Limnological Aspects of Recreational Lakes

U.S. DEPARTMENT OF
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Foreword

Clean lakes are not inalienable gifts of nature. The enrichment of waters in these natural basins often brings about biological excesses that are inimical to recreational and other water uses. The demand for clean, nuisance-free water, ever increasing with more leisure time and the growing population, will exert pressure for development of greater understanding and control of this natural resource for maximum use. These controls involve pollution abatement and water management to minimize nuisances.

This book is written for persons faced with interpreting and managing the biological problems and associated phenomena of recreational lakes.

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Preface

"Limnological Aspects of Recreational Lakes" considers the many problems associated with the recreational use of lakes, reservoirs, and ponds. These standing-water bodies receive the most concentrated and varied recreational use of any waters, and provide enjoyment to the greatest number of people. Lakes, reservoirs, and ponds serve as settling basins and intensify the many problems associated with water and water use. They are the center of many divergent and conflicting interests and desires; competition is increasing for the pursuit of such water sports as fishing, waterfowl hunting, skin diving, skiing, swimming, and high-speed boating.

Accelerating populations with an increased amount of leisure time are placing continuously heavier recreational demands on standing bodies of water suitable for a variety of water sports. Individuals using such areas soon become aware of associated biological problems and often demand remedial measures to alleviate developing nuisances or the prevention of them before they arise. This book is written for the person faced with problems of interpretation and management in dealing with the phenomena of recreational lakes.

Individually, the chapters acquaint the reader with the general problem of aquatic nuisances; review the ecology of lakes, reservoirs, and ponds and present information on biotic production, leading to an understanding of the scope and magnitude of the basic nuisance problems; discuss nutrients and their impact on biological growths; review plant and animal pests affecting recreational water and present simple keys for the identification of some common aquatic plants; discuss the mechanics of establishing a sampling program for a lake, reservoir, or pond to determine the present state of biological growths and possibly predict future trends; and present information leading to the control or alleviation of excessive production of biological nuisances.

General recommendations for control will not fit all specific nuisance problems. In most States, a permit or permission must be obtained from an appropriate agency prior to the institution of controls. When controls are instituted, the recommended controlling agent and its field application must be tempered with a scientist's astute knowledge of both the problem and the ecological ramifications of a control program.

The Authors.

CINCINNATI, OHIO,
January 1, 1964.

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Plates were obtained from the following sources: 1. Lake Geneva Civic Association, Walworth, Wis.; 2. Wisconsin Conservation Department; 3. California Department of Fish and Game; 6 to 9. Palmer, C. M., Algae in Water Supplies (1959); 10 to 35. Martin and Uhler, Food of Game Ducks in the United States and Canada (1939); 36. Ross, H. H., The Mosquitoes of Illinois (1947); 37. Moore, J. P., The Control of Blood-Sucking Leeches of Palisades Interstate Park (1923); 40 and 41. Michigan Water Resources Commission; 47, Aquatic Controls Corporation, Hartland, Wis.; 49. Northwest Weed Service, Tacoma, Wash.; 50. Applied Biochemists, Butler, Wis.; 51. Wisconsin Committee on Water Pollution; 52. Dr. John E. Gallagher, Amchem Products, Ambler, Pa.

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*Formerly with the U.S. Department of Agriculture.

CHAPTER I

Statement of the Problem

Next to prayer, fishing is the most personal relationship of man.

—HERBERT HOOVER.

Investigation and study of standing waters require a knowledge and an understanding of the mutual relations between organisms and their environment. The production of specific types of aquatic life must be considered. Overproduction, or too much of any one thing, does not serve man's best interests. It often results in the development of aquatic nuisances that, in turn, impair or curtail legitimate water uses. Overproduction has often been correlated with overenrichment (fertilization by nutrients) resulting in eutrophication or aging of water. Eutrophication most often results from man-induced nutrients that enter the water body and eventually become a part of the cycle of events that are basic to plant and animal growths.

Investigation necessitates a program of sampling to determine a base for future observations and management. Sampling often entails a comprehensive study followed by periodic monitoring to keep abreast of changes taking place within the water body. Sampling is a broad term, and no approach can be itemized to meet all needs; a sampling program must be tailored to the particular problem.

The control of excessive production is of prime importance to those who use the water for recreation. Once biological nuisances develop, controls are indicated. Controls are often costly, time consuming, and usually temporary. Overproduction is likely to remain a curse unless basic causes can be reduced or eliminated. And the problem of altering basic causes has not been fully solved at the present time. The high cost of control logically should be borne by the water user in much the same manner as a property owner bears the cost of keeping his backyard presentable and usable.

According to the Outdoor Recreation Resources Review Committee, 41 percent of this country's population prefers water-based recreation over any other. Swimming is now one of the most popular outdoor activities, and boating and fishing rank among the top 10. During the past 9 years, the number of residential swimming pools has increased 4,800 percent. Camping, picknicking, and hiking are more attractive near water. A national survey of fishing indicates that one household in every three has one or more fishermen; it is a $3 billion annual business.[1] Water skiing has a following of over 6 million persons. Enthusiasts of the relatively new sport of skin diving spent more than $15 million for equipment in 1959.

Recreational use of the 24 Tennessee Valley Authority (TVA) lakes, estimated for the calendar year 1962, as well as the average annual increase over the past 16 years, is shown in table 1 (Churchill, 1963). Guntersville Reservoir ranks first in number of person-day visits for recreational purposes with a total of 10,647,500; its total number of boats in 1962 was 11,239. The average annual increase in recreational use in the TVA Reservoirs attests to the increasingly great multiple-use demands placed upon waters of suitable quality for various recreational pursuits.

Table 1. Recreational Use of 24 TVA Lakes

	1962	Average annual increase since 1947
Number of inboard recreation boats	3,035	118
Number of all other recreation boats	48,859	2,701
Total value of boats	$42,356,655	$2,466,467
Number of privately owned summer cottages	9,222	576
Number of person-day visits to reservoirs for recreational purposes	44,963,181	2,508,295

A recent survey of boating in Wisconsin [2] indicated more than 200,000 pleasure boats were licensed by the State of Wisconsin. Approximately 130,000 were registered by individual residents of the State, 20,000 by nonresidents, and 50,000 by boat livery operators. Ninety-three percent of all registered boats were outboards. The average boater uses approximately 80 gallons of gasoline annually and boats an average of 32.5 days per year.

The need for recreation and the demands for fulfillment of this urge will continue to increase as population pressures become greater. Keeping the water safe and usable for these many purposes is one of the objectives of the Public Health Service program in Water Supply and Pollution Control.

[1] National Survey of Fishing and Hunting. U.S. Dept. of the Interior, Bureau of Sport Fisheries and Wildlife, Circular 120, 73 pp. (1960).

[2] Pleasure Boating in Wisconsin. Department of Resource Development, State Capitol, Madison, Wisconsin, 17 pp. (1962).

The single purpose use of water may seriously conflict with other desired uses, affecting either the quality or quantity requirements of those uses. Reservoirs for flood control, for instance, lose their effectiveness unless the water held back during floodflow is released as soon thereafter as possible to reestablish storage capacity for subsequent flood waters. Theoretically, this detracts from the efficient use of such waters for hydroelectric power generation, or for longtime storage for subsequent release for irrigation and flow augmentation during periods of low streamflow.

Hydroelectric power for peaking purposes, which may be the most efficient use of this power source, often results in intermittent storage and release of the entire streamflow. This can conflict with downstream and upstream use of a stream for fish and wildlife propagation, water supply, and waste disposal.

Diversion of stream flows for irrigation can likewise interfere with other water needs downstream. Deep reservoirs often produce stratification that results in oxygen depletion in the bottom waters. The water released is frequently from the lower depths and lacks the dissolved

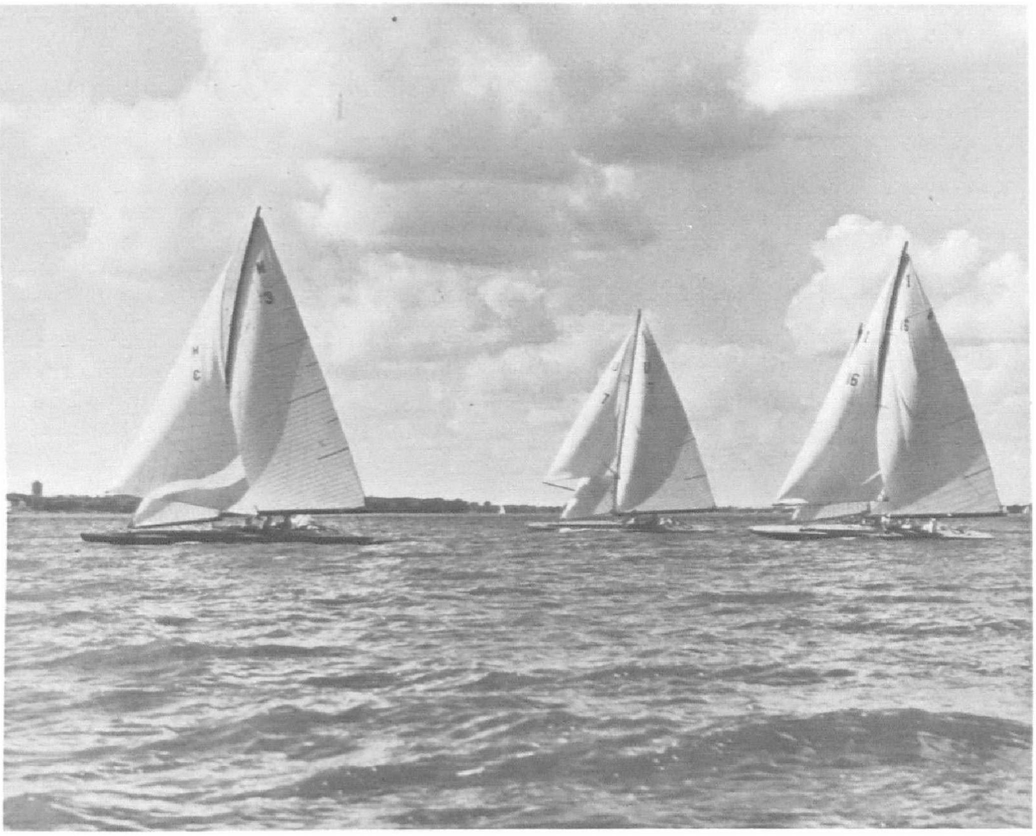

Plate 1. Pleasing recreation on Lake Geneva, Wisconsin—a lake with few biological nuisances.

oxygen essential to support fish life or to oxidize organic wastes in a reach of the stream below the impoundment.

The use of a stream for municipal and industrial waste disposal, and agricultural return flows, may conflict with almost all other uses. The best treatment methods available cannot effect 100 percent removal of all constituents contributed by munipical and industrial wastes. Residual nutrients such as nitrogen and phosphorus stimulate aquatic plant growths to the detriment of recreation, water supply, and other uses.

These examples of conflicts in use clearly demonstrate the close interrelation of water quality and quantity. As water quantity and quality become critical, increased demands can be met only by multiple-purpose use and reuse of the water resource. This requires effective control and abatement of pollution and the incorporation of essential quality control measures in all future water resources planning.

In addition to those pollutants associated with the activities of man, there are natural sources of water pollution. Water, the universal solvent, takes into solution some part of the many things it contacts.

Plate 2. Swimming is an increasingly popular outdoor recreational activity.

As it percolates through the earth's crust, it dissolves minerals in concentrations that may make the water unsuitable for many uses. Salt springs, oilfield brines, and acid mine drainage are examples of this phenomenon. The physical force of flowing water can add undesirable constituents such as silt eroded from open cuts, from hill sides, fields, and streambanks, which is carried along with the surface runoff to be deposited in stream beds and flood water reservoirs. Drainage from land, as well as natural runoff, may carry residuals of pesticides and chemical fertilizers used in agriculture.

Federal water-resources planning has been developing over the past half century. President Theodore Roosevelt first conceived multiple usage of water in 1906, stating: "Every stream should be used to its utmost. No stream can be so used unless such use is planned for in advance." Until the enactment of the Water Pollution Control Act of 1948, the Federal role in water pollution was defined in three acts—the Rivers and Harbors Act of 1899, the Public Health Service Act of 1912, and the Oil Pollution Act of 1924.[3] A section of the Rivers and Harbors Act of 1899 prohibited the discharge or deposit into any navigable waters of any refuse matter except that which flowed in a liquid state from streets and sewers. This provision, designed primarily to prevent impediments to navigation, constituted the first specific Federal water pollution control legislation. The Public Health Service Act of 1912 contained provisions authorizing investigations of water pollution related to the diseases and impairments of man. The Oil Pollution Act of 1924 was enacted to control oil discharges in coastal waters that might be damaging to aquatic life, harbors and docks, and recreational facilities.

In the early 1930's, the National Resources Commission approached the water resource problem on a watershed, multiple-use basis. Multiple-use planning is the key to our current development program.

In 1948, the first Federal Water Pollution Control Act was passed as Public Law 845, 80th Congress. It provides for water pollution control activities in the Public Health Service of the then Federal Security Agency and in the Federal Works Agency. Section 2 of this Act stated: "In the development of such comprehensive programs due regard shall be given to the improvements which are necessary to conserve such waters for public water supply, propagation of fish and aquatic life, recreational purposes, and agriculture, industrial, and other legitimate uses." Comprehensive water pollution control legislation was finally enacted by the 84th Congress, which passed the Federal Water

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[3] A Study of Pollution—Water. A Staff Report to the Committee on Public Works, U.S. Senate. Pat McNamara, Chairman. U.S. Government Printing Office, Washington, D.C., 100 pp. (1963).

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Pollution Control Act, Public Law 660, on July 9, 1956. The 1956 Act extended and strengthened the 1948 Act, which expired on June 30, 1956, and was administered by the Surgeon General of the Public Health Service under the supervision and direction of the Secretary of Health, Education, and Welfare. Further amendments to the Federal Water Pollution Control Act were signed into law on July 20, 1961, as Public Law 87–88, 87th Congress. The 1961 amendments improved and strengthened the Act by extending federal authority to enforce abatement of pollution in intrastate, as well as interstate or navigable waters.

A definition of comprehensive planning is contained in one of the recommendations of the National Conference on Water Pollution held in Washington, D.C., December 12 to 14, 1960, which states:

> "Planning for the comprehensive development of each major basin or water resource area should be established as a fixed national policy. By comprehensive development we mean the application of integrated multiple-purpose design, planning and management which include the joint consideration of ground and surface waters, systematic conservation by water users, and the treatment and management of waters having substandard quality. Consideration of every appropriate technique would be a routine part of planning for such development.
>
> "Such planning, insofar as feasible, should include consideration of all important industrial plant sites. An early and important objective should be a systematic program of flow regulation. State initiative toward comprehensive planning should be encouraged, and participation by all major interests should be encouraged. The objective should be one of eventually producing maximum total benefits from all economic and social uses."

Associated with the municipal and industrial wastes resulting from the activities of man are pathogenic organisms including bacteria, viruses, leeches, worms, and other parasites that affect the use of these waters for recreational pursuits. On the other hand, swimming, boating, and other related recreational activities, as well as commercial boating and fishing, may in themselves cause pollution by contributing organic wastes, pathogens, inorganic wastes, toxic substances from motor exhausts, and just plain trash.

Water oriented recreation contributes to man's well-being and good health. A report on water pollution in the Missouri River Basin states, "Of probably greater value is the relaxation and mental well-being achieved by viewing and absorbing the scenic grandeur of the great and restless Missouri. Many people crowd the 'highline' drives along the bluffs to view this mighty river to achieve a certain restfulness from the proximity of nature."

Porterfield (1952) lists the following effects from severe water pollution: (1) transmission of enteric diseases by water inadequately treated, (2) transmission of diseases by insects from polluted streams, (3) harmful reduction of individual water intake because of water potability, (4) possible toxicity of chemical and metallic wastes, (5) neuroses caused by noxious odors from polluted streams, (6) spread of diseases by cattle and other animals having access to polluted streams, (7) loss of extensive recreational areas, and (8) economic changes.

The Secretary of Health, Education, and Welfare has the re-

Plate 3. A recreational pursuit enjoyed by millions.

sponsibility of supporting the States in preventing and controlling water pollution. He is charged with the development of comprehensive programs for the elimination or the reduction of pollution of interstate waters and tributaries thereof. Considered among other uses are the propagation of fish and other aquatic life and wildlife, and the use of the water for recreational purposes. As the agency designated by the Secretary to administer the Water Pollution Control Act, the Public Health Service has an overall, direct, vital, and continuing concern in water; it is expected that this interest will lead toward the maintenance of our water resources for maximum benefit.

