1 Lake Ecology: Getting Your Feet Wet

Introduction

To understand how to manage a lake, you must know something about the lake itself. This is not easy because lakes are complex, dynamic biological systems that both influence and are influenced by their environment. Countless examples can be found of how lakes and their environments interact. Just ask the people who live in the western Adirondacks or Central New York and must contend with lake effect snowstorms that form over the Great Lakes each winter. In short, lakes are more complex than the simple concept of big fish eating little fish. While this is a prominent feature of lake environments, and a microcosm of the complex interactions that govern lake ecology, it is much too simplified.

The study of freshwater systems, including lakes, is known as **limnology.** A subset, the study of how plants and animals coexist in a freshwater system, is referred to as **ecology**. Lake ecology encompasses chemistry, geology, biology, geomorphology, and even meteorology. Ecologists seek to understand interactions among individual organisms, populations and communities, how these living components interact with their non-living surroundings, and how these relationships change over time. Chemical and biological components change constantly and create a dynamic balance. A change in one part of an ecosystem, such as increased water clarity or algae density, may cause an alteration in other parts of the system, such as fish populations. These changes may cause re-equilibration, creating a new "steady state," or they may create a dynamic response. This has important implications in lake management, for it is difficult to predict whether an intended management action, such as biomanipulation or drawdown, will lead to an unintended consequence, such as an algal bloom or the loss of a valued fish species.

Limnologists and lake ecologists keep striving to learn more about how lakes function, such as how pollutants move through lakes, why exotic plants thrive in some lakes but not others, how quickly some lakes will fill in, and other dynamics. Even as this trove of lake knowledge builds, however, there continue to be many unanswered questions. This chapter provides an introduction to what is currently understood about how New York State lakes function.

A lake by any other name

The term "lake" will be used throughout this manual as the general term encompassing ponds and reservoirs as well as true lakes. While everyone has some idea of the differences among these ponded waters, and while some legal distinctions are unique to each, no hard and fast boundaries separate ponds from lakes from reservoirs in New York State. All ponded waters serve as the lowest point of a watershed, the recipient of all surface and groundwater flow (and the pollutants they bear). The general definitions, however, bear mentioning.

A lake is usually larger than ten acres in area and ten feet in maximum depth. It may be quite large and deep, with an abundance of cold water at the bottom. It may also exhibit areas of rocky, wave-impacted shoreline because of exposure to prevailing winds. It is important to remember that a lake is usually part of a larger river system with water flowing both into and out of it.

The term **reservoir** is commonly used to describe an artificial lake. It probably has a dam that impounds the water for the purpose of flood protection, power generation, drinking water supply, or to maintain canal water levels. A reservoir may also be used for recreation, but that is generally not its primary function, at least in New York State.

A pond is usually described as a shallow body of water that is smaller than a lake. Typically, a pond has uniform water temperature from top to bottom, little wave action, and often an abundance of aquatic plants. Pond waters are generally supplied from a very small area. The term "pond" also refers to small but permanent waterbodies that are water-filled depressions in the earth, whether created by natural contours, by beaver dams, or by people looking for a steady supply of water for fire protection, livestock or attracting wildlife. **Vernal ponds,** also called vernal pools**,** are ephemeral, forming after spring thaw or large storm events, but dissipating before attaining any degree of permanence. In many ways, vernal pools are the transition between lakes and wetlands.

Wetlands are unique habitats that form the transition between the lake and the surrounding land. Wetlands have several common characteristics:

- the dominance of plants that require a wet habitat in order to live;
- soils that have characteristics associated with flooded or saturated conditions, such as a gray color; and
- evidence of predictable annual flooding.

Flooding may only last several days or weeks, and it sometimes occurs only below ground level. Flooding creates **anaerobic** (without oxygen) soil conditions in which only uniquely adapted plants can survive, grow and reproduce. Flooded conditions also slow down the rate of decomposition of leaves and other organic matter, leading to the build-up of a black, rich organic soil. The combination of plants, soils and microbial communities found in wetlands provides important benefits to lakeshore owners, including flood reduction, filtering of contaminants from groundwater before they enter the lake, and nursery areas for fish and other wildlife. **Groundwater** is freshwater found beneath the earth's surface and is often connected to surface waters, meaning lakes, streams and wetlands. Information on regulations and legal issues related to wetlands is included in Chapter 10, "Legal Framework."

In the beginning…

How a lake was originally formed has great influence over many of its characteristics. Most lakes in New York State are the result of the presence and retreat of glaciers. These glacially carved lakes are deep and have inlets and an outlet, reducing the time that nutrients and the resulting algal blooms stay in the lake. Artificially created lakes typically act as wide rivers or streams. Nutrients are flushed out thereby reducing algal blooms. A special kind of glacial lake, called a kettle lake, is frequently dominated by groundwater seepage. Without a significant outlet or inlet, they are repositories of nutrients that allow algae to thrive.

The power of glaciers

Several continental glaciers formed and retreated over the northern hemisphere for more than a million years. The last Laurentian **glaciation** ended with melting and marginal retreat between approximately 22,000 and 8,000 years ago. Most of the northern third of the United States was affected by four major glaciations and minor advances, each followed by warmer periods similar to conditions today. The major effect of these glaciations was erosion and deposition, responsible for the modifications of New York State topography from earlier networks of stream channels to the rounded hills and valleys that dominate today's landscape.

A large ice lobe extended southwest along the St. Lawrence River Valley north of the Adirondacks into the Ontario and Erie basins, eroding and deepening them. A smaller lobe extended into the Champlain-Hudson River Valley, modifying the region east of the

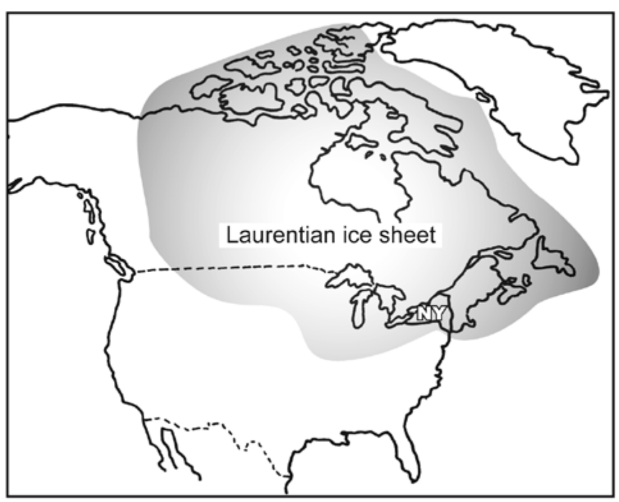

Fig. 1–1. Areas of North America covered by the last of a series of ice sheets. (CREDIT: WENDY SKINNER)

Adirondacks and Catskills. Ice continued to thicken, eventually overtopping the Adirondack and Catskill mountains. The thickening ice over the Ontario and Erie basins expanded onto the lake plain, Appalachian Highlands, and southward into northern Pennsylvania. Ice also extended westward into the Mohawk Valley from the Hudson Valley, and eastward from the Oneida Lake basin.

As the glaciers moved southward and oozed around higher upland areas, erosion of older stream channels was caused by water freezing in bedrock cracks and by debris plucked from its original location to become part of the moving glacial ice base. Continued sliding of the ice caused this entrained debris to act as tools that scraped, gouged and sanded the land surfaces under the ice. These processes are enhanced by thicker ice, so valleys were eroded more deeply than the adjacent uplands. As a result, several of the Finger Lakes and Great Lakes basins are quite deep and some have basins that descend below sea level.

The **glacial margin** is a zone of near equilibrium where the rate of ice melting is balanced by new ice moving into the zone. Water from the melting ice flushes rock debris, ranging from fine clays to large boulders, beyond the ice margin. This develops a **terminal moraine** marking the glacier's maximum advance**.**

Once the melting exceeded the rate of advancing ice, the forward margin of the ice receded during several hundred years, gradually shifting the glacial margin northward. Occasional brief periods of ice-margin equilibrium formed additional **recessional moraine ridges,** and **outwash plains**, or **valley trains** beyond the actual front of the ice. The retreating ice blocked water drainage northward creating temporary glacial lakes in the valleys between the Appalachian Highlands and the ice margin. As the ice continued to melt, waters along the margin eventually drained eastward across lower hills and under the ice into the Mohawk River Valley. Further recession of the ice margin eventually re-established the St. Lawrence drainage north of the Adirondacks. The Lake Ontario and Erie basins were filled with water, and several of the deeper valleys to the south became large lakes**.** The Finger Lakes were formed after glaciers gouged

