Who’s Who in the Water
Algae, Vascular Plants
And HABS

Water Biology
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Five kingdoms

- Plants
- Fungi
- Animals
- Protista
- Monera

- eukaryotic
- prokaryotic
Phylogenetic Tree of Life

Bacteria
- Spirochetes
- Proteobacteria
- Cyanobacteria
- Planctomyces
- Bacteroides
- Cytophaga
- Thermotoga
- Aquifex

Archaea
- Green Filamentous bacteria
- Gram positives
- Methanosarcina
- Methanobacterium
- Methanococcus
- T. celer
- Thermoproteus
- Pyrodictium

Eucarya
- Entamoebae
- Halophiles
- Slime molds
- Animals
- Fungi
- Plants
- Ciliates
- Flagellates
- Trichomonads
- Microsporidia
- Diplomonads
World Hypoxic and Eutrophic Coastal Areas

Eutrophic and Hypoxic Areas
- Yellow: Areas of Concern
- Red: Documented Hypoxic Areas
- Green: Systems in Recovery

Data compiled from various sources by R. Diaz, M. Selman and Z. Sugg.
Effects of nutrient loading:
Increased 1° productivity, clogging of waterways, hypoxia, degradation of algae and aquatic plants imparts an earthy, musty taste and odor to drinking water due to the production of volatile organic molecules.
Habitats and sampling

- plankton tows
- plant or macroscopic algae samples
- rock or log scrapings
Aquatic Vascular Plants

• Vascular plants have a more complex structure than macroscopic algae, including tube-like vascular bundles for nutrient transport.

• Often classified based on physical relationship with water:
  • Floating unattached
  • Floating attached
  • Submersed
  • Emergent
Emergent plants:

- Roots and basal portions grow beneath the surface of shallow water; leaves and stems mostly above the water surface.
- Common species in this group include cattail, pickerelweed, and many species of sedges.
- Found primarily in shallow littoral areas of lakes and along banks of slow moving streams.
Types of Vascular Plants

Pickerel Weed
Pontederia
Types of Vascular Plants

Sedge Marsh
Aquatic Vascular Plants

Floating unattached plants:

- Float with most of the plant body above the water's surface.
- If there are any roots present, they hang free in the water and are not anchored to the bottom.
- These plants move about with wind and water currents.
- Common floating unattached plants include water lettuce, water hyacinth, and duckweed.
The aquatic fern *Azolla* is the only fern that can fix nitrogen. It does so via symbiotic association with a cyanobacterium (*Anabaena azollae*). Azolla is found worldwide and is sometimes used as a valuable source of nitrogen for agriculture. The plants shown here are each about 2 cm across. The pale yellow plant has been deprived of cobalt (essential for the cyanobacterial symbiont) and thus is showing typical signs of N deficiency.
Aquatic Vascular Plants

Floating attached plants:

- Leaves floating on the water's surface but roots anchored to the bottom substrate.
- The leaves are connected by flexible petioles (long, thin, fibrous stems), or by a combination of petioles and stems.
- May have underwater leaves in addition to floating leaves.
- Common example: water lilies.
Aquatic Vascular Plants
Aquatic Vascular Plants

Submersed plants:

- Usually anchored to substrate; vegetative parts do not reach surface. Flowers may be above the water for better dispersal by both wave action and wind.

- Dependent upon water clarity and light penetration throughout the water column.

- Common examples include watermilfoil, elodea, wild celery, coontail, and various other pondweeds.
Aquatic Vascular Plants

Anacharis = Elodea

Water milfoil; Parrotfeather (Myriophyllum)

Hydrilla (left) can be distinguished from Elodea by its sharply serrated leaf margins, spinous midrib & rough texture

Coontail, Hornwort (Ceratophyllum)
Aquatic Vascular Plants

Eurasian milfoil: AN INVASIVE SPECIES
Introduction to the algae

* **BACILLARIOPHYTA** (diatoms)
* **CHLOROPHYTA** (green algae)
* **CHRYSO PHYTA** (golden algae)
* **CYANOBACTERIA** (blue-green algae)
* **DINOPHYTA** (dinoflagellates)
* **PHAEOPHYTA** (brown algae)
* **RHODOPHYTA** (red algae)
BACILLARIOPHYTA (diatoms)

- Eucaryotic; unicellular, planktonic, freshwater & marine species
- Lack flagella (except for gametes) but can locomote by chemical secretion
- Silica frustules -> diatomaceous earth; used for filtration, absorbancy, abrasives, component of TNT
- Most autotrophic; some obligate heterotrophs (must absorb organic carbon because lack chlorophyll)
- Estimated to contribute to 45% of total oceanic primary production
- Indicator species (present and historic)
- Many beautiful species; some HAB/toxin producers (eg: *Pseudo-nitzchia*)
Bacillariophyta: Diatoms