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CHAPTER II

The Environment of Lakes, Reservoirs, and Ponds

"A lake is a landscape's most beautiful and expressive feature; it is earth's eye on looking into which the beholder measures the depth of his own nature."

—THOREAU, "WALDEN," 1854.

The aquatic environment of a standing body of water is a complex focal point for the interaction of many physical, chemical, and biological forces often influenced by meteorological phenomena. To achieve an understanding of the water environment and to project future trends, a comprehensive knowledge of these forces is essential.

Water is a heavy substance, weighing 62.4 lb. per cubic foot, or 8.345 lb. for each gallon at 4° C (39.2° F). It is approximately 0.2 lb. per cubic foot lighter at 80° F than at 40° F. At a depth of 100 ft. the water pressure is 58 lb. per square inch, or approximately four times the pressure at the surface. Pure water reaches its maximum density at 39.2° F (4° C); it becomes lighter as it cools or warms.

TEMPERATURE

Early in the science of limnology, Birge (1904, 1907a and 1907b) and others recognized that physical factors are interrelated in the overall ecology of a body of water. The seasons induce a cycle of physical and chemical changes in the water that are often conditioned by temperature. For a few weeks in the spring, water temperatures may be homogeneous from the top of a water body to the bottom. Vertical water density is also homogeneous, and it becomes possible for the wind to mix the water in a lake, distributing nutrients and flocculent bottom solids from the deeper waters. Oxygen is mixed throughout the water during this time. The advance of summer quickly checks circulation by warming the surface waters; as they warm they become lighter, resting over colder water of greater density. Thus a permanent thermal stratification is formed. In natural deep bodies of water three layers eventually form. The upper layer, or epilimnion, represents the warm, more or less freely circulating region of approximately uniform temperature, and may vary in thickness from 10 feet or less in shallow lakes to 40 feet or more in deeper ones. The middle layer, or thermocline, is the region of rapid change usually defined by a change in temperature of 1.8° F for each 3.28 feet variance in depth. The lower layer, or hypolimnion, is the cold region of approximately uniform temperature. It is cut off from circulation with upper waters and does not receive oxygen from the atmosphere during stratification.

As autumn comes the standing body of water cools; the epilimnion increases in thickness until the lake becomes homothermous, and again a period of complete circulation begins. This occurs from late September to December, depending upon the area and depth of the lake and its geographic and climatic location. It lasts until changes in density reestablish stratification, or until the lake is frozen over. This commonly occurs from November to January, varying with lake and season and geographic location. Circulation then ceases until spring.

During the greater part of the year, free circulation of water and exchange of gases with those in the atmosphere are restricted. The lake is saturated, or nearly so, with atmospheric gases in the fall and in the early spring. As soon as thermal stratification occurs and until the overturn, only the water of the epilimnion has direct contact with the air.

Thermal stratification in reservoirs may assume many patterns depending on geographical location, climatological conditions, depth, surface area, and type of dam structure, its penstock locations, and its power use. Reservoirs or impoundments have been separated into two basic types: main stream and storage (Kittrell, 1959).

The main stream ("run-of-the-river") reservoir is typically an impoundment formed by a relatively low dam that rarely exceeds 60 to 80 feet in height. Much of the impounded water is restricted to the original channel, and water retention ranges from a few days to a few weeks. Man-regulated fluctuations in surface levels usually are controlled within a range of 2 to 3 feet. Main stream impoundments are used principally for navigation and for power production. Thermal stratification often consists of a small but fairly regular gradient of 5° to 10° F from top to bottom during summer. This gradient is most likely to occur in a reservoir with limited surface area where wind action is moderate and velocities are low. Temporary thermoclines have been recorded where the temperature gradient is steep through a rather narrow band of water.

Another form of thermal stratification in main stream reservoirs involves the inflow of a stream of water that is colder than the normal surface water. Since the penstock intake (discharge) may extend from

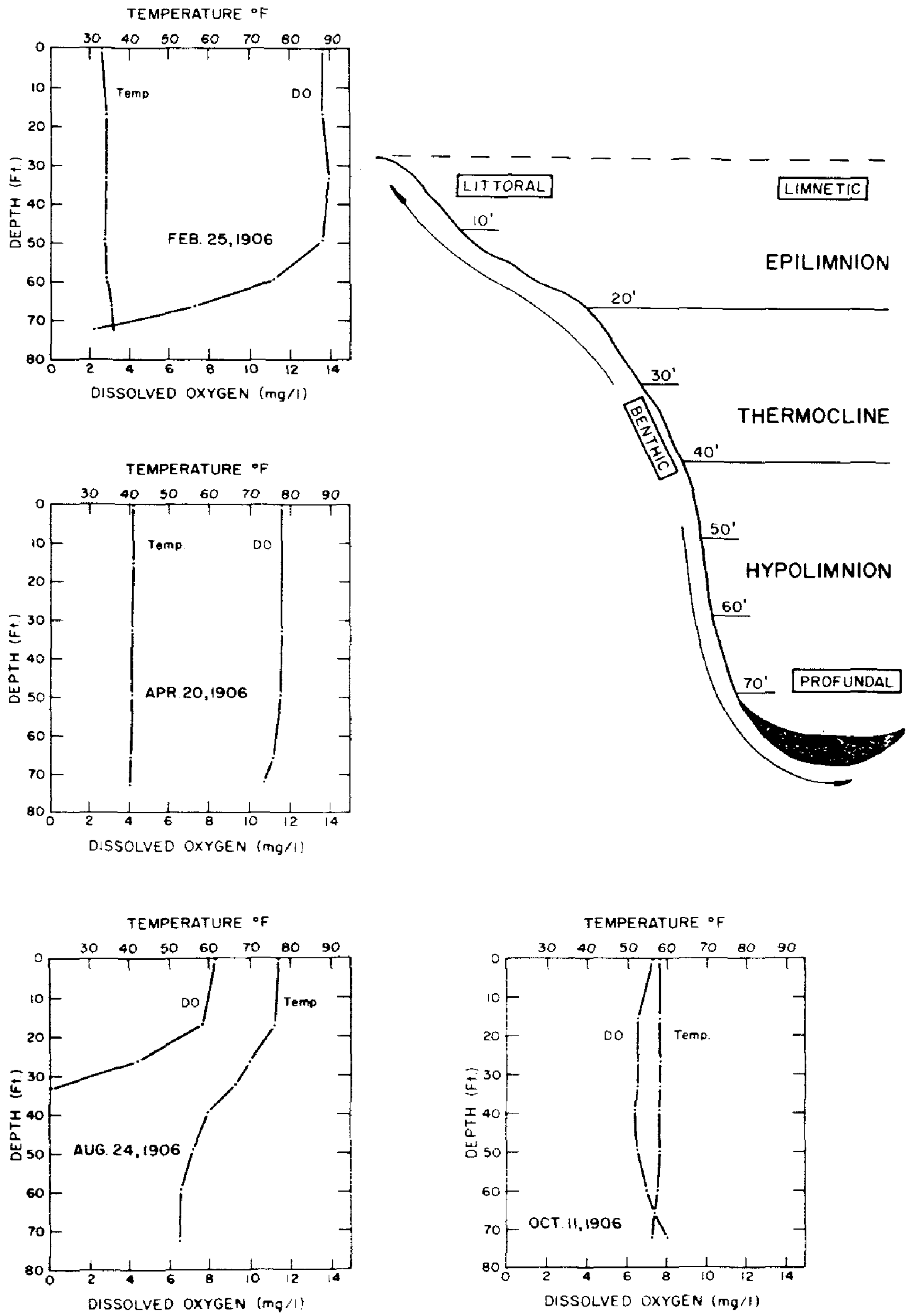

Figure 1. Diagrammatic sketch showing lake zones with seasonal temperature and dissolved oxygen changes observed in Lake Mendota, Wis. (from Birge and Juday, 1911).

near the bottom to within 15 to 20 feet of the water surface, the cold stream of water flows through the impoundment, creating a thermocline below the water surface at the dam and extending upstream parallel to the bottom of the reservoir.

The storage reservoir, as its name implies, is used to impound water when surface runoff is high (i.e. flood flows) for release when runoff is low. As a result the surface water level varies over a wide range, sometimes 70 feet or more during the year, and is generally highest at or near the end of a rainy season and lowest just before the next rainy season. The drawdown of the reservoir requires that the discharge intake be located deep in the reservoir, below the minimum level to which the water will be drawn.

The storage reservoir is often located at the headwaters of a stream that frequently has a steep slope. The dam is high, often more than 100 feet. The stored water spreads far beyond the former river channel into numerous fingers or embayments to provide a large surface area. Vertical cross sections of the reservoir are large in relation to stream flow, and flow velocities are negligible. Water may be retained in the reservoir for many months. Passage of water through the reservoir may be discontinuous, and significant portions of the water may remain in storage for nearly a year.

Most storage reservoirs exhibit the classical type of thermal stratification described for natural deepwater bodies. Reservoirs that do not store substantial volumes of water at winter temperatures or that discharge such water before warm weather occurs do not develop thermoclines; neither do shallow reservoirs with broad expanses of surface areas exposed to strong winds that mix the waters. In the southern portion of the country where surface water temperatures rarely drop below 4° C, there is no stratification in winter and temperatures are nearly uniform throughout the impoundment.

Density currents have been defined at the gravity flow of a fluid within a medium of the same phase. They are caused by differences in temperature; differences in the concentration of electrolytes, especially carbonates; and differences in the silt content. A reservoir that is relatively deep, long, and narrow favors the development of density currents (Wiebe, 1939a, 1939b and 1941). The waters of Norris Reservoir, Tenn., contain four well-defined horizontal zones with respect to dissolved oxygen during thermal stratification. These include a well-aerated surface stratum, a zone of stagnant water within the thermocline, a second stratum of water rich in dissolved oxygen below the thermocline, and a bottom layer of stagnant water. In some instances, density currents have been detected from 60 to 80 feet below the surface. Density currents affect the fish population since game fish orient themselves both to the stratum of stagnant water caused by density currents and to the temperature range that suits them best. Often they become trapped by a lack of oxygen within this zone.

The gradual expansion in depth of any temperature zone is largely the result of water withdrawal from the storage reservoir. As the cold water is removed from a deep penstock at the dam, and the water level drops, the warmer surface water moves downward into the reservoir, increasing the depth of the epilimnion and decreasing the depth of the hypolimnion.

The distribution of fish is greatly influenced by water temperature. Results of TVA netting studies (Eschmeyer, 1950) show that a species with preference for water temperatures of 70° to 80° F would be near the surface in late April and May. By early September, it would be 40 to 60 feet deep. By late October, when water temperatures are uniform at nearly all depths, fish such as bass might be found anywhere between the surface and a depth of 60 or 70 feet.

LIGHT

Rooted, suspended, and floating aquatic plants require light for photosynthesis. Light penetration into waters is exceedingly variable in different lakes. Clarke (1939) pointed out that the diminution of the intensity of light in its passage through water follows a definite mathematical formula. The relationship between the depth of water and the amount of light penetrating to that depth can be plotted as a straight line on semilogarithmic paper. Even the clearest waters impede the passage of light to some extent; light passed through 100 meters of distilled water is reduced to 1 or 2 percent of its incident value.

The principal factors affecting the depth of light penetration in natural waters include suspended microscopic plants and animals, suspended mineral particles such as mineral silt, stains that impart a color, and detergent foams, or a combination of these. The region in which light intensity is adequate for photosynthesis is often referred to as the tropogenic zone, the layer that encompasses 99 percent of the incident light. The depth of the tropogenic zone may vary from 5 to 90 feet.

The length of daylight in water varies inversely with the depth of the water. The seasonal variation in the intensity of solar radiation influences the potential rate of photosynthesis. In winter the presence of ice with an over layer of snow further limits the amount of relatively poor incident light energy that reaches the water. The work of Birge, reported by Neess and Bunge (1957), indicates that the absorptive quality of clear ice is very similar to that of water, although the addition of air

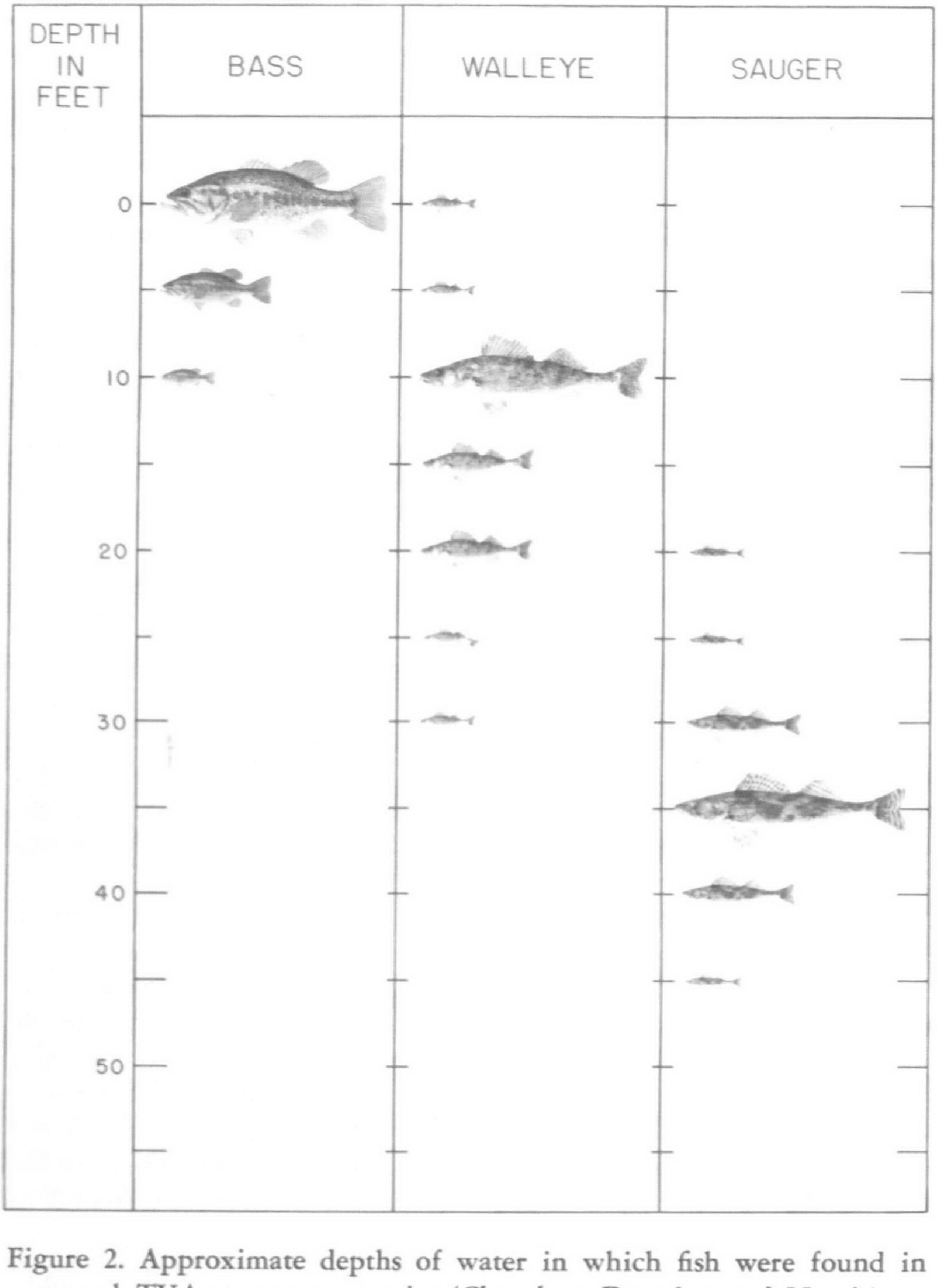

Figure 2. Approximate depths of water in which fish were found in several TVA storage reservoirs (Cherokee, Douglas, and Norris) on June 2, 1946. The figure refers to abundance of fish at that level, not to the size of the fish. Most largemouth bass were near the surface; walleye tended to be 10 feet or more deep; most sauger were over 30 feet deep (from Eschmeyer, 1950).