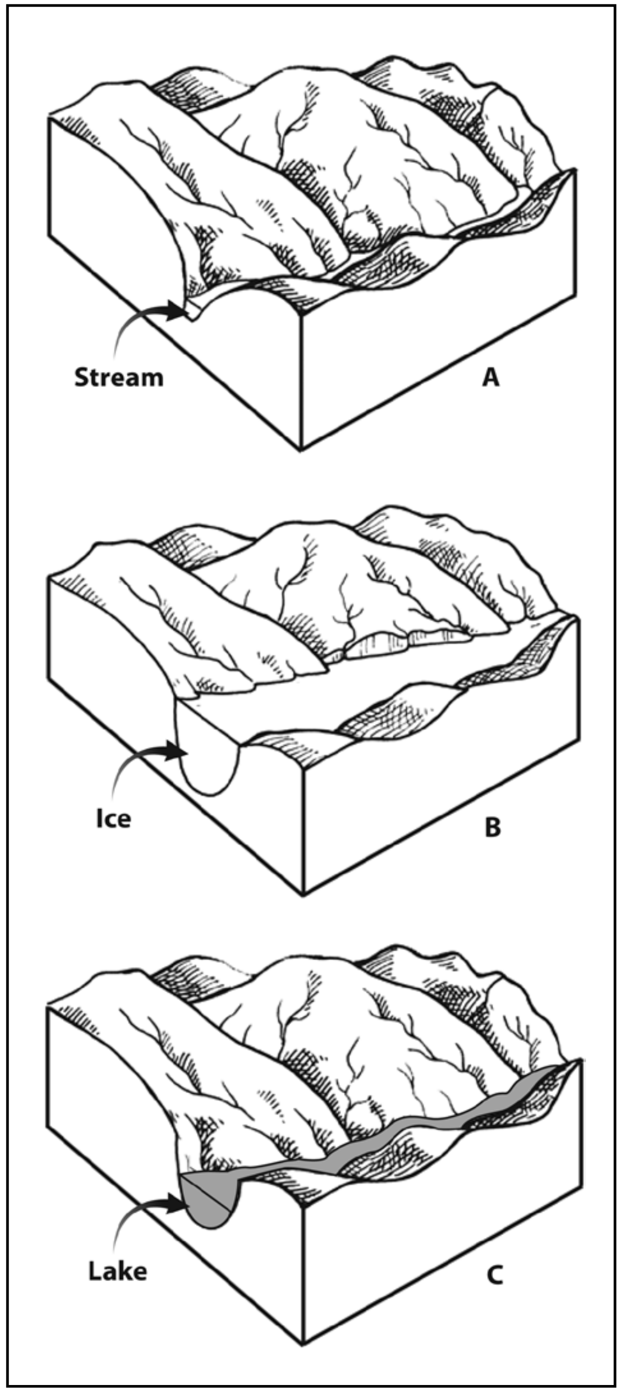

Fig. 1–2. Landscape evolution under glaciation.

A. Preglacial topography formed by stream erosion.

B. Stage of glaciation.

C. Postglacial landscape showing U-shaped valley and lake typical of the Finger Lakes region.

(Credit: A & B - Wendy Skinner;
C - Wendy Skinner, adapted by Chris Cooley)

out old river drainage systems that once flowed south. The jumbled mass of terminal moraine rocks blocked the valleys, damming up the old river channels and forming lakes that drained to the north.

The weight of a large mass of ice was sufficient to make the earth's crust bow downward, much like a child walking across a trampoline. As with the trampoline, the earth rebounds upward when the weight is removed. However, the earth's crust responds very slowly. New York State is still adjusting, particularly in the north where the ice was the thickest. This response to loading and unloading of weight on the earth is called **isostatic adjustment**.

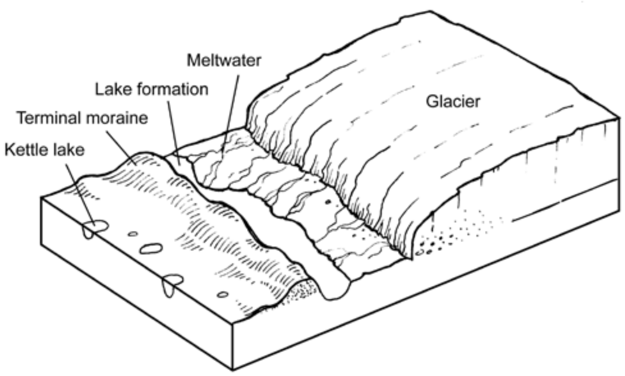

Fig. 1–3. Typical features that develop near the front of a receding glacial ice margin. (CREDIT: WENDY SKINNER)

Erosion-resistant rocks are found near the surface in the northern part of the Finger Lakes, and a series of recessional moraines are found nearly parallel to these rocks. The rocks, recessional moraines, and isostatic adjustment combined to cause a sluggish northward drainage from the water-filled glacial valleys occupied by some Finger Lakes. The slow flow of the Seneca River through the Montezuma Swamp is an example of this restricted drainage. The river cannot keep up with the water volume from springtime rains and snow melt flowing out of Cayuga and Seneca lakes. This causes flooding as the slow-moving Seneca River drains east to the Oswego River.

Smaller **kettle lakes** are found in the outwash materials deposited just beyond the terminal and recessional moraines (see Fig. 1–3). As the glacier melts, ice breaks into various sized blocks that become isolated and later buried under subsequent outwash debris flushing from the melting glacier. These buried, insulated blocks eventually melt, dropping their thin cover of outwash into a depression that fills with groundwater. The numerous kettle lakes in New York State include the Tully chain of lakes south of Syracuse.

Glaciers strongly influenced the terrain from the Great Lakes to Long Island. The area around the Allegany State Park in western New York alone escaped the power of the glaciers, although lake formation throughout the state was also the handiwork of other forces.

Human hands shape the land

Superimposed on this landscape are changes to the topography caused by human activities, such as redirecting streams and creating lakes where none existed before. For example, the Leland Ponds in Madison County previously flowed southward to the Susquehanna River via the Chenango River. With construction of the Erie Canal system, their drainage was redirected to feed the Mohawk and Hudson Rivers.

More commonly, humans create impoundments where water is confined and collected in a reservoir or farm pond. Usually, this is done by damming streams and rivers in order to provide potable water, power, flood control, or recreational opportunities. Farmers create small impoundments of water for animals, irrigation and fire protection. Several of the upland reservoirs in the central area of the state were created as water supplies for the Erie Canal system, although they are now used primarily for recreation.

Water colors

What many of us notice first about a lake is not the geological clues to its origin, but its color. Impurities and suspended particles found in lake water influence its color and clarity. The term color merits further explanation since there is a distinct difference between the color of the lake when viewed from the shore or a boat, and the color of lake water in a bottle.

The color of the lake is related to the uneven absorption of different colors or wavelengths of sunlight. Blue light will penetrate the deepest into pure water and red light will penetrate the least, causing deep, clear lakes to appear blue-green to dark blue in color. A clear, blue sky often intensifies this effect.

The biological palette of water colors, enjoyed by the visually creative but cursed by the lake user, is usually the result of different kinds of algae. **Chlorophyll** is the major pigment in the microscopic plants known as **algae** or phytoplankton that float in lake water. Chlorophyll is green, causing lakes with large amounts of algae to appear green. While chlorophyll is the major pigment, it is not the only pigment present in these tiny plants. Most major groups of algae, such as golden-brown algae *(Chrysophyta)*, green algae *(Chlorophyta)* and yellow-green algae *(Heterokontae)* can be sketched with a mostly full box of crayons. Blue-green algae, which are more correctly identified as bacteria and given the name *Cyanobacteria,* are also adorned with many colors. The most common coloration looks like blue-green paint spilled on the lake. Shades of red can be found in some species of *Oscillatoria* algae, and the less common *Rhodophycaea*, or red algae. Other species of *Oscillatoria*, some species of *Microcystis*, and many types of diatoms (silica-based algae) can be brown, as well as streaked with green and blue-green.

Color in a lake can also come from minerals and organic matter. Brown water may be the result of mineral particles or suspended silt. Some wetlands give off naturally occurring organic compounds called **humic matter**. Humics result from the breakdown of wood and other organic matter by decomposers such as bacteria and fungi. The resulting brownness ranges in color from weak tea to very strong tea. **Hard water** lakes, high in calcium and magnesium compounds, will sometimes appear whitish in color for short periods during the summer. This **whiting** phenomenon is caused by calcium carbonate condensing from solution due to photosynthetic activity in the lake.

The apparent color of the lake is usually related to the color of the water. If you took a bottle of water from a deep clear lake that appeared blue and held it up to a light source, the water would be clear, not blue. Lake water with humic matter will appear clear with a yellowish-brown tint. A bottle of lake water with algae in it will appear cloudy, with remnants of green, red, brown, or whatever other color the algae is. Water containing silt or other mineral particles will appear cloudy and brown. In short, the color of water gives you a good indication of what is in it, or at least of the natural conditions that cause it to be that color.

The water cycle

Each type of waterbody is influenced by its watershed. A **watershed** is the area of land that contributes water to that waterbody. Water may enter a lake from a watershed through streams and rivers, overland sheet flows, or through the ground as shoreline or underwater springs. A watershed may be large or small when compared to the area of a lake. The term watershed is used interchangeably with **catchment basin**, **lake basin** or **drainage basin.** The ridges and hills that divide or direct water movement into one drainage basin or another define the boundaries of a watershed.

Fig. 1–4. A watershed is the area defined by upland ridges that direct waters to a specific waterbody.
(CREDIT: WENDY SKINNER)

When water falls from the atmosphere as either rain or snow within a watershed, only a small portion falls directly on the lake. The water that falls on the watershed may move over the surface, seep into the soil or evaporate and re-enter the atmosphere. The term **runoff** refers to moving water on the surface of the ground. It might be a small trickle or a major torrent. When runoff flows in a well-defined channel, it is called a stream or a river. Some streams flow all year; some are intermittent and dry up during the summer and fall. Of the water that seeps into the ground, some is taken up by plants. The rest moves

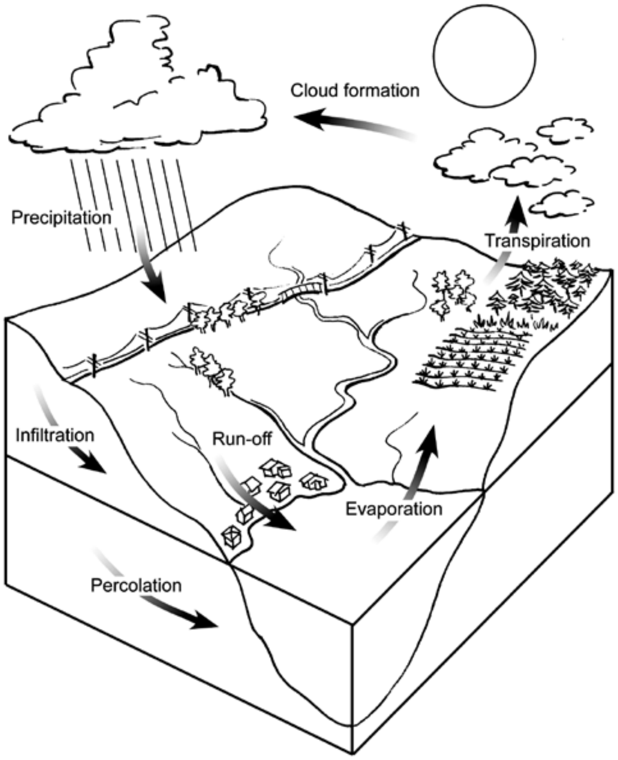

Fig. 1–5. The hydrologic cycle shows that precipitation may seep into the soil as infiltration, move over land as runoff, and then move back into the atmosphere as evaporation or due to the transpiration or respiration activity of plants and animals. (CREDIT: WENDY SKINNER)

below the surface in the pore spaces between the soil particles until it is drawn up from a well or until it re-emerges on the land's surface as springs or streams. Water gets back into the atmosphere by evaporation and the respiration activity of plants and animals, and then falls again as precipitation. This continuous movement and recycling of water is known as the **water cycle** or **hydrologic cycle.** The hydrologic cycle is a closed cycle, since water is neither added to nor removed from it. There is roughly the same amount of water on the planet now as there was millions of years ago.

