VISION. SCIENCE. SOLUTIONS.
Biology and Control of Algae

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<table>
<thead>
<tr>
<th>Algae name</th>
<th>Phylum</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Lyngbya</em></td>
<td>Cyanophyta</td>
<td>filamentous, toxin/taste and odor producer, mucilaginous, mat-former</td>
</tr>
<tr>
<td>Algae name</td>
<td>Phylum</td>
<td>Characteristics</td>
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<tr>
<td><em>Prymnesium</em></td>
<td>Haptophyta</td>
<td>Unicellular, toxin producer, planktonic, flagellated</td>
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<tr>
<td>“golden alga”</td>
<td></td>
<td></td>
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<tr>
<td>Algae name</td>
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<td>Characteristics</td>
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<tr>
<td>Microcystis, Anabaena, Aphanizomenon, Planktothrix</td>
<td>Cyanophyta</td>
<td>Colonial, filamentous, toxin producer, mucilaginous, planktonic, scum-former</td>
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<tr>
<td>Algae name</td>
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<tr>
<td><em>Euglena</em></td>
<td>Euglenophyta</td>
<td>Unicellular, potential toxin-producer, planktonic, scum-former, flagellated</td>
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<tr>
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<td>Characteristics</td>
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<tr>
<td>Spirogyra</td>
<td>Chlorophyta</td>
<td>Filamentous, mucilaginous, mat-former</td>
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<td>“silk algae”</td>
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<tr>
<td><strong>Cyclotella</strong></td>
<td><strong>Bacillariophyta</strong></td>
<td>Unicellular, colonial, planktonic, scum-former</td>
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<tr>
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<tr>
<td><em>Pithophora</em></td>
<td>Chlorophyta</td>
<td>Filamentous, mat-former, branched, Akinetes</td>
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<td>“Cotton algae, Horsehair algae”</td>
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<tr>
<td><em>Nostoc</em></td>
<td>Cyanophyta</td>
<td>Colonial, softer gel balls</td>
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<tr>
<td><em>Chara</em></td>
<td><em>Charophyta</em></td>
<td>Plant-like, smelly, rough</td>
</tr>
<tr>
<td><em>“Muskgrass”</em></td>
<td></td>
<td></td>
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</tr>
<tr>
<td><em>Nitellopsis</em>/<em>Nitella</em></td>
<td>Charophyta</td>
<td>Plant-like, smoother</td>
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</tbody>
</table>
The Algae

• Diverse Classification (many kingdoms)

• Elaborate Characteristics

• No true roots, stems or leaves
• Over 30,000 species
• Identification
  – Important in determining management
Introduction to Algae Phyla

- **Chlorophyta**
  - Green algae

- **Cyanophyta**
  - Blue-green algae

- **Charophyta**
  - Plant like, erect

- **Euglenophyta**
  - Flagellated, eye spot (some red)
Introduction to Algae Phyla

• Pyrrophyta
  – Dinoflagellates, transverse flagellum

• Chrysophyta
  – Yellow-green

• Bacillariophyta
  – Diatoms, silica wall

• Haptophyta
  – Golden algae
Seasonal Succession
General Pattern
Algae Succession
The good?
The bad
Problematic Algae

Algal impacts → Economic

Ecological

Toxins /taste & odor compounds
Disrupt habitat/ Outcompete
Water characteristics

Drinking/irrigation
Tourism
Property values

(Speziale et al. 1991; Falconer 1996; WHO 2003)
Algae Impacts

• Secondary Compounds
  – Toxins
    • Microcystin/Nodularin “liver”
    • Saxitoxins “brain”
    • LPS “stomach”
    • Aplysiatoxins “skin”
  – Taste and odor
    • Geosmin “dirty”
    • MIB “fishy”
Cyanobacterial Toxins