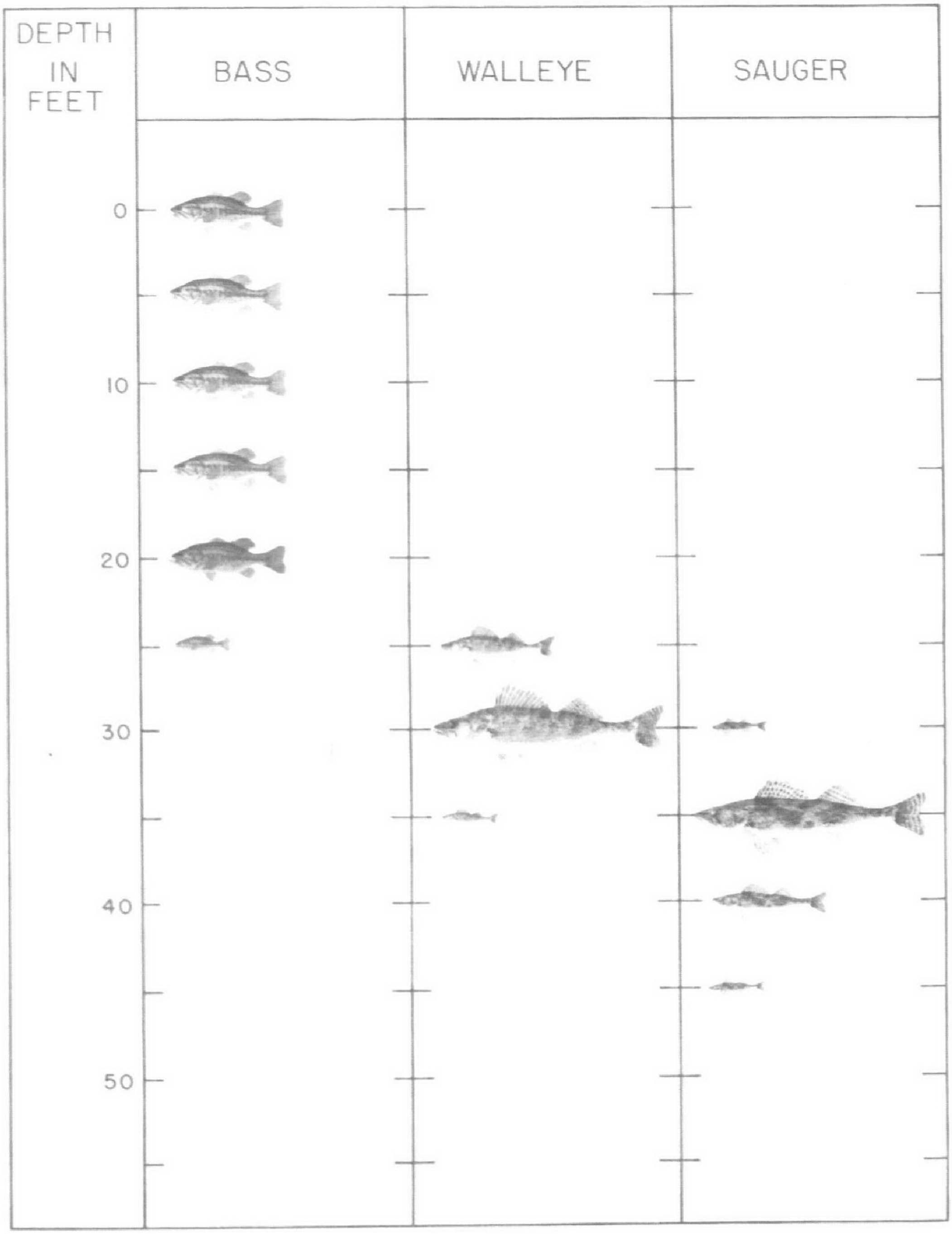

Figure 3. Approximate depths at which fish were distributed in Norris Reservoir, Tenn., in late July, 1946. Note the distribution differs from that of June 2 (fig. 2). Some bass were still near the surface, but the species was spread about evenly from the top to 20 feet or more in depth. Most walleye and sauger were in deeper water (from Eschmeyer, 1950).

bubbles or particulate matter reduces the transmission of light. Snow further reduces light penetration through ice. Greenbank (1945) found 84 percent light transmission through 7½ inches of very clear ice, and 22 percent transmission through 7½ inches of very cloudy ice. A 1-inch snow cover permitted only 7 percent light transmission through the ice and snow; 2 inches of snow permitted only 1 percent light transmission. Bartsch and Allum (1957), studying sewage stabilization ponds, found that in the absence of snow 20 to 55 percent of the incident light passed through 10 to 12 inches of ice, whereas, with a 1- to 3-inch snow cover 93 to 99 percent of the incident light was absorbed by ice and snow, when the ice was 1 to 2 feet thick. Mackenthun and McNabb (1961) found less than 1 percent of light passed through 16 inches of ice covered by 2 inches of snow.

DISSOLVED OXYGEN

Interrelated with temperature and light, living and decaying organisms, and decomposable man-produced wastes, is the dissolved oxygen in the water. Oxygen enters the water by absorption directly from the atmosphere or by plant photosynthesis. That derived from the atmosphere may be by direct diffusion or by surface water agitation by wind and waves. In referring to the ineffectiveness of diffusion as a factor in the distribution of oxygen in a lake, Birge and Juday (1911) cite Hüffner.[4] "According to his [Hüffner] calculations, if the Bodensee which is 250 meters deep should lose its supply of dissolved oxygen, and should then acquire a new supply from the air by diffusion alone, it would require over a million years for the entire body of water to become saturated with this gas."

In photosynthesis, aquatic plants utilize carbon dioxide and liberate a corresponding amount of oxygen. Since energy is required in the form of light, photosynthesis is limited to that depth of water having adequate light. According to Dice (1952), ". . . the ultimate limit of productivity of a given ecosystem is governed by the total effective solar energy falling annually on the area, by the efficiency with which the plants in the ecosystem are able to transform this energy into organic compounds, and by those physical factors of the environment which affect the rate of photosynthesis." Verduin (1956) summarized the literature on primary production in lakes and, based on computations of photosynthetic oxygen production, found that the yields of several lakes were mostly between 42 and 57 pounds of oxygen per acre per day. A

[4] Arch. für Anat. und Physiol. (Physiol. Abteil.) 1897, p. 112.

year-round study under completely natural conditions in western Lake Erie showed winter yields of about 11 pounds of oxygen production per acre per day, and summer maxima of about 85 pounds per acre per day. The annual oxygen production curve closely followed the solar radiation curve. The net oxygen production rate for East Okoboji Lake in Iowa, a producer of large plankton populations, was 79 lbs. per acre per day, with production largely confined to the first 2 meters (Weber, 1958). Whipple et al. (1948) noted that supersaturation in the upper waters is not cumulative to a great extent because circulation is maintained by wind action and convection currents both of which promote contact of the water and the air with a consequent loss of oxygen. Higher saturation is frequently found in the upper region of the thermocline in infertile oligothropic lakes. Wind action seldom disturbs the water of this zone, convection currents are absent, and diffusion is a slow process. Plants find an abundant supply of carbon dioxide and sufficient light in this area to stimulate photosynthesis, resulting in supersaturation values that may exceed 300 percent.

During respiration and decomposition, animals and plants consume oxygen and liberate carbon dioxide at all depths where they occur. Because excreted and secreted products and dead animals and plants sink, most of the decomposition takes place in the hypolimnion; thus, during lake stratification there is a gradual decrease of dissolved oxygen in this zone. After the oxygen is depleted, anaerobic decomposition continues with evolution of carbon dioxide, methane, and hydrogen sulfide.

In the epilimnion, during thermal stratification, dissolved oxygen is usually abundant and is supplied by atmospheric aeration and photosynthesis. Phytoplankton are plentiful in fertile lakes and are responsible for most of the photosynthetic oxygen. The thermocline is a transition zone from the standpoint of dissolved oxygen as well as temperature. The water rapidly cools in this region, incident light is much reduced, and photosynthesis is usually decreased; if sufficient oxygen is present, some cold water fish abound. As dead organisms that sink into the hypolimnion decompose, oxygen is utilized; consequently, the hypolimnion in fertile lakes may become devoid of oxygen following a spring overturn, and this zone may be unavailable to fish and most benthic invertebrates at this time. During the two brief periods in spring and fall when lake water circulates, temperature and dissolved oxygen are the same from top to bottom and fish can use the entire water depth.

OTHER CHEMICAL FACTORS

Whipple et al. (1948) stated that hard-water lakes in which the bicarbonate content is high contain a store of carbon dioxide not found in soft water, although the amount of free carbon dioxide present in the upper water may or may not be greater than in soft water. Bicarbonates may indirectly furnish a large amount of carbon dioxide for plant growth. This is taken from the air when bicarbonates have been largely changed to normal carbonates, for water containing much normal carbonate will absorb carbon dioxide more rapidly than water containing little or none.

Neel et al. (1961), in studying raw-sewage stabilization ponds, found that pH values above 8.0 are produced by a photosynthetic rate that demands more carbon dioxide than the quantities furnished by respiration and decomposition; pH levels below 8.0 indicate failure of photosynthesis to utilize completely the amounts of carbon dioxide so produced. Also, photosynthesis decreases alkalinity by producing weakly soluble calcium carbonate that tends to precipitate; decomposition and respiration increase alkalinity by bringing lost normal carbonate back into solution as calcium bicarbonate. Fish are most commonly found in water with a pH range from about 5 to 9. "Much more extreme pH values, perhaps below 4.0 and well above 10.0, also can be tolerated indefinitely by resistant species. However, regardless of the nature of acid or alkaline wastes responsible, such extreme conditions, associated with industrial pollution, are evidently undesirable and hazardous for fish life in waters which are not naturally so acid or alkaline" (Doudoroff and Katz, 1950).

A total alkalinity of 40.0 mg/l seems to be a natural separation point between soft and hard waters (Moyle, 1949a). Moyle classified fish and plant productivity of natural lakes in Minnesota on the basis of total alkalinity as measured to the methyl orange endpoint at approximately pH 4.0. Lakes with a total methyl orange alkalinity below 20 mg/l were low in fish and plant productivity; between 20 and 40 mg/l productivity was low to medium; between 40 and 90 mg/1 productivity of both fish and plants was medium to high; and above 90 mg/l productivity was high.

ALGAE

Following the spring overturn and throughout the warm summer period, algal populations often play a deciding role in the recreational use of fertile waters. They develop in open water as well as in shallow, warm, shoreline bays and, if conditions are suitable, spread to the remainder of the lake. Algal masses are moved by wind and waves, and thus often create localized nuisances that may be acute. Algal populations are influenced by climate; they tend to rise to the surface during hot, humid days and disperse to greater depths during rain storms or turbulent water conditions. Several successive dark or cloudy days may be sufficient to kill a portion of a dense population, and subsequent decomposition may bring about localized dissolved oxygen depletion that may result in fish kills from suffocation.

It is difficult to estimate the standing plankton crop of a particular body of water because of the diverse horizontal and vertical dispersion of the organisms and the fact that they are transported by water movement. Birge and Juday (1922) found that the largest crop of spring plankton in Lake Mendota, Wis., was approximately 360 pounds per acre on a dry weight basis (10 percent dry matter), and the largest crop of autumn plankton, 324 pounds per acre. The summer and winter minimums were 124 and 98 pounds per acre, respectively. Bluegreen algae are approximately 6.8 percent nitrogen and 0.69 percent phosphorus on a dry weight basis (Gerloff and Skoog, 1954). Thus a plankton population of these proportions could theoretically tie up about 15 pounds of nitrogen and 1.5 pounds of phosphorus per acre. Neil (1958) found that 1 ton or more per acre of the green filamentous alga, *Cladophora*, was produced on a suitable substrate. When the filaments of this alga are washed ashore and decompose in the shallow water, a typical pigpen odor is produced.

SUBMERGED AQUATIC PLANTS

Studies of the standing crop of submerged aquatic plants in Lake Mendota and Green Lake, Wis. (Rickett, 1922, 1924), indicate a wet weight of 14,000 pounds per acre and a dry weight of 1,800 pounds per acre. In Lake Mendota the 0- to 1-meter zone contained 1,600 pounds per acre of submerged plants on a dry weight basis; the 1- to 3-meter zone, 2,400 pounds; and the 3- to 7-meter zone, 1,300 pounds. In Green Lake the 0- to 1-meter zone contained 600 pounds per acre of submerged vegetation on a dry weight basis; the 1- to 3-meter zone, 1,960 pounds; and all deeper areas to the lower limit of plant growth, 1,580 pounds per acre. Low and Bellrose (1944) found similar productions in the Illinois River Valley. Coontail growths approached 2,500 pounds per acre (dry weight); sago pondweed, 1,700 pounds per acre; and duckweed, 244 pounds per acre. They found that the seed production of wild rice approached 32 bushels per acre; of pondweed, *Potamogeton americanus* Chamisso and Schlechtendal, 20 bushels per acre; of sago pondweed, 1.5 bushels per acre; and of coontail, 0.8 bushel per acre. Harper and Daniel (1939) found that submerged weeds were 12 percent dry matter and contained an average of 1.8 percent total nitrogen (dry weight) and 0.18 percent total phosphorus. Schuette and Hoffman (1922) and Schuette and Alder (1928, 1929) found similar results, except that some species such as water milfoil (*Myriophyllum*) may run as high as 3 percent nitrogen and 1.1 percent total phosphorus on a dry weight basis. Thus, a normal population of submerged aquatic plants could contain and liberate on decomposition 32 pounds per acre of nitrogen and approximately one-tenth as much of phosphorus.

BOTTOM FAUNA AND SUBMERGED AQUATIC PLANTS

Investigations show that the production of invertebrates is closely related to aquatic plants that provide living space, food, and shelter. Invertebrates tend to select the particular aquatic plant with leaves that are finely branched and that are compact enough to give suitable protection to the animal. Andrews and Hasler (1943) found coontail and water milfoil in Lake Mendota "most productive," *Chara* and sago pondweed "moderately productive," the wide-leafed pondweeds "less productive," and wild celery "poorly productive." The number of animals per pound of dry weight plant ranged from 3,000 to 29,000. Surber (1930) showed that snails were six times more abundant in weedy areas than in nonweedy areas, mussels 1.5 times more abundant, and larger insects about 10 times more abundant. Needham (1929) found 37.5 times as many invertebrates living in weedy areas as in bare pool bottoms. Needham (1938), in studying bottom fauna production associated with several kinds of aquatic plants in slow streams of New York, observed standing benthic crops of 3,500 pounds per acre for *Chara*, and 300 pounds per acre for sago pondweed. Shelford (1918), rated *Elodea* as excellent in the production of animals; *Myriophyllum* as good, and water lilies and *Chara* only fair. Pate (1932, 1934) found that plant beds were 17.5 times as productive as bare pools, and 6.7 times as rich as the average stream bottom. *Elodea* beds offered a potential food supply about six times the average supply in the ordinary bottom of a similar type. Krocker (1939) did a quantitative population study on several types of aquatic vegetation. His method of sampling was reaching down in the water as far as possible and cutting off a single plant at a time. As the severed portion was lifted clear of the water, it was placed in a glass dish and water was added, and the plants were measured. He found the animal population on *Myriophyllum* species was about two and one-half times as high as on *Elodea*, and nearly four times as high on *Myriophyllum* as on *Najas*. Krocker states that the chemical composition of the plants and the morphological features are the bases for the population difference.

Klugh (1926), who reviewed much of the early literature on the relationship of invertebrates to aquatic plants, concludes that since plants provide both living space and food for invertebrates the abundance of aquatic plants can be used as an "index of productivity" for fish production.

BOTTOM ORGANISMS

Much attention has been given to the bottom invertebrates in lakes and ponds. Data in the literature usually pertain to the standing crop at a specific sampling period. The total production of bottom fauna over the year is several times the standing crop. Many benthic species produce several generations in a year. Hayne and Ball (1956) estimated the total production in two 1-acre ponds to be 17 times the standing crop. Borutsky (1939), working on the deepwater benthos of a lake in Russia, concluded that throughout the year 6 percent of the biological productivity was lost as emerged insects that perished outside the lake basin, 14 percent was eaten by fish, 55 percent was returned to the lake as dead larvae, cast skins, etc., and 25 percent remained to assure the continuation of the species the following year. Eggleton (1934) compared the benthic population in four lakes in northern Michigan that are closely situated geographically, but differ widely ecologically. He concluded that the bottom populations in each of the lakes varied qualitatively and quantitatively with the seasons of the year, and from year to year in the same lake. The bottom fauna was not evenly distributed over the floor in any of the lakes studied, but varied somewhat differently with depth in each of the lakes and very differently with the four seasons of the year. He determined that there was a concentration zone that shifted up and down the slope of the lake floor with the change of seasons. The largest number of organisms that was collected in the greatest depths occurred in November and ranged from 300 to 7,200 per square meter.