At each stage in the hydrologic cycle, water can pick up dissolved substances and particles and carry them into a lake. Some of these substances can be **pollutants** that can impair the use of the water by humans, aquatic life or both. A pollutant carried to a lake by water does not necessarily leave a lake the way water does. It may settle to the bottom and be trapped in sediment, or it may stay in a lake when its water evaporates.

How long a pollutant stays in a lake before being flushed out through the outlet can be one factor in the amount of harm it causes. Since it is impossible to know how long any drop of water, or pollutant, remains in a lake, limnologists work with a calculated measurement known as the **hydraulic retention time.** This term represents the time that it would take to fill the lake if it was drained completely, assuming normal precipitation and runoff and no outflow. A shallow pond with a large watershed, and most impoundments, will have a short retention time, often only a few days. A deep mountain lake, such as Lake George, or small rural lake with a small watershed, such as many of the state's kettle lakes, may have a retention time of five to ten years or more. Lakes with long retention times are, in general, better equipped to resist the onslaught of pollution than lakes with short retention times. Lakes with shorter retention times are more susceptible to high nutrient loading. Fortunately, lakes with shorter retention times can improve dramatically if pollutants are artificially flushed out of the lake.

What's so special about water?

Water possesses many unique properties that serve as the foundation for life and are fundamental to the way a lake behaves. The previous hydrologic cycle discussion introduced a few of the special characteristics of water.

Water does such a good job of picking up and transporting pollutants because it is considered "the universal solvent." It will dissolve more substances than any other liquid. This includes many things that are not pollutants, such as the atmospheric gases oxygen, nitrogen and carbon dioxide. Cold water will hold more dissolved gas (such as oxygen) than warm water, while warm water will dissolve many chemicals and minerals.

The precipitation part of the hydrologic cycle can be influenced by water's remarkable ability to store heat energy. Water warms and cools more slowly than the surrounding air. The deeper and bigger the lake, the slower its temperature will change. This high capacity for retaining heat moderates the climate along the shore of large bodies of water such as the Finger Lakes. The air is generally warmer in the winter and colder in the summer when compared to areas far from the shore. Regions with large lakes also tend to be more humid and produce more rain and snow. Good examples in New York State are the areas to the south and east of Lakes Erie and Ontario, where so-called **lake effect storms** are common. The larger Finger Lakes also produce localized lake effect storms.

Through the hydrologic cycle, we can experience water in all three states of matter. On a hot day sweat and water evaporates. In New York State, precipitation condenses and falls as rain, snow, sleet, and sometimes as hail. At normal atmospheric temperature and pressure, water is a liquid rather than a gas or vapor. Quite simply, this cycle allows lakes to form.

Temperature variations too small to change the state of water will still change its density. The density of water is greatest at 39° F (Fahrenheit) (see Fig. 1–6). It is fortunate that water is neither like most other liquids that get denser as they get colder nor like other substances that are densest in their solid state. Surface waters become denser as they lose heat to the colder fall air and sink to the lake bottom. This continues until the lake water column is a uniform 39ºF. Waters cooling below 39ºF become less dense and remain at the surface. When surface waters cool to 32ºF, ice begins to form. If the coldest water were the densest, lakes would freeze from the bottom up, which would obliterate all aquatic life each winter in shallow waterbodies. Instead, the water just below the ice is 32° F and the densest water at 39ºF is at the bottom of the lake. This temperature demonstrates both a divine sense of humor (why 39?) and the unique qualities of water.

The differing densities of water are important during the warmer months of the year as well. Starting in the spring and early summer, most New York State lakes deeper than about 15 to 20 feet form distinct temperature layers, with the top layer warmer than the bottom layer. During the summer, the top layer gets warmer, while the bottom layer stays pretty cold. This upper layer is called the **epilimnion** (literally *over* [French] the *open water* [Greek]). It is separated

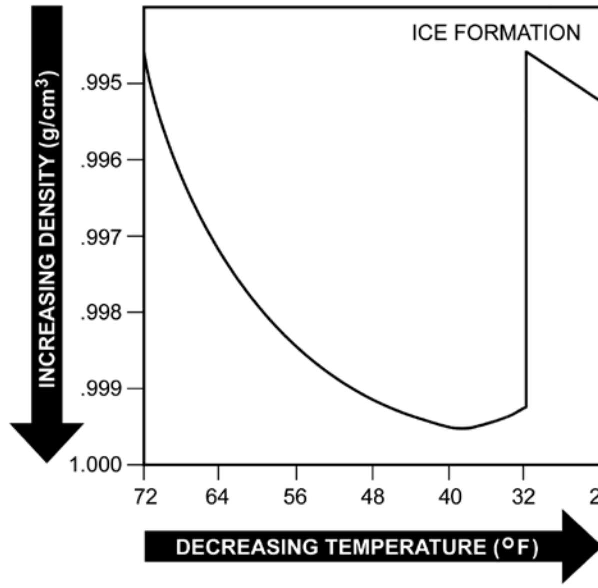

Fig. 1–6. As water cools, it becomes denser until it reaches 39ºF. It becomes lighter as it continues to cool. When water cools to 32ºF and becomes ice, it reaches maximum lightness, causing it to float.

(CREDIT: WENDY SKINNER)

from the lower layer, called the **hypolimnion** *(under water* [Greek]*)* by a very thin layer called the **metalimnion** *(among* or *within* [Greek]*)*. Within the metalimnion, the temperature changes rapidly over a very short vertical distance with the most rapid change occurring at the **thermocline**.

The thermocline creates a thermal barrier to the mixing of surface and bottom waters because different densities created by temperature differences resist mixing. These layers remain until fall air temperatures decrease, causing the water temperature and resulting density differences to decrease sufficiently to allow complete lake mixing.

A similar but less dramatic situation occurs under the ice, when less dense, slightly colder water overlies a dense 39°F bottom layer. This persists until warmer spring air melts the ice and warms the less dense water. As the temperature of the less dense, cold water warms to closer to 39°F, differences in density are again reduced allowing complete lake mixing. In most relatively deep New York State lakes, complete lake mixing occurs in the fall and spring. A **dimictic lake** is one in which this complete lake mixing occurs twice a year. A schematic of these processes is shown in Fig. 1–7.

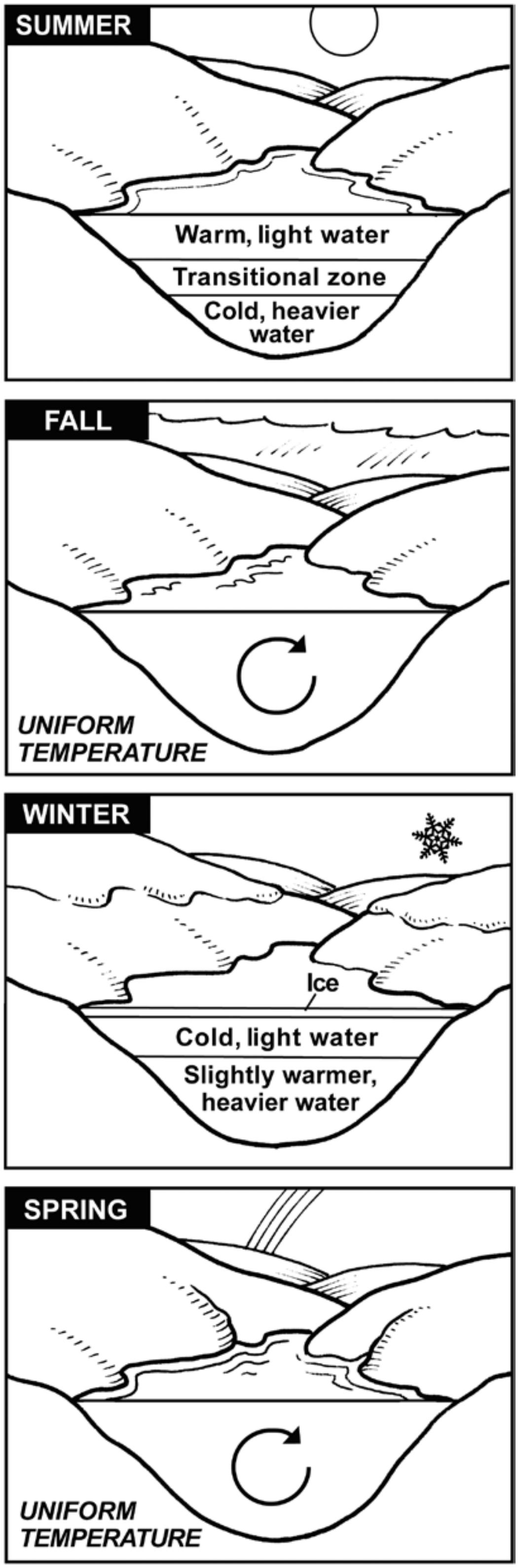

Fig. 1–7. Waters in dimictic lakes in New York State either stratify or mix depending on the season. (Credit: Wendy Skinner)

The process by which thermal layers break down and the lake mixes again is usually called **turnover**, during which time the lake is often referred to as "working." If accelerated by cold, windy weather it can occur rapidly, completing the turnover within a few days. If delayed by calm, warm days, it can occur in stages over a long period.

