Harmful Algae Bloom (HAB) Strategy

Appendices

June 2011

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Appendix A
Common Cyanobacteria in Oregon

The population dynamics of cyanobacteria and, more specifically, of the dominant cyanobacteria species that cause Health Advisories in Oregon were explored as part of the strategy development to better identify environmental factors that cause these blooms. While much of the following discussion can apply both to the dynamics in rivers and lakes, most of the research relates to work done on lakes and is more applicable to an understanding of the dynamics in lakes.

There is a strong seasonal pattern that is typically observed in the algae in deep, temperate[1] lakes. Oliver and Ganf (in Whitton and Potts, 2000) described it as follows:

> "Climatic and meteorological conditions influence the degree of stratification and mixing as well as light and nutrient availability. It is this physical and chemical setting that provides the stage upon which competitive interactions between species are enacted… The strong seasonal climatic signal results in a progression of phytoplankton from diatoms in early spring as thermal stratification commences through populations of green algae to culminate during summer in populations of cyanobacteria and dinoflagellates. The two major environmental variables stimulating the species progressions are changes in the stability of stratification and declining nutrient availability (Reynolds, 1984). Over the growing season the intensity of stratification increases to a maximum in summer when apparently the mixing intensity is insufficient to help maintain heavy phytoplankton, such as diatoms, in suspension. The separation of the water column into an upper epilimnion where light is available for growth and a dark hypolimnion leads to nutrient depauperate conditions developing in the surface layers as a result of phytoplankton growth and sedimentation. It is during calm weather in summer and autumn that surface blooms of cyanobacteria frequently develop, often associated with minimum nutrient concentrations in the surface layer. A secondary peak of diatoms can be associated with the onset of meromixis[2] in autumn before phytoplankton populations are reduced to low levels in winter. This simplified general over-view of the responses observed in deep temperate lakes will be strongly modified by local conditions so that seasonal progressions are altered."

Many studies have addressed the question on why cyanobacteria should be so successful in a wide range of environmental conditions. Explanations include (from Oliver and Ganf in Whitton and Potts, 2000):

- Traits to take advantage of warmer water conditions;
- Traits to capture reduced light densities;
- Traits to utilize low TN:TP ratios or to access low dissolved carbon dioxide concentration (high pH conditions);
- Buoyancy regulation;
- Reduced zooplankton grazing;
- Capacity to store phosphorus;

Huisman et al (2005) summarize the complexity of this undertaking as follows:

> "The population dynamics of harmful cyanobacteria can be governed by a myriad of ecological factors. For instance, several cyanobacterial species are poor competitors for phosphorus that

[1] Latitudes of the globe between the tropics and polar circles
[2] Seasonal mixing of water

> proliferate mainly in eutrophic waters, whereas other cyanobacteria are strong phosphorus competitors favored in oligotrophic systems with low phosphorus availability. Some cyanobacteria are capable of nitrogen fixation and are favored under nitrogen-limited conditions, whereas other cyanobacteria are incapable of nitrogen fixation and require high nitrogen levels to produce their nitrogen-demanding phycobili pigments. Buoyant cyanobacteria can form surface blooms during weak wind mixing, thus accumulating in high densities near the water surface. Other cyanobacteria lack buoyancy, however, and may require dispersal throughout the entire water column. Some cyanobacteria produce powerful toxins that can be used against competing phytoplankton, other cyanobacterial toxins are used as a defense against herbivores, and for several cyanotoxins no clear function has been identified yet. Cyanobacteria form a very diverse group of organisms, and as a result there are a wide variety of different environmental conditions that may determine their population dynamics. A single-factor explanation for 'the dominance of cyanobacteria' is thus bound to fail.
>
> As a consequence, a single remedy to prevent harmful cyanobacteria does not exist. Instead, different measures may be required for different cyanobacterial species in different aquatic ecosystems. The success of water management strategies to combat harmful cyanobacteria hinges on a proper identification of the cyanobacterial species involved and the ecosystem processes that govern their population dynamics."

