2021 NCF-Envirothon Nebraska
Aquatic Ecology Study Resources

Key Topic #3: Wetland and Lake Ecology

7. Identify biological communities in a lake and describe their characteristics
8. Classify the different zones in a lake based on physical structure and explain these distinctions.
9. Define a wetland and describe its major characteristics.
10. Classify the different tropic levels in a lake and explain how energy moves from one level to the next.
11. Describe the effects of human impacts, such as increased nutrient loading and erosion, on aquatic ecosystems.

Study Resources

<u>Study Resources begin on the next page!</u> ➡

What is a Wetland?

United States Environmental Protection Agency, 2018

Definition of a Wetland

Wetlands are areas where water covers the soil, or is present either at or near the surface of the soil all year or for varying periods of time during the year, including during the growing season. Water saturation (hydrology) largely determines how the soil develops and the types of plant and animal communities living in and on the soil. Wetlands may support both aquatic and terrestrial species. The prolonged presence of water creates conditions that favor the growth of specially adapted plants (hydrophytes) and promote the development of characteristic wetland (hydric) soils.

Categories of Wetlands

Wetlands vary widely because of regional and local differences in soils, topography, climate, hydrology, water chemistry, vegetation and other factors, including human disturbance. Indeed, wetlands are found from the tundra to the tropics and on every continent except Antarctica. **Two general categories of wetlands are recognized: coastal or tidal wetlands and inland or non-tidal wetlands.**

<u>Coastal/Tidal Wetlands</u>

Coastal/tidal wetlands in the United States, as their name suggests, are found along the Atlantic, Pacific, Alaskan and Gulf coasts. They are closely linked to our nation's estuaries where sea water mixes with fresh water to form an environment of varying salinities. The salt water and the fluctuating water levels (due to tidal action) combine to create a rather difficult environment for most plants. Consequently, many shallow coastal areas are unvegetated mud flats or sand flats. Some plants, however, have successfully adapted to this environment. Certain grasses and grasslike plants that adapt to the saline conditions form the tidal salt marshes that are found along the Atlantic, Gulf, and Pacific coasts. Mangrove swamps, with salt-loving shrubs or trees, are common in tropical climates, such as in southern Florida and Puerto Rico. Some tidal freshwater wetlands form beyond the upper edges of tidal salt marshes where the influence of salt water ends.

<u>Inland/Non-tidal Wetlands</u>

Inland/non-tidal wetlands are most common on floodplains along rivers and streams (riparian wetlands), in isolated depressions surrounded by dry land (for example, playas, basins and "potholes"), along the margins of lakes and ponds, and in other low-lying areas where the groundwater intercepts the soil surface or where precipitation sufficiently saturates the soil (vernal pools and bogs). Inland wetlands include marshes and wet meadows dominated by herbaceous plants, swamps dominated by shrubs, and wooded swamps dominated by

trees. Certain types of inland wetlands are common to particular regions of the country. For more information, see Wetland Classifications and Types for a full list.
Many of these wetlands are seasonal (they are dry one or more seasons every year), and, particularly in the arid and semiarid West, may be wet only periodically. The quantity of water present and the timing of its presence in part determine the functions of a wetland and its role in the environment. Even wetlands that appear dry at times for significant parts of the year -- such as vernal pools-- often provide critical habitat for wildlife adapted to breeding exclusively in these areas.

For more information about wetlands, please visit our Wetland Factsheet Series. *(This is a supplementary resource if you would like to explore further.)*

Lake Ecology

Water on the Web, 2004

Density Stratification

In the spring, immediately after **ice-out** in **temperate** climates, the **water column** is cold and nearly **isothermal** with depth. The intense sunlight of spring is absorbed in the water column, which also **heats** up as the average daily temperature of the air increases. In the absence of wind, a **temperature profile** with depth might be expected to resemble Figure 2 (see the **Light section**), decreasing exponentially with depth. However, **density**, another physical characteristic of water, plays an important role in modifying this pattern.

Water differs from most other compounds because it is less dense as a solid than as a liquid. Consequently ice floats, while water at temperatures just above freezing sinks. As most compounds change from a liquid to a solid, the molecules become more tightly packed and consequently the compound is denser as a solid than as a liquid. Water, in contrast, is most dense at 4°C and becomes less dense at both higher and lower temperatures. The density/temperature relationship of fresh water is shown in Figure 3. Because of this density-temperature relationship, many lakes in temperate climates tend to stratify, that is, they separate into distinct layers.

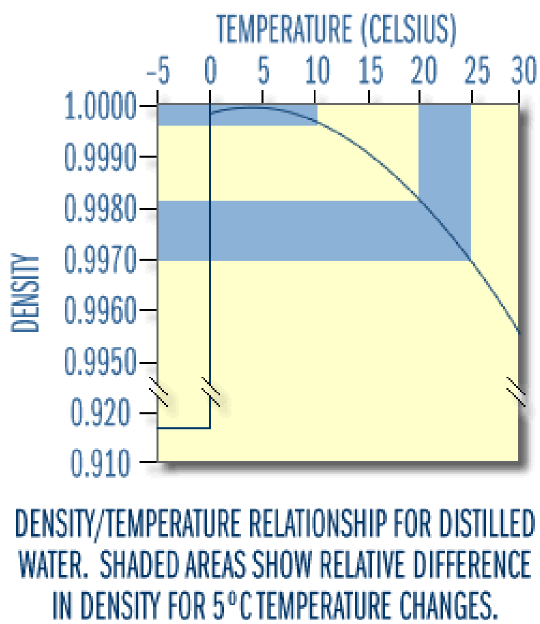

Figure 3

Spring

In lakes of the upper Midwest and at higher elevations, the water near a lake's bottom will usually be at 4°C just before the lake´s ice cover melts in the spring. Water above that layer will be cooler, approaching 0°C just under the ice. As the weather warms, the ice melts. When the temperature (density) of the surface water equals the bottom water, very little wind energy is needed to mix the lake completely. This is called **turnover**. After this **spring turnover**, the surface water continues to absorb heat and warms. As the temperature rises, the water becomes lighter than the water below. For a while winds may still mix the lake from bottom to top, but eventually the upper water becomes too warm and too buoyant to mix completely with the denser deeper water. As Figure 3 suggests, the relatively large differences in density at higher temperatures are very effective at preventing mixing. It simply takes too much energy to mix the water any deeper.

> It is useful to visualize a more extreme example of **density stratification**. Imagine a bottle of salad dressing containing vegetable oil and vinegar. The oil is lighter (more buoyant) than the vinegar which is mostly water. When you shake it up you are supplying the energy to overcome the buoyant force, so the two fluids can be uniformly mixed together. However, if allowed to stand undisturbed, the more buoyant (less dense) oil will float to the top and a two-layer system will develop.
>
> In some cases, such as happened at Ice Lake in April, 1998 and 1999, the surface water may warm up rapidly immediately after ice-out, causing the lake to stratify thermally without completely mixing. This prevents atmospheric oxygen from reaching the bottom waters. As a consequence, the entire water column never reaches 100% oxygen **saturation**. This can be observed for Ice Lake by comparing temperature and oxygen profiles from March 5, 1998 (still frozen), April 18, 1998 (the lake was completely ice-free on April 11, 1998), and April 30, 1998.

Summer

As summer progresses, the temperature (and density) differences between upper and lower water layers become more distinct. Deep lakes generally become physically **stratified** into three identifiable layers, known as the **epilimnion**, **metalimnion**, and **hypolimnion** (Figure 4). The epilimnion is the upper, warm layer, and is typically well mixed. Below the epilimnion is the metalimnion or **thermocline** region, a layer of water in which the temperature declines rapidly with depth. The hypolimnion is the bottom layer of colder water, isolated from the epilimnion by the metalimnion. The density change at the metalimnion acts as a physical barrier that prevents mixing of the upper and lower layers for several months during the summer.

The depth of mixing depends in part on the exposure of the lake to wind (its **fetch**), but is most closely related to the lake's size. Smaller to moderately-sized lakes (50 to 1000 acres) reasonably may be expected to stratify and be well mixed to a depth of 3–7 meters in north temperate climates. Larger lakes may be well mixed to a depth of 10–15 meters in summer (e.g., Western Lake Superior near Duluth, MN).

Note that although "thermocline" is a term often used synonymously with metalimnion, it is actually the plane or surface of maximum rate of decrease of temperature with respect to depth. Thus, the thermocline is the point of maximum temperature change within the metalimnion.

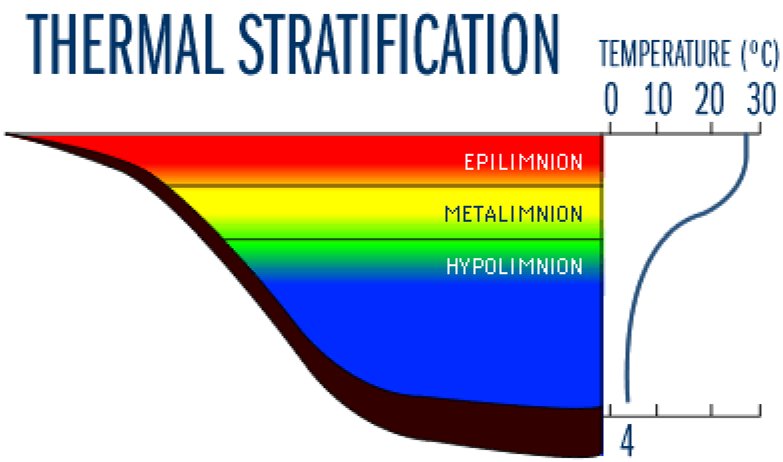

Figure 4

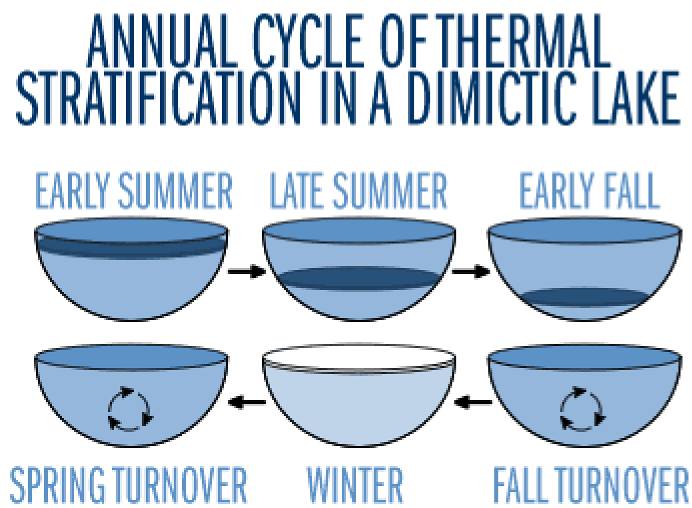

Figure 5

Autumn

As the weather cools during autumn, the **epilimnion** cools too, reducing the density difference between it and the **hypolimnion** (Figure 5). As time passes, winds mix the lake to greater depths, and the **thermocline** gradually deepens. When surface and bottom waters approach the same temperature and density, autumn winds can mix the entire lake; the lake is said to "turn over." As the atmosphere cools, the surface water continues to cool until it freezes. A less distinct density stratification than that seen in summer develops under the ice during winter. Most of the water column is isothermal at a temperature of 4°C, which is denser than the colder, lighter water just below the ice. In this case the **stratification** is much less stable, because the density difference between 0°C and 4°C water is quite small. However, the water column is isolated from wind-induced turbulence by its cap of ice. Therefore, the layering persists throughout the winter.

Here are some videos that demonstrate density stratification. (Our apologies for their quality.)

- **Movie 1** - Here's what happens when warmer water (green) enters the surface of a lake in winter. The second addition shows that the warm water is buoyant (less dense) than the cold water and therefore rises.
- **Movie 2** - Here's what happens when colder water enters a summer-stratified lake.
- **Movie 3** - Same as movie 2 without the dyed green epilimnion.
- **Movie 4** - See what happens to the epilimnion (mixed layer) and thermocline during a storm. Did the lake mix?
- **Movie 5** - Same as movie 4, but with increased turbulence. See what starts to happen when the class 5 tornado hits.
- **Movie 6** - Shows how stream sediment entering a lake or reservoir deposits its load. Why does some material stay in the upper layer and some crash to the bottom?
- **Movie 7** - An estuary is a 2-layer system with freshwater overlying salt water. Here we see how freshwater behaves when added to each layer.
- **Movie 8** - Same as movie 7, but here we introduce water that is saltier than the upper freshwater layer. Example: Hurricanes can "throw" huge amounts of saltwater into coastal lakes. What happens to this water and what might its impact be?

Overview

This pattern (spring turnover — summer stratification — fall turnover — winter stratification) is typical for **temperate** lakes. Lakes with this pattern of two mixing periods are referred to as **dimictic**. Many shallow lakes, however, do not stratify in the summer, or stratify for short periods only, throughout the summer. Lakes that stratify and destratify numerous times within a summer are known as **polymictic** lakes. Both polymictic and dimictic lakes are common in Minnesota.

> Since installing the RUSS unit in Ice Lake we have made an interesting observation. Spring turnover is incomplete. There was not enough mixing in spring, 1998 or 1999 to completely re-aerate the entire water column to 100% saturation. On the other hand, Lake Independence, a lake of comparable depth (15-18 meters) but much larger in size (more fetch) and less sheltered from the wind, mixed completely. We suspect that most aquatic scientists would not have expected to see Ice Lake's bottom water, nearly saturated with **oxygen** in fall, 1998, to be **anoxic** by mid-winter and then persist in this state until the following fall. Once stratified thermally in summer, even the barrage of severe thunderstorms that occurred near Ice Lake in summer, 1999,

lacked the energy to dramatically decrease the thermocline or increase the oxygen content of the hypolimnion. **Heat and Oxygen budget section of Ice Lake**.

It was cold and windy enough during fall, 1998 for Ice Lake to mix thoroughly, bringing oxygen to the bottom waters (to about 100% saturation). This is likely typical for Ice Lake during most autumns, although it is possible for a cold, calm period to allow the lake surface to freeze before the water column has been fully exposed to the atmosphere and re-charged with oxygen.

Visit the data files under **each lake page** or review the entire data set using the **Data Visualization Tools**.