• Alkaloid neurotoxins
  – Anatoxin-a
    depolarizing neuromuscular blockade
  • Anabaena (flos-aqua, circinalis, spiroides); Oscillatoria spp.
    (Carmichael 1975, 1979)
  – Saxitoxin and Neosaxitoxin
    inhibit nerve conduction by blocking sodium channels, PSP
    • Trichodesmium, Anabaena, Aphanizomenon, Cylindrospermopsis
    • Lyngbya wollei (decarbamoylgonyauxin-2, decarbamosaxitoxin, 6 unidentified compounds; Onodera et al. 1997) (PSP gene cluster, Mihali et al. 2011)
Cyanobacterial Toxins

- **Cylindrospermopsin and Deoxycylindrospermopsin**
  (cytotoxic, hepatotoxic, inhibit protein synthesis)
  - *Aphanizomenon*, *Cylindrospermopsis*, *Umezakia*, *Stigonematales*, *Raphidiopsis curvata* (Li et al. 2001); *Lyngbya wollei* (Seifert et al. 2007)

- β-Methylamino-L-alanine (BMAA)
  (limb atrophy, motor skills, neuron degeneration)
  - *Nostoc* (Miller et al. 2006), *Stigonematales*
Cyanobacterial Toxins

• Polycyclic peptide hepatotoxins
  – Microcystin (> 80 analogues), Nodularin
    (Tumor promoters, liver failure, protein disruption, Allelopathy)
  • Anabaena, Anabaenopsis, Coelosphaerium, Gomphosphaeria, Hapalosiphon, Microcystis, Nodularia, Nostoc, Oscillatoria, Planktothrix; Aphanocapsa cumulus (Domingos et al. 1999);
  Merismopedia and Leptolyngbya (Mohammed and Al Shehri 2010)

  – In addition, chemically undefined hepatotoxins are being studied in:
  • Cylindrospermopsis, Aphanizomenon, Gloeotrichia
Cyanobacterial Toxins

- Lipopolysaccharides (LPS)
  - Gastrointestinal impacts, immune system response
- Dermatitis toxins
  - Swimmers itch, abrasions
    - Aplysiatoxins, Lyngbyatoxin-a
      - Lyngbya, Oscillatoria, Schizothrix
- Taste and odor compounds
  - Geosmin “dirty”
  - MIB “fishy”
New Reports

• Endocrine disruption
  • Microcystis spp. (Rogers et al. 2011)

• Shown to be toxic but no toxin has been isolated and characterized
  • Coelosphaerium, Cylindrospermopsis, Fischerella, Gloeotrichia, Gomphosphaeria, Hapalosiphon, Microcoleus, Schizothrix, Scytonema, Spirulina, Symploca, Tolypothrix, Trichodesmium (Scott 1991; Skulberg et al. 1992b)
Mortalities

- Dogs
- Cows
  - Kerr 1987; Mez et al. 1997; Loda et al. 1999
- Pigs, ducks
  - Cook et al. 1989
- Sheep
  - Carbis et al. 1995
Proactive Management

AN OUNCE OF PREVENTION IS WORTH A POUND OF CURE
Sources of Nutrients

• Fertilizer
• Pet waste
• Wildlife
• Livestock/agriculture
• Municipal wastewater
• Industrial effluent
• Atmospheric deposition
Phosphorus

- Limiting nutrient in freshwater
- Correlative to
  - Algae biomass
  - Increased bloom frequency
  - Harmful algae blooms (N:P)
  - Trophic status
  - 1 pound P supports 500 pounds algae
- Prevention approach (NPDES)

<table>
<thead>
<tr>
<th></th>
<th>Phosphorus</th>
<th>Chlorophyll</th>
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<tbody>
<tr>
<td>Oligotrophic</td>
<td>12 ppb</td>
<td>0-2.6</td>
</tr>
<tr>
<td>Mesotrophic</td>
<td>12-24 ppb</td>
<td>2.7-20</td>
</tr>
<tr>
<td>Eutrophic</td>
<td>25-96 ppb</td>
<td>20-56</td>
</tr>
<tr>
<td>Hypereutrophic</td>
<td>&gt; 96 ppb</td>
<td>&gt; 56</td>
</tr>
</tbody>
</table>
Phosphorus Content

Percent phosphorus content per unit mass
1.2% v. 0.8%
Phosphorus (Evil P) Mitigation

