Western Regional Aquaculture Center

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PHYTOPLANKTON AND RECREATIONAL PONDS

Introduction

Phytoplankton are microscopic plants that live in all healthy aquatic systems including freshwater ponds and lakes. The word phytoplankton is derived from the Greek language (phyto = plant; plankton = wanderer). It is a term used to describe plants that are so small that their movement is primarily controlled by the motion of the water. These plants called algae (alga = singular) include a number of microscopic, single and multiple cell forms.

The phytoplankton population in a pond is usually comprised of numerous species of microscopic plants that live in a horizontal band or zone near the water surface. The densest population is usually located in a horizontal band extending from about two to three inches below the surface to a depth of 18 to 20 inches. The depth of the band depends on numerous factors including pond turbidity, light penetration, and available plant nutrients.

The clarity of a pond depends on the presence or absence of suspended materials such as microscopic clay particles and phytoplankton. In the absence of suspended material and phytoplankton, a pond will appear almost crystal clear. When the algal species in the phytoplankton community reproduce, the phytoplankton will reach a density that can be characterized as a slight cloudiness or turbidity in the water. What is being observed is not the individual algal cells, but light reflecting off millions of microscopic, single- and multiple-celled microscopic plants. When the phytoplankton can be observed it is called an algal bloom. Often, the phytoplankton population can become so dense that it will produce a deep, opaque color at the pond's surface.

Phytoplankton as a Source of Oxygen

A concentration of dissolved oxygen in water is required for organisms such as fish, tadpoles and many aquatic insects to live in a pond. The gills of these organisms extract the dissolved oxygen (O_2) from water and release carbon dioxide (CO_2). Sources of oxygen in water result from oxygen exchange between the atmosphere and the surface of the water through wind and wave action, oxygen derived from the photosynthetic action of submerged aquatic vegetation called macrophytes (macrophytes: Greek, macro = large; phyte = plant), and the algal bloom. The major source of oxygen in "healthy" ponds, and the primary source of oxygen in all warmwater ponds, is produced through the photosynthetic action of the phytoplankton.

Oxygen Balance in a Pond

The oxygen content of a pond or lake is never constant. Oxygen is continuously being produced by algae and other aquatic plants and by wind and wave action. It is removed from the system through respiration of aquatic animal organisms, by the biological oxygen demand (BOD) of organisms such as bacteria that break down non-living organic material, and even by a chemical oxygen demand (COD) caused by decay of dead plants and animals.

A frequently misunderstood phenomenon is how algae affect oxygen concentration in a pond during day and night hours. Algae and other plants are consumers as well as producers of oxygen. Algae produce oxygen during the daylight hours and then consume it at night. During the day algae use energy from the sun to drive a chemical reaction

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between carbon dioxide (CO_2) and water (H_2O) to produce sugar and oxygen (O_2). The simplified description of photosynthesis in Figure 1 shows how plants produce sugar for their own metabolic processes, and then produce and release oxygen to the water where it becomes available for use by aquatic animals.

The second respiration process in plants is called dark phase respiration. It occurs primarily during the night and, to a much lesser extent, during daylight hours. During the dark phase process the plant consumes sugar and oxygen to produce energy, carbon dioxide, and water. The critical point is that at night, aquatic plants shut down the oxygen-producing photosynthetic reaction and initiate a process where they consume oxygen (Figure 2).