The depth of the thermocline generally is related to the **transparency** or clarity of the lake water and how exposed the lake is to the wind. Sun penetrates more deeply into a clear lake, resulting in a deeper thermocline than in a turbid lake. A wind-exposed lake will have a deeper thermocline than a protected lake. If the lake is very windy and clear, or very shallow, it may not even have a thermocline. A few deep New York State lakes, such as Green and Round Lakes near Syracuse, never mix due to very steep slopes and small surface areas. This is also related to very high mineral contents in the bottom waters that result in chemical stratification. These unique lakes without thermocline are referred to as **meromictic** lakes.

At the base of the ecosystem

> "If you dig a pond anywhere . . . you will soon have not only waterfowl, reptiles, and fishes in it, but also the usual water plants, as lilies and so on. You will no sooner have got your pond dug than Nature will begin to stock it. Though you may not see how or when the seed gets there, Nature sees to it. She directs all the energies of her Patent Office upon it, and the seeds begin to arrive." (Thoreau, 1854)

What Thoreau noted for Walden Pond applies to most New York State lakes and ponds. We enjoy lakes not just for their water content, but also for the richness of life they support. The origin of life in lakes may appear to be a mix of magic and alchemy, but the fundamentals are readily understood. The lake and watershed ecosystem can be viewed as a machine that converts one form of energy to another. Although there are exceptions, most energy enters the ecosystem as sunlight. Green plants store the energy from sunlight by **photosynthesis,** the process by which sunlight, carbon dioxide and water are used to produce oxygenated organic compounds, such as sugars. **Respiration** is the process that releases this stored energy. It is always occurring, but it becomes critical at night. In the dark, the green plants use oxygen to convert the organic compounds produced during the day. Carbon dioxide and water are byproducts of respiration.

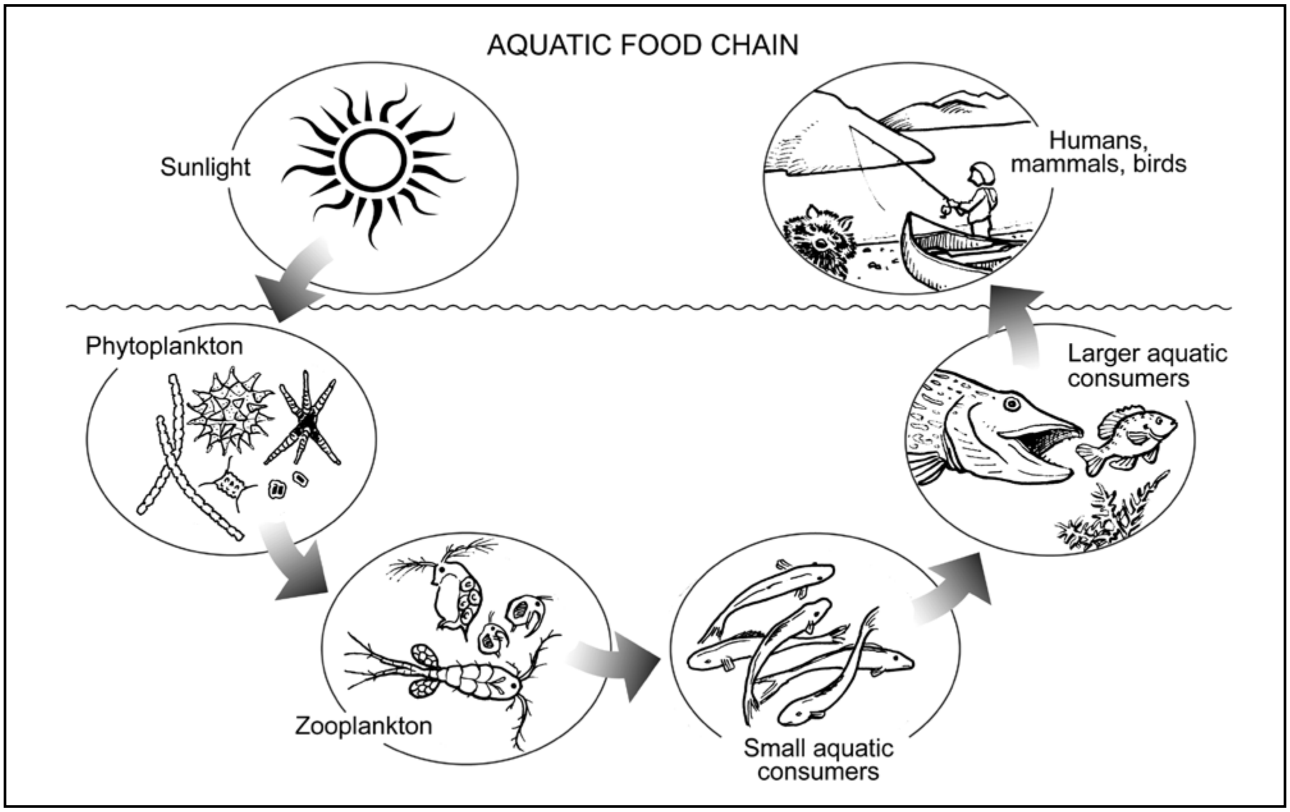

Fig. 1–8. Plants are considered the base of the aquatic food chain since they capture energy from the sun. That energy is passed along to animals in subsequent links in the food chain. (CREDIT: WENDY SKINNER)

Understanding the consequences of photosynthesis and respiration are vital to understanding the ecology of lakes. Oxygen levels in the lake increase during the day and decline during the night. The change can be drastic in lakes that have large quantities of algae and rooted plants.

Surface waters of a lake have higher concentrations of oxygen than the rest of the lake for two main reasons. Most light is available at the surface, allowing for more photosynthesis and greater production of oxygen. Significant amounts of oxygen from the atmosphere are added to the water when it is windy and some oxygen is added even during calm conditions. In contrast, at the bottom of a deep lake there is little or no photosynthesis and only respiration.

When a thermocline exists, it acts as a barrier that prevents mixing of the upper, oxygen-rich layer with the lower oxygen-poor layer. This barrier effectively defines the area where photosynthesis occurs, known as the **photic** zone. The **euphotic zone** is the portion of the photic zone near the surface where light is bright enough for photosynthesis to occur. Below the thermocline, only respiration occurs, resulting in a net consumption of oxygen. As the summer progresses, bottom waters can lose most, or even all, of their oxygen. This **anoxic** condition can trigger a series of chemical reactions that can result in the creation of hydrogen sulfide (rotten egg odor), conversion of some forms of nitrogen to ammonia, and the release of phosphorus and other pollutants from bottom sediments. Oxygen levels can also decline during the winter if the lake surface has a thick layer of ice covered by deep snow. In this condition, little oxygen and light can penetrate into the lake water, and aquatic organisms can use up all of the available oxygen.

Larger animals, such as fish, avoid water with low oxygen levels. If fish cannot find a refuge that has sufficient oxyge-n to sustain life, there will be a large die-off or **fishkill**. This oxygen deficit can also trigger chemical reactions that release nutrients from bottom sediments. Low oxygen levels are exacerbated if there is a rapid dieback of either algae or rooted plants. Bacteria that promote the decay of dead plant material consume large quantities of oxygen. If the oxygen is completely used up, only anaerobic bacteria (living without oxygen) can survive.

Photosynthesis is affected by water's **pH,** which is a measure of its acidity or alkalinity. The term pH refers to the concentrations of hydrogen ions (more literally powers of hydrogen, or pH) on a scale of 1 (many hydrogen ions, very acidic) to 14 (few hydrogen ions, very alkaline, or basic). Pure water is neutral, which is a pH of 7. The pH scale is logarithmic rather than linear. This means that pH 6 is 10 times more acidic than pH 7, and pH 5 is 100 times more acidic than pH 7. Rainfall with a pH below 5.0 is called **acid rain.** Acid rain, caused by the interaction of rain with the emissions of air pollutants, can be 400 times more acidic than rainfall without contaminants, which naturally has a pH of 5.6. In New York State, rain has been measured with pH as low as 3.

Plant photosynthesis removes carbon dioxide from water and adds oxygen. As carbon dioxide molecules are removed from water, an equivalent amount of hydrogen ions are also lost, resulting in an increase in pH. Rapid plant photosynthesis on a sunny summer day, can drive the pH up to 9 or 10. Thus, when you see a lake with a pH of 8.8 to 9.2, as commonly occurs in New York State, it usually means that large amounts of green plants are actively photosynthesizing.

When pH is too high or too low, some aquatic plants and animals die. Approximately 20 percent of lakes in the Adirondacks are so acidic that they cannot support fish life. Many species of fish and plants will die at pH 5.5, although some will survive at pH 5. The upper range for the majority of plants and animals is pH 10.

In most lakes, pH is controlled by the interplay of dissolved substances that impart acidity, including sulfates, nitrates, organic acids to a lesser extent, and dissolved carbon dioxide. Acidifying substances are counteracted by alkaline substances such as the carbonates associated with calcium and magnesium. Carbonates contribute to the **alkalinity** or buffering capacity of water, allowing some lakes to absorb acids without much pH change. Lakes in the Adirondack and Catskill regions have low alkalinity, and thus are susceptible to the strong pH changes caused by acid rain.

