote diatoms
- Biological structure very important to results

Algal Control: In-Lake Management



Aeration/Mixing

Algal Control: In-Lake Management

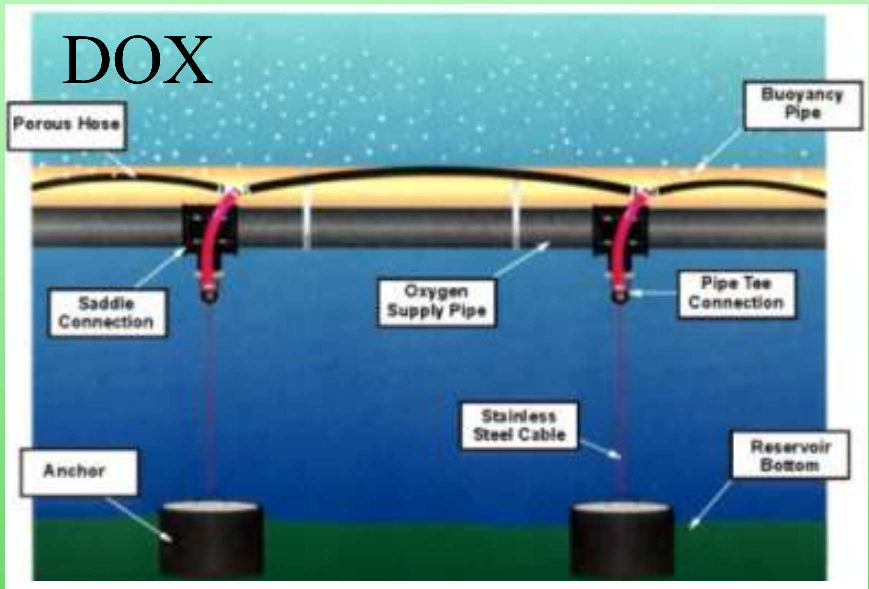
Oxygenation/circulation can work by:

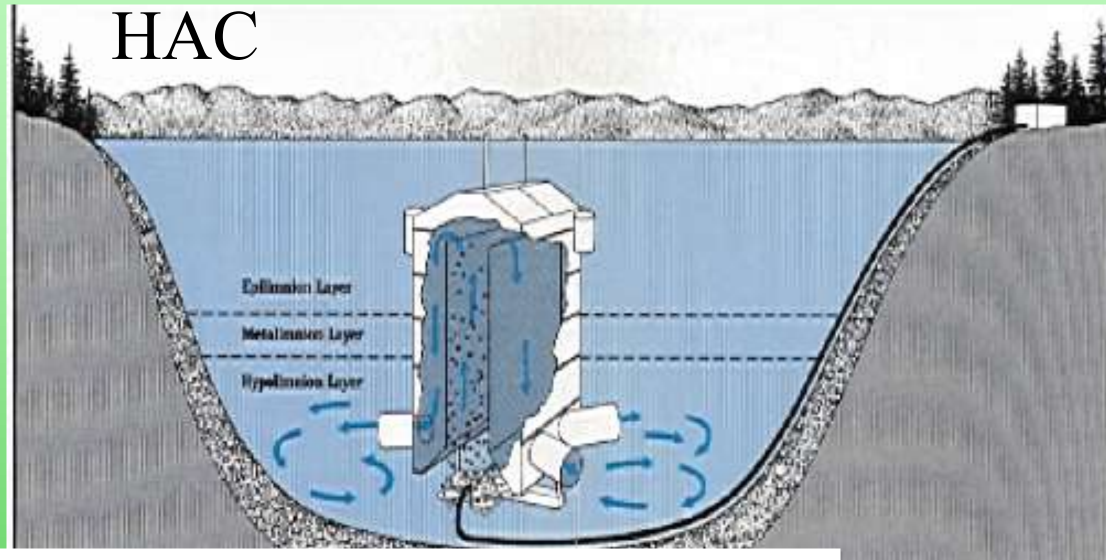
- **Adding oxygen and facilitating P binding while minimizing release from sediments**
- **Alteration of pH and related water chemistry that favors less obnoxious algal forms**
- **Creation of suitable zooplankton refuges and enhancement of grazing potential**
- **Turbulence that neutralizes advantages conveyed by buoyancy mechanisms**
- **Homogenization that yields consistent water quality, even if not optimal quality**