- Internal accumulation (often a significant P fraction)
  - TN:TP ratio 5:1 cyanobacteria overwhelmingly dominant artificially induced (Ghadouani et al. 2003)
  - Low TN:TP cyanobacteria dominate (Lake Michigan) (Seale et al. 1987)
  - TN:TP ratio 29:1, dominated by green algae (Smith 1983; 12 lakes throughout the world)
  - Si:P < 25:1 Microcystis dominates, more silica more Asterionella (Holm & Armstrong 1981)

- Cyanobacteria use: carbon (use CO2 and CO3), Light (Phycocyanin), Temperature (>24C, not always), Moving water (Planktothrix, Anabaena planctonica)
Nitrogen Fixation

\[
\text{N}_2 (g) + 3 \text{H}_2 (g) \rightleftharpoons 2 \text{NH}_3 (g)
\]
Phosphorus Management Options

• Chemical
  – Lanthanum modified bentonite (Phoslock, specific, no buffer, permanent)
  – Aluminum sulfate (Alum, non-specific, pH/other impacts)
  – Algaecide combined with phosphorus remover (SeClear)
  – Polymers (Floc Log, Chitosan)
  – Iron (non-specific, release)/ Calcium (high pH only, release)

• Other
  – Aeration (oxygenate benthic layers)
  – Dredging (remove/re-suspension possible)
  – Bacteria?
Reactive Management
Control Techniques

• **Action Options**
  - Mechanical
    - harvesters, sonication
  - Physical
    - dyes, aeration, raking
  - Biological
    - bacteria, grass carp, Tilapia
  - Chemical
Aeration

• Take the buoyancy (scum) advantage out of play
• Temperature
• Carbon addition
• Keep circulated to select for better types of algae, usually
• Oxygenated benthic zone to decrease internal phosphorus cycling
Dyes

Light Absorbance Spectrum: SePRO Blue

Absorbance (OD)

Chlorophyll a, Chlorophyll b, Phycoerythrin, Phycocyanin

Light Wavelength (nm)

250 300 350 400 450 500 550 600 650 700 750 800

SePRO Blue 64oz/4AF

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DRIVEN TO DISCOVER
Biological

• Grass carp preferences
  – *Hydrilla* >> *Lyngbya*

• Viability of algae

• Other
USEPA Algaeicides

- Diquat Dibromide
- Endothall
- Peroxides
- Copper
  - Chelated v. free ion
- Adjuvants
Copper

Cuprite (CuO)
Chalcocite (Cu₂S)
Bornite (Cu₅FeS₄)
Copper Sulfate
Characteristics of an exposure

- Concentration
  - Concentration (mg/L, moles/cell, mass/mass)
- Duration
  - Residence time
- Form
  - Chelation
- Frequency
- Route
  - Transfer to toxic sites of action

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How copper works (dose)

- Electron transport chain disruption (Jursinic and Stemler 1983)
- Combine with glutathione (GSH) prevents cell division (Stauber and Florence 1997)
- Inhibits enzyme catalase and others, free radical susceptibility (Stauber and Florence 1997)
- Interfere with cell permeability and binding of essential elements (Sunda and Huntsman 1983)
Biotic Ligand Model

- Water residence time depends on water characteristics and copper form
  - pH
  - DO
  - Hardness
  - Alkalinity
  - OM (rapidly binds to algae)
  - Particulates
Both inorganic and organic complexation

Fig. 4. Cell sections of living C. kessleri cells after copper accumulation, magnification 14000×. Arrows show damage of the cells caused by copper.
Chelated copper

Both inorganic and organic complexation

Ca$^{+2}$ Competing cations
Stauber & Florence 1987; Crist et al. 1990; Coesel 1994; Levy et al. 2007
Summary

• Algae are diverse and becoming more problematic in freshwater resources

• Algae can restrict uses of a water resource and pose threats to wildlife and humans

• Both Proactive and Reactive techniques should be considered for efficient algae management

• Algae characteristics, algaecide formulation, and water chemistry can all impact control
Thank You

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