Figure 1. Elementary overall photosynthetic reaction of phytoplankton during daylight hours.

$$\underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{12H_2O} \overset{\text{Energy From Sun}}{\overset{\downarrow}{\rightarrow}} \underset{\text{Sugar}}{C_6H_{12}O_6} + \underset{\text{Water}}{6H_2O} + \underset{\text{Oxygen}}{6O_2}$$

Figure 2. Elementary overall nighttime respiration reaction by phytoplankton.

$$\underset{\text{Sugar}}{C_6H_{12}O_6} + \underset{\text{Water}}{6H_2O} + \underset{\text{Oxygen}}{6O_2} \overset{\text{Energy for metabolism}}{\overset{\uparrow}{\rightarrow}} \underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{12H_2O}$$

This process of oxygen production and consumption are necessary to pond life. A healthy, balance pond provides a fluctuation in oxygen levels between day and night that leaves an adequate concentration of oxygen in the water that can support aquatic animal life during both day and night hours. The highest oxygen levels in a pond are usually measured on sunny afternoons when phytoplankton and other aquatic plants are producing oxygen through photosynthesis. The lowest level occurs just before daybreak after a night of oxygen consumption by aquatic plants and animals. Ponds suitable for supporting fish have a minimum pre-dawn oxygen level near the optimum for the fish in the pond. Most fish do best in water at or greater than 5.0 milligrams of oxygen per milliliter of water (5.0 mg/l). This is also expressed as 5.0 parts per million (ppm) oxygen.

Oxygen Saturation

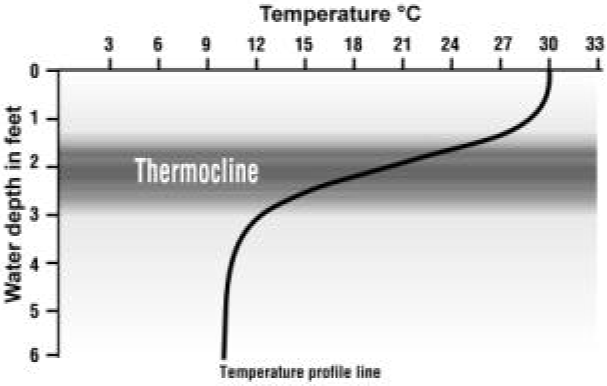
In water, oxygen saturation is the maximum amount of oxygen that water can hold. The amount of oxygen that water can hold varies with such factors as temperature, the dissolved minerals in the water, and pond elevation. The oxygen saturation point of warm water is less than that of cold water. For example, freshwater at sea level and at a temperature of 20º C (68º F) can hold 9.092 mg/l oxygen. Elevate the temperature of that water to 30º C (86º F), and the saturation point for oxygen is 7.558 mg/l. Increase the salinity of the same water from a fresh state to 10 g/kg saltwater, and the saturation point for oxygen decreases to 7.155 mg/l. Elevation adds a third dimension to the equation. If the temperature and salinity of water are constant, water with these same characteristics will hold less oxygen at higher altitudes.

These physical characteristics are contributing factors to oxygen depletion problems in the summer months. Although the intense radiant sunlight of summer stimulates an abundance of phytoplankton, the accompanying heat reduces the total concentration of oxygen that water can hold simply because the water temperature is increased. This is further complicated in areas of higher mineral salts, such as high desert areas of many western states. Ponds in high desert country with these characteristics often require close attention to oxygen levels during periods of hot weather.

Pond Stratification

Pond temperature stratification is a phenomenon that can be detected when diving into a large pond or lake. The water temperature may drop drastically within a few feet of the surface. In contrast, a well-mixed pond will have an almost uniform temperature gradient when measured from the surface to the bottom. Pond temperature stratification often occurs when the surface water is heated or chilled. For example, a pond may undergo temperature stratification in summer months as radiant heat from the sun warms the surface water. From the surface down to a significant depth there is little change in water temperature, yet in the next few inches or feet, the water temperature drops rapidly, then stabilizes to a lower temperature range as the bottom is reached (Figure 3).

Figure 3. Diagrammatic representation of temperature stratification in a pond.



In Figure 3, the warmer, lighter water rests on top of the denser, colder water that lies closer to the bottom. The narrow band that separates the two masses of water in which the rapid change in temperature occurs is called the thermocline. The thermocline can become an actual barrier to circulation between the upper and lower levels of the pond and can even prevent the movement of oxygen and nutrients between the top and bottom of the pond. Similar phenomena exhibiting greater scales of depth occur in larger bodies of water such as lakes and seas.

