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THE LIFE OF INLAND WATERS

An elementary text book of fresh-water biology for American students

By

JAMES G. NEEDHAM
Professor of Limnology in Cornell University

and

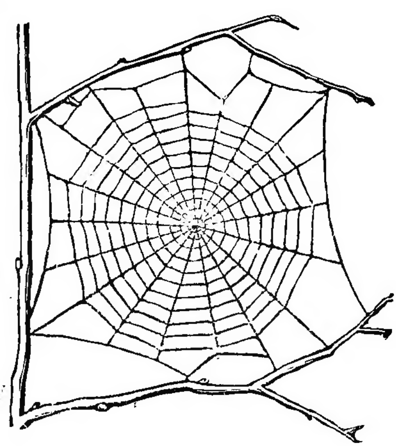
J. T. LLOYD
Instructor in Limnology in Cornell University

Issued for the temporary use of the class in General Limnology in Cornell University

and published by

The Comstock Publishing Company

Ithaca, New York



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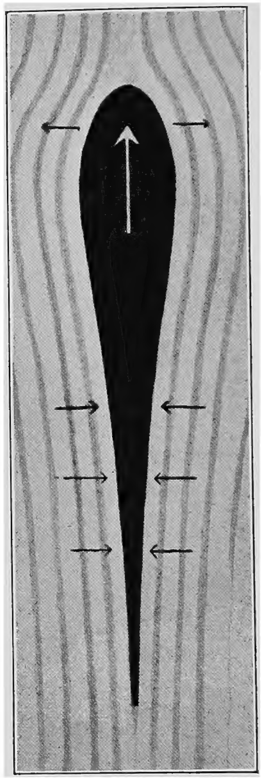
THE LIFE OF INLAND WATERS



SPRING

SUMMER

Conditions on the

AUTUMN

WINTER

Renwick Marsh at Ithaca.

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1915
THE COMSTOCK PUBLISHING COMPANY
ITHACA, NEW YORK

PRESS OF W. F. HUMPHREY, GENEVA, N. Y.

PREFACE

IN THE following pages we have endeavored to present a brief and untechnical account of fresh-water life, its forms, its conditions, its fitnesses, its associations and its economic possibilities. This is a vast subject. No one can have detailed first hand knowledge in any considerable part of it. Hence, even for the elementary treatment here given, we have borrowed freely the results of researches of others. We have selected out of the vast array of material that modern limnological studies have made available that which we deem most significant.

Our interests in water life are manifold. They are in part economic interests, for the water furnishes us food. They are in part aesthetic interests, for aquatic creatures are wonderful to see, and graceful and often very beautiful. They are in part educational interests, for in the water live the more primitive forms of life, the ones that best reveal the course of organic evolution. They are in part sanitary interests; interests in pure water to drink, and in control of water-borne diseases, and of the aquatic organisms that disseminate diseases. They are in part social interests, for clean shores are the chosen places for water sports and for public and private recreation. They are in part civic interests, for the cultivation of water products for human food tends to increase our sustenance, and to diversify our industries. Surely these things justify an earnest effort to make some knowledge of water life available to any one who may desire it.

The present text is mainly made up of the lectures of the senior author. The illustrations, where not otherwise credited, are mainly the work of the junior author. Yet we have worked jointly on every page of the book. We are indebted for helpful suggestions regarding the text to Professor E. M. Chamot, Dr. A. H. Wright, Messrs. W. A. Clemens and Ludlow Griscom. Miss Olive Tuttle has given much help with the copied figures.

Since 1906, when a course in general limnology was first established at Cornell University, we have been associated in developing an outline of study for general students and a program of practical exercises. The text-book is presented herewith: the practical exercises are reserved for further trial by our own classes; they are still undergoing extensive annual revision.

The limitations of space have been keenly felt in every chapter; especially in the chapter on aquatic organisms. These are so numerous and so varied that we have had to limit our discussion of them to groups of considerable size. These we have illustrated in the main with photographs of those representatives most commonly met with in the course of our own work. Important groups are, in some cases, hardly more than mentioned; the student will have to go to the reference books cited for further information concerning them. The best single work to be consulted in this connection is the *American Fresh-water Biology* edited by Ward and Whipple and published by John Wiley and Sons.

Limnology in America today is in its infancy. The value of its past achievements is just beginning to be appreciated. The benefits to come from a more intensive study of water life are just beginning to be disclosed. That there is widespread interest is already manifest in the large number of biological stations at which limnological work is being done. From these and other kindred laboratories much good will come; much new knowledge of water life, and better application of that knowledge of human welfare.

James G. Needham.
J. T. Lloyd.

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CHAPTER I

INTRODUCTION

INDIANS GATHERING WILD RICE, N. MINNESOTA

THE home of primeval man was by the waterside. The springs quenched his thirst. The bays afforded his most dependable supply of animal food. Stream-haunting, furbearing animals furnished his clothing. The rivers were his highways. Water sports were a large part of his recreation; and the glorious beauty of mirroring surfaces and green flower-decked shores were the manna of his simple soul.

The circumstances of modern life have largely removed mankind from the waterside, and common needs have found other sources of supply; but the primeval instincts remain. And where the waters are clean, and shores unspoiled, thither we still go for rest, and refreshment. Where fishes leap and sweet water lilies glisten, where bull frogs boom and swarms of May-flies hover, there we find a life so different from that of our usual surroundings that its contemplation is full of interest. The school boy lies on the brink of a pool, watching the caddisworms haul their lumbering cases about on the bottom, and the planctologist plies his nets, recording each season the wax and wane of generations of aquatic organisms, and both are satisfied observers.

The study of water life, which is today the special province of the science of limnology*, had its beginning in the remote unchronicled past. Limnology is a modern name; but many limnological phenomena were known of old. The congregating of fishes upon their spawning beds, the emergence of swarms of May-flies from the rivers, the cloudlike flight of midges over the marshes, and even the "water bloom" spreading as a filmy mantle of green over the still surface of the lake—such things could not escape the notice of the most casual observer. Two of the plagues of Egypt were limnological phenomena; the plague of frogs, and the plague of the rivers that were turned to blood.

Such phenomena have always excited great wonderment. And, being little understood, they have given rise to most remarkable superstitions.† Little real

**Limnos*=shore, waterside, and *logos*=a treatise: hydrobiology.

†The folk lore of all races abounds in strange interpretations of the simplest limnological phenomena; bloody water, magic shrouds (stranded "blanket-algæ"), spirits dancing in waterfalls, the "will o' the wisp" (spontaneous combustion of marsh gas), etc. Dr. Thistleton Dyer has summarized the folk lore concerning the last mentioned in *Pop. Sci. Monthly* 19: 67, 1881. In Keightly's *Fairy Mythology*, p. 491 will be found a reference to the water and wood maids called Rusalki. "They are of a beautiful form with long green hair: They swing and balance themselves on the branches of trees, bathe in lakes and rivers, play on the surface of the water, and wring their locks on the green mead at the water's edge." On fairies and carp rings see Theodore Gill in *Smithsonian Miscellaneous Collections* 48:203, 1905.

knowledge of many of them was possible so long as the most important things involved in them—often even the causative organisms—could not be seen. Progress awaited the discovery of the microscope.

The microscope opened a new world of life to human eyes—"the world of the infinitely small things." It revealed new marvels of beauty everywhere. It dis-

FIG. 1. Waterbloom (*Euglena*) on the surface film of the Renwick lagoon at Ithaca. The clear streak is the wake of a boat just passed.

covered myriads of living things where none had been suspected to exist, and it brought the elements of organic structure and the beginning processes of organic development first within the range of our vision. And this is not all. Much that might have been seen with the unaided eye was overlooked until the use of the microscope taught the need of closer looking. It would be hard to overestimate the stimulating effect of the invention of this precious instrument on all biological sciences.

With such crude instruments as the early microscopists could command they began to explore the world over again. They looked into the minute structure of everything—forms of crystals, structure of tissues, scales of insects, hairs and fibers, and, above all else, the micro-organisms of the water. These, living in a transparent medium, needed only to be lifted in a drop of water to be ready for observation. At once the early microscopists became most ardent explorers of the water. They found every ditch and stagnant pool teeming with forms, new and wonderful and strange. They often found each drop of water inhabited. They gained a new conception of the world's fulness of life and one of the greatest of them Roesel von Rosenhof, expressed in the title of his book, "*Insekten Belustigung*"* the pleasure they all felt in their work. It was the joy of pioneering. Little wonder that during a long period of exploration microscopy became an end in itself. Who that has used a microscope has not been fascinated on first acquaintance with the dainty elegance and beauty of the desmids, the exquisite sculpturing of diatom shells, the all-revealing transparency of the daphnias, etc., and who has not thereby gained a new appreciation of the ancient saying, *Natura maxime miranda in minimis.*†

Among these pioneers there were great naturalists—Swammerdam and Leeuwenhoek in Holland, the latter, the maker of his own lenses; Malpighi and Redi in Italy; Reaumer and Trembly in France; the above mentioned, Roesel, a German, who was a painter of miniatures; and many others. These have left us faithful records of what they saw, in descriptions and figures that in many biological fields are of more than historical importance. These laid the foundations of

*Belustigung = delight.
†Nature is most wonderful in little things.

our knowledge of water life. Chiefly as a result of their labor there emerged out of this ancient "natural philosophy" the segregated sciences of zoology and botany. Our modern conceptions of biology came later, being based on knowledge which only the perfected microscope could reveal.

A long period of pioneer exploration resulted in the discovery of new forms of aquatic life in amazing richness and variety. These had to be studied and classified, segregated into groups and monographed, and this great survey work occupied the talents of many gifted botanists and zoologists through two succeeding centuries—indeed it is not yet completed. But about two centuries after the construction of the first microscope, occurred an event of a very different kind, that was destined to exert a profound influence throughout the whole range of biology. This was the publication of Darwin's *Origin of Species*. This book furnished also a tool, but of another sort—a tool of the mind. It set forth a theory of evolution, and offered an explanation of a possible method by which evolution might come to pass, and backed the explanation with such abundant and convincing evidence that the theory could no longer be ignored or scoffed out of court. It had to be studied. The idea of evolution carried with it a new conception of the life of the world. If true it was vastly important. Where should the evidence for proof or refutation be found? Naturally, the simpler organisms, of possible ancestral characteristics, were sought out and studied, and these live in the water. Also the simpler developmental processes, with all they offer of evidence; and these are found in the water. Hence the study of water life, especially with regard to structure and development, received a mighty impetus from the publication of this epoch-making book. The half century that has since elapsed has been one of unparalleled activity in these fields.

Almost simultaneously with the appearance of Darwin's great work, there occurred another event which did more perhaps than any other single thing to bring about the recognition of the limnological part of the field of biology as one worthy of a separate recognition and a name. This was the discovery of plancton—that free-floating assemblage of organisms in great water masses, that is self-sustaining and self-maintaining and that is independent of the life of the land. Lilje-borg and Sars found it, by drawing fine nets through the waters of the Baltic. They found a whole fauna and flora, mostly microscopic—a well adjusted society of organisms, with its producing class of synthetic plant forms and its consuming class of animals; and among the animals, all the usual social groups, herbivores and carnivores, parasites and scavengers. Later, this assemblage of minute free-swimming organisms was named plancton.* After its discovery the seas could no longer be regarded as "barren wastes of waters"; for they had been found teeming with life. This discovery initiated a new line of biological exploration, the survey of the life of the seas. It was simple matter to draw a fine silk net through the open water and collect everything contained therein. There are no obstructions or hiding places, as there are everywhere on land; and the fine opportunity for quantitative as well as qualitative determination of the life of water areas was quickly grasped. The many expeditions that have been sent out on the seas and lakes of the world have resulted in our having more accurate and detailed knowledge of the total life of certain of these waters than we have, or are likely to be able soon to acquire, of life on land.

Prominent among the investigators of fresh water life in America during the nineteenth century were Louis

**Planktos* = drifting, free floating.

Aggassiz, an inspiring teacher, and founder of the first of our biological field stations; Dr. Joseph Leidy, an excellent zoologist of Philadelphia, and Alfred C. Stokes of Connecticut, whose *Aquatic Microscopy* is still a useful handbook for beginners.

Our knowledge of aquatic life has been long accumulating. Those who have contributed have been of very diverse training and equipment and have employed very different methods. Fishermen and whalers; collectors and naturalists; zoologists and botanists, with specialists in many groups; water analysts and sanitarians; navigators and surveyors; planktologists and bacteriologists, and biologists of many names and sorts and degrees; all have had a share. For the water has held something of interest for everyone.

Fishing is one of the most ancient of human occupations; and doubtless the beginning of this science was made by simple fisher-folk. Not all fishing is, or ever has been, the catching of fish. The observant fisherman has ever wished to know more of the ways of nature, and science takes its origin in the fulfillment of this desire.

The largest and the smallest of organisms live in the water, and no one was ever equipped, or will ever be equipped to study any considerable part of them. Practical difficulties stand in the way. One may not catch whales and water-fleas with the same tackle, nor weigh them upon the same balance. Consider the difference in equipment, methods, area covered and numbers caught in a few typical kinds of aquatic collecting:

(1). Whaling involves the coöperative efforts of many men possessed of a specially equipped vessel. A single specimen is a good catch and leagues of ocean may have to be traversed in making it.

(2). Fishing may be done by one person alone, equipped with a hook and line. An acre of water affords area enough and ten fishes may be called a good catch.

(3). Collecting the commoner invertebrates, such as water insects, crustaceans and snails involves ordinarily the use of a hand net. A square rod of water is sufficient area to ply it in; a satisfactory catch may be a hundred specimens.

(4). For collecting entomostracans and the larger plancton organisms towing nets of fine silk bolting-cloth are commonly employed. Possibly a cubic meter of water is strained and a good catch of a thousand specimens may result.

(5). The microplancton organisms that slip through the meshes of the finest nets are collected by means of centrifuge and filter. A liter of water is often an ample field for finding ten thousand specimens.

(6). Last and least are the water bacteria, which are gathered by means of cultures. A single drop of water will often furnish a good seeding for a culture plate yielding hundreds of thousands of specimens.

Thus the field of operation varies from a wide sea to a single drop of water and the weapons of chase from a harpoon gun to a sterilized needle. Such divergencies have from the beginning enforced specialization among limnological workers, and different methods of studying the problems of water life have grown up wide apart, and, often, unfortunately, without mutual recognition. The educational, the economic and the sanitary interests of the people in the water have been too often dealt with as though they are wholly unrelated.

The agencies that in America furnish aid and support to investigations in fresh water biology are in the main:

1. Universities which give courses of instruction in limnology and other biological subjects, and some of which maintain field stations or laboratories for investigation of water problems. 2. National, state and municipal boards and surveys, which more or less constantly maintain researches that bear directly upon

their own economic or sanitary problems. 3. Societies, academies, institutes, museums, etc., which variously provide laboratory facilities or equip expeditions or publish the results of investigations. 4. Private individuals, who see the need of some special investigation and devote their means to furthering it. The Universities and private benefactors do most to care for the researches in fundamental science. Fish commissions and sanitary commissions support the applied science. Governmental and incorporated institutions assist in various ways and divide the main work of publishing the results of investigations.

It is pioneer limnological work that these various agencies are doing; as yet it is all new and uncorrelated. It is all done at the instance of some newly discovered and pressing need. America has quickly passed from being a wilderness into a state of highly artificial culture. In its centers of population great changes of circumstances have come about and new needs have suddenly arisen. First was felt the failure of the food supply which natural waters furnished; and this lack led to the beginning of those limnological enterprises that are related to scientific fish culture. Next the supply of pure water for drinking failed in our great cities; knowledge of water-borne diseases came to the fore: knowledge of the agency of certain aquatic insects as carriers of dread diseases came in; and suddenly there began all those limnological enterprises that are connected with sanitation. Lastly, the failure of clean pleasure grounds by the water-side, and of wholesome places of recreation for the whole people through the wastefulness of our past methods of exploitation, through stream and lake despoiling, has led to those broader limnological studies that have to do with the conservation of our natural resources.

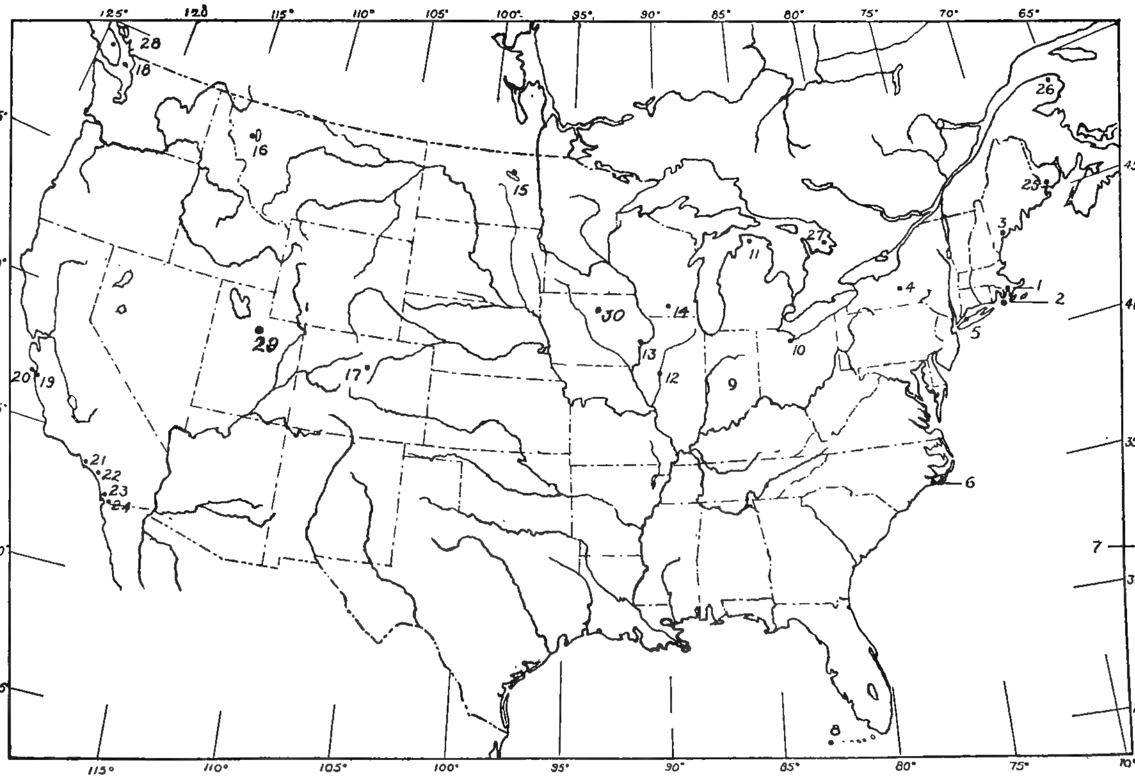


FIG. 2. Map showing location of American Biological Field Stations (after Kofoid, modified).

AMERICAN BIOLOGICAL FIELD STATIONS

Those on fresh water are indicated by an asterisk

1. Woods Hole, Mass. Marine Biological Laboratory.
2. Penikese Island, Mass. Site of Penikese Marine Zoological Station founded in 1873 by Louis Agassiz. (discontinued).
3. South Harpswell, Maine. Harpswell Laboratory.

*4. Ithaca, N. Y., Biological Field Station of Cornell University.

*5. Cold Spring Harbor, N. Y., Biological Laboratory of the Brooklyn Institute of Arts and Sciences.

6. Beaufort, North Carolina. Marine Biological Station of U. S. Bureau of Fisheries.
7. Hamilton, Bermuda Islands. Bermuda Station for Biological Research.
8. Tortugas, Florida. Marine Biological Station of the Department of Marine Biology of the Carnegie Institution.

*9. Winona Lake, Indiana. Biological Field Station of Indiana University (formerly on Turkey Lake)

*10. Sandusky, Ohio. The Lake Laboratory of the Ohio State University.

*11. Douglas Lake, Michigan. Summer Biological Station of the University of Michigan.

*12. Havana, Illinois. Floating headquarters of the river work of the Illinois State Laboratory of Natural History.

*13. Fairport, Iowa. U. S. Bureau of Fisheries Laboratory for the Investigation of Pearlshell Fisheries on the Mississippi River.

*14. Madison, Wisconsin. Zoological Laboratory of the University of Wisconsin. State Natural History Survey.

*15. Devils Lake, North Dakota. North Dakota Biological Station.

*16. Flathead Lake, Montana. Montana Biological Station.

*17. Tolland, Colorado. Colorado Mountain Laboratory.

18. Friday Harbor, Washington. Puget Sound Marine Station.
19. New Monterey, California. Herzstein Research Laboratory of the Department of Physiology of the University of California.
20. Pacific Grove, California. Hopkins Seaside Laboratory of Leland Stanford University.
21. Venice, California. Venice Aquarium and Biological Station of the University of Southern California.
22. Laguna Beach, California. Laguna Marine Laboratory of Pomona College.
23. La Jolla, California. The Marine Biological Station of the University of California.
24. San Diego, California. Earlier location of the preceding.
25. St. Andrews, New Brunswick. Atlantic Biological Station.
26. Gaspe, Quebec. Floating Station of Canadian Bureau of Fisheries.
27. Departure Bay, near Nanaimo, British Columbia. Pacific Biological Station.

*28. Go Home Bay, near Midland Ontario. Canadian Freshwater Biological Station.

*29. Silver Lake, Utah. Field Station of the University of Utah.

*30. Okoboji Lake, Iowa. Field Station of the University of Iowa.

WATER

OF ALL inorganic substances, acting in their own proper nature, and without assistance or combination, water is the most wonderful. If we think of it as the source of all the changefulness and beauty which we have seen in the clouds; then as the instrument by which the earth we have contemplated was modelled into symmetry, and its crags chiseled into grace; then as, in the form of snow, it robes the mountains it has made, with that transcendent light which we could not have conceived if we had not seen; then as it exists in the foam of the torrent, in the iris which spans it, in the morning mist which rises from it, in the deep crystalline pools which mirror its hanging shore, in the broad lake and glancing river, finally, in that which is to all human minds the best emblem of unwearied, unconquerable power, the wild, various, fantastic, tameless unity of the sea; what shall we compare to this mighty, this universal element, for glory and for beauty? or how shall we follow its eternal cheerfulness of feeling? It is like trying to paint a soul.''—RUSKIN.

CHAPTER II

THE NATURE OF AQUATIC ENVIRONMENT

PROPERTIES AND USES

WATER, the one abundant liquid on earth, is, when pure, tasteless, odorless and transparent. Water is a solvent of a great variety of substances, both solid and gaseous. Not only does it dissolve more substances than any other liquid, but, what is more important, it dissolves those substances which are most needed in solution for the maintenance of life. Water is the greatest medium of exchange in the world. It brings down the gases from the atmosphere; it transfers ammonia from the air into the soil for plant food; it leaches out the soluble constituents of the soil; and it acts of itself as a chemical agent in nutrition, and also in those changes of putrefaction and decay that keep the world's available food supply in circulation.

Water is nature's great agency for the application of mechanical energy. It is by means of water that deltas are built and hills eroded. Water is the chief factor in all those eternal operations of flood and floe by which the surface of the continent is shaped.

Transparency.—Water has many properties that fit it for being the abode of organic life. Second only in importance to its power of carrying dissolved food materials is its transparency. It admits the light of the sun; and the primary source of energy for all organic life is the radiant energy of the sun. Green plants use this energy directly; animals get it indirectly with their food. Green plants constitute the producing class of organisms in water as on land. Just in proportion as the sun's rays are excluded, the process of plant assimilation (photosynthesis) is impeded. When we wish to prevent the growth of algae or other green plants in a reservoir or in a spring we cover it to exclude the light. Thus we shut off the power.

Pure water, although transparent, absorbs some of the energy of the sun's rays passed through it, and water containing dissolved and suspended matter (such as are present in all natural water) impedes their passage far more. From which it follows, that the superficial layer of a body of water receives the most light. Penetration into the deeper strata is impeded according to the nature of the water content. Dissolved matters tint the water more or less and give it color. Every one knows that bog waters, for example, are dark. They look like tea, even like very strong tea, and like tea they owe their color to their content of dissolved plant substances, steeped out of the peaty plant remains of the bog.

Suspended matters in the water cause it to be turbid. These may be either silt and refuse, washed in from the land, or minute organisms that have grown up in the water and constitute its normal population. One who has carefully watched almost any of our small northern lakes through the year will have seen that its waters are clearest in February and March, when there is less organic life suspended in them than at other seasons. But it is the suspended inorganic matter that causes the most marked and sudden changes in turbidity—the washings of clay and silt from the hills into a stream; the stirring up of mud from the bottom of a shallow lake with high winds. The difference in clearness of a creek at flood and at low water, or of a pond before and after a storm is often very striking.

Such sudden changes of turbidity occur only in the lesser bodies of water; there is not enough silt in the world to make the oceans turbid.

The clearness of the water determines the depth at which green plants can flourish in it. Hence it is of great importance, and a number of methods have been devised for measuring both color and turbidity. A simple method that was first used for comparing the clearness of the water at different times and places and one that is, for many purposes, adequate, and one that is still used more widely than any other,* consists in the lowering of a white disc into the water and recording the depth at which it disappears from view. The standard disc is 20 cm. in diameter†; it is lowered in a horizontal position during midday light. The depth at which it entirely disappears from view is noted. It is then slowly raised again and the depth at which it reappears is noted. The mean of these two measurements is taken as the depth of its visibility

*Method of Secchi: for other methods, see Whipple's *Microscopy of Drinking Water*, Chap. V. Steuer's *Planktonkunde*, Chapter III.

†Whipple varied it with black quadrants, like a surveyor's level-rod target and viewed it through a water telescope.

beneath the surface. Such a disc has been found to disappear at very different depths. Witness the following typical examples:

Pacific Ocean	59	meters
Mediterranean Sea	42	meters
Lake Tahoe	33	meters
Lake Geneva	21	meters
Cayuga Lake	5	meters
Fure Lake (Denmark), Mar	9	meters
Fure Lake (Denmark), Aug.	5	meters
Fure Lake (Denmark), Dec.	7	meters
Spoon River (Ill.) under ice	3.65	meters
Spoon River (Ill.) at flood	.013	meters

It is certain that diffused light penetrates beyond the depth at which Secchi's disc disappears. In Lake Geneva, for example, where the limit of visibility is 21m. photographic paper sensitized with silver chloride ceased to be affected by a 24-hour exposure at a depth of about 100 meters or when sensitized with iodobromide of silver, at a depth about twice as great. Below this depth the darkness appears to be absolute. Indeed it is deep darkness for the greater part of this depth, 90 meters being set down as the limit of "diffused light." How far down the light is sufficient to be effective in photosynthesis is not known, but studies of the distribution in depth of fresh water algae have shown them to be chiefly confined, even in clear lakes, to the uppermost 20 meters of the water. Ward ('95) found 64 per cent. of the plancton of Lake Michigan in the uppermost two meters of water, and Reighard ('94) found similar conditions in Lake St. Clair. Since the intensity of the light decreases rapidly with the increase in depth it is evident that only those plants near the surface of the water receive an amount of light comparable with that which exposed land plants receive. Less than this seems to be needed by most free swimming algae, since they are often found in greatest number in open waters some five to fifteen meters below the surface. Some algae are found at all depths, even in total darkness on the bottom; notably diatoms, whose heavy silicious shells cause them to sink in times of prolonged calm, but these are probably inactive or dying individuals. There are some animals, however, normally dwelling in the depths of the water, living there upon

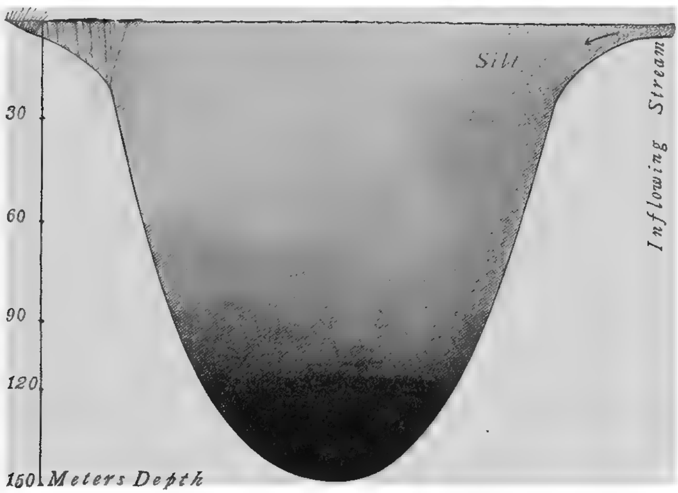


FIG. 3. Diagram illustrating the penetration of light into the water of a lake; also, its occlusion by inflowing silt and by growths of plants on the surface.

the organic products produced in the zone of photosynthesis above and bestowed upon them in a considerable measure by gravity. To the consideration of these we will return in a later chapter.

The accompanying diagram graphically illustrates the light relations in a lake. The deeper it is the greater its mass of unlighted and, therefore, unproductive water, and the larger it be, the less likely is its upper stratum to be invaded by obscuring silt and water weeds.

Mobility—Water is the most mobile of substances, yet it is not without internal friction. Like molasses, it stiffens with cooling to a degree that affects the flotation of micro-organisms and of particles suspended in it. Its viscosity is twice as great at the freezing point as at ordinary summer temperature (77°F.).

Buoyancy—Water is a denser medium than air; it is 775 times heavier. Hence the buoyancy with which it supports a body immersed in it is correspondingly greater. The density of water is so nearly equal to that of protoplasm, that all living bodies will float in it with the aid of very gentle currents or of a very little exertion in swimming. Flying is a feat that only a few of the most specialized groups of animals have mastered, but swimming is common to all the groups.

Pressure—This greater density, however, involves greater pressure. The pressure is directly proportional to the depth, and is equal to the weight of the superposed column of water. Hence, with increasing depth the pressure soon becomes enormous, and wholly insupportable by bodies such as our own. Sponge fishers and pearl divers, thoroughly accustomed to diving, descending naked from a boat are able to work at depths up to 20 meters. Professional divers, encased in a modern diving dress are able to work at depths several times as great; but such depths, when compared with the depths of the great lakes and the oceans are comparative shoals.

Beyond these depths, however, even in the bottom of the seas, animals live, adjusted to the great pressure, which may be that of several hundred of atmospheres. But these cannot endure the lower pressure of the surface, and when brought suddenly to the surface they burst. Fishes brought up from the bottom of the deeper freshwater lakes, reach the surface greatly swollen, their scales standing out from the body, their eyes bulging.

Maximum density—Water contracts on cooling, as do other substances, but not to the freezing point—only to 4° centigrade (39.2° Fahrenheit). On this peculiarity hang many important biological consequences. Below 4° C. it begins to expand again, becoming lighter, as shown in the accompanying table:

Temperature C°	F°	Weight in lbs. per cu. ft.	Density
35	95	62.060	.99418
21	70	62.303	.99802
10	50	62.408	.99975
4	39	62.425	1.00000
0	32	62.417	.99987

Hence, on the approach of freezing, the colder lighter water accumulates at the surface, and the water at the point of maximum density settles to the bottom, and the congealing process, so fatal to living tissues generally is resticted to a thin top layer. Here at 0° C. (32° F.) the water freezes, expanding about one-twelfth in bulk in the resulting ice and reducing its weight per cubic foot to 57.5 pounds.

Stratification of the water—Water is a poor conductor of heat. We recognize this when we apply heat to the bottom of a vessel, and set up currents for its distribution through the vessel. We depend on convection and not on conduction. But natural bodies of water are heated and cooled from the top, when they are in contact with the atmosphere and where the sun's rays strike. Hence, it is only those changes of temperature which increase the density of the surface waters that can produce convection currents, causing them to descend, and deeper waters to rise in their place. Minor changes of this character, very noticeable in shallow water, occur every clear day with the going down of the sun, but great changes, important enough to effect the temperature of all the waters of a deep lake, occur but twice a year, and they follow the procession of the equinoxes. There is a brief, often interrupted, period (in March in the latitude of Ithaca) after the ice has gone out, while the surface waters are being warmed to 0°C.; and there is a longer period in autumn, while they are being cooled to 0°C. Between times, the deeper waters of

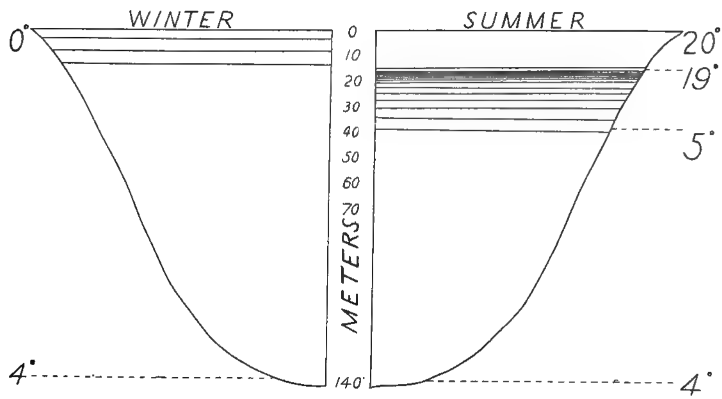


FIG. 4. Diagram illustrating summer and winter temperature conditions in Cayuga Lake. The spacing of the horizontal lines represents equal temperature intervals.

a lake are at rest, and they are regularly stratified according to their density.

