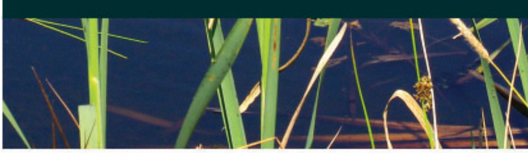
Limnology

An Introduction to the Fresh Water Environment



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LIMNOLOGY

An Introduction to the Fresh Water Environment

By William H. Amos

INTRODUCTION

A great deal has been written about the oceans and the seashore, yet areas for the study of marine science are accessible to relatively few teachers and students. Coastlines often are barren beach or difficult-to-traverse marshland. Without question the marine environment has a strong attraction for all of us, but much of what a student group might study at the shore concerns universal phenomena and basic principles common to all water, fresh and salt alike, and the life it supports.

Rivers, ponds, brooks, lakes, or flooded ditches are aquatic environments as well, and they are available everywhere. For example, there are over a million man-made ponds in the United States today. A pond is easy to study: it has observable limits, little wave action, obvious sources of contributions from the land, and living organisms that are neither difficult to find nor to collect. There are comparatively few species of plants and animals, but very large populations. Zonation of life from land to open water is just as evident as it is at the seashore, and patterns of successive populations which follow one another as a pond grows older may not only be more obvious, but more rapid and dramatic than along the coast. We may think of a pond as a microcosm, or self-contained world; to a degree this is true, although it must be realized a pond is easily affected by surrounding conditions.

The far fewer lakes of our continent have features that clearly distinguish them from shallow ponds. Nevertheless, much of what is evident in anyone body of standing water applies to all, despite differences in size, depth latitude, chemical nature, and productivity. Flowing waters naturally have somewhat different characteristics, but they too can be studied without difficulty wherever they occur. Even an odorous and unsightly polluted stream is a valuable outdoor laboratory. While stream life usually is less tolerant of change than that of ponds and lakes, it frequently is less known and more specialized and offers valuable opportunities for study.

An introduction to limnology in this handbook can suggest only a few basic ideas that concern fresh water and the populations it supports. If some of the topics included here are to be used in science courses, it matters little what level students are at; a fresh water environment offers unlimited material to be presented to younger children as well as challenging areas of serious study for older and more experienced students at the college level. For example, at one preparatory school physics students have worked with wave and circulation patterns in a local pond; chemistry students chart seasonal and diurnal changes in dissolved oxygen, phosphates, nitrates, and other factors; earth science students take core and analyze bottom sediments; and

Figure 1 - Eutrophic ponds produce enormous quantities of plant and animal life along their shores extending out into open water. In summer such a pond may grow opaque with explosive blooms of plankton.

biological studies range from the physiology of fresh water clam mantle tissue to population dynamics of burrowing aquatic worms. Students in separate courses may join forces to investigate the hydrodynamic properties of diving beetles or analyze amino acids in specific animal tissues. There is such a wealth of questions to pursue that few topics have been repeated in this school over a period of twenty years, and some have been developed in depth by successive generations of students.

Our planet occupies a rather narrow belt in the solar system known as the water zone! It is only at this distance from the sun that water exists as a fluid; closer in it vaporizes at once, and on the outer planets, if it exists at all, it does so permanently locked in its solid state.

Nowhere in nature is plain, simple water to be found. On earth, where its geologic origin dates back over three billion years, water in even its purest form is composed of many ingredients. Not only are there H_2O molecules, but hydrogen (H^+) and hydroxyl (OH^-) ions, which may have a profound effect upon the life present, plus ions of sodium, potassium, magnesium, and other elements.

There are dissolved compounds including various chlorides, carbonates, sulfates, and silicates. Even rainwater, often assumed to be the equivalent of distilled water, collects some of these substances while descending through the atmosphere. When water rests in basins it flows across the face of the land, it carries with it varying amounts of dissolved gases, such as oxygen and carbon dioxide, and of course a multitude of minerals and organic substances leached from the soil. A crystal-clear lake is not water alone, but a complex medium of chemical constituents far exceeding the brief list given here, a medium in which highly specialized life occurs.

Water is never stationary, although when it is trapped deep beneath rock strata, it may move very slowly, taking thousands of years to break out into a distant ocean. Some lakes appear to be very still, but they receive water from springs, streams, and surface runoff, and lose water through other streams and evaporation.

The familiar cycle of evaporation, condensation, and precipitation, the hydrologic cycle, is illustrated here in simple fashion, yet who is to know the course of one water molecule? It is free in the atmosphere, collected as a cloud, part of the soil, cascading down in a brook, in the depths of the ocean, or a part of the metabolism of some plant or animal that may be far removed from any obvious source of water in a continental desert.

The hydrologic cycle is a manifestation of an enormous heat engine in which water is raised in the warmer latitudes by a prodigious transformation of solar energy, transferred through the atmosphere by the winds, and eventually deposited far away over sea or land. The science of limnology concerns that water which falls on the solid earth and is retained on the surface, if only temporarily. Its characteristics during this tenure have made it possible for life to colonize the land. While nearly all basic life forms originated in the sea, they slowly crept up rivers and into lakes, ponds, and swamps. Only after they became established in fresh water was the last invasion possible that of the land. Fresh water today is filled with remnants of this glorious migration; in fact, there still are some plants and animals that are making the transition.

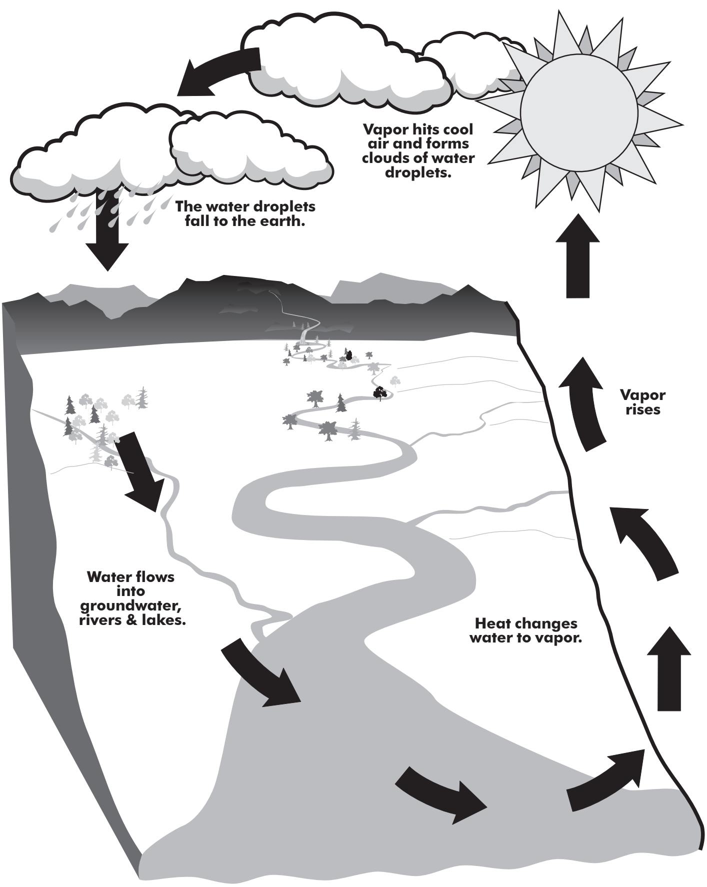


Figure 3 - Water is constantly in motion, evaporating from sea, lakes, and the soil; being transported through the atmosphere; falling to earth; running across the land; and filtering downward to flow along rock strata.