Oliver and Ganf in Whitton and Potts (2000) conclude:

> "In conclusion, we suggest that the occurrence and abundance of various types of gas-vacuolate cyanobacteria is not reliant on any one particular environmental stimulus, but depends on a complex interplay of factors. A flow chart has been used in an attempt to portray these interactions and to highlight the role of environmental conditions in supporting the growth of particular species of gas-vacuolate cyanobacteria. The flow chart is not definitive and is unlikely to be a dependable tool for predicting either the likelihood of cyanobacterial blooms or their identity; it is presented simply for illustrative purposes. It consists of a series of questions assessing the major environmental conditions believed to influence the success of gas-vacuolate cyanobacteria and in this way it summarizes what we view as key interactions. The critical values that are proposed at each level to discriminate between the success or not of gas-vacuolate cyanobacteria must be viewed as hypotheses only and are unlikely to be robust. Most of these are covered in more detail within the text."

This discussion and flow chart are included here as they present some of the environmental factors and suggest several critical values for common cyanobacteria genera found in Oregon including: *Anabaena, Aphanizomenon, Gloeotrichia,* and *Microcystis.*

From Oliver and Ganf (in Whitton, Brian and M. Potts, eds. 2000). The Ecology of Cyanbacteria

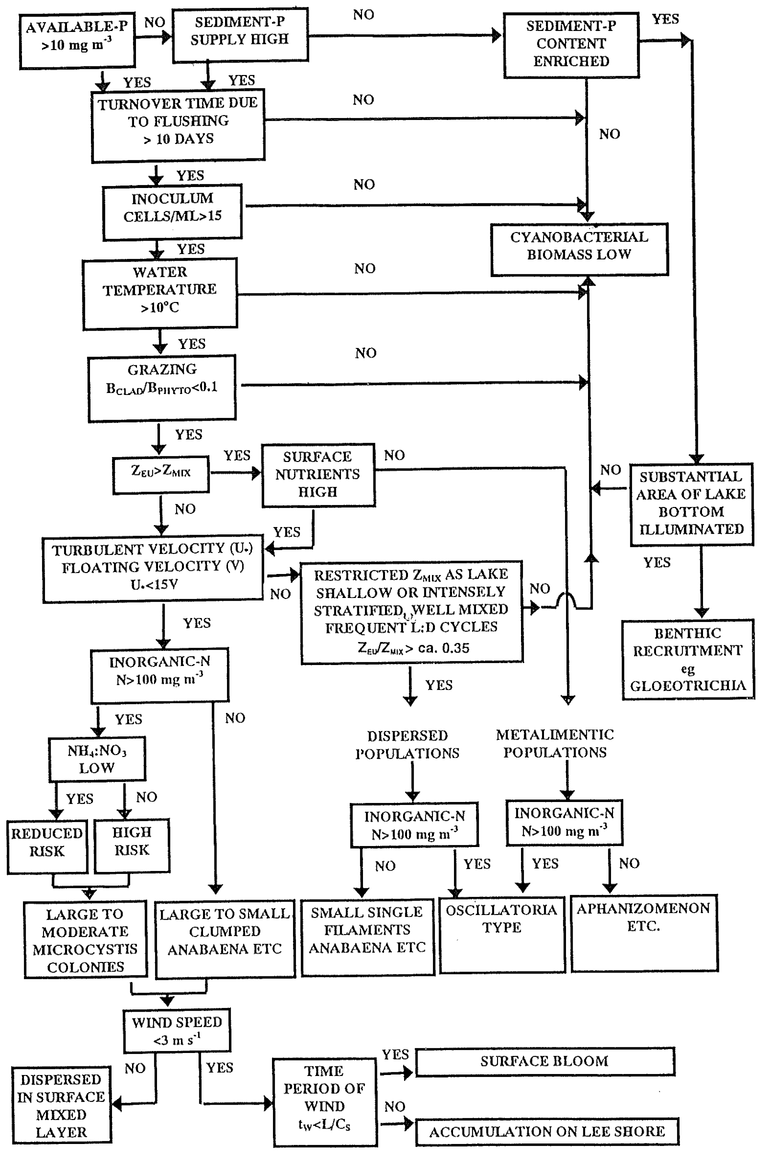


Fig. 10 Flow chart summarising prominent environmental characteristics supporting the development of cyanobacterial blooms and selecting for particular genera. The text provides further detail on some of these components. Key: B_{CLAD} biomass of cladocerans, B_{PHYTO} biomass of phytoplankton, z_{eu} euphotic depth, z_{mix} depth of mixing, u_* shear velocity, V floating or sinking velocity of cyanobacteria, t_w time that the wind blows, L lake fetch, c_s surface current speed.

