Cyanobacteria: How Their Biology and Ecology Can Impair Water Quality

Kim Ward
Ocean Standards Unit
Division of Water Quality
State Water Resources Control Board
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Taxonomy: What are the Cyanobacteria?

- **Kingdom: Bacteria**
- **Phylum: Cyanobacteria**

Often referred-to as “blue-green algae”: they are not eukaryotic algae (i.e., true plants)

Prokaryotes - e.g., microbes with no cell organelles, reproduce through binary fission

*** floating “necklace” (nucleoid) of DNA in protoplasm**
*** photosynthesis in folds of cell membranes (thylakoids)**
*** 3.5 billion years of clonal strains, mutations & horizontal DNA transfer via cyanophages (cyanobacterial viruses)**

Cyanobacteria Are:

Much Bigger than Other Bacteria

Unique in being able to reduce both N_2 and CO_2

Photosynthetic, & some can fix (convert) N_2 into NH_3, nitrite, and/or nitrate

Sometimes unicellular, and sometimes colonial

Colonial taxa can form hollow balls, filaments, sheets (mats), and so on

The Colonial Cyanobacteria

- **Colonial species often display cellular specialization, e.g.;**

  1. Nitrogen-fixing heterocysts
  2. Vegetative cells (look “normal”)
  3. Hormogonia → motile filaments forming new colonies
  4. Akinetes → hypometabolic spores formed during periods of environmental stress: highly resistant to chemical/physical stressors such as desiccation

- **Do colonial species “coordinate” their activites?** Role specialization indicates inter-cellular chemical communication akin to tissue & organ differentiation in multicellular eukaryotes

Cyanobacteria DON'T Swim, But They Can Move

- Hormogonia & some unicellular species glide along surfaces
- *Oscillatoria* named after oscillating movements
- Gas vesicles raise and lower them in the water column as photosynthesis slows/speeds up
- Can't resist strong currents, but can move vertically & horizontal in slower-moving waters

→ *They therefore tend to accumulate (form "scums") in slower-moving water, e.g. estuaries, coastal lagoons, and lakes/reservoirs*

Cyanobacteria & Photosynthesis: An Abundance of Photosynthetic Pigments

- UV light intensities typical of earth's surface discourage their photosynthesis
- A variety of photosynthetic pigments available for lower light intensities
- All cyanobacteria have chlorophyll a and phycocyanin
- Other pigments include allophycocyanin, carotenoids, and phycoerythrin
- Chromatic adaptation
- Electron donors are usually O2 or H2S
- They reduce CO2 to make carbohydrates
- Produce 02 as by-product
- **The Visible Result**: they may appear green, blue-green, violet, magenta, red, rusty-brown, etc.

Cyanobacteria: 3.5 Billion Years of Diversification & Counting

- ***<u>Where We Find Them Now</u>*: Cosmopolitan, Diverse Habitats**
- **Marine, brackish, and freshwater: many tolerate variable salinities**
- **Some thrive in euryhaline environments (e.g., Salton Sea)**
- **Some thrive in geothermal pools**
- **Are found in all latitudes and most at most altitudes, from Antarctic "dry valleys" to Saharan rocks, and form an important component of the marine phytoplankton**
- **Soils, moist or dry**
- **"hypoliths" growing in association with algae in quartz-containing Artcic rocks (undersurfaces)**
- **Often symbiotic, and can be endosymbionts: will grow in some plant tissue, partnering with moss in lichens, fixing nitrogen on root hairs of legumes, providing camouflage on sloth fur, etc.**

- ***<u>Where They've Been</u>* (And Still Are, Or May Be…)**
- **Stromatolites as Living Fossils: Earth's first attempt at "coral reefs"**
- **"The Oxygen Crisis", which enabled aerobic organisms to emerge on Earth**
- **NASA astrobiologists wonder if they travel between planets – then and now….**

What Do Cyanobacteria Do For Humans and Other Organisms?