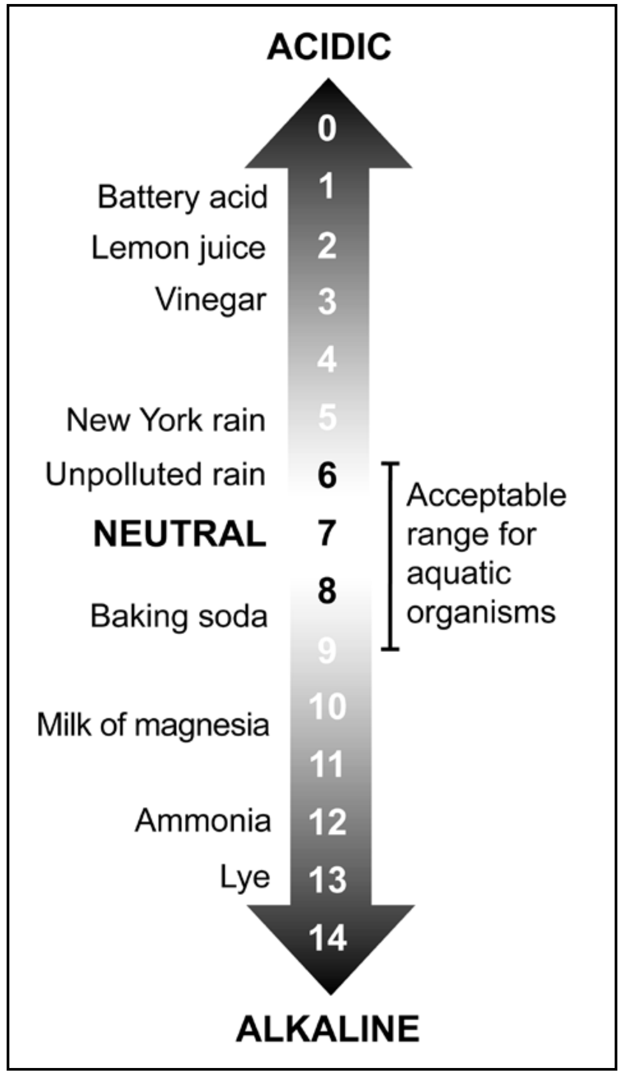

Fig. 1–9. Acidic-to-alkaline pH ranges, comparing the acidity of common items to the pH ranges acceptable for aquatic organisms. (CREDIT: WENDY SKINNER)

The cycles of the elements

In addition to sunlight, plants need **nutrients** to grow. On land, the raw materials for new roots, flowers and leaves are absorbed from the soil. For some aquatic plants, such as algae and weakly rooted plants, key raw materials are obtained from the water, but most rooted aquatic plants ("weeds") derive their nutrition from the sediment that supports their roots.

The hydrologic cycle is the key cycle affecting a lake, but it is not the only important one. The building blocks of all matter are the elements. Living organisms are made mostly of carbon, hydrogen, oxygen, nitrogen and phosphorus, with smaller amounts of sodium, calcium, chloride, iron and trace levels of several other elements. In a lake ecosystem, these elements are neither created nor destroyed, they merely move from one place to another. The movement of a specific element is called a **biogeochemical cycle**. This adjective is used to denote that the cycle consists of specific mechanisms that may, or may not, involve living organisms. As a broad generalization, the cycles of carbon, hydrogen and oxygen are of minimal interest to lake managers since those elements are rarely in short supply for the organisms of the lake. The availability of nitrogen and phosphorus in the water, however, can take up much of a lake manager's attention.

The rate of photosynthesis determines how much life can exist in the lake, since most energy enters the lake via the sunlight that plants use. The element that is in the shortest supply for photosynthesis limits the amount of photosynthesis that can occur. To understand this, imagine a barrel with vertical staves. The level of water in the barrel can only rise to the height of the lowest stave. To translate this image to plant growth, think of each stave as representing a different nutrient needed for photosynthesis such as sunlight, carbon, hydrogen, and nitrogen. The water in the barrel represents algae. The lowest stave controls the water level, the amount of the element that is in the shortest supply controls the amount of algae. This is called the **limiting factor** because the element in short supply limits the ability of plants to use any of the other elements. If more of the element that is the limiting factor becomes available, more photosynthesis can take place and there is more algal growth. This behavior is referred to as **Liebig's Law of the Minimum**, in honor of the scientist who first proposed it as a mechanism.

A number of factors can serve as the limiting factor for the production of algae. In some lakes, light transmission is limited by water clarity or dissolved organic matter making light the limiting factor. In New York State lakes, nutrients are most commonly the limiting factor for plant growth. Phosphorus is frequently the limiting nutrient because it is rare in the water in New York state lakes. Nitrogen may be the limiting factor in some lakes, particularly those with saltwater influences, or lakes dominated by green algae. Limiting factors for rooted plants are more complex, and in New York State lakes these factors are typically light, space, sediment type, and biological competition rather than nutrients. This will be discussed later.

Since the biological functioning of lakes depend heavily on phosphorus and nitrogen, these two nutrients tend to be a focus for lake and watershed management and monitoring plans. There are many other elements required for a healthy ecological balance. For any given lake, any of the trace elements found in the soils or water may be important. The discussion of lake problems in Chapter three, "Lake problems," discusses some of these "lesser" water-quality indicators in greater detail.

Food webs

The algae and rooted aquatic plants (**macrophytes**) are the **primary producers** for a lake ecosystem because they are the organisms that initially capture the sun's energy. Since photosynthesis provides the energy for the lake ecosystem, algae and rooted plants essentially drive the ecosystem. They make up the largest biomass or weight of biological organisms, about 85 percent in a lake or pond. Animals and microorganisms, such as bacteria, cannot photosynthesize. They can only respire, living off the organic matter produced by other living organisms. Without sufficient plants, animals and smaller organisms would soon run out of energy.

All animals are consumers. Primary consumers eat the producers and make up about 10 percent of the biomass. Second-order consumers and beyond eat the primary consumers, and, together with the decomposers, make up less than five percent of the total biomass. Decomposers are bacteria and other microorganisms that break down the waste products and remains of plants and animals. In the process, they make available to themselves and other organisms the nutrients needed for growth. Typically, a well-defined community of plants and animals interacts with and are dependent upon each other. Their interactions are referred to as a **food web**.

Little green dots and other green stuff

As producers, algae and macrophytes have much in common. It is worthwhile to consider them separately, however, since they also have important differences. Hundreds of species of algae are found in New York State lakes, from little green dots, to bubbling masses, to stringy filaments that look a lot like weeds. Algae can be classified by growth habitat. **Phytoplankton** are the free-floating forms (the little green dots). **Periphyton** attach to surfaces, such as stones, dock pilings and macrophytes. Periphytons that attach to macrophytes are referred to as **epiphytes**. In highly productive lakes, stringy masses of **filamentous algae** attach to boats and submerged objects.

Within these main categories, there are many different varieties of algae. There is a general progression from one type of algae to another through the seasons. Three major varieties dominate most New York State lakes: diatoms, green algae, and blue-green algae. The rapid growth of algae on the surface of lakes, streams, or ponds, which is generally stimulated by nutrient enrichment, is referred to as an **algal bloom**.

Lakes that are clear with few algae generally have diatoms, and these are seldom found at nuisance levels in most New York lakes. **Diatoms** are symmetrical, silica-based, mostly unicellular algae that are literally as fragile as glass, although their cell walls can remain intact in sediments for thousands of years. They form a significant portion of diatomaceous earth and the “skeletal” base of fossil fuels. Their persistence in sediments can be used to construct a historical record indicating when a lake started suffering excessive algal blooms. In New York State lakes, diatoms tend to be found primarily during the spring, due to their ability to survive somewhat colder conditions, and to extract silica from the water column at a time of the year when it is abundant in higher spring precipitation and runoff. When diatoms lose their competitive advantage, they tend to be replaced by green algae.

Green algae *(Chlorophyta)* is the most common and abundant form of algae. This group includes plants as well as mobile animals that contain chlorophyll, flagella (whip-like structures used for locomotion) and even eyespots! Green algae thrive where there are elevated nitrogen levels. Excess nitrogen can come from spring runoff due to the import of nitrate-rich water from acid rain and winter field fertilization. It can come from soils that are naturally nitrogen rich, typical for much of central New York and Long Island. It can also come from long-term use of fertilizers. These algal blooms are occasionally associated with taste and odor problems. The green algae tend to be replaced by blue-green algae in the late summer or early fall in many lakes, particularly those that have high lake productivity.

Blue-green algae are more correctly identified as bacteria and given the name *Cyanobacteria*. Although referred to as blue-green, they are also capable of turning water brown or red. *Cyanobacteria* are most often the cause of taste and odor problems, as well as nuisance conditions in lakes and ponds. *Cyanobacteria* maintain a competitive advantage over other algae. They have the ability to extract nitrogen from the atmosphere in a process called nitrogen fixing, allowing them to thrive as phosphorus levels increase in the water. They can avoid predation by producing gas vacuoles to regulate their position in the water. Some species produce toxins or slimy coats that are unpalatable for zooplankton and zebra mussels *(Dreissena polymorpha)*, and they form masses too large to be ingested.

The algae species listed above are usually the cause of algal blooms in the lakes and ponds throughout the northeastern United States. In some New York State lakes, however, other algae and microorganisms may also comprise a significant part of the planktonic community.