Croak (1932), in his studies of the bottom fauna of Shakespeare Island Lake, Ontario, found an average of 1,320 benthos per square meter. There was little variation among the depths studied.

Rawson (1930) found that chironomid (midge) larvae formed the bulk of the bottom organisms of Lake Simco and dictated the curve trend of the total population. The average number of macroscopic bottom organisms over all of the depths studied was 820 per square meter; the greater number occurred in the deeper water. He listed factors affecting bottom fauna production including the type of lake, the fertility of the water, the composition of the benthos, and the size of the lake. A lake of large area, in general, supports a smaller population per unit than a small lake.

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Mackenthun and Cooley (1952) studied bottom fauna in four Wisconsin lakes. The average number of organisms per square meter in Lake Mendota was 7,500; Lake Monona, 1,100; Lake Nagawicka, 2,000; and Lake Pewaukee, 1,600.

Adamstone and Harkness (1923) and Adamstone (1924), in a study of Lake Nipigon in Canada, found the number of all kinds of animals per square meter of lake bottom averaged from 750 to 1,000.

Moyle (1961) quotes a number of investigators converting their data on bottom fauna standing crop to pounds per acre (wet weight). Some typical values include 248 pounds per acre from a Minnesota pond (Dineen, 1953); 67 to 82 pounds per acre in an unfertilized Michigan pond, and 101 to 127 pounds per acre in a fertilized Michigan pond (Ball, 1949); 124 pounds per acre in Lizard Lake, Iowa (Tebo, 1955); 398 pounds per acre in the Mississippi River system with no weeds, and 1,143 pounds per acre in the Mississippi River system in weeds (Moyle, 1940); and as much as 3,553 pounds per acre in a *Chara* bed in a slow stream in New York (Needham, 1938).

FISH

Bennett (1962) states that the fish carrying capacity of a lake or pond may vary with (1) variations in the fertility of water; (2) the age of the water, if this represents age in chemical composition; (3) a change in the fertility of the watershed soil, caused by erosion or artificial fertilization that is carried to the pond in runoff water; and, (4) changes in the kinds of fishes or in the relative abundance of certain kinds and sizes of fishes. Moyle (1956) reasons that the size of a mixed fish population is related to the water fertility and conditions associated with it and that the structure of a fish population adjusts itself until it consists of those species that can best utilize a specific degree of fertility and conditions associated with it.

Moyle found a relationship between the total phosphorus concentration and the standing crop of fishes in Minnesota surface waters. It has been estimated on the basis of surveys that the Mississippi headwater lakes support about 90 pounds of fish per acre; the summer surface waters of these lakes have a mean total phosphorus content of about 0.034 mg/l. In central Minnesota the mean total phophorus content of fish lakes is 0.058 mg/l and the average fish capacity is estimated at about 150 pounds per acre. In southern Minnesota, the total phosphorus content is 0.126 mg/l; seining in 40 fish lakes showed an average standing crop of 280 pounds of rough fish per acre plus about 90 pounds of other fishes, a total of 370 pounds per acre.

Swingle (1950) cites one Alabama pond that was stocked with

140 gizzard shad, 1,500 bluegill fingerlings, and 100 advanced bass fry per acre. Two years later, the pond was drained and 1,079 pounds of fish were recovered: 304 pound of bluegills, 758 pounds of gizzard shad, and 17 pounds of bass. In some 20 ponds with balanced fish populations, the pounds per acre of fishes ranged from 146 to 611, and several ponds were in the 400-pound-per-acre group.

Bennett (1962) states that standing crops of fishes in Illinois ponds varied from 75 pounds per acre in the soft-water ponds in the Ozark hills of southern Illinois, where the population was largemouth bass and green sunfish, to 211 pounds per acre in the blacksoil ponds in the flood plains of central Illinois, where the population was composed of crappies and big mouth buffalo.

THE EFFECT OF STREAM INFLOWS ON THE WATER BODY

The extensive use of organic pesticides and recent controversies associated with the programs for the control of the fire ant, the spruce bud worm, the gypsy moth, and other forest insects, and extensive pesticidal application on food crops have focused attention on the problems created for those interested in the preservation of the aquatic habitat. Most pesticides are toxic to aquatic life: some are highly toxic (e.g. 0.6 pound of Endrin in 120 million gallons of water will kill bluegill sunfish [Henderson et al., 1959]; some are cumulative in the fat and flesh of organisms and in the bottom muds and usage has resulted in the death of fish and waterfowl as well as invertebrates, such as crabs, crayfish, and aquatic insects that are important in food chains.

Pesticides must be considered individually rather than collectively, and the beneficial and harmful effects of each compound must be weighed. The total effect of a proposed application upon the aquatic environment must be assayed, which necessitates a knowledge of the toxicity and associated hazards of the control agent. Rigid controls must govern usage and adequate safeguards must be taken against "careless use" that has so often resulted in unwarranted aquatic-animal mortalities.

Environmental changes caused by industrial waste effluents can be detrimental to aquatic life in varying degrees. These include decreases in dissolved oxygen to harmful levels; increases in turbidity; formation of sludge deposits by settleable solids; increases in chemicals to toxic levels; changes in pH toward extremes in acidity or alkalinity; increases in temperature; tainting of fish flesh; and production of nutrients resulting in undesirable aquatic growths.

Turbidity, which is an expression of the optical property of water that causes light rays to be scattered and absorbed rather than transmitted in straight lines, is caused by a variety of suspended particulate matter. Such matter may be living or dead phytoplankton or zooplankton cells, as algae, protozoans, bacteria, and small crustaceans, or silt or other finely divided inorganic and organic waste materials. Many industrial operations contribute turbidity and settleable solids to water; the resulting bottom deposits affect aquatic life in varying degrees.

Fine particulate inorganic and organic waste materials that remain in suspension limit the penetration of sunlight, thus restricting the growth of attached bottom plants, as well as suspended algae. Also, solids flocculate planktonic algae and animals out of water and carry them to the bottom to die. Thus, in limiting growths of aquatic plant meadows, food chains are interrupted, which results in a sparsity of animal life. As particulate matter settles to the bottom, deposits of settleable solids blanket the substrate and form undesirable physical environments for organisms.

Many thousands of waterfowl have been destroyed by the pollutional effects of oil (Hunt, 1961). This wasteful loss has deprived nature lovers, waterfowl hunters, and bird watchers of immeasurable enjoyment.

Plate 4. Industrial wastes degrade water for recreational use.

The destruction of ducks such as the canvasback, redhead, and scaups comes at a critical period for these species, which are fighting for survival against the forces of nature and man. Additional waterfowl will be destroyed if oil dumping is continued, especially in late winter. In this age of technical development, the discharge of oil into a river system indicates man's irresponsibility in the preservation of our natural resources.

Oil causes matting of the feathers so that ducks become waterlogged, lose their ability to fly, and drown if they cannot get out of the water soon enough. It breaks down the insulating power of the feathers; body heat and stored reserves of energy are rapidly lost. Diving ducks may starve, and following the preening of oil off contaminated feathers, bleeding ulcers may be produced in their digestive tracts causing mortality (Hunt, 1958).

Wastes with concentrations of nitrogen and phosphorus (fertilizers) increase certain organism populations to such magnitudes as to interfere with water uses and create nuisances. Organisms that respond to such nutrients are certain floating and attached algae and rooted aquatic plants. If streams, lakes, and manmade impoundments continue to be enriched with industrial, municipal, and agricultural wastes, existing biological nuisance problems will intensify in many areas, and develop in others that do not now have them.

THE EFFECT OF RESERVOIR DISCHARGE ON THE RECEIVING STREAM

Water flowing from a natural lake would be expected to be of a quality similar to that of the water in the uppermost stratum of the lake. When water in a free-flowing stream is impounded in a large storage reservoir, marked changes are produced in the physical, chemical, and mineral quality of the water.

Churchill (1958) discusses the effect on downstream water quality of large storage reservoirs with discharge intakes located deep within the reservoir. Because the reservoirs are operated primarily for flood control and power production, the magnitude of high stream flows is reduced and the general level of low flows is increased. Discharge releases are usually reduced over weekends and during other periods of offpeak power loads. The temperatures in the receiving stream are substantially lowered, sometimes to 55° F; and may not exceed 68° F even in the summer. Because stratification beginning in March or April stops the vertical circulation that exists all winter, discharge through the low-level power intakes removes cold water from the near intake level.

As the supply of cold water at this level is exhausted from the pool, warmer water from above sinks down and is gradually discharged. By this process the discharged water gradually warms to temperatures approaching 77° F during the summer and fall. Turbidity resulting from intense summer rains of short duration is reduced. Odors of hydrogen sulfide from decaying organic materials in the deeper portions of the reservoir may be a problem.

The dissolved oxygen concentration of the discharged water is lower than that normally present in the inflow and may often approach zero at the point of discharge. "Low rates of released flow are reaerated in relatively short distances downstream from the dam, whereas higher discharges require many miles of open-channel flow before oxygen saturation is reached" (Churchill, 1958).

The ecology of the receiving stream is drastically altered as a result of the low-level discharge water characterized by low temperatures and reduced oxygen concentrations. Dendy and Stroud (1949) noted that the warm-water habitats that formerly supported a bass and walleye fisheries below Fontana Reservoir, Tenn., no longer exist. The highest water temperature recorded was 68.5° F and the lowest concentration of dissolved oxygen was 1.6 mg/1, both reached in late October. Pfitzer (1954) investigated a number of reservoir tailwaters in Tennessee. He found that many of the minnow species had disappeared, and only a few of those remaining were reproducing successfully. The bottom fauna pattern had changed from one dominated by large immature stoneflies and hellgrammites to an assortment of cold-water species such as immature midges, blackflies, and caddisflies along with the scud, *Gammarus*, and snails. The plant populations were dominated entirely by algae of several species.

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CHAPTER III

Nutrients and Biological Growths

"Fixed like a plant on his peculiar spot to draw nutrition, propagate and rot."

—POPE.

Reservoirs or lakes are the settling basins of drainage areas. The potential productivity of a body of water is determined to a great extent by the natural fertility of the land over which the runoff drains and by the contributions of civilization. Biological activity within the lake influences such chemical characteristics as dissolved oxygen, pH, carbon dioxide, hardness, alkalinity, iron, manganese, phosphorus, and nitrogen; it is varied through temperature fluctuations and stimulated by nutrient variations (e.g., phosphorus and nitrogen). A lake's basin gives dimension to biological activity and may, because of unique physical characteristics, concentrate the nutrients it receives as well as the developing biomass.

BASIC NUTRIENT SUPPLIERS

Basic sources of nutrients to lakes and reservoirs are (a) tributary streams carrying land runoff and waste discharges, (b) the interchange of bottom sediments, and (c) precipitation from the atmosphere.

Sewage and sewage effluents enrich tributary streams. Rudolfs (1947) studied the content of sewages from 12 separate sources and concluded that the annual per capita contribution of phosphorus ranged from 0.6 to 1.5 pounds. Studies of Wisconsin waste stabilization ponds indicate annual per capita contributions of 4.1 pounds of inorganic nitrogen and 1.1 pounds of soluble phosphorus (Mackenthun and McNabb, 1961). The Nine-Springs Sewage Treatment Plant provides primary and secondary treatment for all wastes from Madison, Wis., metropolitan area of 85 square miles with a population of about 135,000. The effluent from the secondary processes—one-fourth settled sewage from trickling filters and three-fourths from activated sludge—has an annual per capita contribution of 8.5 pounds of inorganic nitrogen and 3.5 pounds of soluble phosphorus. By diverting its treated sewage effluent around Lakes Waubesa and Kegonsa, this city reduced the inflow of nutrients into those waters by 3,000 pounds per day of inorganic nitrogen and 1,300 pounds per day of soluble phosphorus (Mackenthun et al., 1960).

Lakes and reservoirs located on heavily used duck flyways receive "flying" or "bombed in" nutrients from a transient duck population. Sanderson (1953) found the annual raw-waste contribution of a domestic duck to be 2.1 pounds of total nitrogen and 0.9 pound of total phosphorus. Paloumpis and Starrett (1960) applied a factor of 0.5 to these data to compensate for dietary differences of wild ducks, and determined that the annual nutrient contribution to Lake Chautauqua, Ill., from the wild duck population was 12.8 pounds of total nitrogen and 5.6 pounds of total phosphorus per acre.

Land runoff may often be the major contributor of nutrients to the tributary stream. The annual loss of nitrogen and phosphorus per acre from a planting of corn on a 20-percent slope of Miami silt loam was found to be 38 pounds and 1.8 pounds respectively; [5] on an 8-percent slope, this was reduced to 18 pounds of nitrogen and 0.5 pounds of phosphorous. In a study of the lower Madison lakes, Sawyer et al.,[6] and Lackey and Sawyer (1945) found that the annual contribution of inorganic nitrogen per acre of drainage area tributary to Lake Monona was 4.4 pounds, Lake Waubesa, 4.9 pounds, and Lake Kegonsa, 6.4 pounds.

Sylvester (1960) tabulated the results of analyses of samples collected from gutters on Seattle, Wash., streets anywhere from 30 minutes to several hours after a rainstorm had commenced. The mean nitrate nitrogen (N) was 0.53 mg/l, total phosphorus (P) 0.21 mg/l and soluble phosphorus 0.076 mg/l. Nutrient values in three streams emerging from forested areas where no human habitation contributes any significant amount of waste water averaged 0.065 to 0.20 mg/1 nitrates as N and 0.004 to 0.009 mg/l soluble phosphorus as P. Surface irrigation return flows from diversified farming in Yakima Valley, Wash., contained 1.19 to 1.90 mg/l nitrate nitrogen as N, 0.165 to 0.360 mg/l total phosphorus as P, and 0.127 to 0.210 mg/l soluble phosphorus. In the surface drains, the total phosphorus in the drainage water varied from 0.9 to 3.9 pounds per acre per year while the total nitrogen varied from 2.5 to 24 pounds per acre per year.

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[5] Eck, P., M. L. Jackson, O. E. Hayes and C. E. Bay, 1957. Runoff Analysis as a Measure of Erosion Losses and Potential Discharge of Minerals and Organic Matter into Lakes and Streams. Summary Report, Lakes Investigations, University of Wisconsin, Madison, 13 pp. (mimeo.).

[6] Sawyer, C. N., J. B. Lackey and R. T. Lenz, 1945. An Investigation of the Odor Nuisances Occurring in the Madison Lakes, Particularly Monona, Waubesa and Kegonsa from July 1942–July 1944. Report of Governor's Committee, Madison, Wis., 2 vols. (mimeo).

Inorganic nitrogen compounds are present in small amounts in rainwater, predominantly as nitric acid and ammonia. These compounds come from the atmosphere and are the products of electrical discharges, terrestrial decomposition, and volcanic eruptions. If the concentrations quoted by Hutchinson (1957) are used and a 30-inch annual precipitation is assumed, the contribution of ammonia and nitrate nitrogen in the temperate region would be 5.5 pounds per acre. In an 18-month investigation at Hamilton, Ontario, Matheson (1951) determined the annual fall of atmospheric nitrogen to be 5.8 pounds per acre. Sixty-one percent of the total nitrogen fell on the 25 percent of the days when precipitation occurred; the balance was attributed solely to the sedimentation of dust.

As fixed nitrogen enters the reservoir, it is incorporated in the biomass as an element of protein. Upon death or excretion, nitrogen is liberated for reuse. During this process some is lost: (a) in the lake effluents (as much as 40 percent), (b) by diffusion of volatile nitrogen compounds from surface water, (c) by denitrification in the lake, and (d) in the formation of permanent sediments.

Likewise, phosphorus, taken up in the web of life, is liberated for reuse upon death of the organism (Cooper, 1941). Some may settle into the hypolimnion with the sedimentation of seston (all living and nonliving floating or swimming plants or animals) or in fecal pellets, and some may be released at the mud-water interface (Hooper and Elliott, 1953).

Ruttner (1953) states that phosphorus occurs in the biosphere almost exclusively in a fully oxidized state. It comes from the weathering of phosphatic rock and from the soil. In contrast, however, phosphate is avidly held by the soil and is not so easily leached by rainwater as are the nitrates. When ferrous iron and phosphate occur together in the hypolimnion of a lake, an insoluble ferric phosphate is precipitated at times when oxygen is introduced and the reaction is made alkaline. Thus, the whole phosphorus content of a lake may be carried to the bottom at the time of the fall overturn. When there is a lack of oxygen in the sediments, the iron can be reduced from the ferric to the ferrous form and the phosphorus freed to go into solution.

