Understanding why cyanobacteria are successful: their ecological strategies, unintended consequences and monitoring considerations

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Cyanobacteria

- gram negative
- thylakoids
Why are we concerned about cyanoHABs?

- Toxicity
- Hypoxia
- Taste and odors
- Aesthetics
Ecological strategies for cyanobacteria

Morphology
- Grazing, floating

Pigments
- Phycoerythrin
- Phycocyanin
- Photosystem

Buoyancy

Regulation

Rapid Growth
- Temperature
- Trace, P, C, N

Toxicity
- Microcystin
- LR complex

Nitrogen Fixation

Nutrient Storage
Ecological Strategies: bacteria in a eukaryotic world—thermophiles grow faster

**Rapid Growth**

3 “doublings” or divisions

temperature
Ecological Strategies: Motility
Ecological Strategies: morphology for staying in the water column
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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
Ecological Strategies: complimentary pigments for maximizing photosynthesis
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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 source
Ecological Strategies: desiccation tolerant (polysaccharide sheath—often pigmented)
Ecological Strategies: morphology to prevent grazing
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Only a few examples:

• increase in cell toxin content when exposed (Jang et al. 2007)
• some zooplankton inhibit or cease feeding (Haney 1987; Lampert 1987)
• some zooplankton exhibit physiological resistance (Kurmayer and Juttner 1999)
• some just avoid the toxin producers
Key toxin-producing organisms: a diverse group

Unicellular forms
*Microcystis*

Filamentous
*Lyngbya, Oscillatoria, Planktothrix*

Filamentous
*Anabaena, Aphanizomenon, Cylindrospermopsis, Nodularia*
Occurrence and health significance of cyanotoxins

- Microcystins - most common, widespread poisonings
- Anatoxins - common; many animal poisonings
- Cylindrospermopsins - common; poisonings Australia
- Nodularin - world-wide in brackish water
- Lyngbyatoxins - probably in continental US; poisonings in South & Central Pacific
- Saxitoxins - sporadic; animal deaths
- *beta*-methylamino-*L*-alanine - BMAA - world wide; potential major health significance
- LPS - world-wide; health significance unclear
Cyanotoxins are highly potent

<table>
<thead>
<tr>
<th>Compounds</th>
<th>LD$_{50}$ (ug/kg)</th>
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<tbody>
<tr>
<td>Saxitoxin</td>
<td>9</td>
</tr>
<tr>
<td>Anatoxin-a(s)</td>
<td>20</td>
</tr>
<tr>
<td>Microcystin LR</td>
<td>50</td>
</tr>
<tr>
<td>Anatoxin-a</td>
<td>200-250</td>
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<tr>
<td>Nodularin</td>
<td>50</td>
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<tr>
<td>Cylindrospermopsins</td>
<td>200</td>
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<tr>
<td>Ricin</td>
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<tr>
<td>Cobra toxin</td>
<td>20</td>
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<tr>
<td>Curare</td>
<td>500</td>
</tr>
<tr>
<td>Strychnine</td>
<td>2000</td>
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</tbody>
</table>
• **Microcystis aeruginosa**
• non-N fixer
• Very common
  – Also produced by a number of other species.

• Peptide Toxins:
  90+ structural variants
  + 200 others related compounds: nodularins, anabaenapeptins, etc.

• Microcystins are hepatotoxic
  LD-50: 25-60 μg kg⁻¹
• Called “fast death factor”
  Potent tumor promoter
Microcystin exposure: response

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

Hepatotoxicity

Wayne Carmichael ISOC-HAB Ch. 4, Scientific American, January, 1994
Microcystin exposure: tumor promotion

• Epidemiology in China:
  • Contaminated drinking water ↔ primary liver and colon cancer.

• Injection of toxin ± initiator:
  • Increased size/number of liver cancer precursors.

• Oral *M. aeruginosa*. extract:
  • Skin papillomas larger/heavier
  • No effect on duodenal tumours or lymphoma.
  • Colon cancer precursors larger
Microcystin-producing strains include:

- *Microcystis aeruginosa*
- *M. wesenbergii*
- *M. botrys*
- *Oscillatoria limosa*
- *Anabaena flos-aquae*
- *A. lemmermannii*
- *A. circinalis*
- *Planktothrix agardhii*
- *P. mougeotii*
- *Nostoc spumigena*
- *N. species*
- *Anabaenopsis millerii*
- *Haphalosiphon hibermicus*
- *Gloeotrichia sp.*
Can not use taxonomy to predict toxicity
Anatoxin-a
actylcholine agonist

Anatoxin-a(S)
acetylcholinesterase inhibitor

Very Fast
Death Factor

Anabaena
flos-aquae &
lemmermannii
Anatoxin-producing strains include:

- *Anabaena circinalis*
- *A. flos-aquae*
- *A. planctonica*
- *Planktothrix sp.*
- *Aphanizomenon flos-aquae*
- *A. ovalisporum*
- *Cylindrospermopsis raciborskii*
Anabaena

**Anatoxin-a and a(s)**

**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).

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

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

**Alkaloid Toxin**

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

**Cylindrospermopsin**
WARNING
LIFE GUARD, BACTERIOLOGIST, MICROBIOLOGIST, TOXICOLOGIST NOT ON DUTY
SWIM AT YOUR OWN RISK.
Thank You!