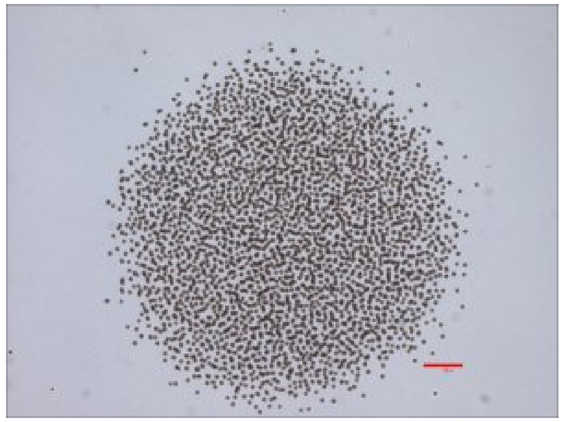
The following are brief summaries of the appearance and some characteristics of common cyanobacteria genera found in Oregon including: *Anabaena, Aphanizomenon, Gloeotrichia, Microcystis and Phormidium.* This is by no means a complete summary but includes some interesting characteristics the author found in the literature which can be added to over time.

Microcystis aeruginosa

Appearance[3]:

Microcystis can grow either unicellularly or in large colonies. Microcystis can grow very thick, often looking like a spill of blue-green paint during bloom events. It is naturally occurring and grows in fresh and low salinity waters. It has gas vesicles for controlling buoyancy but does not have heterocysts for fixing nitrogen or form akinetes. Cells range from 2.61 to 5.40µm in diameter, and can be either ovoid or spherical in shape. It is non-filamentous (unlike *Anabaena*, *Aphanizomenon* and *Gloeotrichia).*

Microcystis sp



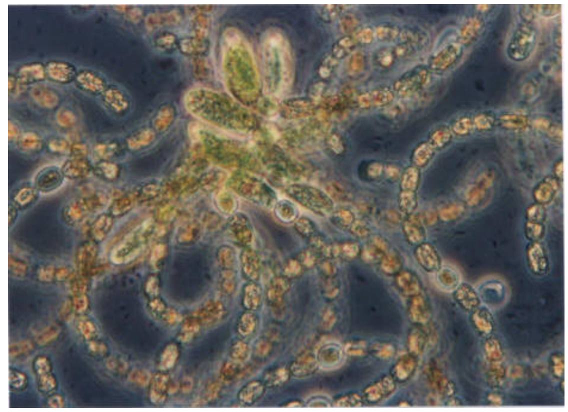
Some Characteristics:

- *Microcystis* aeruginosa is light dependent and oxygenic, but cells may live under the dark anaerobic conditions for periods of time in eutrophic lakes.[4]
- *Microcystis* can produce a group of toxins including microcystin and anatoxin-a (see Table 3-1).
- *Microcystis* has been found to be severely limited at temperatures below 15ºC with optimal temperatures around 25ºC (Oberholster et al, 2004).
- As it does not have heterocysts, it does not do as well as other cyanobacteria that have heterocysts in a low nitrogen environment but does better in areas with greater concentrations of ammonium (e.g. near sediment or anaerobic areas). As *Microcystis* does not have akinetes but it can develop a sizable over-winter population in or near the sediment which can be recruited quickly as a seed population and quickly expand when environmental conditions are favorable.
- *Microcystis* is a storage specialist which is in accord with its ability to regulate buoyancy to gain access to phosphorus in deeper water layer when epilimnetic concentrations are low. It has a high ability for phosphorus uptake, a low minimum P content and a large capacity to accumulate phosphorus.

[3] From http://www.ecy.wa.gov/programs/wq/plants/algae/publichealth/microcystis.html
[4] From MicrobeWike

Anabaena sp

Anabaena Sp



Appearance[5]:

Anabaena is heterocyst-forming, photoautotrophic cyanobacterium that performs oxygenic photosynthesis. *Anabaena* grows in long filaments of vegetative cells. *Anabaena* has uniseriate, straight, curved, or coiled trichomes that may be constricted at the cell walls. The blue-green to yellow-green colored cells may be spherical, ellipsoidal, cylindrical, or bent, but overall look much like a string of beads. Some species have soft and colorless mucilage. It has gas vesicles for controlling buoyancy. During times of low environmental nitrogen, about one cell out of every ten will differentiate into a heterocyst. Heterocysts then supply neighboring cells with fixed nitrogen in return for the products of photosynthesis that they can no longer perform. There are about 40 common species of Anabaena. Vegetative cells may be spherical to oblong (4 – 14 µm diameter, 6 – 12 µm long) Akinetes are larger than vegetative cells and may appear spherical to sausage-shaped (6 – 13 µm diameter, 20 - 50 µm long). Heterocysts, which appear empty, are somewhat spherical (7 – 9 µm diameter, 6 – 10 µm long).