During extreme stratification in a lake during the summer, the phosphorus cycle may involve the following processes (Ruttner, 1953):

1. Liberation of the phosphorus in the epilimnion from the decay of littoral vegetation.

2. Uptake of phosphorus from water by littoral vegetation.

3. Uptake of liberated phosphorus by phytoplankton.

4. Loss of phosphorus as a soluble compound from the phytoplankton, probably followed by a slow regeneration of ionic phosphate.

5. Sedimentation of phytoplankton and other phosphorus-containing seston, perhaps largely fecal pellets, in the hypolimnion.

6. Liberation of phosphorus from the sedimenting seston in the hypolimnion, or the liberation of phosphorus when it arrives at the mud-water interface.

7. Diffusion of phosphorus from the sediments in the water at those depths at which the superficial layer of the mud lacks an oxidized microzone.

Sawyer et al.[7] found the nitrogen and phosphorus content of bottom muds in the Madison lakes to be 7,000 to 9,000 $\mu g/g$ (micrograms per gram) dry weight and 1,000 to 1,200 $\mu g/g$ dry weight respectively. Some of this is recirculated through mixing of the lake waters at the time of lake overturns twice a year from the bottom ooze into the upper lake water, and some is recirculated by the movement of organisms and eddy diffusion.

NUTRIENT UTILIZATION

Important factors affecting aquatic growths include temperature; sunlight; size, shape, type of substratum, and slope of lake basin; and water quality. The total supply of an available nutrient depends on the total volume of water, as well as the concentration of the element in the water. Gerloff and Skoog (1957) in laboratory investigations determined that 5 units of nitrogen plus 0.08 unit of phosphorus (a ratio of 60:1) would produce 100 units of algae. The N–P ratio, as it naturally occurs in algae and submerged plants, is more nearly 10:1. Allen (1955) found that the maximum algal crop that can be grown on the nutrients present in domestic sewage was 1 to 2 g/l (dry weight); to obtain any appreciable increase it was necessary to supplement the sewage with nitrogen as well as carbon.

Sawyer (1947) studied the southeastern Wisconsin lakes and concluded that a 0.30 mg/l concentration of inorganic nitrogen (N) and a 0.01 mg/l concentration of soluble phosphorus (P) at the start of the active growing season could produce nuisance algal blooms. Nitrogen appears to be the more critical factor limiting algal production in

[7] Sawyer, C. N., J. B. Lackey and R. T. Lenz, 1945. An Investigation of the Odor Nuisances Occurring in the Madison Lakes, Particularly Monona, Waubesa and Kegonsa from July 1942–July 1944. Report of Governor's Committee, Madison, Wis., 2 vols. (mimeo.)

natural waters (Gerloff and Skoog, 1957), since phosphorus is stored in plankton as excess and may exceed the actual need.

A continued high rate of nutrient supply is not necessary for continued algal production. After an initial stimulus, the recycling of nutrients within the lake basin is sufficient to promote algal blooms for a number of years without substantial inflow from contributing sources.

Algae and other plant growths in lakes, ponds, and reservoirs eventually die and many of them settle to the bottom where they are subjected to aerobic or anaerobic decomposition. Some of the nutrient elements that are soluble become immediately available and are passed into solution in the epilimnion. The remainder become part of the stabilized bottom deposits. The amount of nutrients back-feeding from bottom deposits is directly related to the rate of deposition. Back-feeding from bottom deposits continues for some time even though further additions to the decomposing mass are prevented, since there is a considerable lag imposed by the slow rate of the involved reaction, which is comparable to sludge digestion at low temperatures (Sawyer, 1954).

Provasoli (1961) points out that many algae require vitamins for growth in addition to inorganic salts. The most important vitamins appear to be B_{12}, thiamine, and biotin, alone or in various combinations. A great part of the vitamins in fresh waters come from soil runoff especially during spring floods, from bottom muds, and from domestic sewage as solutes in the water. Basic nutrient suppliers and nutrient utilization through existing food chains form a natural cycle of events. In appraising nutrient impact on the environment, the engineer needs a figure representing a given contribution that may be compared to some base. A population equivalent (PE) is appropriate for such purposes. The population equivalents suggested in table 2 recognize variability in both the base (domestic contribution in sewage) and the selected contributions.

Sawyer (1954) discusses various factors that influence the development of nuisance algal growths in lakes. The surface area is important since the accumulations of algae along the shoreline of a large lake under a given set of wind conditions could easily be much larger than on a small lake, providing the fertilization per acre were equal. The shape of the lake determines to some degree the amount of fertilizing matter the lake can safely assimilate since prevailing winds blowing along a long axis will concentrate the algal production from a large water mass into a relatively small area. The most offensive conditions develop during periods of very mild breezes that tend to skim the floating algae and push them toward shore. Shallow lakes, too, respond differently than deep stratified lakes in which the deeper waters are sealed off by a thermocline. In the

Table 2. Nutrient Population Equivalents

Nutrient source	Basic reference	Contribution		Population equivalent (PE per year)	
		N	P	N	P
Treated domestic contribution in sewage.	Bush and Mulford, 1954. Metzler et al., 1958.	6–12* (9 lb/yr). 6**lb/yr.	2–4 (3 lb/yr). 2.25 lb/yr.	1	1.
Domestic duck	Sanderson, 1953	2.1 lb/yr	0.9 lb/yr	0.23 to 0.35	0.3.
Wild duck	Paloumpis and Starrett, 1960.	1.0 lb/yr	0.45 lb/yr	0.11 to 0.17	0.15.
Runoff—20 percent slope corn	Eck et al., 1957[1]	38 lb/A/yr	1.8 lb/A/yr	4.2 to 6.3/A	0.6/A.
Runoff—8 percent slope corn	Eck et al., 1957[1]	18 lb/A/yr	0.5 lb/A/yr	2.1 to 3.0/A	0.166/A.
Surface irrigation diversified farming.	Sylvester, 1960	2.5–24.0 lb/A/yr	0.9–3.9 lb/A/yr	0.27 to 4.0/A	0.3 to 1.3/A.
Rainwater	Hutchinson, 1957	5.5 lb/A		0.6 to 0.9/A	
Killed algae (summer maximum).	Birge and Juday, 1922	24 lb/A	2.4 lb/A	2.7 to 4.0/A	0.8/A.
Killed submerged plants	Rickett, 1922	32 lb/A	3.2 lb/A	3.6 to 5.3/A	1.1/A.
Killed fish	Beard, 1926	50 lb/ton	4 lb/ton	5.6 to 8.3/ton	1.3/ton.

[1] Eck, P., M. L. Jackson, O. E. Hayes and C. E. Bay, 1957. Runoff Analysis as a Measure of Erosion Losses and Potential Discharge of Minerals and Organic Matter into Lakes and Streams. Summary Report, Lakes Investigations, University of Wisconsin, Madison, 13 pp. (mimeo.).

* Normal range of domestic sewage for 15 California communities was given as 20 to 40 mg/1 N and PO_4.

** The concentration in treated water was subtracted from the concentration in sewage to obtain domestic contribution.

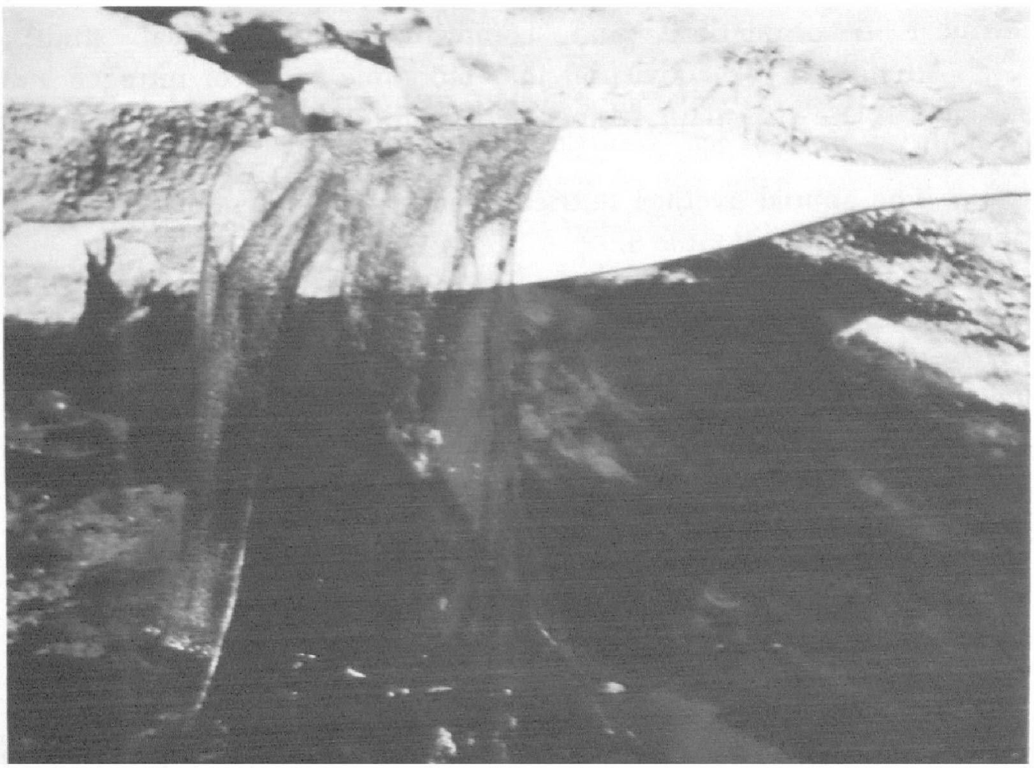
nonstratified waters all the nutrients dissolved in the water are potentially available to support an algal bloom. In stratified waters, only the nutrients confined to the epilimnion are available except during those brief periods when complete circulation occurs.

PRODUCTION IN ABUNDANCE

The literature records many lakes capable of excessive algal production (Hasler 1947). It is clear that any increase in the rate of eutrophy, even if this involves only the acceleration of a natural and inevitable process is, from a human point of view, thoroughly undesirable.

Anderson (1961) discusses recent eutrophication of Lake Washington near Seattle. In 1950, the standing crop of phytoplankton was 0.6 ppm (parts per million wet measure by volume); in 1955, 1.6 ppm; and in 1956, 4.2 ppm. The phosphate accumulation in the hypolimnion was 23 ppb (parts per billion) in 1950, 89 ppb in 1957, and 74 ppb in 1958. These factors were correlated with changes in the flora, especially the initial observation in 1955 of *Oscillatoria rubescens* DeCandolle, ". . . a notorious indicator of pollution in many lakes." Hasler (1947) describes eutrophication in the Zürichsee and Hallwilersee, Switzerland, Lake Windermere, England, and in several other lakes. Phinney and Peek (1961) discussed Klamath Lake, Oreg. and Benoit and Curry (1961), Lake Zoar, Conn.; Deevey and Bishop (1942) found Linsley Pond to be the most biologically productive of 30 lakes studied in Connecticut. Here, again, evidence was found of rapid eutrophy in comparatively recent times.

Plate 5. Algal scums often result from warm temperature, abundant sunshine, and nutrients.



The Madison Lakes problem at Madison, Wis., has been a subject of nationwide discussion, intensive investigation, and legislative and legal action for many years. The series of Yahara River lakes at Madison, Wis., includes Lake Mendota, Lake Monona, Lake Waubesa, and Lake Kegonsa, respectively. Madison, Wis., is located between Lake Mendota and Lake Monona. In the early history of the city, Lake Monona received raw sewage and later treated sewage effluent from the City of Madison. In 1926, the Nine-Spring Sewage Treatment Plant was placed in operation and the effluent from this installation was carried via Nine-Springs Creek to the Yahara River above Lakes Waubesa and Kegonsa. The enrichment of these lower Madison Lakes by the highly nutritious effluent produced nuisance algal growths, offensive odors, and periodic fish kills. These conditions led to innumerable complaints, much debate, and eventually, in December 1958, legislative and legal action forced the diversion of the effluent from the Madison Metropolitan Sewerage District's Nine-Springs Treatment Plant around the lower Madison Lakes.

The 1942–43 report to the Governor's Committee on a study of the Madison Lakes [8] contained results of over 15,000 chemical determinations mostly on nitrogen and phosphorus, along with appropriate flow data. Algal counts were also made and correlated with nutrients found. Major conclusions reached were that (1) the biological productivity of the local lakes is a function of the loading of inorganic nitrogen on each lake, (2) the soluble phosphorus content of the water may be a factor in limiting the rate of biological activity and in determining the nature of the growths when its concentration drops below 0.01 mg/1, (3) drainage from improved marsh land is approximately two to three times as rich in inorganic nitrogen as drainage from ordinary farm land, and (4) high biological productivity and nuisance conditions do not always occur simultaneously.

The 1943–1944 report, which gives the results of over 21,000 chemical determinations and complementary biological studies, ". . . strengthen the conviction that inorganic forms of nitrogen and phosphorus are the main factors in providing fertilizing elements for algal blooms."

The annual average nutrient loading and retention within the lakes are presented in table 3.

On 26 biweekly sampling dates, samples were collected from

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[8] Sawyer, C. N., J. B. Lackey and R. T. Lenz, 1945. An Investigation of the Odor Nuisances Occurring in the Madison Lakes, Particularly Monona, Waubesa and Kegonsa from July 1942–July 1944. Report of Governor's Committee, Madison, Wis., 2 vols. (mimeo.)

Table 3. Nutrient Loading and Retention in Lower Madison Lakes, 1942–1944

Lake	Inorganic nitrogen		Inorganic phosphorus	
	Loading lbs/acre/yr	Retention in lake, percent	Loading lbs/acre/yr	Retention in lake, percent
Monona	90	70	9	88
Waubesa	448	64	64	25
Kegonsa	156	61	38	12

the receiving stream both before and after diversion [December 1958] of the effluent around the lower Madison Lakes (Mackenthun et al., 1960). Analyses of these data (table 4) from a station midway down the receiving stream show the quantity of nutrients removed from the lower lakes following diversion.

Table 4. The Receiving Stream Before and After Diversion of Treated Sewage, Madison, Wisconsin

	Before	After
Phytoplankton, lb/day	259	622
Organic Nitrogen, lb/day	30	286
Inorganic Nitrogen, lb/day	110	3,153
Soluble Phosphorus, lb/day	9	1,351
BOD, lb/day	75	1,602
DO, lb/day	475	904
Average Flow, cfs	8.7	43.0

The characteristics of eutrophication are many; most important to the layman on the scene are those readily noted through visual inspection. The secchi disc is a polished measure of visual inspection. The vertical dissolved-oxygen concentrations, the increase in nutrients in the hypolimnion, significant changes in the algal population and in the fishery, and increases in rooted weed beds, are all factors closely correlated with enriched conditions in a lake basin.

PHOTOSYNTHETIC OXYGEN PRODUCTION

Purdy (1916) showed that great masses of submerged plants covering the Potomac River flats functioned as oxygenators of the water.

He demonstrated a different oxygen saturation level between night and day, and between forenoon and afternoon. Rudolfs and Huekelekian (1931) noted the effects of sunlight and green organisms on the reaeration of streams and found that the dissolved oxygen in water containing large quantities of algae decreased from supersaturation to 17 percent saturation by placing the water in darkness, and increased to 282 percent saturation by subjecting it to diffuse light.

In recent years, the measurement of primary production has stimulated interest among investigators (Ryther, 1956). Several methods of determination are applicable where the inflows of energy and material balance the outflows. These include (a) the oxygen method (light-dark bottle, diurnal oxygen curve, and oxygen deficit in the hypolimnion); (b) the carbon dioxide method; (c) determinations with radioactive materials; and (d) the chlorophyll method (Odum, 1959).

Green algae, utilizing energy from the sun, produce carbohydrates from carbon dioxide and water, and then assimilate these carbohydrates together with the liberated ammonia and other essentials to produce additional algal cells. Oswald and Gotaas (1956) found that the growth of 1 pound of algae is usually accompanied by the production of a minimum of 1.6 pounds of molecular oxygen. In stabilization ponds, it has been found that a photosynthetic efficiency of 1 percent is equivalent to the production of about 25 pounds per acre per day of organic matter with the liberation of about 40 pounds of oxygen. Photosynthetic efficiencies in pilot plant sewage stabilization ponds have ranged from 2 to 9 percent under varying conditions of depth, detention time, recirculation time, and mixing. (Oswald and Gotaas, 1956.)