Weeding through the larger plants

The larger rooted plants that inhabit lakes, referred to as macrophytes, resemble the plants that grow on land since they usually have roots, stems, leaves, flowers and seeds. A few species of macrophytes found in New York State lack true roots, such as coontail

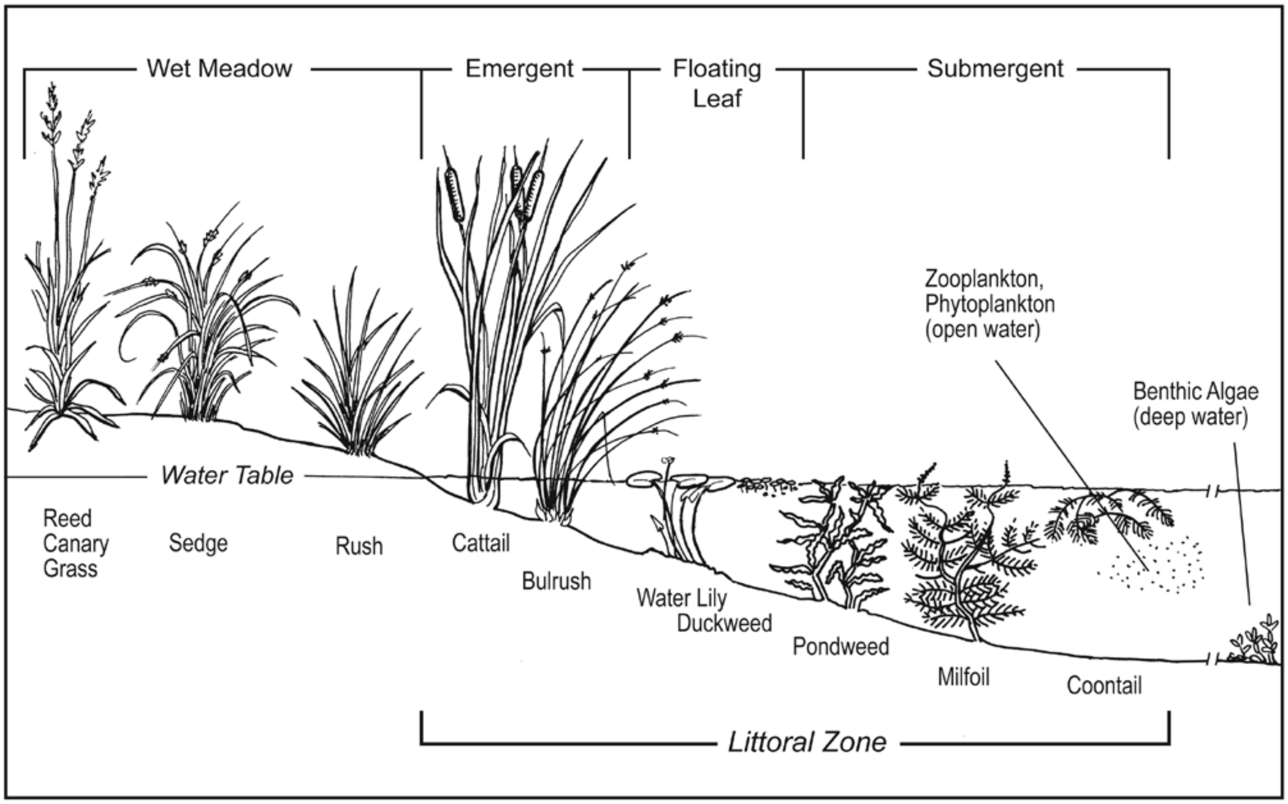

Fig. 1–10. Typical shoreline zone of a lake, pond or marsh showing the transition from upland plants to submerged macrophytes to algae. (CREDIT: WENDY SKINNER)

(Ceratophyllum spp.*)* and bladderwort *(Utricularia* spp*)*. Macrophytes are either **bryophytes,** primarily mosses and liverworts, or vascular plants that transport nutrients and water through their stems. Bryophytes are found in many New York State lakes, but they are generally inconspicuous. Most of the visible macrophytes are vascular plants.

Aquatic plants may be most noticeable to lake users when they are problematic, but functions served by aquatic plants are extensive and impressive. They harbor aquatic insects that serve as the food for fish, as well as providing a launching pad for these insects from the water to the air. They provide cover, nurseries and spawning areas for amphibians, fish and **zooplankton,** the microscopic animals found in every drop of water. They supply food for waterfowl and other creatures of the wild. They hold sediment in place, dampen wave action and otherwise control flow patterns, thereby reducing erosion and the transit of turbidity and nutrients into open waters. They create oxygen and aid in the water purification process by providing habitat for microbial degradation and converting toxic compounds to useful raw materials. Many of these macrophytes are quite beautiful, from the colorful flowers of pickerelweed or water lilies, to the delicate but dangerous nets cast by the carnivorous bladderwort, to the fern-like simplicity of Robbins pondweed. In short, aquatic plants are absolutely essential to the proper maintenance and function of a healthy and attractive lake or pond.

Macrophytes are commonly grouped by their location in the lake. Some emerge from the water, some float on the water, and some are submerged below the water surface. Most macrophytes can be classified into one of these groups, though some macrophytes exhibit characteristics of several of these categories such as having a floating leaf with most of the plant mass below the water.

Emergent plants grow out of the water at the water's edge, in the boundary between dry land or wetlands and the shallow open-water area known as the littoral zone. These plants are rooted in less than one to two feet of water and have the majority of their stems and leaves above the water. The root and stem structures in these plants are robust to withstand the highly variable water level, desiccation and scouring from ice and sediment found near the shoreline.

A large number of emergent plant species are found throughout New York State. Grasses, sedges and rushes are the most abundant, although cattails and non-native plants such as purple loosestrife and phragmites are perhaps the most prominent. The latter are considered **invasive plants** because they can disrupt the natural ecological diversity. An invasive **exotic plant or animal** is one that is not native to the area but has been introduced by animal or human activity.

Floating-leaf plants, such as water lilies, watershield, and more delicate free-floating plants such as duckweed and watermeal can be found just beyond the emergent plants. These plants grow in water ranging from a few inches to as much as six to eight feet deep. Duckweed and watermeal, growing in shallow water, look like surface algae from a distance. Although floating-leaf plants tend to grow in the most heavily used parts of lakes and ponds, they are usually not associated with nuisance conditions. Like emergent plants, they are rooted under the water (sometimes with thick rootstocks called rhizomes), but the floating leaves usually constitute the bulk of the plant mass. The exotic water chestnut, for example, is considered a floating-leaf plant, despite some underwater architecture. The floating leaves shield light from penetrating to the plant below, reducing the amount of underwater plant growth.

The plants that cause the most nuisance problems are generally **submergent plants**, which are plants with the majority of their mass below the water's surface. These are perhaps the most diverse of the aquatic plants, ranging in size from tiny grass-like plants 20 feet under water that barely peek above the sediment layer, to very tall, conspicuous leafy plants that look a little like redwoods when viewed from the lake bottom. Although the bulk of the plant resides under the water surface, some of these plants sprout a floating leaf or rosette of leaves, and even a spike of flowers above the surface, reminding us that the definitions of submergent and floating-leaf are somewhat arbitrary and confusing. Other plants grow to the lake surface and then spread laterally, forming a dense canopy that ultimately prevents other plants from growing in their shade. Several of the most problematic exotic plants, such as Eurasian watermilfoil *(Myriophyllum spicatum)*, curly-leafed pondweed *(Potamogeton crispus)*, and fanwort *(Cabomba caroliniana)* are submergent plants. In addition to annoying humans, many exotic invasive plants don't fill the important function of providing food for the next rung of the food web, the primary consumers.

Primary consumers

Primary consumers, also known as first-order consumers, feed on the primary producers. Algae are food for the small invertebrates such as snails, worms, immature insects and zooplankton. The activities of the smaller lake animals may go completely unnoticed by the casual lake user, yet they have an important role in controlling the levels of algae and influencing the kinds and numbers of fish in the lake. For example, in the early 1980s, alewives, a member of the herring family, were introduced into Conesus Lake, one of the Finger Lakes. The alewives grazed voraciously on *Daphnia*, a type of zooplankton. When *Daphnia* populations plummeted, algae grew largely unchecked and water clarity suffered. The increase in algae occurred despite continuing decreases in nutrient concentrations. Without the disruption to the primary consumers *(Daphnia)*, a decrease in algae levels and increase in water transparency would have been anticipated as nutrient levels declined. In contrast, the water clarity of several other Finger Lakes has increased because of an increase in a primary consumer, the zebra mussel *(Dreissena polymorpha)*. Populations of this exotic bivalve spread to the Finger Lakes and beyond after its accidental introduction into the Great Lakes in the early 1980s. Zebra mussels have filtered out large quantities of algae resulting in a substantial increase in water clarity. Zebra mussels further alter the ecology of a lake by not consuming blue-green algae, which they avoid due to the algae's gelatinous coating.

Size does not determine placement within the food web. While most of the primary consumers are inconspicuous, primary consumers also include clams, sponges, several fish species, wood ducks, muskrats, and moose. Some of the smallest animals in a lake or pond, including the zooplankton, may eat the primary consumers and are therefore known as secondary or second-order consumers. Many animals, including some fish, are less selective **omnivores**, consuming both primary producers and primary consumers. The majority of fish are primarily **planktivores** (zooplankton-eating) or **piscivores** (fish-eating), but most also include algae within their diet. So while the big fish usually do eat the little fish, the size of an organism does not always dictate their culinary habits.

Second-order consumers and beyond

Second-order consumers feed on primary consumers. Second-order consumers include conspicuous members of the lake community, such as planktivorous fish, most turtles and amphibians, as well as the smaller backswimmers, water striders and *Hydra,* which are common in the shallow waters of ponds and crowded college biology and mythology classes. Second-order consumers are eaten by **third-order consumers**, and so on. This pecking order is not always sequential. Sometimes, tertiary or third-order consumers will eat primary as well as secondary consumers. Third-order consumers include some of the large animals found in the marginal or shoreline habitat including raccoons, herons and snapping turtles. As the consumer order increases, the number of species and the abundance of individuals within the species tend to decrease so there are fewer top predators. Consumers, in turn, are fed on after death by scavengers such as leeches, flatworms, waterboatmen and crayfish.