In deep freshwater lakes the bottom temperature remains through the year constantly near the point of maximum density, 4° C. This is due to gravity. The heavier water settles, the lighter, rises to the top. Were gravity alone involved the gradations of temperature from bottom to top would doubtless be perfectly regular and uniform at like depths from shore to shore. But springs of ground water and currents come in to disturb the horizontal uniformity, and winds may do much to disturb the regularity of gradations toward the surface. Water temperatures are primarily dependent on those of the superincumbent air. The accompanying diagram of comparative yearly air and water temperatures in Hallstätter Lake (Austria) shows graphically the diminishing influence of the former on the latter with increasing depth.

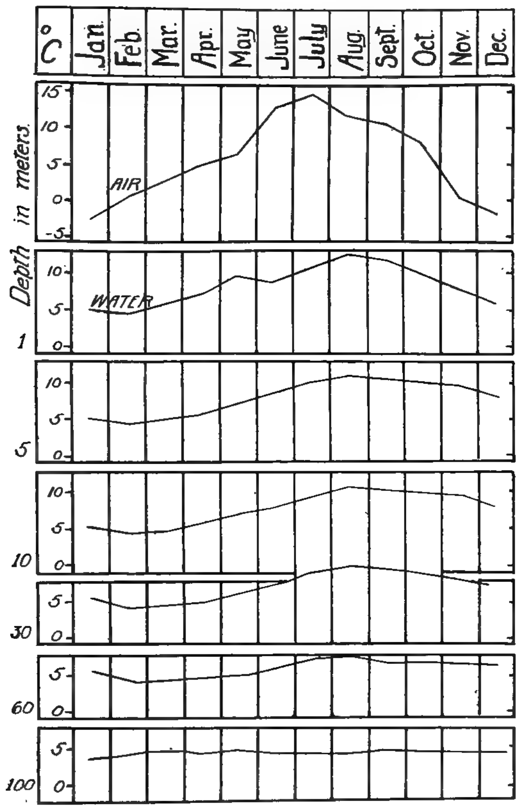


FIG. 5. Diagram illustrating the relation of air and water temperatures at varying depths of water in Hallstätter Lake (after Lorenz).

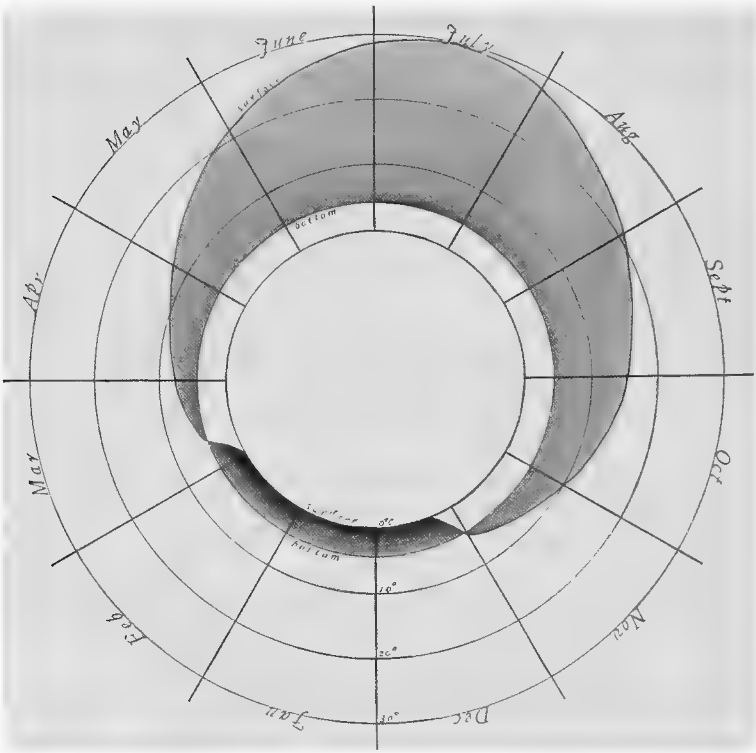


FIG. 6. Diagram illustrating the distribution of temperature in Cayuga Lake throughout the year.

The yearly cycle—The general relation between surface and bottom temperatures for the year are graphically shown in the accompanying diagram, wherein the two periods of thermal stratification, "*direct*" in summer when the warmer waters are uppermost, and "*inverse*" in winter when the colder waters are uppermost, are separated by two periods of complete circulation, when all the waters of the lake are mixed at 4° C. The range of temperatures from top to bottom is much greater in the summer "stagnation period"; nevertheless there is more real stagnation during the winter period; for, after the formation of a protecting layer of ice, this shuts out the disturbing influence of wind and sun and all the waters are at rest. The surface temperature bears no further relation to air temperature but remains constantly at 0° C.

After the melting of the ice in late winter the surface waters begin to grow warmer; so, they grow heavier, and tend to mingle with the underlying waters. When all the water in the lake is approaching maximum density strong winds heaping the waters upon a lee shore, may put the entire body of the lake into complete circulation. How long this circulation lasts will depend on the weather. It will continue (with fluctuating vigor) until the waters are warm enough so that their thermal stratification and consequent *resistance to mixture* are great enough to overcome the disturbing influence of the wind. Thereafter, the surface may be stirred by storms at any time, but the deeper waters of the lake will have passed into their summer rest.

On the approach of autumn the cooling of surface waters starts convection currents, which mix at first the upper waters only, but which stir ever more deeply as the temperature descends. When nearly 4°C., with the aid of winds, the entire mass of water is again put in circulation. The temperature is made uniform throughout, and what is more important biologically, the contents of the lake, in both dissolved and suspended matters, are thoroughly mixed. Nothing is thereafter needed other than a little further cooling of the surface waters to bring about the inverse stratification of the winter period.

Vernal and autumnal circulation periods differ in this, that convection currents have a smaller share, and winds may have a larger share in the former. For the surface waters are quickly warmed from 0° C. to 4° C., and further warming induces no descending currents, but instead tends toward greater stability. It sometimes happens that in shallow lakes there is little vernal circulation. If the water be warmed at 4° C. at the bottom before the ice is entirely gone, and if a period of calm immediately follow, so that no mixing is done by the wind, there may be no general spring circulation whatever.

The shallower the lake, other things being equal, the greater will be the departure of temperature conditions from those just sketched, for the greater will be the disturbing influence of the wind. In south temperate lakes, temperature conditions are, of course, reversed with the seasons. In tropical lakes whose surface temperature remains always above 4° C., there can be no complete circulation from thermal causes, and inverse stratification is impossible. In polar lakes, never freed from ice, no direct stratification is possible.

It follows from the foregoing that gravity alone may do something toward the warming of the waters in the spring, and much toward the cooling of them in the fall. By gravity they will be made to circulate until they reach the point of maximum density, when going either up or down the scale. Beyond this point, however, gravity tends to stabilize them. The wind is responsible for the further warming of the waters in early summer, and the heat in excess of 4° C. has been called by Birge and Juday "wind-distributed" heat. They estimate that it may amount to 30,000 gram-calories per square centimeter of surface in such lakes as those of Central New York, and the following figures for Cayuga Lake show its distribution by depth in August, 1911, in percentage remaining at successive ten-meter intervals below the surface:

Below	0	10	20	30	40	50	60	70	80	100	133 meters
%	100	50.2	16.7	7.1	3.7	2.4	1.8	1.2	.7	.3	remaining

These figures indicate the resistance to mixing that gravity imposes, and show that the wind is not able to overcome it below rather slight depths.

Vernal and autumnal periods of circulation have a very great influence upon the distribution of both organisms and their food materials in a lake; to the consideration of this we will have occasion to return later.

The thermocline—In the study of lake temperatures at all depths, a curious and interesting peculiarity of temperature interval has been commonly found pertaining to the period of direct stratification (midsummer). The descent in temperature is not regular from surface to bottom, but undergoes a sudden acceleration during a space of a very few meters some distance below the surface. The stratum of water in which this sudden drop of temperature occurs is known as the *thermocline* (German, *Sprungschicht*). It appears to represent the lower limit of the intermittent summer circulation due to winds. Above it the waters are more or less constantly stirred, below it they lie still. This interval is indicated by the shading on the right side of figure 4. Birge has designated the area above the thermocline as the epilimnion; the one below it as hypolimnion.

Further study of the thermocline has shown that it is not constant in position. It rises nearer to the surface at the height of the midsummer season and descends a few meters with the progress of the cooling of the autumnal atmosphere. This may be seen in figure 7, which is Birge and Juday's chart of temperatures of Lake Mendota as followed by them through the season of direct stratification and into the autumnal circulation period in 1906. This chart shows most graphically the growing divergence of surface and bottom temperatures up to August, and their later approximation and final coalescence in October. Leaving aside the not unusual erratic features of surface temperature (represented by the topmost contour line) it will be noticed that there is a wider interval somewhere between 8 and 16 meters than any other interval either above or below it. Sometimes it falls across two spaces and is rendered less apparent in the charting by the selection of intervals. It first appears clearly in June at the 10–12 meter interval. It rises in July above the 10 meter level.

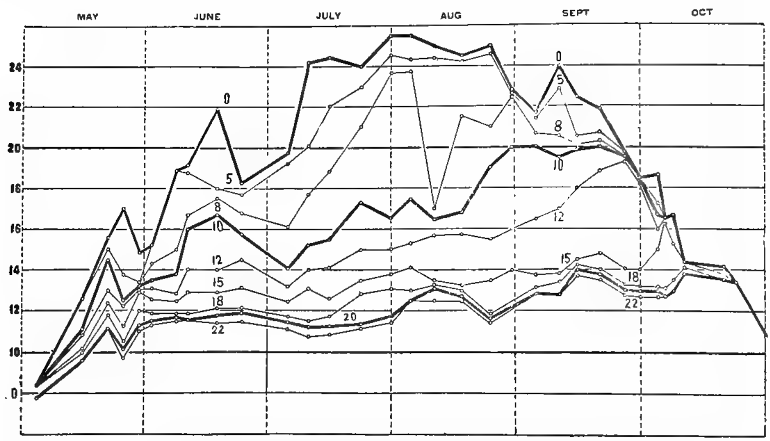


FIG. 7. Temperature of the water at different depths in Lake Mendota in 1906. The vertical spaces represent degrees Centigrade and the figures attached to the curves indicate the depths in meters. (Birge and Juday).

In the middle of August it lies above the 8 meter level, though it begins to descend later in the month. It continues to descend through September, and is found in early October between 16 and 18 meters. It disappears with the beginning of the autumnal circulation.

The cause of this phenomenon is not known. Richter has suggested that convection currents caused by the nocturnal cooling of the surface water after hot summer days may be the cause of it. If the surface waters were cooled some degrees they would descend, displacing the layers underneath and setting up shallow currents which would tend to equalize the temperature of all the strata involved therein. And if the gradation of temperatures downward were regular before this mixing, the result of it would be a sudden descent at its lower limit, after the mixing was done. This would account for the upper boundary of the thermocline, but not for its lower one. Perhaps an occasional deeper mixing, extending to its lower boundary, and due possibly to high winds, might bring together successional lower levels of temperature of considerable intervals. Perhaps the thermocline is but an accumulation of such sort of thermal disturbance-records, ranged across the vertical section of the lake, somewhat as wave-drift is ranged in a shifting zone along the middle of a sloping beach. At any rate, it appears certain that the thermocline marks the lower limit of the chief disturbing influences that act upon the surface of the lake. That it should rise with the progress of summer is probably due to the increasing stability of the lower waters, as differences in temperature (and therefore in density) between upper and lower strata are increased. Resistance to mixing increases until the maximum temperature is reached, and thereafter declines, as the influence of cooling and of winds penetrates deeper and deeper.

In running water the mixing is more largely mechanical, and vertical circulation due to varying densities is less apparent. Yet the deeper parts of quiet streams approximate closely to conditions found in shallow lakes. Such thermal stratification as the current permits is direct in summer and inverse in winter, and there are the same intervening periods of thermal overturn when the common temperature approaches 4° C. In summer and in winter there is less "stagnation" of bottom waters owing to the current of the stream.

The thermal conservatism of water—Water is slower to respond to changes of temperature than is any other known substance. Its specific heat is greater. The heat it consumes in thawing (and liberates in freezing) is greater. The amount of heat necessary to melt one part of ice at 0° C. without raising its temperature at all would be sufficient to raise the temperature of the same when melted more than 75 degrees. Furthermore, the heat consumed in vaporization is still greater. The amount required to vaporize one part of water at 100° C. without raising its temperature would suffice to raise 534 parts of water from 0° C. to 1° C.; and the amount is still greater when vaporization occurs at a lower temperature. Hence, the cooling effect of evaporation on the surrounding atmosphere, which gives up its heat to effect this change of state in the water; hence, the equalizing effect upon climate of the presence of large bodies of water; hence the extreme variance between day and night temperatures in desert lands; hence the delaying of winter so along after the autumnal, and of summer so long after the vernal equinox. Water is the great stabilizer of temperature.

The content of natural waters—Water is the common solvent of all foodstuffs. These stuffs are, as everybody knows, such simple mineral salts as are readily leached out of the soil, and such gases as may be washed down out of the atmosphere. And since green plants are the producing class among organisms, all others being dependent on their constructive activities, water is fitted to be the home of life in proportion as it contains the essentials of green plant foods, with fit conditions of warmth, air and light.

Natural waters all contain more or less of the elementary foodstuffs necessary for life. Pure water (H_2O) is not found. All natural waters are mineralized waters—even rain, as it falls, is such. And a comparatively few soluble solids and gases furnish the still smaller number of chemical elements that go to make up the living substance. The amount of dissolved solids varies greatly, being least in rainwater, and greatest in dead seas, which, lacking outlet, accumulate salts through continual evaporation. Here is a rough statement of the dissolved solids in some typical waters:

In rain water	30—40	parts per million
In drainage water off siliceous soils	50—80	" " "
In springs flowing from siliceous soils	60—250	" " "
In drainage water off calcareous soils	140—230	" " "
In springs flowing from calcareous soils	300—660	" " "
In rivers at large	120—350	" " "
In the ocean	33000—37370	" " "

Thus the content is seen to vary with the nature of the soils drained, calcareous holding a larger portion of soluble solids than siliceous soils. It varies with presence or absence of solvents. Drainage waters from cultivated lands often contain more lime salts than do springs flowing from calcareous soils that are deficient in carbon dioxide. Spring waters are more highly charged than other drainage waters, because of prolonged contact as ground water with the deeper soil strata. And evaporation concentrates more or less the content of all impounded waters.

All natural waters contain suspended solids in great variety. These are least in amount in the well filtered water of springs, and greatest in the water of turbulent streams, flowing through fine soils. At the confluence of the muddy Missouri and the clearer Mississippi rivers the waters of the two great currents may be seen flowing together but uncommingled for miles.

The suspended solids are both organic and inorganic, and the organic are both living and dead, the latter being plant and animal remains. From all these non-living substances the water tends to free itself: The lighter organic substances (that are not decomposed and redissclved) are cast on shore; the heavier mineral substances settle to the bottom. The rate of settling is dependent on the rate of movement of the water and on the specific gravity and size of the particles. Fall Creek at Ithaca gives a graphic illustration of the carrying power of the current. In the last mile of its course, included between the Cornell University Campus and Cayuga Lake, it slows down gradually from a sheer descent of 78 ft. at the beautiful Ithaca Fall to a scarcely perceptible current at the mouth. It carries huge blocks of stone over the fall and drops them at its foot. It strews lesser blocks of stone along its bed for a quarter of a mile to a point where the surface ceases to break in riffles at low water. There it deposits gravel, and farther along, beds and bars of sand, some of which shift position with each flood rise, and consequent acceleration. It spreads broad sheets of silt about its mouth and its residual burden of finer silt and clay it carries out into the lake. The lake acts as a settling basin. Flood waters that flow in turbid, pass out clear.

Whipple has given the following figures for rate of settling as determined by size, specific gravity and form being constant:

Velocity of particles falling through water

Diameter	1.	inch,	falls	100.	feet	per	minute.
"	.1	"	"	8.	"	"	"
"	.01	"	"	.15	"	"	"
"	.001	"	"	.0015	"	"	"
"	.0001	"	"	.000015	"	"	"

Suspended mineral matters are, as a rule, highly insoluble. Instead of promoting, they lessen the productivity of the water by shutting out the light.

Suspended organic solids likewise contribute nothing to the food supply as long as they remain undissolved. But when they decay their substance is restored to circulation. Only the dissolved substances that are in the water are at once available for food. The soil and the atmosphere are the great storehouses of these materials, and the sources from which they were all originally derived.

Gases from the atmosphere—The important gases derived from the atmosphere are two: carbon dioxide (CO_2) and oxygen (O). Nitrogen is present in the atmosphere in great excess (N, 79% to O, nearly 21%, and CO_2, .03%), and nitrogen is the most important constituent of living substance, but in gaseous form, free or dissolved, it is not available for food. The capacity of water for absorbing these gases varies with the temperature and the pressure, diminishing as warmth increases (insomuch that by boiling they are removed from it), and increasing directly as the pressure increases. Pure water at a pressure of 760 mm. in an atmosphere of pure gas, absorbs these three as follows:

	Oxygen	CO_2	Nitrogen
At 0°C	41.14	1796.7	20.35
At 20°C	28.38	901.4	14.03

At double the pressure twice the quantity of the gas would be dissolved. Natural waters are exposed not to the pure gas but to the mixture of gases which make up the atmosphere. In such a mixture the gases are absorbed independently of each other, and in proportion to their several pressures, which vary as their several densities: the following table* shows, for

*Abridged from a table of values to tenths of a degree by Birge and Juday in Bull. 22, Wisc. Geol. & Nat. Hist. Survey, p. 20.

example, the absorbing power of pure water at various temperatures for oxygen from the normal atmosphere at 760 mm. pressure:

Water at	0°C	9.70 cc. per liter	at	15°C	6.96 cc. per liter
"	5°C	8.68 cc. " "	"	20°C	6.28 cc. " "
"	10°C	7.77 cc. " "	"	25°C	5.76 cc. " "

The primary carbon supply for the whole organic world is the carbon dioxide (CO_2) of the atmosphere. Chlorophyll-bearing plants are the gatherers of it. They alone among the organisms are able to utilize the energy of the sun's rays. The water existing as vapor in the atmosphere is the chief agency for bringing these gases down to earth for use. Standing water absorbs them at its surface but slowly. Water vapor owing to better exposure, absorbs them to full saturation, and then descends as rain. In fresh water they are found in less varying proportion, varying from none at all to considerable degree of supersaturation. Birge and Juday report a maximum occurrence of oxygen as observed in the lakes of Wisconsin of 25.5 cc. per liter in Knight's Lake on Aug. 26, 1909 at a depth of 4.5 meters. This water when brought to the surface (with consequent lowering of pressure by about half an atmosphere) burst into lively effervescence, with the escape of a considerable part of the excess oxygen into the air. ('11, p. 52). They report the midsummer occurrence of free carbon dioxide in the bottom waters of several lakes in amounts approaching 15 cc. per liter.

The reciprocal relations of CO_2 and O—Carbon dioxide and oxygen play leading roles in organic metabolism, albeit, antithetic roles. The process begins with the cleavage of the carbon dioxide, and the building up of its carbon into organic compounds; it ends with the oxidation of effete carbonaceous stuffs and the reappearance of CO_2. Both are used over and over again.

Plants require CO_2 and animals require oxygen in order to live and both live through the continual exchange of these staple commodities. This is the best known phase in the cycle of food materials. The oxygen is freed at the beginning of the synthesis of organic matter, only to be recombined with the carbon at the end of its dissolution. And the well-being of the teeming population of inland waters is more dependent on the free circulation and ready exchange of the dissolved supply of these two gases than on the getting of a new supply from the air.

The stock of these gases held by the atmosphere is inexhaustible, but that contained in the water often runs low; for diffusion from the air is slow, while consumption is sometimes very rapid. We often have visible evidence of this. In the globe in our window holding a water plant, we can see when the sun shines streams of minute bubbles of oxygen, arising from the green leaves. Or, in a pond we can see great masses of algae floated to the surface on a foam of oxygen bubbles. We cannot see the disappearance of the carbon dioxide but if we test the water we find its acidity diminishing as the carbon dioxide is consumed.

At times when there is abundant growth of algae near the surface of a lake there occurs a most instructive diurnal ebb and flow in the production of these two gases. By day the well lighted layers of the water become depleted of their supply of CO_2 through the photosynthetic activities of the algae, and become supersaturated with the liberated oxygen. By night the microscopic crustaceans and other plancton animals rise from the lower darker strata to disport themselves nearer the surface. These consume the oxygen and restore to the water an abundance of carbon dioxide. And thus when conditions are right and the numbers of plants and animals properly balanced there occur regular diurnal fluctuations corresponding to their respective periods of activity in these upper strata.

Photosynthesis is, however, restricted to the better lighted upper strata of the water. The region of greatest carbon consumption is from one to three meters in depth in turbid waters, and of ten meters or more in depth in clear lakes. Consumption of oxygen, however, goes on at all depths, wherever animal respiration or organic decomposition occurs. And decomposition occurs most extensively at the bottom where the organic remains tend to be accumulated by gravity. With a complete circulation of the water these two gases may continue to be used over and over again, as in the example just cited. But, as we have seen, there is no circulation of the deeper water during two considerable periods of the year; and during these stagnation periods the distribution of these gases in depth becomes correlated in a wonderful way with the thermal stratification of the water. This has been best illustrated by the work of Birge and Juday in Wisconsin. Figure 8 is their diagram illustrating the distribution of free oxygen in Mendota Lake during the summer of 1906. It should be studied in connection with figure 7, which illustrates conditions of temperature. Then it will be seen that the two periods of equal supply at all levels correspond to vernal and autumnal circulation periods. The season opens with the water nearly saturated (8 cc. of oxygen per liter of water) throughout. With the warming of the waters the supply begins to decline, being consumed in respiration and in decomposition. In the upper six or seven meters the decline is not very extensive, for at these depths the algae continually renew the supply. But as the lower strata settle into their summer rest their oxygen content steadily disappears, and *is not renewed* until the autumnal overturn. For three months there is no free oxygen at the bottom of the lake, and during August there is not enough oxygen below the ten meter level to keep a fish alive.

Correspondingly, the amount of free CO_2 in the deeper strata of the lake increases rather steadily until the autumnal overturn. It is removed from circulation, and in so far as it is out of the reach of effective light, it is unavailable for plant food.

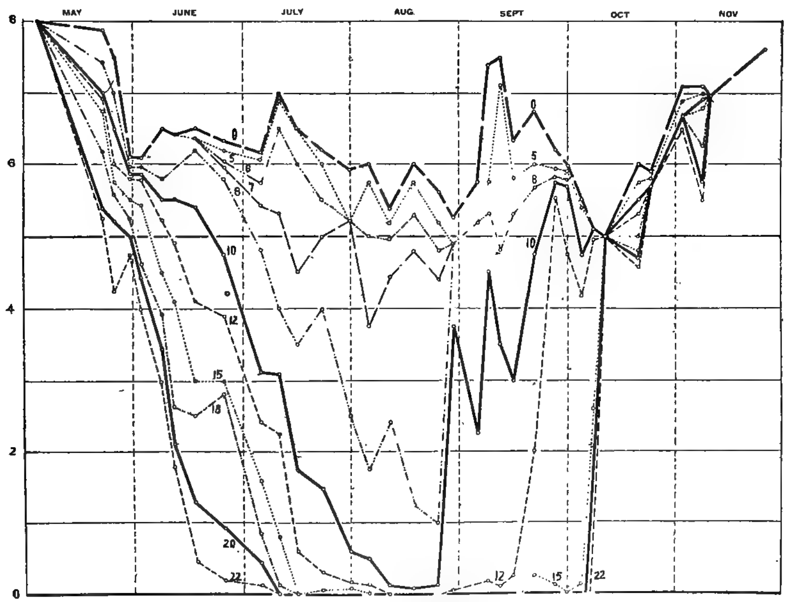


FIG. 8. Dissolved oxygen at different depths in Lake Mendota in 1906. The vertical spaces represent cubic centimeters of gas per liter of water and the figures attached to the curves indicate the depths in meters. (Birge and Juday.)

Other gases—A number of other gases are more or less constantly present in the water. Nitrogen, as above stated, being absorbed from the air, methane (CH_4), and other hydrocarbons, and hydrogen sulphide (H_2S), etc., being formed in certain processes of decomposition. Of these, methane or marsh gas, is perhaps the most important. This is formed where organic matter decays in absence of oxygen. In lakes such conditions are found mainly on the bottom. In marshes and stagnant shoal waters generally, where there is much accumulation of organic matter on the bottom, this gas is formed in abundance. It bubbles up through the bottom ooze, or often buoys up rafts of agglutinated bottom sediment.

Nitrogen—The supply of nitrogen for aquatic organisms is derived from soluble simple nitrates (KNO_3, $NaNO_3$, etc.) Green plants feed on these, and build proteins out of them. And when the plants die (or when animals have eaten them) their dissolution yields two sorts of products, ammonia and nitrates, that become again available for plant food. Ammonia is produced early in the process of decay and the nitrates are its end products.

Bacteria play a large role in the decomposition of proteins. At least four groups of bacteria successively participate in their reduction. The first of these are concerned with the liquefaction of the proteins, hydrolyzing the albumins, etc., by successive stages to albumoses, peptones, etc., and finally to ammonia. A second group of bacteria oxidizes the ammonia to nitrites. A third group oxidizes the nitrites to nitrates. A fourth group, common in drainage waters, reduces nitrates to nitrites. Since these processes are going on side by side, nitrogen is to be found in all these states of combination when any natural water is subjected to chemical analysis. The following table shows some of the results of a large number (415) of analyses of four typical bottomland bodies of water, made for Kofoid's investigation of the plancton of the Illinois River by Professor Palmer.

The relative productiveness in open-water life of these situations is shown in the last column of the table.

In parts per million	Solids		Free Ammonia	Organic Nitrogen	Nitrites	Nitrates	Plancton cm^3 per m^3
	Sus-pended	Dis-solved					
Illinois River .	61.4	304.1	.860	1.03	.147	1.59	1.91
Spoon River .	274.3	167.1	.245	1.29	.039	1.01	.39
Quiver Lake .	25.1	248.2	.165	.61	.023	.66	1.62
Thompson's L.	44.6	282.9	.422	1.05	.048	.64	6.68

The difference between these four adjacent bodies of water explains some of the peculiarities of the table. The rivers hold more solids in suspension than do the lakes, although these lakes are little more than basins holding impounded river waters. Spoon River holds the least amount of dissolved solids, and by far the greatest amount of suspended solids. Since the latter are not available for plant food, naturally this stream is least productive of plancton. Illinois River drains a vast and fertile region, and receives in its course the sewage and other organic wastes of two large cities, Chicago and Peoria, and of many smaller ones. Hence, its high content of dissolved matter, the cities being remote, so there has been time for extensive liquefaction. Hence, also, its high content of ammonia, of nitrites and of nitrates.

The two lakes are very unlike; Quiver Lake is a mere strip of shoal water, fed by a clear stream that flows in through low sandy hills. It receives water from the Illinois River only during high floods. Thompson's Lake is a much larger body of water, fed directly from the Illinois River through an open channel. Naturally, it is much like the river in its dissolved solids, and in its total organic nitrogen. That it falls far below the river in nitrates and rises high above it in plancton production may perhaps be due to the extensive consumption of nitrates by plancton algae. Nitrates, because they furnish nitrogen supply in the form at once available for plant growths, are, in shallow waters at least, an index of the fertility of the water. As on land, so in the water, the supply of these may be inadequate for maximum productiveness, and they may be added with profit as fertilizer.

The carbonates—Lime and magnesia combine with carbon dioxide, abstracting it from the water, forming

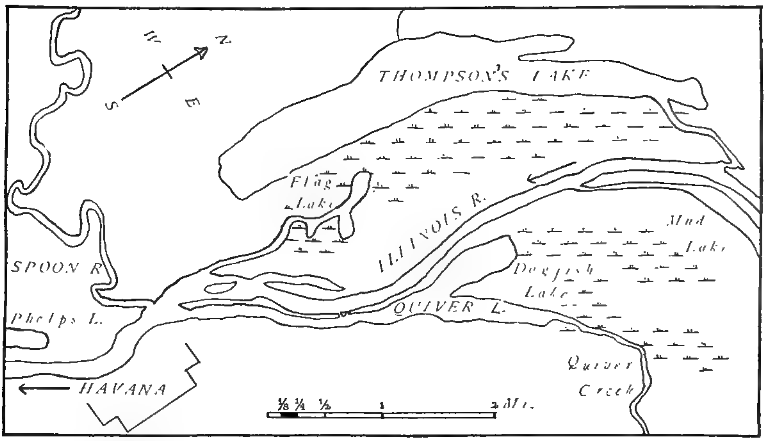


FIG. 9. Environs of the Biological Field Station of the Illinois State Laboratory of Natural History, the scene of important work by Kofoid and others on the life of a great river.

solid carbonates ($CaCO_3$ and $MgCO_3$). These accumulate in quantities in the shells of molluscs, in the stems of stoneworts, in the incrustations of certain pond weeds, and of lime-secreting algae. The remains of such organisms accumulate as marl upon the bottom. The carbonates (and other insoluble minerals) remain; the other body compounds decay and are removed. By such means in past geologic ages the materials for the earth's vast deposits of limestone were accumulated. Calcareous soils contain considerable quantities of these carbonates.

In pure water these simple carbonates are practically insoluble; but when carbon dioxide is added to the water, they are transformed into bicarbonates* and are readily dissolved.† So the carbonates are leached out of the soils and brought back into the water. So, the solid limestone may be silently removed, or hollowed out in great caverns by little underground streams. So the Mammoth Cave in Kentucky, and others in Cuba, in Missouri, in Indiana and elsewhere on the continent, have been formed.

The water gathers up its carbon dioxide in part as it descends through the atmosphere, and in larger part as it percolates thro soil where decomposition is going on and where oxidation products are added to it.

Carbon dioxide, thus exists in the water in three conditions: (1) Fixed (and unavailable as plant food) in the simple carbonates; (2) "half-bound" in the bicarbonates; and (3) free. Water plants use first for food, the free carbon dioxid, and then the "half bound" that is in loose combination in the bicarbonates. As this is used up the simple carbonates are released, and the water becomes alkaline.§ Birge and Juday have several times found a great growth of the desmid *Staurastrum* associated with alkalinity due to this cause. In a maximum growth which occurred in alkaline waters at a depth of three meters in Devil's Lake, Wisconsin, on June 15th, 1907, these plants numbered 176,000 per liter of water.

*$CaCO_3$, for example, becoming $Ca(HCO_3)_2$, the added part of the formula representing a molecule each of CO_2 and H_2O.

†If "hard" water whose hardness is due to the presence of these bicarbonates be boiled, the CO_2 is driven off and the simple carbonates are re-precipitated (as, for example, on the sides and bottom of a tea kettle). This is "temporary hardness." "Permanent hardness" is due to the presence of sulphates and chlorides of lime and magnesia, which continue in solution after boiling.

§Phenolphthalein, being used as indicator of alkalinity.

Waters that are rich in calcium salts, especially in calcium carbonate, maintain, as a rule, a more abundant life than do other waters. Especially favorable are they to the growth of those organisms which use much lime for the building of their hard parts, as molluscs, stoneworts, etc. There are, however, individual preferences in many of the larger groups. The crustaceans for example, prefer, as a rule, calcium rich waters, but one of them, the curious entomostracan, *Holopedium gibberum*, (Fig. 10) is usually found in calcium poor waters, in lakes in the Rocky Mountains and in the Adirondacks, in waters that flow off archæan rocks or out of siliceous sands. The desmids with few exceptions are more abundant in calcium poor waters. The elegant genus micrasterias is at Ithaca especially abundant in the peat-stained calcium-poor waters of sphagnum bogs.

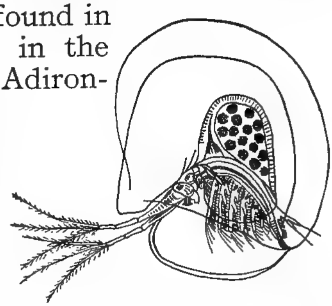


FIG. 10. A gelatinous-coated microcrustacean, *Holopedium gibberum*, often found in waters that are poor in calcium.

Other minerals in the water—The small quantities of other mineral substances required for plant growth are furnished mainly by a few sulphates, phosphates and chlorids: sulphates of sodium, potassium, calcium and magnesium; phosphates of iron, aluminum, calcium and magnesium, and chlorids of sodium, potassium, calcium and magnesium. Aluminum alone of the elements composing the above named compounds, is not always requisite for growth, although it is very often present. Silica, likewise, is of wide distribution, and occurs in the water in considerable amounts, and is used by many organisms in the growth of their hard parts. As the stoneworts use lime for their growth, some 4% of the dry weight of Chara being CaO, so diatoms require silica to build their shells. When the diatoms are dead their shells, relatively heavy though extremely minute, slowly settle to the bottom, slowly dissolving; and so, analyses of lake waters taken at different depths usually show increase of silica toward the bottom.