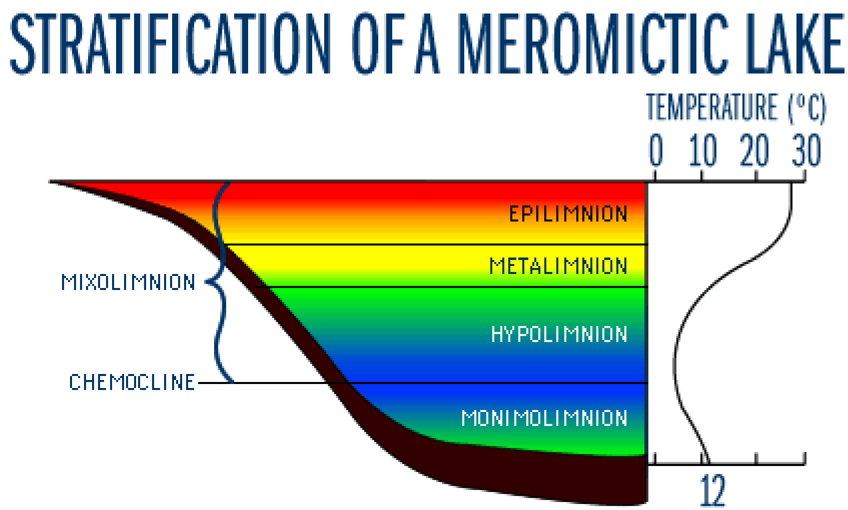

Figure 6

The West Upper Lake Station of Lake Minnetonka, Lake Independence and thousands of other Upper Midwestern lakes that are relatively deep (>10 meters) and reasonably large (>100-200 acres or 40-80 ha) are probably dimictic, leading to complete re-oxygenation of the water column for at least some period of time. Ice Lake, though small (41 acres or 16.6ha), is sheltered and deep (16 m) for its size. Lakes that have formed in former open pit mines in Northeastern Minnesota are unusually deep for their size. Lakes with these characteristics probably only mix completely once a year in the fall for a brief period before freezing. Some of the deeper mine pit lakes (>75 meters deep) probably never mix completely to the bottom, although data are sparse. Much less common are lakes that circulate incompletely resulting in a layer of bottom water that remains stagnant. To distinguish them from the **holomictic** (mixing from top to bottom) lakes, these partially mixing lakes are referred to as **meromictic**. They mix partially, in the sense that they may have extensive mixing periods which go quite deeply into the hypolimnion, but they do not turn over completely, and a layer of bottom water remains stagnant and anoxic for years at a time. The non-mixing bottom layer is known as the **monimolimnion** and is separated from the **mixolimnion** (the zone that mixes completely at least once a year) by the **chemocline** (Figure 6). The stagnant, and typically **anaerobic**, monimolimnion has a high concentration of dissolved solids compared to the mixolimnion. In general, meromictic lakes have large **relative depths**. These lakes are typically small and sheltered from the wind by the morphology of their **basin**. In this case, the density differences caused by temperature are smaller than density differences due to the high dissolved solids (salts) concentration of the monimolimnion. Large lakes that rarely freeze over are also typically monomictic, mixing throughout the fall, winter and spring and stratifying in the summer.

> To visualize this effect, try dissolving several tablespoons of table salt (NaCl) in hot water. Add a few drops of food coloring and then fill a mayonnaise jar half-full. Now, very gently add cool tap water with a small measuring cup to fill the glass. Set up a second jar half full with clear, cool water and then add the colored hot water to fill the glass - but don't add the salt. Compare the stability of the density stratification in the two systems by gently shaking or stirring the water columns.

Table 2

MIXING REGIME	**LAKES**	**MAX DEPTH (m)**	**AREA (acres/hectares)**
DIMICTIC (2mixes/yr)	**Lake Minnetonka** (Minneapolis, MN)	34	14,004 acres (5,670 ha)
	Grindstone Lake (Sandstone, MN)	46	500 acres (200 ha)
	Lake Independence (Minneapolis, MN)	18	850 acres (344 ha)
	Pike Lake (Duluth, MN)	18	500 acres (200 ha)
MONOMICTIC (1mix/yr – mixed all winter and spring)	**Lake Erie**	70	6.4 x 106 acres (2.6 x 106 ha)
	Lake Huron	228	14.8 x 106 acres (6.0 x 106 ha)
	Ice Lake* (Grand Rapids, MN)	16	41 acres (16.6 ha)
	Lake Michigan	281	14.4 x 106 acres (5.8 x 106 ha)
	Lake Ontario	244	4.9 x 106 acres (2.0 x 106 ha)
	Lake Superior	300	20.3 x 10^6 acres (8.2 x10^6 ha)
	Lake Tahoe (CA/NV)	499	123,253 acres (49,900 ha)
	Lake Mead (NV – largest US reservoir)	180	163,320 acres (66,096 ha)
POLYMICTIC (many mixes/yr)	Shallow lakes & ponds	< 4	wide range
	Mille Lacs Lake, MN	13	132,510 acres (53,648 ha)

	St. Louis River and Duluth-Superior Harbor	1-8	11,993 acres (4,856 ha)
MEROMICTIC (never totally mixed because of stagnant bottom layer)	**Miners Pit Lake** (Ely, MN)	48	138 acres (56 ha)
	Pennington Pit Lake, (Crosby, MN)	79	57 acres (23 ha)
	Brownie Lake (Minneapolis, MN)	15	18 acres (7.3 ha)
	Deming Lake (Itasca State Park, MN)	14	12.3 acres (5.0 ha)
	Big Soda Lake (Fallon, NV)	60	400 acres (160 ha)
* variable from year to year			

For additional information, Learn about ARCHIMEDES's principle at **EXPLORATORIUM** and a shockwave demonstration of **density and water displacement**

The Watershed

The **watershed**, also called the drainage **basin**, is all of the land and water areas that drain toward a particular river or lake. Thus, a watershed is defined in terms of the selected lake (or river). There can be subwatersheds within watersheds. For example, a **tributary** to a lake has its own watershed, which is part of the larger total drainage area to the lake.
A lake is a reflection of its watershed. More specifically, a lake reflects the watershed's size, **topography**, geology, **landuse**, soil fertility and erodibility, and vegetation. The impact of the watershed is evident in the relation of **nutrient loading** to the watershed:lake surface area ratio (Figure 7). See also the section on **conductivity**.

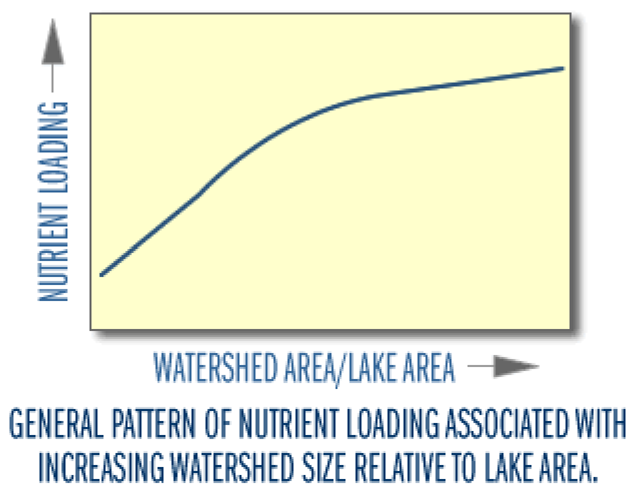

Figure 7

Typically, water quality decreases with an increasing ratio of **watershed area** to lake area. This is obvious when one considers that as the watershed to lake area increases there are additional sources (and volumes) of runoff to the lake. In larger watersheds, there is also a greater opportunity for water from precipitation to contact the soil and **leach** minerals before discharging into the lake. Lakes with very small watersheds that are maintained primarily by groundwater flow are known as **seepage lakes**. In contrast, lakes fed primarily by inflowing streams or rivers are known as **drainage lakes**. In keeping with the watershed:lake area relationship, seepage lakes tend to have good water quality compared with drainage lakes. However, lakes are often more susceptible to acidification from **acid rain** because of their low **buffering capacity**.

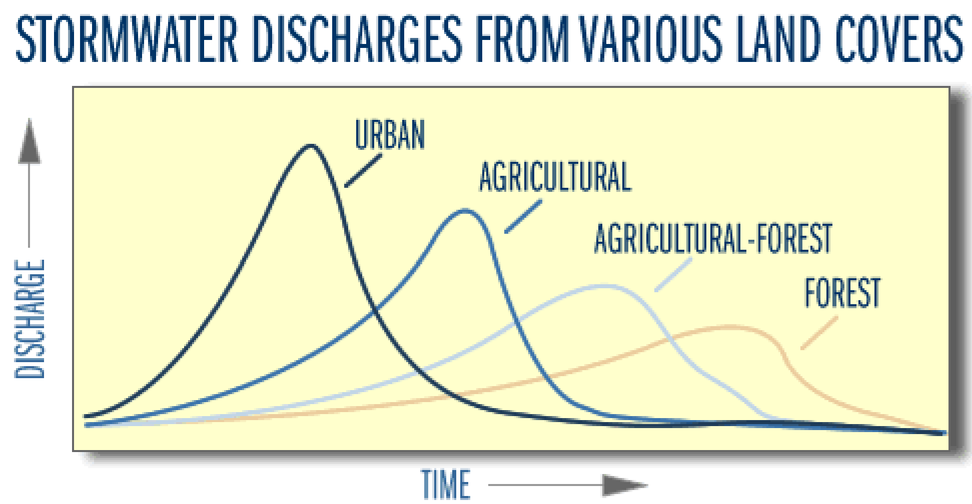

Figure 8

Landuse has an important impact on the quality and quantity of water entering a lake. As Figure 8 shows, the **stormwater discharge** to a lake differs greatly among landuses. In urban areas, the high proportion of **impervious surfaces** prevents absorbance of rainwater into the soil and increases the rate of surface water flow to the lake. The high **flushing rates** from urban areas can increase erosion of stream banks and provide sufficient force to carry large particles (i.e., soil) to the lake. Thus, water quantity affects water quality.

Additionally, as water flows over roads, parking lots and rooftops, it accumulates nutrients and contaminants in both dissolved and particulate form.

Table 3. Phosphorus export coefficients (from Reckhow and Simpson, 1980).			
	Phosphorus (kg/km^2yr)		
	HIGH	**MID**	**LOW**
Urban	500	80-300	50
Rural/Agriculture	300	40-170	10
Forest	45	14-30	2
Precipitation	60	20-50	15

Table 3 gives representative values of **export rates** of **phosphorus** from various landuses and other sources. Phosphorus is particularly important because its availability often controls the amount of algae and the overall **productivity** of a lake. These values are in units of $kg/km^2/yr$ (mass of phosphorus per unit area per year). Not included here, but also important, is the influence of soil type and slope. Finer particles and steeper slopes mean higher **export rates**. To clarify the relative landuse impacts, we can compare annual loads from 10 hectare (24 acre) plots of the selected landuses using the high export coefficients in Table 3.

Forest	4.5 kg phosphorus
Rural/Agriculture	30.0 kg phosphorus
Urban	50.0 kg phosphorus

One can see that, all other things being equal, converting a forest into a city can increase the phosphorus export to a lake more than ten times. Another way to look at these numbers is that almost seven years of **phosphorus** loading from a forested area can be deposited within one year by mixed agriculture areas and almost eleven years of phosphorus loading from a forested area can be deposited within a year from urbanized areas. A greater **loading rate** puts a greater strain on the system to assimilate the nutrients.

Dissolved Oxygen

Biological activity peaks during the spring and summer when photosynthetic activity is driven by high solar **radiation**. Furthermore, during the summer most lakes in **temperate** climates are **stratified**. The combination of **thermal stratification** and biological activity causes characteristic patterns in water chemistry. Figure 9 shows the typical seasonal changes in **dissolved oxygen** (DO) and temperature. The top scale in each graph is **oxygen** levels in mg O_2/L. The bottom scale is temperature in °C. In the spring and fall, both **oligotrophic** and **eutrophic** lakes tend to have uniform, well-mixed conditions throughout the **water column**. During summer **stratification**, the conditions in each layer diverge.

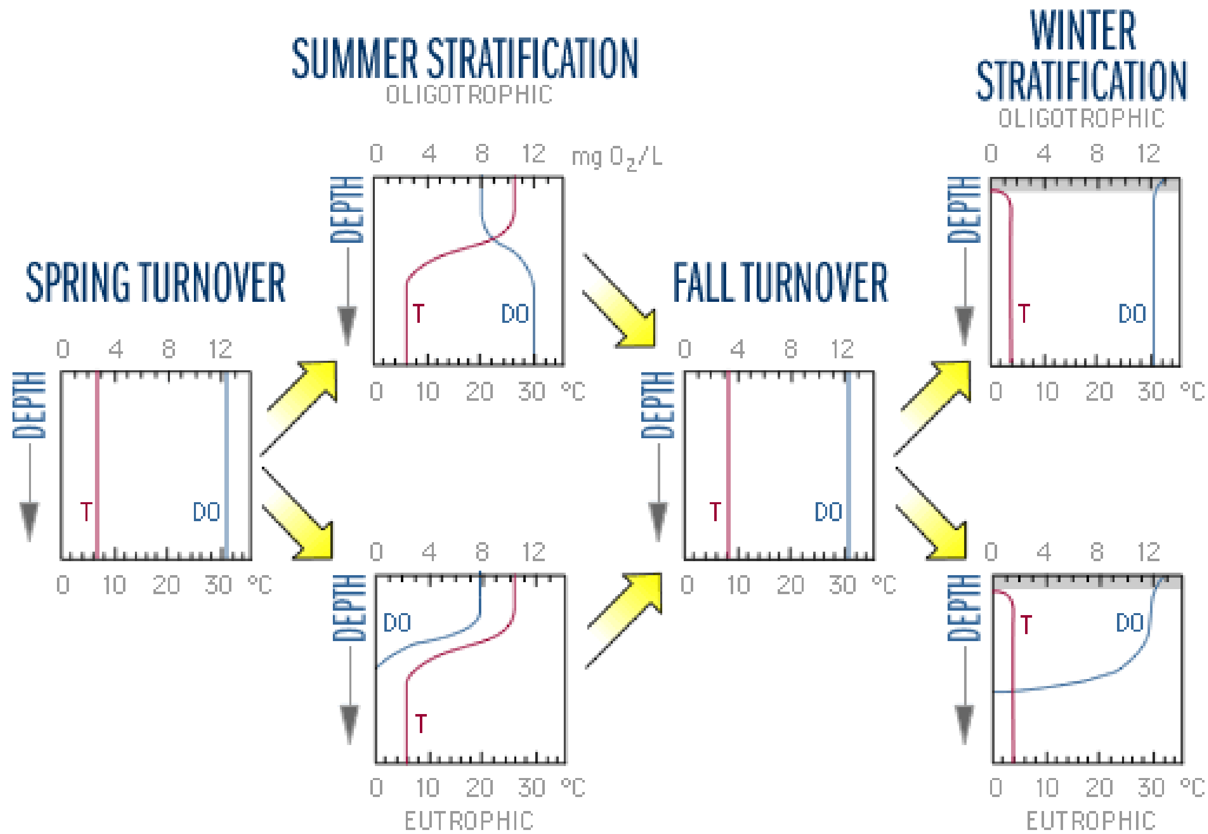

Figure 9 - *(adapted from Figure 8-1 in Wetzel, R.G. 1975. Limnology. W.B. Saunders Company)*

The **DO** concentration in the **epilimnion** remains high throughout the summer because of **photosynthesis** and **diffusion** from the atmosphere. However, conditions in the **hypolimnion** vary with **trophic** status. In eutrophic (more productive) lakes, hypolimnetic DO declines during the summer because it is cut-off from all sources of oxygen, while organisms continue to respire and consume oxygen. The bottom layer of the lake and even the entire hypolimnion may eventually become **anoxic**, that is, totally devoid of **oxygen**. In oligotrophic lakes, low algal **biomass** allows deeper light penetration and less **decomposition**. Algae are able to grow relatively deeper in the **water column** and less oxygen is consumed by decomposition. The DO concentrations may therefore increase with depth below the **thermocline** where colder water is "carrying" higher DO leftover from spring mixing (recall that oxygen is more soluble in colder water). In extremely deep, unproductive lakes such as Crater Lake, OR, Lake Tahoe, CA/NV, and Lake Superior, DO may persist at high concentrations, near 100% saturation, throughout the water column all year. These differences between eutrophic and oligotrophic lakes tend to disappear with fall **turnover** (Figure 9).