All of these organisms become food for the **decomposers,** the bacteria and fungi that break down all living things and are invisible to the naked eye. Decomposers convert large quantities of organic matter back to carbon dioxide and nutrients, the basic elements needed to support photosynthetic organisms. The process is called **nutrient recycling.** Not only does this prevent the accumulation of thick layers of organic material, it also renews the food web necessary for the maintenance of the entire lake ecosystem. Oxygen is used in the decomposition process, which reduces the amount of oxygen in bottom waters. When oxygen is depleted, noxious or even poisonous chemicals are produced in large quantities. The result is “rotten egg gas” (hydrogen sulfide), and “swamp gas” (methane and ammonia). Some decomposers are pathogenic, and will be discussed in more detail in Chapter four, “Problem Diagnosis.”

The vanishing Common Loon: Harbinger of trouble in the food chain

There is probably no better symbol of the Adirondacks than the loon. Furtive and mysterious, its haunting call beckons those longing for a simple yet rugged life. Nearly 1,000 loons are in New York State, mostly found in remote Adirondack lakes from spring to late fall. Although four loon species are found in North America, the common loon is the only one that breeds in New York. While not an endangered species, the common loon is a species of special concern due to low numbers and to their symbolic importance.

The common loon, like the secluded Adirondack Lake, is threatened by increasing residential and recreational demands. Loons are considered excellent environmental beacons, since they live 20-30 years as second-order consumers often returning to the same lakes each year. Loons are affected by environmental stressors when they ingest mercury-tainted fish and lead sinkers, and when acid rain causes fish populations to plummet. Many organizations are concerned about environmental factors causing a decline in the health and reproductive success of loons. The Adirondack Cooperative Loon Program studies these magnificent birds and the effect of mercury contamination on reproductive success of loons in the Adirondacks. Their work is coordinated with similar research throughout northeastern North America, according to their website (see Appendix F, “Internet resources”).

Lake habitats

To help make sense of the richness of life within water bodies, biologists have identified discrete regions of lakes called **habitats**. A habitat is a zone where environmental conditions are rather uniform spatially. Each habitat will support a food web made up of certain types of plants and animals. In most lakes, there are several important habitats: the near shore, **littoral zone,** the open-water, **limnetic zone**, and the deeper, bottom water of the **profundal zone**. The littoral zone is generally found within the epilimnion, while the profundal zone is within the hypolimnion. In each habitat, there is a well-defined community of plants and animals and their interactions are referred to as a food web. The composite of the food webs in the three different habitats makes up a larger food web for the whole lake. In a shallow lake, the bottom and littoral organisms dominate the lake's food web. In a deep lake, the open-water zone is more important than the littoral and deep-water zones.

Some simple physical factors determine the amount and kinds of plants and animals that will be present in the food web. If the slope of the bottom is very steep or the water is very turbid, the littoral zone will be very narrow since the water's depth and clarity limit how much light reaches the bottom. If the littoral zone is exposed to the continuous pounding of wave action, plants may be scarce. In a windy location, the bottom may be sand, gravel or large boulders, limiting the accessible soil needed by many rooted plants.

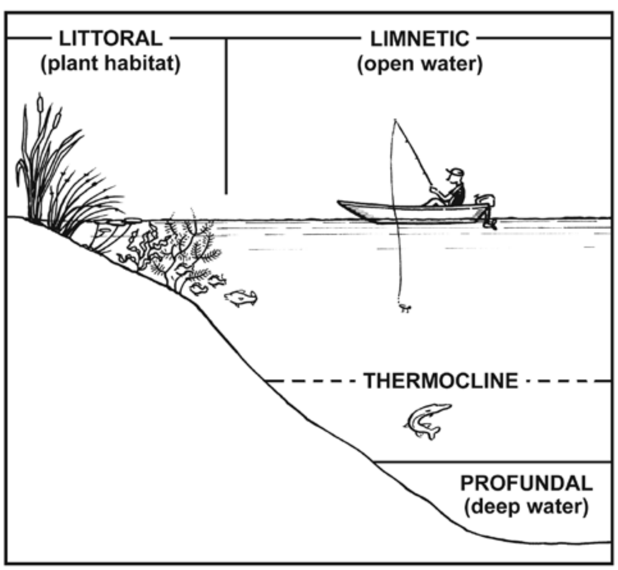

Fig. 1–11. Biologists divide lakes into habitat zones. Each zone—littoral, limnetic and profundal—supports a different aquatic community. (Credit: Wendy Skinner)

The littoral zone extends from the water's edge and includes the area containing macrophytes or rooted plants. Some of these plants are discussed in much greater detail in Chapter six "Aquatic Plants." The littoral zone is ecologically similar to terrestrial habitats. It is very productive and rich in diversity, meaning it has many kinds of plants and animals. Many larger animals, such as fish, frogs, birds and turtles find food and refuge among the plants. The aquatic plant beds serve as a nursery area for young of the warmwater fish that occupy the littoral zone. A wide variety of algae, crustaceans, insects, worms, snails, clams and microscopic animals inhabit this zone.

In the open-water limnetic zone, algae (phytoplankton) and small animals (zooplankton) form the base of the food web. Phytoplankton move at the whim of water movements and gravity, although some can regulate their buoyancy. Zooplankton slowly propel themselves up and down in the water column, which allows them to graze on the phytoplankton and avoid predators. Zooplankton include **crustaceans** and other small animals without backbones (**invertebrates**). Crustaceans are the freshwater relatives of shrimp and lobsters and under the microscope look quite similar to their larger marine cousins. The zooplankton are food for larger invertebrates and most fish, at least at some developmental stage.

At night, the open water may also contain bottom-dwelling animals, such as immature forms of insects (**larvae**) that migrate from the bottom to the lake's surface. They may hatch and fly away, or feed and then return to the bottom before daylight. The open water is also home to some free-floating fungi and bacteria. Larger animals such as fish, fish-eating birds and turtles may be found in this zone occasionally.

The profundal zone has still, cold water, and little sunlight. The plankton that sinks to the bottom of the lake provides the energy and raw materials that fuels the decomposers, such as bacteria and fungi that dominate the bottom region. If there is sufficient dissolved oxygen, there are also some invertebrates and large predatory fish, such as lake trout, that are attracted to the cold bottom waters during the summer months.

In extremely clear lakes, the bottom may be colonized by microscopic or macroscopic algae. The colonial forms may attain heights of several feet and even look like the more complex plants that grow along the shore. These forms are termed **benthic algae** and sometimes are confused with rooted vascular plants. Two common types are brittlewort *(Nitella)* and muskgrass *(Chara)*.

Lake eutrophication and the succession of lakes

> "Lakes are so ephemeral that they are seldom developed in the geologic record. They are places where rivers bulge, as a temporary consequence of topography. Lakes fill in, drain themselves, or just evaporate and disappear. They don't last." (McPhee, 1986)

Although lakes seem permanent in our human time perspective, they are temporary in geologic time, changing more slowly than we can perceive. Lakes act as sediment traps, and it is natural for them to gradually fill in with sand, silt and organic matter. Natural lake aging is the process of nutrient enrichment and basin filling. It moves lake **trophic levels** from a nutrient-poor (**oligotrophic**) condition to an intermediate (**mesotrophic**) stage of nutrient availability and biological productivity, and finally to a nutrient-rich or highly productive (**eutrophic**) state.

It should be understood that this is an inevitable natural process, just as human aging is inevitable. However, the lifespan of lakes, or at least entities that we recognize as lakes or ponds, occur over hundreds to thousands of years unless eutrophication is greatly accelerated by disruptions to a watershed.

Trophic conditions in lakes are relative, not absolute. There is no definitive line between oligotrophic and mesotrophic, or between mesotrophic and eutrophic. Each trophic state, however, has characteristic conditions. Oligotrophic lakes have little organic productivity, clear water and low nutrient levels. These lakes area often characterized by deep water

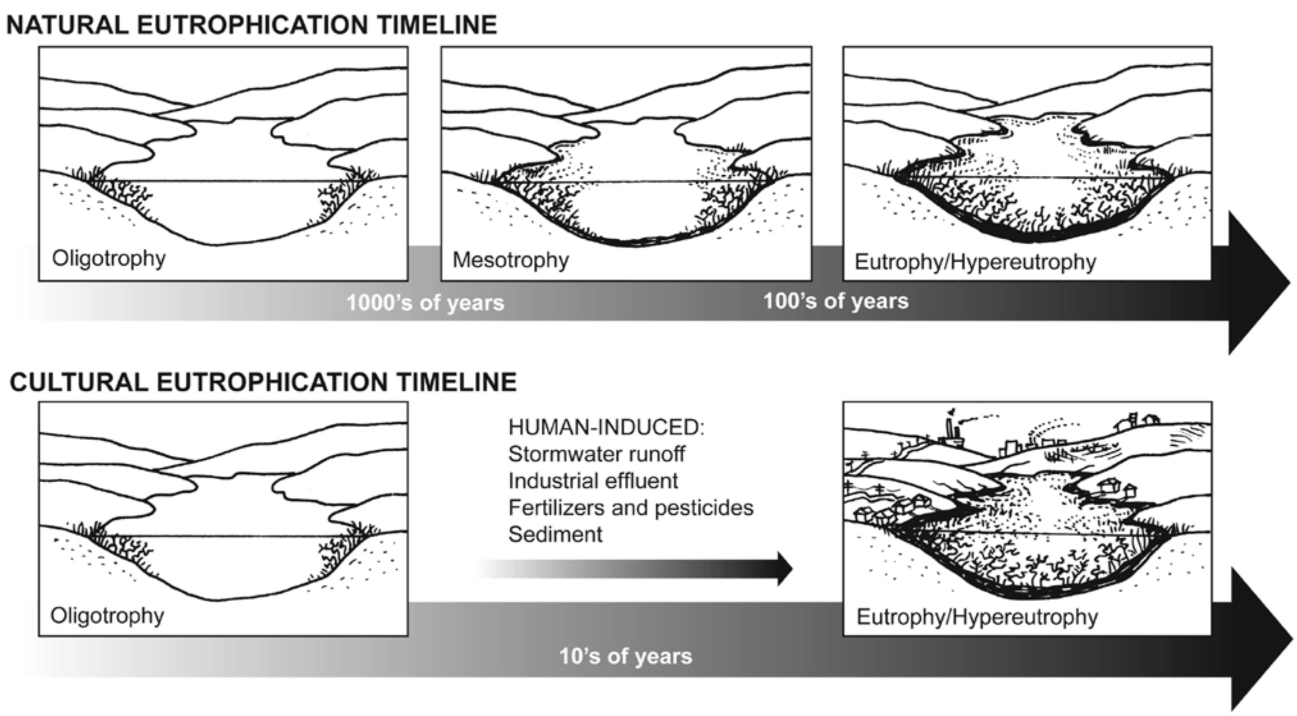

Fig. 1–12. Lakes naturally and slowly progress towards eutrophic conditions. When human activities accelerate the process, it is called cultural eutrophication. (CREDIT: WENDY SKINNER)