Unicellular or can exist as colonies in the shape of filaments, ribbons, fans, zigzags and stellate colonies.
Bacillariophyta: Diatoms
CHLOROPHYTA (green algae)

• Eukaryotes

• Unicellular, filamentous, colonial, sheets

• Most aquatic; some terrestrial, on snow, trees, symbionts

• Green color associated 1° with chlorophyll

• Calcified green algae (e.g. Halimeda) important as contributors of marine sediments

• Freshwater HABs associated with nutrient loading → hypoxia
CHLOROPHYTA (green algae)

Ulva

Hydrodictyon

Halimeda
CHRYSOPHYTA
(golden algae)

• Eukaryotic; may be unicellular, filamentous, branched, amoeboid

• Typically flagellated (1 or 2 flagella) in motile stage

• Abundant in freshwater and marine environments

• Chlorophylls a and c often masked by accessory carotenoid pigment, fucoxanthin

• Formerly included diatoms and brown algae; includes Rhaphidophytes
**CHRYSOPHYTA**  
(golden algae)

- **Raphidophytes** are a small class of mainly marine, planktonic Chrysophytes. Single-celled, naked flagellates (lack cell walls).

- *Heterosigma* and *Fibrocapsa* species have been associated with ‘red tide’ blooms off the coasts of Japan and New England. Fish kills have occasionally been observed related to the species.

- Can produce brevetoxin-like toxins.

- In Delaware during 2000, a fish kill was associated with a toxic bloom of *Chattonella verruculosa*.
• **Prokaryotic**: lack the organized chloroplasts of eukaryotes; their photosynthetic apparatus distributed peripherally in cytoplasm.

• Instead of bacteriochlorophylls found in purple and green bacteria, blue-greens contain chlorophyll a (as in eukaryotic phototrophs), and produce free $O_2$ as a product of photosynthesis.

• Phycobilins are major light-gathering pigment bound to protein granules (phycobilisomes).

• Large blooms of freshwater blue-greens may produce toxins: anatoxin-a, anatoxin-as, aplysia toxin, cylindrospermopsin, domoic acid, microcystin LR, nodularin R, or saxitoxin

• Others grown commercially and marketed as high-protein dietary supplement (eg *Aphanizomenon flos-aquae* and *Arthrospira platensis* (*Spirulina*)).

• Believed important in genesis of Earth’s oxygen atmosphere in Proterozoic Era (0.5-2.5 bya)
Left: Free-living colonies ("balls") of *Nostoc* in a fresh water pond. Each ball is about 0.5 to 1.0 cm in diameter. Note small Pacific chorus frog.

Right: Micrograph of *Nostoc* filaments with specialized nitrogen-fixing cells known as *heterocyst*:s.
Microcystis bloom
RHODOPHYTA (Red algae)

• One of the largest and oldest groups of algae
• Mostly multicellular, marine species (“seaweeds”)
• Many species are coralline algae that secrete \( \text{CaCO}_3 \), hence important for development and stability of coral reefs
• Variety of species food items and source of agar and carrageenan

Phymatolithon purpureum
RHODOPHYTA (Red algae)

*Palmaria palmata*  
*Chondrus crispus*
RHODOPHYTA (Red algae)

Nori

Porphyra
PHAEOPHYTA (Brown algae)

• Kelps; “seaweeds”

• Many forms: filamentous, macroscopic/microscopic; encrusting; large fronds

• Critical role in shallow marine habitats and in Sargasso Sea for food and shelter

• Commercial harvest for food

Ascophyllum  Fucus  Macrocystis
A variety of fishes, including filefishes and triggerfishes, reside in and among the brown Sargassum.
PHAEOPHYTA (Brown algae)
Laminaria holdfast community
DINOPHYTA (dinoflagellates)

- Flagellated; unicellular; common marine and freshwater plankton
- Most photosynthetic. Some species are zooxanthellae, endosymbionts of marine protozoa; critical role in coral biology.
- Some parasitic (e.g., Oodinium, Pfiesteria)
- Blooms can have concentrations of $>10^6$/mL
- Some species produce neurotoxins
When algae go bad: ...HARMFUL ALGAE

Dead fish from a *Karenia brevis* bloom.

Seaweeds (i.e., macroalgae) can also cause harm. Expansive blooms of *Caulerpa* off the Florida coast have transformed some reefs into "Caulerpa meadows" where more than 70% of the coral surface is now dominated by these macroalgal HAB species.