In the winter, oligotrophic lakes generally have uniform conditions. Ice-covered eutrophic lakes, however, may develop a winter stratification of dissolved oxygen. If there is little or no snow cover to block sunlight, **phytoplankton** and some **macrophytes** may continue to photosynthesize, resulting in a small increase in DO just below the ice. But as microorganisms continue to decompose material in the lower water column and in the sediments, they consume oxygen, and the DO is depleted. No oxygen input from the air occurs because of the ice cover, and, if snow covers the ice, it becomes too dark for photosynthesis. This condition can cause high fish mortality during the winter, known as "winter kill." Low DO in the water overlying the sediments can exacerbate water quality deterioration, because when the DO level drops below 1 mg O_2/L chemical processes at the sediment-water interface frequently cause release of **phosphorus** from the sediments into the water. When a lake mixes in the spring, this new phosphorus and ammonium that has built up in the bottom water fuels increased algal growth.

Nutrients

Aquatic organisms influence (and are influenced by) the chemistry of the surrounding environment. For example, **phytoplankton** extract nutrients from the water and **zooplankton** feed on phytoplankton. Nutrients are redistributed from the upper water to the lake bottom as the dead plankton gradually sink to lower depths and decompose. The redistribution is partially offset by the active vertical migration of the plankton.
In contrast to DO, essential nutrients such as the **bioavailable** forms of **phosphorus** and nitrogen (dissolved phosphate, nitrate, and ammonium) typically increase in the spring from snowmelt runoff and from the mixing of accumulated nutrients from the bottom during **spring turnover**. Concentrations typically decrease in the **epilimnion** during summer **stratification** as nutrients are taken up by algae and eventually transported to the **hypolimnion** when the algae die and settle out. During this period, any "new" input of nutrients into the upper water may trigger a "bloom" of algae. Such inputs may be from upstream tributaries after rainstorms, from die-offs of aquatic plants, from pulses of urban stormwater, direct runoff of lawn fertilizer, or from leaky lakeshore septic systems. In the absence of rain or snowmelt, an injection of nutrients may occur simply from high winds that mix a portion of the nutrient-enriched upper waters of the hypolimnion into the epilimnion. In less productive systems, such as those in Northeastern Minnesota, significant amounts of available nitrogen may be deposited during rainfall or snowfall events (**wet deposition**) and during the less obvious deposition of aerosols and dust particles (**dry deposition**). For instance, Lake Superior has been enriched by as much as 300 µg/L during this century, presumably due to air pollution. Nitrogen and phosphorus in dry fallout and wet precipitation may also come from dust, fine soil particles, and fertilizer from agricultural fields.

Biological

Lake Zones

A typical lake has distinct zones of biological communities linked to the physical structure of the lake (Figure 10). The **littoral** zone is the near shore area where sunlight penetrates all the way to the sediment and allows aquatic plants (**macrophytes**) to grow. Light levels of about 1% or less of surface values usually define this depth. The 1% light level also defines the **euphotic zone** of the lake, which is the layer from the surface down to the depth where light levels become too low for **photosynthesizers**. In most lakes, the sunlit euphotic zone occurs within the **epilimnion**.

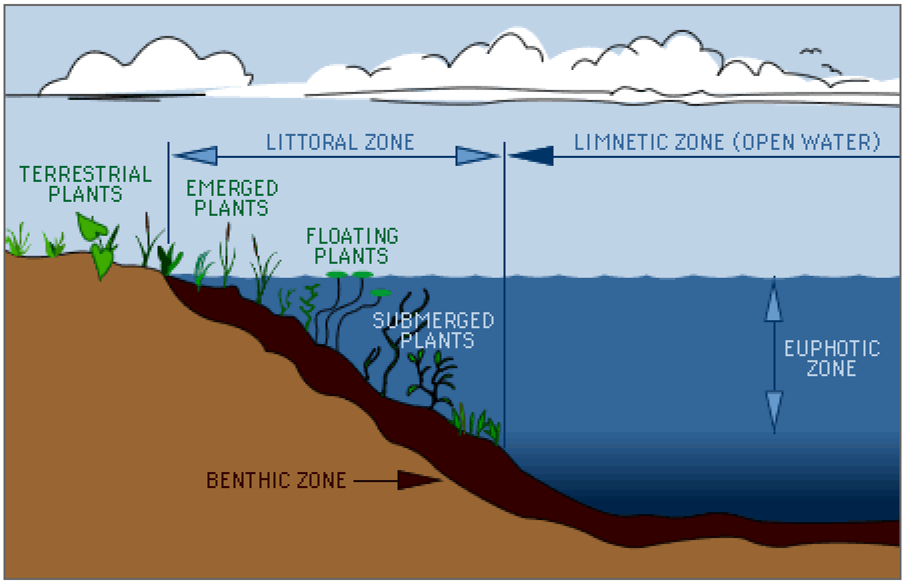

Figure 10

However, in unusually transparent lakes, **photosynthesis** may occur well below the **thermocline** into the perennially cold **hypolimnion**. For example, in western Lake Superior near Duluth, MN, summertime algal photosynthesis and growth can persist to depths of at least 25 meters, while the mixed layer, or **epilimnion**, only extends down to about 10 meters. Ultra-**oligotrophic** Lake Tahoe, CA/NV, is so transparent that algal growth historically extended to over 100 meters, though its mixed layer only extends to about 10 meters in summer. Unfortunately, inadequate management of the Lake Tahoe **basin** since about 1960 has led to a significant loss of transparency due to increased algal growth and increased sediment inputs from stream and **shoreline** erosion.

The higher plants in the littoral zone, in addition to being a food source and a **substrate** for algae and invertebrates, provide a habitat for fish and other organisms that is very different from the open water environment.

The **limnetic zone** is the open water area where light does not generally penetrate all the way to the bottom. The bottom sediment, known as the **benthic zone**, has a surface layer abundant with organisms. This upper layer of sediments may be mixed by the activity of the **benthic** organisms that live there, often to a depth of 2-5 cm (several inches) in rich **organic** sediments. Most of the organisms in the **benthic zone** are invertebrates, such as **Dipteran** insect larvae (midges, mosquitoes, black flies, etc.) or small crustaceans. The **productivity** of this zone largely depends upon the organic content of the sediment, the amount of physical structure, and in some cases upon the rate of fish predation. Sandy substrates contain relatively little organic matter (food) for organisms and poor protection from predatory fish. Higher plant growth is typically sparse in sandy sediment, because the sand is unstable and nutrient deficient. A rocky bottom has a high diversity of potential habitats offering protection (refuge) from predators, substrate for attached **algae** (**periphyton** on rocks), and pockets of organic "ooze" (food). A flat mucky bottom offers abundant food for benthic organisms but is less protected and may have a lower diversity of structural habitats, unless it is colonized by higher plants.

Lake Organisms

THOSE THAT GO WHERE THEY CHOOSE		
FISH	**AMPHIBIANS TURTLES**	**LARGER ZOOPLANKTON AND INSECTS**

THOSE THAT GO WHERE THE WATER TAKES THEM	
LIVING THINGS = PLANKTON animals - zooplankton algae - phytoplankton bacteria - bacterioplankton	**DEAD STUFF = DETRITUS** internal - produced within lake external - washed in from watershed

THOSE THAT LIVE ON THE LAKE BOTTOM		
BENTHOS = ANIMALS aquatic insects molluscs - clams, snails other invertebrates - worms, crayfish	**PLANTS** higher plants - macrophytes attached algae - periphyton	**BACTERIA & FUNGI** **sewage sludge** **aufwuchs** - mixture of algae, fungi and bacteria

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The Food Web

The biological communities within lakes may be organized conceptually into **food chains** and **food webs** to help us understand how the **ecosystem** functions (Figures 12 and 13). The simplest illustration of the organization of the organisms within an ecosystem is the **ecological pyramid** (Figure 14). The broad base of **primary producers** supports overlying levels of **herbivores** (**zooplankton**), **planktivores** and much smaller numbers of **carnivores** (predators). These individual **trophic** levels may be idealized as a food chain, but in fact many organisms are **omnivorous** and not necessarily characterized by a particular level. Further, **consumers** in particular often shift levels throughout their life cycle. For example, a larval fish may initially eat fine particulate material that includes **algae**, bacteria and detritus. Then it may switch and graze on larger zooplankton and ultimately end up feeding on so called "forage fish" or even young game fish (i.e., top predators) when it reaches maturity (Figure 13).

TYPICAL FOOD CHAIN

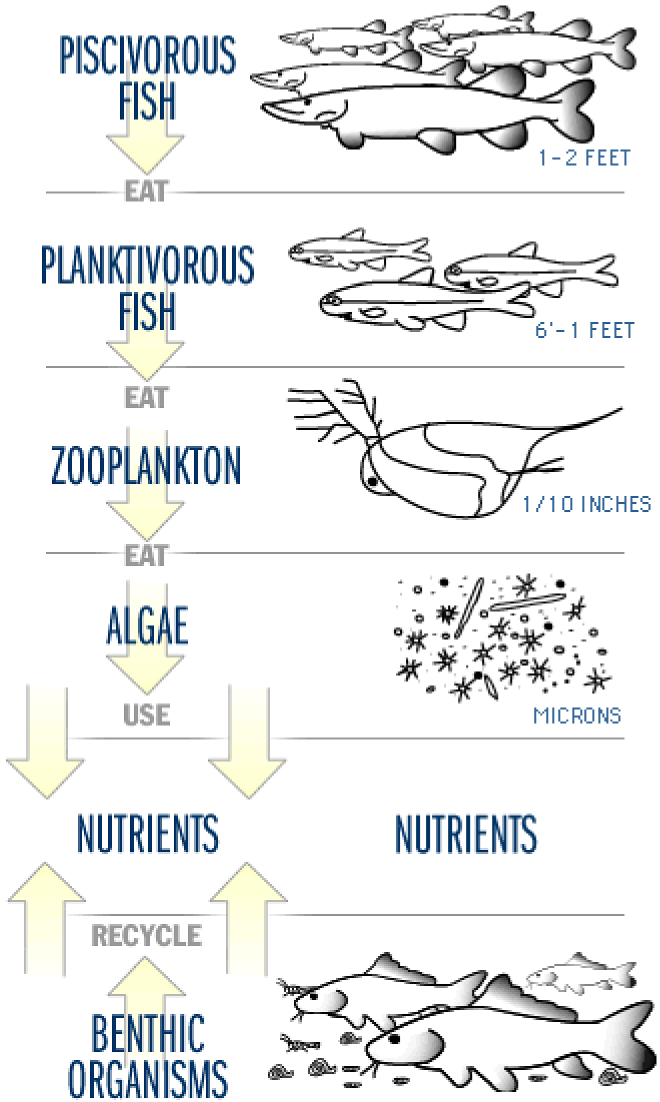


Figure 12

FOOD WEB FOR LAKE MEAD, NV

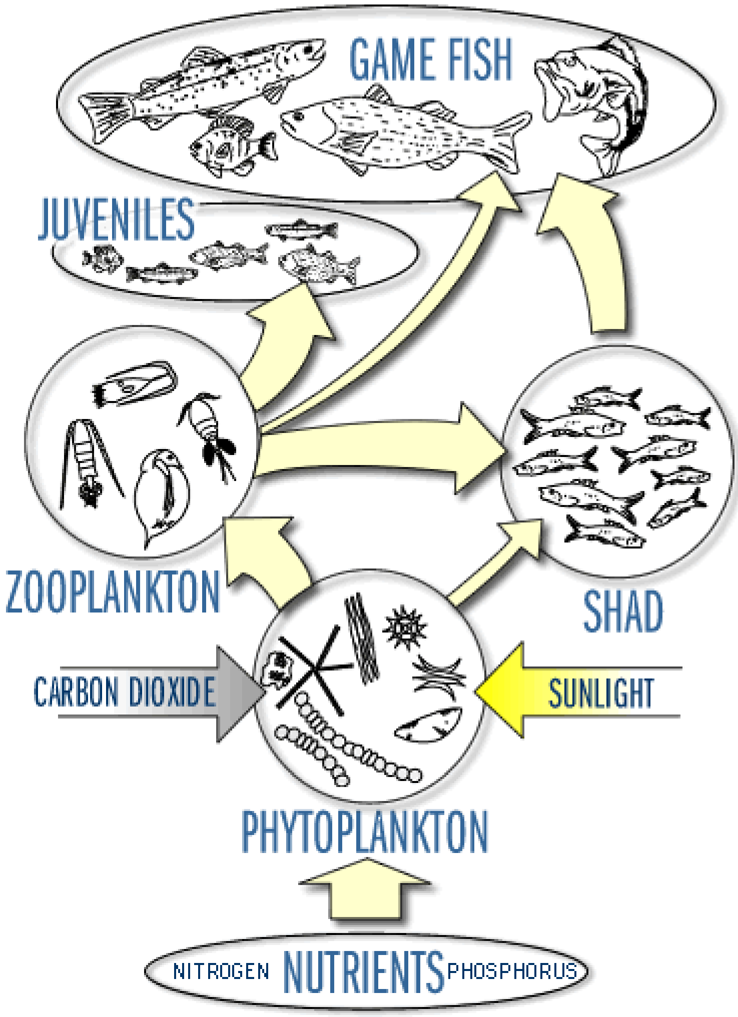


Figure 13

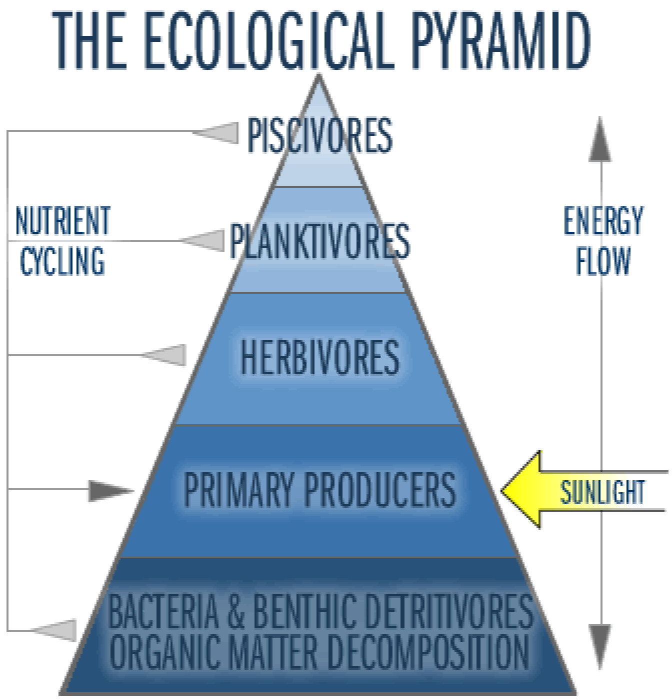


Figure 14

Food webs may be described in terms of both energy and nutrient (carbon, nitrogen or **phosphorus**) flows (Figure 15). Although the process typically begins with sunlight-driven **photosynthesis** by algae and plants, balanced nutrition is also required to sustain life. For example, we cannot live strictly on sugar, despite its high caloric content, irrespective of what our kids may argue.

