Introduction to Algae

According to the Whittaker five-kingdom system of classification, single-celled algae and protozoa belong to the Kingdom **Protista**. Although sometimes divided into other kingdoms (including Chromista, Alveolata, Parabasala, etc.), the microscopic algae and protozoa are frequently referred to as protists, and for the sack of simplicity will be left as protista here. The lecture information for algae and protozoa will be presented in two parts with algae described first.

Microscopic algae (singular = alga) are plant-like organisms occurring as single cells, thread-like filaments, or colonies of various shapes and composition. They are abundant in water (both fresh and marine), in damp soil and on moist surfaces. Some types of algae live inside other organisms and some form symbiotic relationships with fungi in structures called lichens.

Phycology – The science or study of algae is called **phycology** (phykos = sea weed), and initially involved the investigation of macroscopic organisms common in marine habitats. Many types of marine algae are macroscopic, sometimes reaching nearly 100 feet in length, but since this is a microbiology course, those organisms are not included here.

Algae are **oxygenic photoautotrophs** and contain green-colored pigments called **chlorophylls** within folded membranous **thylakoids** of organelles called **chloroplasts** (recall eukaryotic cell structure and function). The green chlorophyll pigments are light-sensitive and allow algae to convert light energy into chemical energy (ATP) through a process called **photophosphorylation**. Algae produce oxygen (are oxygenic) by splitting water molecules and are sometimes credited with producing up to 70% of the oxygen present in the earth's atmosphere (though reaching this percentage probably requires the inclusion of oxygen produced by cyanobacteria as well). As **autotrophs**, algae take in inorganic carbon (carbon dioxide) from the atmosphere and use it to form organic compounds (sugars) that can be metabolized in a variety of ways. They are self-feeding, but also provide food for other organisms. Algae are ecologically categorized as **producers** and play an essential role at the bottom of multiple food chains (webs).

Algae cells, like those of fungi, are surrounded by rigid, non-living layers called **cell walls**. Most algae have walls made of polysaccharide (cellulose or agar), but some contain quantities of glass (silica dioxide). Walls give algae cells their characteristic shape and allow them to live in hypotonic environments without being damaged. Though plant-like in some ways, algae do not have stems, leaves or roots. The body of a multicellular alga is called a thallus and may have structures resembling stems, leaves and roots. Single-celled, filamentous, and colonial forms of algae are much simpler in composition.

Algae Reproduction

Algae reproduce both sexually and asexually, with asexual reproduction occurring more commonly. Some variation in asexual reproduction are described below.

a) **Fission** – Fission in algae (like fission in other cells) involves **mitosis** (the separation of chromosomes) and **cytokinesis** (the division of the protoplasm into two parts). Some algae, such as *Spirogyra* and *Oedogonium*, undergo **binary fission**, i.e., divide in half across their long axis. Other types, such as *Chlamydomonas*, undergo **longitudinal fission**, i.e., divide in half lengthwise.
b) **Shrinking division** – Asexual reproduction in diatoms involves a specialized type of fission called "shrinking division" which results in the formation of two cells of unequal size. Diatoms have glass walls composed of two parts called **frustules** or valves (depending on sources) that fit together like the two sections (lid and bottom) of a Petri plate. When a diatom undergoes fission, the two wall sections separate, and a new wall is formed on the inside of each. The diatom receiving the "lid" section of wall will be the same sized as the original cell, but the one receiving the "bottom" will be smaller. Repeating fission cycles will produce smaller and smaller diatoms until a minimum size is reached, and then stops. This explains the size variation typical of diatoms in the same species. Sometimes produce asexual spores.
c) **Fragmentation** – Filamentous forms of algae can undergo fragmentation (like fungus hyphae), and each fragment can grow into a new filament.
d) **Spore formation** – Algae, like fungi, produce asexual spores of various types.

Sexual Reproduction

Sexual reproduction as it occurs in algae is similar to that occurring in fungi in that it involves three stages or steps called **plasmogamy**, **karyogamy** and **meiosis**. This similarity is largely due to historical events, i.e., algae and fungi were both considered members of the kingdom Plantae, and the reproductive processes of both groups were described by botanists.