When shellfish accumulate dangerous toxins after filtering algae, public health is at risk. State and federal agencies monitor these shellfish for biotoxins and close affected areas, posting signs like this. Note that although the water appears clear, there is a danger present.
Domoic Acid: ASP

Pseudo-nitzchia (diatom)

- Amnesic shellfish poisoning (ASP) caused by consumption of domoic acid bioaccumulated from shellfish.

- DA acts as a neurotoxin; symptoms include vomiting, diarrhea, and in some cases, there followed confusion, loss of memory, disorientation and even coma. In humans may cause permanent short-term memory loss, brain damage, and death in severe cases.

- Toxicity to nervous system is believed to occur on excitatory amino acid receptors and on synaptic transmission.
Although human illness due to domoic acid has only been associated with shellfish, the toxin can bioaccumulate in many marine organisms that consume phytoplankton, such as anchovies, and sardines.

Intoxication by domoic acid in non-human organisms is frequently referred to as "domoic acid poisoning" or "DAP."

2007 blooms off California coast resulted in deaths of grebes, gulls, cormorants, American avocets and loons. Mammals affected included sea lions, dolphins and whales.
Saxitoxin: PSP

STX: neurotoxin produced by some species of marine dinoflagellates (*Alexandrium, Gymnodinium, Pyrodinium*) and some cyanobacteria (*Anabaena, Aphanizomenon, Cylindrospermopsis, Lyngbya*).

The term saxitoxin originates from the butter clam (*Saxidomus giganteus*) in which it was first recognized.

In the US, *paralytic shellfish poisoning* is limited to New England and the West Coast. The dinoflagellate *Pyrodinium bahamense* is the source of STX found in Florida.

STX block voltage-gated sodium channels; produces a flaccid paralysis that leaves its victim calm and conscious through the progression of symptoms. Death often occurs from respiratory failure.

PSP toxins have been implicated in various marine animal mortalities involving *trophic transfer* of the toxin from its algal source up the food web to higher predators.
One dramatic incident occurred in 1990 when six fishermen almost died from eating mussels during a fishing trip on Georges Bank, a productive offshore finfish and shellfish area 100 miles east of Cape Cod, MA. After a hard day of fishing, the fishermen settled down in the ship's galley to eat a pot of steamed mussels that they had inadvertently caught in their nets. The Captain, who had joined the meal later than the rest of the crew, witnessed his fellow fishermen become incapacitated due to the paralytic effects of the toxin. He himself also became ill, but was capable of sending an urgent radio message to the US Coast Guard. The Coast Guard airlifted the men to the nearest hospital located on Nantucket Island, MA where they were treated using respiratory therapy to sustain their breathing and prevent them from dying due to paralysis of the lungs. Fortunately, all the men recovered and were back fishing within a few weeks. The event, presumably caused by a massive *Alexandrium* bloom transported offshore from areas along the northeast coast, closed the surf clam industry on Georges Bank to further harvest. Georges Bank is an offshore area too vast to monitor and is outside the states' jurisdiction, so the US government maintains jurisdiction and currently bans the harvest of surf clams which are known to retain the toxins for many years.

Puffer fish have been determined to be a hazardous reservoir of STXs, and the dinoflagellate *Pyrodinium bahamense* is thought to be the toxin source.
Ciguatoxin: CFP

Gambierdiscus toxicus: an armored dinoflagellate

• CFP is most commonly reported marine toxin disease in the world; associated with consumption of contaminated reef fish such as barracuda, grouper, and snapper. Second-most problematic HAB species in Florida.

• Ciguatoxin is lipid soluble.

• MOA of CFP based due to opening of voltage-dependant sodium channels in cell membranes, inducing membrane depolarization. The depolarizing action associated with selective increases in sodium permeability in nerve cells and striated muscle. The respiratory arrest induced by a lethal dose results mainly from depression of the central respiratory center.
Ciguatera presents primarily as an acute neurologic disease manifested by a constellation of gastrointestinal (diarrhea, abdominal cramps and vomiting), neurologic (paresthesias, pain in the teeth, pain on urination, blurred vision, temperature reversal) and cardiovascular (arrhythmias, heart block). Signs and symptoms within a few hours of contaminated fish ingestion. Hot/cold temperature reversal is pathneumonic, although not all patients report this.

Under-diagnosis and under-reporting common; CDC and others estimate that only 2-10% of Ciguatera cases are actually reported in the US.

Like many naturally and artificially occurring toxins, ciguatoxin bioaccumulates in lower-level organisms, resulting in higher concentration of the toxin at higher levels of the food chain, an example of biomagnification.
Fish vectors of ciguatera toxins
PbTx is a group of neurotoxins isolated from the marine dinoflagellate *Karenia brevis* (formerly *Gymnodinium breve*; *Ptychodiscus brevis*).

