Eutrophication & Biodegradable Waste

Background

Algae play an important role as primary producers in aquatic ecosystems. Like plants, they contain chlorophyll and produce both food and oxygen through photosynthesis. They are eaten by zooplankton, filter feeders (such as mussels), and aquatic grazers (such as snails). Algae are classed in several different groups, e.g., green algae, dinoflagellates, diatoms, euglenoids, yellow-green algae, red algae, and brown algae. *Ankistrodesmus* and *Chlorella* are in the green algae group.

A large or sudden expansion in algae population is called a bloom. Some "algae" blooms are actually blooms of cyanobacteria. Although these photosynthetic prokaryotes were once called blue-green algae, the term *algae* now applies only to eukaryotic forms. Under certain conditions, some blooms of algae and of cyanobacteria are capable of producing toxins that can cause sickness or death in animals, including humans.

Harmful algal blooms (HABs) are often referred to as red, brown, or green tides. Red tides are often attributed to dinoflagellates, which sometimes over-proliferate due to an influx of nutrients. During these population explosions, certain species produce neurotoxins that sicken or even kill people who eat shellfish taken from contaminated areas. For this reason, collection of filter-feeding organisms is prohibited in areas experiencing red tides.

Nitrogen is an important component of all living organisms. It occurs in amino acids, which make up proteins, and in nucleic acids (DNA and RNA). Animals obtain nitrogen through consuming other organisms. Terrestrial plants absorb nitrogen through their roots from the soil in the form of nitrates and ammonium. Aquatic algae, plants, and cyanobacteria acquire nitrogen by absorbing nitrates that are dissolved in water. The biological process of decomposition is a natural source of nitrates in both terrestrial and aquatic environments. Waste and decaying organisms produce ammonia, which is converted to nitrite and then to nitrate by different types of bacteria. Human activities can contribute to nitrate levels that are many times higher than an ecosystem would normally sustain, producing explosive algal growth (e.g., through fertilizer runoff, sewage treatment malfunction, agricultural animal waste).

Phosphorus, another essential element, is a component of DNA and ATP. It is typically found in nature in the form of phosphate salts in rock and ocean sediment. Algae and plants obtain phosphorus as phosphate ions from soil and water. Animals obtain phosphorus through the consumption of other organisms. Marine sediments and rocks containing phosphorus are natural sources of this essential element. Weathering of these materials slowly erodes compounds that contain phosphate ions into the environment. Phosphorus is often a limiting factor for primary production because most soils and bodies of water normally contain little of the nutrient.

Nitrate levels in unpolluted freshwater are typically less than 1 mg/L. Anthropogenic sources of nitrogen, such as fertilizer runoff and animal waste from feedlots, may result in the elevation of nitrate levels above 3 mg/L. Natural levels of phosphate typically range from 0.01 to 0.03 mg/L in uncontaminated surface waters. Phosphate concentrations even as low as 0.025 mg/L may accelerate eutrophication in certain conditions.

Dissolved oxygen (DO) is oxygen gas (O_2) dissolved in water. DO is the oxygen that fish and many other aerobic aquatic organisms use in respiration. Bacteria's aerobic decomposition of organic material in water is critical in cycling nutrients. Because adequate DO is essential for a healthy aquatic ecosystem, we monitor its level when assessing water quality. DO enters water through diffusion from the atmosphere and through the photosynthesis of primary producers that live in the water. Oxygen diffuses into water from air because oxygen is more concentrated in air than in water. Currents and waves increase diffusion by increasing the surface area of the water and by dispersing the DO as oxygen diffuses in. Aquatic plants and algae (including phytoplankton) are the producers that contribute DO.

The amount of oxygen contained in water may be expressed in parts per million (ppm). One ppm DO is equivalent to 1 milligram of O_2 per liter of H_2O (mg/L). The critical level of dissolved oxygen varies among species. A level above 5 ppm is necessary for many aquatic organisms, including warm-water fish such as bluegill and bass. Some cold-water fish, such as trout, require a DO level of at least 6 ppm. A DO level between 3 and 5 ppm causes stress for many aquatic organisms. A DO level below 3 ppm is considered hypoxic. In hypoxic conditions, motile organisms move to areas of greater DO if they can find them, and non-motile organisms often die. Anoxia results when DO drops below 0.5 ppm. Organisms that require oxygen are unable to survive in anoxic conditions.