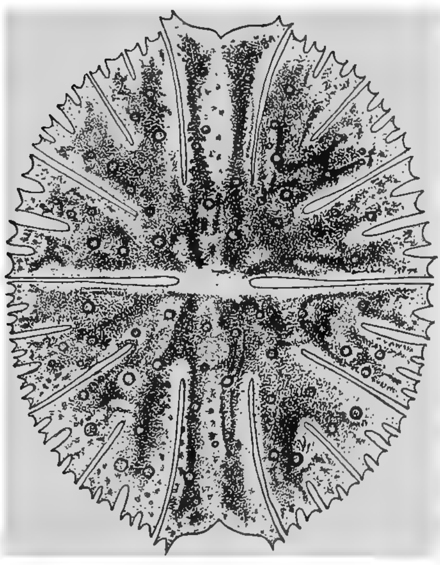


FIG. 11. A beautiful green desmid, *Micrasterias* that is common in bog waters.

Iron, common salt, sulphur, etc., often occur locally in great abundance, notably in springs flowing from special deposits, and when they occur they possess a fauna and flora of marked peculiarities and very limited extent.

An idea of the relative abundance of the commoner mineral substances in lake waters may be had from the following figures that are condensed from Birge and Juday's report of 74 analyses.

MINERAL CONTENT OF WISCONSIN LAKES

Parts per million

	SiO_2	Fl_2O_3 + Al_3O_3	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl
Minimum	0.8	0.4	0.6	0.3	0.3	0.3	0.0	4.9	0.0	1.5
Maximum	33.0	11.2	49.6	32.7	6.2	3.1	12.0	153.0	18.7	10.0
Average	11.7	2.1	26.9	19.6	3.2	2.2	2.1	91.7	9.8	3.9

This is the bill of fare from which green water plants may choose. Forel aptly compared the waters of a lake to the blood of the animal body. As the cells of the body take from the blood such of its content as is suited to their need, so the plants and animals of the water renew their substance out of the dissolved substances the water brings to them.

Organic substances dissolved in the water may so affect both its density and its viscosity as to determine both stratification and distribution of suspended solids. This is a matter that has scarcely been noticed by limnologists hitherto. Dr. J. U. Lloyd ('82) long ago showed how by the addition of colloidal substances to a vessel of water the whole contents of the vessel can be broken into strata and these made to circulate, each at its own level, independent of the other strata. Solids in suspension can be made to float at the top of particular strata, according to density and surface tension.

Perhaps the "false bottom" observed in some northern bog-bordered lakes is due to the dissolved colloids of the stratum on which it floats. Holt ('08, p. 219) describes the "false bottom" in Sumner Lake, Isle Royal, as lying six to ten feet below the surface, many feet above the true bottom; as being so tenuous that a pole could be thrust through it almost as readily as through clear water; and as being composed of fine disintegrated remains of leaves and other light organic material. "In places there were great breaks in the 'false bottom,' doubtless due to the escape of gases which had lifted this fine ooze-like material from a greater depth: and through these breaks one could look down several feet through the brownish colored water."

Perhaps the colloidal substances in solution are such as harden upon the surface of dried peat, like a water-proof glue, making it for a time afterward impervious to water.

WATER AND LAND

OCEANS are the earth's great storehouse of water. They cover some eight-elevenths of the surface of the earth to an average depth of about two miles. They receive the off-flow from all the continents and send it back by way of the atmosphere.

The fresh waters of the earth descend in the first instance out of the atmosphere. They rise in vapor from the whole surface of the earth, but chiefly from the ocean. Evaporation frees them from the ocean's salts, these being non-volatile. They drift about with the currents of the atmosphere, gathering its gases to saturation, together with very small quantities of drifting solids; they descend impartially upon water and land, chiefly as rain, snow and hail.

They are not distributed uniformly over the face of the continents for each continent has its humid regions and its deserts. Rainfall in the United States varies from 5 to 100 inches per annum. Two-thirds of it falls on the eastern three-fifths of the country. For the Eastern United States it averages about 48 inches, for the Western United States about 12 inches; the average for the whole is about 30 inches. The total annual precipitation is about 5,000,000,000 acre-feet.*

*An acre-foot is an acre of water 1 foot deep or 43,560 cubic feet of water.

It is commonly estimated that at least one-half of this rainfall is evaporated, in part from soil and water surfaces, but much more from growing vegetation; for the transpiration of plants gives back immense quantities of water to the atmosphere. Hellriegel long ago showed that a crop of corn requires 300 tons of water per acre: of potatoes or clover, 400 tons per acre. At the Iowa Agricultural Experiment Station it was shown that an acre of pasturage requires 3,223 tons of water, or 28 inches in depth (2⅓ acre-feet). Before the days of tile drainage it was a not uncommon practice to plant willow trees by the edges of swales, in order that they might carry off the water through their leaves, leaving the ground dry enough for summer cropping. The rate of evaporation is accelerated also, by high temperatures and strong winds.

The rain tends to wet the face of the ground everywhere. How long it will stay wet in any given place will depend on topography and on the character of the soil as well as on temperature and air currents. Showers descending intermittently leave intervals for complete run-off of water from the higher ground, with opportunity for the gases of the atmosphere to enter and do their work of corrosion. The dryer intervals, therefore, are times of preparation of the materials that will appear later in soil waters. Yet all soils in humid regions retain sufficient moisture to support a considerable algal flora. Periodical excesses of rainfall are necessary also to maintain the reserve of ground water in the soil. Suppose, for example, that the 35 inches of annual rainfall at Ithaca were uniformly distributed. There would be less than one-tenth of an inch of precipitation each day—an amount that would be quickly and entirely evaporated, and the ground would never be thoroughly wet and there would be no ground water to replenish the streams. Storm waters tend to be gathered together in streams, and thus about one-third of our rainfall runs away. In humid areas small streams converge to form larger ones, and flow onward to the seas. In arid regions they tend to spread out in sheet floods, and to disappear in the sands.

In a state of nature little rain water runs over the surface of the ground, apart from streams. It mainly descends into the soil. How much the soil can hold depends upon its composition. Dried soils have a capacity for taking up and holding water about as follows: sharp sand 25%, loam 50%, clay 60%, garden mould 90% and humus 180% of their dry weight. Water descends most rapidly through sand and stands longest upon the surface of pure clay. Thick vegetation with abundant leaf fall, and humus in the soil tend to hinder run-off of storm waters, and to prolong their passage through the soil. Thus the excess of rainfall is gradually fed into the streams by springs and seepage. Under natural conditions streams are usually clear, and their flow is fairly uniform.

Unwise clearing of the land and negligent cultivation of the soil facilitate the run-off of the water before the storm is well spent, promote excessive erosion and render the streams turbid and their volume abnormally fluctuating. Little water enters the soil and hence the springs dry up, and the brooks, also, as the seepage of ground water ceases. Two great evils immediately befall the creatures that live in the streams and pools: (1) There is wholesale direct extermination of them with the restriction of their habitat at low water. (2) There occurs smothering of them under deposits of sediment brought down in time of floods, with indirect injury to organisms not smothered, due to the damage to their foraging grounds.

The waters of normal streams are derived mainly from seepage, maintained by the store of water accumulated in the soil. This store of ground water amounts according to recent estimates to some 25% of the bulk of the first one hundred feet in soil depth. Thus it equals a reservoir of water some 25 feet deep covering the whole humid eastern United States. It is continuous over the entire country. Its fluctuations are studied by means of measurements of wells, especially by recording the depth of the so-called "water table." On the maintenance of ground water stream-flow and organic productiveness of the fields alike depend.

CHAPTER III

TYPES OF AQUATIC ENVIRONMENT

I. LAKES AND PONDS

OUT of the atmosphere comes our water supply —the greatest of our natural resources. It falls on hill and dale, and mostly descends into the soil. The excess off-flowing from the surface and outflowing from springs and seepage, forms water masses of various sorts according to the topography of the land surface. It forms lakes, streams or marshes according as there occur basins, channels or only plant accumulations influencing drainage.

The largest of the bodies of water thus formed are the lakes. Our continent is richly supplied with them, but they are of very unequal distribution. The lake regions in America as elsewhere are regions of comparatively recent geological disturbance. Lakes thickly dot the peninsula of Florida, the part of our continent most recently lifted from the sea. Over the northern recently glaciated part of the continent they are innumerable, but in the great belts of corn and cotton, and on the plains to the westward, they are few and far between. They are abundant in the regions of more recent volcanic disturbance in our western mountains, but are practically absent from the geologically older Appalachian hills. They lie in the depressions between the recently uplifted lava blocks of southern Oregon. They occur also in the craters of extinct volcanoes. They are apt to be most picturesque when their setting is in the midst of mountains. There are probably no more beautiful lakes in the world than some of those in the West, such as Lake Tahoe (altitude 6200 ft.) on the California-Nevada boundary, and Lake Chelan in the state of Washington*, to say nothing of the Coeur d'Alene in Idaho and Lake Louise in British Columbia. Eastward the famous lake regions that attract most visitors are those of the mountains of New York and New England, those of the woodlands of Michigan and Wisconsin and those of the vast areas of rocks and water in Canada.

Lakes are temporary phenomena from the geologists point of view. No sooner are their basins formed than the work of their destruction begins. Water is the agent of it, gravity the force employed, and erosion the chief method. Consequently, other things being equal, the processes of destruction go on most rapidly in regions of abundant rainfall. Inwash of silt from surrounding slopes tends to fill up their basins. The most extensive filling is about the mouths of inflowing streams, where mud flats form, and extend in Deltas out into the lake. These deltas are the exposed summits of great mounds of silt that spread out broadly underneath the water on the lake floor. At the shorelines these deposits are loosened by the frosts of winter,

*Descriptions of these two lakes will be found in Russell's *Lakes of North America.*

pushed about by the ice floes of spring, and scattered by every summer storm, but after every shift they settle again at lower levels. Always they are advancing and filling the lake basin. The filling may seem slow and insignificant on the shore of one of the Great Lakes but its progress is obvious in a mill pond, and the difference is only relative.

FIG. 12. An eroding bluff on the shore of Lake Michigan that is receding at the rate of several feet each year. The broad shelving beach in the foreground is sand, where the waves ordinarily play. Against the bare rising boulder-strewn strip back of this, the waves beat in storms; at its summit they gather the earth-slides from the bank above and carry them out into the lake. The black strip at the rear of the sand is a line of insect drift, deposited at the close of a midsummer storm by the turning of the wind on shore.

On the other hand, lakes disappear with the cutting down of the rim of their basins in outflow channels. The Niagara river, for example, is cutting through the limestone barrier that retains Lake Erie. At Niagara Falls it is making progress at the rate of about five feet a year. Since the glacial period it has cut back from the shore of Lake Ontario a distance of some seventeen miles, and if the process continues it will in time empty Lake Erie.

FIG. 13. Evans' Lake, Michigan; a lake in process of being filled by encroachment of plants. A line of swamp loose-strife (*Decodon*) leads the invading shore vegetation. Further inwash of silt or lowering of outlet is precluded by density of the surrounding heath. The plants control its fate.

Photo by E. McDonald.

When the glacier lay across the St. Lawrence valley, before it had retreated to the northward, all the waters of the great lakes region found their way to the ocean through the Mohawk Valley and the Hudson. At that time a similar process of cutting an outlet through a limestone barrier was going on near the site of the present village of Jamesville, New York, where on the

Clark Reservation one may see today a series of abandoned cataracts, dry rock channels and plunge basins. Green Lake at present occupies one of these old plunge basins, its waters, perhaps a hundred feet deep, are surrounded on all sides but one, by sheer limestone cliffs nearly two hundred feet high.

When lakes become populated then the plants and animals living in the water and about the shore line contribute their remains to the final filling of the basin. This is well shown in figure 13.

The Great Lakes constitute the most magnificent system of reservoirs of fresh water in the world; five vast inland seas, whose shores have all the sweep and majesty of the ocean, no land being visible across them. All but one (Erie) have the bottom of their basins below the sea level. Their area, elevation and depth are as follows:

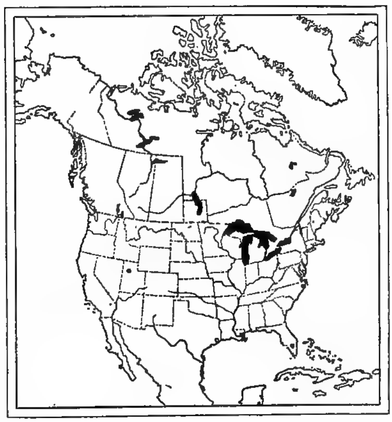


FIG. 14. The larger lakes and rivers of North America.

	Area in sq. mi.	Surface alt. in ft.	Depth in feet mean†	maximum
Lake Ontario	7.240	247	300	738
" Erie	9.960	573	70	210
" Huron*	23.800	581	250	730
" Michigan	22.450	581	325	870
" Superior	31.200	602	475	1.008

*Including Georgian Bay.
†Approximate.

They are stated by Russell to contain enough water to keep a Niagara full-flowing for a hundred years.

The Finger Lakes of the Seneca basin in Central New York constitute an unique series occupying one section of the drainage area of Lake Ontario, with which they communicate by the Seneca and Oswego rivers. They occupy deep and narrow valleys in an upland plateau of soft Devonian shales. Their shores are rocky and increasingly precipitous near their southern ends. The marks of glaciation are over all of them. Keuka, the most picturesque of the series, occupies a forking valley partially surrounding a magnificent ice-worn hill. The others are all long and narrow and evenly contoured, without islands (save for a single rocky islet near the east Cayuga shore) or bays.

The basins of these lakes invade the high hills to the southward, reaching almost to the head-waters of the tributaries of the Susquehanna River. Here there is found a wonderful diversity of aquatic situation. At the head of Cayuga Lake, for example, beyond the deep water there is a mile of broad shelving silt-covered lake bottom, ending in a barrier reef. Then there is a broad flood plain, traversed by deep slow meandering streams, and covered in part by marshes. Then come the hills, intersected by narrow post-glacial gorges, down which dash clear streams in numerous beautiful waterfalls and rapids. Back of the first rise of the hills the streams descend more slowly, gliding along over pebbly beds in shining riffles, or loitering in leaf-strewn woodland pools. A few miles farther inland they find their sources in alder-bordered brooks flowing from sphagnum bogs and upland swales and springs.

Thus the waters that feed the Finger Lakes are all derived from sources that yield little aquatic life, and they run a short and rapid course among the hills, with little time for increase by breeding: hence they contribute little to the population of the lake. They bring in constantly, however, a supply of food materials, dissolved from the soils of the hills.

Bordering the Finger Lakes there no extensive marshes, save at the ends of Cayuga, and the chief irregularities of outline are formed by the deltas of inflowing streams. The two large central lakes, Cayuga and Seneca, have their basins extending below the sea level. Their sides are bordered by two steeply-rising, smoothly eroded hills of uniform height, between which they lie extended like wide placid rivers. The areas, elevations and depths of the five are as follows:

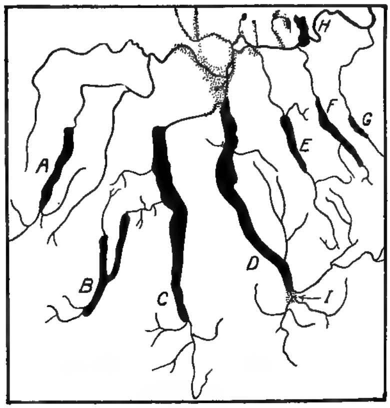


FIG. 15. The finger-lakes of Central New York.

A, Canandaigua; B, Keuka; C, Seneca; D, Cayuga; E, Owasco; F, Skaneateles; G, Otisco; H, the Seneca River; I, The arrow indicates the location of the Cornell University Biological Field Station at Ithaca. The stippled area at the opposite end of Cayuga Lake marks the location of the Montezuma Marshes.

	Area sq. mi.	Surface alt. in ft.	Depth in feet mean	Depth in feet maximum
Lake Skaneateles	13.9	867	142	297
" Owasco	10.3	710	95	177
" Cayuga	66.4	381	177	435
" Seneca	67.7	444	288	618
" Keuka	18.1	709	99	183
" Canandaigua	16.3	686	126	274

Birge and Juday found the transparency of four of these lakes as measured by Secchi's disc in August, 1910, to be as follows:

Canandaigua	12.0 ft.	Seneca	27.0 ft.
Cayuga	16.6 ft.	Skaneateles	33.5 ft.

The Lakes of the Yahara Valley in Southern Wisconsin are of another type. They occupy broad, shallow basins formed by the deposition of barriers of glacial drift in the preglacial course of the Yahara River. Their outlet is through Rock River into the Mississippi. Their shores are indented with numerous bays, and bordered extensively by marshes. The surrounding plain is dotted with low rounded hills, some of which rise abruptly from the water, making attractive shores. The city of Madison is the location of the University of Wisconsin, which Professor Birge has made the center of the most extensive and careful study of lakes yet undertaken in America. The area, elevation and depth of these lakes is as follows:

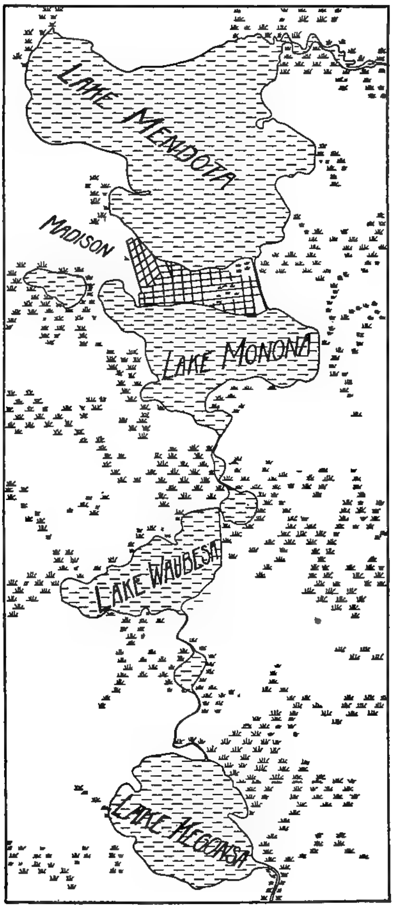


FIG. 16. The four-lake region of Madison, Wisconsin.

	Area in sq. mi.	Surface alt. in ft.	Depth in feet mean	maximum
Lake Kegonsa	15	842	15	31
" Wabesa	3	844	15	36
" Monona	6	845	27	75
" Mendota	15	849	40	85

Lakes resulting from Erosion—Although erosion tends generally to destroy lakes by eliminating their basins, here and there it tends to foster other lakes by making basins for them. Such lakes, however, are shallow and fluctuating. They are of two very different sorts, *floodplain lakes* and *solution lakes*.

Floodplain Lakes and Ponds—Basins are formed in the floodplains of rivers by the deposition of barriers of eroded silt, in three different ways.

1. By the deposition across the channel of some large stream of the detritus from a heavily silt-laden tributary stream. This blocks the larger stream as with a partial dam, creating a lake that is obviously but a dilatation of the larger stream. Such is Lake Pepin in the Mississippi River, created by the barrier that is deposited by the Chippewa River at its mouth.

2. By the partial filling up of the abandoned channels of rivers where they meander through broad alluvial bottom-lands. Phelps Lake partly shown in the figure on page 50 is an example of a lake so formed; and all the other lakes of that figure are partly occluded by similar deposits of river silt. Horseshoe bends are common in slow streams, and frequently a river will cut across a bend, shortening its course and opening a new channel; the filling up with silt of the ends of the abandoned channel results in the formation of an "ox-bow" lake; such lakes are common along the lower course of the Mississippi, as one may see by consulting any good atlas.

3. By the deposition in times of high floods of the bulk of its load of detritus at the very end of its course, where it spreads out in the form of a delta. Thus a barrier is often formed on one or both sides, encircling a broad shallow basin. Such is Lake Pontchartrain at the left of the ever extending delta of the Mississippi.

Solution Lakes and Ponds—Of very different character are the lakes whose basins are produced by the dissolution of limestone strata and the descent of the overlying soil in the form of a "sink." This is erosion, not by mechanical means at first, but by solution. It occurs where beds of soluble strata lie above the permanent ground water level, and are themselves overlaid by clay. Rain water falling through the air gathers carbon dioxide and becomes a solvent of limestone. Percolating downward through the soil it passes through the permeable carbonate, dissolving it and carrying its substance in solution to lower levels, often flowing out in springs. As the limestone is thus removed the superincumbent soil falls in, forming a sink hole. The widening of the hole, by further solution and slides results in the formation of the pond or lake, possibly, at the beginning, as a mere pool.

FIG. 17. Solution lakes of Leon County, Florida, (after Sellards).

The white spots in the lakes indicate sinks
A. Lake Iamonia; area at high water 10 sq. mi.
B. Lake Jackson; area 7 sq. mi.
C. Lake Fafayette; area 3½ sq. mi.
D. Lake Miccosukee; are a 7⅞ sq. mi.; depth of north sink 28 ft. Water escapes through this sink at the estimated rate of 1000 gals. per minute.
O. Ocklocknee River; S, St. Mark's River; T, Tallahassee.

Such a lake doubtless begins as a mere pool filling a sink hole. Its area is gradually increased by the settling of the bottom around the sink. Its configuration is in part determined by the original topography of the land surface, and in part by the course of the streamflow underground: but its bed is unique among lake bottoms in that all its broad shoals suddenly terminate in one or more deep funnel-shaped outflow depressions.

Lime sinks occur over considerable areas in the southern states, and in those of the Ohio Valley, but perhaps the best development of lakes about them is in the upland region of northern Florida. These lakes are shallow basins having much of their borders ill-defined and swampy. Perhaps the most remarkable of them is Lake Alachua near Gainesville. At high water this lake has an area of some twenty-five square miles and a depth (outside the sink) of from two to fourteen feet. At its lowest known stage it is reduced to pools filling the sinks. During its recorded history it has several times alternated between these conditions. It has been for years a vast expanse of water carrying steamboat traffic, and it has been for other years a broad grassy plain, with no water in sight. The widening or the stoppage of the sinks combined with excessive or scanty rainfall have been the causes of these remarkable changes of level.

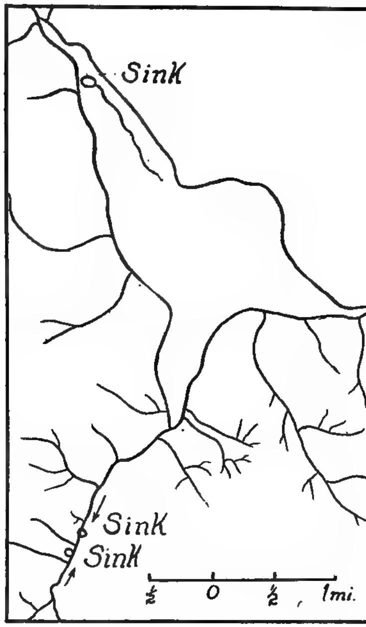


FIG. 18. Lake Miccosukee, (after Sellards), showing sinks; one in lake bottom at north end, two in outflowing stream, 2½ miles distant. Arrows indicate normal direction of stream flow, (reversed south of sinks in flood time when run-off is into St. Mark's River).

The sinks are more or less funnel-shaped openings leading down through the soil into the limestone. Ditchlike channels often lead into them across the lake's bottom. The accompanying diagram shows that they are sometimes situated outside the lake's border, and suggest that such lakes may originate through the formation of sinks in the bed of a slow stream.

Such lakes, when their basins lie above the level of the permanent water table, may sometimes be drained by sinking wells through the soil of their beds. This allows the escape of their waters into the underlying limestone. Sometimes they drain themselves through the widening of their underground water channels. Always they are subject to great changes of level consequent upon variation in rainfall.

Enough examples have now been cited to show how great diversity there is among the fresh-water lakes of North America. Among those we have mentioned are the lakes that have received the most attention from limnologists hitherto; but hardly more than a beginning has been made in the study of any of them. Icthyologists have collected fishes from most of the lakes of the entire continent, and plancton collections have been made from a number of the more typical: from Yellowstone Lake by Professor Forbes in 1890 and from many other lakes, rivers and cave streams since that date.

Lakeside laboratories—On the lakes above mentioned are located a number of biological field stations. That at Cornell University is at the head of Cayuga Lake. That of the Ohio State University is at Sandusky on Lake Erie. The Canadian fresh-water station is at Go Home Bay on Lake Huron. The biological laboratories of the University of Wisconsin are located directly upon the shore of Lake Mendota. Other lakeside stations are as follows:

That of the University of Michigan is on Douglas Lake in the northern end of the southern peninsula of Michigan. This is an attractive sheet of water at an altitude of 712 ft., covering an area of 5.13 square miles, and having (as far as surveyed) a maximum depth of 89 feet and an average depth of 22 feet. Its transparency by Secchi's disc as measured in August is about four meters.

That of the University of Indiana is on Winona Lake, a shallow hard water lake of irregular outline, having an area of something less than a square mile, an elevation of 810 feet, a maximum depth of 81 feet and a transparency (Secchi's disc) varying with the season between 7 and 15 feet.

That of the University of Iowa is on Okoboji Lake.

That of the University of North Dakota is on Devils Lake, an alkaline upland lake (salinity 1%) having an area of 62½ square miles and a maximum depth of 25 feet. The salt-marsh ditch-grass (*Ruppia maritima*) is the only seed plant growing in its waters.

That of the University of Montana is on Flathead Lake, a cold mountain lake some thirty miles long by ten miles broad having an elevation of 2916 ft. and a maximum depth of 280 ft.

That of the University of Utah is on Silver Lake (altitude 8728 ft.) some twenty miles from the Great Salt Lake. Six small nearby mountain lakes all have an altitude of more than 9000 feet.

Doubtless, with the growing interest in limnological work, other lakeside stations will be added to this list.

Depth and Breadth—The depth of lakes is of more biological significance than the form of their basins; for, as we have seen in the preceding chapter, with increase of depth goes increased pressure, diminished light, and thermal stratification of the water. Living conditions are therefore very different in shallow water from what they are in the bottom of a deep lake, where there is no light, and where the temperature remains constant throughout the year. Absence of light prevents the growth of chlorophyl-bearing organisms and renders such waters relatively barren. The lighted top layer of the water (zone of photosynthesis) is the productive area. The other is a reservoir; tending to stabilize conditions. Lakes may therefore be roughly grouped in two classes: first, those that are shallow enough for complete circulation of their water by wind or otherwise at any time; and second those deep enough to maintain through a part of the summer season a bottom reservoir of still water, undisturbed by waves or currents, and stratified according to temperature and consequent density. In these deeper lakes a thermocline appears during midsummer. In the lakes of New York its upper limit is usually reached at about thirty-five feet and it has an average thickness of some fifteen feet. Our lakes of the second class may therefore be said to have a depth greater than fifty feet.

Lakes of this class may differ much among themselves according to the relative volume of this bottom reservoir of quiet water, Lakes Otisco and Skaneateles (see map on page 65) serve well for comparison in this regard, since they are similar in form and situation and occupy parallel basins but a few miles apart.

Lake	Area in sq. mi.	Max. depth in ft.	% of vol. below 50 ft.	Trans-parency*	Free CO_2† at surface	bottom	Oxygen† at surface	bottom
Otisco	2.64	66	7.0	9.2	—2.50	+3.80	6.72	0.00
Skaneateles.	13.90	297	70.2	31.8	—1.25	+1.00	6.75	7.89

*In feet, measured by Secchi's disc.

†In cc. per liter of water. Alkalinity by phenolthalein test is indicated by the minus sign.

The figures given are from midsummer measurements by Birge and Juday. At the time these observations were made both lakes were alkaline at the surface. tho still charged with free carbon dioxide at the bottom. Apparently, the greater the body of deep water the greater the reserve of oxygen taken up at the time of the spring circulation and held through the summer season. Deep lakes are as a rule less productive of plancton in summer, even in their surface waters, because their supply of available carbon dioxide runs low. It is consumed by algae and carried to the bottom with them when they die, and thus removed from circulation.

Increasing breadth of surface means increasing exposure to winds with better aeration, especially where waves break in foam and spray, and with the development of superficial currents. Currents in lakes are not controlled by wind alone, but are influenced as well by contours of basins, by outflow, and by the centrifugal pull due to the rotation of the earth on its axis. In Lake Superior a current parallels the shore, moving in a direction opposite to that of the hands of a clock. Only in the largest lakes are tides perceptible, but there are other fluctuations of level that are due to inequalities of barometric pressure over the surface. These are called *seiches*.

Broad lakes are well defined, for they build their own barrier reefs across every low spot in the shores, and round out their outlines. It is only shores that are not swept by heavy waves that merge insensibly into marshes. In winter in our latitude the margins of the larger lakes become icebound, and the shoreline is temporarily shifted into deeper water (compare summer and winter conditions at the head of Cayuga lake as shown in our frontispiece).

Increasing breadth has little effect on the life of the open water, and none, directly, on the inhabitants of the depths; but it profoundly affects the life of the shoals and the margins, where the waves beat, and the loose sands scour and the ice floes grind. Such a beach as that shown on page 61 is bare of vegetation only because it is storm swept. The higher plants cannot withstand the pounding of the waves and the grinding of the ice on such a shore.

The shallower a lake is the better its waters are exposed to light and air, and, other things being equal, the richer its production of organic life.

High and low water—Since the source of this water is in the clouds, all lakes fluctuate more or less with variation in rainfall. The great lakes drain an empire of 287,688 square miles, about a third of which is covered by their waters. They constitute the greatest system of fresh water reservoirs in the world, with an unparalleled uniformity of level and regularity of outflow. Yet their depth varies from month to month

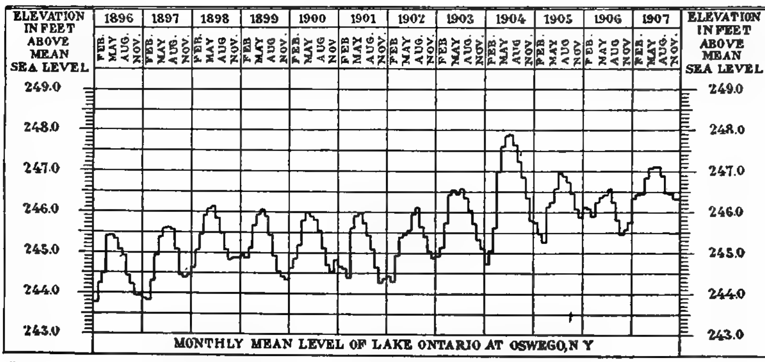


FIG. 19. Diagram of monthly water levels in Lake Ontario for twelve years; from the Report of the International Waterways Commission for 1910.

and from year to year, as shown on the accompanying diagram. From this condition of relative stability to that of regular disappearance, as of the strand lakes of the Southwest, there are all gradations. Topography determines where a lake may occur, but climate has much to do with its continuance. Lakes in arid regions often do not overflow their basins. Continuous evaporation under cloudless skies further aided by high winds, quickly removes the excess of the floods that run into them from surrounding mountains. The minerals dissolved in these waters are thus concentrated, and they become alkaline or salt. We shall have little to say in this book about such lakes, or about their population, but they constitute an interesting class. Life in their waters must meet conditions physiologically so different that few organisms can live in both fresh and salt water.

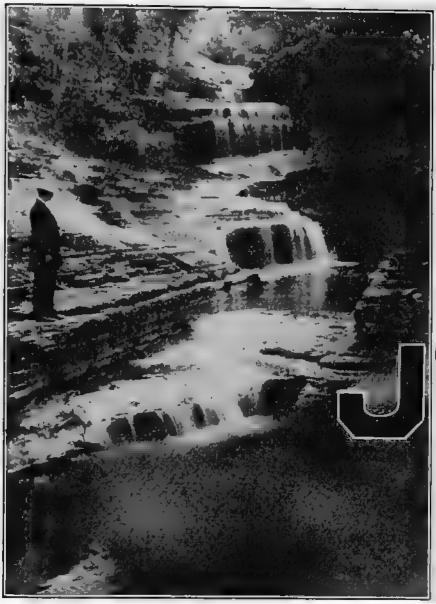
Large lakes in arid regions are continually salt; permanent lakes of smaller volume are made temporarily fresh or brackish by heavy inflowing floods; while

FIG. 20. Marl pond near Cortland, N. Y., at low water. The whiteness of the bed surrounding the residual pool is due to deposited marl, largely derived from decomposed snail shells. The marl is thinly overgrown with small freely-blooming plants of *Polygonum amphibium*. Tall aquatics mark the vernal shore line. (Photo by H. H. Knight).

strand lakes (called by the Spanish name *playa* lakes, in the Southwest) run the whole gamut of water content, and vanish utterly between seasons of rain.

Complete withdrawal of the waters is of course fatal to all aquatic organisms, save a few that have specialized means of resistance to the drought. Partial withdrawal by evaporation means concentration of solids in solution, and crowding of organisms, with limitation of their food and shelter. The shoreward population of all lakes is subject to a succession of such vicissitudes.

The term *limnology* is often used in a restricted sense as applying only to the study of freshwater lakes. This is due to the profound influence of the Swiss Master, F. A. Forel, who is often called the "Father of Limnology." He was the first to study lakes intensively after modern methods. He made the Swiss lakes the best known of any in the world. His greatest work "*Le Leman*," a monograph on Lake Geneva, is a masterpiece of limnological literature. It was he who first developed a comprehensive plan for the study of the life of lakes and all its environing conditions.