Light-dark bottle data on sewage stabilization ponds in the Dakotas indicated gross oxygen production of 231 pounds per acre per day, respiration of 169 pounds, or a net oxygen production of 62 pounds per acre per day (Bartsch, 1960). Gross production was highest during midmorning at Lemmon, S.D. (18.7 pounds per acre per hour) and lowest during early evening (0.3 pounds per acre per hour). Highest net oxygen production was 10.7 pounds per acre per hour. There is generally no measurable oxygen production under winter ice in stabilization ponds.

In measuring in situ aeration of Wisconsin's sewage stabilization ponds, McNabb (1960) found net oxygen production proceeding at a rapid rate in the morning, and oxygen consumption by biota exceeding production throughout most of the afternoon in spite of light intensities favorable for photosynthesis. Highest oxygen production was 21.4 pounds per acre per hour with a phytoplankton population of 180 ppm (by volume) and a nutrient inflow of approximately 4.0 pounds per acre per day total nitrogen and 1.3 pounds per acre per day total phosphorus.

Verduin (1956) summarized the literature on primary production in lakes and concluded that the net photosynthetic rate of autotrophic organisms under optimum light was 35 x 10^{-6} pounds of O_2 per ml of organisms per hour. Lakes with an epilimnion layer of the order of 1 meter are likely to have standing crops of about 5 ppm by volume. Computations of photosynthetic oxygen production for several lakes yielded values lying mostly between 42 to 57 pounds per acre per day.

An increase in the hypolimnetic oxygen deficit has been taken as evidence of increased lake productivity. In Lake Washington, near Seattle, the hypolimnetic oxygen deficit was determined to be 105 pounds per acre per month (3.5 pounds per acre per day) in 1933, 178 pounds per acre per month in 1950, and 279 pounds per acre per month in 1955 (Edmondson et al., 1956). The standing crop of phytoplankton in the top 20 meters of water in 1950 was 0.6 ppm (by volume), and in 1955, 1.6 ppm (by volume) (Anderson, 1961).

THE PRICE OF EUTROPHY

The disadvantages of algae as a source of oxygen have been summarized by Bartsch (1961). Algae respond to complex, changing, unpredictable environmental factors including solar radiation, opacity of the medium, rate of bacterial activity, rise and fall of nutrients, climatic phenomena, and ecological succession. When algal cells die and sink to the hypolimnion, oxygen is used in decomposition. The nutrients' stimulation of algal production can lead to the formation of a mass of organic matter greater than that of the original waste source (Renn, 1954). In an enriched environment, algae respond so well to incoming nutrients that the oxygen required for the respiration of the resultant algal mass alone surpasses the biochemical oxygen demand (BOD) of the incoming food material. Lake Winnebago, Wis. (area 213 square miles) produces heavy algal populations. In July, when the lower Fox River carried a heavy algal load from Lake Winnebago, the ultimate BOD in the river above the sources of industrial and municipal wastes ranged to 660,000 pounds of oxygen demand each day.[9]

Enrichment often results in domination of the algal mass by a relatively small group of blue-green algae that become well established. Indications are that many species of fresh-water algae are capable of producing physiologically active metabolites that may function as toxins,

[9] Scott, R. H., B. F. Lueck, T. F. Wisniewski and A. J. Wiley, 1956. Evaluation of Stream Loading and Purification Capacity. Committee on Water Pollution Madison, Wis., Bull. No. 101 (mimeo.).

growth inhibitors (autointoxication), or growth stimulators to themselves or to associated algae (Hartman, 1960). Most of the adverse effects resulting from an algal mass occur when one species of algae dominates the population.

Fish kills have resulted from a supersaturation of oxygen (Woodbury, 1941). A heavy loss of fish was accompanied by a dense algal bloom and extremely high dissolved oxygen (30 to 32 mg/1) in the surface water. Gas emboli were present in the gill capillaries and gas bubbles occurred in the subcutaneous tissues. Death of the fish was attributed to the blocking of the circulation through the gills by the gas bubbles with subsequent respiratory failure. Fish kills have also resulted from a natural depletion of oxygen (Mackenthun et al., 1948). An example occurred in October 1946 when tremendous quantities of blue-green algae, *Aphanizomenon flos aquae* (Linnaeus), entered the Yahara River from Lake Kegonsa near Madison, Wis., decomposed in passing downstream, and caused oxygen depletion resulting in the death of tons of fish.

Provost (1958) indicated that overproduction of tendipedids (midge larvae or bloodworms) in lakes is caused by excessively nutritious waters. Midgeflies have become a nuisance in several areas where conditions are especially suitable for the concentration of a swarming mass of adults following an emergence (e.g., Clear Lake, Calif.; Lake Winnebago, Wis.; and several lakes in Florida). Larval development is no doubt fostered by the deposition of the dead cells of a rich plankton population on the bottom sediments.

Both weed and algal nuisances develop in enriched water; fishing may be impaired, and bathing, boating, and water skiing often must be indefinitely postponed in waters that otherwise offer maximum multiple recreational use. Industrial or municipal water treatment is hampered or made inefficient by extensive aquatic growths; property values are lowered, and resort trade may be cancelled as a result of these nuisances.

Excessive submerged aquatic vegetation often develops in shallow enriched waters. A critical time in development occurs in the early spring during seed germination. If sufficient light reaches the lake bottom at this time, weeds will develop. Weed development utilizes local nutrients and often will limit excessive algal growth in the area inhabited by the submerged aquatic plants. Elimination of a substantial area of weed growth, in turn, often gives rise to localized algal development.

Rapid decomposition of dense algal scums with associated organisms and debris gives rise to odors and hydrogen sulfide gas that create strong citizen disapproval; often the gas stains the white lead paint on residences adjacent to the shore to ugly hues of grey and even black.

Efforts to minimize conditions leading to water enrichment necessitate an understanding of the basic problem and the cooperation of all who use the water. Ideally, sewage and decomposable organic industrial wastes, the effluents from which contain concentrations of nitrogen and phosphorus, should not be discharged into a watercourse where the impact of nutrients will manifest in nuisance growths of aquatic plants. Runoff and drainage from land on which leeching fertilizers have been used should be minimized. Drainage from garbage or trash dumps should not enter water. Private sewage treatment units serving shoreline dwellings should not discharge into recreational waters. Those who use the water for recreational purposes should observe good housekeeping and not litter beaches and waterways with the trash and remains of recreational pursuits.

Long-term remedial measures might be focused on reducing the nutrient concentration in troublesome areas or in altering some aspect of the topography that concentrates or fosters the development of nuisance algae or aquatic weeds. Such measures often involve costly physical modifications to correct existing conditions, as well as future planning to assure wise use of the area's natural aquatic resources.

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CHAPTER IV

Plant Pests Affecting Recreational Water Use

"A weed is a plant whose virtues have not yet been determined."

—EMERSON.

Plant nuisances affecting recreation waters may curtail or eliminate bathing, boating, water skiing, and sometimes fishing; impart tastes and odors to water supplies; shorten filter runs or otherwise hamper industrial and municipal water treatment; impair areas of picturesque beauty; reduce or restrict resort trade; lower water front property values; interfere with the manufacture of a product in industry, such as paper; and on occasion become toxic to certain warm-blooded animals that ingest the water. These plant nuisances may be grouped into the algae and the higher aquatic plants. Algae appear as floating scums; suspended matter giving rise to murky, turbid water or water having a "pea soup" appearance; attached filaments; and bottom dwelling types that may be confused with the rooted higher aquatic plants. The higher aquatic plants grow as submerged, floating, or emergent plants. There are many different kinds of both algae and higher aquatic plants, the vast majority of which can be properly identified only by experts in the field.

ALGAE

Most algal problems occur when growth conditions permit the formation of a "bloom." A bloom is an unusually large number of cells (usually one or a few species) per unit of surface water, which often can be discerned visually by the green, blue-green, or brown discoloration of the water. Lackey (1949) arbitrarily defined a bloom as 500 individuals per ml of raw water. He found bloom conditions 509 times during a 2-year survey of 16 southeastern Wisconsin lakes and of three rivers in 1942–43. Of this number, only 13 percent were blue-green algae, generally the most troublesome nuisance-producing group. Diatoms are rarely obnoxious except in water supplies; they predominated in 40 percent of the blooms. The lake with the highest concentration of inorganic nitrogen (N) and inorganic phosphorus (P), 0.79 and 0.38 mg/l respectively, had the most blooms—112 during the 2-year period.

Prescott (1960) points out that when a bloom develops, a single species usually predominates. *Aphanizomenon flos-aquae* (Linnaeus), for example, is never in abundance, or scarcely present at all, when *Microcystis aeruginosa* Kuetzing is in peak production, and vice versa.

Prescott (1960) further states that ". . . of the countless species of fresh-water algae, only a few produce disturbances which attract our attention." The American freshwater species are listed as follows:

I. Cyanophyta (blue-green algae)
Microcystis aeruginosa Kuetzing
Coelosphaerium Kuetzingianum Nageli
Oscillatoria rubescens De Candolle
O. lacustris (Klebahn)
Anabaena circinalis Kuetzing
A. flos-aquae (Linnaeus)
A. Lammermanni Richter
Anabaenopsis Elenkini Miller

II. Chrysophyta (yellow-green algae and diatoms)
Dinobryon sertularia Ehrenberg
D. sociale Ehrenberg
Synura uvella Ehrenberg
Fragilaria spp.
Tabellaria fenestrata Kuetzing
Asterionella gracillima (Hantzsch)
Coscinodiscus spp.
Melosira granulata (Ehrenberg)
Stephanodiscus niagarae Ehrenberg

III. Pyrrophyta (dinoflagellates)
Ceratium hirundinella (Mueller)

In further discussion, Prescott states, "It follows that lakes which have been enriched by various kinds of pollution from human habitats, runoff from agricultural lands, wastes from farm animals, etc. are the ones in which blooms appear. Accordingly, blue-green algae follow man about as he colonizes and pioneers, creating situations favorable for his worst aquatic pests."

Algae are found in the fresh water of ponds, lakes, rivers, brooks, ditches, pools, and swamps, and in the salt water of the oceans. Constituting a primary source of food for fish and other aquatic animals, they may be free-floating and free-swimming, or attached to the bottom substratum.

Palmer and Ingram (1955) point out a lack of agreement and a resulting nonuniformity of classification existing among botanists and zoologists as to a definite line of demarcation between algae and protozoa important in the field of sanitary science. They recommend that the presence or absence of photosynthetic pigments (indicating the ability or inability to produce oxygen) be used to separate the flagellates into the pigmented (algal) and nonpigmented (protozoan) types.

There exist some 1,500 genera and 17,400 species of algae, according to Fuller and Tippo (1954). Fresh-water algae fall into major groups including blue-green algae; green algae; yellow-green algae; golden-brown algae and diatoms; euglenoids and dinoflagellates.

The blue-green algae (Cyanophyta) are extremely primitive in several respects. The plant body is a single cell; colonies may be formed that are loose aggregations of similar cells among which there is little or no differentiation. The nuclear material is not organized into a definite nucleus, but is scattered throughout the center of the cell. Green chlorophyll is not localized in definitely formed bodies, but is diffused throughout the peripheral portion of the cell. In addition to the green chlorophyll there is a blue pigment and sometimes a red pigment. Reproduction is by simple division (fission). Blue-green algae produce "water blooms", "pea soup" appearance, septic "pigpen" odors; impart a "fishy taste"; and cover rocks with slimy gelatinous masses.

Green algae (Chlorophyta) have pigments that are principally chlorophyll confined to chloroplasts or definite bodies. There is an organized nucleus, and the motile cells, either vegetative or reproductive, have flagella.

The yellow-green algae, golden-brown algae, and diatoms (Chrysophyta) have the pigment confined to definite bodies. There is a greater proportion of yellow or brown pigment than chlorophyll. The cell wall of the diatoms is composed of silica.

The euglenoids (Euglenophyta) are unicellular, motile, and bear one to four flagella. They have a definite nucleus with grass-green chlorophyll localized in definite chlorophyll bearing bodies (plastids).

The group of dinoflagellates (Pyrrophyta) includes a great diversity of mostly pigmented and mobile unicellular organisms. Two flagella are present. Brown pigments predominate, although chlorophyll is present.

Algae have also been grouped according to their ecological association (Prescott, 1956). These may be classified according to (1) their position in water, such as those drifting in the open water, those occurring near shore intermingled with other vegetation or forming floating mats, those growing attached to the bottom substratum in water deeper than 15 feet, and those attached on shoreline rocks in the littoral region; (2) the chemical composition of their habitat, such as those in alkaline waters as opposed to those in acid waters; and (3) their relationships with other organisms, such as those living on host organisms that serve as attachment sites, those actually parasitic on or inducing pathological conditions in a host plant, and those in which an exchange of benefits apparently occurs between the attached alga and a host plant.

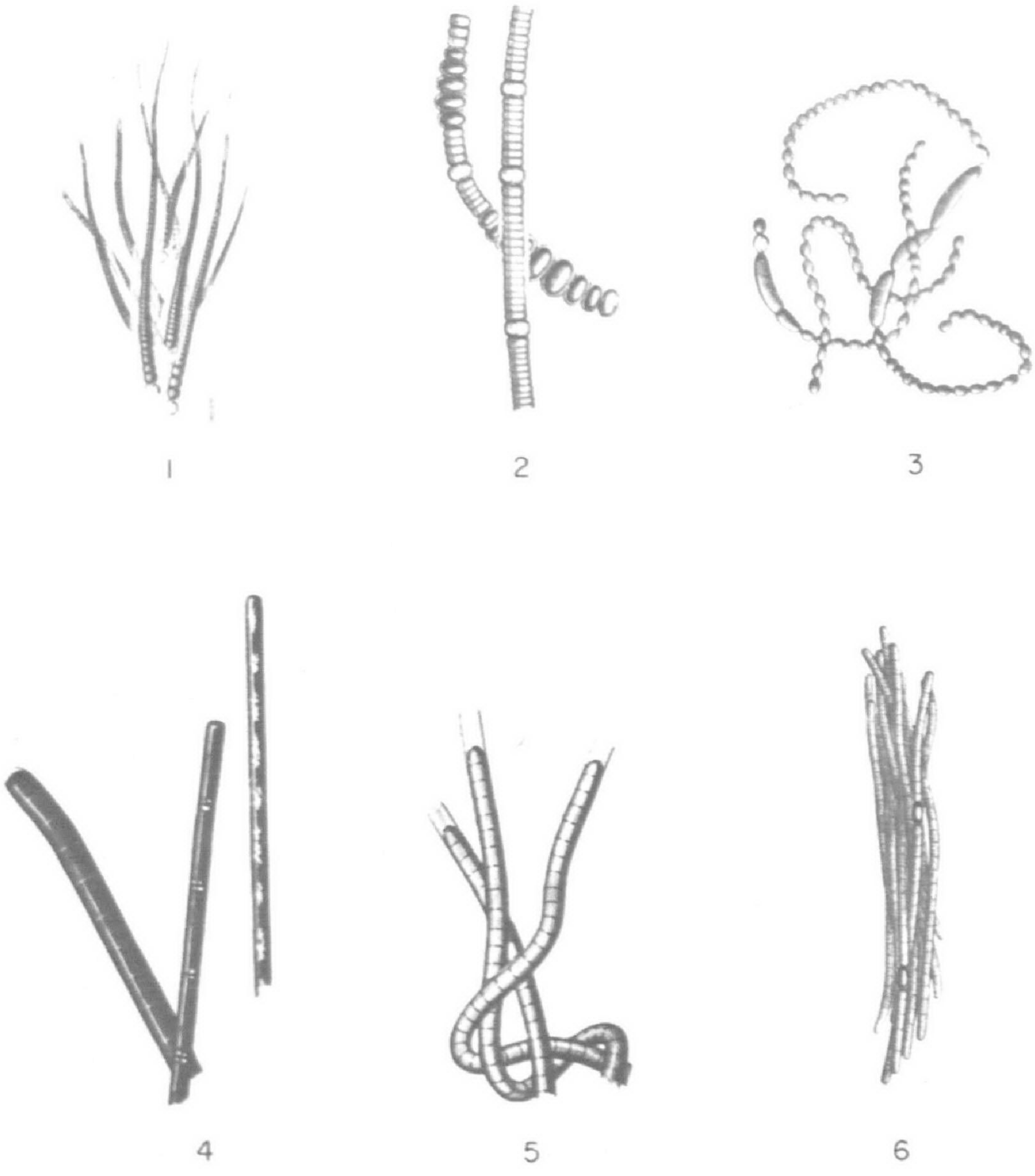

Plate 6. Nuisance Algae

1. *Rivularia,* 2. *Nodularia,* 3. *Anabaena,*
4. *Oscillatoria,* 5. *Lyngbya,* 6. *Aphanizomenon,*