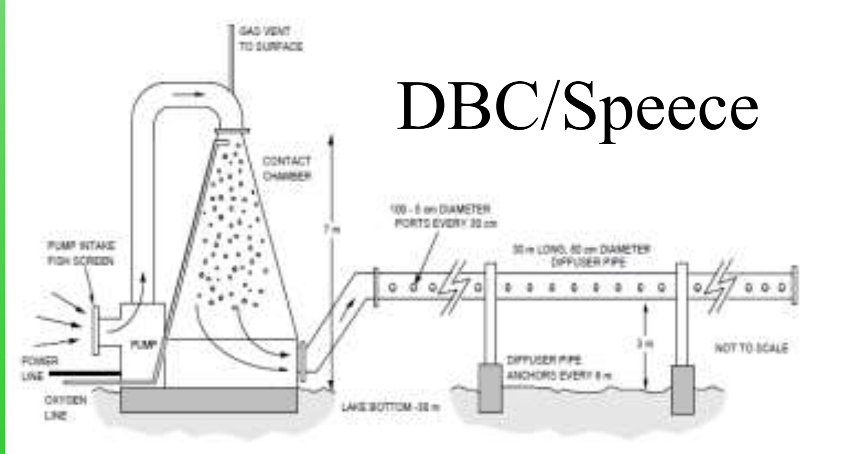
Algal Control: In-Lake Management

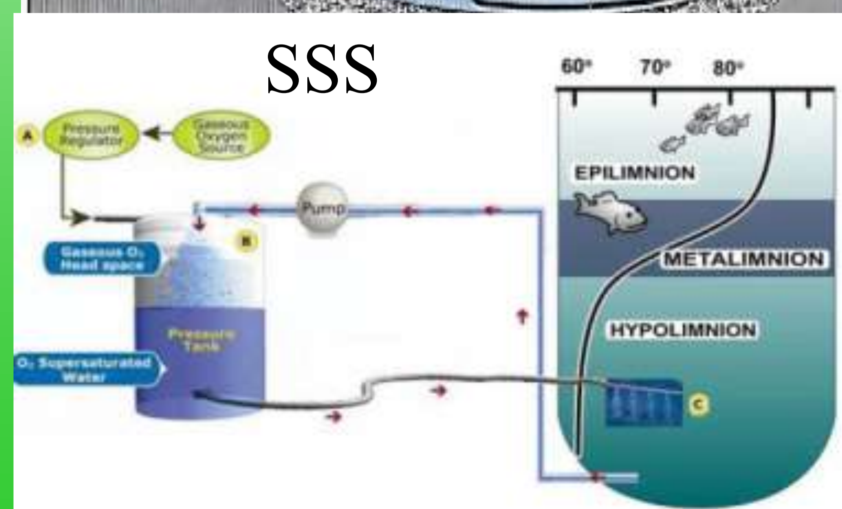
Non-destratifying oxygenation:

Bottom layer is oxygenated, but top layer is unaffected; oxygen input can be air or pure oxygen