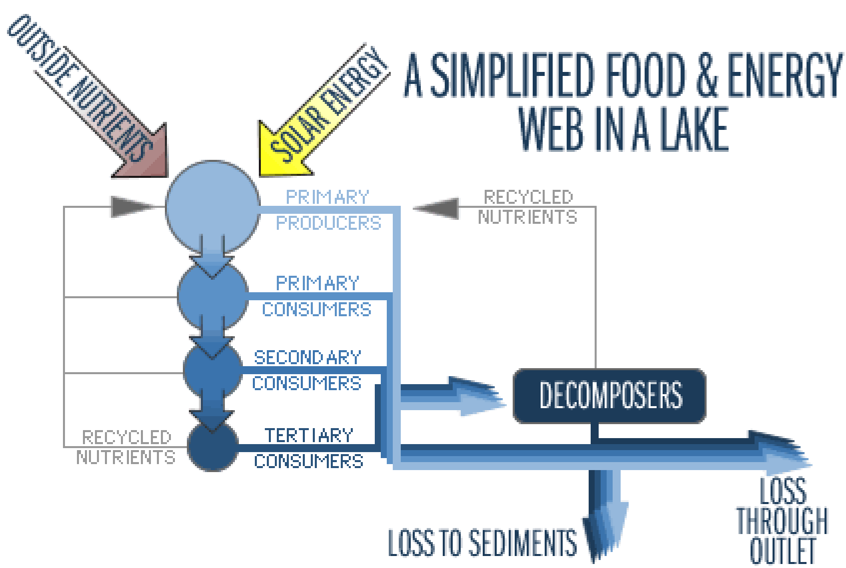


Figure 15

There are two basic life-sustaining processes in lakes, just as on land; **photosynthesis** and **respiration**. Green plants capture energy from sunlight to convert nonliving, **inorganic** chemicals (**carbon dioxide**, water, and mineral compounds) into living, **organic** plant tissue. Lake **photosynthesizers** include algae and **macrophytes**. Together, they are the primary producers, because they create the organic material required by most other organisms for nutrients and energy. Oxygen, the waste product of photosynthesis, adds to the **oxygen** supplied to the lake by the atmosphere. In water layers where photosynthetic rates are very high, such as during an algal bloom, the water may become supersaturated. That is, the oxygen content may exceed 100% of **saturation** with respect to the amount the water could hold if it was allowed to equilibrate with the atmosphere. This saturation value, in turn, depends on the temperature of the water. Colder water can hold more O_2 than warmer water. During periods of **stratification**, the only potential source of O_2 to the deeper zones of the lake is photosynthesis. This occurs only if light penetrates below the **thermocline**. In lakes where light does not penetrate below the **thermocline**, there is no internal source of oxygen to the deeper waters.

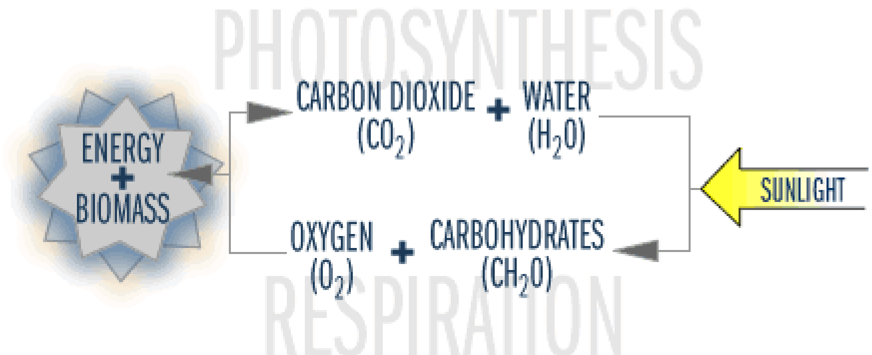


Figure 16

Besides light, algae and higher plants need oxygen, **carbon dioxide** (CO_2), and mineral nutrients to survive and grow. Except for a very few species of blue green algae, most are unable to survive in **anoxic** (no O_2) water. CO_2 is virtually always available and comes from the **weathering** of carbonate rocks, such as limestone, in the watershed, **diffusion** from the atmosphere (very important in **softwater**, **acid rain** sensitive lakes), and from the respiration of organic matter by all of the organisms in the lake (see below). Dissolved mineral nutrients are absorbed from the water by algae and from the water and the sediments by higher plants.

Typically, the most important nutrients are phosphorus and nitrogen, because they are present in very low concentrations unless there are sources of pollution (see **trophic state** section) and are typically low enough to limit the growth of algae. Other minerals essential to life, such as the major ions (calcium, magnesium, sodium, and potassium) and certain trace metals (iron, cobalt, molybdenum, manganese, copper, boron, and zinc), are usually present at sufficient concentrations. Silicon is required by **diatoms** and a few other groups of algae and is usually, though not always, present at sufficient levels. Another mineral required by all living things, sulfur (in the form of sulfate), is typically not deficient in lakes.

The whole interaction of photosynthesis and respiration by plants, animals, and microorganisms represents the food web. Food webs are usually very complex and, in any one lake ecosystem, hundreds of different species can be involved. Because the available energy decreases at each trophic level, a large food base of primary producers (mostly plants) is necessary to support relatively few large fish.

These plants may die and decompose or be eaten by **primary consumers** – the second trophic level. This link in the food chain typically involves zooplankton grazing on algae but also includes larval fish eating zooplankton and a variety of invertebrates that eat attached algae (**periphyton**) and higher plants. Other animals, such as small fish, **secondary consumers** (third trophic level) eat the primary consumers and thus are considered secondary consumers. Still larger consumers such as large fish, ospreys, and people are **tertiary consumers** (fourth trophic level). Thus, energy and nutrients originating from the photosynthetic production of **biomass** and energy cascade through the food web (Figure 15). There is some recycling of nutrients back up to the top of the cascade. Respiration, the oxidation of organic material, releases the energy that was originally captured from sunlight by photosynthesis. Both plants and animals respire to sustain their lives, and in doing so, consume oxygen. Microorganisms (bacteria and fungi) consume a large fraction of available oxygen in the **decomposition** of excreted and dead organic material.

Decomposers are sinks for plant and animal wastes, but they also recycle nutrients for photosynthesis. The amount of dead material in a lake far exceeds the living material. Detritus is the organic fraction of the dead material, and can be in the form of small fragments of plants and animals or as dissolved organic material. In recent years, scientists have recognized that zooplankton grazing on **detritus** and its associated bacterial community represent an additional important trophic pathway in lakes.

Primary Producers

Much of modern limnological study revolves around the **primary productivity** of lakes. The ecology of plant growth is of great importance to the character and history of lakes and to all other organisms that live in lakes. The major threat to lakes involves the excessive growth of primary producers due to nutrient inputs caused by poor **landuse** management. Therefore, it is worth a closer look at these organisms.
The **littoral** zone is defined by the growth of rooted and floating aquatic plants, or **macrophytes**. Figure 17 provides examples of common macrophytes found in Minnesota lakes. The macrophyte community can also include large **algae**, such as *Chara,Nitelle,*or*Cladophora.*In shallow, clear lakes, macrophytes may represent most of the green plant material present and may account for most of the **photosynthesis**.

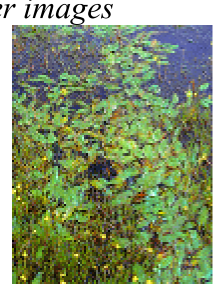
SOME COMMON MACROPHYTES

click on the photos to see larger images

FLOATING

WATER LILY
Nymphaea

DUCKWEED
Spirodela



PONDWEED
Potamogeton

SUBMERGENT

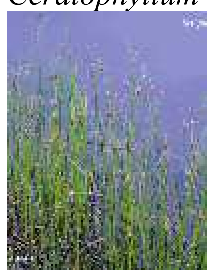
STONEWORT
Chara

COONTAIL
Ceratophyllum

BLADDERWORT
Utricularia

EMERGENT

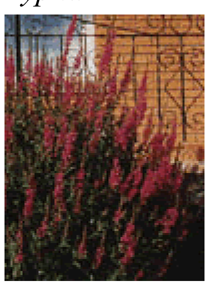
CATTAIL
Typha



BULRUSH
Scirpus

WILD RICE
Zizania

EXOTICS



PURPLE LOOSESTRIFE
Lythrum salicaria

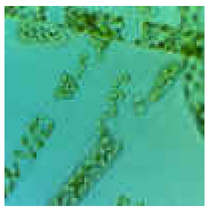
EURASIAN WATER MILFOIL
Myriophyllum spicatum

Figure 17
Photos from the ***University of Florida's Aquatic, Wetland, and Invasive Plant Information Retrieval System***

There may be few macrophytes in a lake when the bottom is too rocky or too sandy for the plants to anchor themselves, wave action too severe, or the water too deep. Also, sunlight may not reach the bottom even in shallow areas if the concentration of algae or silt is high.
Algae constitute the other main group of primary producers (Figure 18). They come in countless forms and live in nearly all kinds of environments. Most are microscopic, growing as single cells, small colonies, or filaments of cells. Suspended algae are called **phytoplankton**, while attached algae are called **periphyton**. Phytoplankton grow suspended in open water by taking up nutrients from the water and energy from sunlight. If their populations are dense, the water will become noticeably green or brown and will have low transparency.

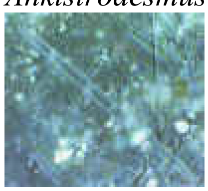
ALGAL PHOTOS
click on the photos to see larger images


Ankistrodesmus

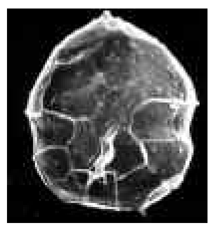

Spirogyra


Fragillaria


Microcystis


Synedra


Dinobryon


Peridinium


Oscillatoria


Cryptomonas


Anabaena

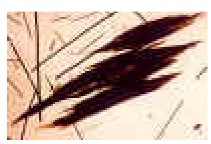

Aphanizomenon

Figure 18
*Images courtesy of the **Susquehanna University Algal Image Archive and Cyanosite** (Purdue University).*

Phytoplankton are classified into groups by the type of pigments they use to perform photosynthesis. While **chlorophyll**-a is common to all groups there are many other accessory pigments that allow the algae to capture different types of light. Green algae are considered the most closely related to higher plants. Within this group alone there is a great diversity of size, shape, and growth form (single celled, colonial, filamentous, and flagellated). **Diatoms** belong to a large group, classified as the golden-brown algae, which also includes chrysophytes and dinoflagellates. The most striking characteristic of diatoms and chrysophytes is the ability to form silica (glass) cell walls. **Diatoms** cell walls are similar to a **petri dish**, having two halves that fit together. Some chrysophytes have elaborate silica scales, spines, or vase-like shells called **loricas**. Diatoms are **non-motile** (unable to swim), so they depend on water turbulence to remain suspended. Chrysophytes have **flagella** (whip-like appendages) that allow them to control their position in the **water column**. There are other important algal groups containing **motile** forms.

Dinoflagellates are another group of golden-brown algae that also have flagella. These cells are capable of moving very rapidly; positioning themselves where light and nutrients are optimal for growth. Another flagellated group called the cryptomonads are very small algae and contain pigments that enable them to photosynthesize under very low light conditions, either very deep in the water column or during those times of the year when sunlight isn't very strong. Blue-green "algae" are technically referred to as **cyanobacteria** since, except for their chlorophyll-based photosynthesis, they are bacteria. They generally receive the greatest amount of research and management attention because of their ability to form **nuisance blooms** in **eutrophic lakes**. It is important to remember, however, that blue-green algae are very important primary producers in both freshwater and marine systems, despite often being a nuisance.

Blue-greens have several characteristics that often enable them to dominate and create nuisance or noxious conditions. Some blue-green species have the ability to adjust their buoyancy. They can float or sink depending on light conditions and nutrient supply. All plants, including all algae, typically satisfy their nitrogen requirement by absorbing nitrate (NO_3^-) and/or ammonium (NH_4^+) from the water. However, some blue-greens can **fix** molecular nitrogen (N_2) derived from the atmosphere and dissolved in the water and convert it to ammonium in the cell through a process called **nitrogen fixation**. This allows them to maintain high rates of growth when other forms of nitrogen are sufficiently depleted to limit growth by other types of algae. Blue-green algae typically are well-adapted to **phosphorus** deficiency because of their ability to absorb and store excess phosphorus when it is available -- enough to last days to weeks in some cases.

Unlike the green algae and diatoms, the blue-green algae are less suitable food for **primary consumers**. This is partly because some blue-greens can form large colonies of cells embedded in a gelatinous matrix which may pose handling problems for **grazers**. They also may produce chemicals that inhibit grazers or makes them "taste bad" to the grazers. Consequently, blue-greens have advantages over other algae at using nutrient and light resources, as well as avoiding being eaten.

Aphanizomenon flos-aquae is a common species of filamentous blue-green algae (see Figure 18) with the ability to regulate its buoyancy, fix nitrogen, form large inedible colonies, and form algal blooms. Other common bloom genera are *Anabaena* (N_2-fixing filamentous algae) and *Microcystis* (colonial; not a N_2-fixer). These bloom-forming algae are known to produce toxins in farm ponds that can poison cattle and, more recently, have been found to produce potent neurotoxins and hepatotoxins that may be a greater public health concern than previously realized.

Chlorophyll-a Measure of Algae

An in-depth microscopic enumeration of the dozens of species of **algae** present in a **water column** each time a lake is sampled is prohibitively costly and technically impossible for most monitoring programs. Further, in many lakes a large portion of the algal **biomass** may be unidentifiable by most experts (these are appropriately called LRGTs or LRBGTs -- little round green things and little round blue-green things). However, measuring the concentration of **chlorophyll**-a is much easier and provides a reasonable estimate of algal biomass. Chlorophyll-a is the green pigment that is responsible for a plant's ability to convert sunlight into the chemical energy needed to **fix** CO_2 into carbohydrates. To measure chlorophyll-a, a volume of water from a particular depth is filtered through a fine glass-fiber filter to collect all of the particulate material greater than about 1 micron (1/1000th of a millimeter) in size. The chlorophyll-a in this material is then extracted with a **solvent** (acetone or alcohol) and quantified using a spectrophotometer or a fluorometer.

> Note regarding Water on the Web: Although the RUSS units do not currently have chlorophyll sensors, a prototype sensor is being developed by Apprise Technologies, Inc. and the **Natural Resources Research Institute** at the University of Minnesota Duluth. In the interim, surface water (0-2 meter composites) values of chlorophyll-a are being determined at 2-4 week intervals at Ice Lake and Grindstone Lake (by NRRI) and at two week intervals at Lakes Independence and Minnetonka during the ice-free season (by **Hennepin Parks Natural Resources**). These data, along with secchi disk depth data and ancillary nutrient data are posted on the WOW Web site as they become available (**Data/Other**).

Both chlorophyll-a and secchi depth are long-accepted methods for estimating the amount of algae in lakes. Secchi depth is much easier and less expensive to determine. However, care must be used in interpreting secchi data because of the potential influence of non-algal particulate material, such as silt from stream discharge or re-suspended bottom sediment. Also, the tea color of some lakes that's due to dissolved organic matter from bogs, can have an effect on secchi depth readings as well. Even if chlorophyll-a is measured, it may be important to also examine the algal community microscopically on occasion, since the mix of species may influence lake management decisions.

Algal Succession

A lake's biological characteristics are determined in large part by physical characteristics of the **water column**. Important physical characteristics include temperature, light transparency, and wave action, as well as the total abundance of **inorganic** nutrients, which is largely a watershed characteristic. In addition, preceding populations influence successive populations by assimilating critical nutrients. Populations also have varying susceptibilities to grazing by **zooplankton**, which vary seasonally in type and abundance. As physical, chemical, and biological conditions in the lake change over time, some species will be effectively eliminated from a lake because they cannot tolerate the new conditions. Other species will be out-competed by organisms that are better adapted to the new environment.