THE PHYSICAL STATES OF WATER

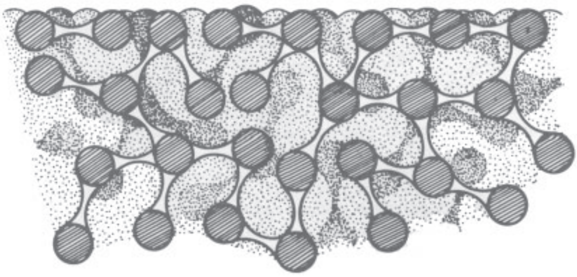


Figure 4 - SURFACE FILM The four hydrogen bonds connecting each water molecule with its neighbors extend in all directions except at the surface, thus creating a tough film.

Water is not only the most common substance on the surface of the earth, but also one of the most unique chemical compounds known. It is exceptionally stable. Each asymmetrical H_20 molecule consists of a single oxygen atom to which are bonded two hydrogen atoms lying 105° apart from one another. In liquid water, every molecule establishes hydrogen bonds with four of its neighbors, eventually forming long, branching chains. At normal temperatures, these hydrogen bonds form and break at an equal rate, but when the temperature rises and molecular activity increases, the linkages break more rapidly than they form and water molecules escape into the atmosphere. If the temperature drops, the tetrahedral network becomes firmly locked together into crystals that form at random, pushing against one another, leaving air spaces in between. The result is one of the most peculiar properties of water; it is most dense in its liquid state at approximately 4°C , and less dense not only as a gas but as a solid. Were it not for this last characteristic which allows ice to float, most deep waters, lake and ocean alike, would be frozen solid to within a short distance of the surface, an impossible medium for life.

The hydrogen bonds that make water a stable compound create another familiar characteristic, the surface film of liquid water. Beneath the surface water molecules exert an equal attraction for one another and in all direct ions, but at the surface similar molecules all lie beneath and to the sides. This means that a surface molecule has its four bonds extending sideways and downward; the result is a strong, elastic film that becomes very important to plants and animals living at the surface in fresh water. Surface tension is also important in drawing water through the soil of the surrounding shoreline of pond and stream, and helps it to rise through the conducting tissues of plants.

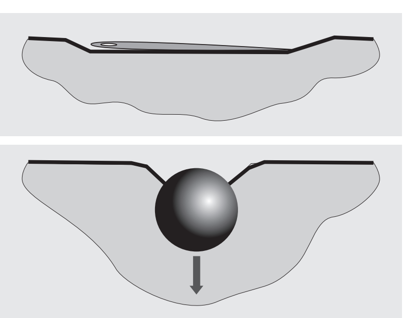


Figure 5 - The surface film will support relatively heavy objects with much surface area (i.e. needle) but not those of compact shape with little surface area compared to their mass (i.e. marble).

Other unique characteristics of water are its temperature relationships. A large amount of heat is needed to raise water temperature even a little; in other words, water is a vast storehouse for heat energy derived from the sun and the atmosphere. A pond, small though it is, warms or cools very slowly in accordance with the seasons, a matter of great importance to aquatic life that cannot cope with sudden, drastic changes. Larger bodies of water may be almost totally unaffected except close to the surface. This phenomenon, the storing of heat, is known as specific heat and is exceeded by only a few other substances.

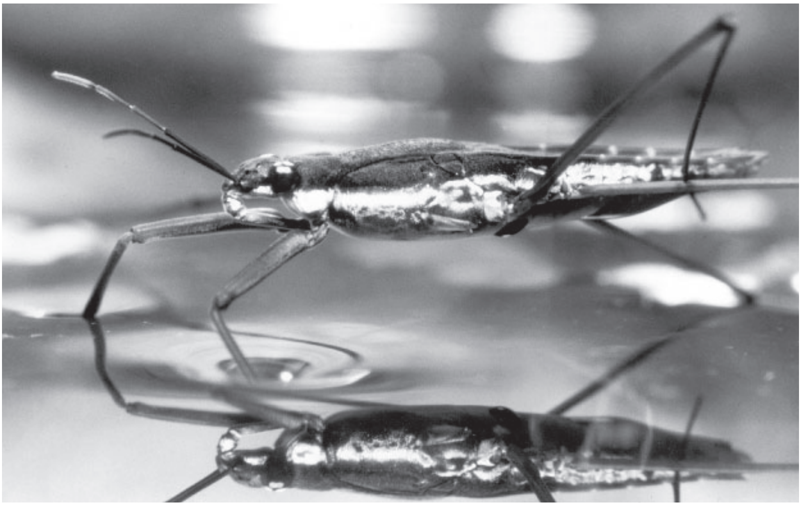


Figure 6 - The water film serves as a habitat for many specialized organisms. Water striders have water repellent pads on their feet which keeps them supported on the surface film.

Latent heat refers to the temperature exchange necessary to convert water from one state to another. For example, a large amount of heat is lost when it changes from liquid to solid, and much heat is required to change it back again. Latent heat becomes an important matter to consider when studying weather, for evaporation and condensation, the essence of the hydrologic cycle, involve an enormous transformation of energy.

The density of water varies little, reaching a maximum at 4°C as described earlier. This slight variance has an effect upon life in fresh water, but far more important is the high viscosity of water which, considered one way, is the resistance between layers of flowing water in a stream, or between the gentle currents in pond or lake. A cross section of a stream shows distinctly separate layers flowing unmixed past one another, a fact animals and some plants must cope with. Furthermore, an animal swimming through water must use far more energy than a similar creature in the air, with the result that in aquatic animals there are all kinds of anti-frictional surfaces and a high degree of streamlining, which allow effective movement through a medium of high viscosity.

Another factor of importance to aquatic plants, and to all life everywhere, is the dissolving power of water. It is a universal solvent: more than any other liquid, it allows the dispersal of other molecules through its own substance, and in doing so, makes available vital nutrients and gases to the myriad lives existing in water. The gases of greatest importance to life are oxygen and carbon dioxide, but the manner in which they dissolve in water does not result in the familiar situation found in air. Under ordinary conditions, water contains 30 times less oxygen for a given volume than is present in air. Terrestrial animals have no difficulty in acquiring sufficient quantities of this essential gas, but a fish, for example, must not only be very efficient at removing oxygen from the water, but is in jeopardy whenever the quantities of dissolved oxygen diminish during normal seasonal changes (high temperatures or an impervious ice cover) or when it is consumed in large quantities by other organisms, such as bacteria. The animals that are present in a body of water are either restricted to oxygenated regions near the surface, or have special means of utilizing this gas in oxygen-poor regions (certain midge larvae and segmented worms, with hemoglobin in their blood, are in the latter category). On the other hand, there is about as much dissolved carbon dioxide dissolved in a given volume of water as there is in air, The result - as one might guess from looking at a pond - is that aquatic plants of all types find favorable conditions for growth. Finally, the most abundant gas in the atmosphere, nitrogen, occurs in very small quantities in water where it can be used only by bacteria, blue-green algae, and some fungi.