An artificial key is presented for a few algal genera that the writers have commonly encountered in recreational waters. Because of a preponderance of genera associated with the fresh-water environment, other publications useful in supplying descriptive comments and pictures

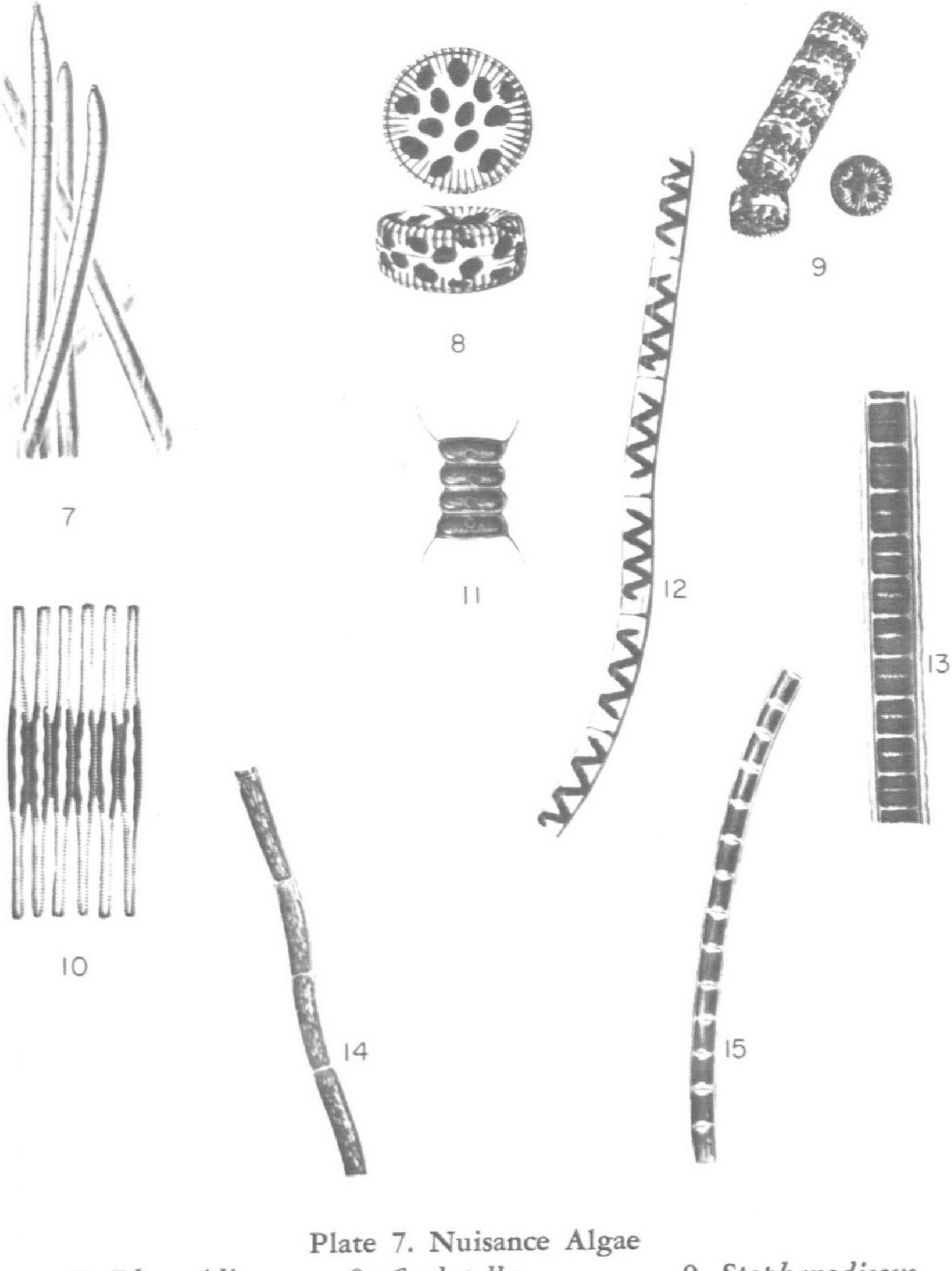

Plate 7. Nuisance Algae

7. *Phormidium,* 8. *Cyclotella,* 9. *Stephanodiscus,* 10. *Fragilaria,* 11. *Scenedesmus,* 12. *Spirogyra,* 13. *Zygnema,* 14. *Oedogonium,* 15. *Ulothrix*

for identification are listed. These include Forest (1954), Palmer (1959), Prescott (1951), Prescott (1954), Smith (1950), Taft (1961), and Tiffany and Britton (1952).

*An Artificial Key to Some Aquatic Nuisance Algae**

To use the key, the specimen must be observed under a microscope to determine its pertinent characteristics. These characteristics are compared against the first couplet in the key. After the one that best fits the specimen is chosen, one must proceed to the designated couplet following and repeat the operation until a genus is reached.

1. Plant consisting of a thread, strand, ribbon, or membrane composed of cells; frequently visible to the unaided eye ---------- 2

1. Plants of microscopic cells that are isolated or in irregular, spherical, or microscopic clusters; cells not grouped into threads -- 25

2. Heterocysts present. (Heterocysts are specialized cells, larger, clearer, and thicker walled than the regular cells in a filament; they separate from other algal cells permitting portions of chains to grow into completely new individuals) ---------------- 3

2. Heterocysts absent ---------------------------------- 8

3. Threads gradually narrowed to a point at one end, appearing as radii, in a gelatinous bead or mass ------------------------ 4

3. Threads same width throughout -------------------- 5

4. Spore (an asexual reproductive structure) present, adjacent to the terminal heterocyst ------------------------ *Gloeotrichia*

4. No spore present ------------------------------ *Rivularia*

5. Branching absent, heterocysts contained within the filament, threads encased in a gelatinous bead or mass -------------- *Nostoc*

5. Threads not encased in a definite gelatinous mass ---------- 6

6. Heterocysts and vegetative cells shorter than the thread width -- *Nodularia*

6. Heterocysts and vegetative cells not shorter than the thread width -- 7

7. Heterocysts rounded ---------------------------- *Anabaena*

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*Modified from Palmer, C. M. (1959)

7. Heterocysts cylindric------------------------ *Aphanizomenon*

8. Branching absent------------------------------------ 9

8. Branching (including "false" branching) present---------- 20

9. Cell pigments distributed throughout the protoplasm------- 10

9. Cell pigments limited to plastids (bodies within plant cell that contain photosynthetic pigments)------------------------- 12

10. Threads long, not forming a spiral, one thread per sheath; sheath or gelatinous matrix present---------------------- 11

10. No sheath or gelatinous matrix apparent----------- *Oscillatoria*

11. Sheath distinct; no gelatinous matrix between threads---- *Lyngbya*

11. Sheath indistinct or absent; threads interwoven with gelatinous matrix between----------------------------------- *Phormidium*

12. Cells forming a thread or ribbon, cells separating readily into discs or short cylinders, their circular face showing radial markings------------------------------ *Cyclotella, Stephanodiscus*

12. Cells either not separating readily, or if so, no circular end wall with radial markings------------------------------- 13

13. Cells in a ribbon, attached side by side or by their corners--- 14

13. Cells in a thread, attached end to end------------------ 15

14. Numerous regularly spaced markings in the cell wall---- *Fragilaria*

14. Numerous markings in the cell wall absent---------- *Scenedesmus*

15. Plastid in the form of a spiral band----------------- *Spirogyra*

15. Plastid not a spiral band---------------------------- 16

16. Plastids two per cell, cells with a smooth outer wall------ *Zygnema*

16. Plastids either one or more than two per cell-------------- 17

17. Plastids close to the cell wall, occasional cells with one to several transverse wall lines near one end------------ *Oedogonium*

17. Occasional terminal transverse wall lines not present------- 18

18. Cells with one plastid that has a smooth surface, cells with flat ends----------------------------------- *Ulothrix*

18. Cells with several plastids or with one modular plastid------ 19

19. Iodine test for starch positive, one plastid per cell, threads when broken separating irregularly or between cells--- *Rhizoclonium*

19. Iodine test for starch negative, several plastids per cell, side walls of cells straight, not bulging. A pattern of fine lines or dots present in the wall but often indistinct----------------- *Melosira*

20. Branches reconnected, forming a distinct net------ *Hydrodictyon*

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20. Branches not forming a distinct net------------------- 21

21. Each cell in a conical sheath open at the broad end----- *Dinobryon*

21. No conical sheath around each cell-------------------- 22

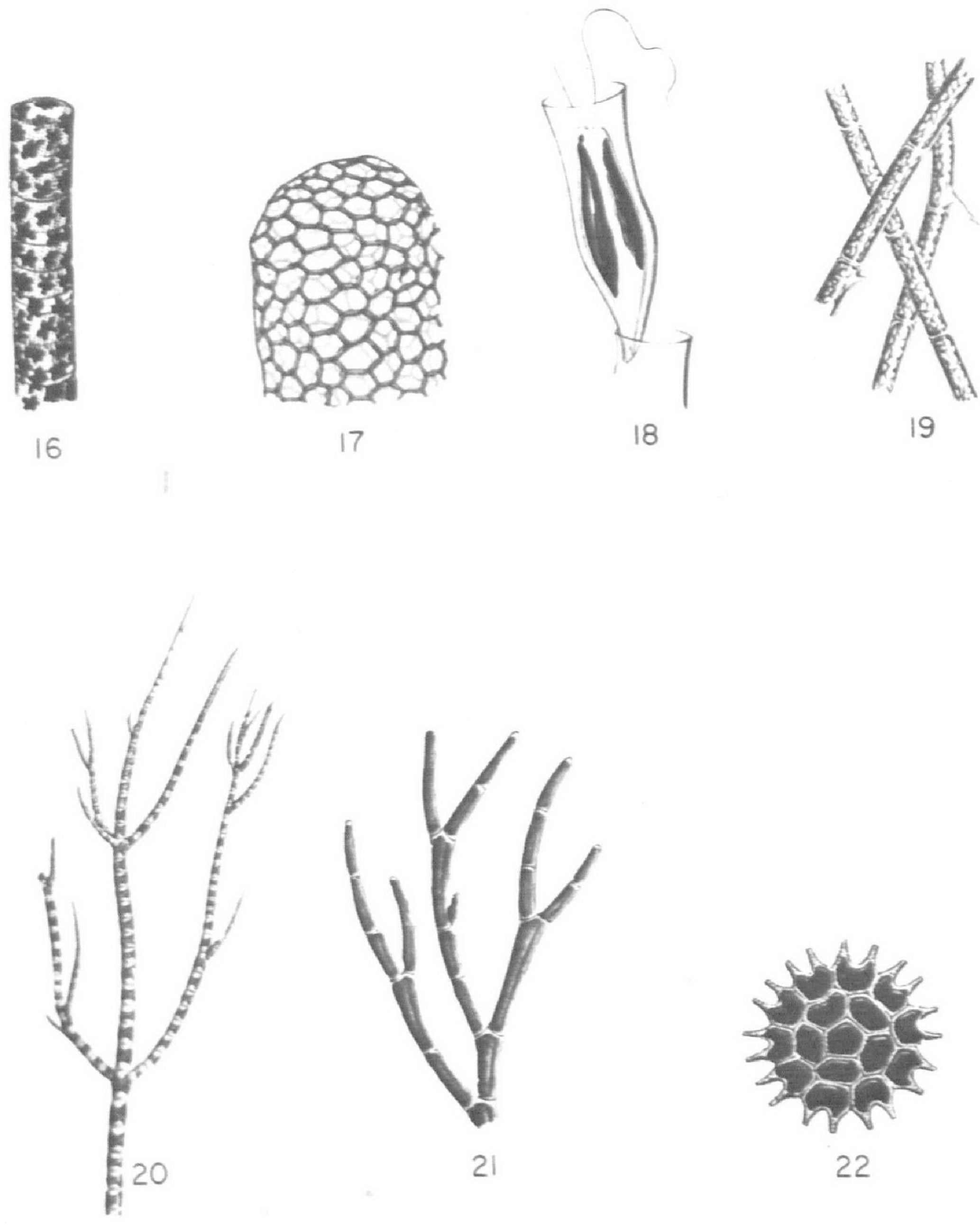


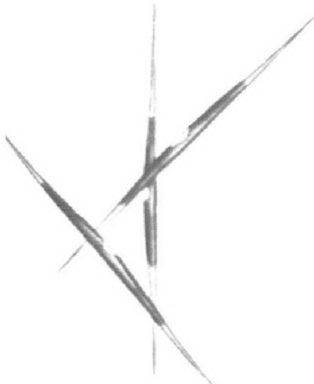
Plate 8. Nuisance Algae

16. *Melosira,*
17. *Hydrodictyon,*
18. *Dinobryon,*
19. *Rhizoclonium,*
20. *Stigeoclonium,*
21. *Cladophora,*
22. *Pediastrum*

22. Branching commonly single or in pairs, cells green, threads not surrounded by a gelatinous mass, light and dense dark cells intermingled in the thread ---------------------------- *Pithophora*

22. Most of cells essentially alike in density ----------------- 23

23. Branches few in number, and short, colorless ------- *Rhizoclonium*



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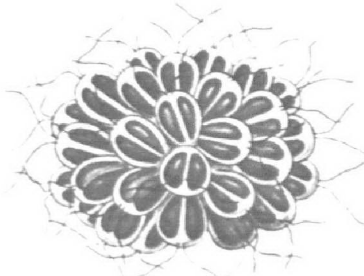

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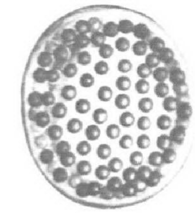

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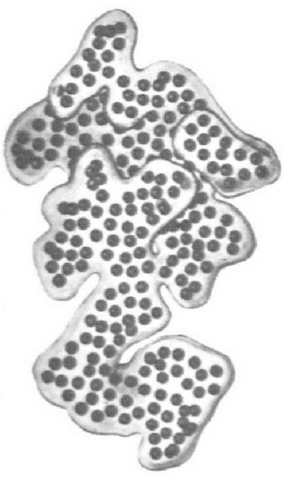

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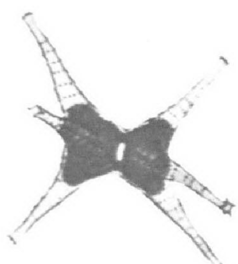

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Plate 9. Nuisance Algae

23. *Ankistrodesmus*,
24. *Synura*,
25. *Coelosphaerium*,
26. *Microcystis*,
27. *Ceratium*,
28. *Staurastrum*

23. Branches numerous and green-------------------------- 24

24. Terminal attenuation (a continuous decrease in width of a filament, often to a point or thin hair) gradual, involving two or more cells-------------------------------------- *Stigeoclonium*

24. Terminal attenuation absent or abrupt, involving only one cell -- *Cladophora*

25. Cells in colonies generally of a definite form or arrangement-- 26

25. Cells isolated, in pairs or in loose, irregular aggregates---- 31

26. Cells without transverse rows of markings, cells arranged as a layer one-cell thick-- 27

26. Cells without transverse rows of markings, cell cluster more than one-cell thick and not a flat plate---------------------- 28

27. Cells elongate, united side by side in one or two rows-- *Scenedesmus*

27. Cells about as long as wide, not immersed in colorless matrix, cells angular with spines, projections, or incisions-------- *Pediastrum*

28. Cells sharp-pointed at both ends; often curved like a bow, loosely arranged or twisted together--------------- *Ankistrodesmus*

28. Cells not sharp-pointed at both ends; not bent as a bow---- 29

29. Flagella present, cells touching one another in a dense colony, cells arranged radially, facing outward, plastids brown-------- *Synura*

29. Flagella absent-- 30

30. Cells not elongate, often spherical, plastids absent, pigment throughout, cells equidistant from center of colony---- *Coelosphaerium*

30. Cells irregularly distributed in the colony, not equidistant from the center, cells rounded----------------------- *Microcystis*

31. Cells with an abrupt median transverse groove or incision; cells brown, flagella present------- armored flagellates (e.g. *Ceratium*)

31. Cells with an abrupt median transverse groove or incision; cells green, no flagella---------------- Desmid (e.g. *Staurastrum*)

TOXIC ALGAE

More and more interest is being aroused in the toxic effects of fresh-water algae on animals. This interest stems partly from a recent upswing in the number of reported cases of animal poisonings related to algal blooms, and from a growing appreciation of the strictly scientific and biological problems involving the physiology of algae, especially those that produce toxic substances (possibly toxins), antibiotics, and growth-stimulating excretions (Ingram and Prescott, 1954). Ingram and Prescott summarize their review as follows: "Outbreaks of human gastroenteritis have not been positively traced to algae. Algae that have been responsible for mammalian, avarian, and fish deaths through some toxic action are all to be found in the blue-green algal group, the Cyanophyta. The Cyanophyta species that have been associated with animal deaths belong in the genera: *Microcystis, Aphanizomenon, Anabaena, Nodularia, Coelosphaerium,* and *Gloeotrichia.* Often when deaths of animals occur, a wind has been reported blowing, thus tending to concentrate algae in lee-shore areas. Cattle that drink only small quantities of water containing *Microcystis* may not die but do show a series of illness symptoms, one of which is a drop in milk yield. Symptomatic treatment has been recommended by Steyn (1945) for cattle poisoned by algae. Various writers have made reference to several toxic substances associated with blue-green algae. Substances that are toxic enough to cause illness or death in animals are not present in all blue-green algae. Water in which certain blue-green algae have bloomed may produce death in mammals and fish when the algal cells themselves are excluded. The toxic material from certain algae may survive the laboratory equivalent of water treatment using alum coagulation, filtration and chlorination. It may survive activated carbon treatment in amounts corresponding to that used in water treatment plants, and after massive treatment with Norite A."