STREAMS

JOURNEYING seaward, the water that finds no basins to retain it, forms streams. According as these differ in size we call them rivers, creeks, brooks, and rills. These differ as do lakes in the dissolved contents of their waters, according to the nature of the soils they drain. Streams differ most from the lakes in that their waters are ever moving in one direction, and ever carrying more or less of a load of silt. From the geologist's point of view the work of rivers is the transportation of the substance of the uplands into the seas. It is an eternal levelling process. It is well advanced toward completion in the broad flood plains of the larger continental streams (see map on page 63); but only well begun where brooks and rills are invading the high hills, where the waters seek outlets in all directions, and where every slope is intersected with a maze of channels. The rapidity of the grading work depends chiefly upon climate and rainfall, on topography and altitude and on the character of the rocks and soil.

The rivers of America have been extensively studied as to their hydrography, their navigability, their water-power resources, and their liability to overflow with consequent flood damage; but it is the conditions they

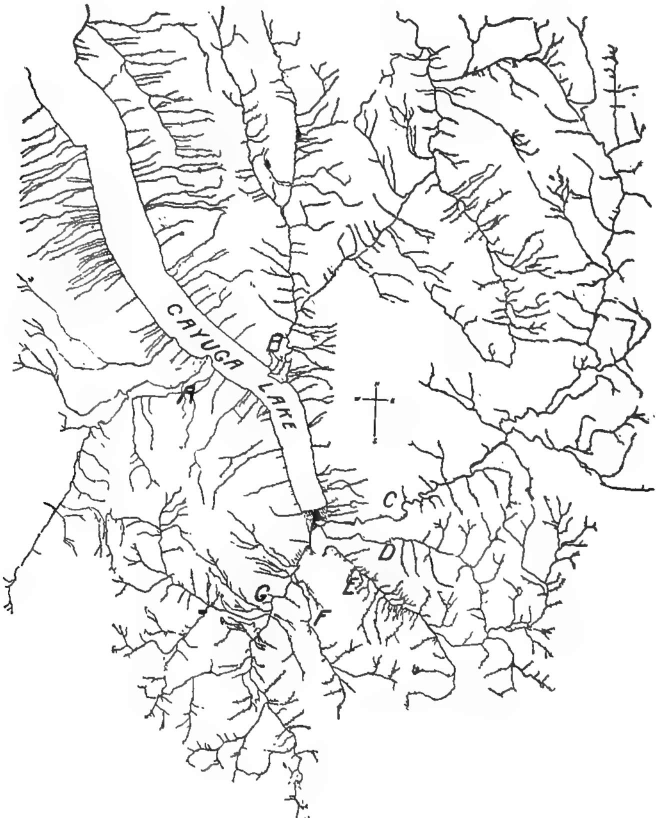


FIG. 21. Streams of the upper Cayuga basin.

A. Taughannock Creek, with a waterfall 211 feet high near its mouth; *B*. Salmon Creek; *C*. Fall Creek with the Cornell University Biological Field Station in the marsh at its mouth (views on this stream are shown in the initial cuts on pages 24 and 82); *D*. Cascadilla Creek (view on page 55); *E*. Sixmile Creek; *F*. Buttermilk Creek with Coys Glen opposite its mouth. (View on page 77; of the Glen on page 25); *G*. Neguena Creek or the Inlet. The southernmost of these streams rise in cold swamps, which drain southward also into tributaries of the Susquehanna River.

afford to their plant and animal inhabitants that interest us here; and these have been little studied. Most has been done on the Illinois River, at the floating laboratory of the Illinois State Laboratory of Natural History (see page 50). A more recently established river laboratory, more limited in its scope (being primarily concerned with the propagation of river mussels) is that of the U. S. Fish Commission at Fairport, Iowa, on the Mississippi River.

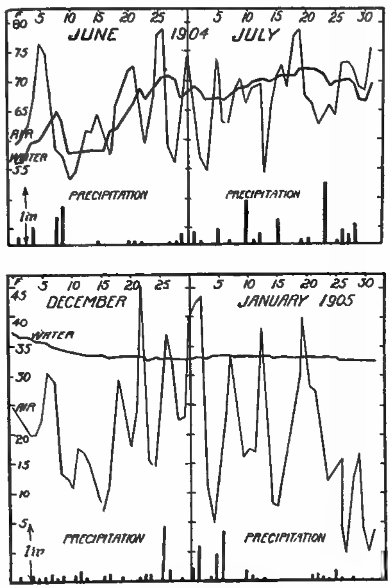


FIG. 22. Diagram showing summer and winter conditions in Fall Creek at Ithaca, N. Y. Data on air temperatures furnished by Dr. W.M. Wilson of the U. S. Weather Bureau. Data on water temperatures by Professor E. M. Chamot.

In large streams, especially in their deeper and more quiet portions, the conditions of life are most like those in lakes. In lesser streams life is subject to far greater vicissitudes. The accompanying figure shows comparative summer and winter temperatures in air and in water of Fall Creek at Ithaca. This creek (see the figure on page 24), being much broken by waterfalls and very shallow, shows hardly any difference between surface and bottom temperatures. The summer temperatures of air and water (fig. 22) are seen to maintain a sort of correspondence, in spite of the thermal conservatism of water, due to its greater specific heat. This approximation is due to conditions in the creek which make for rapid heating or cooling of the water.

It flows in thin sheets over broad ledges of dark colored rocks that are exposed to the sun, and it falls over projecting ledges in broad thin curtains, outspread in contact with the air.

The curves for the two winter months, show less concurrence, and it is strikingly apparent that during that period when the creek was ice-bound (Dec. 15–Jan. 31) the water temperature showed no relation to air temperature, but remained constantly at or very close to 0° C. (32° F.).

Forbes and Richardson (13) have shown how great may be the aerating effect of a single waterfall in such a sewage polluted stream as the upper Illinois River. "The fall over the Marseilles dam (710 feet long and 10 feet high) in the hot weather and low water period of July and August, 1911, has the effect to increase the dissolved oxygen more than four and a half times, raising it from an average of .64 parts per million to 2.94 parts. On the other hand, with the cold weather, high oxygen ratios, and higher water levels of February and March, 1912, and the consequent reduced fall of water at Marseilles, the oxygen increase was only 18 per cent.—from 7.35 parts per million above the dam to 8.65 parts below * * * The beneficial effect is greatest when it is most needed—when the pollution is most concentrated and when decomposition processes are most active."

Ice—The physical conditions that in temperate regions have most to do with the well- or ill-being of organisms living in running water are those resulting from the freezing. The hardships of winter may be very severe, especially in shallow streams. One may stand beside Fall Creek in early winter when the thin ice cakes heaped with snow are first cast forth on the stream, and see through the limpid water an abundant life gathered upon the stone ledges, above which these miniature floes are harmlessly drifting. There are great black patches of *Simulium* larvae, contrasting strongly with the whiteness of the snow. There are beautiful green drapings of *Cladophora* and rich red-purple fringes of *Chantransia*, and everywhere amber-brown carpetings of diatoms, overspreading all the bottom. But if one stand in the same spot in the spring, after the heavy ice of winter has gone out, he will see that the rocks have been swept clean and bare, every living thing that the ice could reach having gone.

The grinding power of heavy ice, and its pushing power when driven by waves or currents, are too well known to need any comment. The effects may be seen on any beach in spring, or by any large stream. But there is in brooks and turbulent streams a cutting with fine ice rubble that works through longer periods, and adds the finishing touches of destructiveness. It is driven by the water currents like sand in a blast, and it cleans out the little crevices that the heavy ice could not enter. This ice rubble is formed at the front of water falls under such conditions as are shown in the accompanying figure of Triphammer Falls at Ithaca. The pool below the fall froze first. The winter increasing cold, the spray began to freeze where it fell. It formed icicles, large and small, wherever it could find a support above. It built up grotesque columns on the edge of the ice of the pool beneath. It grew inward from the sides and began to overarch the stream face; and then, with favoring intense cold of some days duration, it extended these lines of frozen spray across the front of the fall in all directions, covering it as with a beautiful veil of ice.

The conditions shown in the picture are perfect for the rapid formation of ice rubble. From thousands of points on the underside of this tesselated structure minute icicles are forming and their tips are being broken off by the oscillations of the current. These broken tips constitute the rubble. They are sometimes remarkably uniform in size--those forming when this picture was taken were about the size of peas—and though small they are the tools with which the current does its winter cleaning. In the ponds formed by damming rapid streams this rubble accumulates under the solid ice.

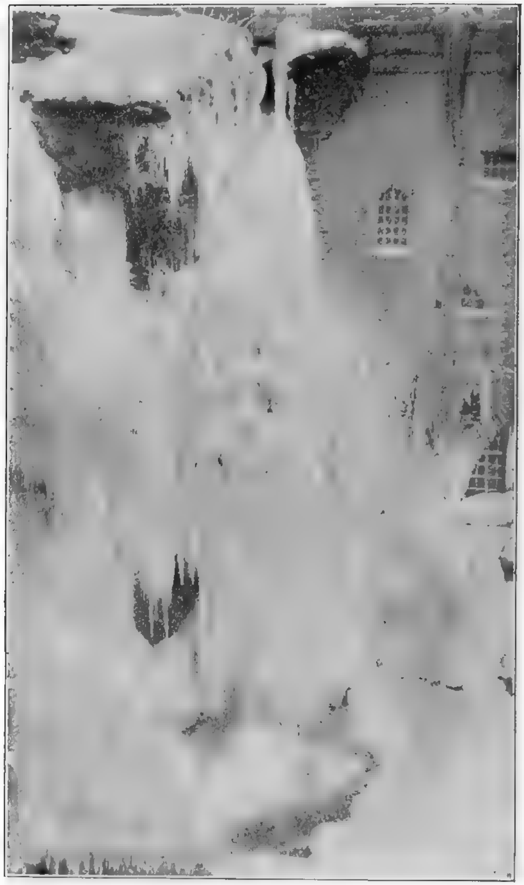


FIG. 23. The ice veil on Triphammer Falls, Cornell University Campus. The fall is at the left, the Laboratory of Hydraulic Engineering at the right in the picture, the only open water seen is in the foaming pool at the foot of the fall.

"Anchor ice" forms in the beds of rapid streams, and adds another peril to their inhabitants. The water, cooled below the freezing point by contact with the air, does not freeze in the current because of its motion, but it does freeze on the bottom where the current is sufficiently retarded to allow it. It congeals in semi-solid or more or less flocculent masses which, when attached to the stones of the bed, often buoy them up

Fig. 24. A brook in winter. Country Club woods, Ithaca, N. Y.
Photo by John T. Needham.

and cause them to be carried away. Thus the organisms that dwell in the stream bed are deprived of their shelter and exposed to new perils.

Below the frost-line, however, in streams where dangers of mechanical injuries such as above mentioned are absent, milder moods prevail. In the bed of a gentle meandering streamlet like that shown in the accompanying figure, life doubtless runs on in winter with greater serenity than on land. Diatoms grow and caddis-worms forage and community life is actively maintained.

Silt—Part of the substance of the land is carried seaward in solution. It is ordinarily dissolved at or near the surface of the ground, but may be dissolved from underlying strata, as in the region of the Mammoth Cave in Kentucky, where great streams run far under ground. But the greater part is carried in suspension. Materials thus carried vary in size from the finest particles of clay to great trees dropped whole into the stream by an undercutting flood. The lighter solids float, and are apt to be heaped on shore by wave and wind. The heavier are carried and rolled along, more or less intermittently, hastened with floods and slackened with low water, but ever reaching lower levels. The rate of their settling in relation to size and to velocity of stream has been discussed in the preceding chapter.

Silt is most abundant at flood because of the greater velocity of the water at such times. Kofoid ('03) has studied the amount of silt carried by the Illinois River at Havana. Observations at one of his stations extending over an entire year show a minimum amount of 140 cc. per cubic meter of river water; a maximum of 4,284 cc., and an average for the year (28 samples) of 1,572 cc. Silt in a stream affects its population in a number of ways. It excludes light and so interferes with the growth of green plants, and thus indirectly with the food supply of animals. It interferes with the free locomotion of the microscopic animals by becoming entangled in their swimming appendages. It clogs the respiratory apparatus of other animals. It falls in deposits that smother and bury both plants and animals living on the bottom. Thus the best foraging grounds of some of our valuable fishes are ruined.

Professor Forbes ('00) has shown that the fine silt from the earlier-glaciated and better weathered soils of southern Illinois, has been a probable cause of exclusion of a number of regional fishes from the streams of that portion of the state.

It is heavier slit that takes the larger share in the building of bars and embankments along the lower reaches of a great stream, in raising natural levees to hold impounded backwaters, and in blocking cut-off channels to make lakes of them.

Current—Rate of streamflow being determined largely by the gradient of the channel, is one of the more constant features of rivers, but even this is subject to considerable fluctuation according to volume. Kofoid states that water in the Illinois River travels from Utica to the mouth (227 miles) in five days at flood, but requires twenty-three days for the journey at lowest water. The increase in speed and in turbulence in flood time appears to have a deleterious effect upon some of the population, many dead or moribund individuals of free swimming entomostraca being present in the waters at such times.

With the runoff after abundant rainfall a rapid rise and acceleration occurs, to be followed by a much slower decline. The stuffs in the water are diluted; the plancton is scattered. A new load of silt is received from the land; plant growths are destroyed and even contours in the channel are shifted.

Current is promoted by increasing gradient of stream-bed. It is diminished by obstructions, such as rocks or plant growths, by sharp bends, etc. It is slightly accelerated or retarded by wind according as the direction is up or down stream. Even where a stream appears to be flowing steadily over an even bed between smooth shores, careful measurements reveal slight and inconstant fluctuations. The current is nowhere uniform from top to bottom or from bank to bank. In the horizontal plane it is swiftest in midstream and is retarded by the banks. In a vertical plane, it is swiftest just beneath the surface and is retarded more and more toward the bottom. The pull of the surface film retards it a little and when ice forms on the surface, friction against the ice retards it far more and throws the point of maximum velocity down near middepth of the stream. A sample measurement made by Mr. Wilbert A. Clemens in Cascadilla Creek at Ithaca in open water seventeen inches deep gave rate of flow varying from a maximum of 3.91 feet per second two inches below the surface down to 1.73 feet per second one inch above the bottom, as shown in the columns above. Below this, in the last inch of depth the retardation was more rapid, but irregular. The current slackens more slowly toward the surface and toward the side margins of the stream.

Depth in inches	Feet per sec.
2	3.91
3	3.73
4	3.60
5	3.32
6	3.04
7	2.89
8	2.81
10	2.73
12	2.64
14	2.46
15	2.17
16	1.73

Current and Depth in Cascadilla Creek. Measured by W. A. Clemens.

Mr. Clemens, using a small Pitot-tube current meter, made other measurements showing that in the places where dwell the majority of the inhabitants of swift streams there is much less current than one might expect. In the shelter of stones and other obstructions there is slack water. On sloping bare rock bottoms under a swiftly gliding stream the current is often but half that at the surface. On stones exposed to the current a coating of slime and diatomaceous ooze reduces the current 16 to 32 per cent.

This accounts for the continual restocking of a stream whose waters are swifter than the swimming of the animals found in the open channels. In these more or less shoreward places they breed and renew the supply. Except in a stream whose waters run a long course seaward, allowing an ample time for breeding, there is little indigenous free-swimming population.

FIG. 25. Annually inundated bulrush-covered flood-plain at the mouth of Fall Creek, Ithaca, N. Y., in 1908. Clear growth of *Scirpus fluviatilis* and a drowned elm tree. The Cornell University Biological Field Station at extreme right. West Hill in the distance.

High and Low Water—Inconstancy is a leading characteristic of river environment, and this has its chief cause in the bestowal of the rain. Streams fed mainly by springs, lakes, and reservoirs are relatively constant; but nearly all water courses are subject to overflow; their channels are not large enough to carry flood waters, so these overspread the adjacent bottomlands. Every change of level modifies the environment by connecting or cutting off back waters, by shifting currents, by disturbing the adjustment of the vegetation, and by causing the migration of the larger animals. At low water the Illinois River above Havana has a width of some 500 feet; in flood times it spreads across the valley floor in an unbroken sheet of water four miles wide. Kofoid estimates that at time of high flood (18 feet above low-water datum) less than one-tenth as much of this water is in the channel as lies beyond its boundaries.

The rise of a river flood is often sudden; the decline is always much more gradual, for impounding barriers and impeding vegetation tend to hold the water upon the lowlands. The period of inundation markedly affects the life of the land overflowed. Cycles of seasons with short periods of annual submergence favor the establishment of upland plants and trees. Cycles of years of more abundant rainfall favor the growth of swamp vegetation. Certain plants like the flood-plain bulrush shown in the preceding figure seem to thrive best under inconstancy of flood conditions.

MARSHES, SWAMPS AND BOGS

A GREAT aquatic environment may be maintained with much less water than there is in a lake or a river if only an area of low gradient, lacking proper basin or channel, be furnished with a ground cover of plants suitable for retaining the water on the soil. Enough water must be retained to prevent the complete decay of the accumulating plant remains. Then we will have, according to circumstances, a marsh, a swamp or a bog.

There are no hard and fast distinctions between these three; but in general we may speak of a marsh as a meadow-like area overgrown with herbaceous aquatic plants, such as cat-tail, rushes and sedges; of a swamp as a wet area overgrown with trees; and of a bog as such an area overgrown with sphagnum or bog-moss, and yielding under foot. The great Montezuma Marsh of Central New York (shown in the initial above) is typical of the first class; the Dismal Swamp of eastern Virginia, of the second; and over the northern lake region of the continent there are innumerable examples of the third. These types are rarely entirely isolated, however, since both marsh and bog tend to be invaded by tree growth at their margins. Such wet lands occupy a superficial area larger by far than that covered by lakes and rivers of every sort. They cover in all probably more than a hundred million acres in the United States; great swamp areas border the Gulf of Mexico, the South Atlantic seaboard, and the lower reaches of the Mississippi, and of its larger tributaries, and partially overspread the lake regions of upper Minnesota, Wisconsin, Michigan and Maine. In the order of the areas of "swamp land" (officially so designated) within their borders the leading states are Florida, Louisiana, Arkansas, Mississippi, Michigan, Minnesota, Wisconsin and Maine.

Swamps naturally occupy the shoal areas along the shores of lakes and seas. Marine swamps below mean tide occur as shoals covered with pliant eel-grass. Above mean tide they are meadow-like areas located behind protecting barrier reefs, or they are mangrove thickets that fringe the shore line, boldly confronting the waves. With these we are not here concerned. Fresh-water marshes likewise occupy the shoals bordering the larger lakes, where protected from the waves by the bars that mark the shore line. In smaller lakes, where not stopped by wave action, they slowly invade the shoaler waters, advancing with the filling of the basin, and themselves aiding in the filling process.

That erosion sometimes gives rise to lakes has already been pointed out; much oftener it produces marshes; for depositions of silt in the low reaches of streams are much more likely to produce shoals than deep water.

Cat-tail Marshes—In the region of great lakes every open area of water up to ten feet in depth is likely to be invaded by the cat-tail flag (*Typha*). The ready dispersal of the seeds by winds scatters the species everywhere, and no permanent wet spot on the remotest hill-top is too small to have at least a few plants. Along

Fig. 26. An open-water area (Parker's Pond) in the Montezuma Marsh in Central New York. Formerly it teemed with wild water fowl. It is surrounded by miles of cat-tail flags (Typha) of the densest sort of growth.

the shores of the Great Lakes and in the broad shoals bordering on the Seneca River there are meadow-like expanses of Typha stretching away as far as the eye can see. Many other plants are there also, as will be noted in a subsequent chapter, but Typha is the dominant plant, and the one that occupies the fore-front of the advancing shore vegetation. It masses its crowns and numberless interlaced roots at the surface of the water in floating rafts, which steadily extend into deeper water. The pond in the center of Montezuma Marsh shown in the preceding figure is completely surrounded by a rapidly advancing, half-floating even-fronted phalanx of cat-tail.

FIG. 27. "The Cove" at the Cornell University Biological Field Station, in time of high water. Early summer. Two of the University buildings appear on the hill in the distance.

Later conditions in such a marsh are those illustrated by our frontispiece: regularly alternating spring floods, summer luxuriance, autumn burning and winter freezing. This goes on long after the work of the cat-tail, the pioneer landbuilding, has been accomplished. The excellent aquatic collecting ground shown in the accompanying figure is kept open only by the annual removal of the encroaching flag.

The Okefenokee Swamp. In southern Georgia lies this most interesting of American swamps. It is formed behind a low barrier that lies in a N., N. E.—S., S. W. direction across the broad sandy coastal plain, intersecting the course of the southernmost rivers of

FIG. 28. A view of "Chase's Prairie" in the more open eastern portion of the Okefenokee Swamp, taken from an elevation of fifty feet up a pine tree on one of the incipient islets. The water is of uniform depth (about four or five feet). This is one of the most remarkable landscapes in the world.
Photo by Mr. Francis Harper.

Georgia that drain into the Atlantic. Behind the barrier the waters coming from the northward are retained upon a low, nearly level plain, that is thinly overspread with sand and underlaid with clay. They cover an area some forty miles in diameter, hardly anywhere too deep for growth of vascular plants. There is little discoverable current except in the nascent channels of the two outflowing streams, St. Mary's and Suwannee Rivers. The waters are deeper over the eastern part of the swamp, the side next the barrier; and here the vegetation is mainly herbaceous plants, principally submerged aquatics, with occasional broad meadow-like areas overgrown with sedges. These are the so-called "prairies." The western part of the swamp (omitting from consideration the islands) is a true swamp in appearance being covered with trees, principally cypress. A few small strips of more open and deeper water (attaining 25 feet) of unique beauty, owing to their limpid brown waters and their setting of Tillandsia-covered forest, are called lakes.

The whole swamp is in reality one vast bog. Its waters are nearly everywhere filled with sphagnum. Whatever appears above water to catch the eye of the traveler, whether cypress or tupelo in the western part or sedges and water lilies on the "prairie," everywhere beneath and at the surface of the water there is sphagnum; and it is doubtless to the waterholding capacity of this moss that the relative constancy of this great swamp on a gently inclined plain near the edge of the tropics, is due.

Climbing bogs—In-so-far as swamps possess any basin at all they approximate in character to shallow lakes; but there are extensive bogs in northern latitudes that are built entirely on sloping ground; often even on convex slopes. These are the so-called "climbing bogs." They belong to cool-temperate and humid regions. They exist by the power of certain plants, notably sphagnum, to hold water in masses, while giving off very little by evaporation from the surface. A climbing bog proceeds slowly to cover a slope by the growth of the mass of living moss upward against gravity, and in time what was a barren incline becomes a deep spongy mass of water soaked vegetation.

Conditions of life—In the shoal vegetation-choked waters of marshes there is little chance for the formation of currents and little possibility of disturbance by wind. Temperature conditions change rapidly, however, owing to the heat absorbing and heat radiating power of the black plant-residue. The diurnal range is very great, water that is cool of a morning becomes repellantly hot of a summer afternoon. Temperatures above 90° F. are not then uncommon. Unpublished observations made by Dr. A. A. Allen in shoal marsh ponds at the Cornell Biological Field Station throughout the year 1909, show a lower temperature at the surface of the water than in the bottom mud from December to April, with reverse conditions for the remainder of the year. The black mud absorbs and radiates heat rapidly.

Conditions peculiar to marshes, swamps and bogs are those due to massed plant remains more or less permanently saturated with water. Water excludes the air and hinders decay. Half disintegrated plant fragments accumulate where they fall, and continue for a longer or shorter time unchanged. According to their state of decomposition they form peat or muck.

In peat the hard parts and cellular structure of the plant are so well preserved that the component species may be recognized on microscopic examination. To the naked eye broken stems and leaves appear among the finer fragments, the whole forming a springy or spongy mass of a loose texture and brownish color. The color deepens with age, being lightest immediately under the green and living vegetation, and darkest in the lower strata, where always less well preserved.

The water that covers beds of peat acquires a brownish color and more or less astringent taste due to infusions of plant-stuffs. Humous acids are present in abundance and often solutions of iron sulphate and other minerals.

Muck is formed by the more complete decay of such water plants as compose peat. The process of decay is furthered either by occasional exposure of the beds to the air in spells of drought, or by the presence of lime in the surrounding soil, correcting the acidity of the water and lessening its efficiency as a preservative. Muck is soft and oozy, paste-like in texture and black in color. In the openings of marshes, like that shown on page 89 are beds of muck so soft that he who ventures to step on it may sink in it up to his neck. In such a bed the slow decomposition that goes on in hot weather in absence of oxygen produces gases that gather in bubbles increasing in size until they are able to rise and disrupt the surface.* So are formed marsh gas (methane) which occasionally ignites spontaneously, in mysterious flashes over the water—the well known "Jack-o-lantern" or "Will-o-the-wisp" or "*Ignis fatuus*"—and hydrogen sulphide which befouls the surrounding atmosphere.

The presence in marsh pools of these noxious gases, of humous acids, and of bitter salts, and of the absence of oxygen—except at the surface, limits their animal population in the main to such creatures as breathe air at the surface or have specialized means of meeting these untoward conditions.

High and Low Water—Swamps being the shoalest of waters are subject to the most extreme fluctuations. That they retain through most dry seasons enough water for a permanent aquatic environment is largely due to the water-retaining power of aquatic plants. Notable among these is sphagnum, which holds enmeshed in its leaves considerable quantities of water, lifted above the surrounding water level. Aquatic seed

*See Penhallow, "A blazing beach" in *Science*, 22:794-6, 1905.

plants, also, whose stems in life are occupied with capacious air spaces, fill with water when dead and fallen, and hold it by capillarity. So, they too, form in partial decay a soft spongy water-soaked ground cover.

Marshes develop often a wonderful density of population, for they have at times every advantage of water, warmth and light. The species are fewer, however, than in the more varied environment of land. Comparatively few species are able to maintain themselves permanently where the pressure for room is so great when conditions for growth are favorable, and where these conditions fail more or less completely every dry season. Aquatic creatures that can endure the conditions shown in the accompanying figure must have specialized means of tiding over the period of drouth.

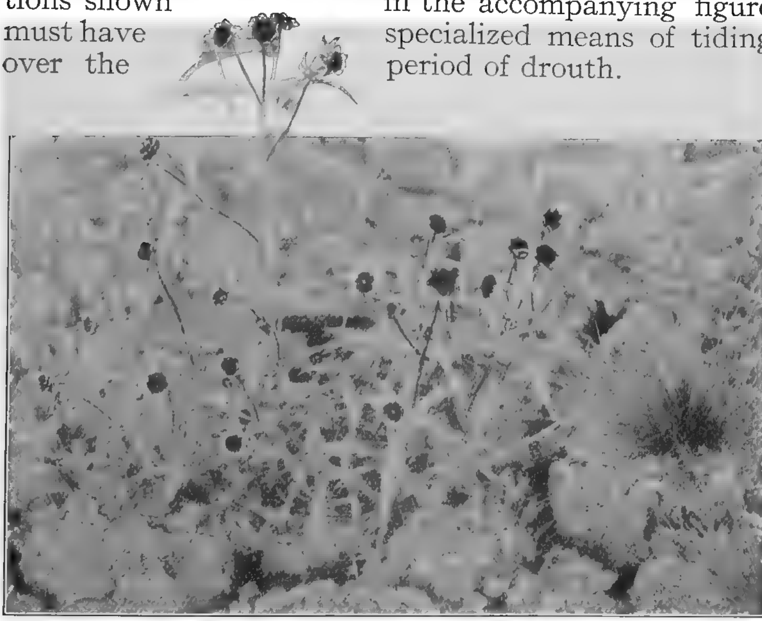


FIG. 29. The bed of a marsh pool in a dry season, showing deep mud cracks, and a thin growth of bur-marigold and club rush.

CHAPTER IV

AQUATIC ORGANISMS

TIS the testimony of all biology that the water was the original home of life upon the earth. Conditions of living are simpler there than on the land. Food tends to be more uniformly distributed. The perils of evaporation are absent. Water is a denser medium than air, and supports the body better, and there is, in the beginning, less need of wood or bone or shell or other supporting structures. Life began in the water, and the simpler forms of both plants and animals are found there still.

But not all aquatic forms have remained simple. For when they multiplied and spread and filled all the waters of the earth the struggle for existence wrought diversification and specialization among them, in water as on land. The aquatic population is, therefore, a mixture of forms structurally of high and low degree. All the types of plant and animal organization are represented in it. But they are fitted to conditions so different from those under which terrestrial beings live as to seem like another world of life.

The population of the water includes besides the original inhabitants—those tribes that have always lived in the water—a mixture of forms descended from ancestors that once lived on land. The more primitive groups are most persistently aquatic. Comparatively few members of those groups that have become thoroughly fitted for life on land have returned to the water to live.

WATER PLANTS

EVERY large group of plants has its aquatic members. The algae alone are predominantly aquatic. Most of them live wholly immersed; some live in moist places, and a few in dry places, having special fitnesses for avoiding evaporation. In striking contrast with this, all the higher plants, the seed plants, ferns, and mosses, center upon the land, having few species in wet places and still fewer wholly immersed. Their heritage of parts specially adapted to life on land is of little value in the water. Rhizoids as foraging organs, a thick epidermis with automatic air pores, and strong supporting tissues are little needed under water. These plants have all a shoreward distribution, and do not belong to the open water. Only algae, molds and bacteria are found in all waters.

THE ALGAE

It is a vast assemblage of plants that makes up this group; and they are wonderfully diverse. Most of them are of microscopic size, and few of even the larger ones intrude upon our notice. Notwithstanding their elegance of form, their beauty of coloration and heir great importance in the economy of water life, few of them are well known. However, certain mass effects produced by algae are more or less familiar. Massed together in inconceivably vast numbers upon the surface of still water, their miscroscopic hosts compose the "water bloom." Floating free beneath the surface they give to the water tints of emerald* of amber† or of blood‡. Matted masses of slender green filaments compose the growths that float on oxygen bubbles to the surface in the spring as "pond scums." Lesser masses of delicately branched filaments fringe the rocky ledges in the path of the cataract, or encircle submerged sticks and piling in still waters. Mixtures of various gelatinous algae coat the flat rocks in clear streams, making them green and slippery; and a rich amber-tinted layer of diatom ooze often overspreads the stream bed in clear waters.

These are all mass effects. To know the plants composing the masses one must seek them out and study them with the microscope. Among all the hosts of fresh water algae, only a few of the stoneworts (Characeae) are in form and size comparable with the higher plants.

Many algae are unicellular; more are loose aggregates of cells functioning independently; a few are well integrated bodies of mutually dependent cells.

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*Volvox in autumn in waters over submerged meadows of water weed.

†Dinobryon in spring in shallow ponds.

‡*Trichodesmium erythræum* gives to the Red Sea the tint to which its name is due. The little crustacean, Dioptomus, often gives a reddish tint to woodland pools.

The cells sometimes form irregular masses, with more or less gelatinous investiture. Often they form simple threads or filaments, or flat rafts, or hollow spheres. Algal filaments are sometimes simple, sometimes branched; sometimes they are cylindric, sometimes tapering; sometimes they are attached and grow at the free end only; sometimes they grow throughout; sometimes they are free, sometimes wholly enveloped in transparent gelatinous envelopes. And the form of the ends, the sculpturing and ornamentation of the walls and the distribution of chlorophyll and other pigments are various beyond all enumerating, and often beautiful beyond description. We shall attempt no more, therefore, in these pages than a very brief account of a few of the commoner forms, such as the general student of fresh water life is sure to encounter; these we will call by their common names, in so far as such names are available.

The flagellates—We will begin with this group of synthetic forms, most of which are of microscopic size and many of which are exceedingly minute. That some of them are considered to be animals (Mastigophora) need not deter us from considering them all together, suiting our method to our convenience. The group overspreads the undetermined borderland between plant and animal kingdoms. Certain of its members (*Euglena*) appear at times to live the life of a green plant, feeding on mineral solutions and getting energy from the sunlight; at other times, to feed on organic substances and solids like animals. The more common forms live as do the algae. All the members of the group are characterized by the possession of one or more living protoplasmic swimming appendages, called flagella, whence the group name. Each flagellum is long, slender and transparent, and often difficult of observation, even when the jerky movements of the attached cell give evidence of its presence and its activity. It swings in front of the cell in long serpentine curves, and draws the cell after it as a boy's arms draw his body along in swimming.

Many flagellates are permanently unicellular; others remain associated after repeated divisions, forming colonies of various forms, some of which will be shown in accompanying figures.