Fish, birds and mammals are all susceptible to the brevetoxins.

Found along Florida's coastlines and in the Gulf of Mexico, similar species occur throughout the world. Observed during Florida's red tides in the late summer and autumn months almost every year with massive fish and bird kills. Fish kills associated with these red tides have been estimated up to 100 tons of fishes per day.

These HABs are believed to be increasing in incidence, time length and geographic spread. Although the possibility of anthropogenic influences such as nutrient run-off is being investigated, it should be noted that these red tides in Florida occurred even prior to significant pollution from human population.

*K. brevis* relatively fragile organism; ruptured by wave action to release toxins. During an active in-shore red tide, the aerosol of contaminated salt spray will contain the toxins and organism fragments both in the droplets and attached to salt particles; this can be carried inland depending on wind and other environmental conditions.

The brevetoxins are lipid soluble polyethers with molecular weights around 900. These toxins are depolarizing substances that open voltage gated sodium ion channels in cell walls, leading to uncontrolled Na+ influx into the cell.

Respiratory, nasal and conjunctival irritation. Coughing, bronchoconstriction. Some reports of dizziness, tunnel vision, paraesthesia, skin rashes.
Brevetoxin: Affects on wildlife
Cyanophytes: Microcystis

Hepatotoxic; hepatic tumor promotor in animal models

By using amino acid single letter code classification, each microcystin is designated a name depending on the variable amino acids which complete their structure. For instance, one of the most common toxins found in water supplies around the world, microcystin-LR contains the amino acids Leucine (L) and Arginine (R) in these variable positions.

This cyanobacterial bloom has the typical appearance of a thick layer of green paint. The bloom was found to consist of toxic species in the genus Microcystis.
Lyngbya normally grows in dense, filamentous mats at the bottoms of nutrient enriched lakes and spring fed systems. These mats produce gasses during photosynthesis that often causes the mats to rise to the surface. At the surface, winds pile the algal mats against shorelines or in navigation channels; these mats can be several acres in size.

In Florida, Lyngbya smothers eelgrass, a food of the endangered West Indian manatee.

Some Lyngbya species have been linked to the production of a skin irritant leading to "swimmers' itch".
Anabaena is a genus of filamentous cyanobacteria, or blue-green algae, found as plankton. It is known for its nitrogen fixing abilities, and some species form symbiotic relationships with certain plants, such as the mosquito fern. They are one of four genera of cyanobacteria that produce neurotoxins (Anatoxin-a, saxitoxins), which are harmful to local wildlife, as well as farm animals and pets.

Under nitrogen-limiting conditions, vegetative cells differentiate into heterocysts at semi-regular intervals along the filaments. Heterocysts are cells that are terminally specialized for nitrogen fixation.
Diarrhetic Shellfish Poisoning (DSP) is a gastrointestinal illness without neurologic manifestations reported worldwide. Stomach pains, vomiting and diarrhoea, typically pass after a few days.

DSP is caused by the consumption of shellfish that have bioaccumulated toxin-producing, marine dinoflagellate, *Dinophysis*. These dinoflagellates are widely distributed, but do not always form red tides. The associated toxins produced by the *Dinophysis* dinoflagellates are okadaic acid and its derivatives; there are at least 9 total toxins produced by these dinoflagellates.

**Okadaic acid** is lipophilic and is a potent inhibitor of protein phosphorylase phosphatase 1 and 2A in the cytosol of the mammalian cells that dephosphorylates serine and threonine. It probably causes diarrhea by stimulating the phosphorylation that controls sodium secretion by intestinal cells similar to *Vibrio cholerae*, although by a different mechanism.
Dinophagellata Life Cycle. 1-Binary fission, 2-Sexual reproduction, 3-planozygote, 4-hypnozygote, 5-planomeiocyte.
Swelling, erosion and fusion of gill respiratory lamellae.
This massive "red tide" of the dinoflagellate *Noctiluca* stretched for more than 20 miles along the southern California coast. Non-toxic blooms such as these can cause extensive mortalities of plants and animals in shallow waters when the bloom biomass decays, stripping oxygen from the water.

Noctiluca scintillans in New Zealand.
Red Tides: Karenia brevis
Red Tides: Karenia brevis

Red Tide Blamed For More Sea Turtle Deaths Tuesday, December 11, 2007 [News Channel 13]
Mid-Atlantic Region of US: 1997
“Mutifactorial nature of ulcerative lesions”
Mid-Atlantic Region of US: 1997

"Mutifactorial nature of ulcerative lesions"
Pfiesteria piscicida

Photo: J. Burkholder et al., NCSU
This is the typical condition during fish kills in nature.
Other factors associated with ulcers