Fresh waters may be divided into those that flow downhill and those that rest quietly in basins, shallow or deep. Some of the terms employed to distinguish these different aquatic environments are brooks, streams, rivers, estuaries, bogs, swamps, marshes, ponds, and lakes; each has its own subdivisions. Classifications of this sort are highly arbitrary, but necessary and useful. A handbook of this size can only sketch a few characteristics of each, but in the bibliography will be found many useful references that will help a student or instructor to pursue his studies in greater detail.

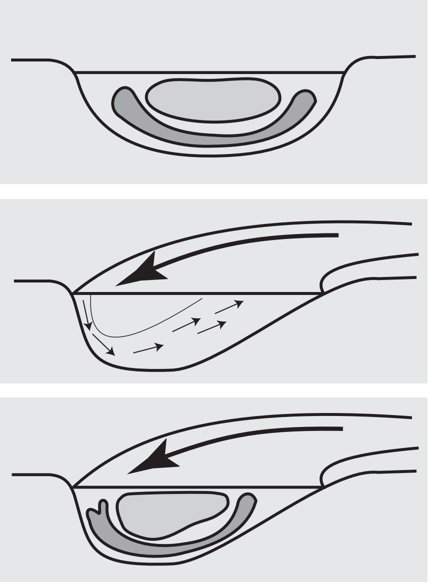


Figure 7 - STREAM FLOW All the water in a stream does not flow at the same rate. **Top**: *A central thread of high velocity water runs down the center, separated from the quiet water along the shore and bottom by a layer of turbulence (dark gray area).* **Middle**: *Not only does water flow down a stream, but flows laterally away from the great pressures exerted against the outer curve.* **Bottom**: *In a curve, the zone of high velocity water is displayed by centrifugal force toward the outer bank, where the layer of turbulence is also greatest.*

For a worthwhile limnological study, it makes little difference which of these aquatic environments is selected, but it is wise to select only one and work with it as thoroughly as possible before moving on to another. A single pond can keep successive generations of students occupied for years; following the seasonal variations in one small stream may demand an entire class's attention throughout a year, and no two years will be precisely the same.

In attempting to define a particular fresh water environment, it is important to measure accurately as many physical and chemical characteristics as possible before proceeding with biological studies. The presence or absence of organisms is understood largely in the light of the environment in which they live. Some of the more important factors are temperature, transparency (turbidity), color, velocity, dissolved oxygen, pH, salinity (if a stream is influenced in any way by the sea), and whatever other chemical factors it may be possible to discover, including nitrogen, phosphorus, sulfur, calcium, and a variety of other elements. These last occur in compound form and, if their quantities cannot be determined, at least their presence may be ascertained by simple chemical tests.

RUNNING WATERS

An upland brook is cold, very turbulent, and descends a steep slope very rapidly. It consists of water that has recently fallen or run off the hillsides, therefore is clear or perhaps stained a tea color by the humic acids and tannins of fallen leaves and pine needles. Because of its recent origin, the high altitude, and shaded streambed, the water remains cold and unaffected by the atmosphere, however warm a summer day it may be. The turbulence around every rock and below every riffle means a high degree of aeration, so the water is generally saturated with oxygen. The great velocity and turbulence also immediately carry away all fine particles, so there is no mud and very little sand except in the lee of a large rock. Deep pools may be scoured out by strong eddies which spin rocks around in cavities, grinding even bedrock into basins.

Such an environment presents challenges and hazards that overcome all but the most specialized inhabitants. A screen held across a riffle area will collect little in the way of active life, but all sorts of vegetable and animal debris being carried down the swift stream. If stones and rocks are lifted and disturbed a few feet upstream, the screen will suddenly be filled with crawling and wriggling creatures. Understanding something of the viscosity of water, friction and laminar flow, will provide the answer. No matter how swift the current, the region immediately adjacent to the bottom is relatively quiet, and animals live there in abundance as well as in even more secure cavities under rocks. Brook animals may be bottom-hugging fish, such as the darters, or simpler animals like flatworms. By far the most numerous are aquatic insects. Some are spraddle-legged and crawl about clinging to the surfaces of stones; others burrow into crevices; still others construct secure houses of sand grains and silk on the face of riffle stones. Nearly all depend upon the organic matter brought down by the current, and may even weave intricate nets of silk with which to capture their food. Plants are not to be outdone: one form of moss grows precisely under the crest of a plunging miniature waterfall in a riffle, and within the tiny forest created by the moss, protected from the raging current overhead, live multitudes of small, delicate creatures.

Figure 10 - Small streams have alternating pools (background) and riffle areas (foreground). Different forms of life exist in these two regions which vary in degree of turbulence and dissolved oxygen.

While these and many more organisms can be collected from a brook, it is fruitless to try to keep them alive unless a laboratory has a refrigerated, highly aerated, imitation brook. In an ordinary aquarium equipped with aerators, most brook animals quickly suffocate.

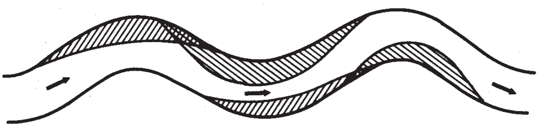


Figure 11 - MEANDER A meandering stream cuts away the outside bank of a curve, transports the sediment, and deposits it along the next inside curve.

One temperature reading at a brook is sufficient, for the water is so turbulent that there is no layering. On the other hand if one can measure the velocity of a brook at different depths and across the width, a great diversity in rate of flow will be found; each area containing its own representative community of organisms.

Lowland streams owe their existence to the joining of many brooks throughout a valley watershed. They are older, and their temperatures more nearly approximate that of the atmosphere. They still may be turbulent in riffle areas, but the velocity is reduced and there is less dissolved oxygen. No longer is the water clear, but quite turbid with suspended silt; the bottom often is carpeted with thick sandy mud interspersed with rocks swept bare; sand bars and mud banks line the shore. There is a steady transport of material downstream.

A stream never flows straight down a valley floor, but twists and turns upon itself in a series of inevitable meanders. A meander is created when a stream is diverted, even slightly, from one bank to another. The cause may be a slight curvature of the bank itself, a small stone, or a fallen log. The flow thus diverted crosses the stream to the other side where it is reflected back, sluggishly at first. Eventually each bank is scoured in an alternating fashion and soon the streambed is a series of sinuous curves. Even in fairly straight streams, there is always a thread of high velocity water that wanders back and forth within the bed itself.

Figure 12 - This view suggests the high velocity of a mountain brook. Living in this turbulent environment are carpets of fountain moss and caddisfly larval cases constructed of tiny pebbles.

When water rushes into a curve, it creates zones of graded velocity: high on the outside, and low on the inner curve where silt and sand bars tend to grow. Each of these zones supports distinct populations and should be examined in turn by whatever methods are available. Bottom-dwelling animals are very sensitive when it comes to selecting the right velocity and proper particle size for their survival.