Pond stratification can be disrupted by rapid changes in temperature and strong winds; two events that occur regularly in the spring and late fall. The physical action of strong winds can cause mixing of water at the surface with the water at lower levels. Cold temperatures can chill the surface water to a temperature lower than that found at lower depths, causing it to become more dense and sink to the bottom. One term for this event is called “turnover”. Pond turnover is a seasonal event in healthy ponds that redistributes nutrients in the pond.

Oxygen depletion can result if a substantial phytoplankton bloom exists at turnover. A combination of the effects of cold water, and the current that carries the phytoplankton to the bottom which is usually devoid of sunlight, causes the phytoplankton to die. Oxygen concentration is lowered as the dead algae decompose by a chemical process that removes oxygen from the water. In addition, oxygen-depleted water near the bottom rises and mixes with the water near the surface thereby lowering the overall oxygen concentration in the pond.

Oxygen Problems Caused By Algal Blooms

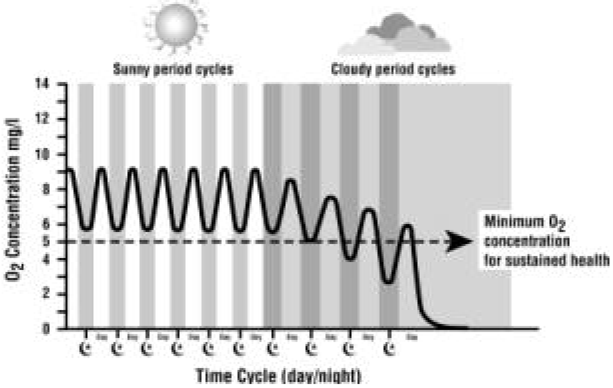
Although the algal bloom benefits the life in the pond, it must be controlled or will result in the loss of aquatic animals such as fish and crustaceans. Oxygen problems in warmwater ponds often occur when the microscopic algae are either absent or overly abundant. If the phytoplankton is absent, there may not be enough oxygen produced from other sources such as wind and/or macrophytes in the pond to support a good population of fish. However, if an algal bloom becomes excessive, it often has three pronounced negative effects on the oxygen concentration and animal life in a pond.

The first negative effect of excessive phytoplankton in a pond is the result of the cyclic events of algal respiration that occur over a 24-hour period. An excessive algal bloom will produce an abundance of oxygen during the day, often resulting in at- or near-saturation of oxygen in the water. At night, however, the same excessive algal bloom consumes a near equal quantity of oxygen during dark phase respiration. The oxygen concentration in the pond may drop to a level that causes stress or death in a population of fish. This often occurs at night or during the early morning hours before the algae can replace the lost oxygen through photosynthesis. This may be complicated by several days of cloudy weather that reduce the level of daytime photosynthesis. Nighttime respiration will continue at the same rate with lower oxygen levels in the pond, but there will not be enough daytime photosynthesis for the oxygen to be replaced (Figure 4).

Oxygen depletion resulting in fish stress and loss is a common occurrence in ponds during the hot summer months as the pond heats up and reduces the oxygen holding capacity of the water. If this occurs along with an excessive algal bloom and/or cloudy weather, oxygen loss is usually significant, and the onset of oxygen depletion is rapid.

A second common effect of an excessive bloom on a pond is sudden death of the phytoplankton population. This can occur for a number of reasons including depletion of nutrients used by the algae, a seasonal change in water temperature, high winds that turn over the water in the pond, rapidly chilling of the surface waters, and destruction of the phytoplankton bloom with algaecides during periods of hot weather. Although individual members of the phytoplankton community are microscopic, the sum total of the community makes up a large biomass in the water. If the phytoplankton biomass is suddenly killed, it will sink to the pond bottom and rapidly decompose. The BOD created by bacteria decomposing a high-density phytoplankton community is significant. The combination of the absence of an oxygen producing plant community and the additional BOD that results from a decomposing algal population can strip enough oxygen from the water to kill a fish population.