Anabaena is filamentous. For example, *Anabaena circinalis* can aggregate to form macroscopic colonies visible to the naked eye (Whitton and Potts, 2000).

Some Characteristics:

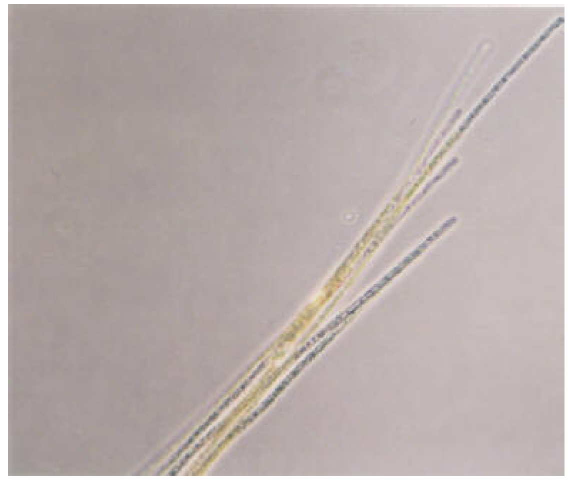
- *Anabaena* can produce a group of toxins including microcystin and anatoxin-a (see Table 3-1).
- The following are notes on the distribution and ecology of some *Anabaena* sp from Sweet (1985) which was based on his earlier work in the Atlas of Oregon Lakes and relative values (e.g. lower or higher) are based on data from the Atlas:
    - *Anabaena circinalis*: most common in coastal lakes but also in Willamette Reservoirs and Suttle Lk. Found in mesotrophic to eutrophic warm lakes with high pH, medium phosphorus, low secchi depths and moderate conductivities.
    - *Anabaena flos-aquae*: More common in Cascade lakes than other *Anabaena* species. Mesotrophic to eutrophic lakes with high phosphorus, high pH and high conductivity. It is associated with lower trophic conditions (higher secchi depths and deeper lakes) than are other *Anabaena* species.

[5] From http://www.ecy.wa.gov/programs/wq/plants/algae/publichealth/anabaena.html

Aphanizomenon flos-aquae

Appearance[6]:

Aphanizonmenon flos-aquae



Aphanizomenon flos-aquae cells unite to form a straight, unbranched filament, which tapers slightly toward both ends. It has gas vesicles for controlling buoyancy. *Aphanizomenon* is filamentous and filaments are usually clustered to form a bundle of parallel filaments (looking like a bundle of straw or blades of grass) which is free-floating. These bundles appear to the unaided eye as prominent, blue-green, "lens-shaped bodies" suspended in the water sample. Individual cells are at least twice as long as wide (5-6 µm diameter, 8-12 µm long). Each filament shows a slight tapering toward the ends, with the cells near the ends being much more elongated and empty looking. There may be one centrally-located akinete and heterocyst per filament. Akinetes and/or heterocysts may be absent at times.

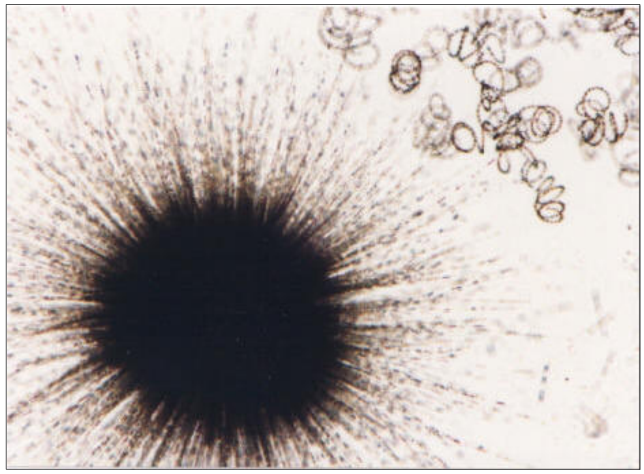
Some Characteristics:

- *Aphanizomenon* can produce a group of toxins including anatoxin-a but evidently not microcystin (see Table 3-1).
- *Aphanizomenon flos-aquae* is sold as a dietary supplement and is harvested from Upper Klamath Lake. The supplements are marketed for their putative beneficial effects including "detoxification", increased energy, elevated mood, and weight loss (Gilroy et al, 2000).
- While some forms of *Aphanizomenon* can produce toxins, evidently *Aphanizomenon flos-aquae* found in North America does not (Jake Kann, personal communication). Colony-forming morphology is on e of the characteristics of the non-toxic species *Aphanizomenon flos-aquae;* conversely, toxin-producing species of *Aphanizomenon* are not known to form colonies.[7] This is still a focus of much needed research and supports the need for increased genetic monitoring and identification based on DNA sequences (see Section 6.1.2).
- Based on a study of supplements after a co-occurance of *Aphanizomenon flow-aquae* and *Microcystis* aeruginosa blooms in Upper Klamath Lake in 1996, OHA and ODA established a regulatory limit of 1 ug/g for microcystins in blue-green algae-containing products (Gilroy et al, 2000).
- The following are notes on the distribution and ecology of *Aphanizomenon flow-aquae* from Sweet (1985) which was based on his earlier work in the Atlas of Oregon Lakes and relative values (e.g. lower or higher) are based on data from the Atlas:
    - Common in Eastern Oregon reservoirs; definitely found in eutrophic, very high phosphorus, low secchi depth, high conductivity, very high pH and warm lakes

[6] From http://www.ecy.wa.gov/programs/wq/plants/algae/publichealth/aphanizomenon.html
[7] http://en.wikipedia.org/wiki/Aphanizomenon_flos-aquae_(dietary_supplement)

Gloeotrichia echinulata

Gloeotrichia echunulata



Appearance[8]:

The word *Gloeotrichia* comes from the Greek meaning "gelatinous hair." *Gloeotrichia echinulata* is found in free-floating globose colonies formed by numerous filaments radiating from a common center. It has gas vesicles for controlling buoyancy. *Gloeotrichia* is filamentous and colonies can be seen easily with the unaided eye as floating “fuzz-balls” or urchin-like balls about 2 mm (or 1/16”) in diameter. Each filament tapers from a basal heterocyst into a fine hair-like tip extending beyond the mucilage, which holds the colony together. Vegetative cells near the base of each filament are spherical to barrel-shaped (8-10 µm diameter), becoming long and noticeably tapered at the opposite end. Highly refractive pseudovacuoles are present which allow colonies to be buoyant. The single, basal heterocyst is spherical (10 µm diameter). Akinetes are adjacent to heterocysts and are cylindrical (10 – 18 µm diameter, up to 50 µm long).

Some Characteristics:

- *Gloeotrichia* can produce a group of toxins including microcystin but evidentially not anatoxin-a (see Table 3-1).
- *Gleotrichia echunulata* has been described as being an extreme storage-adapted species, with its P-assimilation and growth phases completely separated in time and space. Newly recruited colonies from sediments can account for a major portion of the planktonic bloom. They tend to accumulate phosphorus in the sediments prior to migration into the plankton and use this internal store to support planktonic growth. *Microcystis, Anabaena* and *Aphanizomenon* have similar abilities but their populations typically increase from growth in the water column and are reliant on obtaining on-going supplies of phosphorus (Oliver and Ganf in Whitton and Potts, 2000)

[8] From http://www.ecy.wa.gov/programs/wq/plants/algae/publichealth/gleotrichia.html

Phormidium favosum

Phormidium favosum[9]

Some Characteristics:

- *Phormidium* can produce a group of toxins including microcystin and anatoxin-a (see Table 3-1).
- *Phormidium favosum* is an endolithic, benthic cyanophyte that lives on or within cracks in rocks. It can be found on and cause deterioration of stone monuments, statues and historic buildings. Often prefers limestone and marble substrates. Has a gelatinous sheath that acts as a reservoir of water, where it is bound through strong molecular forces, allowing these cyanobacteria to colonize stone even when dry conditions prevail.[10]

[9] http://protist.i.hosei.ac.jp/PDB5/PCD1052/htmls/18.html
[10] http://mic.sgmjournals.org/cgi/content/full/155/11/3476