Carteria—This is a very minute flagellate of spherical form and bright green in color (fig. 30*a*). It differs from other green flagellates in having four flagella: the others have not more than two. It is widely distributed in inland waters, where it usually becomes more abundant in autumn, and it appears to prefer slow streams. Kofoid's notes concerning a maximum occurrence in the Illinois River are well worth quoting:

"The remarkable outbreak of Carteria in the autumn of 1907 was associated with unusually low water, and

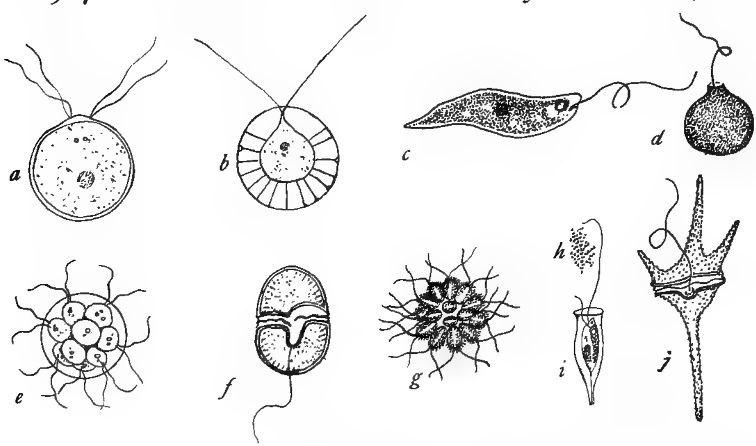

FIG. 30. Flagellates.

a, *Carteria;* ***b***, *Sphærella;* ***c***, *Euglena;* ***d***, *Trachelomonas;* ***e***, *Pandorina;* ***f***, *Glenodinium;* ***g***, *Synura;* ***h***, and ***i***, *Dinobryon;* a colony as it appears under low power of the microscope and a single individual highly magnified; ***j***, *Ceratium.*

concentration of sewage, and decrease of current. The water of the stream was of a livid greenish yellow tinge. * * * The distribution of Carteria in the river was remarkable. It formed great bands or streaks visible near the surface, or masses which in form simulated cloud effects. The distribution was plainly uneven, giving a banded or mottled appearance to the stream. The bands, 10 to 15 meters in width, ran with the channel or current, and their position and form were plainly influenced by these factors. No cause was apparent for the mottled regions. This phenomenon stands in somewhat sharp contrast with the usual distribution of waterbloom upon the river, which is generally composed largely of Euglena. This presents a much more uniform distribution, and unlike Carteria, is plainly visible only when it is accumulated as a superficial scum or film. Carteria was present in such quantity that its distribution was evident at lower levels so far as the turbidity would permit it to be seen. It afforded a striking instance of marked inequalities in distribution."

Similar green flagellates of wide distribution are Chlamydomonas and Sphaerella (fig. 30*b*) commonly found in rainwater pools.

Certain aggregates of such cells into colonies are very beautiful and interesting. Small groups of such green cells are held together in flat clusters in Gonium and Platydorina, or in a hollow sphere, with radiating flagella that beat harmoniously to produce a regular rolling locomotion in Pandorina (fig. 30 *e*), Eudorina and Volvox.

Volvox—The largest and best integrated of these spherical colonies is Volvox (fig. 31). Each colony may consist of many thousands of cells, forming a sphere that is readily visible to the unaided eye. It rotates constantly about one axis, and moves forward therefore through the water in a perfectly definite manner. Moreover, the "eye spots" or pigment flecks of the individual cells are larger on the surface that goes fore-

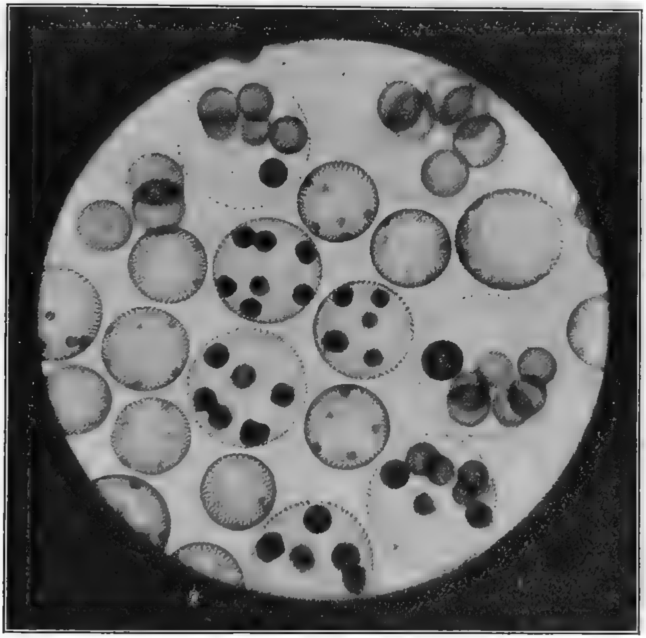

FIG. 31. Volvox, showing young colonies in all stages of development.

most. Sex cells are fully differentiated from the ordinary body cells. Nevertheless, new colonies are ordinarily reproduced asexually. They develop from single cells of the old colony which slip inward somewhat below the general level of the body cells, repeatedly divide, (the mass assuming spherical form), differentiate a full complement of flagella, a pair to each cell, and then escape to the outer world by rupturing the gelatinous walls of the old colony. Many developing colonies are shown within the walls of the old ones in the figure.

Often, when a weed-carpeted pond shows a tint of bright transparent green in autumn, a glass of the water, dipped and held to the light, will be seen to be filled with these rolling emerald spheres.

Euglena—Several species of this genus (fig. 30*c*) are common inhabitants of slow streams and pools. They are all most abundant in mid-summer, being apparently attuned to high temperatures. They are common constituents of the water-bloom that forms on the surface of slow streams. Figure 1 (p. 15) shows such a situation, where they recur every year in June. Certain of them are common in pools at sewer outlets, where bloodworms dwell in the bottom mud. When abundant in such places they give to the water a livid green color. Their great abundance makes them important agents in converting the soluble stuffs of the water into food for rotifers and other microscopic animals.

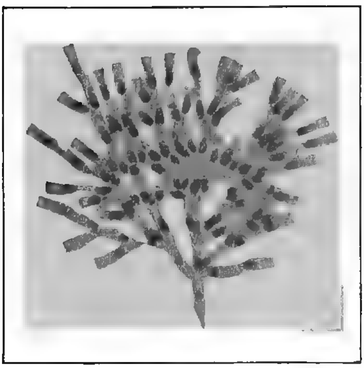

FIG. 32. A Dinobryon colony.

Dinobryon—This minute, amber-tinted flagellate forms colonies on so unique a plan (fig. 30*h*) they are not readily mistaken for anything else under the sun. Each individual is enclosed in an ovoid conic case or lorica, open at the front where two flagella protrude (fig. 30*i*) and many of them are united together in branching, a more or less tree-like colony. Since flagella always draw the body after them, these colonies swim along with open ends forward, apparently in defiance of all the laws of hydromechanics, rotating slowly on the longitudinal axis of the colony as they go. Dinobryon is of an amber yellow tint, and often occurs in such numbers as to lend the same tint to the water it inhabits. It attains its maximum development at low temperatures. In the cooler waters of our larger lakes it is present in some numbers throughout the year, though more abundant in winter. Kofoid reports it as being "sharply limited to the period from November to June" in Illinois River waters. Its sudden increase there at times in the winter is well illustrated by the pulse of 1899, when the numbers of individuals per cubic meter of water in the Illinois River were on successive dates as follows:

Jan. 10th,	1,500
Feb. 7th,	6,458,000
" 14th,	22,641,440

followed by a decline, with rising of the river.

Dinobryon often develops abundantly under the ice. Its optimum temperature appears to be near 0° C. It thus takes the place in the economy of the waters that is filled during the summer by the smaller green flagellates.

Synura (fig. 30*g*) is another winter flagellate, similar in color and associated with Dinobryon, much larger in size. Its cells are grouped in spherical colonies united at the center of the sphere, and equipped on the outer ends of each with a pair of flagella, which keep the sphere in rolling locomotion. The colonies appear at times of maximum development to be easily disrupted, and single cells and small clusters of cells are often found along with well formed colonies. Synura when abundant often gives to reservoir waters an odor of cucumbers, and a singularly persistent bad flavor, and under such circumstances it becomes a pest in water supplies.

Glenodinium (fig. 30*f*), Peridinium, and Ceratium (fig. 30*j*) are three brownish shell-bearing flagellates of wide distribution often locally abundant, especially in spring and summer. These all have one of the two long flagella laid in a transverse groove encircling the body, the other flagellum free (fig. 33). Glenodinium is the smallest, Ceratium, much the largest. Glenodinium has a smooth shell, save for the grooves where the flagella arise. Peridinium has a brownish chitinous shell, divided into finely reticulate plates. Ceratium has a heavy grayish shell prolonged into several horns.

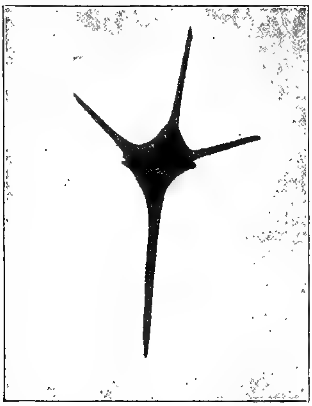

FIG. 33. Ceratium (The transverse groove shows plainly, but neither flagellum shows in the photograph.)

On several occasions in spring we have seen the waters of the Gym Pond on the Campus at Lake Forest College as brown as strong tea with a nearly pure culture of Peridinium and concurrently therewith we have seen the transparent phantom-larvæ of the midge *Corethra* in the same pond all showing a conspicuous brown line where the alimentary canal runs through the body, this being packed full of Peridinia.

Trachelomonas (fig. 30 *d*) is a spherical flagellate having a brownish shell with a short flask-like neck at one side whence issues a single flagellum. This we have found abundantly in pools that were rich in oak leaf infusions.

Diatoms—Diatoms are among the most abundant of living things in all the waters of the earth. They occur singly and free, or attached by gelatinous stalks, or

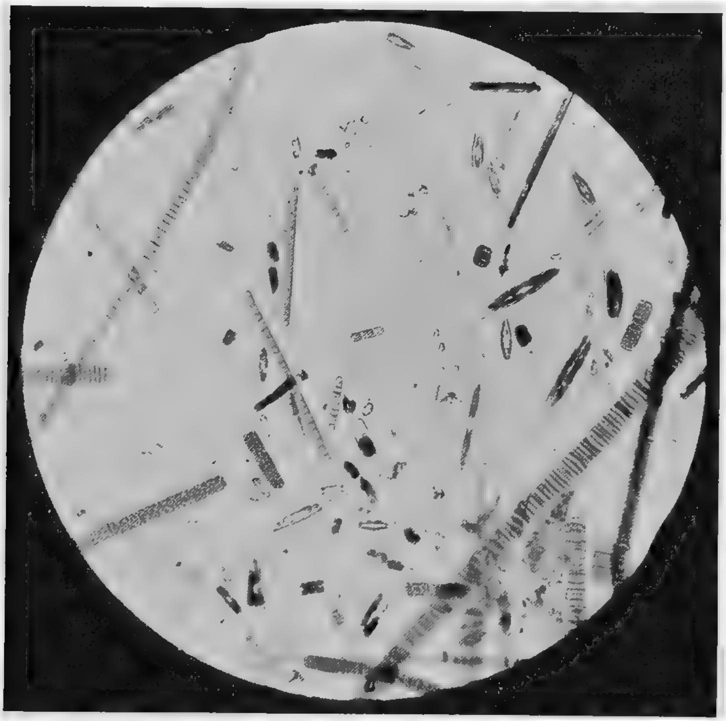

FIG. 34. Miscellaneous diatoms, mostly species of *Navicula;* the filaments are blue-green algae, mostly *Oscillatoria.*

aggregated together in gelatinous tubes, or compactly grouped in more or less coherent filaments. All are of microscopic size. They are most easily recognized by their possession of a box-like shell, composed of two *valves*, with overlapping edges. These valves are stiffened by silica which is deposited in their outer walls, often in beautiful patterns. The opposed edges of the valves are connected by a membraneous portion of the cell wall known as the *girdle*. A diatom may appear very different viewed from the face of the valve, or from the girdle (see fig. 35*a* and *b*, or *j* and *k*). They are circular-like pill-boxes in one great group, and more or less elongate and bilateral in the others.

Diatoms are rarely green in color. The chlorophyll in them is suffused by a peculiar yellowish pigment known as *diatomin*, and their masses present tints of amber, of ochre, or of brown; sometimes in masses they appear almost black. The shells are colorless; and, being composed of nearly pure silica, they are well nigh indestructible. They are found abundantly in guano, having passed successively through the stomachs of marine invertebrates that have been eaten by fishes, that have been eaten by the birds responsible for the guano deposits, and having repeatedly resisted digestion and all the weathering and other corroding effects of time. They abound as fossils. Vast deposits of them compose the diatomaceous earths. A well-known bed at Richmond, Va., is thirty feet in thickness and of vast extent. Certain more recently discovered beds in the Rocky Mountains attain a depth of 300 feet. Ehrenberg estimated that such a deposit at Biln in Bohemia contained 40,000,000 diatom shells per cubic inch.

Singly they are insignificant, but collectively they are very important, by reason of their rapid rate of increase, and their ability to grow in all waters and at all ordinary temperatures. Among the primary food gatherers of the water world there is no group of greater importance.

In figure 35 we present more or less diagrammatically a few of the commoner forms. The boat-shaped, freely moving cells of *Navicula* (*a*, *b*, *c*) are found in every pool. One can scarcely mount a tuft of algae, a leaf of water moss or a drop of sediment from the bottom without finding Naviculas in the mount. They are more abundant shoreward than in the open waters of the lake. The "white-cross diatom" *Stauroneis* (*d*), is a kindred form, easily recognizable by the smooth cross-band which replaces the middle nodule of Navicula.

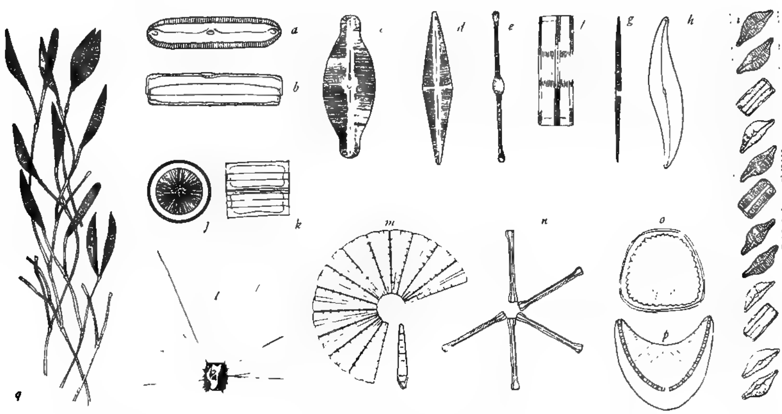

FIG. 35. Diatoms.

a, valve view showing middle and end nodules, and ***b***, girdle view of *Navicula*. ***c***, another species of *Navicula*; ***d***, *Stauroneis*; ***e***, valve view and ***f***, girdle view of *Tabellaria*; ***g***, *Synedra*; ***h***, *Gyrosigma*; ***i***, a gelatinous cord-like cluster of *Encyonema* showing girdle view of nine individuals and valve view of three. ***j***, valve view and ***k***, girdle view of *Melosira*; ***l***, *Stephanodiscus*; ***m***, *Meridion* colony, with a single detached individual shown in valve view below; ***n***, a small colony of *Asterionella*; ***o***, valve view, and ***p***, girdle view of *Camplylodiscus*; ***q***, cluster of *Cocconema*. (Figures mostly after Wolle).

Tabellaria (*e* and *f*) is a thin flat-celled diatom that forms ribbon-like bands, the cells being apposed, valve to valve. Often the ribbons are broken into rectangular blocks of cells which hang together in zig-zag lines by the corners of the rectangles. The single cell is long-rectangular in girdle view (slightly swollen in the middle and at each end, as shown at *e*, in valve view), and is traversed by two or more intermediate septa. Tabellaria abounds in the cool waters of our deeper northern lakes, at all seasons of the year. It is much less common in streams.

The slender cells of the "needle diatoms," *Synedra* (*g*), are common in nearly all waters and at all seasons. They are perhaps most conspicuously abundant when found, as often happens, covering the branches of some tufted algae, such as Cladophora, in loose tufts and fascicles, all attached by one end.

Gyrosigma (*h*) is nearly allied to Navicula but is easily recognized by the gracefully curved outlines of its more or less S-shaped shell. The sculpturing of this shell (not shown in the figure) is so fine it has long been a classic test-object for the resolving power of microscopic lenses. Gyrosigma is a littoral associate of Navicula, but of much less frequent occurrence.

Encyonema (*i*) is noteworthy for its habit of developing in long unbranched gelatinous tubes. Sometimes these tubes trail from stones on the bottom in swift streams. Sometimes they radiate like delicate filmy hairs from the surfaces of submerged twigs in still water. The tubes of midge larvae shown in figure oo were encircled by long hyaline fringes of Encyonema filaments, which constituted the chief forage of the larvae in the tubes and which were regrown rapidly after successive grazings. When old, the cells escape from the gelatine and are found singly.

The group of diatoms having circular shells with radially arranged sculpturing upon the valves is represented by *Melosira* (*j* and *k*) and *Stephanodiscus* (*l*) of our figure. Melosira forms cylindric filaments, whose constituent cells are more solidly coherent than in other diatoms. Transverse division of the cells increases the length of the filaments, but they break with the movement of the water into short lengths of usually about half a dozen cells. They are common in the open water of lakes and streams, and are most abundant at the higher temperatures of midsummer. *Cyclotella* is a similar form that does not, as a rule, form filaments.

Its cells are very small, and easily overlooked, since they largely escape the finest nets and are only to be

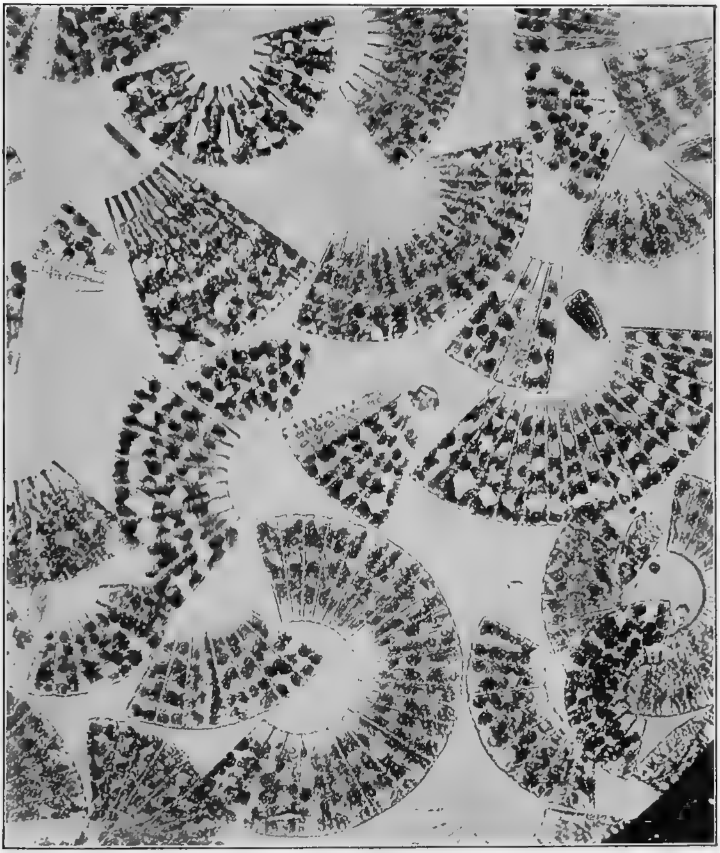

FIG. 36. A nearly pure culture of Meridion, showing colonies of various sizes.

gathered from the water by filtering. Often, however, their abundance compensates for their size. Kofoid found their average number in the waters of the Illinois

River to be 36,558,462 per cubic meter of water, and he considered them as one of the principal sources of food supply of Entomostraca and other microscopic aquatic animals. *Stephanodiscus* (*l*) is distinguished by the long, hyaline filaments that radiate from the ends of the box, and that serve to keep it in the water. A species of Stephanodiscus having shorter and more numerous filaments is common in the open waters of Cayuga Lake in spring.

The cells of *Meridion* are wedge-shaped, and grouped together side by side, they form a flat spiral ribbon of very variable length, sometimes in one or more complete turns, but oftener broken into small segments. This form abounds in the brook beds about Ithaca, covering them every winter with an amber-tinted or brownish ooze, often of considerable thickness. It appears to thrive best when the temperature of the water is near 0° C. Its richest growth is apparent after the ice leaves the brooks in the spring. As a source of winter food for the lesser brook-dwelling animals, it is doubtless of great importance. A view of a magnified bit of the ooze is shown in figure 36.

The colonies of *Asterionella* (*n*) whose cells, adhering at a single point, radiate like the spokes of a wheel, are common in the open waters of all our lakes and large streams. It is a common associate of Cyclotella, and of Tabellaria and other band-forming species, and is often more abundant than any of these. The open waters of Lake Michigan and of Cayuga Lake are often yellowish tinted because of its abundance in them. Late spring and fall (especially the former) after the thermal overturn and complete circulation of the water are the seasons of its maximum development. Asterionella abounds in water reservoirs, where, at its maxima, it sometimes causes trouble by imparting to the water an aromatic or even a decidedly "fishy" odor and an unpleasant taste.

Campylodiscus (*o* and *p*) is a saddle-shaped diatom of rather local distribution. It is found abundantly in the ooze overspreading the black muck bottom of shallow streams at the outlet of bogs. In such places in the upper reaches of the tributaries of Fall Creek near Ithaca it is so abundant as to constitute a large part of the food of a number of denizens of the bottom mud—notably of midge larvae, and of nymphs of the big Mayfly, Hexagenia.

These are a few—a very few—of the more important or more easily recognized diatoms. Many others will be encountered anywhere, the littoral forms especially being legion. Stalked forms like *Cocconema* (fig. 35*q* and fig. 37) will be found attached to every solid support. And minute close-clinging epiphytic diatoms, like *Cocconeis* and *Epithemia* will be found thickly besprinkling the green branches of many submerged aquatics. These adhere closely by the flat surface of one valve to the epidermis of aquatic mosses.

FIG. 37. A stalked colony *Cocconema*.

In open lakes, also, there are other forms of great importance, such as *Diatoma*, *Fragillaria*, etc., growing in flat ribbons, as does Tabellaria. It is much to be regretted that there are, as yet, no readily available popular guides to the study of a group, so important and so interesting. Equipped with a plancton net and a good microscope, the student would never lack for material or for problems of fascinating interest.

Desmids—This is a group of singularly beautiful unicellular fresh-water algae. Desmids are, as a rule, of a refreshing green color, and their symmetry of form and delicacy of sculpturing are so beautiful that they have always been in favor with microscopists. So

FIG. 38. A good slide-mount from a Closterium culture as it appears under a pocket lens. Two species.

numerous are they that their treatment has of late been relegated to special works. Here we can give only a few words concerning them, with illustrations of some of the commoner forms.

Desmids may be recognized by the presence of a clear band across the middle of each cell, (often emphasized by a corresponding median constriction) dividing it symmetrically into two semicells. Superficially they appear bicellular (especially in such forms as *Cylindro-*

cystis, fig. 40 *e*), but there is a single nucleus, and it lies in the midst of the transparent crossband. The larger ones, such as *Closterium* (fig. 38) may be recognized with the unaided eye, and may be seen clearly with a pocket lens. Because it will grow perennially in a culture jar in a half-lighted window, Closterium is a very well known laboratory type.

FIG. 39. Photomicrographs of a Closterium dividing. The lowermost figure is one of the newly formed daughter cells, not yet fully shaped.

Division is transverse and separates between the semicells. Its progress in Closterium is shown in figure 39, in a series of successive stages that were photographed between 10 P. M. and 3 A. M. Division normally occurs only at night.

In a few genera (*Gonatozygon*, (fig. 40*a*) *Desmidium*, etc.) the cells after division remain attached, forming filaments.

Desmids are mainly free floating and grow best in still waters. They abound in northern lakes and peat bogs. They prefer the waters that run off archaean rocks and few of them flourish in waters rich in lime. A few occur on mosses in the edges of waterfalls, being attached to the mosses by a somewhat tenacious gelatinous investment. One can usually obtain a fine variety of desmids by squeezing wisps of such water plants as Utricularia and Sphagnum, over the edge of a dish, and examining the run-off. The largest genus of the group and also one of the most widespread is

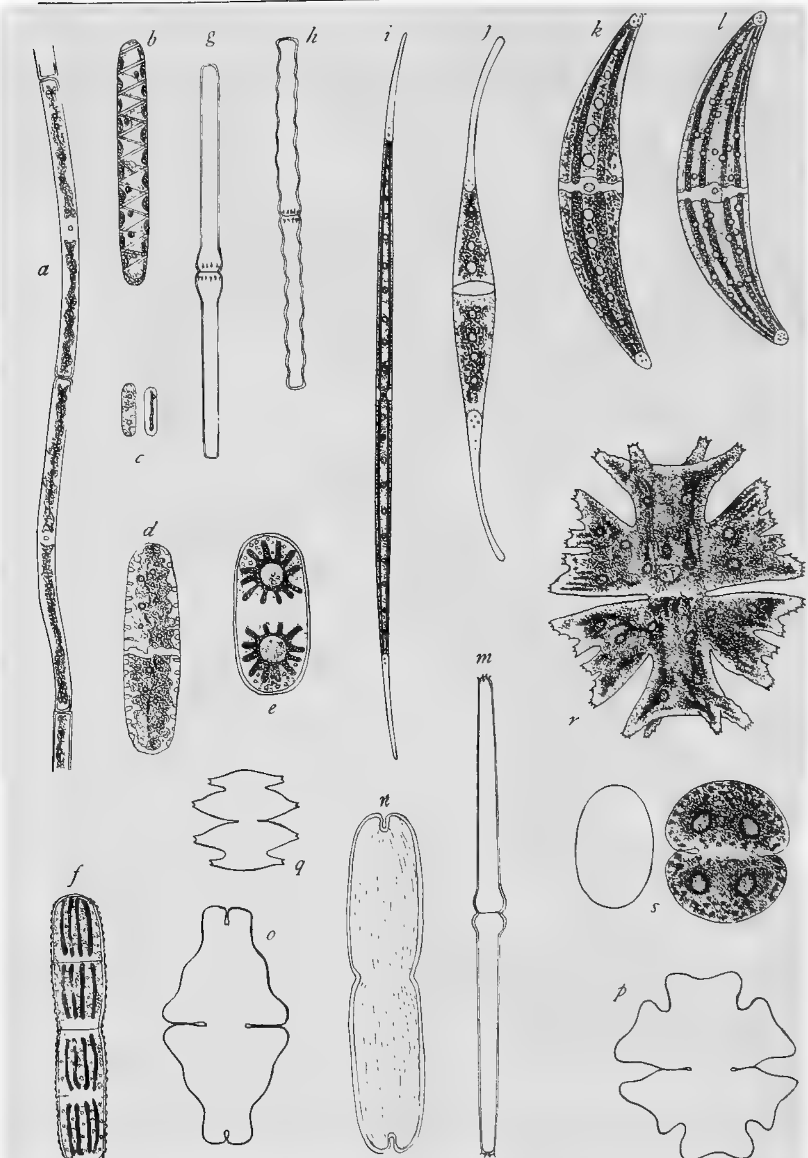

Fig. 40. Desmids.

Cosmarium (fig. 40 *s*). The most bizarre forms are found in the genera *Micrasterias* (figs. 40 *q* and *r*) and *Staurastrum*. These connect in form through *Euastrum* (fig. 40 *o*) *Tetmemorus* (fig. 40 *n*) *Netrium* (fig. 40 *d*), etc., with the simpler forms which have little differentiation of the poles of the cell; and these, especially *Spirotaenia* (fig. 40 *b*) and *Gonatozygon* (fig. 40 *a*) connect with the filamentous forms next to be discussed.

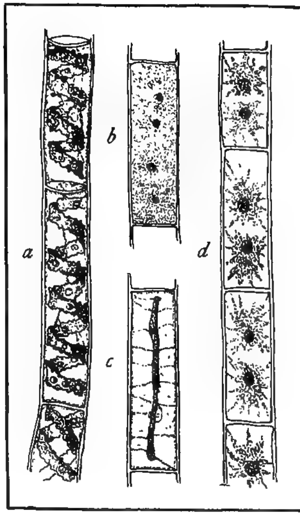

FIG. 41. Filamentous conjugates.

a, *Spirogyra*; *b*, flat view, and *c*, edgewise view of the chlorophyll plate in cells of *Mougeotia*; *d*, *Zygnema*.

The Filamentous Conjugates—This is the group of filamentous algae most closely allied with the desmids. It includes three common genera (fig. 41)—Spirogyra, Zygnema, and Mougeotia. The first of these being one of the most widely used of biological "types" is known to almost every laboratory student. Its long, green, unbranched, slippery filaments are easily recognized among all the other greenery of the water by their beautiful spirally-wound bands of chlorophyll. The other common genera have also distinctive chlorophyll arrangement. Zygnema has a pair of more or less star-shaped green masses in each cell, one on either side of the central nucleus. In Mougeotia the chlorophyll

a, a little more than two cells from a filament of *Gonatozygon*
b Spirotænia
c Mesotænium
d Netrium
e Cylindrocystis
f Penium
g Docidium baculum
h Docidium undulatum
i Closterium pronum
j Closterium rostratum
k Closterium moniliferum
l Closterium ehrenbergi
m Pleurotænium
n Tetmemorus
o Euastrum didelta
p Euastrum verrucosum
q Micrasterias oscitans
r Micrasterias americana; (for a third species see page 53).
s Cosmarium, face view, and outline as seen from the side

is in a median longitudinal plate, which can rotate in the cell: it turns its thin edge upward to the sun, but lies broadside exposed to weak light. Spirogyra is the most abundant, especially in early spring where it is found in the pools ere the ice has gone out. All, being unattached (save as they become entangled with rooted aquatics near shore), prefer quiet waters. Immense accumulations of their tangled filaments often occur on the shores of shallow lakes and ponds, and with the advance of spring and subsidence of the water level, these are left stranded upon the shores. They chiefly compose the "blanket-moss" of the fishermen. They settle upon and smother the shore vegetation, and in their decay they sometimes give off bad odors. Sometimes they are heaped in windrows on shelving beaches, and left to decay.

We most commonly see them floating at the surface in clear, quiet, spring-fed waters in broad filmy masses of yellowish green color, which in the sunlight fairly teem with bubbles of liberated oxygen. These dense masses of filaments furnish a home and shelter for a number of small animals, notably Haliplid beetle larvæ and punkie larvæ among insects; and entanglement by them is a peril to the lives of others, notably certain Mayfly larvæ (*Blasturus*). The rather large filaments afford a solid support for hosts of lesser sessile algæ; and their considerable accumulation of organic contents is preyed upon by many parasites. Their role is an important one in the economy of shoal waters, and its importance is due not alone to their power of rapid growth, but also to their staying qualities. They hold their own in all sorts of temporary waters by developing protected reproductive cells known as *zygospores*, which are able to endure temporary drouth, or other untoward conditions. Zygospores are formed by the fusion of the contents of two similar cells (the process is known as conjugation, whence the group name) and the development of a protective wall about the resulting reproductive body. This rests for a time like a seed, and on germinating, produces a new filament by the ordinary process of cell division. These filamentous forms share this reproductive process with the desmids, and despite the differences in external aspect it is a strong bond of affinity between the two groups.

The siphon algæ—This peculiar group of green algæ contains a few forms of little economic consequence but of great botanical interest. The plant body grows out in long irregularly branching filaments which, though containing many nuclei, lack cross partitions. The filaments thus resemble long open tubes, whence the name siphon algæ. There are two common genera *Vaucheria* and *Botrydium* (fig. 42). Both are mud-loving, and are found partly out of the water about as often as wholly immersed. Vaucheria develops long, crooked, extensively interlaced filaments which occur in dense mats that have suggested the name "green felt." These felted masses are found floating in ponds, or lying on wet soil wherever there is light and a constantly moist atmosphere (as, for example, in greenhouses, where commonly found on the soil in pots). Botrydium is very different and much smaller. It has an oval body with root-like branches growing out from the lower end to penetrate the mud. It grows on the bottom in shoal waters, and remains exposed on the

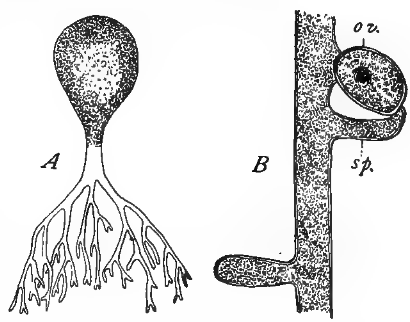

FIG. 42. Two siphon algæ.

A, *Botrydium;* *B*, a small fruiting portion of a filament of *Vaucheria.;* *ov*, *ovary;* *sp*, spermary.

mud after the water has receded, dotting the surface thickly, as with greenish beads of dew.

The water net and its allies—The water net (*Hydrodictyon*) wherever found, is sure to attract attention by its curious form. It is a cylindric sheet of lace-like tissue, composed of slender green cells that meet at

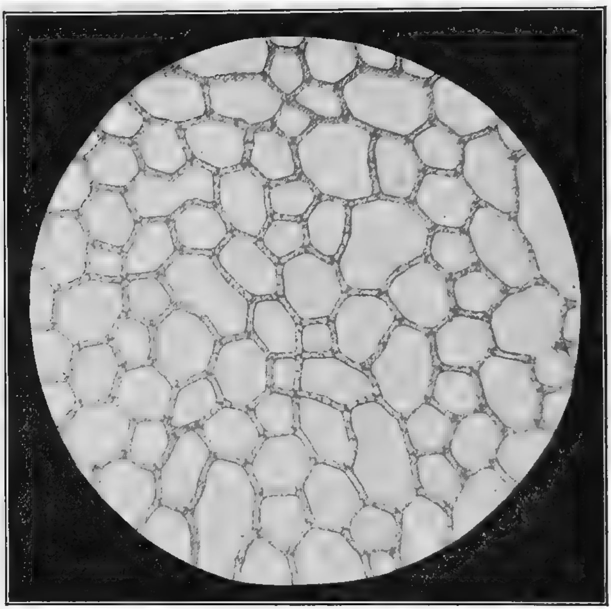

FIG. 43. A rather irregular portion of a sheet of water net (*Hydrodictyon*)

their ends, usually by threes, forming hexagonal meshes like bobbinet (fig. 43). Such colonies may be as broad as one's hand, or microscopic, or of any intermediate size; for curiously enough, cell division and cell growth are segregated in time. New colonies are formed by repeated division of the contents of single cells of the old colonies. A new complete miniature net is formed within a single cell; and after its escape from the old cell wall, it grows, not by further division, but by increase in size of its constituent cells.