Sexual reproduction requires the participation of two genetically dissimilar algae (of the same species) and typically occurs in three stages or steps as outlined below:

1. **Plasmogamy** – Plasmogamy involves the joining of the protoplasm (plasma = protoplasm, gamous = union or marriage), and requires decomposition of the cell walls separating the cells involved.
2. **Karyogamy** – Karyogamy involves the joining of two haploid nuclei (karyon = nucleus) and results in the formation of a diploid cell called a **zygote**. **Haploid** cells/nuclei have only one set of chromosomes, while **diploid** cells/nuclei have two.
3. **Meiosis** – Meiosis (reduction division) is a process involving separation of chromosomes and the division of the diploid nucleus into two, haploid parts. An important feature of meiosis is the formation of new genetic combinations, not possible through asexual reproduction.

These stages may be separated in time, and result in the formation of two separate generations of algae known as **sporophytes** and **gametophytes**. The **gametophyte generation** is composed of haploid cells that can undergo plasmogamy and karyogamy to form diploid zygotes. The diploid cells form the **sporophyte generation**, and these can undergo meiosis to form gametophytes. Since cells of the gametophyte and sporophyte generations are often morphologically similar (or identical) it is difficult/impossible to determine if any given sample includes haploid or diploid cells by simple observation.

Algae Pigments

The classification of algae (seaweeds) was initially based on the types of pigments present, and three major groups included the green algae, red algae and brown algae. Microscopic algae can also contain different types of pigments including those listed below:

a) **Chlorophylls** – Chlorophylls a, b, and c are the green pigments primarily involved in capturing light energy for photophosphorylation (making ATP using light energy).
b) **Phycobilins** – Phycobilins are red-colored pigments found in red algae, cyanobacteria and certain other groups. These pigments absorb light energy and then pass it on to chlorophylls.
c) **Carotenoids** – Carotenoids are yellow and orange-colored pigments associated with several types of algae and green plants (e.g., in carrots, yellow and orange-colored flowers and orange and yellow-colored fall leaves). Beta-carotene and lutein, a type of xanthophil are two examples.

Some Interesting features of Algae

Eutrophication – Eutrophication is an increase in algae populations in a body of water (fresh or salt), and occurs when nutrients are abundant and light intensity is high. When microscopic algae are involved, they are referred to as **phytoplankton** (phyton = plant and planktos = wanderer or drifter). Although algae potentially provide a food source for other organisms and are oxygenic, eutrophication is usually considered to be detrimental rather than beneficial. In swimming pools, fish tanks, and clear mountain lakes (like Tahoe), the growth of algae is unwanted. Eutrophication, sometimes referred to as an **algae bloom** or **red tide** (when involving dinoflagellates in marine habitats), causes water to become green (or red), cloudy and in some cases to have a foul odor. Some consequences of eutrophication are described below:

1) **Algae can kill fish and other organisms living in water.**
   Algae are **respiratory organisms** (require an inorganic compound as their final electron acceptor), and although they can make oxygen, they also use it. Algae, like other oxygenic phototrophs, can make oxygen only during daylight hours; at night they use up oxygen and can cause fish and other organisms living in the water to die from suffocation. Fish kills resulting from eutrophication are usually observed during summer months when light intensity is high, and can occur in both fresh-water and marine habitats (for example in Clear Lake and San Francisco Bay).

2) **Algae can cause paralytic shellfish poisoning.**
   When eutrophication occurs in ocean waters and involves dinoflagellates (organisms containing red pigments), it can create "red tides". Dinoflagellates, like other types of algae, can use up oxygen and kill fish; but they can also kill large animals (bears, sea otters, humans, etc.) by producing potent **neurotoxins** (gonyautoxins) that cause paralytic shellfish poisoning (PSP). Shellfish such as mussels, clams, scallops and oysters feed on dinoflagellates filtered from the water and accumulate neurotoxins in their tissues. When animals eat the shellfish, they experience PSP, and potentially deadly paralysis of skeletal muscles. Dinoflagellates in the genera *Alexandrium*

(formerly *Gonyaulax*) and *Gymnodinium* are commonly associated with PSP. Though multiple factors may influence eutrophication, "red tides" are most common along California's northern coast during months without the letter "r" in them (May, June, July and August), because that is when light intensity is greatest.

3) ***Pfiesteria* threatens both fish and fishermen.**
Dinoflagellates identified as *Pfiesteria piscicida* cause considerable damage along the eastern coast of the US by attacking and killing fish in large numbers. Though the fish being killed by these dinoflagellates are small in size, they are important to the fishing industry because they feed other, larger fish of commercial interest. *Pfiesteria* also produce neurotoxins that are harmful to humans, causing neurological symptoms such as headache, dizziness and memory loss. When present in high concentrations, these toxins may become airborne and cause damage to people not contacting contaminated fish or water.