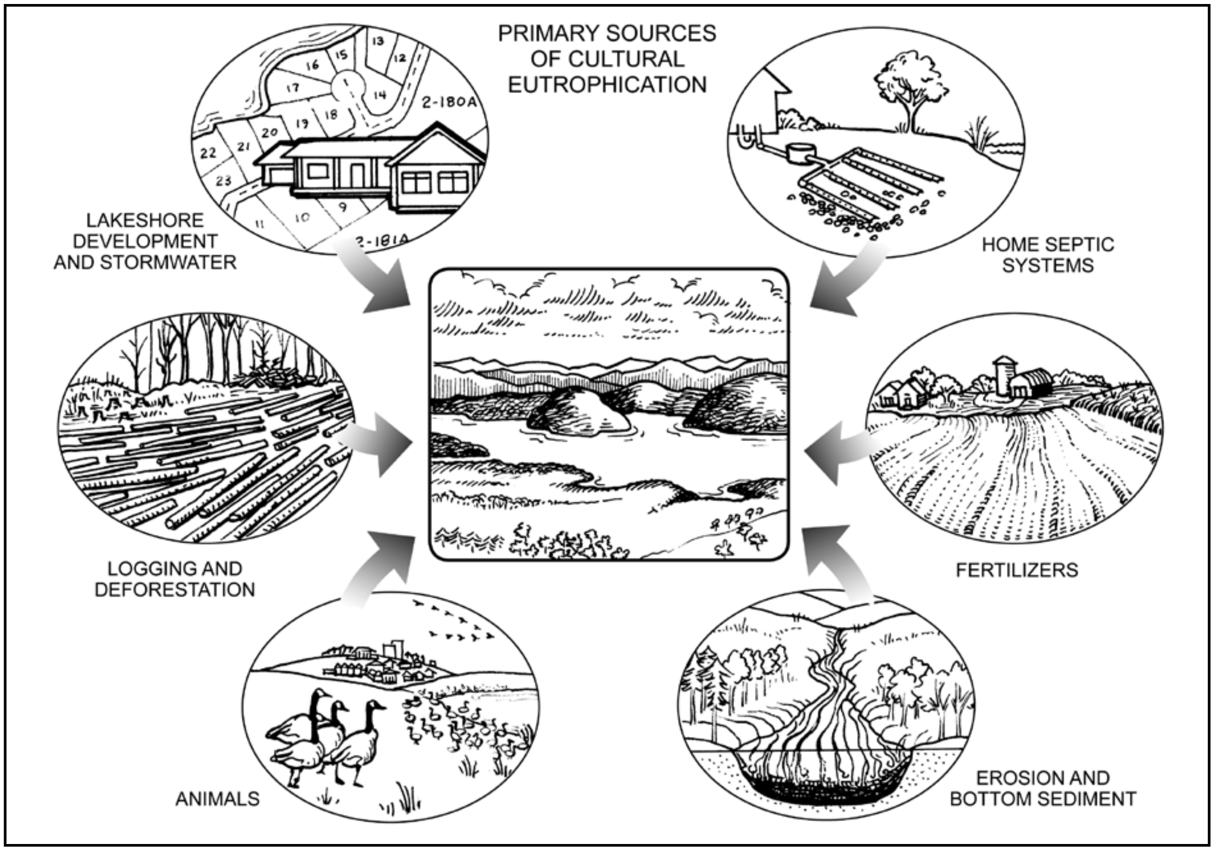

Fig. 1–13. Primary sources of cultural eutrophication. Human activities such as housing, logging, and farming accelerate the rate of natural eutrophication. (CREDIT: WENDY SKINNER)

and steep basin walls. Water in mesotrophic lakes contains a moderate supply of nutrients and organic production. Eutrophic lakes are characterized by a very high level of nutrients that cause a significant increase in the rate of plant growth, usually algae, but sometimes rooted plants as well. Water clarity is greatly reduced, and oxygen depletion is common during the summer months as that organic matter decomposes. Eutrophic lakes tend to be shallow and, typically, have elevated water temperatures.

Lake ecologists may inherently view high productivity in a very different way than an economist. In lakes, high productivity is often thought of as bad. However, these trophic states do not necessarily indicate the existence or even threat of water-quality problems. Some lakes are naturally more productive than others, due to underlying geological influences, slopes and other geomorphic characteristics. **Geomorphology** relates to the geology and shape of the lake basin. The ecosystem and water-quality conditions associated with these lakes have evolved over time to support certain flora and fauna that represent "natural" conditions for the lake. Different species of organisms, from algae to plants, and from insects to fish, inhabit lakes with different trophic conditions. Some naturally more productive lakes, such as Oneida Lake, support healthy warmwater fisheries. Other less productive, oligotrophic lakes, such as some remote and/or acidic lakes in the Adirondacks, may not support warmwater fisheries or may be too cold during much of the summer to promote swimming. So oligotrophic is not necessarily synonymous with healthy, and eutrophic does not necessarily mean unhealthy. However, a shift in trophic condition away from "normal" for a particular lake will often signify underlying water-quality problems and result in use impairments.

Human activities that increase nutrient and sediment loadings to a lake are termed **cultural eutrophication** and include forest clearing, road building and maintenance, farming, construction and

wastewater discharges. If appropriate precautions are taken, damages from these necessary activities can be minimal. Without precautions, these activities can greatly accelerate the natural aging process of lakes; cause successional changes in plant and animal life within the lake, shoreline and surrounding watershed; and impair the water quality and value of a lake. They may ultimately extend aquatic plants and emergent vegetation throughout the lake, resulting in the transformation of the lake into a marsh, prairie, and forest. The influence of cultural eutrophication in the short term may be seen in reduced water depth, decreasing water clarity or more frequent algal blooms. The period of time for such changes to be seen can sometimes be as short as several decades, although it is important to remember that fluctuations in water transparency, algae levels, and other measures of eutrophication also occur naturally from year to year.

Really big picture stuff

While a watershed profoundly affects a lake, there are even larger systems at work. As in localized cultural eutrophication, human activities can accelerate changes in the larger systems of atmosphere and climate. Greenhouse gases, including carbon dioxide and other air pollution, collecting in the atmosphere, trap the sun's heat and cause the planet to warm up. Most scientists believe this global trend, referred to as global climate change**,** or **global warming**, is dramatically affecting the ecological balance of the planet and is likely to increase severe weather conditions, including more hurricanes, flooding and droughts. Most of the climate change research has not been conducted at a sufficiently detailed scale to evaluate how it affects the small lakes and ponds in New York State. The normal changes from year to year make it difficult to sort out which are caused by global climate change, but some patterns are emerging.

An evaluation of more than 150 years of ice-in/ice-out data from about 40 lakes around the world, including Oneida, Otsego, Schroon, and Cazenovia lakes in New York State, demonstrated that the period of ice cover decreased in about 95 percent of these lakes over this period. For the first 100 years, until about 1950, the duration of ice cover decreased about 12 days, starting about six days later and ending about six days earlier. Since 1950, ice-in started about nine days later and ice-out ended about 10 days earlier, although on average the decrease in the duration of ice coverage in the four New York State lakes was about half the worldwide average. While there was some evidence that this followed a nearly 400-year-old trend, based on sediment core analyses, it appears that the warming trend escalated in the last 150 years.

Changes in water temperatures could impact coldwater fisheries habitats, forcing some fish to relocate. Half of the coldwater habitat in the New York portions of Lake Ontario and Lake Erie could be lost. If temperature and oxygen mixing patterns change, significant reductions in phytoplankton and zooplankton, the base of the food chain, could result. The migration and establishment of historically southern-climate exotic species in the northern temperate climate New England and Mid Atlantic states can be attributed at least in part to global climate change. And it may not be coincidental that increasing occurrences of harmful algal blooms and toxic algae in recent years has been coincident with these warming trends.

The effect of global climate change on lake ecology will continue to be studied in great detail. As this research progresses, however, the effects from global climate change may still not approach the way local actions influence all components of small lake systems in New York State.

Summing it up

This basic introduction to lake ecology is fundamental to understanding the subsequent chapters including how to address the many problems that plague lake users. It was not intended to be a primer on lake ecology. Entire textbooks, college courses, and endless sunrise debates between waiting fishermen have been dedicated to some of these topics. The reader is encouraged to seek out additional resources related to the management activities for the lake he or she loves. Biomanipulation and drawdown are examples of strategies discussed later in this manual that call for a more focused knowledge of the interactions of the biology, physical and chemical aspects of a lake.