Meanders also develop in major rivers providing they flow through the flood plains of old valleys. A meander may curve enough to loop back upon itself; the river then cuts through into a new and more direct channel, isolating the old loop with mud dams. The result is an ox-bow lake that eventually fills in and disappears, leaving only a faint, cursive scar on the face of the plain.

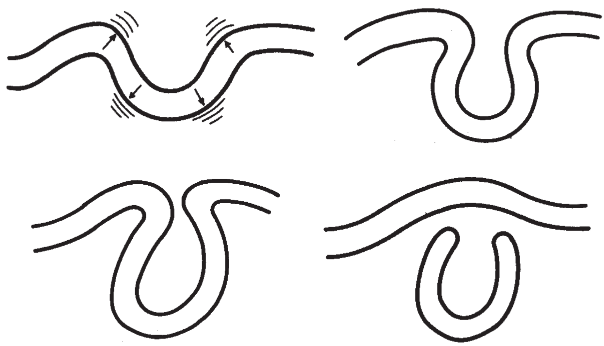


Figure 13 - OX-BOW LAKES The erosion of the banks of a meandering stream eventually cause a semi-circular loop to form.When the stream cuts through the narrow neck, the old loop is isolated, forming a quiet pond (ox-bow shape) with a plant and animal population quite unlike that of the stream.

A river is a confluence of many streams, and perhaps the only drainage channel for an entire watershed. It transports an enormous volume of water that varies perceptibly with the seasons as a result of melting snow, spring rains, and drought. Much of what was said above about streams is also true here, but moderated somewhat. Water temperature is close to that of the atmosphere; the color of the water usually is brown and opaque with vast quantities of suspended sediment. Velocity is not great, but the power of transport of small particles is considerable due to the volume and unremitting flow of the river. The bottom usually is carpeted with gravel, but across the width of the stream, out of the channel proper, extensive mud banks develop. Huge populations of burrowing animals live in the soft, loose sediments, yet there are few plants in rivers other than those along the shore, since light cannot penetrate far in the muddy, opaque water.

Estuaries are not truly the province of this handbook, for they are rivers which feel the influence of the sea, both in tides and the invasion of salinity. Because of tidal fluctuations and density differences between fresh and salt water, an estuarine system is extremely complex, with its plants and animals tolerating great extremes of environmental conditions. It is in estuaries that a genuine plankton population is met for the first time in flowing waters. Rivers at times support minor plankton populations, but in estuaries, because of the tidal excursion back and forth, planktonic organisms may remain in approximately the same region for long periods of time despite the net flow down-stream. For example, in the Delaware River estuary, it takes three months for a suspended particle to travel about a hundred miles, while in the same river, above the tidal portion, the water and its contents may flow about four miles an hour.

STILL WATERS

Lakes and ponds may either be very ancient or transitory. Those that have the shortest duration are known as vernal ponds and generally are flooded only in the late winter and spring from melt-water and heavy rains. As the summer begins, they usually dry up completely, but because their shallow basins contain water during the latter part of an academic year, they can be studied with profit by classes, and perhaps even followed to extinction. Without exception they are very shallow, the quality of their water is strongly influenced by the soils that form the basin, and their temperatures closely follow that of the air.

One might think that vernal ponds exist too short a time to support life, but this is far from true. As soon as the ice melts to form water, branchiopod crustaceans - the well-known fairy shrimp - hatch out and swarm in the chilly water. Rotifers, protozoan, nematodes, and algae emerge from their cysts and spores to lead active lives. Soon the wood frog, one of the earliest breeding frogs, seeks the pool to mate and lay its eggs that hatch shortly into rapidly developing tadpoles.

It is impossible to generalize about permanent ponds (there is no such thing as permanence for a pond), for all differ from one another even if they lie close together. A pond may be defined roughly by the following characteristics: (1) it is shallow enough to permit aquatic plants to reach the surface anywhere over its entire area; (2) its area is not so great as to allow formation of large waves which could erode the shoreline; (3) there is no temperature layering, but simply a gradient of temperatures extending from surface to bottom. Other features concern age and productivity. A pond that is unproductive of plant life, planktonic or rooted, and therefore supports little in the way of animal life, is said to be oligotrophic, or poorly nourished. Such ponds generally are quite clear and may be fairly new. Ponds that are highly productive and contain large populations of plants and animals are eutrophic, a condition that can result in an unhealthy pond if there is extreme enrichment by nutrients in the form of sewage and other organic substances.

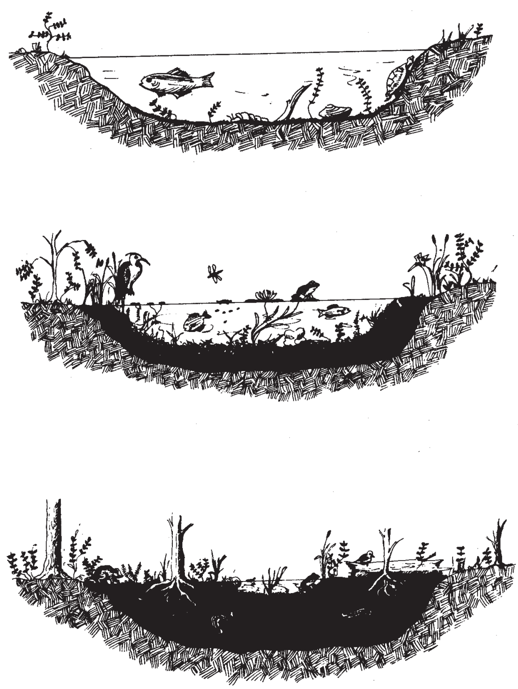
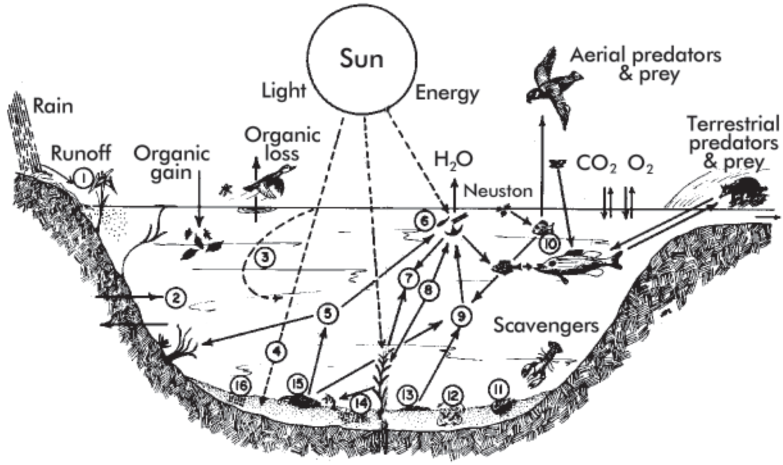


Figure 15 - POND SUCCESSION Once a depression fills with water, pioneer plants and animals take up residence immediately. Their growth and decay, added to sediment accumulating from the land, cause the pond to become shallow, and eventually a wet woodland. Different organisms are characteristic of each stage.