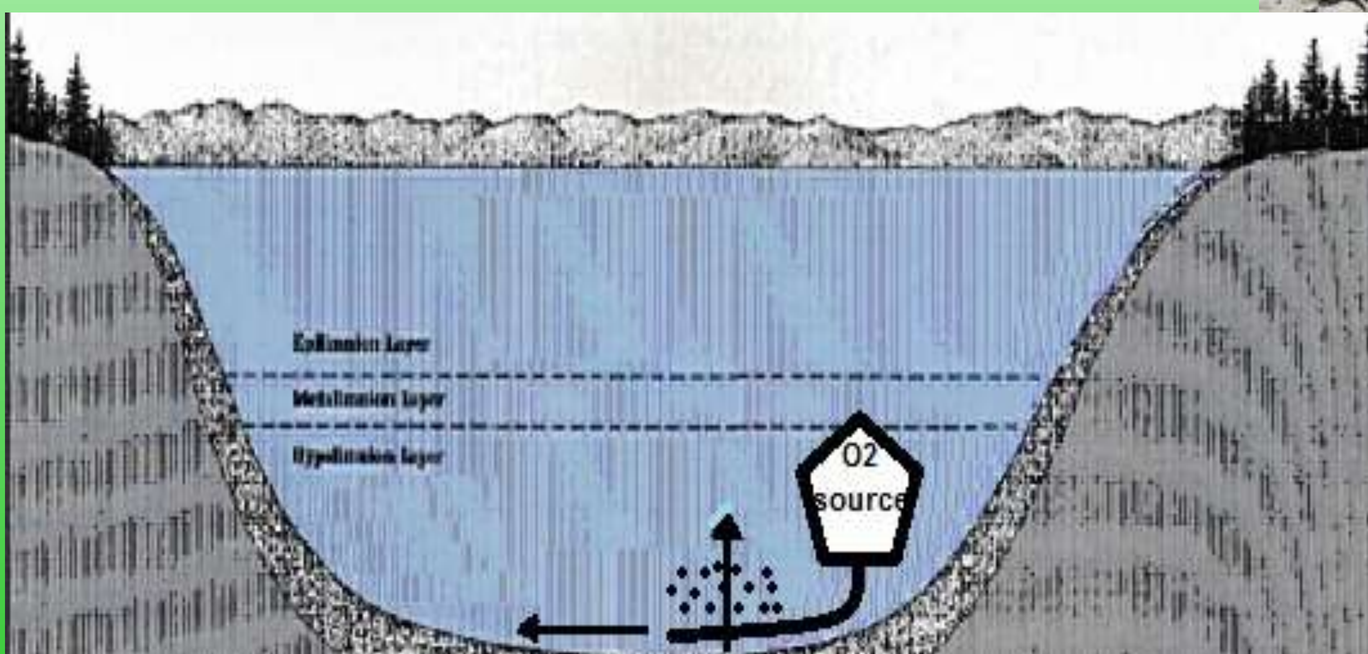






Algal Control: In-Lake Management

Biggest challenge to successful oxygenation is induced oxygen demand (IOD), created by movement of water in contact with sediment, which increases the rate of oxygen consumption. Ironically, action taken to satisfy oxygen demand causes increased demand.