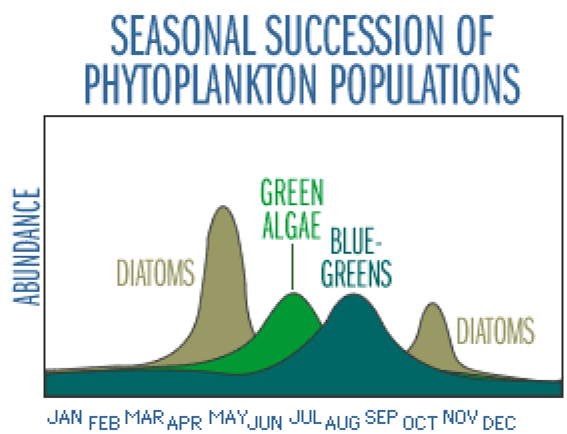


Figure 19

These changes represent an important ecological pattern in lakes known as algal succession. In most natural systems the seasonal succession of **algae** (and macrophytes) is a recurrent, if not exactly repetitive, yearly cycle. A typical algal succession is shown in Figure 19. Some species flourish for a period of time and then give way to other species more compatible with changed conditions, such as warmer water, more daylight, or lower concentrations of **phosphorus** or nitrogen. Short-lived plankton communities are characterized by these seasonal fluctuations; longer-lived organisms, such as fish, must be tolerant of lake conditions all year.

Consumers

Zooplankton, small animals that swim about in open water (Figure 20), are **primary consumers**. They graze on **algae**, bacteria, and **detritus** (partially decayed **organic** material). Some species can be seen with the naked eye, although they are more easily observed with a hand lens or low-power microscopes. If you wish to see them, stare into the water of a pond or lake on a calm night with a flashlight beam shining from above.
Secondary consumers, such as planktivorous fish or predaceous invertebrates, eat **zooplankton**. While **photosynthesis** limits plant growth to the sunlit portions of lakes, **consumers** can live and

grow in all lake zones, although the lack of **oxygen** (**anoxia**) may limit their abundance in bottom waters and sediments.

ZOO PLANKTON

click on the photos to see larger images

Daphnia Pulicaria

Diaptomus

Keratella (right imange)

Chaoborus

Figure 20

Images courtesy of University of Minnesota Limnology

Benthic organisms are major consumers and are also important recyclers of nutrients otherwise trapped in the sediments. **Benthic** organisms include invertebrates and bottom-feeding fish. Their feeding strategies vary widely. Some, such as clams, filter small bits of organic material from water as it flows by. Others eat detritus that has sunk to the bottom. The spread of the exotic invader, the zebra mussel, has caused dramatic changes in the water quality and ecology of Lake Erie in the past decade due to its high rates of filtration and high reproductive rate (See **Ohio Sea Grant**).

Not all organisms are easily classified as planktonic or benthic. For example, *Chaoborus,***Dipteran** insect larvae, remain near the sediments in daytime and migrate to upper waters at night. These transparent predators ("phantom midges") migrate upward to feed on zooplankton, and are, themselves, a favorite food for fish. Mysid shrimp behave in a similar fashion and have been shown to migrate enormous distances (>100 meters) in Lake Tahoe each night.

The best known group of aquatic consumers is fish. Many small fish, such as sunfish and perch, primarily eat zooplankton. **Tertiary consumers** that prey on the smaller fish include larger fish and other carnivorous animals (loons, grebes, herons, and otters). Different species exploit different habitats (niches). Bass and pike are found in lakes that have beds of aquatic **macrophytes** suitable for spawning. Walleyes, on the other hand, spawn on a gravel bottom. Lake trout live only in very clear lakes with cold, well-oxygenated deep water. In contrast, carp are adapted to warm turbid, low oxygen lakes with mucky, high organic matter bottoms. View images of fish, **Figure 21**.

Decomposers

Decomposers, which include bacteria, fungi, and other microorganisms, are the other major group in the **food web**. They feed on the remains of all aquatic organisms and in so doing break down or decay organic matter, returning it to an **inorganic** state. Some of the decayed material is subsequently recycled as nutrients, such as **phosphorus** (in the form of phosphate, PO_4^{-3}) and nitrogen (in the form of ammonium, NH_4^+) which are readily available for new plant growth. Carbon is released largely as **carbon dioxide** that acts to lower the **pH** of bottom waters. In **anoxic** zones some carbon can be released as methane gas (CH_4). Methane gas causes the bubbles you may have observed in lake ice.

The decomposers can be found in all biological zones of a lake, although they are the dominant forms in the lower **hypolimnion** where there is an abundance of dead organic matter. Oxidation of organic matter by the decomposers (respiration) in the hypolimnion is responsible for the depletion of **dissolved oxygen** over the course of the summer, potentially leading to anoxic conditions (no dissolved oxygen). There is no source of oxygen in the hypolimnion to replace oxygen lost through **decomposition**. **Stratification** prevents atmospheric oxygen from being mixed deeper than the **thermocline**, and it is usually too dark for photosynthesis. Consequently, a large volume of organic matter from a variety of sources (e.g., wastewater, sinking algae, dying macrophytes, and organic sediment washed in from the watershed) leads to faster oxygen depletion and often complete removal of oxygen in the hypolimnion. The resulting **anoxia** has a profound effect on both the chemistry and the biology of the lake.

Trophic Status

Since the early part of the 20th century, lakes have been classified according to their trophic state. "**Trophic**" means nutrition or growth. A **eutrophic** ("well-nourished") lake has high nutrients and high plant growth. An **oligotrophic** lake has low nutrient concentrations and low plant growth. **Mesotrophic** lakes fall somewhere in between eutrophic and oligotrophic lakes. While lakes may be lumped into a few trophic classes, each lake has a unique constellation of attributes that contribute to its trophic status. Three main factors regulate the trophic state of a lake:

1.Rate of nutrient supply

- Bedrock geology of the watershed
- Soils
- Vegetation
- Human **landuses** and management

2.Climate

- Amount of sunlight
- Temperature
- **Hydrology** (precipitation + lake **basin** **turnover time**)

3.Shape of lake basin (**morphometry**)

- Depth (maximum and mean)
- Volume and surface area
- Watershed to lake surface area ratio (A_w : A_o)

Trophic status is a useful means of classifying lakes and describing lake processes in terms of the **productivity** of the system. Basins with infertile soils release relatively little nitrogen and **phosphorus** leading to less productive lakes, classified as **oligotrophic** or **mesotrophic**. Watersheds with rich organic soils, or agricultural regions enriched with fertilizers, yield much higher nutrient loads, resulting in more productive, **eutrophic** (even hyper-eutrophic) lakes.

Eutrophication, the progress of a lake toward a eutrophic condition, is often discussed in terms of lake history. A typical lake is said to age from a young, oligotrophic lake to an older, **eutrophic lake**. Geological events, such as glaciation, created lakes in uneven land surfaces and depressions. The landscapes surrounding lakes were often infertile, and thus many lakes were oligotrophic. Eventually some of the **shoreline** and shallow areas supported colonizing organisms that decomposed unconsolidated materials into reasonably fertile sediments. Active biological communities developed and lake basins became shallower and more eutrophic as decaying plant and animal material accumulated on the bottom. Shallow lakes tend to be more productive than deep lakes, in part because they do not stratify, thereby allowing nutrients to remain in circulation and accessible to plants. They also tend to have a smaller lake volume, so nutrient loading from their watershed has a larger impact. There are undoubtedly exceptions to this typical progression from oligotrophy to eutrophy,where geology, **topography**, and lake morphology caused eutrophic conditions from the start.

This concept of lake aging has unfortunately been interpreted by some as an inevitable and irreversible process whereby a lake eventually "dies." In fact, many oligotrophic lakes have persisted as such since the last glaciation and some ultra-oligotrophic lakes, such as Lake Tahoe may have been unproductive for millions of years. Furthermore, research in **paleolimnology** has provided evidence that contradicts the idealized version of a lake becoming more and more eutrophic as it ages. Studies of sediment cores have suggested that the algal productivity of Minnesota lakes actually may have fluctuated a great deal during the past 12 - 14,000 years (the period since the last glaciation). Changes in climate and watershed vegetation seem to have both increased and decreased lake productivity over this period. Some lakes probably experienced high rates of **photosynthesis** fairly soon after glacial retreat and then became less productive until recent times. It is also possible that water sources for some lakes have changed over the past thousands of years through diversions of stream flow, for example. In such cases water supplies to a lake (and therefore nutrient supplies) could have changed, leading to changes in the lake's productivity.

However, lakes may be culturally eutrophied by accelerating their natural rate of nutrient **inflow**. This occurs through poor management of the watershed and introduction of human wastes through failing septic systems. Such changes may occur over periods of only decades and are reversible if **anthropogenic** **nutrient loading** can be controlled. In the 1960s this was a serious issue, exemplified by the hyper-eutrophic condition of Lake Erie. Although it was pronounced "dead," it eventually returned to less eutrophic conditions, when major point sources of phosphorus were controlled in the early 1970s (by spending millions of dollars to build advanced wastewater treatment plants).

In North America, most of the problems associated with the direct discharge of domestic wastewater have been successfully mitigated. Now the regulatory focus is on the much more difficult problem of controlling **non-point sources** (NPS) of nutrient pollution such as agricultural drainage, stormwater runoff, and inadequate on-site septic systems. NPS pollution is particularly difficult to address because it is diffuse, not attributable to a small number of polluters, and associated with fundamental changes in the landscape, such as agriculture, urbanization and shoreline development.

Biological Differences

Populations of **algae** and the animals that feed on them are lower in **oligotrophic** lakes because of low nutrient concentrations. Thus the water remains clear. Decay of the relatively small amount of **organic** matter in oligotrophic lakes does not completely deplete the hypolimnetic supply of **dissolved oxygen**. Therefore, lack of oxygen does not restrict animals from living in the **hypolimnion** of oligotrophic lakes. Lake trout, for example, require cold, well-oxygenated water and primarily live in the hypolimnion of oligotrophic lakes. Minnesota's oligotrophic lakes are found in the northeast region of the state, where infertile soils are covered with mixed conifer forests.

Extremely deep oligotrophic lakes such as Lake Superior and Lake Tahoe have hypolimnia that remain completely saturated with **oxygen** the entire year. However, many moderately deep lakes (with maximum depths greater than about 30 meters) may develop **anoxia** in the lower hypolimnion during late summer but may still be classified as oligotrophic because of their very low nutrient concentrations, low algal abundance, and relatively high transparency (high secchi depth). These lakes may have a **two-story fishery**, with warm and cool water fish in the **epilimnion** and **metalimnion** and cold water fish (such as trout) in the cold, oxygen rich portion of the hypolimnion. The cold-water fishery is therefore very sensitive to increased inputs of organic matter from sewage or erosion (external inputs), and to increased algal and macrophyte production (internal inputs) due to **eutrophication** since these factors will accelerate the rate and extent of **hypolimnetic oxygen depletion** in the summer.

Algae or **macrophytes** grow so thickly in some **eutrophic lakes** that light penetrates only a short distance and nutrients below that depth are not assimilated. As discussed earlier, **phosphorus** is typically the limiting nutrient in freshwater lakes, meaning that the plants deplete all available phosphorus before depleting other nutrients. In a hypereutrophic lake, algae may become so abundant that they suffer from self-shading. In those cases, **photosynthesis** is limited by light rather than by nutrients. When a great abundance of phosphorus is available in a lake, nitrogen may become limiting. In such lakes, certain species of blue-green algae that can **fix** atmospheric nitrogen have a clear competitive advantage and frequently become dominant. They dominate the algal community until another nutrient, or usually light, becomes limiting. In many infertile lakes in northeastern Minnesota, both phosphorus and nitrogen may be extremely low during midsummer. Since most sources of either point source or nonpoint-source pollution involve increased inputs of **both** N and P, these lakes are extremely sensitive to such pollution, irrespective of which is technically "most" deficient.

Eutrophic lakes show wide seasonal changes in their biological and chemical conditions. Because of the great amount of organic matter produced in these lakes, the decay rate is high in the hypolimnion, causing oxygen to be depleted. Therefore, eutrophic lakes frequently show a complete loss of dissolved oxygen below the **thermocline** during summers. Clearly, fish and most other animals cannot live in the hypolimnion of such lakes. Warm-water fish that can live in the epilimnion, however, can be quite productive. Bass, panfish, northern pike, walleye, carp, and bullheads thrive in many of Minnesota's eutrophic lakes. Complete or nearly complete oxygen depletion below the thermocline may also be a common feature of many moderately deep (10 to 30 m) **mesotrophic** lakes, if deep enough to stratify throughout the summer. Therefore, virtually complete anoxia below the thermocline does not necessarily mean that the lake is eutrophic.

> Ice Lake, one of our WOW lakes, is an example of a mesotrophic lake that becomes **anoxic** below the thermocline in the summer, (see **Ice Lake** section) as is Hale Lake, a somewhat less productive lake immediately downstream of Ice Lake. Both are ~16-18 meters deep.

Another oxygen-related problem in eutrophic lakes is **winterkill**. A dense snow cover over the ice reduces light penetration and keeps oxygen-producing photosynthesis from occurring. The high organic content of the water, however, provides considerable food for the decomposers. If the decomposers succeed in using all the available dissolved oxygen, a fish kill can occur.

In certain cases, a winterkill may lead to a more balanced fishery and possibly even improved water quality. Fish that survive a winterkill will have reduced competition for food for a period of time and so may grow faster and to a larger size. Fewer small fish reduces predation on the larger **zooplankton**, such as the water flea, *Daphnia sp.,* leading to increased zooplankton grazing on algae and a resultant increase in water **clarity**. This general scheme, involving fishery manipulations to reduce the abundance of zooplanktivorous fish, has been termed **biomanipulation**, and is being tried in many urban lakes where it is economically impractical to reduce nutrient inputs enough to significantly reduce algae. In these situations the offending fish may be removed by intense stocking of gamefish, by intensive netting and trapping, or even by poisoning the entire fishery and starting over with greatly reduced **planktivores**.

Aquatic Ecology And The Food Web

Some Understanding of the aquatic ecosystem is necessary before fisheries managers or pond owners can begin to understand changes in fish populations**.** The aquatic ecosystem is a complex of interrelated species and their reaction to each other and their habitat.

Changes in one part of the system often cause changes, large and small, throughout the system.

Eradication of aquatic plants in a pond with a healthy largemouth bass population is a good example of this concept. When all plants are eliminated from the pond in an effort to improve angling access**;** forage fish such as bluegill lose their protective cover and are exposed to excessive predation by largemouth bass. Bass initially respond by growing and reproducing rapidly, however, as the forage fish population declines, the once healthy bass population, limited by declining food supplies, becomes numerous, small and stunted.

The basic ecological concepts discussed in this section will provide the pond owner with the knowledge necessary to understand the reasoning behind fish and plant management techniques.

Succession

The aquatic ecosystem is a dynamic, changing environment. Daily and annual bio-geo-chemical cycles drive changes in water chemistry and the species composition of aquatic communities.