Another way of classifying ponds is by their age, for every pond has a “life span” of its own, usually reckoned in decades or a century or two. A pond may be a young pond with little sediment but invaded by pioneer plants along the shore,

Figure 16 - The interactions of organisms with one another and with their environment are complex even in a small pond. (Some of the more obvious are shown here.)



(1) Soil and organic materials
(2) Mineral compounds leached from soil
(3) Heat distribution through circulation
(4) Heat conduction
(5) Nitrogen compounds (protein, nitrates, nitrites, ammonia, etc.) and nitrogen
(6) Phytoplankton
(7) Oxygen
(8) Carbon dioxide
(9) Phosphates
(10) Feces
(11) Filter feeders
(12) Worm activity in substrate
(13) Detritus
(14) Bacteria
(15) Decay
(16) Compounds trapped in sediments

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and representative plankton, invertebrates, and fishes. A mature pond is carpeted with rich sediment, has aquatic vegetation extending out into open water, and a great diversity of plankton, invertebrates, and fishes. A senescent pond is filled with so much sediment the bottom has risen close to the surface, plants growing into the air everywhere over the entire area. It has a reduced population of plants, plankton, invertebrates, and perhaps no fishes at all other than one or two very tolerant species. Obviously a mature, normally eutrophic pond is the most rewarding one to study, but one at any stage is useful for a class. The succession patterns exhibited by ponds may occur over such a short period of time, with changes apparent in shoreline vegetation and animal populations, that each year of study will yield perceptible differences.

To understand a pond, measurements should be made of the temperature gradient (which will not show distinct layering), the dissolved oxygen content at several levels especially along the bottom where it may be very low, the pH and various nutrients and minerals in solution. Bottom samples provide material for the analysis of particle size as well as an opportunity to capture representatives of the benthic population of the substrate. Running sediment through a series of graded sieves can yield information about the physical nature of the bottom, converted into percentages of clay, silt, sand, and gravel, or even finer distinctions. A known volume of the substrate can be weighed, then dried and weighed to determine the water content. The dried residue could then be incinerated over a flame and weighed a third time; all that is left will be the mineral content, so by subtraction it is possible to estimate the amount of organic material the substrate contained.

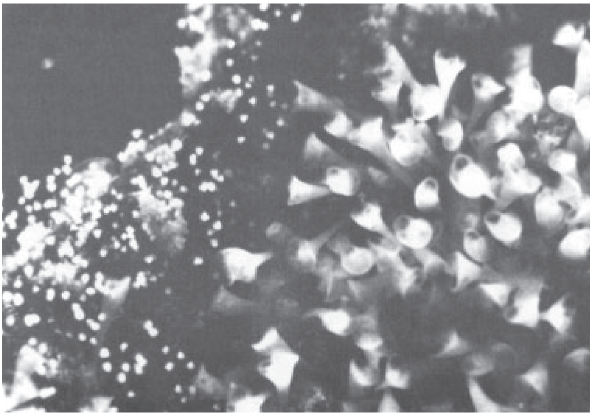


Figure 17 - Many bottom dwellers are filter feeders, removing large quantities of bacteria and detritus from the water. Some are protists (Stentor and Vorticella are shown here) while others are sponges, bryozoans, mollusks, crustaceans, and insects.

Animals which burrow into the bottom compose the infauna, while those which crawl upon or are fixed to the bottom are known as epifauna. Each has its characteristic way of life: infaunal organisms often are detritus feeders, consuming quantities of the soft organic particulate matter of the bottom; epifaunal forms frequently are filter feeders, removing from the water plankton and the ultramicroscopic nanoplankton which are mostly bacteria. When benthic animals are collected, every attempt should be made to obtain a quantitative sample (number of organisms per unit of area or volume), although if this is not possible, qualitative data (the kinds or species present) is of interest. Often benthic populations can be related to the types of substrate in which they are found and experience will soon suggest, merely from a small sample of the bottom, whether or not it is a likely place to find fresh water clams, certain burrowing worms, and other forms. The small grab sampler illustrated later is capable of securing both a quantitative sample of the benthic populations of a soft bottom and enough sediment to analyze by chemical and physical means.

On harder bottoms where the grab may not bite satisfactorily, other means of sampling are possible. A fine wire mesh screen can be placed beneath the rocks and pebbles of the bottom, rearranging them in as natural a fashion as possible. A week or two later, the screen can be raised and the animals it contains examined and counted. Another

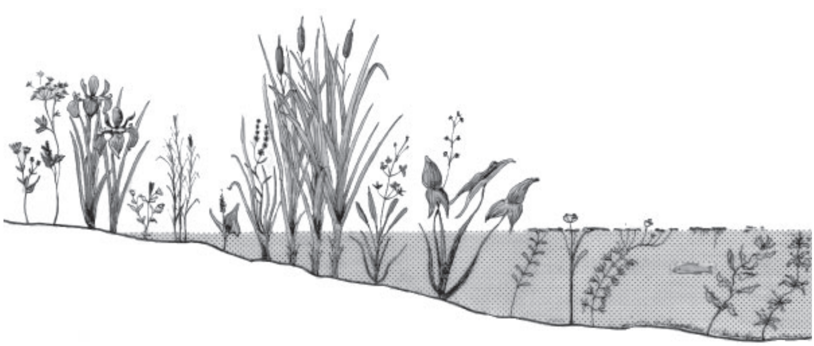


Figure 18 - ZONATION OF POND SHORE Nearly any pond or quiet stream bank shows obvious patterns of zonation among plants. First are the shoreline plants; then the emergents which grow from the bottom to produce leaves and flowers in the air; next the floating leaf plants; and finally the submerged plants which seldom if ever reach the surface. Each zone has its characteristic animal populations as well.

device is a square quadrant box without a bottom ($0.25m^2$ is a convenient size) which is lowered into shallow water and everything removed from the substrate by means of hands, scoops, or whatever is available. Finally, in any lake or pond, a rack holding microscope slides can be suspended beneath the surface, to any depth desired. Slides are removed periodically and examined under a low power microscope for the kind and quantity or organisms that seek out surfaces and attach. Such sessile plants and animals can be of great importance to the total biological economy of the pond.

Even a small pond contains a number of quite distinct habitats, each inhabited by specifically adapted organisms. Besides the plants and animals of the bottom, or benthos, there are those larger creatures that swim freely in the water, the nekton; those which are so small and feeble they exist at the mercy of currents, the plankton; and finally, plants and animals living on the surface film, the neuston. Each of these populations can be graded into small subdivisions, often the result of biotic zonation in the pond.

The most obvious zonation is found along the shoreline, the littoral zone, where plants grow in moist, saturated soil of a pond bank. Other plants, the emergents, rise through shallow water before producing foliage and flowers, and thus invade the pond a meter or more from the actual shoreline. Next are the floating-leaf plants that usually are rooted in the bottom, but have long flexible stems anchoring their broad buoyant leaves in place. Almost invariably they begin where the emergents stop, and continue the invasion further out in the pond; in small or old ponds, they may extend completely across the surface. Finally come the submerged plants which seldom if ever reach the surface, but are dependent upon light filtering down through the water; if the pond is especially turbid, underwater plants may be almost totally absent. Beyond this is the limnetic zone of open water.