4) **Some dinoflagellates are bioluminescent.**
Dinoflagellates in the genus *Noctiluca* carry lux genes and produce luciferase enzymes involved in converting chemical energy into light energy. Like bioluminescent bacteria, these dinoflagellates produce their own light, or glow in the dark. During red tides, *Noctiluca* can cause waves to light up as they break on the shore, sand to sparkle under foot, and ships to leave light trails as they travel through the water.

5) **Diatom cell walls form diatomaceous earth.**
Diatoms, microscopic algae with glass cell walls, are often abundant in both fresh and salt water. During earlier periods in the earth's history, diatoms inhabited inland seas that are no longer present. Their cell walls accumulated at the sea bottom, forming a sedimentary rock type called **diatomite**. This material now occurs as deposits on dry land and can be "mined" and ground into **diatomaceous earth**. Diatomaceous earth is used extensively in filters for water, honey, apple juice and other liquids. It is also used as an abrasive in car polish, toothpaste and cleansers. Diatoms have clinical significance because diatomaceous earth can be used to determine blood clotting time. Some diatoms produce a neurotoxin called **domoic acid** that can cause damage to humans or other animals eating seafood that was formerly feeding on diatoms.

6) **Coccolithophores form an important carbon sink.**
Algae commonly called **coccolithophores** or **coccolithophorids** occur in large numbers within the sunlit waters of the earth's oceans. These phytoplankton form external scales or plates of calcium carbonate called **coccoliths** that cover their cell surfaces. Coccoliths are formed internally (in association with the golgi complex), gradually move to the cell surface, and are shed throughout an organism's lifetime. Shed coccoliths form the basis of **chalk** a sedimentary carbonate rock type.

Because of their abundance, coccolithophores play an important role as producers of food (organic compounds) and oxygen for other organisms. Their coccoliths also play an important role as **carbon sinks**, i.e., they take carbon dioxide from the atmosphere and sink it to the ocean bottom as they are shed. Currently there is concern about the long term survival of coccolithophores, because although their populations appear to be increasing as atmospheric carbon dioxide levels have increased, scientists fear that acidification of the oceans due to increased levels of carbonic acid (formed as water absorbs carbon dioxide), will interfere with coccolith formation.

7) **Red algae make agar**.
Agar, the polysaccharide commonly used as a solidifying agent in microbiological media is made by red algae (Phylum Rhodophyta).

8) **Psychrophilic algae form watermelon snow.**
Algae in the genus *Chlamydomonas* (and usually green in color) are responsible for the formation of pink surfaces on snowfields, a phenomenon sometimes called watermelon snow. The algae (*C. nivalis*) are psychrophiles and the red color is actually due to a type of carotenoid pigment called astaxanthin, rather than to phycobilins.

9) **Some Algae form endosymbiotic relationships**
Though green chlorophyll pigments occur in nearly all types of algae, green-colored protista are not necessarily algae. Sometimes algae live inside other organisms, causing them to appear green. Since algae are photoautotrophs, they cannot be considered as parasites (recall parasites are chemoheterotrophs), but they do take up residence inside a variety of organisms, so are called **endosymbionts**.

Dinoflagellates in the genus *Symbiodinium* are the most abundant, and live inside a wide variety of organisms including sea anemones, various types of coral, jellyfish, sponges, flatworms and mollusks. These symbionts, initially taken in through phagocytosis, live within vacuoles (symbiosomes) resistant to lysosome digestion. They also multiply within their hosts and exchange oxygen and nutrients with them. Coral bleaching and death associated with rising ocean temperatures (and probably other factors) appear to be due to the loss of algae symbionts or loss of the chloroplasts within these.

Green algae identified as *Zoochlorella parasitica* live within giant green sea anemones along the California coast and give them their beautiful green color. Other types of green algae (sometimes called zoochlorellae) live inside *Paramecium bursaria* and *Hydra* species, making them appear green.

The term **endophytic** formerly applied to endosymbiotic algae is no longer applicable.

10) **Some algae help form Lichens**
Lichens are organisms made up of algae (or cyanobacteria) and fungi living together symbiotically. Though classified as individual organisms, lichens are actually composed of two different types of organisms living together. The relationship between fungus and algae/cyanobacteria cells is mutualistic, with the algae/cyanobacteria providing food through photosynthesis (by collecting and processing carbon dioxide) and the fungi providing protection and metabolic water.

Lichens are extremely hardy, often colonizing environments where few other organisms can grow (e.g., on rock surfaces). Sometimes they are the first organisms to return after a fire or volcano removes all vegetation.