A number of factors influence DO level. Throughout the course of a day, the DO level changes according to changing efficiencies in aquatic photosynthesis. During the day, due to photosynthesis, the DO level tends to be higher than during the night. During the night, the aquatic producers contribute to oxygen depletion because their respiration is not being offset by a surplus production of oxygen from photosynthesis as it is in daylight. Wind increases the amount of water exposed to the atmosphere, thus increasing the diffusion of oxygen into the water. Heavy cloud cover during daylight hours can decrease photosynthetic activity and thus decrease DO.

The solubility of oxygen in water is also influenced by pressure, salinity, and temperature. The solubility of oxygen in water increases as pressure increases. The solubility of oxygen in water decreases as salinity and temperature increase. Therefore, freshwater can hold more DO than saltwater, and cold water can hold more than warm water.

Dissolved oxygen is also influenced by depth. In a lake, the top layer of water contains photosynthetic organisms that produced oxygen. Decomposition, a process that uses oxygen, occurs mainly at the bottom, where organic material has accumulated. In deep lakes this difference in DO level may be very pronounced. Oxygen stratification is not as pronounced in shallow lakes or lakes mixed by wind. The presence of biodegradable waste has a profound effect on the DO level of an aquatic system. Biodegradable waste is waste that originates from a living source and can be broken down (degraded) by other living organisms. Biochemical oxygen demand (BOD) is a measure of the amount of dissolved oxygen required by decomposers to metabolize the quantity of biodegradable material in an aquatic system. As the quantity of material increases, BOD rises, and, typically, DO falls. In this activity, you will model the effect of biodegradable waste on DO in a body of water. Your pollutant is milk, and your decomposer is yeast. A simple redox reaction using methylene blue indicates the presence of dissolved oxygen. In its oxidized form, methylene blue appears blue; however, when the oxygen level drops below a critical point, the methylene blue is reduced and becomes colorless. Due to the use of milk as the pollutant in this activity, the solution appears white, rather than colorless, in the absence of oxygen.

Objective(s)

- ✓ to observe and describe the effects of biodegradable waste on dissolved oxygen concentrations and water quality
- ✓ to design and conduct a scientific investigation on the effects of excess nutrients on algal growth and water quality
- ✓ to describe the causes and process of cultural eutrophication and its effect on water quality

Materials

- small plastic cups (x6)
- stirring rod
- warm water (37-40 °C)
- milk solution
- yeast solution
- methylene blue
- thermometer
- blank, white paper
- masking tape
- 10 mL syringe
- 250 ml beaker
- 150 mL beaker (x2)

Pre-Lab Questions

Answer the following questions below on a separate sheet of paper. You must either write out the questions, or include the questions in your responses. Be sure to use complete sentences.

1. What are some biodegradable materials that may be present in an aquatic ecosystem? What represents the biodegradable material in this activity?
2. What organism is used to represent an aquatic decomposer in this activity? Explain how this representative organism models the role of decomposers in an aquatic ecosystem.