Algal Control: In-Lake Management

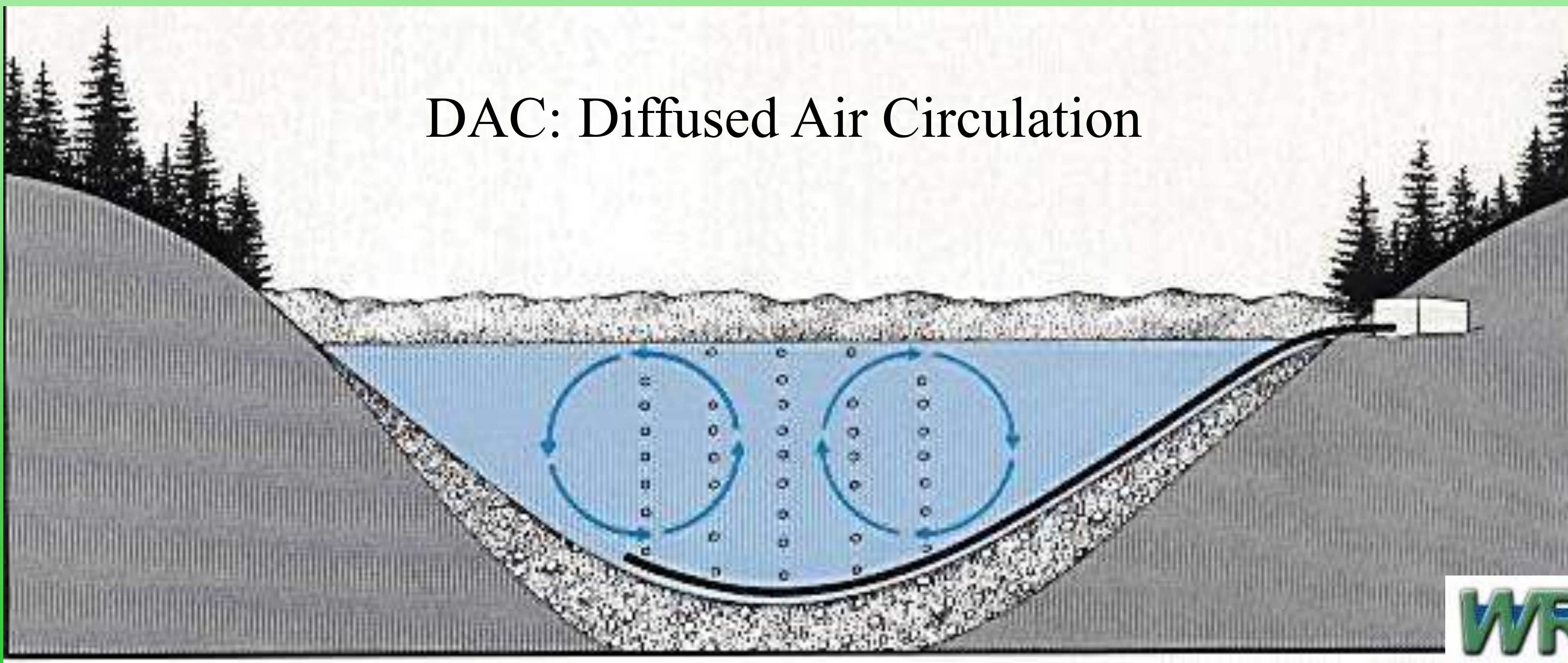
Key factors in oxygenation:

- Add enough oxygen to counter the demand in the lake and distributing it where needed; note that adding oxygen will induce extra demand that is hard to predict (expect 2X with O_2 or 5X with air)
- Maintain oxygen levels suitable for target aquatic fauna (fish and invertebrates)
- Having enough P binder (usually Fe, Ca or Al) present to inactivate P in presence of oxygen
- Not breaking stratification if part of goal is to maintain natural summer layering of the lake

Algal Control: In-Lake Management

Destratifying oxygenation (artificial circulation by aeration):

Lake is mixed, top to bottom. Oxygen comes from bubbles but more from interaction with lake surface and movement of higher oxygen surface water to lower oxygen deep water.