Water net is rather local and sporadic in occurrence, but it sometimes develops in quantities sufficient to fill the waters of pools and small ponds.

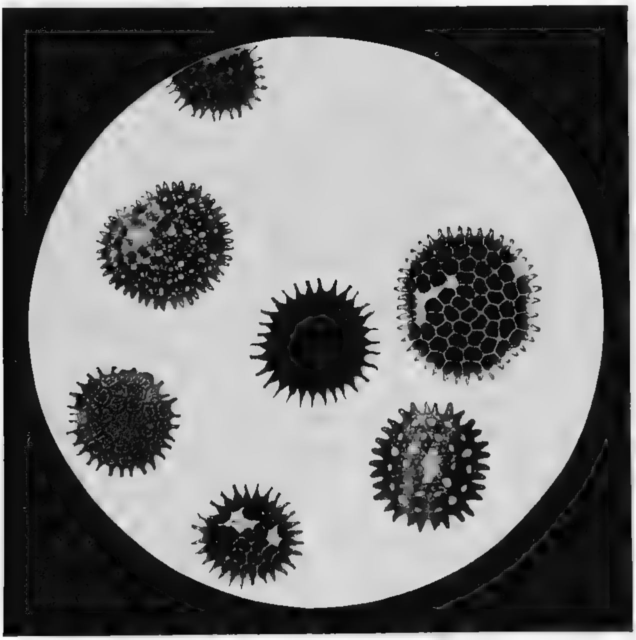

FIG. 44. *Pediastrum:* Several species from the plancton of Cayuga Lake.

Pediastrum is a closely related genus containing a number of beautiful species, some of which are common and widespread. The cells of a Pediastrum colony are arranged in a roundish flat disc, and those of the outermost row are usually prolonged into radiating points. Several species are shown in figure 44. In the openmeshed species the inner cells can be seen to meet by threes about the openings, quite as in the water net; but the cells are less elongate and the openings smaller. Five of the seven specimens shown in the figure lack these openings altogether.

New colonies are formed within single cells, as in Hydrodictyon. In our figure certain specimens show marginal cells containing developing colonies. One shows an empty cell wall from whence a new colony has escaped.

Other green algæ—We have now mentioned a few of the more strongly marked groups of the green algæ. There are other forms, so numerous we may not even name them here, many of which are common and widely dispersed. We shall have space to mention only a few of the more important among them, and we trust that the accompanying figures will aid in their recognition. Numerous and varied as they are, we will dismiss them from further consideration under a few arbitrary form types.

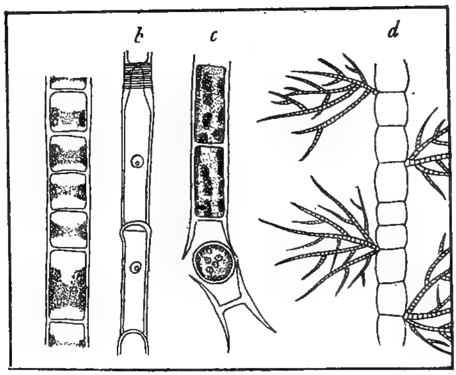

FIG. 45. Filamentous Green Algæ.

a, *Ulothrix*; *b*, *Œdogonium*, showing characteristic annulate appearance at upper end of cell; *c*, (*Tribonema*) *Conferva*; *d*, *Draparnaldia*. (After West).

1. *Simple filamentous forms.* Of such sort are *Ulothrix*, *Œdogonium*, *Conferva*, etc., (fig. 45). Ulothrix is common in sunny rivulets and pools, especially in early spring, where its slender filaments form masses

half floating in the water. The cells are short, often no longer than wide, and each contains a single sheet of

FIG. 46. A spray of Cladophora, as it appears when outspread in the water, slightly magnified.

chlorophyl, lining nearly all of its lateral wall. *Œdogonium* is a form with stouter filaments composed of much longer cells, within which the chlorophyl is disposed in anastomosing bands. The thick cell walls, some of which show a peculiar cross striation near one end of the cell, are ready means of recognition of the members of this great genus. The filaments are attached when young, but break away and float freely in masses in quiet waters when older; it is thus they are usually seen. *Conferva* (Tribonema) abounds in shallow pools, especially in spring time. Its filaments are composed of elongate cells containing a number of separate disc-like chlorophyl bodies. The cell wall is thicker toward the ends of the cell, and the filaments tend to break across the middle, forming pieces (halves of two adjacent cells) which appear distinctly H-shaped in optic section. This is a useful mark for their recognition. It will be observed that these then are similar in form and habits to the filamentous conjugates discussed above, but they have not the peculiar form of chlorophyl bodies characteristic of that group. Œodgonium is remarkable for its mode of reproduction.

FIG. 47. Two species of Chætophora, represented by several small hemispherical colonies of *C. pisiformis* and one large branching colony of *C. incrassata*.

2. *Branching filamentous forms*—Of such sort are a number of tufted sessile algæ of great importance: *Cladophora*, which luxuriates in the dashing waterfall, which clothes every wave-swept boulder and pier with delicate fringes of green, which lays prostrate its pliant sprays (fig. 46) before each on-rushing wave, and lifts

them again uninjured, after the force of the flood is spent. And *Chætophora* (fig. 47; also fig. 89 on p. 182); which is always deeply buried under a transparent mass

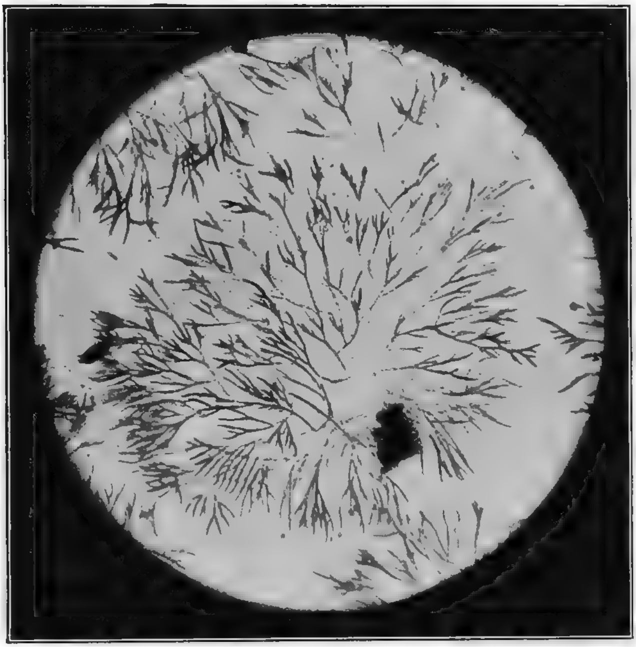

Fig. 48. Chætophora (either species) crushed and outspread in its own gelatinous covering and magnified to show the form of the filaments.

of gelatin; which form little hemispherical hillocks of filaments in some species, and in one, extends outward in long picturesque sprays, but which has in all much the same form of plant body (fig. 48)—a close-set branching filament, with the tips of some of the branches ending in a long hyaline bristle-like point. Chætophora grows very abundantly in stagnant pools, and ponds in midsummer, adhering to every solid support that offers, and it is an important part of the summer food of many of the lesser herbivores in such waters.

Then we must not omit to mention two that, if less important, are certainly no less interesting: *Draparnaldia* (fig. 45*d*) which lets its exceedingly delicate sprays trail like tresses among the submerged stones in spring-

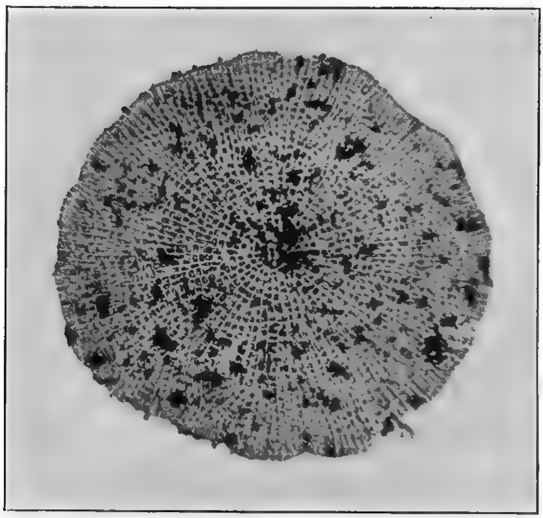

FIG. 49. *Coleochæte scutata.* "Green doily."

fed rivulets; and *Coleochæte* (fig. 49), which spreads its flattened branches out in one plane, joined by their edges, forming a disc, that is oftenest found attached to the vertical stem of some reed or bulrush.

Miscellaneous lesser green algæ—Among other green algæ, which are very numerous, we have space here for a mere mention of a few of the forms most likely to be met with, especially by one using a plancton net in open waters. These will also illustrate something of the remarkable diversity of form and of cell grouping among the lesser green algæ.

Botryococcus grows in free floating single or compound clusters of little globose green cells, held together in a scanty gelatinous investment. The clusters are sufficiently grape-like to have suggested the scientific name. They contain, when grown, usually 16 or 32 cells each. They are found in the open waters of bog pools, lakes,

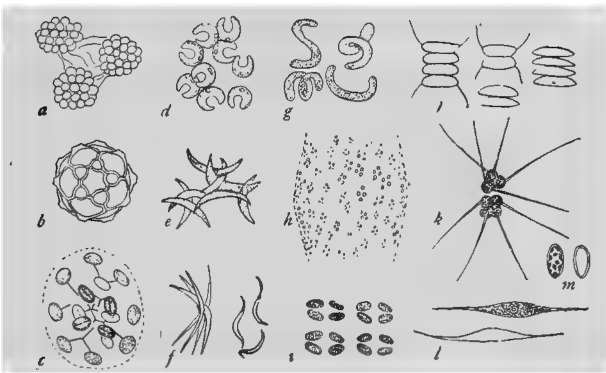

FIG. 50. Miscellaneous green algæ (mostly after West).

a, Botryococcus; b, Cœlastrum; c, Dictosphærium; d, Kirchnerella; e, Selenastrum; f, Ankistrodesmus falcatus; g, Ophiocytium; h, Tetraspora; i, Crucigenia; j, Scenedesmus;, k, Rhicteriella; l, Ankistrodesmus setigerus; m, Oocystis.

and streams, during the warmer part of the season, being most abundant during the hot days of August. When over-abundant the cells sometimes become filled with a brick-red oil. They occur sparingly in water-bloom.

Dictyosphærum likewise grows in more or less spherical colonies of globose cells. The cells are connected together by dichotomously branching threads and all are enveloped in a thin spherical mass of mucus. The colonies are free floating and are taken in the plancton of ponds and lakes and often occur in the water-bloom.

Cœlastrum is another midsummer plancton alga that forms spherical colonies of from 8 to 32 cells, it has much firmer and thicker cell walls, and the cells are often angulate or polyhedral. New colonies are formed within the walls of each of the cells of the parent colony, and when well grown these escape by rupture or dissolution of the old cell wall. Our figure shows merely the outline of the cell walls of a 16-celled colony, in a species having angulate cells, between which are open interspaces. Kofoid found Cœlastrum occurring in a maximum of 10,800,000 per cubic meter of water in the Illinois River in August.

Crucigenia is an allied form having ovoid or globose cells arranged in a flat plate held together by a thin mucilaginous envelope. The cells are grouped in fours, but 8, 16, 32, 64 or even more may, when undisturbed, remain together in a single flat colony. During the warmer part of the season, they are common constituents of the fresh-water plancton, the maximum heat of midsummer apparently being most favorable to their development.

Scenedesmus is a very hardy, minute, green alga of wide distribution. There is hardly any alga that appears more commonly in jars of water left standing about the laboratory. When the sides of the jar begin to show a film of light yellowish-green, Scenedesmus may be looked for. The cells are more or less spindle-shaped, sharply pointed, or even bristle-tipped at the ends. They are arranged side by side in loose flat rafts of 2, 4 or 8 (oftenest, when not broken asunder, of 4) cells. They are common in plancton generally, especially in the plancton of stagnant water and in that of polluted streams, and although present at all seasons, they are far more abundant in mid and late summer.

Kirchnerella is a loose aggregate of a few blunt-pointed U-shaped cells, enveloped in a thick spherical mass of jelly. It is met with commonly in the plancton of larger lakes. *Selenastrum* grows in nearly naked clusters of more crescentic, more pointed cells which are found amid shore vegetation. *Ankistrodesmus* is a related, more slender, less crescentic form of more extensive littoral distribution. The slenderest form of this genus are free floating, and some of them like *A. setigera* fig. 50 *l* are met with only in the plancton.

Richteriella is another plancton alga found in free floating masses of a few loosely aggregated cells. The cells are globose and each bears a few long bristles upon its outer face. Kofoid found Richteriella attaining a maximum of 36,000,000 per cubic meter of water in September, while disappearing entirely at temperatures below 60° F.

Oocystis grows amid shore vegetation, or the lighter species, in plancton in open water. The ellipsoid cells exist singly, or a few are loosely associated together in a clump of mucus. The cells possess a firm smooth wall which commonly shows a nodular thickening at each pole.

Ophiocytium is a curious form with spirally coiled multinucleate cells. The bluntly rounded ends of the cells are sometimes spine-tipped. These cells sometimes float free, sometimes are attached singly, sometimes in colonies. Kofoid found them of variable occurrence in the Illinois River, where the maximum number noted was 57,000,000, per cubic meter occurring in September. The optimum temperature, as attested by the numbers developing, appeared to be about 60° F.

Tetraspora—We will conclude this list of miscellanies with citing one that grows in thick convoluted strings and loose ropy masses of gelatin of considerable size. These masses are often large enough to be recognized with the unaided eye as they lie outspread or hang down upon trash on the shores of shoal and stagnant waters. Within the gelatin are minute spherical bright green cells, scattered or arranged in groups of fours.

BLUE-GREEN ALGÆ (*Cyanophyceæ* or *Myxophyceæ*). The "blue-greens" are mainly freshwater algæ, of simple forms. The cells exist singly, or embedded together in loose gelatinous envelope or adhere in flat rafts or in filaments. Their chlorophyll is rather uniformly distributed over the outer part of the cell (quite lacking the restriction to specialized chloroplasts seen in the true green-algæ) and its color is much modified by the presence of pigment (*phycocyanin*), which gives to the cell usually a pronounced bluish-green, sometimes, a reddish color.

Blue-green algæ exist wherever there is even a little transient moisture—on tree trunks, on the soil, in lichens, etc.; and in all fresh water they play an important role, for they are fitted to all sorts of aquatic situations, and they are possessed of enormous reproductive capacity. Among the most abundant plants in the water world are the *Anabænas* (fig. 00), and other blue-greens that multiply and fill the waters of our lakes in midsummer, and break in "water-bloom" covering the entire surface and drifting with high winds in windrows on shore. Such forms by their decay often give to the water of reservoirs disagreeable odors and bad flavors, and so they are counted noxious to water supplies.

There are many common blue-greens, and here we have space to mention but a few of the more common forms. Two of the loosely colonial forms composed of spherical cells held together in masses of mucus are *Cœlosphærium* and *Microcystis*. Both these are often associated with Anabæna in the water-bloom. Cœlosphærium is a spherical hollow colony of microscopic size. It is a loose association of cells, any of which on separation is capable of dividing and producing a new colony. Microcystis (fig. 51*A*) is a mass of smaller cells, a very loose colony that is at first more or less spherical but later becomes irregularly lobed and branching. Such old colonies are often large enough to be observed with the naked eye. They are found most commonly in late summer, being hot weather forms. When abundant these two are often tossed by the waves upon rocks along the water's edge, and from them the dirty blue-green deposit that is popularly known as "green paint."

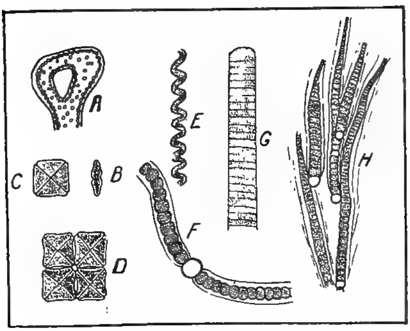

FIG. 51. Miscellaneous blue-green algæ (mostly after West).

A, *Microcystis* (Clathrocystis); *B*, *C*, *D*, *Tetrapedia*; *E*, *Spirulina*; *F*, *Nostoc*; *G*, *Oscillatoria*; *H*, *Rivularia*.

Among the members of this group most commonly seen are the motile blue-greens of the genus *Oscillatoria* (fig. 51*G*). These grow in dense, strongly colored tufts and patches of exceedingly slender filaments attached to the bottoms and sides of watering troughs, ditches and pools, and on the beds of ponds however stagnant. They thickly cover patches of the black mud bottom and the formation of gases beneath them disrupts their attachment and the broken flakes of bottom slime that they hold together, rise to the surface and float there, much to the hurt of the appearance of the water.

The filaments of Oscillatoria and of a few of its near allies perform curious oscillating and gliding movements. Detached filaments float freely in the open water, and during the warmer portion of the year, are among the commoner constituents of the plancton.

There are a number of filamentous blue-greens that are more permanently sessile, and whose colonies of filaments assume more definite form. *Rivularia* is typical of these. *Rivularia* grows in hemispherical gelatinous lumps, attached to the leaves and stems of submerged seed plants. In autumn it often fairly smothers the beds of hornwort (*Ceratophyllum*) and water fern (*Marsilea*) in rich shoals. Rivularia is

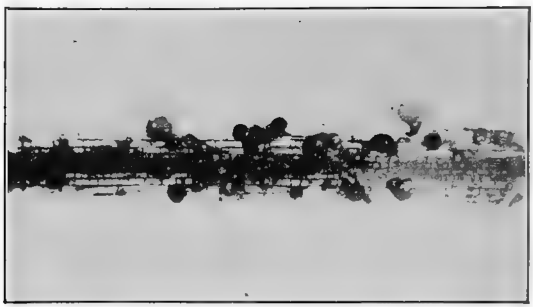

FIG. 52. Colonies of Rivularia on a disintegrating Typha leaf.

brownish in color, appearing dirty yellowish under the microscope. Its tapering filaments are closely massed together in the center of the rather solid gelatinous lump. The differentiation of cells in the single filament is shown in fig. 51*H*. Such filaments are placed side by side, their basal heterocysts close together, their tips diverging. As the mass grows to a size larger than a pea it becomes softer in consistency, more loosely attached to its support and hollow. Strikingly different in form and habits is the raftlike *Merismopœdia* (fig. 53). It is a flat colony of shining blue-green cells that divide in two planes at right angles to each other, with striking regularity. These rafts of cells drift about freely in open water, and are often taken in the plancton, though rarely in great abundance. They settle betimes on the leaves of the larger water plants, and may be discovered with a pocket lens by searching the sediment shaken therefrom.

FIG. 53. Merismopædia.

RED and BROWN ALGÆ (*Rhodophyceæ* and *Phæophyceæ*)—These groups are almost exclusively marine. A few scattering forms that grow in fresh water are shown in figure 54. *Lemanea* is a torrent-inhabiting form that grows in blackish green tufts of slender filaments, attached to the rocks in deep clear mountain streams where the force of the water is greatest. It is easily recognizable by the swollen or nodulose appearance of the ultimate (fruiting) branches. *Chantransia* is a beautiful purplish-brown, extensively branching form that is more widely distributed. It is common in clear flowing streams. It much resembles Cladophora in manner of growth but is at once distinguished by its color.

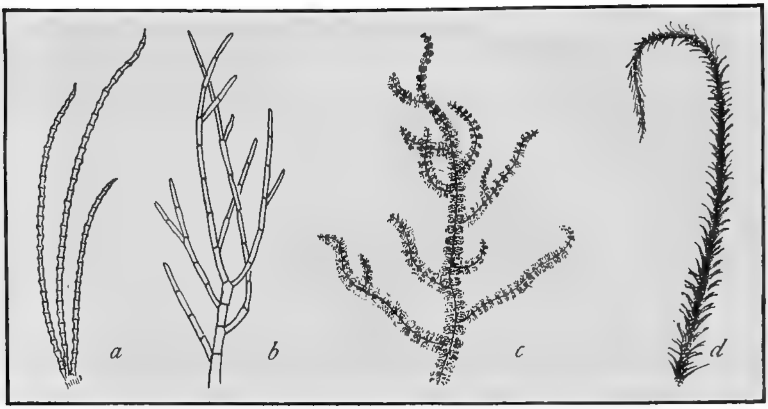

FIG. 54. Red and brown algæ (after West).
a, Lemanea; b, Chantransia; c, Batrachospermum; d, Hydrurus.

Batrachospermum is a freshwater form of wide distribution, with a preference for spring brooks, though occurring in any water that is not stagnant. It grows in branching filaments often several inches long, enveloped in a thick coat of soft transparent mucus. The color is bluish or yellowish-green, dirty yellow or brownish. Attached to some stick or stone in a rivulet its sprays, of more than frond-like delicacy, float freely in the water.

Hydrurus grows in branched colonies embedded in a tough mucilage, attached to rocks in cold mountain streams. The colonies are often several inches long. Their color is olive green. They have a plumose appearance, and are of very graceful outline.

The stoneworts (*Characeæ*).—This group is well represented in freshwater by two common genera, well known to every biological laboratory student, *Chara* and *Nitella*. Both grow in protected shoals, and in the borders of clear lakes at depths below the heavy beating of the waves. Both are brittle and cannot withstand

FIG. 55. Nitella glomerulifera.

wave action. Both prefer the waters that flow off from calcareous soils, and are oftenest found attached to a stony bottom.

The stoneworts, are the most specialized of the freshwater algæ: indeed, they are not ranked as algæ by some botanists. In form they have more likeness to certain land plants than to any of the other algæ.

They grow attached to the soil. They grow to considerable size, often a foot or more in length of stem. They grow by apical buds, and they send out branches in regular whorls, which branch and branch again, giving the plant as a whole a bushy form. The perfect regularity of the whorled branches and the brilliant coloration of the little spermaries borne thereon, doubtless have suggested the German name for them of "Candelabra plants."

The stoneworts are so unique in structure and in reproductive parts that they are easily distinguished from other plants. The stems are made up of nodes and internodes. The nodes are made up of short cells from which the branches arise. The internodes are made up of long cells (sometimes an inch or more long), the central one of which reaches from one node to another. In Nitella there is a single naked internodal cell composing entirely that portion of the stem. In Chara this axial cell is covered externally by a single layer of slenderer cortical cells wound spirally about the central one. A glance with a pocket lens will determine whether there is a cortical layer covering the axial internodal cell, and so will distinguish Chara from Nitella. Chara is usually much more heavily incrusted with lime in our commoner species, and in one very common one, *Chara fœtida*, exhales a bad odor of sulphurous compounds.

The sex organs are borne at the bases of branchlets. There is a single egg in each ovary, charged with a rich store of food products, and covered by a spirally wound cortical layer of protecting cells. These, when the egg is fertilized form a hard shell which, like the coats of a seed, resist unfavorable influences for a long time. This fruit ripens and falls from the stem. It drifts about over the bottom, and later it germinates.

At the apex of the ovary is a little crown of cells, between which lies the passageway for the entrance of the sperm cell at the time of fertilization. This crown is composed of five cells in Chara; of ten cells in Nitella. It is deciduous in Chara; it is persistent in Nitella.

The stoneworts, unlike many other algæ, are wonderfully constant in their localities and distribution, and regular in their season of fruiting. They cover the same hard bottoms with the same sort of gray-green meadows, year after year, and although little eaten by aquatic animals, they contribute important shelter for them, and they furnish admirable support for many lesser epiphytes.

CHLOROPHYLLESS WATER PLANTS, BACTERIA AND FUNGI

Nature's great agencies for the dissolution of dead organic materials, in water as on land, are the plants that lack chlorophyl. They mostly reproduce by means of spores that are excessively minute and abundant, and that are distributed by wind or water everywhere; consequently they are the most ubiquitous of organisms. They consume oxygen and give off carbon dioxide as do the animals, and having no means of obtaining carbon from the air, must get it from carbonaceous organic products—usually from some carbohydrate, like sugar, starch, or cellulose. Some of them can utilize the nitrogen supply of the atmosphere but most of them must get nitrogen also from the decomposition products of pre-existing proteins. Many of them produce active ferments, which expedite enormously the dissolution of the bodies of dead plants and animals. Some bacteria live without free oxygen.

It follows from the nature of their foods, that we find these chlorophylless plants abounding where there is the best supply of organic food stuffs. Stagnant pools filled with organic remains, and sewers laden with the city's waste. But there is no natural water free from them. Let a dead fly fall upon the surface of a tumbler of pond water and remain there for a day or two and it becomes white with water mold, whose spores were present in the water. Let any organic solution stand exposed and quickly the evidence of rapid decomposition appears in it. Even the dilute solutions contained in a laboratory aquarium, holding no organic material other than a few dead leaves will often times acquire a faint purple or roseate hue as chromogenic bacteria multiply in them.

Bacteria—A handful of hay in water will in a few hours make an infusion, on the surface of which a film of "bacterial jelly" will gather. If a bit of this "jelly" be mounted for the microscope, the bacteria that secrete it may be found immersed in it, and other bacteria will be found adherent to it. All the common form-types, *bacillus*, *coccus* and *spirillum* are likely to be seen readily. Thus easy is it to encourage a rich growth of water bacteria. Among the bacteria of the water are numerous species that remain there constantly (often called "natural water bacteria"), commingled at certain times and places with other bacteria washed in from the surface of the soil, or poured in with sewage. From the last named source come the species injurious to human health. These survive in the open water for but a short time. The natural water bacteria are mainly beneficial; they assist in keeping the world's food supply in circulation. Certain of them begin the work of altering the complex organic substances. They attack the proteins and produce from them ammonia and various ammoniacal compounds. Then other bacteria, the so-called "nitrifying" bacteria attack the ammonia, changing it to simpler compounds. Two kinds of bacteria successively participate in this: one kind oxidizes the ammonia to nitrites; a second kind oxidizes the nitrites to nitrates. By these successive operations the stores of nitrogen that are gathered together within the living bodies of plants and animals are again released for further use. The simple nitrates are proper food for the green algæ, with whose growth the cycle begins again. And those bacteria which promote the processes of putrefaction, are thus the world's chief agencies for maintaining undiminished growth in perpetual succession.

Bacteria are among the smallest of organisms. Little of bodily structure is discoverable in them even with high powers of the microscope, and consequently they are studied almost entirely in specially prepared cultures, made by methods that require the technical training of the bacteriological laboratory for their mastery. Any one can find bacteria in the water, but only a trained specialist can tell what sort of bacteria he has found; whether pathogenic species like the typhoid bacillus, or the cholera spirillum; or whether harmless species, normal to pure water.

The higher bacteria—Allied to those bacilli that grow in filaments are some forms of larger growth, known as *Trichobacteria*, whose filaments sometimes grow attached in colonies, and in some are free and motile. A few of those that are of interest and importance in fresh-water will be briefly mentioned and illustrated here.

*Leptothrix** (Fig. 56*a*, *b* and *c*) grows in tufts of slender, hairlike filaments composed of cylindric cells surrounded by a thin gelatinous sheath. In reproduction the cells are transformed directly into spores (*gonidia*) which escape from the end of the sheath and, finding favoring conditions, grow up into new filaments.

*Known also as *Streptothrix* and *Chlamydothrix*.

Crenothrix (Fig. 56 *d, e* and *f*) is a similar unbranched sessile form which is distinguished by a widening of the filaments toward the free end. This is caused by a division of the cells in two or three planes within the sheath of the filament, previous to spore formation. Often by the germination of spores that have settled upon the outside of the old sheaths and growth of new filaments therefrom compound masses of appreciable

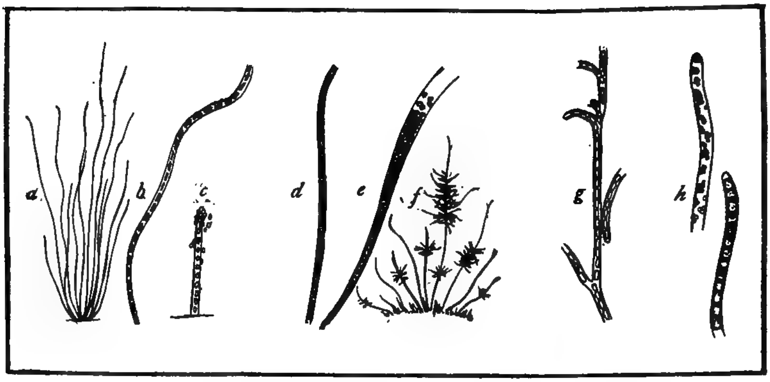

FIG. 56. Trichobacteria.

a, b, c, Leptothrix (*Streptothrix*, or *Chlamydothrix*). *a*, a colony; *b*, a single filament; *c*, spore formation; *d*, e, *f*, *Crenothrix*; *d*, a single growing filament; *e*, a fruiting filament; *f*, a compound colony; *g*, *Cladothrix*, a branching filament; *h*, *Beggiatoa*, younger and older filaments, the latter showing sulphur granules, and no septa between cells of the filament.

size are produced. In the sheaths of the filaments a hydroxide of iron is deposited (for Crenothrix possesses the power of oxidizing certain forms of iron); and with continued growth the deposits sometimes become sufficient to make trouble in city water supply systems by stoppage of the pipes. In nature, also, certain deposits of iron are due to this and allied forms properly known as iron bacteria. *Cladothrix* (Fig. 56 *g*), is a related form that exhibits a peculiar type of branching in its slender cylindric filaments.

Beggiatoa (fig. 56 *h*) is the commonest of the so-called sulfur bacteria. Its cylindric unbranched and unattached filaments are motile, and rotate on the long axis with swinging of the free ends. The boundaries between the short cylindric cells are often obscure, especially when (as is often the case) the cells are filled with highly refractive granules of sulfur. Considerable deposits of sulfur, especially about springs, are due to the activities of this and allied forms.

Water molds—True fungi of a larger growth abound in all fresh waters, feeding on almost every sort of organic substance contained therein. The commonest of the water molds are the Saprolegnias, that so quickly overgrow any bit of dead animal tissue which may chance to fall upon the surface of the water and float there. If it be a fly, in a day or two its body is surrounded by a white fringe of radiating fungus filaments, outgrowing from the body. The tips of many of these filaments terminate in cylindric sporangia, which when mature, liberate from their ruptured tips innumerable biciliated free-swimming swarm spores. These wander in search of new floating carcases, or other suitable food. Certain of these water molds attack living fishes, entering their skin wherever there is a a slight abrasion of the surface, and rapidly producing diseased conditions. These are among the worst pests with which the fish culturist has to contend. They attack also the

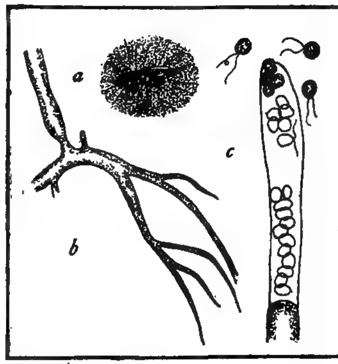

FIG. 57. A common water mold, *Saprolegnia*. (After Engler and Prantl.)

a, a colony growing on a dead fly; *b*, a bit of the mycelium that penetrates the fly's body; *c*. a fruiting tip, with escaping swarm spores.

eggs of fishes during their incubation (see fig. oo on p. oo).

Most water molds live upon other plants. Even the Saprolegnias have their own lesser mold parasites. Many living algæ, even the lesser forms like desmids and diatoms are subject to their attack. Fine cultures of such algæ are sometimes run through with an epidemic of mould parasites and ruined.

THE HIGHER PLANTS

(*Mossworts, Fernworts and Seed Plants*)

In striking contrast with the algæ, the higher plants live mainly on land, and the aquatics among them are restricted in distribution to shoal waters and to the vicinity of shores. There is much in the bodily organization of nearly all of them that indicates ancestral adaptation to life on land. They have more of hard parts, more of localized feeding organs, more of epidermal specialization, and more differentiation of parts in the body, than life in the water demands.

FIG. 58. The marsh mallow, *Hibiscus Moscheutos.*

They occupy merely the margins of the water. A few highly specialized genera, well equipped for withstanding partial or complete submergence occupy the shoals and these are backed on the shore line by a mingled lot of semi-aquatics that are for the most part but stray members of groups that abound on land. Often they are single members of large groups and are sufficiently distinguished from their fellows by a name indicating the kind of wet place in which they grow. Thus we know familiarly the floating riccia, the bog mosses, the brook speedwell, the water fern and water cress, the marsh bell flower and the marsh fern, the swamp horsetail and the swamp iris, etc. All these and many others are stragglers from large dry land groups. That readaptation to aquatic life has occurred many times independently is indicated by the fact that the more truly aquatic families are small and highly specialized, and are widely separated systematically.