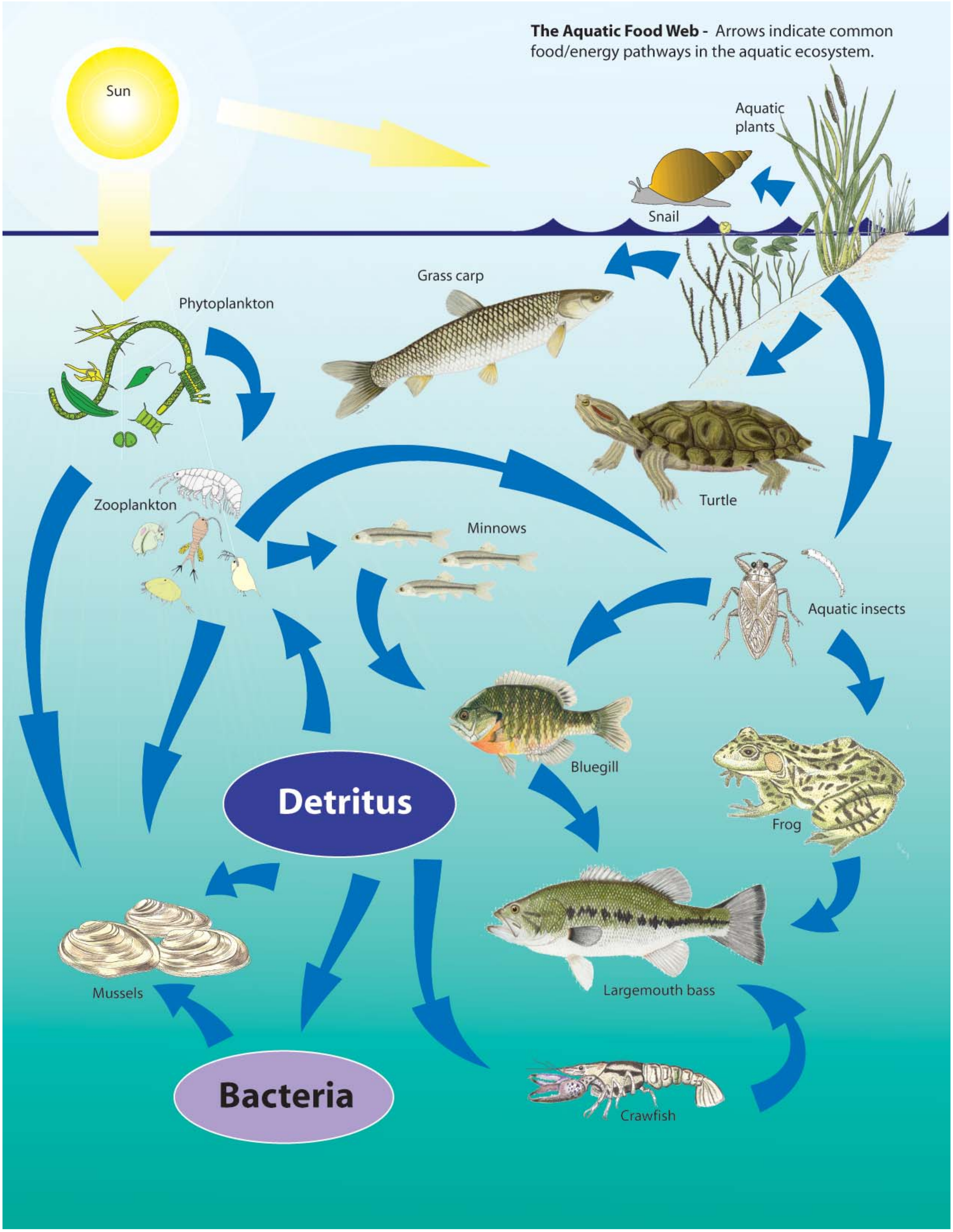
Ponds and lakes go through a cycle of changes over time, from newly created aquatic environment back to terrestrial habitat.

New ponds and lakes are usually **oligothrophic**. Oligotrophic waters have very little nutrients, a small phytoplankton population and consequently, clear water unless it is colored by dissolved or suspended minerals.

As the pond ages, leaves and other material wash into it from the watershed and plants and animals die and decay; gradually increasing the amount of nutrients available to the ecosystem. The phytoplankton community increases and the water becomes less clear and more green. Vascular aquatic plants colonize the shoreline and extend into the water as nutrients become available. Lakes with high levels of nutrients are said to be **eutrophic**. The pond has reached a mature stage of development.

Highly eutrophic or polluted lakes can result from activities in the watershed that release plant nutrients. Farm fertilizers, livestock manure, some detergents or other waste material containing nitrogen or phosphorous washing into the water produce noxious algae blooms and excessive phytoplankton production that is characteristic of this condition.

Over time, leaves, dead plants and animals and other detritus accumulates on the pond bottom. The pond becomes progressively shallower to the point that light penetrates all areas of the pond bottom and


The Aquatic Food Web - Arrows indicate common food/energy pathways in the aquatic ecosystem.
Sun
Aquatic plants
Snail
Grass carp
Phytoplankton
Turtle
Zooplankton
Minnows
Aquatic insects
Bluegill
Detritus
Frog
Mussels
Largemouth bass
Bacteria
Crawfish

aquatic vegetation covers the waters surface. The pond has reached the age of **senescence**.
Willows, cypress, cattail and other shoreline plants advance toward the ponds center.

Eventually rooted plants cover the pond bottom and the pond becomes a bog or marsh. Dry land trees begin to invade areas that were once under water. The marsh eventually fills in and drys up. Surrounding terrestrial vegetation replaces aquatic and semi-aquatic plant species and succession is complete. This successional cycle can be disrupted at any time by natural events such as floods that can scour, deepen and rejuvenate the pond. Human activity such as draining and dredging the pond also can interrupt the successional cycle.

Energy movement in the aquatic ecosystem

An ecosystem can be thought of as a conduit of energy derived from sunlight. Energy from the sun plus inorganic materials are the basis of all life**.** Energy can not be recycled. It moves through the ecosystem and ultimately dissipates as heat. Energy transfer efficiencies are low, usually about 10 % between each trophic level of the ecosystem.

Trophic levels contain groups of organisms with similar methods of food (energy)consumption. Energy moves from one trophic level to the next through the **food web** fig. 1. An example of a common, linear aquatic food chain is:

Phytoplankton (microscopic plants) - Zooplankton (microscopic animals) -Insects - Blue gill - Largemouth Bass -Turtle -Bacteria

In reality, most food chains are usually complex and interconnected. They are more accurately described as **food webs**.

Producers are the first trophic level in the ecosytem and form the base of the food chain. Producers obtain nutrition from inorganic materials and sunlight energy. In aquatic ecosystems phytoplankton are the primary producers; other aquatic plants also contribute but to a lesser extent. The total amount of energy per unit of time fixed as plant tissue is called **primary production**. Plants are able to convert only about 1-2 percent of the available sunlight energy into chemical energy usable for plant production.

Each time energy passes from one trophic level to the next, for example, a grass carp eating an aquatic plant or a largemouth bass consuming a bluegill, about 90 percent of the energy will be lost. Consequently, ecosystems require a large base of primary production to support a relatively modest level of production at higher trophic levels. The Eltonian trophic pyramid shown in fig, 2 illustrates this concept graphically.

Light is needed for all plant growth. Because clear ponds allow light penetration to greater depths than muddy ponds, more phytoplankton and other plants can grow, resulting in greater primary production in the base of the food chain.
More production in the food web base allows more production through out the aquatic ecosystem; and consequently, greater natural fish production in clear ponds than in muddy ponds.

Fish production in muddy ponds can be increased by clearing the pond or by addition of supplemental fish food to compensate for lack of primary production.

Fish production in clear ponds can be increased

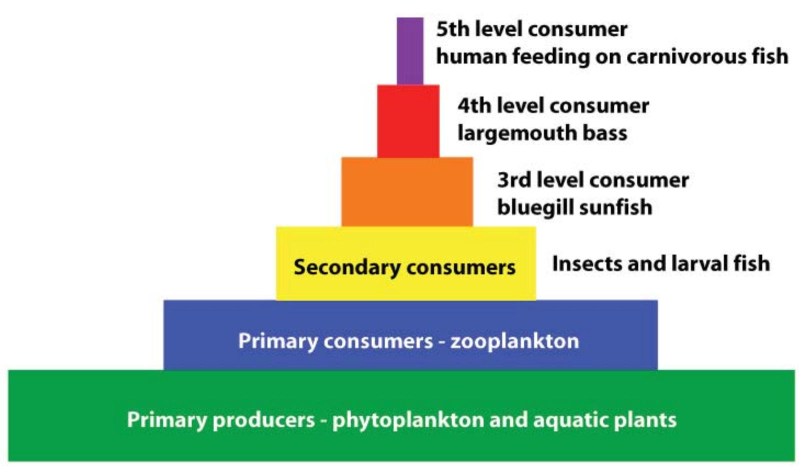


Figure 2. An Eltonian pyramid depicting relative abundance of organisms at six trophic levels.

by the addition of plant fertilizers to stimulate primary production. Fertilization only improves fish production if plant nutrients are lacking and light penetration is sufficient to allow increased plant growth. (When a specific factor is not available in sufficient quantity and restricts the growth of organisms it is called a **limiting factor**. For example, light is a limiting factor for plant growth in muddy ponds.)

In most situations, nutrients are actually over abundant, due to livestock waste or farm fertilizers. An over abundance of nutrients in clear ponds results in green, phytoplankton rich water; or excessive growth of rooted aquatic plants.

Consumers make up the next trophic level; and must eat other organisms to obtain their energy. Consumers, in turn, occupy different trophic levels. Trophic levels of common aquatic organisms are shown in table 1.

Primary consumers are herbivores, they eat plants. In our aquatic ecosystem example, zooplankton feeding on phytoplankton occupy the primary consumer trophic level. Cattle are primary consumers in terrestrial ecosystems.

Secondary consumers, represented by certain aquatic insects are carnivores and feed upon primary consumers, the zooplankton.

Our example also includes a **tertiary consumer**, the largemouth bass that feeds upon other carnivores.

The turtle, although opportunistic in its feeding habits, is represented in the example as a **scavenger**. Organisms at this trophic level feed on large bits of dead or decaying organic matter.

Organisms of the final trophic level break down organic matter and animal waste products. These creatures are called **decomposers**, and they break down organic material back to its constituent elements Bacteria are the most numerous and important decomposing organisms.

Ecological pyramids can be constructed using numbers of organisms, energy consumption in the

Trophic levels and feeding habits of common aquatic organisms.

Organism	Trophic level	Foods
Phytoplankton	Primary producers	Sunlight energy and dissolved nutrients
Zooplankton	Primary consumers	Phytoplankton, bacteria and detritus
Bacteria	Decomposers	Chemicacl molecules / detrtus
Snails	Primary consumer scavenger, herbivore	Detritus / plant material
Mussels	Primary consumer filter feeders	Phytoplankton, zooplankton, detritus
Red eared slider turtle	Herbivore, scavenger	Plants, decomposing organic matter, sometimes fish
Crayfish	Scavengers, carnivore	Decomposing organic matter, fish, insects, opportunistic
Common carp	Herbivore	Plants, organic matter
Channel catfish	Scavenger, carnivore	Carrion, small fish
Largemouth bass	Carnivore	Fish, insects, frogs, crayfish
Frog	Carnivore	Insects, fish

ecosystem or total biomass to visually illustrate relationships and relative abundance of organisms among
trophic levels.

The first trophic level which includes algae, phytoplankton and aquatic vascular plants, usually makes up the bulk by weight of organisms (about 85%) in natural aquatic ecosystems and forms the base of the food chain.(In some systems bacteria may actually be more abundant than plants.) Because there is up to a 90 percent loss of energy in each step of the food chain, each higher level of consumer will constitute a correspondingly lower amount of the total weight of living organisms in the pond. For example, about 100 lbs of insects, crayfish and small fish are required to produce 10 lbs of bluegill sunfish; and about 8 -10 lbs of bluegill sunfish are required to produce 1 lb of largemouth bass. This ecological fact explains why there are usually more than 10 times as many prey animals as there are predators. This is also the reason why ponds and lakes can not produce large numbers of big bass without an adequate forage base.

The same principle explains why muddy ponds, containing little phytoplankton can not produce as many pounds of fish per acre as a clear pond filled with phytoplankton, algae and vascular plants. The base of the food chain in a muddy pond is not large enough to support large populations of fish.

Many aquatic organisms occupy more than one trophic level and also feed on a variety of foods items from different trophic levels. Thus the concept of the ecological pyramid though useful, does not fully explain the complexities and interrelationships that exist among organisms in the pond.

Individual organisms and their roll in the aquatic community

An organism's **niche** includes all of the characteristics of its way of life. It includes the animal's habitat, physical and chemical tolerance limits, food, behavior and habits. Niche can be thought of as having multiple dimensions that define the organism's place in the environment. Aspects of a species ecological niche can be plotted on a graph to visually show how the animal fits into its community. Plots can include temperature tolerance, oxygen requirements, food requirements, habitat preferences or any other aspect of interest concerning a particular species (fig. 3) .

Niches of different species may overlap to varying degrees. Overlapping niches usually result in competition among species. Two species with the same niche requirements for food will compete for this resource. Closely related species may have very similar niches, however, it is rarely possible for two different species to have identical niches. One species will eventually out compete the other. This theory is known as the **competitive exclusion principle**.
It has not been proven to be universally true although documented incidences of competitive exclusion have been observed. Two species with identical niche requirements could coexist in a habitat that contained essentially unlimited resources necessary for survival and reproduction.

Niches also can overlap only during certain life stages. For example, young bluegill and young green sunfish may compete for similar sized food items.

Species with overlapping niches may reduce competitive pressures by diversifying or partitioning the niche. Niche partitioning or diversification is accomplished in many ways. A common food resource may be used during the day by one species and at night by another; for example, hawks may feed on mice during the day while owls feed on them at night.

The aquatic habitat

Changes in light penetration and plant growth dictate much of the habitat variety found in the aquatic ecosystem.

The **benthic** or bottom dwelling aquatic communities begin at the shore line and extend to the deepest parts of the pond. Many bacteria, phytoplankton and protozoa live between the damp particles of sand and soil. Sedge species, bullrush and cattail also colonize the area and often extend out into the pond to depths of 4 feet or more.

The **littoral zone** extends into the body of water from the shore to the deepest area of rooted plant growth. The extent of the littoral zone depends on water clarity, light penetration and wave action. The littoral zone must have adequate light for photosynthesis.

The depth of this zone in your pond can be roughly calculated by lowering a white coffee cup on a string into the water and measuring the depth at which it just disappears. Multiply this depth by 2.75 to estimate the depth of the deepest rooted plants in the pond.

The littoral zone contains a large and diverse community of aquatic organisms. Vascular aquatic plants in this region support a variety of insects, snails, crawfish, mussels, frogs, turtles, larval fish and their predators. Many of the mobile organisms such as turtles and fish occupy more than one habitat zone.

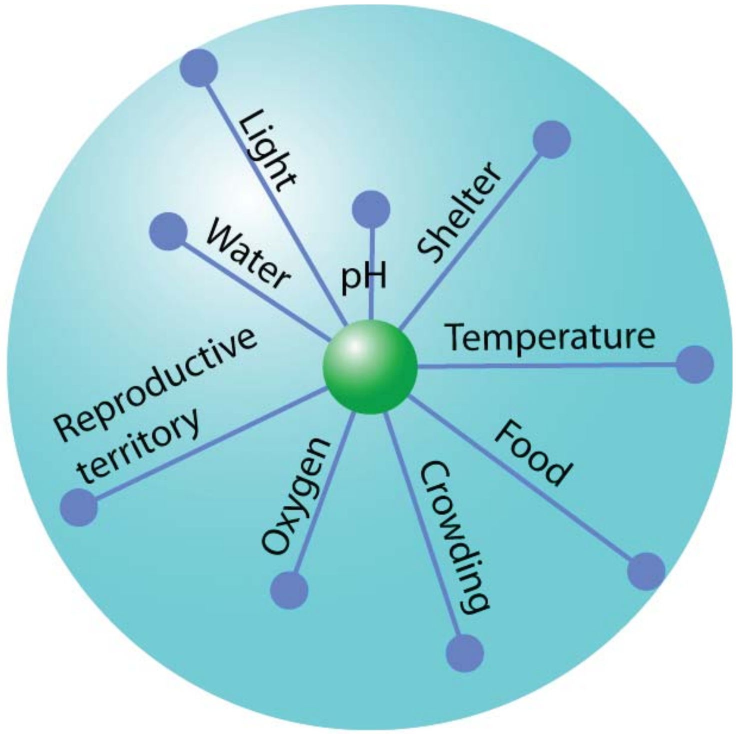


Fig. 3 Multi-dimensional niche space.