Algal Control: In-Lake Management

Circulation can also be by pumping

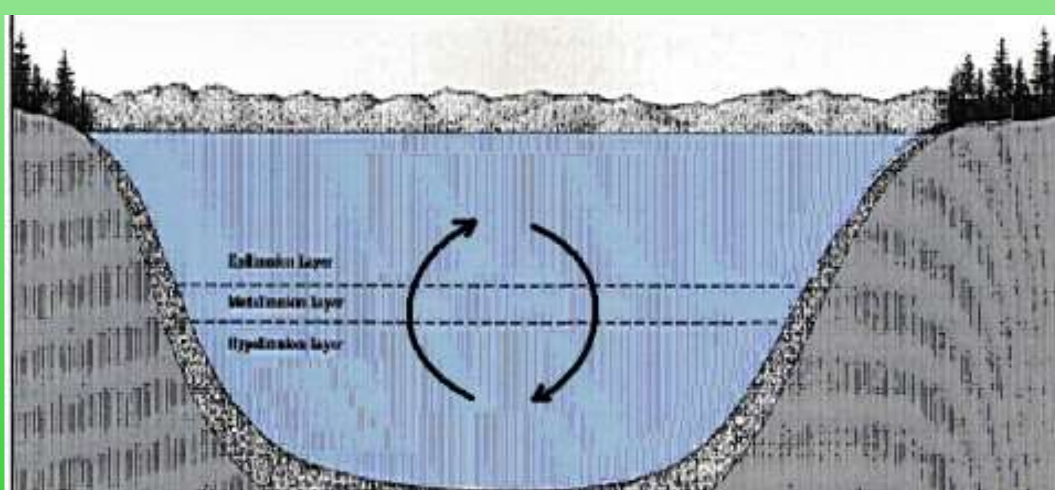
Downdraft

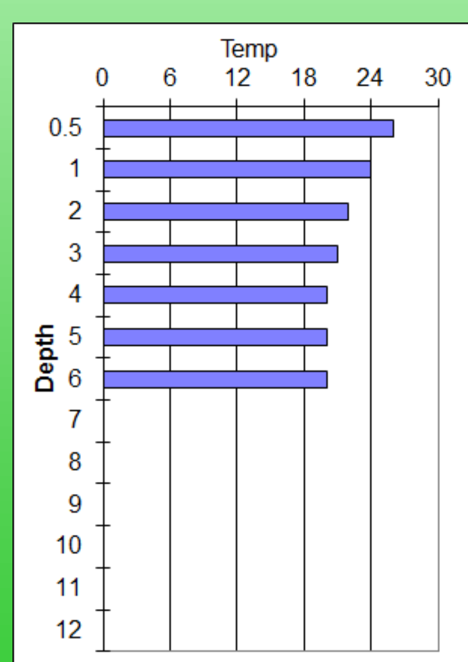
Updraft

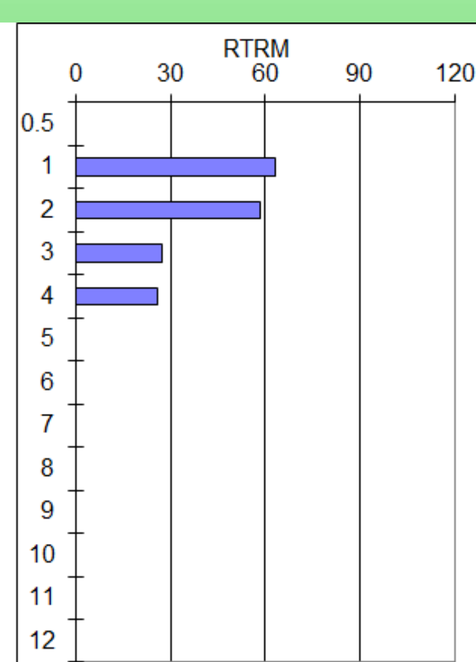
UDP/Fountain

Algal Control: In-Lake Management

Biggest challenge to successful circulation is maintaining mixed conditions as the water warms through summer. More energy is needed to mix water for each increment of temperature difference as the water warms. Mixing systems do not dissipate much heat, they just homogenize it.







Algal Control: In-Lake Management

Key factors in circulation:

- Moving enough water to prevent thermal gradients from setting up (need <3 C difference in target layer)
- General guide of >1.3 cfm/ac for air systems, but will have difficulty overcoming sun's heat input during prolonged sunny weather without much more air
- General guide of pumping at least 20% of target volume per day, sometimes need to move 100%/day
- Balance delivery of oxygen to near bottom with avoiding sediment resuspension
- Move surface water to depth >3X Secchi reading to lower biomass; otherwise expect only shift in types of algae