Bryophytes—Both liverworts and mosses are found in our inland waters, though the former are but sparingly represented. Two simple Riccias, half an inch long when grown, are the liverworts most commonly found. One, *Riccia fluitans*, grows in loose clusters of flat slender forking sprays that drift about so freely that fragments are often taken in pond and river plancton. The larger unbroken more or less spherical masses of sprays are found rolling with the waves upon the shores of muddy ponds. The other, *Ricciocarpus natans*, has larger and thicker sprays of green and purple hue, that float singly upon the surface, or gather in floating masses covering considerable areas of quiet water. They are not uncommonly found in springtime about the edges of muddy ponds. Underneath the flat plant body there is a dense brush of flattened scales.

Water mosses are more important. The most remarkable of these are the bog mosses (*Sphagnum*). These cover large areas of the earth's surface, especially in northern regions, where they chiefly compose the thick soft carpet of vegetation that overspreads open bogs and coniferous swamps. They are of a light grey-green color, often red or pink at the tips. These mosses do not grow submerged, but they hold immense quantities of water in their reservoir cells, and are able to absorb water readily from a moist atmosphere; so they are always wet. Supported on a framework of entangled rootstocks of other higher plants, the bog mosses extend out over the edges of ponds in floating mats, which sink under one's weight beneath the water level and rise again when the weight is removed. The part of the mat which the sphagnum composes consists of erect, closely-placed, unbranched stems, like those shown in fig. 59, which grow ever upward at their tips,

FIG. 59. Bog-moss, *Sphagnum*.

and die at the lower ends, contributing their remains to the formation of beds of peat.

The leaves of Sphagnum are composed of a single layer of cells that are of two very different sorts. There are numerous ordinary narrow chlorophyl-bearing cells, and, lying between these, there are larger perforate reservoir cells, for holding water.

The true water mosses of the genus *Fontinalis* are fine aquatic bryophytes. These are easily recognized, being very dark in color and very slender. They grow in spring brooks and in clear streams, and are often seen in great dark masses trailing their wiry stems where the current rushes between great boulders or leaps into foam-flecked pools in mountain brooks.

Another slender brook-inhabiting moss is *Fissidens julianum*, which somewhat resembles Fontinalis, but which is at once distinguished by the deeply channeled bases of its leaves, which enfold the stem. The leaves are two ranked and alternate along the very slender flexuous stem, and appear to be set with edges toward it.

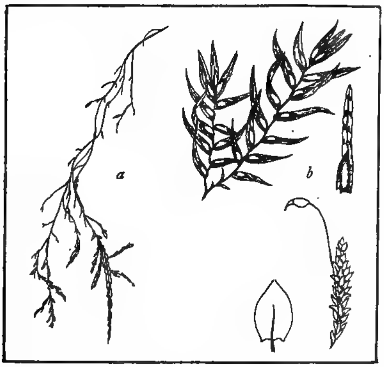

FIG. 60. Water mosses.
a, *Fontinalis*; *b*, *Fissidens julianum*, with a single detached leaf, more enlarged; *c*, *Rhynchostegium rusciforme*, with a single detached leaf at the left. (After Grout.)

There are also a few lesser water mosses allied to the familiar trailing hypnums, so common in deep woods. They grow on stones in the bed of brooks. They cover the face of the ledges over which the water pours in floods and trickles in times of drouth, as with a fine feathery carpet of verdure that adds much to the beauty of the little waterfalls. They give shelter in such places to an interesting population of amphibious animals, as will be noted in chapter VI, following. The leaves of the hypnums are rather short and broad, and in color they are often very dark—often almost black.*

*Grout has given a few hints for the recognition of these "Water-loving hypnums" in his *Mosses with a Hand Lens*, 2d edition, p. 128. New York, 1905.

There are also a few hypnums found intermixed with sphagnum on the surface of bogs, and as everyone knows there are hosts of mosses in all moist places in woods and by watersides.

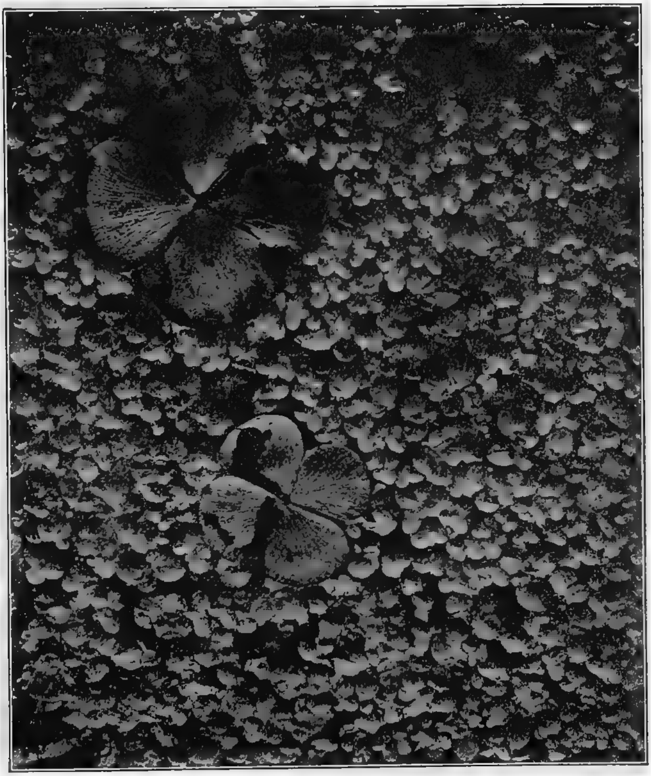

FIG. 61. Two floating leaves of the "water shamrock," *Marsilea*, in the midst of a surface layer of duck-meat (*Spirodela polyrhiza*).

Pteridophytes—Aquatic fernworts are few and of very unusual types. There are at least two of them, however, that are locally dominant in our flora. *Marsilea*, the so-called water shamrock or water fern, abounds on the sunny shoals of muddy bayous about Ithaca and in many places in New England. It covers the zone between high and low water, creeping extensively over the banks that are mostly exposed, and there forming a most beautiful ground cover, while producing longer leaf-stalks where submerged. These leaf-stalks carry the beautiful four-parted leaf-blades to the surface where they float gracefully. Fruiting bodies the size

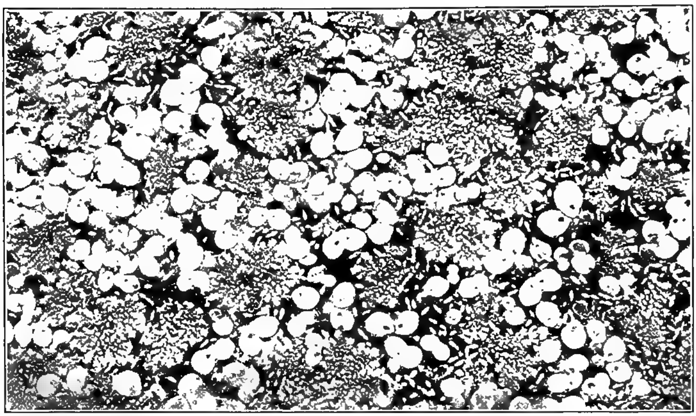

Fig. 62. Floating plants: The largest branching colonies are *Azolla;* the smallest plants are *Wolffia;* those of intermediate size are *Lemna minor*. *Photo by Dr. Emmeline Moore.*

of peas are produced in clusters on the creeping stems above the water line, often in very great abundance.

Then there are two floating pteridophytes of much interest. *Salvinia*, introduced from Europe, is found locally along our northeastern coast, and in the waters of rich bottom lands south and westward the brilliant little *Azolla* flourishes. Azolla floats in sheltered bogs and back waters, intermingled with duckweeds. It is reddish in color oftener than green and grows in minute mosslike pinnately branched sprays, covered with closely overlapping two-lobed leaves, and emits a few rootlets from the under side which hang free in the water. In the back waters about the Illinois Station at Havana, Illinois, Azolla forms floating masses often several feet in diameter, of bright red rosettes.

Shoreward there are numerous pteridophytes growing as rooted and emergent aquatics; the almost grass-like *Isoetes*, and the marsh horsetails and ferns, but these latter differ little from their near relatives that live on land.

Aquatic Seed Plants—These are manifestly land plants in origin. They have much stiffening in their stems. They have a highly developed epidermal system, often retaining stomates, although these can be no longer of service for intake of air. They effect fertilization by means of sperm nuclei and pollen tubes, and not by free swimming sperm cells.

Seed plants crowd the shore line, but they rapidly diminish in numbers in deepening water. They grow thickest by the waterside because of the abundance of air moisture and light there available. But too much moisture excludes the air and fewer of them are able to grow where the soil is always saturated. Still fewer grow in standing water and only a very few can grow wholly submerged. Moreover, it is only in protected shoals that aquatic seed plants flourish. They cannot withstand the beating of the waves on exposed shores. Their bodies are too highly organized, with too great differentiation of parts. Hence the vast expanses of open waters are left in possession of the more simply organized algæ.

An examination of any local flora, such as that of the Cayuga Lake Basin* will reveal at once how small a part of the population is adapted for living in water.

*The following data are largely drawn from Dudley's *Cayuga Flora*, 1886.

In this area there are recorded as growing without cultivation 1278 species. Of these 392 grow in the water. However, fewer than forty species grow wholly submerged, with ten or a dozen additional submerged except for floating leaves. Hardly more than an eighth, therefore, of the so-called "aquatics" are truly aquatic in mode of life: the remaining seven-eighths grow on shores and in springs, in swamps and bogs, in ditches, pools, etc., where only their roots are constantly wet.

FIG. 63. The ruffled pond-weed; *Potamogeton crispus*, one of the most ornamental of fresh water plants.

The aquatic seed plants are representative of a few small and scattered families. Indeed, the only genus having any considerable number of truly aquatic species is the naiad genus Potamogeton. Other genera of river-weeds, or true pond weeds, are small scattered and highly diversified. They bear many earmarks of independent adaptation to the special situations in the water which they severally occupy. In the economy of nature the Potamogetons or river weeds constitute the most important single group of submerged seed plants. They are rooted to the bottom in most shoal waters, and compose the greater part of the larger water meadows within our flora. They have alternate leaves and slender flexuous stems that are often incrusted with lime.

There are evergreen species among the Potamogetons, and other species that die down in late summer. There are broad leaved and narrow leaved species. There are a few, like the familiar *P. natans* whose uppermost leaves (see fig. 00 on page 00) float on the surface, but the more important members of the genus live wholly submerged. Tho seed-plants, they mainly reproduce vegetatively, by specialized reproductive buds that are developed in the growing season, and are equipped with stored starch and other food reserves, fitting them when detached for rapid growth in new situations. These reproductive parts are developed in some species as tuberous thickenings of underground parts (see figure 00 on page 00); in others as burr-like clusters of thickened apical buds; and in still others they are mere thickenings of detachable twigs.

The Potamogetons enter largely into the diet of wild ducks and aquatic rodents and other lesser aquatic herbivores. They are as important for forage in the water as grasses are on land.

Other naiads are *Nais* (fig. 85) and *Zannichellia.*

Eel-grass (*Vallisneria*) is commonly mixed with the pond weeds in lake borders and water meadows. Eel-grass is apparently stemless and has long, flat, flexuous, translucent, ribbonlike leaves, by which it is easily recognized. The duckweeds (Lemnaceæ, figs. 61 and 62) are peculiar free-floating forms in which the plant body is a small flat thallus, that drifts about freely on the surface in sheltered coves, mingled with such liverworts as Ricciocarpus, with such fernworts as Azolla, with seeds, eel-grass flowers, and other flotsam. There are definite upper and lower surfaces to the thallus with pendant roots beneath hanging free in the water. Increase is by budding and outgrowth of new lobes from pre-existing thalli. Flowering and seed production are of rare occurrence.

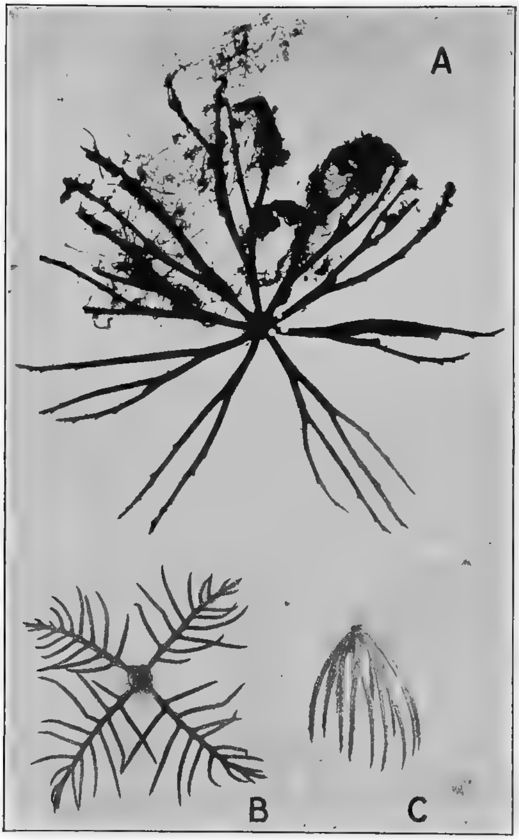

FIG. 64. Leaf-whorls.

A, and *C*, the hornwort (*Ceratophyllum*); *B*, the water milfoil (*Myriophyllum*). *A* is an old leaf, the upper half normally covered with algæ and silt; the lower half cleaned, save for a closely adherent dwelling-tube of a midge larva in the fork at the right. *C*, is a young partly expanded leaf whorl from the apical bud.

The water lily family includes the more conspicuous of the broad-leaved aquatics, which pre-empt the rich bottom mud with stout root stocks, and heavily shade the water with large shield-shaped leaves, either floating upon the surface, as in the water shield and water lilies or lifted somewhat above it, as in the spatterdock and the lotus. They are long-lived perennials, requiring a rich muck soil to root in. These are distinguished for the beauty and fragrance of their flowers.

The bladderworts (*Utricularia*) comprise another peculiar group. They are free-floating, submerged plants with long, flexuous branching stems that are thickly clothed with dissected leaves. Attached to the leaves are the curious traps or "bladders" (discussed in Chapt. VI) which have suggested the group name. Being unattached they frequent the still waters of sheltered bays and ponds where they form beautiful feathery masses of green. They shoot up stalks above the surface bearing curious bilabiate flowers.

FIG. 65. The water weed, *Philotria* (*Anacharis* or *Elodea*), with two young black-and-green-banded nymphs of the dragonfly *Anax* on its stem, and a snail, *Planorbis*, on a leaf.

The hornwort (*Ceratophyllum*) is another non-rooting water plant that grows wholly submerged and branching. It is coarser, however, and hardier than Utricularia and much more widespread. Its leaves are stiff, repeatedly forking, and spinous-tipped (fig. 64 *A* and *C*).

The water milfoils (*Myriophyllum*) are rooted aquatics, superficially similar to the hornwort but distinguishable at a glance by the simple pinnate branching of the softer leaves (fig. 64*B*).

Then there are a few very common aquatics that form patches covering the beds of lesser ponds, bogs and pools. The common water weed, *Philotria*, (fig. 65), with its neat little leaves regularly arranged in whorls of threes; and two water crowfoots, *Ranunculus*, (fig. 66), white and yellow, with alternate finely dissected leaves; and the water purslane, *Ludvigia palustris*, with its closely-crowded opposite ovate leaves.

These are the common plants of the waterbeds about Ithaca. They are so few one may learn them quickly, for so strongly marked are they that a single spray or often a single leaf is adequate for recognition.

Fig. 66. A leaf of the white water-crowfoot, *Ranunculus*.

Then there are three small families so finely adapted to withstanding root submersion that they dominate all our permanent shoals and marshes. These are (1) the Typhaceæ including the cat-tails and the bur-reeds, which form vast stretches of nearly clear growth, as discussed in the last chapter; (2) the Alismaceæ, including arrow heads and water plantain, and (3) the Pontederiaceæ, represented by the beautiful blue pickerel-weed. All these are shown in their native haunts in the figures of chapter VI.

Another family of restricted aquatic habitat is the Droseraceæ, the sun-dews, which grow in the borders of sphagnous upland bogs. They are minute purplish-tinted plants whose leaves bear glandular hairs.

Few other families are represented in the water by more than a small proportion of their species. Those families are best represented whose members live chiefly on low grounds and in moist soil. A few rushes (Juncaceæ) invade the water on wave-washed shores at fore front of the standing aquatics. A few sedges

FIG. 67. Fruit clusters of four emergent aquatic seed plants; arrow-arum (*Peltandra*), pickerel-weed (*Pontederia*), burr-reed (*Sparganium*), and sweet flag (*Acorus*).

(Carices) overrun flood-plains or fringe the borders of ditches. A very few grasses preëmpt the beds of shallow and impermanent pools. A few aroids, such as arrow arum and the calla adorn the boggy shores. A few heaths, such as, Cassandra and Andromeda overspread the surface of upland sphagnum bogs with dense levels of shrubs, and numerous orchids occupy the surface of the bog beneath and between the shrubs. Willows and alders fringe all the streams, associated there with a host of representatives of other families crowding down to the waterside. A few of these on account of their usefulness or their beauty, we shall have occasion to consider in a subsequent chapter.

Such are the dominant aquatic seed plants in the Cayuga Basin; and very similar are they over the greater part of the earth. The semi-aquatic representatives of the larger families are few and differ little from their terrestrial relatives: the truly aquatic families are small and highly diversified.

ANIMALS

MANY of the lower groups of animals are wholly aquatic, never having departed from their ancestral abode. Other groups are in part adapted to life on land. A few others, after becoming fit for terrestrial life, have been readapted in part to life in the water. Aquatic insects and mammals, especially, give evidence of descent from terrestrial ancestors. As with plants, so with animals, it is the lower groups that are predominantly aquatic. The simplest of animals are the protozoans; so with these we will begin.

Protozoans—One of the best known animals in the world, one that is pedagogically exploited in every biological laboratory, is the *Amœba* (fig. 69*a*). Plastic, ever changing in form and undifferentiated in parts, this is the animal that is the standard of comparison among things primitive. Its name has become a household word, and an every-day figure of speech. A little living one-celled mass of naked protoplasm, that creeps freely about amid the ooze of the pond bottom, and feeds on organic foods. It grows just large enough to be recognized by the naked eye when in most favorable light, as when creeping up the side of a culture jar: on the pond bottom it is undiscoverable and a microscope is essential to study it.

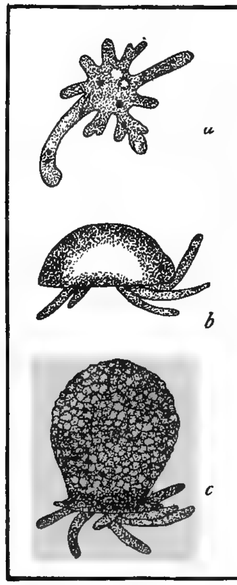

FIG. 69. Protozoans. *a*, Amœba; *b*, Arcella; *c* Difflugia.

Related to Amœba are several common shell-bearing forms of the group of Sarcodina (Rhizopoda) that often become locally abundant. *Difflugia* (fig. 69*c*) forms a flask-shaped shell composed of minute granules, that, magnified, look like grains of sand stuck together over the outside. The soft amœba-like body protrudes in pseudopodia from the mouth of the flask, when traveling or foraging, or withdraws inside when disturbed. *Arcella* (fig. 69*b*) secretes a broadly domeshaped shell, having a concave bottom, in the center of which is the hole whence dangle the clumsy pseudopodia. One species of Arcella, shown in the following figure, has the margin of the shell strongly toothed. Both of these genera, and other shell-bearing forms, secrete

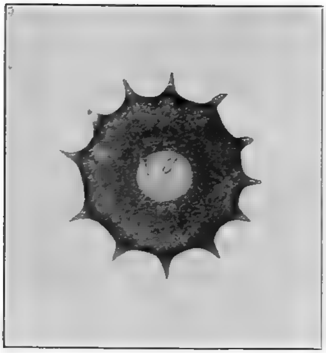

FIG. 70. *Arcella dentata.* Through the central opening there is seen a diatom, recently swallowed.

bubbles of gas within their shells whereby they are caused to float. Thus they are often taken in the plancton net from open water of the ponds and streams.

Other protozoans that have the body more or less covered with vibratile cilia (Ciliata), are very common in fresh water, especially in ponds and pools. Best known of these is *Paramecium*, (fig. 71*a*) another familiar biological-laboratory "type" that grows abundantly in plant infusions. It is found in stagnant pools, swimming near the surface. There are many species of Paramecium. Some of them and some members of allied genera are characteristic of polluted waters. Other allied genera are parasitic, and live within the bodies of the higher animals. *Stentor* is (as the name signifies) a more or less trumpet-shaped ciliate protozoan, that may detach itself and swim freely about, but that is ordinarily attached by its slender base to some support. Its base is in some species surrounded by a soft gelatinous transparent lorica, as shown in the figure. Some species are of a greenish color. Stentor and Paramecium, tho unicellular, are quite large enough to be seen (as moving specks) with the unaided eye.

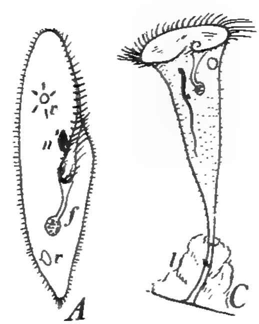

FIG. 71. Ciliate protozoans.

A, *Paramœcium*; *n*, nucleus; *v*, *v*, vacuoles; *f*, food-ball at the bottom of the rudimentary esophagus: *C*, *Stentor*; *l*, lorica.

Cothurnia (fig. 73*c*) is a curious double form that is often found attached to the stems of water weeds. The two cells of unequal height are surrounded by a thin transparent lorica. For beauty of form and delicacy or organization it would be hard to find anything surpassing this little creature.

Vorticella and its allies are among the commonest and most ubiquitous of protozoans. They are sessile and stalked, with some portion or all of the base contractile. Vorticella forms clusters of many separate individuals, while Epistylis forms branching, tree-like compound colonies (fig. 72). Oftentimes they completely clothe twigs and grass stems lying in the water, as with a white fringe. Often they cluster about the appendages of crustaceans and insects, or thickly clothe their shells. Sometimes they cling to floating algal filaments in the water-bloom (see fig. 00 on p. 00).

FIG. 72. A colony of *Epistylis*.

The dark object on the side of the stalk is an egg, probably the egg of a rotifier.

Ophrydium forms colonies of a very different sort. Numerous weak-stalked individuals have their bases imbedded in a roundish mass of gelatin. The colonies lie scattered about over the bottom of a lake or pond. They are roundish, or often rather shapeless masses varying in size from mere specks up to the dimensions of a hen's egg. In the summer of 1906 the marl-strown shoals of Walnut Lake in Michigan were so thickly covered that a boat-load of the soft greenish-white colonies could easily have been gathered from a small area of the bottom.

Other forms of protozoa there are in endless variety. We cannot even name the common ones here: but we will mention two that are very different from the foregoing in form and habit. *Podophyra* will often be encountered by searching the backs of aquatic insects or the sides of submerged twigs, or other solid support, to which it is attached. It is sessile, and reaches out its suctorial pseudopodia in search of soft-bodied organisms that are its prey.

Anthophysa is a curious sessile form that is common in polluted waters. It forms very minute spherical colonies that are attached to the transparent tip of a

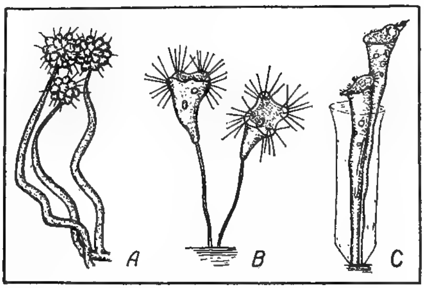

FIG. 73. Three sessile protozoans.
A, Anthophysa; *B*, Podophora; *C*, Cothurnia.

rather thick brownish stalk. The stalk increases in length and diameter with age, occasionally forking when the colony divides. It soon becomes much more conspicuous than the colonies it carries. It often persists after the animals are dead and gone. After a vigorous growth, the accumulated stalks sometimes cover every solid support as with a soft flocculent brownish fringe.

Besides these and other free-living forms, there are parasitic Protozoa whose spores get into the water. Some of these are pathogenic; many of them have changes of host; all of them are biologically interesting; but we have not space for their consideration here. We must content ourselves with the above brief mention of a few of the more common and interesting free-living forms.

METAZOANS

Hydras are the only common fresh-water representatives of the great group of Cœlenterates, so abundant in the seas; and of hydras there are but a few species. Two of these, the common green and brown ones, *H. virdis* and *H. fusca*, are well enough known, being among the staples of every biological laboratory. Pedagogically it is a matter of great good fortune that this little creature lives on, a common denizen of fresh-water pools; for its two-layered sac-like body represents well the simplest existing type of metazoan structure.

Hydras are ordinarily sessile, being attached by a disc-like foot to some solid support or to the surface film, from which they often hang suspended. But at times of abundance (and under conditions that are not at present well understood) they become detached and drift about in the water. A hydra of a brick-red color swarms about the outlet of Little Clear Pond at Saranac Inn, N. Y., in early summer, and drifts down the outflowing stream, often in such abundance that the water is tinged with red. The young trout in hatching ponds through which this stream flows, neglect their regular ration of ground liver, and feed exclusively upon the hydras, so long as the abundance continues. The hydras play fast-and-loose in the stream, attaching themselves when they meet with some solid support, and then loosening and drifting again.

Clear, sunlit pools are the favorite haunts of hydras, and the early summer appears to be the time of their maximum abundance. They attach themselves mainly to submerged stems and leaves, and to the underside of floating duckmeat. They feed upon lesser animals which abound in the plancton, and, multiplying rapidly by a simple vegetative process of budding with subsequent detachment, they become numerous when plancton abounds. Kofoid ('08) found a maximum number of 5335 hydras per cubic meter of water in Quiver Lake during a vernal plancton pulse in 1897.

Fresh-water sponges grow abundantly in the margins of lakes and pools and in clear, slow-flowing streams. They are always sessile upon some solid support. In sunlight they are green, in the shade they grow pale. The species that branch out in slender finger-like processes are most suggestive of plants in both form and color, but even the slenderest sponge is more massive than any plant body; and when one looks closely at the surface he sees it roughened all over with the points of innumerable spicules, and sees open osteoles at the tips. By these signs sponges of whatever form or color are easily recognized.

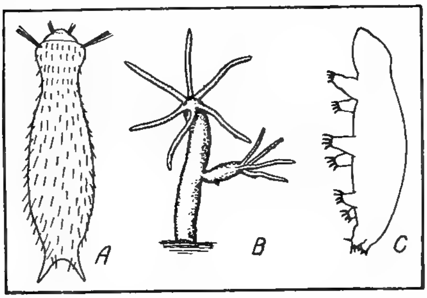

FIG. 74. Three simple metazoans of isolated structural types.
A, a scruff back, *Chætonotus;* *B*, *Hydra*, bearing a bud; *C*, a tardigrade, *Macrobiotus*.

The commonest sponges are low encrusting species that grow outspread over the surfaces of logs and timbers. When, in early summer, one overturns a floating log that has been long undisturbed he may find it dotted with young sponges, growing as little yellow, circular, fleshy discs, bristling with spicules, and each with a large central osteole. Later they grow irregular in outline, and thicker in mass. Toward the end of their growing season they develop statoblasts or gemmules (winter-buds) next to the substratum (see fig. 00 on p. 00), and then they die and disintegrate. So our fresh-water sponges are creatures of summer, like daffodils.

All sponges are aquatic, and most of them are marine. Only the fresh-water forms produce statoblasts, and live as annuals.

In figure 74 we show two other simple metazoans (unrelated to Hydra and of higher structural rank

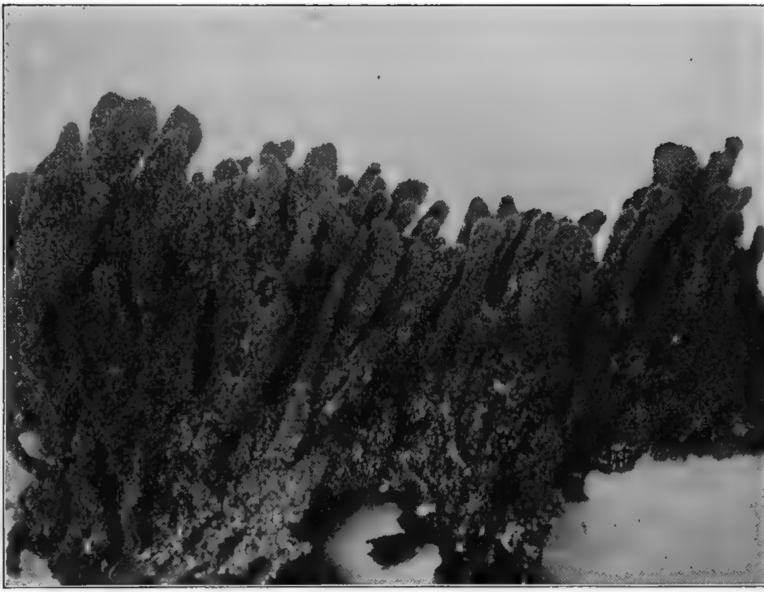

Fig. 75. A semi-columnar sponge from the Fulton Chain of Lakes near Old Forge, N. Y. Half natural size. Photo. kindly loaned by Dr. E. P. Felt of the N. Y. State Museum.

than the sponges) that during the history of systematic zoology, have been much bandied about among the groups, seeking proper taxonomic associates. *Chætonotus* often appears on the side of an aquarium jar gliding slowly over the surface of the glass as a minute oblong white speck. It is an inhabitant of water containing plant infusions, and an associate of Paramecium which to the naked eye it somewhat resembles.

Macrobiotus may be met in the same way and place, but less commonly. It may also be taken in plancton; but its favorite habitat appears to be tangles of water-plants, over whose stems it crawls clumsily with the aid of its four pairs of stubby strong-clawed feet. It also inhabits the most temporary pools, even rainspouts and stove urns, and is able to withstand dessication.

FIG. 76. Bryozoan colonies, slightly enlarged; a dense colony of *Plumatella* on a grass-stem; a beginning colony on a leaf (above); and a loosely grown colony of *Fredericella*.

Chætonotus is probably most nearly related to the Rotifers; Macrobiotus, to the mites.

Bryozoans — The Bryozoans or "moss animals" (called also Polyzoans) are colonial forms that are very common in fresh water. They grow always in sessile colonies, which have a more or less plant-like mode of branching. Their fixity in place, their spreading branches and the brownish color of the test they secrete give the commoner forms an aspect enough like minute brown creeping water mosses to have suggested the name. The individual animals (zooids) of a colony are minute, requiring a pocket lens for their examination, but the colonies are often large and conspicuous. Two of the commoner genera are shown in figure 76, natural size. These may be found in every brook or pond, growing in flat spreading colonies on leaves or pieces of bark or stones. Often a flat board that has long been floating on the water, if overturned, will show a complete and beautiful tracery of entire colonies outspread upon the surface. New zooids are produced by budding. The buds remain permanently attached, each at the tip of a branch. With growth in length and the formation of a tough brownish cuticle over every portion except the ends, the skeleton of the colony develops. This skeleton is what we see when we lift the leaf from the water and look at the colony—brown, branching tubes, with a hole in the end of each branch. Nothing that looks like an animal is visible, for the zooids which are very sensitive and very delicate have all withdrawn into shelter. They suddenly disappear on the slightest disturbance of the water, and only slowly extend again.

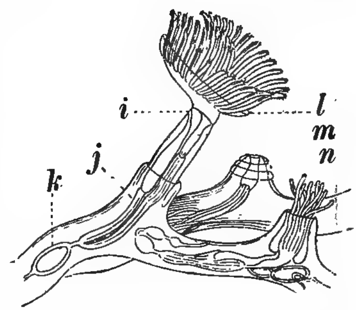

FIG. 77. Three zooids of the bryozoan, *Plumatella*, magnified.

l, expanded; *m*, retracted; *n*, partly retracted; *i*, anus; *j*, intestine; *k*, developing statoblast.

If we put a leaf or stone bearing a small colony into a glass of water and let it stand quietly for a time the zooids will slowly extend themselves, each unfolding a beautiful crown of tentacles. There are few more beautiful sights to be witnessed through a lens than the blossoming out of these delicate transparent, flower-like, crowns of tentacles from the tips of the apparently lifeless branches of a populus colony. They unfold from each bud, like a whorl of slender petals and slowly extend their tips outward in graceful curves. Then one sees a mouth in the midst of the tentacles, and water-currents set up by the lashing of the cilia which cover

FIG. 78. A colony of Pectinatella, one-half natural size. Note the distribution of buds in close groups over the surface. The large hole marks the location of the stick around which the colony grew.

them. A close examination with the microscope will reveal in each zooid the usual system of animal organs. The alimentary canal is U-shaped its two openings being near together at the exposed end of the body.