Associated with the conditions established by plant zonation are animals, large and small, simple or complex. Fishermen know well which fishes are likely to be in very close to shore, in weedy portions, or out in open water. Many aquatic insects, snails, clams, worms, and other invertebrates are clearly zoned. Working out such patterns can be a stimulating experience for a class, and may tax an investigator’s ingenuity to devise methods of collecting representative populations from the various communities. Dredges, traps, dip nets, seine nets, quadrant boxes, scrapes, coring devices, sieves, and so on may have to be called into service; there is no one instrument which will sample adequately all the zones found in a pond.

Figure 19 - Dragonfly nymphs are some of the larger bottom-dwelling predators. When prey enters within the focal range of its large compound eyes, a hinged, jawed lip it shot out. The victim is then brought back and thrust against the true jaws under the head.

BOGS, LAKES & OTHER BODIES OF WATER

A bog can be a fascinating study in itself, for it has properties unlike those of lakes and ponds. It may have some open water, but usually is almost completely covered by a thick mat of spongy vegetation. Because there is little drainage in such an area, and there is such profusion of vegetation, notably sphagnum moss, pitcher plants, and sedges, that plant material piles up without much opportunity for decay, and peat is formed. The waters in a bog are acidic and have much carbon dioxide, thereby restricting a wide range of animal life from being present. Thick mats of vegetation extend out into what little open water is left, floating above the bottom which is not far beneath. These mats may be firm enough to walk upon, but they flex and quake with a person's weight and seem insecure although they usually are quite tough.

Fresh water marshes may develop from senescent ponds that are on their way to extinction. They can be recognized by tussocks of grasses and sedges, and by tall stands of cattails rising above all else. As shrubs and trees begin to appear, often willows and alders, the marsh may be known as a swamp, or wet woodland. Such spots are favorite breeding grounds for tree frogs, especially the familiar spring peeper. Often the distinction between a swamp and a vernal pond, described earlier, is difficult to make.

If a miniature aquatic habitat is sought, nothing can be more intriguing than a tree-hole community. Usually this takes the form of a deep, rotted cavity in a tree trunk; it contains much detritus, thoroughly saturated, with a little overlying water, often stained a tea color. Analysis of the water, the organic detritus, and the highly specialized life forms present can be a rewarding experience.

Much of what has been written about ponds also applies to lakes, especially to their shorelines and shallows. But lakes are large bodies of water and very deep; they may continue to exist for ten thousand years or more. Natural eutrophic lakes are rare, if in fact they exist at all, but man is converting once-healthy lakes, such as Lake Erie, into vast eutrophic basins and in the process altering and destroying much of the life

Figure 20 - Oligotrophic lakes are clear, sparsely vegetated and relatively unproductive of life.

once supported. Even a large lake cannot withstand the dumping of industrial and domestic wastes for long. The oldest, deepest, and most interesting lake in the world, Lake Baikal, in the Soviet Union, has been saved from a similar fate by Russian conservationists, a lesson we might well heed, for some of our other Great Lakes are now in danger.

One of the major characteristics of a lake is its depth, for this gives rise to phenomena not found in ponds. While Lake Baikal has a depth of 1706 meters and Lake Erie a depth of 64 meters, a lake only 10 or 20 meters deep is sufficient for temperature layering or stratification to occur in the summer (remember that ponds have no stratification, but only a temperature gradient). In the spring a temperate lake has water nearly the same temperature, about 4°C, throughout its entire depth. During summer, the upper levels (epilimnion) of the lake warm up, possibly to over 20°C, while the deepest portions (hypolimnion) retain their 4°C temperature. These two layers are separated by a rather narrow horizontal zone of abrupt temperature change known as the thermocline. In summer most of the plankton and nekton are found in the epilimnion where there is a sufficiency of dissolved oxygen rather than below the thermocline in the hypolimnion where oxygen values are very low. Because of the differences in viscosity, the epilimnion tends to be circulated by the wind like an endless belt on top of the colder water, while the hypolimnion remains quiet and almost lifeless.

In the fall a lake is cooled at the surface by the falling air temperatures until it reaches its maximum density at 4°C. Circulation by wind and the descent of heavier water through warmer water mix the upper layers so thoroughly that soon the entire lake, from top to bottom, is the same temperature. Of course the air temperatures continue to fall, and before long water begins to freeze at the surface, the lighter ice remaining on top of the water which is at its maximum density of 4°C. With a complete ice cover, the lake's circulation is stilled, and an inverted temperature gradient exists: 0°C at the surface, increasing in depth to 4°C. When the ice melts in late winter and early spring, the surface water is warmed a little and wind-driven circulation assures a constant temperature throughout to start the cycle over again. During those seasons when water circulates throughout the lake basin, oxygen values remain high, and fishes that are restricted to the epilimnion in summer can safely go to the deepest portions of the lake. During winter, if the ice cover is prolonged, eliminating contact with the atmosphere, dissolved oxygen may be depleted, since there are few active plants, either rooted or phytoplankton, to replenish the supply. At such times there can be massive fish kills.

Identifying the thermocline is not difficult if there is a means of determining temperature at various depths. This can be done precisely with remote-reading thermostat probes or hydrographic thermometers, but a perfectly adequate means is to use a thermometer in a weighted bottle that can be uncorked at a predetermined depth. If it is raised quickly and the thermometer read at once, error will not be great. In measuring the thermocline, it may be discovered that it is deeper at one end of the lake than at the other; plotted out on a graph or chart it will take the form of a tilted plane. This is known as an internal seiche and is caused by both wind action and differences in density of water masses with different temperatures. When the wind force decreases, the thermocline may tilt back in the other direction, creating a slow rocking type of motion of internal water masses. A more observable phenomenon is the external, or surface, seiche that resembles the sloshing of water back and forth in a bathtub; it too is caused by wind. A person at one end of a lake could place measured vertical stakes in shallow water, or mark the water line, and make observations of water level at frequent intervals. If there is much wave action, stakes could be placed in a perforated drum or behind a breakwater made of stones or logs.