Figure 4. Diagrammatic representation of oxygen concentration in a pond as it is affected by the day/night cycle, density of phytoplankton and an event of phytoplankton death.



The third negative effect that excessive algal blooms can have on ponds and fish populations is production of near or at saturation levels of oxygen in the upper level of the pond. If the pond then stratifies, it can produce a saturated level of oxygen in the surface water and an oxygen-depleted layer in the middle and lower levels (e.g. 20 ppm at the surface and >1.0 ppm below). This may force the fish to the surface where they can become easy prey for birds.

A healthy warmwater pond will have a phytoplankton bloom that provides the pond a minimum oxygen concentration of 5.0 ppm in a sample taken just off the bottom of the deep end of the pond right before daylight. The bloom provides a balance between daytime oxygen production and nighttime oxygen consumption. Water samples can be taken from the bottom of the pond and oxygen concentrations determined using any commercially available water monitoring kit.

Monitoring the Algal Bloom

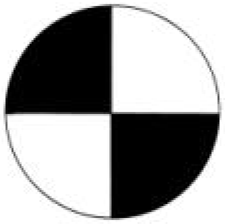
Pond color is an indication of the presence of phytoplankton in warmwater ponds. The color is caused by sunlight reflecting from the phytoplankton population, and color can range from shades of green through golden-brown. The color produced by the algae will depend on factors such as the predominant species of algae present, the age of the bloom, and the condition of the algae. Algal blooms usually consist of a mixed population of a number of algal species. The color of the pond may change gradually, reflecting a succession of dominant species.

Algal blooms are monitored by visual observation and by measuring the turbidity of the water caused by the phytoplankton. This should not be confused with turbidity caused by minute clay particles in the water. Clay turbidity is usually milky-gray in color, and if in colloidal suspension, will not settle out in a water sample. Excessive turbidity caused by the presence of colloidal clay in a pond can block light penetration and retard or prevent the formation of an algal bloom. Steps should be taken to prevent the ongoing problem and/or to clear the pond of the clay.

Hand Monitoring: A quick method for estimating the density of the algae bloom is to submerge your arm in the water and use it as a reflective surface. It is not as accurate as the Secchi disk method described below, but can be used as a quick measurement. The observer's hand is lowered into the water to about elbow-level. The hand is then flexed so that the palm is facing upward and horizontal to the surface of the water. If the pond has a healthy bloom the fingers may appear hazy, but visible when moved. If the fingers are not visible, the bloom is probably becoming too dense. Variations in arm length and differences in vision between individuals will affect the determination, but common sense should be employed. A hand is not as visible as a Secchi disk, and the hand test is only a good indicator of heavy blooms. In a healthy pond the visible distance of a hand is about 12 to 20 inches (30.5 to 50.8 cm). Distance between the elbow and the hand of a moderate-sized arm is about 12 inches, and the distance from the shoulder to the hand is about 20 inches.

Secchi Disk Monitoring: A more accurate and consistent procedure for monitoring an algal bloom can be accomplished with a Secchi disk attached to the end of a pole or weighted and attached at the end of a line. The Secchi disk is a 20-cm diameter flat plate that is colored with alternating black and white quarters, and is used to determine the depth of light penetration of water (Figure 5). The disk is usually attached to a calibrated pole or to a line by a centered ring so that when it is lowered into the water the surface of the plate is horizontal to the surface of the water. The disk is used to determine a Secchi Disk Average (SDA), which is an average light penetration measurement used in data to determine condition of a body of water.

Figure 5. Diagrammatic representation of the surface pattern of a Secchi disk used to estimate water turbidity and phytoplankton density.