- **They make flamingos pink (*Spirulina)***
- **They make the Red Sea red – occasionally – (*Oscillatoria*)**
- **They play a critical role in the biogeochemical cycling of nitrogen on Earth**
- **They help maintain 02 levels in our atmosphere that are necessary for the survival of humans and other aerobic organisms**
- **They fix nitrogen for various important human food crops, e.g. legumes such as beans, soybeans, peanuts, peas…**
- **They fertilize 75% of world rice production by fixing nitrogen on the leaves of the Asian water-fern *Azolla* (which is found in rice paddies)**
- **They are primary producers of nitrogen among the marine phytoplankton, thus helping to sustain marine food webs**

***   Some produce ethanol – a potential source of "biofuel"**

Cyanobacteria Vs. Other Phytoplankton

- ***True algae grow faster largely because they can thrive in full sunlight, but:***
- **Cyanobacteria out-compete algae for nutrients (i.e., N & P)**
- **Cyanobacteria thrive in low dissolved oxygen (they don't need 02), photosynthesize more efficiently in lower light levels due to turbidity, and are indifferent to NH3 and warm waters characteristic of eukaryotic algal bloom die-off triggering conditions**

- ***Cyanobacteria can thus seize the advantage in eutrophic waterbodies***
- **Eutrophic waters created by human activities are increasingly common in CA, & elsewhere in both the developed and developing world**
- **Nutrient and sediment-laden runoff from the use of fertilizers, manure, etc. & accelerated erosion of soils accentuate the long-term water quality problems: hydromodification of watersheds may create stagnant conditions, constrict flows and thus exacerbate the eutrophic watershed conditions**
- **Cyanobacteria can, under such conditions, largely replace eukaryotic algae, and thereby contribute to the decline of other indigenous aquatic species such as some fish and invertebrates**
- **This effect is not confined to freshwater – e.g., the Baltic, Puget Sound, Vancouver Island**
- **Chemical "warfare": cyanobacteria have an arsenal of cyanotoxins**

Official Designations: CWA 303(d) Listings of "Impaired Waterbodies" in CA

- ***2 of the top 3 reasons for listing waterbodies as impaired in CA contribute to eutrophication, and are therefore creating conditions favorable to cyanobacterial "blooms" – i.e., excessive nutrients and sediments***
- ***Much systematic survey data remains to be done, but regional information is becoming more available – for example;***
- **The Klamath watershed; the Eel River; Big Lagoon; Lake Isabella, The Salton Sea**
- **Clear Lake; San Francisco Estuary; various southern CA reservoirs/lakes**

Cyanotoxins: 3.5 Billion Years of Diversification Revisited

- **An area of active research: more toxins are identified than have been formally named**
- **Whole-cell extracts consistently more toxic than individual, identified toxins**
- **No generally available lab standards for all known toxins**
- **Analytical methods, availability of field tests and lab facilities lag behind growing list of known toxins**
- **The presence/absence of one toxin does not predict the presence/absence of others**
- **Cyanotoxin production not well-correlated with cell-counting techniques for waterbody surveillance**
- **Some identified toxins (e.g., microcystin) are recalcitrant to one or more common methods of drinking water treatment**
- **Toxin-producing genera generally produce more than one cyanotoxin**
- **Fish/wildlife, livestock, aquaculture and recreational/drinking water contact problems include centuries of episodic poisonings**

Major Types of Cyanotoxins

- ***Protein phosphatase blockers*: cyclic peptides damage the liver, either through acute or lower-dose chronic cumulative ingestion**

  - Most research has focused on the 60 congeners of <u>Microcystin</u>

  - <u>Nodularin</u> produced by *Nodularia spumegina*

- ***Cytotoxin*: This toxin attacks the entire organism by blocking protein synthesis**

  - <u>Cylindrospermopsin</u>

- ***Neurotoxins*: 3 Major Types**

  <u>Anatoxin-a</u>: blocks post-synaptic depolarization

  <u>Anatoxin-a(s):</u> effects resembling organophosphate pesticide poisoning/ blocks acetylcholinesterase

  <u>The Saxitoxins</u>:* carbamate alkaloids which act like carbamate pesticides by blocking sodium channels (*Note: various marine algae also produce saxitoxins)

What Progress is Being Made in Cyanotoxin Research?

- **More researchers are working to identify, name, study, and develop methods of toxin detection since the publication of the WHO guidelines in 1999**
- **International public health community awareness growing, so increased funding in some countries is being devoted to more research, e.g., Australia and the EU**
- **More university researchers are developing methods of cyanotoxin detection in various media, including tissue samples and water**
- **Recent progress in field test kit development, e.g. for microcystins**
- **Research in evaluating and developing drinking water treatment technology continues**

“New” Trends in Cyanotoxin Research

BMAA – A Toxic Amino Acid?