Several Bryzoans secrete a gelatinous covering instead of a solid tube, and the colonies become invested in a soft transparent matrix. *Pectinatella* (fig. 78) is one of these. It grows in large, more or less spherical colonies, often resembling a muskmelon in size, shape and superficial appearance. It is a not uncommon inhabitant of bayous and ditches and slow-flowing streams. It grows in most perfect spherical form when attached to a rather small twig. The clustered zooids form grayish rosettes upon the surface of the huge translucent sphere. Late in the season when statoblasts appear the surface becomes thickly besprinkled with brown. Still later, after the zooids have died, and the statoblasts have been scattered the supporting gelatin persists, blocks and segments of it, derived from disintegrating colonies, now green from an overgrowth of algæ, are scattered about the shores.

There are but a few genera of fresh-water bryozoans —some six or seven—and *Plumatella* is much the commonest one. Plumatella and allied forms grow in water pipes. They gather in enormous masses upon the sluice-ways and wiers of water reservoirs. They sometimes cover every solid support with massive colonies of interlaced and heaped-up branches. Thus they form an incrusting layer thick enough to be removed from flat surfaces with shovels. Its removal is demanded because the bryozoans threaten the potability of the water supply. They do no harm while living and active, but when with unfavorable conditions they begin to die, their decomposing remains may befoul the water of an entire reservoir.

Cristatella is a flat, rather leech-shaped form that is often found on the under side of lily pads. It is remarkable for the fact that the entire colony is capable of a slow creeping locomotion. The zooids act together as one organism.

The free-living flatworms abound in most shoal fresh waters. Some live in shallow pools; others in lakes and rivers, others in spring-fed brooks. They gather on the under sides of stones, sticks and trash, and conceal themselves amid vegetation, usually shunning the light. They are often collected unnoticed, and crawl at night from cover and lie outspread upon the

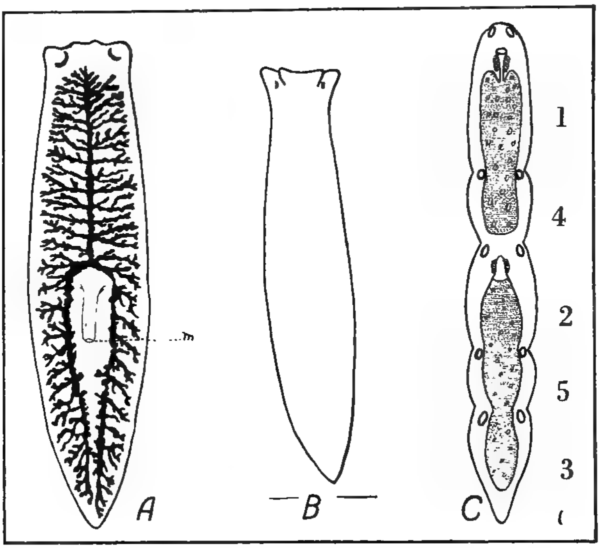

FIG. 79. Flatworms.

A, diagram of a planarian, showing food cavity; *M*, mouth at end of cylindric pharynx, directed downward underneath the body; *B*, *Dendrocœlum;* *C*, a chain of five individuals of *Stenostomum* formed by automatic division of the body, (after Keller). Note the anterior position of the mouth and the unbranched condition of the alimentary canal in this *Rhabdocœle* type.

sides of our aquaria. We may usually find the larger species by lifting stones from a stream bed or a lake shore, and searching the under side of them.

Flatworms are covered with vibratile cilia and travel from place to place with a slow gliding motion. They range in length from less than a millimeter to several centimeters. The smaller among them are easily mistaken for large ciliate protozoans, if viewed only with the unaided eye; but under the microscope the alimentary canal and other internal organs are at once apparent. They are multicellular and have little likeness to any infusoria, save in the ciliated exterior. Most members of the group are flattened, as the common name suggests, but a few are cylindric, or even filiform. A few are inclined to depart from shelter and to swim in the open water, especially at time of abundance. Kofoid ('08) found them in the channel waters of the Illinois River in average numbers above 100 per cubic meter, with a maximum record of 19250 per cubic meter.

The large flatworms resemble leeches somewhat in form of body, but they have more of a head outlined at the anterior end. They lack the segmentation of body and the attachment discs of leeches, and their mode of locomotion is so very different they are readily distinguished. They do not travel by loopings of the body as do leeches, but they glide along steadily, propelled by invisible cilia.

The most familiar flatworms are the planarians: soft and innocuous-looking little carnivores, having the mouth opening near the midventral surface of the body, and the food-cavity spreading through the body in three complexly ramifying branches. They are often brightly colored, mottled white, or brick red, or plumbeous, and they have a way of changing color with every full meal; for the branched alimentary canal fills, and the color of the food glows through the skin in the more transparent species. The eggs of planarians are often found in abundance on stones in streams in late summer. They are inclosed in little brownish capsules, of the size and appearance of mustard seeds, and each capsule is raised on a short stalk from the surface of the stone. Increase is also by automatic transverse division of the body, the division plane lying close behind the mouth. When a new head has been shaped on the tail-piece, and a new tail on the head-piece, and two capable organisms have been formed, then they separate. In some of the simple (Rhabdocœle) flatworms the body divides into more than two parts simultaneously and thus chains of new individuals arise (fig. 79 *c*).

Thread-worms or *Nematodes*, abound in all fresh waters, where they inhabit the ooze of the bottom, or thick masses of vegetation, They are minute, colorless, unsegmented, smoothly-contoured cylindric worms rarely more than a few millimeters long. The tail end is usually sharply pointed. The mouth is terminal at the front end of the body, and is surrounded by a few short microscopic appendages. Within the mouth cavity there are often little tooth-like appendages. The alimentary canal is straight and cylindric and unappendaged, and the food is semifluid organic substances.

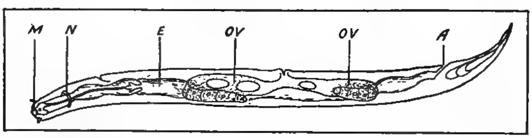

FIG. 80. Diagram of a Nematode worm.

m, mouth; *n*, nerve ring; *e*, alimentary canal; *ov*, *ov*, ovaries. (After Jagerskiold).

We can hardly collect any group of pond-dwellers without also collecting nematodes. They may occupy any crevice. They slip in between the wing-pads of insect nymphs, and into the sheaths of plant stems. When we disturb the trash in the bottom of our collecting dish, we see them swim forth, with violent swings and reversals of the pliant body. They may easily be picked up with a pipette.

Oligochetes—Associated with the nematodes in the trash and ooze, there is a group of minute bristle-bearing worms, the naiads (Family Naidæ), similar in slenderness and transparency of body, but very different on close examination; for the body in Nais is segmented, and each segment is armed with tufts of bristles of variable length and form. There are many common members of this family. Besides the graceful Nais shown in our figure there is *Chætogaster*, which creeps on its dense bristle-clusters as on feet. There is *Stylaria* with a long tongue-like proboscis. There is *Dero* that lives at the surface in a tube of some floating plant stuffs, such as seeds (fig. 82) or Lemna leaves, slipping in and out or changing ends in the tube with wonderful celerity; and there are many others.

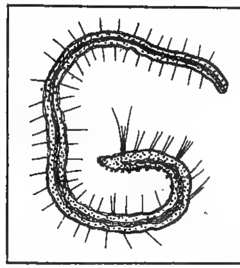

FIG. 81. Nais. (after Leunis).

Dero bears usually two pairs of short gill-lobes at the posterior end of the body.

All these naiads reproduce habitually by automatic division of the body, which when in process of development, forms chains of incompletely formed individuals, as in certain of the flatworms before described.

Another group of Oligochetes is represented by *Tubifex* and its allies. These dwell in the bottom mud, living in stationary tubes, which are in part burrows, and in part chimneys extended above the surface. The worms remain anchored in these and extend their lithe bodies forth into the water. On disturbance they vanish instantly, retreating into their tubes. They are often red in color, and when thickly associated, as on sludge in the bed of some polluted pool, they often cover the bottom as with a carpet of a pale mottled reddish color.

FIG. 82. Dero, in its case made of floating seeds.

Aquatic earth-worms, more like the well-known terrestrial species, burrow deeply into the mud of the pond bottom.

Other worms occur in the water in great variety; we have mentioned only a few of the commonest, and those most frequently seen. There are many parasitic worms that appear in the water for only a brief period of their lives: hair-worms (*Gordius*, etc.), which are freed from the bodies of insects and other animals in which they have developed; these often appear in watering troughs and were once widely believed to have generated from horse-hairs fallen in the water. There are larval stages (*Cercaria*) of Cestodes and others, found living in the water for only a brief interval of passage from one host animal to another. There are lesser groups also like the Nemertine worms, sparingly represented in fresh-water; for information concerning these the reader is referred to the larger textbooks of zoology.

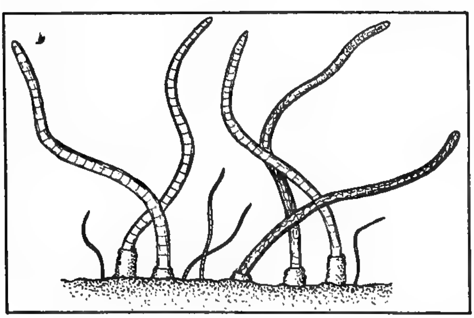

FIG. 83. Tubifex in the bottom mud.

Leeches—The leeches constitute a small group whose members are nearly all found in fresh-water. They occur under stones and logs, in water-weeds or bottom mud, or attached to larger animals. The body is always depressed, and narrowed toward the ends, more abruptly toward the posterior end where a strong sucker is developed. The front end is more tapering and neck-like, and very pliant. There is no distinct head, but at the front is a sort of cerebral nerve ring and there are rudimentary eyes in pairs, and surrounding the mouth is a more or less well-developed anterior sucker. The great pliancy of the muscular body, the presence of the two terminal suckers, and the absence of legs or other appendages determine the leeches mode of locomotion. It ordinarily crawls about by a series of loopings like a "measuring worm," using the suckers like legs for attachment. The more elongate leeches swim readily with gentle undulations of the ribbon-like body. The shorter broader forms hold more constantly with the rear sucker to some solid support, and when detached tend to curl up ventrally like an armadillo.

Leeches range in size from little pale species half an inch long when grown, to to the huge blackish members of the horse-leech group (*Hæmopis*) a foot or more in length. Many of them are beautifully colored with soft green and yellow tints. The much branched alimentary canal, when filled with food, shows through the skin of the more transparent species in a pattern that is highly decorative.

Leeches eat mainly animal food. They are parasites on large animals or foragers on small animals or scavengers on dead animals. Very commonly one finds the parasites attached to the thinner portions of the skins of turtles, frogs, fishes and craw-fishes. There is no group in which the boundary between predatory and parasitic habits is less distinct than in this one; many leeches will make a feast of vertebrate blood, if occasion offers, or in absence of this will swallow a few worms instead.

FIG. 84. A clepsine leech (*Placobdella rugosa*), overturned and showing the brood of young protected beneath the body. (From the senior author's *General Biology*).

The mouth of leeches is adapted for sucking, in some cases it is armed for making punctures, as well: hence the food is either more or less fluid substances like blood or the decomposing bodies of dead animals, or else it consists of the soft bodies of animals small enough to be swallowed whole.

The eggs of leeches are cared for in various ways: commonly one finds certain of them in minute packets, attached to stones. Others (*Hæmopis*, etc.) are stored in larger capsules and hidden amid submerged trash. Others are sheltered beneath the body of the parent, and the young are brooded there for a time after hatching, as shown in the accompanying figure. Nachtrieb (12) states that they are so carried "until the young are able to move about actively and find a host for a meal of blood."

Leeches are doubtless fed upon by many carnivorous animals. They are commonly reported to be taken freely by the trout in Adirondack waters. In Bald Mountain Pond they swim abundantly in the open water.

The Rotifers constitute a large group of minute animals, most characteristic of fresh-water. They abound in all sorts of situations, and present an extraordinary variety of forms and habits. Their habits vary from ranging the open lake to dwelling symbiotically within the tissues of water plants; from sojourning in the cool waters of perennial springs, to running a swift course during the temporary existence of the most transient pools. They even maintain themselves in rain-spouts and stone urns, where they become dessicated with evaporation between times of rain.

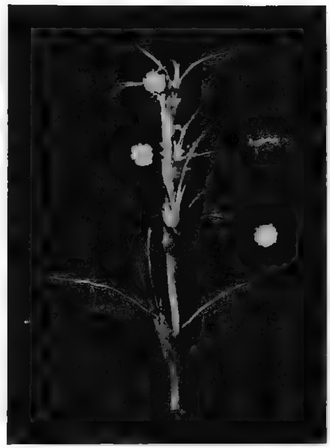

FIG. 85. Three colonies of the rotifer, *Conochilus*, attached to the tips of leaves of the pond-weed, *Nais*.

Rotifers are mainly microscopic, but a few of the larger forms are recognizable with the unaided eye. Often they become so abundant in pools as to give to the water a tinge of their own color. Grouped together in colonies they become rather conspicuous. The spherical colonies of *Conochilus* when attached to leaf-tips, as in the accompanying picture, present a bright and flower-like appearance. Entire colonies often become detached, and then they go bowling along through the water, in a most interesting fashion, the individuals jostling each other as they stand on a common footing, and all merrily waving their crowns of cilia in unison. Often a little roadside pool will be found teeming with the little white rolling spheres, that are quite large enough to be visible to the unaided eye.

Melicerta is a large sessile rotifer that lives attached to the stems of water-plants and when undisturbed protrudes its head from the open end of the tube, and unfolds an enormous four-lobed crown of waving cilia. It is a beautiful creature. Our picture shows the cases of a number of Melicertas, aggregated together in a cluster, one case serving as a support for the others.

FIG. 86. Two clusters of rotifers (*Melicerta*), the upper but little magnified. Only the cases (none of the animals) appear in the photographs.

The crown of cilia about the anterior end of the body is the most characteristic structure possessed by rotifers. It is often circular, and the waving cilia give it an aspect of rotation, whence the group name. It is developed in an extraordinary variety of ways as one may see by consulting in any book on rotifers the figures of such as *Stephanoceros*, *Floscularia*, *Synchæta*, *Trochosphæra* and *Brachionus*.

The cilia are used for driving food toward the mouth that lies in their midst, and for swimming. Most of the forms are free-swimming, and many alternately creep and swim.

Brachionus (fig. 87) shows well the parts commonly found in rotifers. The body is inclosed in a lorica or shell that is toothed in front and angled behind. From its rear protrudes a long wrinkled muscular "foot," with two short "toes" at its tip. This serves for creeping. The lobed crown of cilia occupies the front. Behind the quadrangular black eyespot in the center of the body appears the food communicating apparatus (mastax), below which lie ovaries and alimentary canal. Any or all the external parts may be wanting in certain

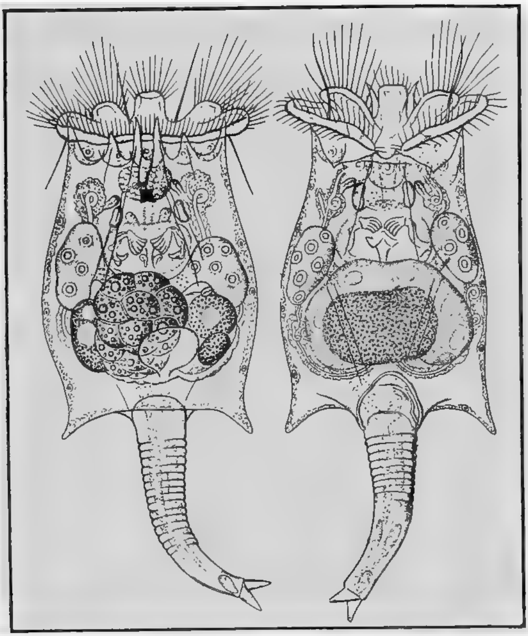

FIG. 87. A rotifer (*Brachionus entzii*) in dorsal and ventral views. (After Francé).

rotifers. The smaller and simpler forms superficially resemble ciliate infusoria, but the complex organization shown by the microscope will at once distinguish them.

Rotifers eat micro-organisms smaller than themselves. They reproduce by means of eggs, often parthenogenetically. The males in all species are smaller than the females and for some species males are not known.

Molluscs—A large part of the population of lake and river beds, shores, and pools is made up of molluscs. They cling, they climb, they burrow, they float—they do everything but swim in the water. They are predominantly herbivorous, and constitute a large proportion of the producing class among aquatic animals. Two great groups of molluscs are common in fresh water, the familiar groups of mussels and snails.

FIG. 88. A living mussel, *Anodonta*, with foot retracted and shell tightly closed. A copious growth of algæ covers the portion of the shell that is exposed above the mud in locomotion: the remainder is buried in oblique position with the foot projecting still more deeply into the mud.

Fresh-water mussels (clams, or bivalves) abound in suitable places, where they push through the mud or sand with their muscular protrusible foot, and drag the shell along in a vertical position leaving a channel-like trail across the bottom. They feed on micro-organisms.

The two commonest sorts of fresh-water mussels are roughly distinguished by size and reproductive habits thus: *Unios* and their allies are large forms that have pearly shells and that live mainly in large streams and lake borders. They produce enormous numbers of young, and use mostly the outer gill for a brood chamber. They cast the young forth while still minute as *glochidia*, to become attached to and temporarily parasitic on fishes. The relations of these larval glochidia with the fishes will be discussed in chapter V.

The lesser mussels (family Sphæridæ) dwell in small streams and pools and in the deeper waters of lakes. Their shells are not pearly. They produce but a few young at a time and carry these until of large size, using the inner gill for a brood-pouch. The stouter species, half an inch long when grown, burrow in stream-beds like the unios. The slenderer species climb up the stems of plants by means of their excessively mobile adhesive and flexible foot. On this foot the dainty white mussel glides like a snail or a flatworm, up or down, wherever it chooses.

Snails are as a rule more in evidence than are mussels, for they come out more in the open. They clamber on plants and over every sort of solid support. They hang suspended from the surface film, or descend therefrom on strings of secreted mucus. They traverse the bottom ooze. We overturn a floating board and find dozens of them clinging to it, and often we find a filmy green mass of floating algæ thickly dotted with their black shells.

They eat mainly the soft tissues of plants, and micro-organisms in the ooze covering plant stems. A ribbon-like rasp (*radula*) within the mouth drawn back and forth across the plant tissue scrapes it and comminutes it for swallowing. Because snails wander constantly and feed superficially without, as a rule, greatly altering the form and appearance of the larger plants on which they feed, their work is little noticed; yet they consume vast quantities of green tissue and dead stems. The commoner pond snails lay their eggs in oblong gelatinous clumps that are outspread upon the surfaces of leaves and other solid supports. Other snails are viviparous.

The two principal groups of fresh-water snails may roughly be distinguished as (1) operculate snails which live mainly upon the bottom in larger bodies of water, and have an operculum closing the aperture of their shell when they retreat inside, and which breathe by

FIG. 89. Two pond snails (*Limnæa palustris*) foraging on a dead stem that is covered with a fine growth of the alga, *Chætophora incrassata.*

means of gills: (2) pulmonate snails, which most abound in vegetation-filled shoals, breathe by means of a simple lung (and come to the surface betimes, to refill it with air) and have no operculum.

The snails we oftenest see are members of three genera of the latter group: *Limnæa*, shown in the accompanying figure, having a shell with a right-hand spiral and a slender point; *Physa*, having a shorter spiral, twisted in the opposite way, and *Planorbis*, shown in fig. 65 on p. 155, having a shell coiled in a flat spiral. *Ancylus* is a related minute limpet-shaped snail, having a widely open shell that is not coiled in a spiral. Its flaring edges attach it closely to the smooth surfaces of plant stems or of stones.

ARTHROPODS

We come now to that great assemblage of animals which bear a chitinous armor on the outside of the body, and, as the name implies, are possessed of jointed feet. This group is numerically dominant in the world today on sea and land. It is roughly divisible into three main parts; crustaceans, spiders and insects. The crustaceans are the most primitive and the most wide-spread in the water-world; so with them we will begin.

The Crustaceans include a host of minute forms, such as the water fleas and their allies, collectively known as *Entomostraca,* and a number of groups of larger forms, such as scuds, shrimps, prawns and crabs, collectively known as the higher Crustacea or *Malacostraca.* A few of the latter (crabs, sow-bugs, etc.) live in part on land, but all the groups are predominately aquatic, and the Entomostraca are almost wholly so.

The Entomostraca are among the most important animals in all fresh waters. They are perhaps the chief means of turning the minute plant life of the waters into food for the higher animals. They are themselves the chief food of nearly all young fishes.

There are three groups of Entomostraca, so common and so important in fresh water, that even in this brief discussion we must distinguish them. They are: *Branchiopods, Ostracods* and *Copepods.*

The Branchiopods, or gill-footed crustaceans, have some portion of the thoracic feet expanded and lamelliform, and adapted to respiratory use. The feet are moved with a rapid shuttle-like vibration which draws the water along and renews the supply of oxygen. The largest of the entomostraca are members of this group; they are very diverse in form.

The fairy shrimp, shown in the accompanying figure, is one of the largest and showiest of Entomostraca. It is an inch and a half long and has all of the tints of the rainbow in its transparent body. It appears in spring in rainwater pools and is notable for its rapid growth and sudden disappearance. It runs its rapid course while the pools are filled with water, and lays its eggs and dies before the time of their drying up. The eggs settle to the bottom and remain dormant, awaiting the return of favorable season. The animal swims gracefully on its back with two long rows of broad, thin, fringed, undulating legs uppermost, and its forked tail streaming out behind, and its rich colors fairly shimmering in the light.

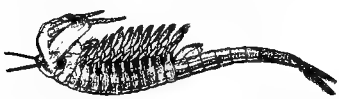

FIG. 90. The Fairy Shrimp, *Chirocephalus* (after Baird).

Of very different appearance is the related mussel-shrimp (*Estheria*), which has its body and its long series of appendages inclosed in a bivalve shell. Swimming through the water, it looks like a minute clam a centimeter long, traveling in some unaccountable fashion; for its legs are all hidden inside, and nothing but the translucent brownish shell is visible. This shell is singularly clam-like in its concentric lines of growth on the surface and its umbones at the top. This, in America, is mainly Western and Southern in its distribution, as is also *Apus*, which has a single dorsal shell or carapace, widely open below and shaped like a horseshoe crab.

These large and aberrant Branchiopods are all very local in distribution and of sporadic occurrence. As the seasons fluctuate, so do they. But they are so unique in form and appearance that when they occur they will hardly escape the notice of the careful observer of water life.

Water-fleas—The most common of the Branchiopods are the water-fleas (order Cladocera) such as are shown in outline in figure 91. These are smaller, more transparent forms, having the body, but not the head, inclosed in a bivalve shell. The shell is thin, and finely reticulate or striated or sculptured, and often armed with conspicuous spines. The post-abdomen is thin and flat, armed with stout claws at its tip and fringed with teeth on its rear margin, and it is moved in and out between the valves of the shell like a knife blade in its handle. The pulsating heart, the circulating blood, the contracting muscles, and the vibrating gill-feet all show through the shell most clearly under a microscope. Hence these forms are very interesting for laboratory study, requiring no preparation other than mounting on a slide.

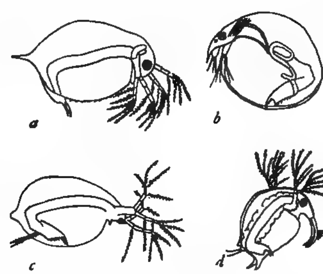

FIG. 91. Water-fleas

a, Daphne; *b*, Chydorus; *c*, Simocephalus; *d*, Bosmina. Note the "proboscis."

Some water-fleas, like *Simocephalus*, shown in figures 91 and 92 swim freely on their backs, in which position gravity may aid them in getting food into their mouths. When the swimming antennæ are developed to great size, as in *Daphne* (fig. 91*a*), the strokes are slow and progress is made through the water in a series of jumps. When the antennæ are shorter, as in *Chydorus* (fig. 91*b*), their strokes are more rapidly repeated, and progression steadier.

The Cladocerans are abundant plancton organisms throughout the summer season. They forage at a little depth by day, and rise nearer to the surface by night.

The food of water-fleas is mainly the lesser green algæ and diatoms. They are among the most important herbivores of the open water. They are themselves important food for fishes.

The importance of water fleas in the economy of water is largely due to their very rapid rate of reproduction. During the summer season broods of eggs suc-

FIG. 92. A water-flea (*Simocephalus vetulus*) in its ordinary swimming position. Note the striated shell, and the alimentary canal, blackish where packed with food-residue in the abdomen.

cessively appear in the chamber enclosed by the shell on the back of the animal (see figure 93) at intervals of only a few days. The young develop rapidly and are themselves soon producing eggs. In *Daphne pulex*, for example, it has been calculated that the possible progeny of a single female might reach the astounding number of 13,000,000,000 in sixty days.

The Ostracods are minute crustaceans, averaging perhaps a millimeter in length, having the head, body and appendages all inclosed in a bivalve shell. The shell is heavier and less transparent than that of the water fleas. It is often sculptured, or marked in broad patterns

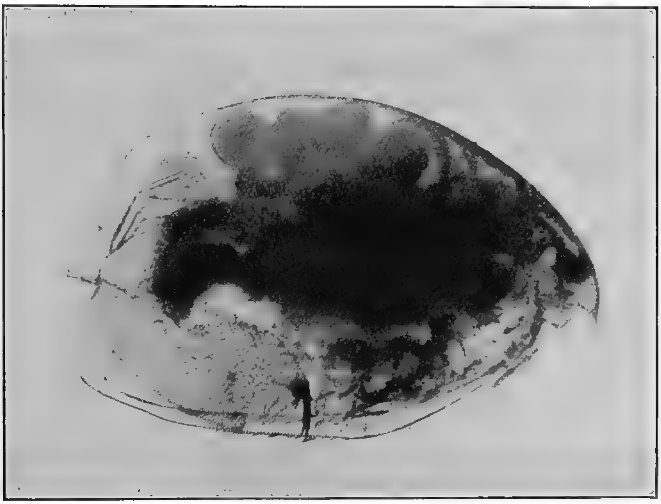

FIG. 93. One of our largest water-fleas, *Eurycerus lamellatus*, twenty times natural size. Note the eggs in the brood chamber on the back. Note also the short beak and the broad post-abdomen (shaped somewhat like a butcher's cleaver) by which this water-flea is readily recognized.

with darker and lighter colors. The inclosed appendages are few and short, hardly more than their tips showing when in active locomotion. There are never more than two pairs of thoracic legs. The identification of ostracods is difficult, since, excepting in the case of strongly marked forms, a dissection of the animal from its shell is first required.

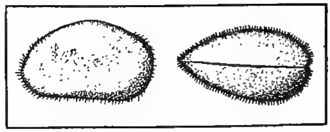

FIG. 94. An Ostracod (*Cypris virens*), lateral and dorsal views, (after Sharpe.)

Some Ostracods are free-swimming (species of *Cypris*, etc.) and some (*Notodromas*) haunt the surface in summer; but most are creeping forms that live among water plants or that burrow in the bottom ooze. In pools where such food as algæ and decaying plants abound Ostracods frequently swarm, and appear as a multitude of moving specks when we look down into the still water.

Relicit pools in a dry summer are likely to be found full of them. Both sexes are constantly present in most species of Ostracods, but a few species are represented by females only, and reproduce by means of unfertilized eggs.

The Copepods are the perennial entomostraca of open water. Summer and winter they are present. Three of the commonest genera are shown in figure 95, together with a nauplius—the larval form in which the members of this group hatch from the egg. Nothing is more familiar in laboratory aquaria than the little white *Cyclops* (fig. 96, swimming with a jerky motion, the female carrying two large sacs of eggs.

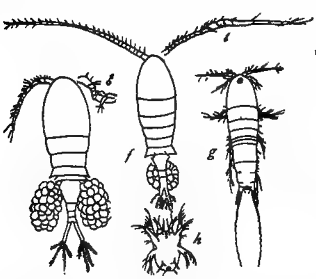

FIG. 95. Common copepods
e, Cyclops; *f*, Diaptomus; *g*, Canthocamptus; *h*, a nauplius (larva) of Cyclops. Figures *e* and *f* show females bearing egg sacs, while the detached antenna at the right shows the form of that appendage in the male.

A more or less pear-shaped body tapering to a bifurcate tail at the rear, a single median eye and a pair of large swimming antennæ at the front, and four pairs of thoracic swimming feet beneath, characterize the members of this group.

The species of *Diaptomus* are remarkable for having usually very long antennæ and often a very lively red color. Sometimes they tinge the water with red, when present in large numbers.

Copepods feed upon animals plancton and algæ, especially diatoms. They are themselves important food for fishes, especially for young fishes.

FIG. 96. A female Cyclops, with eggs.

The higher crustacea, (Malacostraca) are represented in our fresh waters by four distinct groups, all of which agree in having the body composed of twenty segments that are variously fused together on the dorsal side, each, except the last, bearing (at least during development) a pair of appendages. Of these segments five belong to the head, eight to the thorax and the remainder to the abdomen. *Mysis* (fig. 97) is the sole representative of the most primitive of these groups, the order Mysidacea. Its thoracic appendages are all biramous and undifferentiated; and still serve their primal swimming function. Mysis lives in the open waters of our larger lakes, in their cooler depths. It is a delicate transparent creature half an inch long.

The Scuds (order Amphipoda) are flattened laterally, and the body is arched. The thoracic legs are adapted for climbing, and the abdominal appendages for swimming and for jumping. The body is smooth and pale; often greenish in color. The scuds are quick and active. They dart about amid green water-weeds, usually keeping well to shelter, and they swim freely and rapidly when disturbed. The following figure shows the three commonest genera of the eastern United States.

The scuds are herbivores, and they abound among green water plants everywhere. They are of much importance as food for fishes. They are hardy, and capable of maintaining themselves under stress of

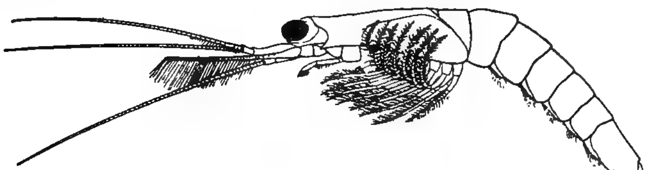

FIG. 97. *Mysis stenolepis*. (After Paulmier).

competition. They carry their young in a pectoral broodpouch until well developed; and altho they are not so prolific as are many other aquatic herbivores, yet they have possibilities of very considerable increase, as is shown by the following figures for *Gammarus fasciatus*, taken from Embody's studies of 1911:

Reproductive season at Ithaca, Apr. 18th to Nov. 3d, includes 199 days.

Average number of eggs laid at a time 22. Egg laying repeated on an average of 11 days.

Age of the youngest egg-laying female 39 days: number of her eggs, 6.

Possible progeny of a single pair 24221 annually.

Asellus is the commonest representative of the order Isopoda; broad, dorsally-flattened crustaceans of somewhat larger size, that live sprawling in the mud of the bottom in trashy pools. Their long legs and hairy bodies are thickly covered with silt. Two pairs of thoracic legs are adapted for grasping and five pairs for walking, and the appendages of the middle abdominal segments are modified to serve for respiration. Asellus feeds on water-cress and on other soft plants, living and dead, are found in the bottom ooze. It reproduces rapidly, and, in spite of cannibal habits when young,

FIG. 98. Three common Amphipods.
A, Gammarus fasciatus; B, Eucrangonyx gracilis; C, Hyalella knickerbockeri. (Photo. by G. E. Embody).

often becomes exceedingly abundant. An adult female of *Asellus communis* produces about sixty eggs at a time and carries them in a broodpouch underneath her broad thorax during their incubation. There is a new brood about every five or six weeks during the early summer season.

Both this order and the preceding have blind representatives that live in unlighted cave waters, and pale half-colored species that live in wells.

The crawfishes are the commonest inland representatives of the order Decapoda. These have the thoracic segments consolidated on the dorsal side to form a hard carapace, and have but five pairs of walking legs (as the group name indicates), the foremost of these bear ing large nipper-feet. This group contains the largest crustacea, including all the edible forms, such as crabs, lobsters, shrimps, and prawns, most of which are marine. Southward in the United States there are fresh-water prawns (*Palæmonetes*) of some importance as fish food.

The eggs of crawfishes are carried during incubation, attached to the swimmerets of the abdomen, and the young are of the form of the adult when hatched. They cling for a time after hatching to the hairs of the swimmerets by means of their little nipper-feet, and are carried about by the mother crawfish.

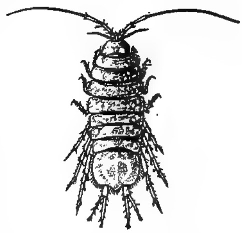

FIG. 99. *Asellus aquaticus*, (x2, after Sars)

Crawfishes are mainly carnivorous, their food being smaller animals, dead or alive, and decomposing flesh. In captivity they are readily fed on scraps of meat. Southward, an omnivorous species is a great depredator in newly planted fields of corn and cotton. Hankinson ('08) reports that the crawfishes "form a very important if not the chief food of black bass, rock bass, and perch" in Walnut Lake, Michigan.

Spiders and *Mites* are nearly all terrestrial. Of the true spiders there are but a few that frequent the water. Such an one is shown in the initial cut on page 158. This spider is conspicuous enough, running on the surface of the water, or descending beneath, enveloped in a film of air that shines like silver; but neither this nor any other true spider is of so great importance in the economy of the water as are many other animals that are far less conspicuous. In habits these do not differ materially from their terrestrial relatives.