For the purpose of estimating algal density in a pond, a modified and simplified application of the same principle is appropriate. Because our use of the disk is simply to estimate the relative density of an algal bloom as being either to heavy or too light one can eliminate the concept of establishing an SDA and use a less sophisticated approach.

Secchi Disk for Determining Algal Density: A Secchi disk can be made from an 8-inch disk of a material such as wood, metal or plastic. The disk is attached to the end of a pole, which is marked in 1-inch increments starting at the surface of the disk. The pole may be attached in the center of the disk, or at one edge of the disk to improve visibility. The pole is marked with a highly visible band at the 12-, 18-, and 24-inch marks. The marks are used to indicate the level of light penetration, and readings should be recorded to learn how the pond responds seasonally to changes in algal concentration. Ponds with high levels of suspended clay will give inaccurate readings.

Taking a Secchi Disk Reading: Secchi disk readings will be different among individuals performing the measurements. To reduce this type of error, the readings should be taken by one person using standardized procedures. Measurements should be made from the lee-side of a boat or pier, in open sunlight and with the sun behind the observer. Observations should be taken at the same time of day between 9:00 AM and 3:00 PM. Readings taken at different times of day and under different weather conditions more often result in error (Table 1).

Light penetrating to depths greater than 24 inches indicates an inadequate algal bloom. Light penetrating less than 18 inches is becoming dense and should be closely monitored. As the reading approaches 12 inches, monitoring should be increased and freshwater flushed through the pond to remove some of the algae. A measurement of 6 to 12 inches represents an excessive bloom, and flushing should be increased along with nighttime aeration to counter oxygen depletion. The most effective methods are water exchanges using fresh oxygenated water and supplementary aeration. Readings less than 6 inches indicate a critical condition, possibly resulting in an algal die-off leading to total oxygen depletion and a fish kill. Maximum flushing and supplementary aeration should be implemented until the crisis has passed.

Preparation for Oxygen Depletion

If an algal bloom seems to be approaching excessive, steps should be taken to lessen the problem and preparations made to provide supplemental oxygen if conditions worsen. Flushing the pond with a supply of fresh water can reduce the density of an algal bloom. If oxygen concentrations continue to drop in the pre-dawn hours, supplemental oxygen should be provided to the pond.

Supplemental oxygen can be provided using a number of methods including spraying water from the surface back over the pond with a suction pump and with mechanical aeration devices such as paddlewheels and air injection pumps. Aerators

Table 1. Secchi disk readings, relative condition of the algal bloom, and management recommendations (Modified from Masser and Wurts, 1992).

Secchi Disk Reading	Condition of Bloom	Pond Recommendation
Greater than 24-inches	Inadequate	Fertilize pond
18 to 24-inches	Healthy	Continue monitoring
12 to 18-inches	Dense	Increase monitoring and periodic flushing
6 to 12-inches	Excessive	Flush with water, aerate, and find cause
Less than 6-inches	Critical	Maximum flushing and increase aeration

that float at the pond's surface and use a spinning propeller to splatter the water into the air are good for maintaining oxygen in a pond, but they are not an effective emergency technique for adding oxygen. During an oxygen crisis more aggressive methods are needed. Commercial fish farms use tractor driven paddle wheel aerators and air injector pumps that force a massive infusion of oxygen into the water. However, these mechanisms are often not affordable to recreational pond owners

A more common technique used by recreational pond owners is to use a suction pump that sprays water back over the surface of the pond. In this instance, the intake hose should be floated about a foot below the water surface because the water at the bottom of the pond will be devoid of oxygen and if drawn up will compromise the water at the surface. By taking water near the surface, the spray-back action improves the oxygen content near the surface. Fish will migrate to the area of improved water quality. As the spray-back action continued, the improved zone gradually spreads to the rest of the pond. Pumping is maintained both day and night until the crisis is over, then only at night until the phytoplankton community reestablishes a bloom and begins manufacturing enough oxygen to support the pond.

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