Below the littoral zone is the **sub-littoral** region. This habitat is characterized by accumulations of crustacean, mussel shells, and some dead plant material. This region is well oxygenated but poorly lighted. Fewer species are found here than in the littoral zone.

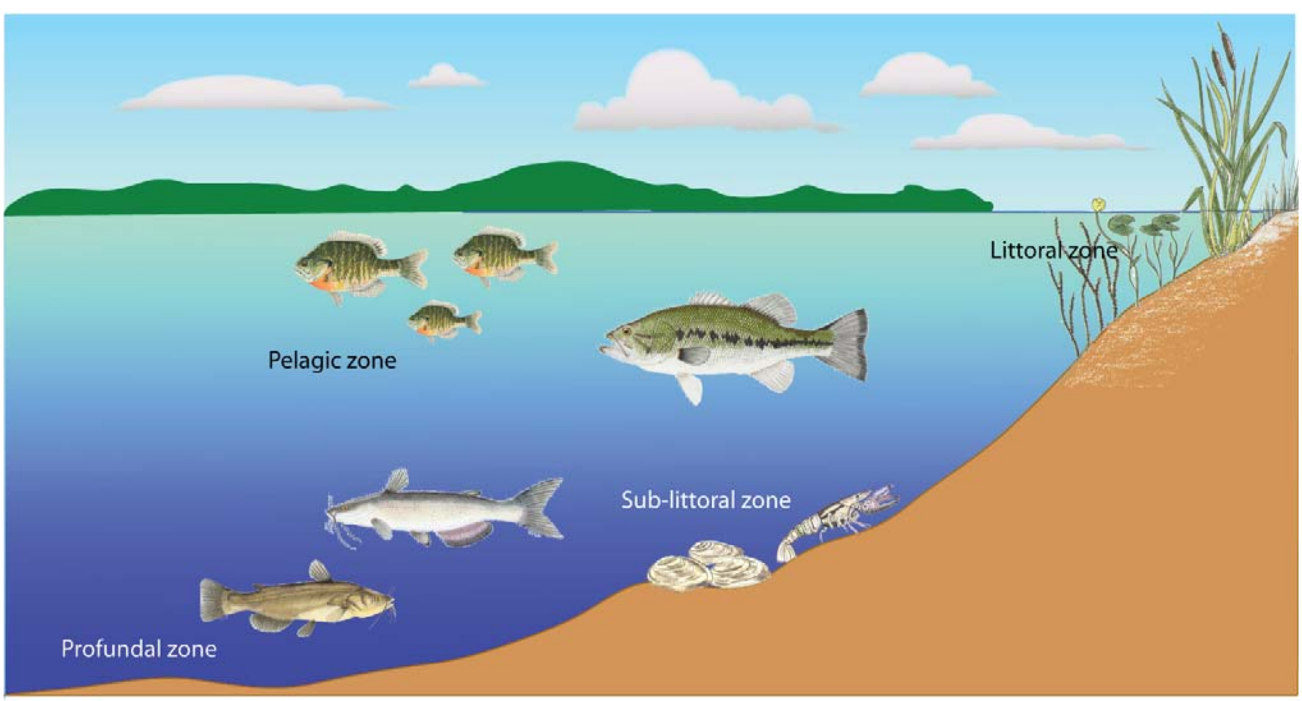


Fig. 4 Aquatic habitat zones in freshwater lakes and ponds.

In ponds large enough to thermally stratify, a profundal zone exists. The **profundal zone** is usually a stable environment except during periods of pond turn over. Oxygen levels are low or absent and there is little light penetration and no plant growth. Water temperature is usually cool and fluctuates little. The profundal zone is composed of detritus, and the bacteria and other organisms that feed on and decompose this material.

The open water is known as the **pelagic zone**. Plankton and other free swimming or drifting plants and animals inhabit this region as well as fish and other large, mobile organisms.

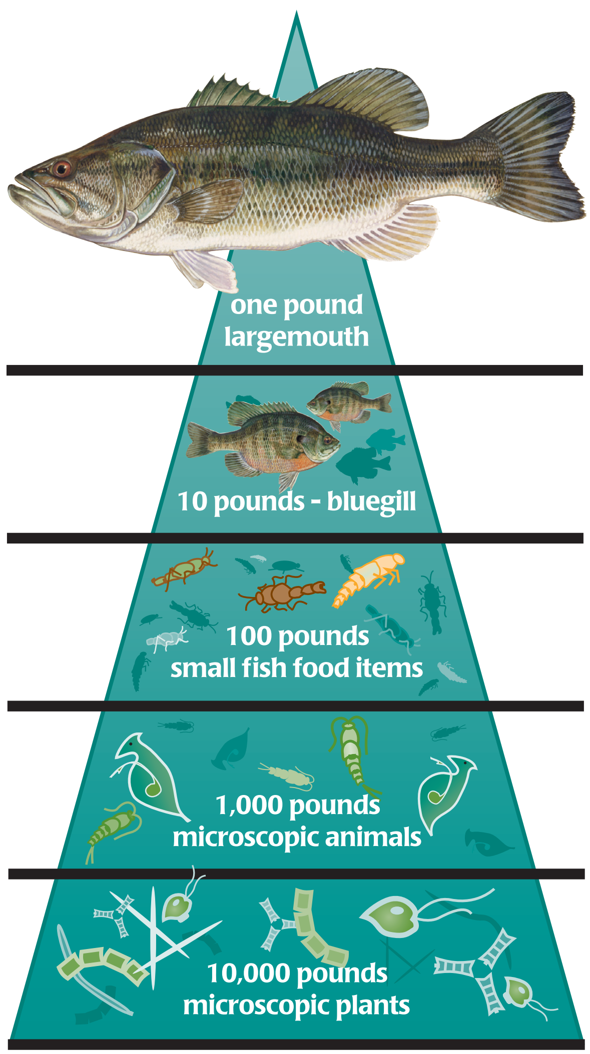
ENVIRONMENTAL MODIFICATIONS

The natural foods of fish are either produced in the pond, washed in by rain, or fall into the pond. Food produced in the pond has its origins in the nutrients found in the pond. A variety of plants, from microscopic algae to rooted plants, use these nutrients to grow. In turn, the plant material can be eaten by microscopic zooplankton or aquatic insects. These organisms are then eaten by bluegills and young bass. Bigger bass may then eat these smaller fish. Bass will also eat other items, such as crayfish and frogs, which also rely on plant material and insects in the pond for food. A pond has a series of food chains, or more accurately a food web, that starts with nutrients in the watershed and ultimately ends with big fish. Small fish concentrate the energy taken from the food they eat and, in return, become a high-energy food for larger fish. A pond will support 5 to 10 times as many pounds of bluegills as it does bass because bluegills are lower on the food chain.

The total weight of fish that a pond can support is called the carrying capacity.

Much like a pasture can only support so many cattle, or a garden can only grow so many vegetables, a pond can only support a certain biomass, or weight, of fish. A pond will achieve its maximum carrying capacity about 3 to 4 years after it is initially stocked. Without supplemental feeding, an average pond in Nebraska supports about 250 pounds of fish per acre: about 190 pounds of bluegill, 35 pounds of bass, and 25 pounds of catfish and/ or other species. Once the carrying capacity is reached, fish growth rates decline. Individual populations can be

AQUATIC FOOD CHAIN



comprised of many small fish, or a few large ones, but the total weight will be the same and equal what the pond can support.

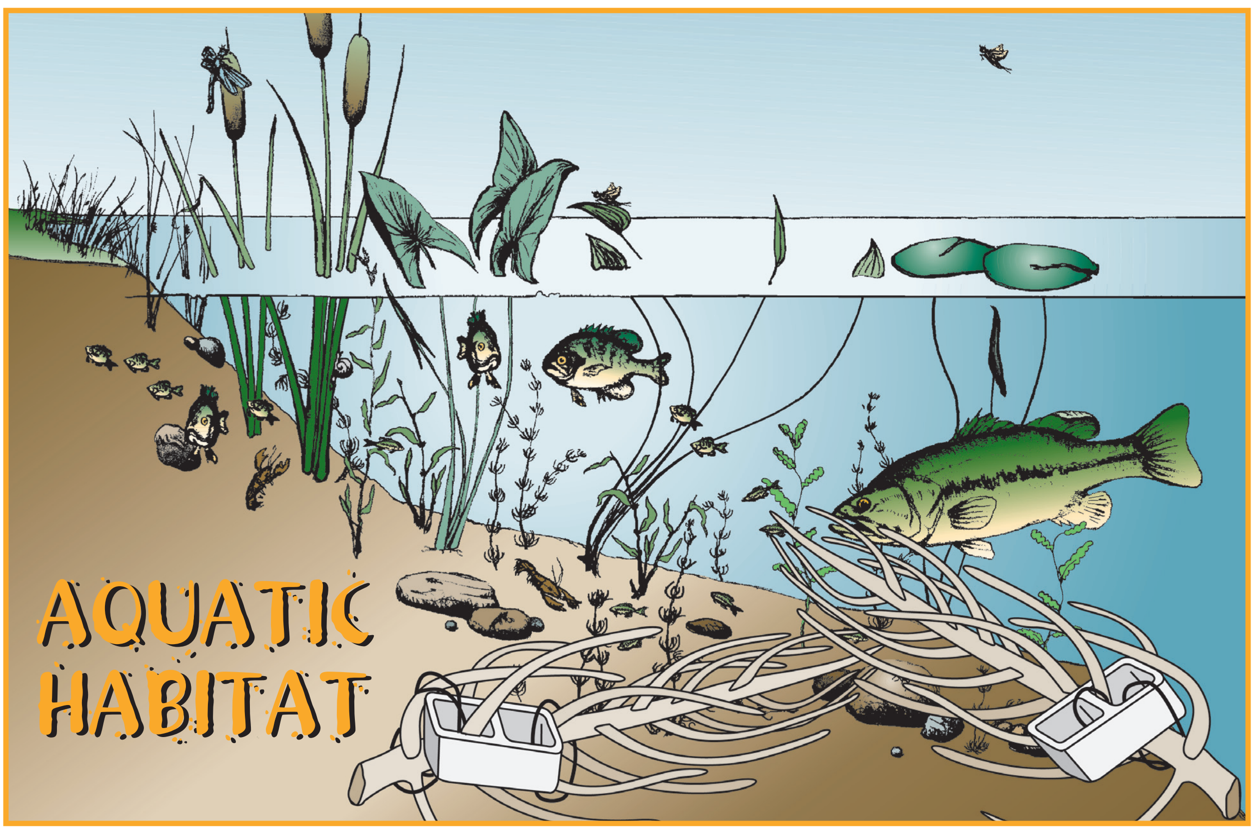
The wildlife productivity of a pond and the immediate surrounding land can be increased by making beneficial environmental modifications, or supplementing what is already present, depending on management goals. These changes can involve manipulating aquatic and terrestrial habitats that will then benefit associated wildlife, whether it is a rabbit, a small catfish, or even a dragonfly.

Aquatic Habitat

Trees and brush removed during construction can be returned to the pond basin before the pond fills. After a new pond fills, the flooded trees, brush, grasses, and weeds become underwater structures and create an excellent, nutrient-rich environment for aquatic life. Underwater structures provide shade and cover for fish, substrate on which aquatic organisms, such as aquatic insects, can grow and feed, and concentrate fish. Small fish will come to the cover to eat the insects found there, and bigger fish will come to eat the small fish. However, as the pond ages, inundated vegetation eventually decays and disappears, reducing the amount of fish a pond can support. Some of the natural effects of aging and subsequent habitat loss can be counteracted by encouraging development of natural habitat and/or the addition of cheap, but sometimes labor-intensive, artificial habitat.

Natural Habitat

Aquatic vegetation is also considered structure and will eventually become established in most ponds. A good fishing pond usually will be about 40% covered with emergent and submergent aquatic vegetation. Aquatic vegetation is often considered a nuisance and removed by pond owners. It is, however, a natural and necessary component of a healthy pond. Aquatic plants provide cover, food, and

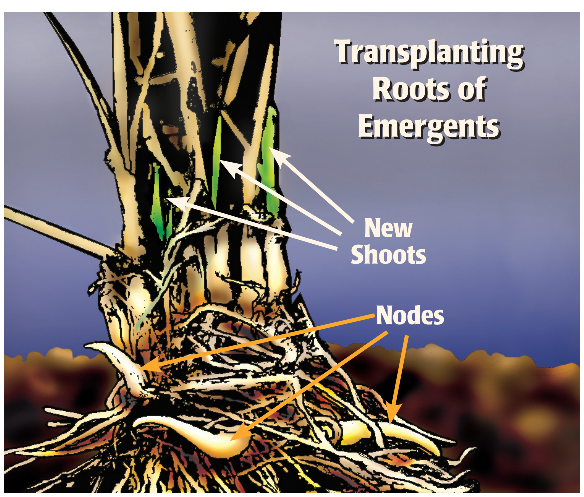


nesting sites for fish and other organisms. They also help to oxygenate the water, reduce nutrient levels, and improve water clarity by decreasing wave strength and minimizing shoreline erosion. Emergent and submergent vegetation tie up a portion of the nutrients present in a pond, which reduces the likelihood of nuisance planktonic algae blooms that can cause fish kills.

Although emergents – rigid plants which have the bulk of the plant above the water and grow along the shoreline – can become established naturally in a pond, they can also be transplanted to speed colonization. Most emergents, especially cattail, bulrush and arrowhead, are relatively easy to transplant. This should be done in the spring when new growth starts. Rootstock can be dug up and cut or pulled apart and planted along the shoreline. Make sure at least two new shoots/nodes are present for each section when utilizing cattails. Some of the transplants should be placed adjacent to and immediately above the water line, while others can be placed in water less than 10 inches deep. Cattails are very aggressive and can spread over extensive shoreline areas. Mechanical or chemical means may be necessary to eliminate them in wading, swimming, and some fishing areas.

See page 61 for additional information on identification, benefits, potential problems, and control of aquatic vegetation.

Even though submergents – non-rigid plants which are normally completely submerged and attached to the bottom – can also be transplanted, they usually become established in the pond naturally by waterfowl transporting seeds and incoming water transporting seeds and plant fragments. Some types, including curleyleaf pondweed, Eurasian watermilfoil, and coontail, can colonize extensive shallow-water areas. The best way to restrict their growth is to make sure ponds contain adequate depths, as outlined on page 12. Although it is best to transplant locally acquired plants, some can also be purchased. Contact your area Commission fisheries personnel for a listing of aquatic vegetation dealers.



Some of the natural effects of aging and subsequent habitat loss can also be counteracted with water level manipulation. The water level of ponds with gated draw-down valves can be lowered 2 to 3 feet, provided adequate depth remains to prevent a summer fish kill, and maintained at the lower level for an extended period of time. Grasses and broadleaf plants will sprout naturally on the exposed pond bottom, or exposed areas can be seeded with sorghum or Japanese millet. Draw-down can commence in late spring. Hand seeding should be done when mud flats are initially exposed and still moist. The pond should be refilled to flood the established vegetation, either in the fall if a winter fish kill is possible or the following spring. Although pumps can be used to partially drain and refill ponds for water level manipulation, pumping costs can be considerable.