Algal Control: In-Lake Management

Barley straw as an algal inhibitor

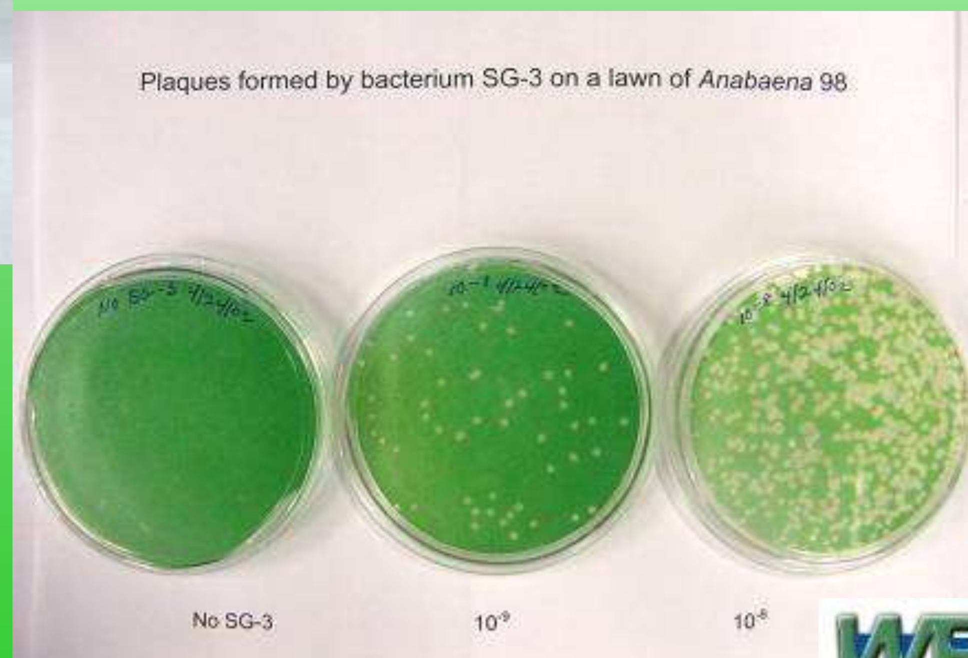
- Decay of barley straw appears to produce allelopathic substances
- Bacterial activity may also compete with algae for nutrients
- Limited success with an "unlicensed herbicide" in USA

WRS

Algal Control: In-Lake Management

Viral controls were attempted without much success in the 1970s and more recent research did not yield commercial products

Virus SG-3 in tests at Purdue Univ.



Algal Control: In-Lake Management

Bacterial additives

- Many formulations and modes of action, details usually proprietary
- Simplistic claim of allowing bacteria to outcompete algae
- Potential organic sediment reduction
- Often paired with circulation
- Variable results, inadequate scientific documentation

Algal Control: In-Lake Management

Bacterial additive sequence of "kill, chop, eat, settle"
(courtesy of P. Simmsgeiger of Diversified Waterscapes)

- Use algaecide to kill algae
- Use enzymes to break down long chain hydrocarbons
- Allow bacteria to metabolize shorter chain hydrocarbons, often requiring added oxygen
- Use a settling agent to drop out particulates

This process can work, but is not consistently used.

Open issue of whether addition of enzymes without an algaecide attacks algae directly, thereby functioning as an unregistered algaecide.

Algal Control: In-Lake Management

Biomanipulation - altering fish and zooplankton communities to reduce algal biomass

At elevated P (>80 ppb), altering biological structure is unlikely to reduce algae

Algal Control: In-Lake Management

Alewife and other planktivore control
- cascading effects

WRS

Algal Control: In-Lake Management

"Rough" fish removal - limiting nutrient regeneration

Algal Control: In-Lake Management

Rooted plant assemblages as algal inhibitors

Algal Control: In-Lake Management

Roll call for algal control

- Watershed management (where external load is high)
- Phosphorus inactivation (for internal load or inflow)
- Circulation to >3X Secchi depth (deep systems)
- Circulation, possibly with inactivators, dyes or bacterial additives (shallow systems)
- Oxygenation (deeper lakes, internal load dominant)
- Dredging (where feasible, especially for mats)
- Algaecides (with proper timing, limited usage)
- Sonication (for susceptible algae, nutrient control limited)
- Biomanipulation (P<80 ug/L, high variability acceptable)
- Other techniques as scale and circumstances dictate (do not throw away any tool!)

Algal Monitoring

Basic dilemma: Frequent and immediate algae data are needed to facilitate proactive management of lakes and reservoirs, but there are relatively few people trained in algal identification and quantification is an inexact science.