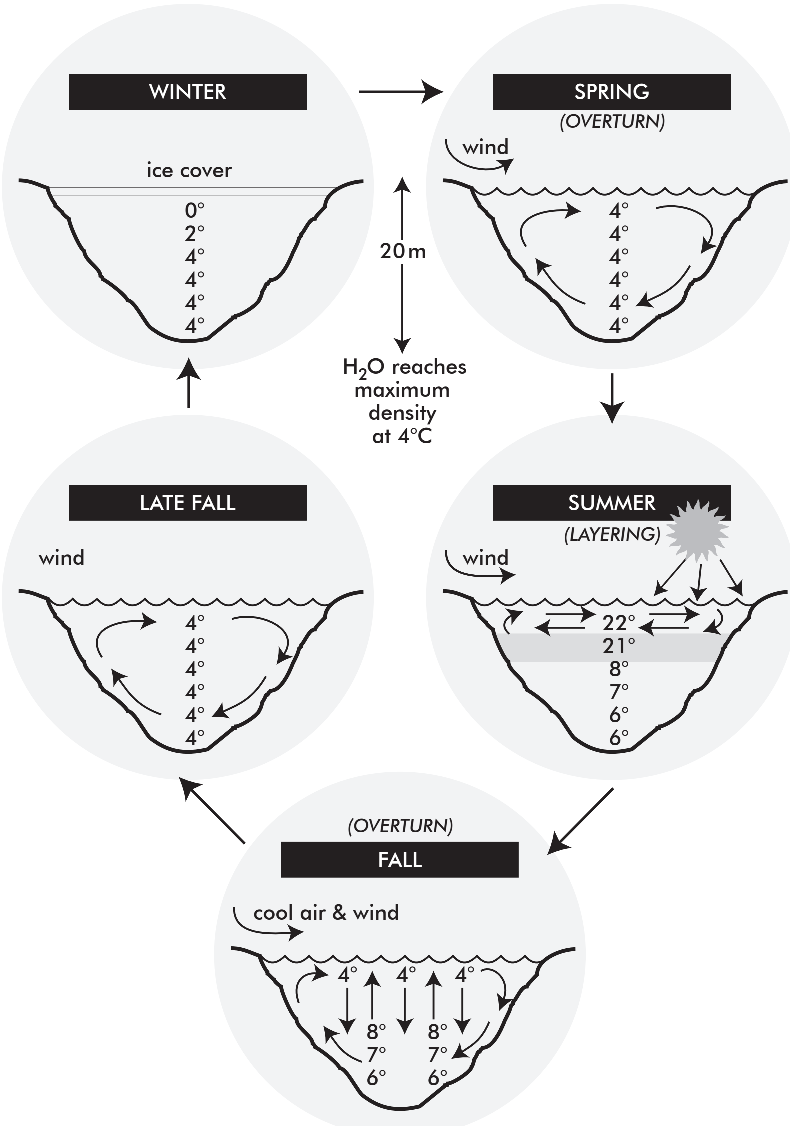
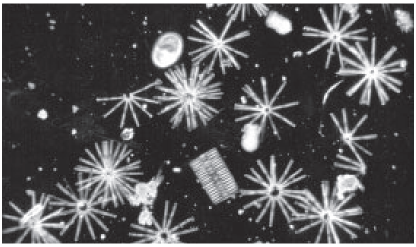
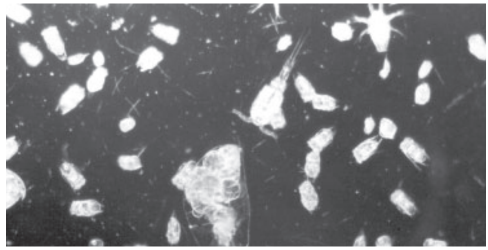


Figure 21 - TEMPERATURE CYCLES IN A LAKE Typical events of warming, cooling, and stratification in a temperate lake. Tropical lakes are permanently layered with life found only near the surface.





PLANKTON

Lake plankton usually is abundant at all seasons, even beneath the ice, and should be studied as possibly the most important life forms in bodies of still water. The simplest means is to use a tow net of fine mesh that will concentrate these minute plants and animals in a container at the end of the conical net. Doing so will at least tell an investigator what is present, but if quantitative means of plankton study are available, they should be used. The net itself can be used if it is towed exactly the same distance each time at about the same speed. The diameter of the net is known; therefore a plankton sample is being made of a long, horizontal column of water, the dimensions and volume of which are known. While this is not precisely true for several reasons, if consistency of method is used over and over again, the results are comparable and reliable. Another means is to use a portable generator and a submersible pump for a certain number of minutes, the sample filtered out by a small sieve. This has the advantage of being practical in mid-winter, for all that is needed is a small hole in the ice. Furthermore, it is a good means of acquiring samples from predetermined depths.

The study of plankton through the year can be most rewarding, for not only do populations wax and wane, appear and completely disappear, but the shape or form (morphology) of many species changes in relation to the differing densities of water as it cools or warms. Plankton organisms are successful only if they remain fairly close to the surface. Plant plankton (phytoplankton) achieve some degree of buoyancy by means of oil droplets, but also are prevented from sinking by spines and flattened shapes, a large surface area compared to their mass. Animal plankton (zooplankton) cannot afford to expend much energy swimming vertically, but do best to swim horizontally; they too may have oil droplets or flotation devices in the form of spines and plates. In summer, when the surface water is less dense, such flotation devices are more noticeable than in winter; in some species, the entire shape of the body changes.

Should only a short period of time be available for the study of plankton, investigations over a twenty-four hour period can provide much of interest. The zooplankton, including copepods, cladocerans, protozoan, and predatory midge larvae, usually rise to the surface at night and descend deeper into the lake during the daytime. Samples taken at hourly intervals at selected depths during one day and night will reveal this phenomenon, even if the identities of all the zooplankton are not known. One quick way of determining the size of such a population is to preserve a quantitative plankton sample in 5% formalin and place it in a glass or plastic settling cone. It may take a day for all the tiny creatures to drift down to the apex of the cone, but when they do and the fluid above is clear, a rough comparison can be made with other samples taken at different times.

Phytoplankton also shows diurnal differences in their metabolism. Because they are photosynthesizers, or primary producers, they produce carbohydrates and oxygen only in the daytime; at night their biochemical requirements and activities are the same as animals – they consume oxygen and give off carbon dioxide, and make use of the food-stuffs they manufactured during the day. To obtain an idea of the amount of photosynthetic activity they engage in, a simple device can be used. Two bottles are filled with water containing phytoplankton and suspended a short distance under the surface, in the photic (illuminated) zone for a day. The only difference between the two bottles is that one is transparent and the other has been painted an opaque black. In late afternoon they are raised and the water tested for dissolved oxygen; the difference between the two readings will be a rough guide to the production going on in the lake as a whole. Other more accurate methods using the amount of chlorophyll present in a sample of water can also be used; descriptions of many of these techniques may be found in several of the books listed in the bibliography.

Because limnology is not only the study of bodies of fresh water but of the life they contain, it is important that a group investigating a pond or stream become familiar with the major groups of plants and animals likely to be encountered. This is more easily said than done, for the variety is almost endless. The most important tools in this endeavor are not nets or dredges, but books. While it may be impossible to acquire all the books listed in the bibliography, an attempt should be made to use two kinds of available books: identification manuals, and books describing the way of life, or ecological niches, of common forms.

With only a few exceptions, representatives of every major group of plants and animals in the world are found in fresh waters. Some bear close resemblances to their marine relatives; others are so modified as to be unrecognizable. Many fresh water forms were formerly terrestrial and only in recent geological history have returned to water. All the insects and many of the snails are such examples. On the other hand, creatures such as fresh water jellyfish, sponges, and clams have never left water but simply became adapted to fresh water after leaving or being isolated from their original home in the sea. There are fresh water lakes in the world that contain sharks, seals, “sea” weeds, and many other forms of life associated with the marine environment. Once a local pond or stream is known, however, most of its inhabitants will be met in other similar bodies of water. Such knowledge is useful, for some organisms can be used as indicators: if they are found, certain physical and chemical features may be expected.