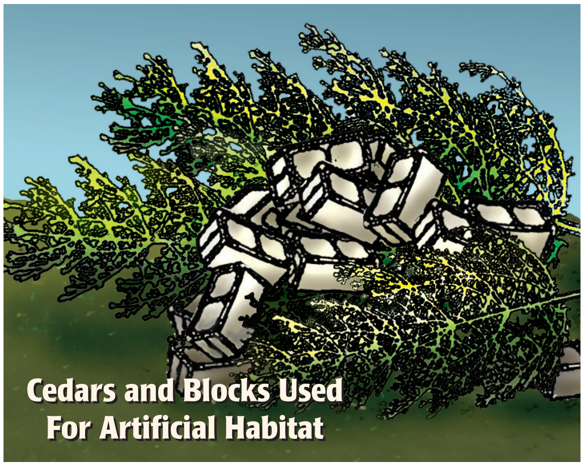
Water level manipulation can also be used to enhance emergents, with dewatering starting about mid-May and a slow, refilling process starting in September. It also crowds fish, which can make small bluegills more susceptible to predators. Water level manipulations should ideally be done every 4 to 5 years.

Pallets Used For Artificial Habitat

Artificial Habitat

A pond owner can install underwater structures, commonly referred to as artificial habitat, to enhance habitat available for numerous aquatic organisms. Research has shown that structures made of natural materials, such as brush and trees, are the most economical and effective types. Rocks, boat docks, wooden pallets, drain tiles, and piles of concrete blocks or bricks can all function as structure.

The easiest time to install structures is while the pond is being built. They can be built quickly by pushing downed trees together with a bulldozer and then anchoring them in place. Timber left standing in the pond basin creates natural structure that is very attractive to fish. Most small trees and brush will decompose in a relatively short period of time and will need to be replaced, but hardwoods, cedars, and large trees can last for decades. Trees can be tied together in various configurations or anchored separately with concrete blocks. Trees can also be kept in place by cabling them to existing stumps or steel posts driven into the pond bottom, as long as there is no concern about the posts causing the pond to leak or becoming a boating hazard.



Cedars and Blocks Used For Artificial Habitat

Although any type of tree will work as habitat structure, hardwoods, osage orange, and especially red cedar, work best. Christmas trees can be used; however, they decompose rapidly and last only a few years. Large pines should be avoided because of their acidity. Plastic banding, polypropylene rope, or heavy, non-corrosive wire can be used to attach anchors directly to trees. Shoreline structure can be made by felling trees along the edge of the pond into the water. To keep these trees in place, cable them to the stump. Or half cut them, leaving a portion of the top connected to the stump.

Artificial habitat can also be added after the pond fills to intentionally attract and concentrate fish for anglers. The best locations for attractors are near natural gathering places for fish and in areas accessible to anglers. Good locations are off points, at the edges of drop-offs, in the mouths of coves, and near boat docks and fishing piers. The structures can be built on the ice during the winter over 4 to 10 feet of water or, if possible, the pond can be partially drained and the structures placed on the exposed bottom. Structures can also be built on the bank and pulled out into the water or hauled in a boat to the ideal fishing spot.

Structures placed in 5 to 10 feet of water can be used by fish year-round. Structures placed in water deeper than 10 feet may not be used during summer months if there is insufficient oxygen at those depths. Good attractors will be about 10 by 15 feet, or larger. Trees can be grouped together in several large piles, which is more effective than spreading individual trees across the entire pond bottom. A good rule of thumb for ponds larger than 5 acres is to build one large brush pile for every 2 to 3 acres of water. For safety's sake, do not place any structures in swimming or wading areas or within 100 feet of spillways or overflow pipes.

Before adding any structure into any surface waters of the state, you must first obtain a Section 404 Permit from the ACOE (see Appendix A for technical assistance contacts).

Spawning Habitat

Bass and bluegill are typically generalists, thereby eliminating the need to add spawning substrate such as sand or gravel. Some studies have shown bass prefer to spawn near a downed log, or similar structure, when available. There is the likelihood that excessive amounts of sediment in the older ponds can smother eggs in a nest if it is stirred up and then resettles. If an older pond can be partially drained, the exposed pond bottom will then dry out and become somewhat firm, making it better for nest builders. Or, once the pond bottom is exposed, equipment can be used to remove accumulated sediment in several areas. The operation of heavy equipment will also compact the bottom.

Channel catfish usually nest in a cavity. This can be a trash barrel on its side, a large piece of PVC pipe with one end plugged, or any other object that creates a "cave" the fish can lay in and defend. They will also nest alongside protective structure if no cavity is available. However, there will be limited survival of young catfish if the water is clear and bass are present.

Shallow-Water Habitat

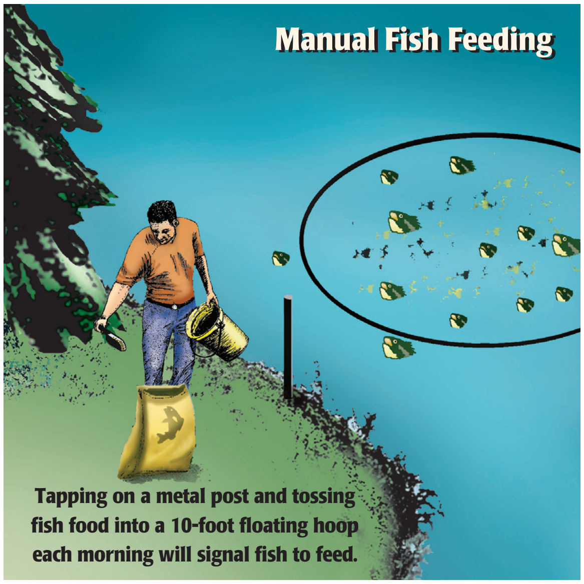
If a pond owner desires, habitat can be further diversified by creating additional shallow-water areas. A small wetland area might be constructed below the dam, or a small pond can be placed above the main pond to provide sediment detention and additional habitat. Perhaps additional shallow-water areas can also be created in the upper reaches of the pond. All of these areas will eventually become vegetated and provide habitat for waterfowl, bullfrogs, and other wildlife.

Fish Feeding

Feeding may be appropriate if the owner is willing to spend the time and money required to produce rapidly-growing, large-bodied bluegills, catfish, wipers, hybrid sunfish, or trout. However, fish must learn to eat commercial food pellets. Pellets should be provided at the same time and location each day. This can be easily accomplished with an automatic, timer-controlled, fish feeder placed on shore or on floats and anchored in the pond. Feeding only when you feel like it is usually a waste of time and money as most fish will never learn to eat the pellets, especially if there is no signal to indicate food is being provided. Fish will learn to react to signals, such as the whirr of the feeder as it turns on, or can be trained to come and eat dispersed pellets by banging on a pipe or post that has been driven into the nearby bank.

Nebraska ponds are usually fertile enough that fish feeding is not necessary.

Artificial feeding can increase the biomass of a pond beyond its normal carrying capacity. If a feeding program is discontinued, the pond may not be able to maintain the extra fish biomass, resulting in poor fish health and growth. Also, the accumulation of nutrients from uneaten pellets and the increased waste output by artificially fed fish may age a pond quickly, consume oxygen, and stimulate algae blooms. When the algae die, their decomposition can lower dissolved oxygen levels, stressing or killing fish during the night or following several hot, calm, overcast days. When this occurs, fish can be seen at the surface gasping for oxygen early in the morning. An aeration system will help reduce the likelihood of fish kills due to low oxygen levels.



Tapping on a metal post and tossing fish food into a 10-foot floating hoop each morning will signal fish to feed.

If a pond owner insists on feeding fish, bluegills and/or hybrid sunfish should be provided about 5 pounds of pellets per acre, per day. Make sure the pellets are small enough for them to eat. Largemouth bass do not normally eat commercial pellets because they prefer to eat live aquatic organisms, but they may benefit from increased bluegill production. To increase bluegill and hybrid sunfish growth rates and produce large fish with feeding, there still has to be adequate bass predation on small bluegills and hybrids, unless the owner is willing to spend a fortune on food.

Channel catfish and wipers are practical to feed and quickly learn to eat pellets, resulting in increased growth rates. When catfish and wipers are present in relatively high numbers in multi-species ponds, they may consume the majority of the pellets, leaving little for other fish. Trout also readily accept dry pellets, and can be grown to larger sizes.

The amount and size of pellets to feed will depend on the fish species present, relative numbers and size range of target fish species, and the time of year. The following guidelines will help improve the success of a feeding program:

- Do not feed more than the fish will consume in 10 minutes. Keep in mind fish must first learn to come to the pellets, so start out with a small amount.
- If fish stop eating, stop feeding and check for low dissolved oxygen levels in the water, diseases, spoiled pellets, or other problems. Consumption of spoiled pellets can stress or even kill fish.
- Stop feeding catfish, wipers, bluegills, and hybrid sunfish when water temperatures are above 90 degrees or below 60 degrees. Stop feeding trout when water temperatures are above 70 degrees or below 50 degrees. Reduce the amount fed as water temperatures approach these temperatures.
- Do not feed after sunset or before sunrise.
- Feed only once and at the same time each day – preferably in the morning.
- Check automatic feeders periodically to make sure they are operating properly.
- Use floating pellets so you are able to observe fish while they are feeding and evaluate their health.
- Consider using a floating hoop to confine the pellets, which will prevent them from drifting to the bank.
- Only use pellets formulated for fish.
- Do not use old pellets – check the packaging date. Nutrient benefits decrease with time. Discard pellets if more than 6 months old.

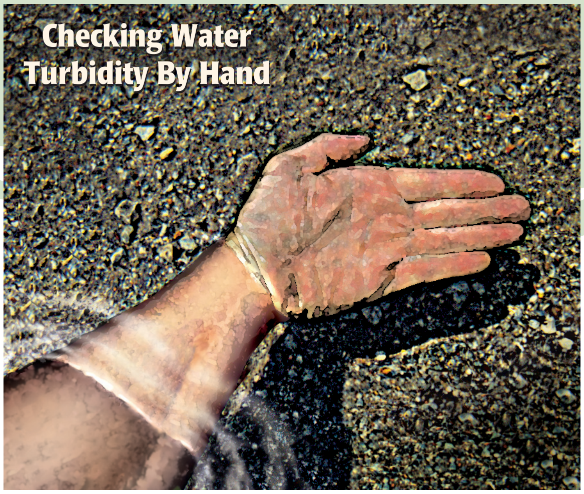
- Store pellets indoors with room temperatures preferably under 75 degrees.

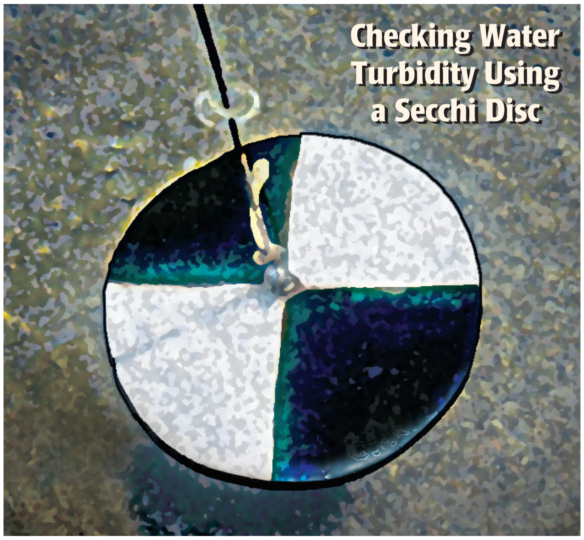
Contact a local livestock supply store for a source for commercial fish food.

Pond Fertility

Water fertility determines a pond's productivity. A more productive pond will support more fish and a larger harvest than a less productive pond. A pond is considered about right for good fish production if you can see your fingers when you extend your arm 18 inches downward into the water while in direct sunlight or when a secchi disc is impossible to see at 18 to 24 inches below the pond surface. The level of visibility should be due to the density of existing fish food organisms (such as zooplankton, phytoplankton and aquatic insects), not suspended soil particles. Keep in mind most soils and pond water supplies in Nebraska are nutrient rich; therefore, adding more nutrients to ponds is typically not necessary. Exceptions could be newly created ponds. In Chapter 1, we discussed the various benefits of placing removed organic-enriched topsoil, brush and trees back in the pond and establishing a cover crop in the basin, when construction was completed. One ensuing benefit was the likelihood of creating a nutrient boost that facilitates initial establishment and expansion of the aforementioned fish food items. With this in mind, the addition of agricultural fertilizer to increase fertility is not necessary and is actually prohibited since it would violate Title 117 Water Quality Standards set by the Nebraska Department of Environmental Quality. Also, if nutrients become excessive, there is the likelihood of excessive aquatic vegetation growth, especially algae, that could negatively impact fish populations.

In general, fertilization is not needed in most Nebraska ponds, and adding agricultural fertilizer is prohibited.





Terrestrial Habitat

Although fish production is the primary interest for most pond owners, the impounded water will provide habitat for a multitude of organisms, ranging from aquatic insects to terrestrial wildlife. We have already discussed planting areas in and immediately around the pond to control erosion and sediment; however, the vegetative cover near the pond also greatly influences the types of wildlife that will regularly use the pond.

The basic needs of most upland wildlife species are simple: food and cover. Buffer strips

adjacent to ponds become important habitat that provide both. Cover is needed for nesting or denning, escape from predators, and shelter from harsh weather. The lack of any of these may limit populations. This cover can also improve water quality and lengthen the life expectancy of a pond by entrapping sediment from erosion on land surrounding the pond.

A pond is a community of many living organisms, with most of them depending on each other for survival. A pond forms a connecting link between the aquatic and terrestrial worlds.

In open rangeland and small pastures, fencing should be used to protect at least a 100-foot wide grassed buffer around the pond. A strip of this width provides excellent habitat, particularly for small mammals and ground-nesting birds, and makes it more difficult for predators to locate prey. If the pond is to be located in or near cropland or over-grazed pasture, a mixture of native grass and legumes, such as alfalfa and clover, should be planted within the 100-foot wide fenced buffer. Depending on the amount of land available, trees and shrubs can also be considered. Establishing windbreaks near the south and west sides of the pond will provide cover for a variety of wildlife and help to reduce wave action and turbidity. These various plantings will provide winter and escape cover, food production, and nesting areas for wildlife.

It is necessary to periodically set back plant succession to yield greater wildlife benefits and diversity.

The grassed buffer areas need to be periodically manipulated to produce a wide diversity of grasses and broadleaf plants, also known as forbs, that can be utilized as food and cover for the various kinds of wildlife desired. Wildlife utilization of a habitat can then be increased by maintaining a stage of plant succession. Since vegetation cannot be held at a particular stage for any great length of time, it becomes necessary to set back succession and allow the process to start over; thus, recycling the most beneficial successional stages. This can be accomplished by controlled burning, mowing, lightly discing and interseeding with legumes or forbs, grazing, or even careful use of chemicals. These practices, when done correctly, do not destroy the grass, but improve plant diversity and maintain vigorous growth within the stand, yielding greater wildlife benefits and diversity. Other wildlife requirements can also be met if there is a need to plant additional trees and shrubs. Contact your area Commission wildlife biologist or the NRCS about habitat planning and periodic manipulation.

Waterfowl Production

Most pond owners enjoy seeing waterfowl use their ponds and most ponds can be