Identification options:

- Macroscopic visual assessment
- Microscopic examination
- Automated photomicrographic systems

Quantification options:

- Cell counts with biomass conversion
- Secchi transparency or turbidity
- Chlorophyll extraction
- Fluorometric pigment assessment

Algal Monitoring

Who collects the data?

- Remote automated or manually operated instrument readings
  - Turbidity, chlorophyll, phycobilin
  - Set thresholds for action and react to changes
- Properly trained staff collect and process samples
  - Microscopic assessment – slow (often days), laborious
  - Automated systems with reservoir-specific training
- Staff collect samples but send out for analysis
  - Turnaround time is main issue
  - Not inexpensive
  - Higher speed option in the works
- Staff collects samples, takes photomicrographs with digital scope, send images for analysis.

Algal Monitoring

How to use algae data:

- Know the problem genera – probably <10 for any given lake or reservoir; can make a waterbody-specific key
- Many indices available, best to develop something simple for your situation based on algae that occur and timing of blooms
- Look for thresholds that indicate trouble
  - Turbidity above or Secchi transparency below a value that corresponds to impairment
  - Chlorophyll or fluorescence above a problem limit, especially as relates to phycobilins
    - Knowledge of ratios of biomass to pigments important – not the same for all algae, but many instruments assume they are unless otherwise programmed/calibrated.

Algal Control: Project Issues

Algae management can include:

- Prevention – mainly watershed actions to limit nutrient inputs
- Early Detection/Rapid Response – treatment or other action before a serious bloom forms
- Maintenance – repetitive action to limit blooms, usually at a smaller scale and cost than true problem resolution
- Rehabilitation – infrequent action to avoid blooms, removes or controls sources of nutrients in most cases



Algal Control: Project Issues

3 legged stool of lake management

- Technical effectiveness
- Affordability
- Institutional acceptability

Being institutionally up to the challenge is at least as important as having a grasp of the scientific and economic factors governing environmental management.

Message: You can't just be a good scientist to be a successful lake manager

Algal Control: Project Issues

Institutionalized myths to be dispelled

- All lake problems can be fixed with watershed management
- Letting nature take its course is the best approach
- If conditions are desirable, they will stay desirable
- When in doubt, deny a permit to avoid harm
- The internet is a reliable source of information

From: http://www.epa.gov/nutrient-policy-data/control-and-treatment
"An effective but expensive management practice for small watersheds is the application of compounds to chemically precipitate phosphorus, followed by removal of the sediment by dredging." and
"Mechanical mixing to prevent blooms… has been successfully implemented in 350+ waterbodies in the U.S."

Algal Control: Project Issues

Some Solutions to Institutional Problems

1. New Clean Water Act (and Safe Drinking Water Act?)
2. Combining piecemeal state laws into a NRCA
3. Add management responsibility to regulatory programs for at least state owned lakes
4. Put adequate funding back into well conceived programs that have been defunded (e.g., Sec 314)
5. Revise permit programs for consistency and logic
6. Facilitate permitting in advance of a problem
7. Require lake management training for anyone involved in its regulation
8. Establish reasonable expectations for regulators and the regulated community

Algal Control: Project Issues

Reasonable expectations from project proponents

- Properly characterize the resources involved
- Clearly identify the problem(s)
- Demonstrate consideration of options
- Thoroughly explain the chosen option
- Provide an evaluation of non-target impacts
- Show how the interests of applicable laws and regulations are affected
- Provide an appropriate monitoring program
- List follow up and contingency actions
- Identify who will be responsible for what actions

Algal Control: Project Issues

Reasonable expectations from regulators

- Be familiar with available guidance on lake management
- Know what permitting processes apply
- Do not base feasibility or applicability conclusions on any one example; consider range of possible outcomes, avoid secondary sources and unsubstantiated claims
- Keep an open mind; do not limit options due to personal prejudices for or against any technique
- Help craft reasonable monitoring programs that advance management; focus on effectiveness and impacts
- Avoid requiring actions not related to the problem
- Seek to be part of a solution to any problem; be more of a teammate than an umpire