Safety

Glassware hazard | Eye & face hazard | Heat hazard

Procedure

1. With masking tape, label six plastic cups (1 through 6) within a centimeter of the top. Place the cups in numerical order on the sheet of white paper.
2. Fill the 250 mL beaker with approximately 100 mL warm water (37–40 °C).
3. Use the syringe to fill cup 2 with 10 mL warm water. Repeat with cups 3–6.
4. In a 150 mL beaker, get approximately 25 mL milk from the supply station.
5. Perform a serial dilution for cups 2–5. Each cup will be a dilution of the previous solution by half.
   a. Use the syringe to place 10 mL milk in cup 1. Cup 1 now contains only milk.
   b. Use the syringe to place 10 mL milk in cup 2. Cup 2 now contains 10 mL milk and 10 mL water. Mix well.
   c. Use the syringe to remove 10 mL of the mixture from cup 2 and place it in cup 3. Cup 3 now contains a total of 20 mL.
   d. Likewise, remove 10 mL from cup 3 and place it in cup 4. Mix well.
   e. Then, remove 10 mL from cup 4 and place it in cup 5. Mix well.
   f. Finally, remove and discard 10 mL from cup 5.
   Note: *Cup 6 should contain only water.*
6. Get the dropper bottle of methylene blue from the central station. Add 3 equal-sized drops to each of the six cups. Return the methylene blue to the central station.
7. Beginning with cup 6 and moving down the series, use the stirring rod to mix the contents of each cup to ensure even distribution of the methylene blue. Mixing in this order (from less to more concentrated mixtures) minimizes the potential of transferring residue and affecting concentrations. To further minimize this possibility, rinse the rod between each stirring.
8. Into the other 150 mL beaker, place approximately 30 mL yeast solution from the supply station. **Note:** Do not use any foam that may be on top of the solution. Use your syringe to collect yeast solution from below the foam.
9. Rinse the syringe with remaining water from the 250 mL beaker.
10. Use the syringe to measure 4 mL yeast solution and place it in cup 1. Record the time on your data table.
11. Repeat the previous step for cups 2–6.
12. Beginning with cup 6, gently mix each solution with the stirring rod to ensure even distribution of the yeast in each cup.

13. Observe the solutions for a color change from blue to white. A thin layer at the surface of the sample may remain blue due to gas exchange with the air. Once the rest of the solution turns white and shows no signs of additional color change, record the time on your data table. Color change should be evident in all samples within 30 minutes. If any sample exhibits no color change within the allotted time period, simply record that sample's appearance as an observation on your data table. It may be useful to take photos of all the samples for comparison purposes.