There was a time when biologists and limnologists could refer to particular aquatic organisms as being simple, but today, with a better understanding of biochemical and behavioral matters, none seem to be very simple. The ability of aquatic organisms to regulate their water intake and balance is intricate beyond belief; the sensitivity of organisms in selecting just the right conditions in which to grow and feed defies our most sensitive measurements; the dynamics of rising and falling populations in even a tiny pond would tax the best efforts of a major computer. Puddle or lake, every aquatic environment can challenge anyone of us, beginning student or professional limnologist. Such challenges are not merely academic, for our nation and the world are facing grave problems with our water supplies, Little mention has been made here of pollution, but if we are to continue to enjoy the pleasures and rewards of natural bodies of fresh water, we must prevent their destruction and at the same time correct the extensive damage that has been done. One sobering thought: there is not a single unpolluted river in the United States today. The effects of even mild pollution on a small brook or pond result in profound alterations of their biological structure.

While pollution may be inadvertent or accidental, man does purposely alter some bodies of water. There are highly worked out techniques for encouraging the production of game fish in ponds and for keeping reservoirs free of certain kinds of unwanted plankton that contribute unpleasant, tastes and odors to the water. Some day ponds and lakes may be "farmed" for the food they can produce, although there is nothing new in the concept: throughout the Orient, man has been farming an aquatic grass, rice, for thousands of years, developing a high degree of skill in the creation and maintaining of artificial ponds known as rice paddies. Long before science came into existence, man became a practical limnologist, ecologist, and hydraulic engineer.

APPARATUS FOR LIMNOLOGY STUDIES

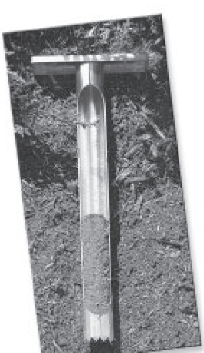
BOTTOM SAMPLING DREDGE

On soft bottoms, this J sampler will not only cover a known area, but brings up a constant volume of substrate and the organisms it contains. When closed all the way, the sample remains undisturbed as it is raised to the surface. Careful release into a pan may distribute the sediments approximately as they were on the bottom.

SECCHI DISK

A Secchi Disk is a white, or black and white, circular plate, 20 cm. in diameter that is used to determine the turbidity or degree of visibility in natural water supplies. A measured line is attached to the center of the disk by means of a special fitting that stabilizes the disk so that it will be parallel to the surface. The disk is lowered into the water until it disappears from sight. The disk is raised and lowered by means of its measured line several times to obtain an average reading. Best results are obtained in the lee of a boat or dock and out of direct sunlight.

The Secchi Disk is also used with the Forel-Ule scale for classifying the color of water supplies. The disk is lowered one meter into the water. The operator looks through the color scale at the submerged disk and compares the color of the water with colors of known value in the scale.



SOIL SAMPLING TUBE

A simple but effective coring device can be made of aluminum pipe hammered down into the substrate. A plunger is then used to push out the core of sediment into a V-shaped trough. If the mud core is then sliced lengthwise with a knife, a perfect cross-section of pond or stream sediments can be obtained.

DISSOLVED OXYGEN/TEMPERATURE SAMPLER

A simple water sampler capable of obtaining samples from various depths. A measured line is attached to the sampler so that readings can be obtained at various depths. The sampler has an inner chamber that is flushed out as a bottle is being filled. Samples for analysis are removed from this chamber. A weight is affixed to the base of the unit. This weight insures rapid descent of the sampler and minimizes sideward drift due to currents. The regulating inlet orifice and the flushing of the collecting chamber eliminates the need for a messenger-activated tripping device. A thermometer placed inside will indicate the temperature if it is read at once after being pulled up.

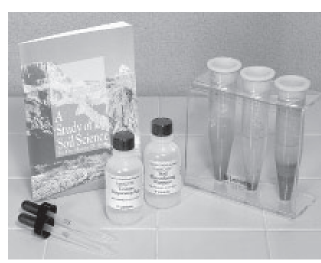
PLANKTON NET

A Plankton Net is a cone shaped net of fine mesh cloth that will permit water to pass through it, but yet it is fine enough to filter out minute plankton particles. The plankton is collected in the tip of the net. The tip of the net is usually fitted with a collecting jar.

KICK NET

A plastic or wire screen, supported by two poles, collects not only stream debris but animal life when rocks and stones are disturbed directly upstream.

TEXTURE CLASSIFICATION OF SEDIMENT UNIT



This unit consists of three calibrated conical tubes, a plastic stand for the tubes and a reagent for speeding the settling of finely divided particles. The instructions include the method for breaking down sediment into sand, silt and clay fractions. The tubes can also be used for determining the amount of suspended solids and plankton in natural water supplies.

For further information on the measurement and sampling equipment described here, contact the Educational Products Division, LaMotte Company, Chestertown, Maryland, 21620 USA, 410-778-3100, 800-344-3100, www.lamotte.com

CHEMICAL ANALYSIS OF FRESH WATER SUPPLIES PROVIDE ESSENTIAL DATA AFFECTING THEIR BIOLOGICAL ACTIVITIES

The measurement of various chemical factors in fresh water supplies provides valuable information about the aquatic environment. A study of the changes in these chemical factors is extremely important. These variations can be brought about by natural changes (the seasonal changes that affect the water temperature, the amount of ice coverage, the amount of sunshine, wind and wave action affecting the body of water, increases or decreases in rainfall, etc.) or they may occur as the result of man's activities (agricultural chemicals in rain runoff, pollution contributed by mining operations and industrial waste water discharges, thermal pollution, etc.).

BIBLIOGRAPHY

The books listed below are only a partial bibliography of those available to students interested in limnology. Although some have been out of print for several years, they are valuable enough to search for in libraries. All books on specific fresh water subjects (fishes, algae, etc.) have been omitted due to space limitations. In large libraries, Limnology and Oceanography, a professional journal, should be sought for papers, methods, and book reviews.

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[A small but useful book that is primarily biological in approach.]

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[Despite being out of print, this book is worth searching for in libraries and second-hand bookstores.]

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[Although somewhat out of date now, this book is still useful for developing methods and procedures in fresh water studies.]

ABOUT THE AUTHOR

William H. Amos was active in aquatic and marine biology for over 20 years. He was the former chairman of the Science Department, St. Andrew's School, Middletown, DE, and a research associate of the Department of Biological Sciences (Marine Laboratories), University of DE. He was on the staff of the Marine Biological Laboratory, Woods Hole, MA, the New York Zoological Society, the American Institute of Biological Studies, the Smithsonian Institution, and engaged in research in a number of laboratories in this country and abroad. His major interests concerned ecological and physiological adaptations of freshwater and marine invertibrates. He was a member of a number of professional societies including the American Society of Limnology and Oceanography, the American Society of Zoologists, the Ecological Society of America, and the Biological Photographic Association. He was the author of many books, texts, and articles, some of which appeared in Scientific American and the National Geographic magazine.

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