IDENTIFICATION, ECOLOGY AND CONTROL OF NUISANCE FRESHWATER ALGAE

KENNETH J. WAGNER, Ph.D, CLM
WATER RESOURCE SERVICES, INC.
ALGAL PROBLEMS

Algal problems include:
• Ecological imbalances
• Physical impacts on the aquatic system
• Water quality alteration
• Aesthetic impairment
• Taste and odor
• Toxicity
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

- Bioassay (mouse)
- Mass Spec
- HPLC
- LC/MS
- ELISA
- Phosphatase Assay

Sensitivity

Selectivity

μg  ng  pg
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 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 (70,000 cells/mL common.
- 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
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

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
  o Cell structures
  o 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 Nostoceneae
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
Algal Taxonomy

Separating Cyano Species

- Cell shape and size
- Color
- Granulation
- Presence/Absence of Aeropores
- 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

Filaments with long attenuated end cells split from Aphanizomenon into Cuspidothrix

Aphanizomenon

Cuspidothrix
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

Aphanizomenon
(Cuspidothrix)

Dolichospermum
(Anabaena)

Microcystis

Woronichinia
(Coelosphaerium)
Algal Types: Planktonic Blue-greens

- Planktolyngbya (Lyngbya)
- Limnornaphis (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

Scenedesmus

Schroederia

Oocystis

Lagerheimia

Dictyosphaerium
Algal Types: Planktonic Greens

Carteria (Order Volvocales)

Pyramichlamys

Eudorina

Chlamydomonas

Volvox
Algal Types: Mat Forming Greens

Zygnematales - Unbranched filaments, highly gelatinous

Spirogyra

Mougeotia

Zygnema

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
- Prymnesium
- Dinobryon
Algal Types: Mat Forming Goldens

Tribonema

Vaucheria
Algal Types: Other Plankton

(Euglenoids)
- Ceratium
- Peridinium
- Euglena
- Trachelomonas
- Phacus

(Dinoflagellates)
- Ceratium
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
• High P also leads to more cyanobacteria, from considerable empirical research. Key transition range is between 10 and 100 ug/L
As algal biomass rises, a greater % of that biomass is cyanobacteria. So more P = more algae + more cyanos.
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: In-Lake Management

Data needs include:

- Algal types and quantity (planktonic and benthic)
- Water quality (nutrients, pH, temp., 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 hypolimnmonic 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

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 deep 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

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
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
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
Algal Control: In-Lake Management

Selective nutrient addition

- Addition of nutrients (most likely N or Si) to shift ratio (N:P:Si) to favor more desirable algae
- Used in fertilization for fish production
- Recent evidence that nitrate addition can prevent cyanoblooms
- Biological structure very important to results
Algal Control: In-Lake Management

Aeration/Mixing

Diffusion Aeration  Full Lift Aeration  Partial Lift Aeration  Layer Aeration  Down or Up draft Circulation

(Non-destratifying)

(Destratifying)

DIFFUSER (PNEUMATIC INPUT)

MECHANICAL PUMP

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

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
(really 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 be by air or pumping

DAC

DDP

UDP/Fountain

UDP
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 >2X 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
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
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

Techniques that didn’t quite make the list
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 >2X 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!)
After that, we might need another one of these…

QUESTIONS?