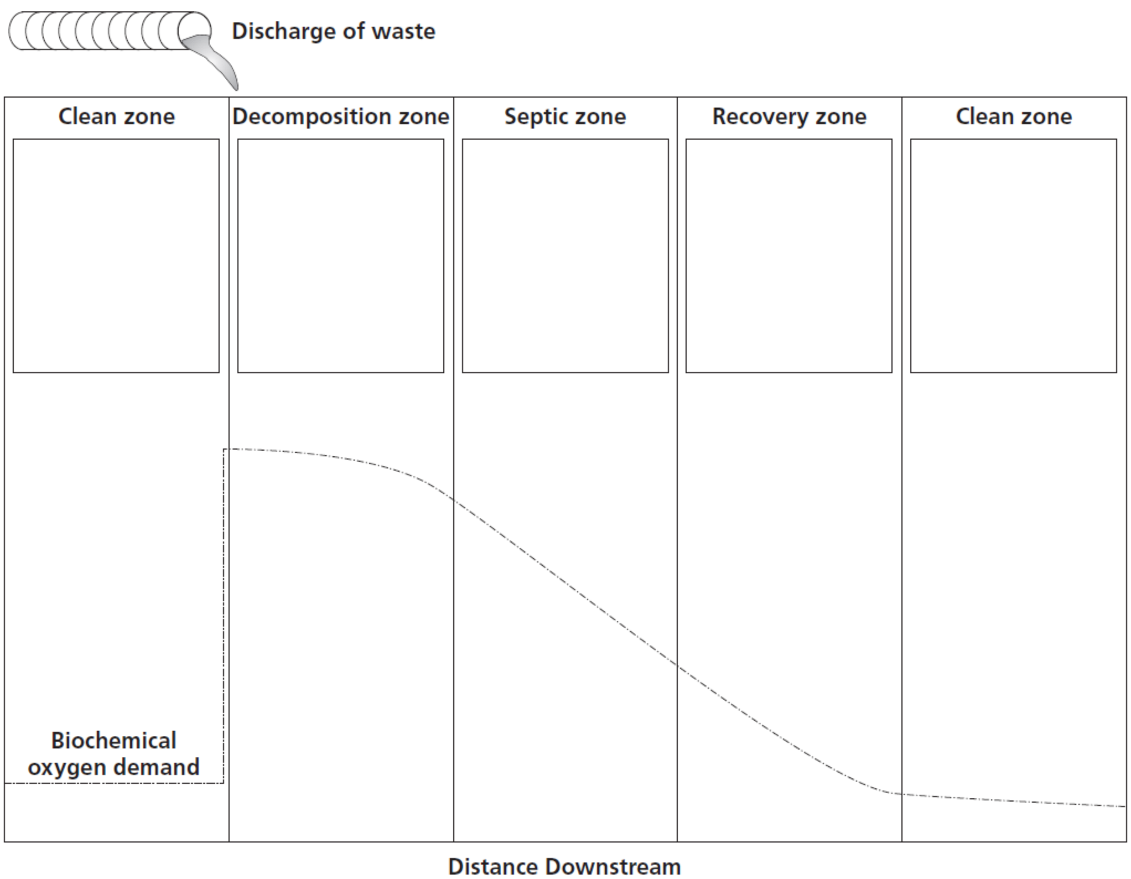
Clean Up

- ✓ sink: milk solution, yeast solution
- ✓ trash: masking tape
- ✓ rinse (no need to dry): plastic cups, stirring rod, syringe, beakers
- ✓ everything else returned to its original location

Results & Analysis

Answer the following questions on your lab paper. For actual questions, you must either write out the questions, or include the questions in your responses. Be sure to use complete sentences and show your work for math problems.

1. The following is a graph of the biochemical oxygen demand in a stream as the result of introduction of biodegradable waste. The biochemical oxygen demand (dashed line) represents the quantity of oxygen required by aerobic microorganisms to break down biodegradable waste. The different zones are labeled clean zone, decomposition zone, septic zone, and recovery zone.



   a. Based on the oxygen demand, add a solid line to the graph that demonstrates how the dissolved oxygen level (ppm) would be expected to change throughout these zones. This graph is called a dissolved oxygen sag curve.
   b. Indicate two types of organisms you would expect to find in each zone. Write these organisms in the space below the zone name.
   c. What factors would affect the intensity of the oxygen sag curve you added to the graph?
   d. Explain how this graph relates to the Guided Activity procedure involving milk and yeast.

2. Residents of a picturesque town on a lake rely on summer income from recreational fisherman. The townspeople notice a die-off of lake trout and hire you to determine the cause of the fish kill. As you investigate, you make several observations: an increasing amount of algae in the lake, the presence of an industrial facility on a cove of the lake, and a dairy farm upstream. In a detailed paragraph, address how you would proceed in determining the cause of the fish kill and describe other evidence you would need before drawing any conclusions.
3. Environmental concerns are rising in regard to water quality of a local stream that runs near a hog farm. Students have decided to test the water at various sites and collected the following data:

	Site A	Site B	Site C	Site D	Site E
Phosphate (ppm)	0.5	0.9	1.3	1.1	0.7
Nitrate (ppm)	1.2	12.6	18.3	14.2	7.6
Dissolved Oxygen (ppm)	6.9	4.1	2.4	3.2	6.1

   Site A is upstream from the hog farm, Site B is located on the part of the stream that runs through the farm, and Sites C, D, and E are all downstream from the farm.
   a. On the basis of the data collected by the students, what is the likelihood that the hog waste is affecting water quality? Defend your argument.
   b. Dissolved oxygen, phosphates, and nitrates are just three parameters that can serve as indicators of water quality. Suggest two more tests that might be informative in this situation, and explain the results you would expect to find at the various sites.
4. Create a concept map describing the process of cultural eutrophication as it relates to dissolved oxygen level. Include the following terms: fertilizers, runoff, sewage, nitrates, phosphates, algal bloom, detritus, decomposers, biochemical oxygen demand (BOD), dissolved oxygen levels, hypoxia.