Wheeler et al. (1942) state that no human outbreaks have ever been traced to algal contamination of drinking water, and that it is probable that the tastes and odors almost invariably associated with severe algal pollution would cause human beings to seek other sources for drinking water before a harmful amount of the polluted water would be consumed. These authors state: "It should be noted that the presence of algae in drinking water, in addition to causing tastes and odors, may have some importance from the standpoint of the allergist as algae may, on occasion, liberate considerable amounts of protein in water. If allergic reactions to algae proteins do occur, they would be as uncommon as they would be obscure and hardly likely to occur as a public health problem."

Schwimmer and Schwimmer (1955) chronologically summate 38 incidents of animal intoxications by phytoplankton from 1878 to 1951. In most cases the attacks occurred after the animals had drunk from lakes or ponds containing heavy algal growth, usually during hot weather. The reported symptoms of algae intoxications vary but the most striking clinically are the involvements of neuromuscular and respiratory systems. As aptly described by Francis (1878), "the animals developed stupor and unconsciousness, falling and remaining quiet, as if asleep unless touched, when convulsions came on, with the head and neck drawn back by rigid spasm which subsided before death."

During the past 25 years, phytoplankton has also been incriminated in human reactions resulting in dysenterial disorders, systemic allergic reactions, and local allergic eruptions (tables 5A, 5B and 5C). The epidemic intestinal disorders of the early 1930's involved many thousands of people; however, it was pointed out that the outbreaks were of no known specific etiology, but, significantly enough, were always concomitant with the presence of extensive algal blooms in the local water supply.

Heise (1949) described two cases in one of which itching, conjunctivitis, blocked nares, and bronchial asthma occurred following swimming in Wisconsin lakes, and in the other swollen eyelids, nasal stuffiness, and a severe generalized urticarial eruption. Cohen and Reif (1953) reported phycocyanin, the blue pigment in *Anabaena* as the cause of an erythematous papulo-vesicular contact dermatitis in a 6-year-old child who had bathed in a Pennsylvania lake.

Dr. Robertson* reported from Regina, Saskatchewan, on a physician who went for an evening swim and failed to recognize that an algal scum had blown onto his shore. He slipped on the diving board, fell in, swallowed several mouthfuls of lake water, and within a few hours suffered severe gastrointestinal distress that caused him to be hospitalized for 36 hours. Algae were recognized in his stool specimen and no bacterial or enteric viruses were discovered despite a thorough search.

HIGHER AQUATIC PLANTS

Higher aquatic plants are most abundant in old lakes or those fertile water bodies in which there has been sedimentation. Higher plants provide food, shelter and attachment surfaces for other organisms, add dissolved oxygen to the water under favorable light conditions, remove and temporarily store nutrients, and serve as spawning areas for some fish. Plants also contribute to the filling in of a lake through both the precipitation of calcium carbonate and the accumulation of their remains upon death and decay. Plant populations may become sufficiently dense to limit or restrict water use by physical obstruction, to remove large

*Personal communication, dated Feb. 5, 1960, to K. M. Mackenthun from Dr. H. E. Robertson, Director, Division of Laboratories, Department of Public Health, Province of Saskatchewan.

Table 5A. Human Gastro-Intestinal Disorders Associated With Algae*

Year	Locale and Author	Victims	Algae involved	Manifestations of toxicity
1842	London, England (Farre, 1844; Küchenmeister, 1857).	35-year-old married female....	***Oscillatoria intestini* Küchenmeister**	Dyspepsia, griping, bowel obstruction.
1930	Puerto Rico (Ashford, Ciferri and Dalmau, 1930).	Woman..................	***Prototheca portoricensis*......**	"Atypical sprue."
1930	Puerto Rico (Ashford, Ciferri and Dalmau, 1930).	.....do..................	***Prototheca portoricensis* var. *trispora*.**	"Suspicious of sprue."
1930	Suburbs of Washington, D.C., U.S.A. (Tarbett and Frank cited in Tisdale, 1931).	Many families...............	unidentified algae...........	Sudden onset of nausea, vomiting, epigastric pain, diarrhea with cramps of 1–4 days duration.
1930	Charleston, W. Va., U.S.A. (Tisdale, 1931; Veldee, 1931; Tarbett cited in Tisdale, 1931).	8,000 to 10,000 people......	Blue-green algae............	Do.
1931	Ironton and Portsmouth, Ohio, U.S.A. (Waring cited in Tisdale, 1931; Veldee, 1931).	Many people..............	unidentified algae...........	"Intestinal influenza."
1930–1931	Louisville, Ky., U.S.A. (Tisdale, 1931; Veldee, 1931).	.....do..................	.....do..................	"Intestinal disorders."
1930–1931	Weston, W. Va., U.S.A. (Tisdale, 1931).	.....do..................	.....do..................	Do.
1930–1931	Sisterville, Ohio, U.S.A. (Tisdale, 1931).	.....do..................	.....do..................	Do.
1925, 1929, 1930	Yellowstone National Park, Wyo., U.S.A. (Spencer, 1930).	500 people..............	....	Nausea, vomiting, diarrhea, cramp, pains of 6–48 hours duration. Frontal headaches.

See footnotes at end of table.

Table 5A. Human Gastro-Intestinal Disorders Associated With Algae*—Continued

Year	Locale and Author	Victims	Algae involved	Manifestations of toxicity
1931	Huntington, W. Va.; Ashland, Ky.; Cincinnati, Ohio, U.S.A. (Veldee, 1931).	Thousands of people	"Algae"	Abdominal pain, nausea, vomiting and diarrhea.
1940	New Jersey, U.S.A. (Nelson in Monie, 1940).	Humans	*Anabaena*	"Gastrointestinal disorders."
1959	Gull Lake, Saskatchewan, Canada (Dillenberg, 1959; Dillenberg and Dehnel, 1960; Senior, 1960).	Oregon tourist	*Microcystis*	Headache, nausea, and gastro-intestinal upset.
1959	Govan, Long Lake, Saskatchewan, Canada (Dillenberg, 1959; Senior, 1960).	Ten children at a camp	*Anabaena*	Diarrhea and vomiting.
1959	Fort Qu'Appelle, Echo Lake, Saskatchewan, Canada (Dillenberg, 1959; Dillenberg and Dehnel, 1960; Senior 1960).	Dr. M., a physician, practicing part-time.	1. *Microcystis* 2. *Anabaena circinalis*	Crampy stomach pains, nausea, vomiting, painful diarrhea, fever, headache, weakness, pains in muscles and joints.
1960	Regina, Saskatchewan, Canada (Dillenberg, 1962).	Physician's 4-year-old son	*Aphanizomenon*	Abdominal pain, nausea, vomiting, diarrhea, wooziness, headache, thirst.
1961	Saskatchewan, Canada (Dillenberg, 1962).	Four students	1. *Microcystis* 2. *Anabaena*	Headaches, general malaise, loose stools.

See footnotes at end of table.

Table 5B. Human Respiratory Disorders Associated With Algae*

Year	Locale and Author	Victims	Algae involved	Manifestations of toxicity
1916	West Coast of Florida, U.S.A. (Taylor, 1917).	Many people	Dinoflagellates	Sneezing, coug ing, chest tightness, dyspnea, sore throat, stuffed nose.
1934–1935	Texas Coast, U.S.A. (Lund, 1935).	Humans	"Heavy inshore plankton growth."	Irritation.
1934	Muskego Lake, Waukesha County, Wis., U.S.A. (Heise, 1949).	42-year-old man	***Oscillatoriaceae***	Itching of eyes, complete blockage of nose.
1935	.....do	Same man, 1 year later	.....do	Itching of eyes, complete blockage of nose, plus mild asthma.
1936–1946	North Lake, Waukesha County, Wis., U.S.A. (Heise, 1949).	Same patient	.....do	Nasal discharge and blockage asthma.
1945	Lake Keesus, Waukesha County, Wisconsin, U.S.A. (Heise, 1949).	39-year-old woman	.....do	Swollen eyelids, blocked nares, generalized urticaria.
1946	.....do	Same patient	.....do	Do.
1946–1947	Captiva Island, Fla., U.S.A. (Gunter, Williams, Davis and Smith, 1948).	Humans	***Gymnodinium brevis***	Burning of eyes, stinging of nostrils, hard cough.
1946–1947	Captiva Island, and other islands off the west coast of Florida, (Galtsoff, 1948).	.....do	.....do	Burning in throat, nostrils and eyes; sneezing and coughing.
1946–1947	West Coast of Florida, U.S.A. (Hutner and McLaughlin, 1958).	.....do	.....do	Irritation of respiratory tract.
1947	Venice, Fla., U.S.A. (Thompson cited in Woodcock, 1948).	.....do	***Gymnodinium* sp**	Hard cough, burning in respiratory tract.
1947	Venice, Fla., U.S.A. (Woodcock, 1948).	Author and two companions	.....do	Do.
1947	Venice Beach, Fla., U.S.A. (Woodcock, 1948).	.....do	.....do	Throat irritation.
1947	Lower west coast of Florida, U.S.A. (Ingle, 1954).	People near shoreline	***Gymnodinium brevis***	Irritation of eyes, nose and throat.

See footnotes at end of table.

Table 5C. Human Skin Disorders Associated With Algae*

Year	Locale and Author	Victims	Algae involved	Manifestations of toxicity
1937–1949	Lower east coast of Florida, U.S.A. (Sams, 1949).	67 ocean bathers	"Plankton"	Erythematous wheals (in areas covered by bathing suit) itching, fever.
1950	Lake Carey, Pa., U.S.A. (Cohen and Reif, 1953).	4-year-old girl	*Anabaena*	Erythematous papulo-vesicular dermatitis.
1951	Lake Carey, Pa., and Canada (Cohen and Reif, 1953).	Same patient 1 year later	do	Do.
1952	do	Same patient 2 years later	do	Do.
1953	Pennsylvania, U.S.A. (Cohen and Reif, 1953).	Swimmers	Blue-green algae	Itching, swelling and redness of conjunctivae.
1958	Oahu, Hawaii, U.S.A. (Grauer, 1959; Banner, 1959; Grauer and Arnold, 1962).	125 cases received treatment; hundreds of mild unreported cases.	*Lyngbya majuscula* Gomont	Itching and burning of skin, erythema, blisters, desquamation in areas covered by bathing suit.
1959	Oahu, Hawaii, U.S.A. (Grauer and Arnold, 1962).	31-year-old medical officer	do	Do.
1959	do	Nine-year-old niece	do	Do.
1959	do	Two other adults	do	Do.
1961	Georgia, U.S.A. (Hardin, 1961).	People who swam in seawater off Florida coast.	"Ocean organism"	Do.

*Tabular data and the special references at the end of this chapter were graciously supplied by Dr. Morton Schwimmer on Jan. 13, 1964. Table 5 is a modification of data in:

(1) Schwimmer, M. and D. Schwimmer, 1955. The Role of Algae and Plankton in Medicine. Grune and Stratton, N.Y., 85 pp.

(2) Schwimmer, D. and M. Schwimmer. Algae and Medicine. Presented Aug. 2, 1962, NATO Advanced Institute, "Algae and Man" at Potamological Institute, University of Louisville, Louisville, Ky.

(3) Schwimmer, D. and M. Schwimmer. Algae and Disease. To be published.

quantities of water through transpiration, and to contribute to the stunting of fish populations. Upon death and decay, stored nutrients are released for reuse.

Factors that limit growth include lack of sufficient light, insufficient nutrients, physical instability because of water level fluctuation and current and wave action, an unsuitable bottom stratum, and competition by other plants and animals.

Dispersal of water plants is accomplished largely by water, migratory birds, and, to a lesser extent, domestic and other animals. Seeds may remain viable after passing through the digestive tract of animals, and seeds and other means of propagation may be carried externally. Water plants usually produce an abundance of seeds, but propagation through vegetative means is a most effective method of distribution. A small broken portion of a healthy plant may soon reestablish itself as another healthy individual, when, in settling out of water, it roots again on a suitable substrate. Most aquatic plants are perennials and are well adapted to withstand drought and heavy cropping by animals.

When green plants are actively growing in sufficient light, they produce more oxygen through photosynthesis than they use in respiration. This is important to aquatic organisms since the excess oxygen production comes at a time when high water temperatures preclude maximum oxygen retention within the water and, concurrently, maximum organism production utilizes a maximum amount through respiration. On the other hand, extensive plant mortality in a pond or small lake may cause an oxygen depletion through plant decomposition.

Ducks commonly feed on the seeds, tubers, rootstocks, and foliage of water plants. Martin and Uhler (1939) in a summary based on a study of the stomach contents of 7,998 ducks of 18 species collected in 247 localities scattered in all but six of the States and in one Canadian province reported that nearly half the food consumed was derived from the higher freshwater plants (table 6).

Table 6. Plants That Constitute Over 1 Percent of the Total Game Duck Food. (From Martin and Uhler, 1939)

Plant	Percent	Plant	Percent
Pondweed ***Potamogeton***	11.04	Wild rice ***Zizania***	1.95
Bulrush ***Scirpus***	6.42	Chufa ***Cyperus***	1.41
Smartweed ***Polygonum***	4.71	Watershield ***Brasenia***	1.36
Wigeongrass ***Ruppia***	4.27	Spikerush ***Eleocharis***	1.25
Muskgrass ***Chara***	2.47	Duckweed ***Lemnaceae***	1.23
Wild millet ***Echinochola***	2.38	Waterlily ***Nymphaea***	1.07
Wild celery ***Vallisneria***	2.33	Coontail ***Ceratophyllum***	1.04
Naiad ***Najas***	1.98		

Specific identification of acquatic plants is possible sometimes only through the examination of minute plant parts by experienced individuals.

A key is presented that will aid in the identification of the common plant groups. It is divided as follows:

A. Plants floating on water surface.

B. Plants submerged beneath water surface.

C. Plants erect and emergent; rooted to the substratum and extending upward out of the water.

Other manuals supplying descriptive comments and pictures as an aid to more specific identification include: Eyles and Robertson (1944), Fassett (1960), Martin et al. (1957), Morgan (1930), and Muenscher (1944).

An Artificial Key to Some Common Aquatic Plants

To use the key, one must select the proper group and read the description in the first couplet. The description that best fits the unknown specimen will indicate either the plant group or genus to which the specimen belongs or an additional couplet, in which case the process is repeated until the description for a particular plant or genus best fits the unknown specimen.

A. Plants floating on water surface.

1. A lobed or regularly forked plant body, usually small in size, roots usually suspended free in the water, with no connection to lake bottom; capable of drifting________________________ 2

The duckweed group includes the smallest of the aquatic flowering plants. They have no true leaves nor stems, but the floating green plant body, usually possessing tiny roots that penetrate the water, looks like a leaf and is often so-called. Duckweed floats on the surface of pools, marshes, and ponds, and may grow abundantly in enriched streams from where it may enter standing water areas and become a nuisance as it is held by plant and other obstructions. It may become sufficiently dense to prohibit sunlight from penetrating the water, thus killing algae and other aquatic plants. It causes physical obstruction to water use, creates an unsightly condition, and upon decomposition produces odors. It is difficult to kill because of the waxy sheen to the plant body and the characteristic "layering" effect of one upon another. Wind or currents aid greatly in dispersing

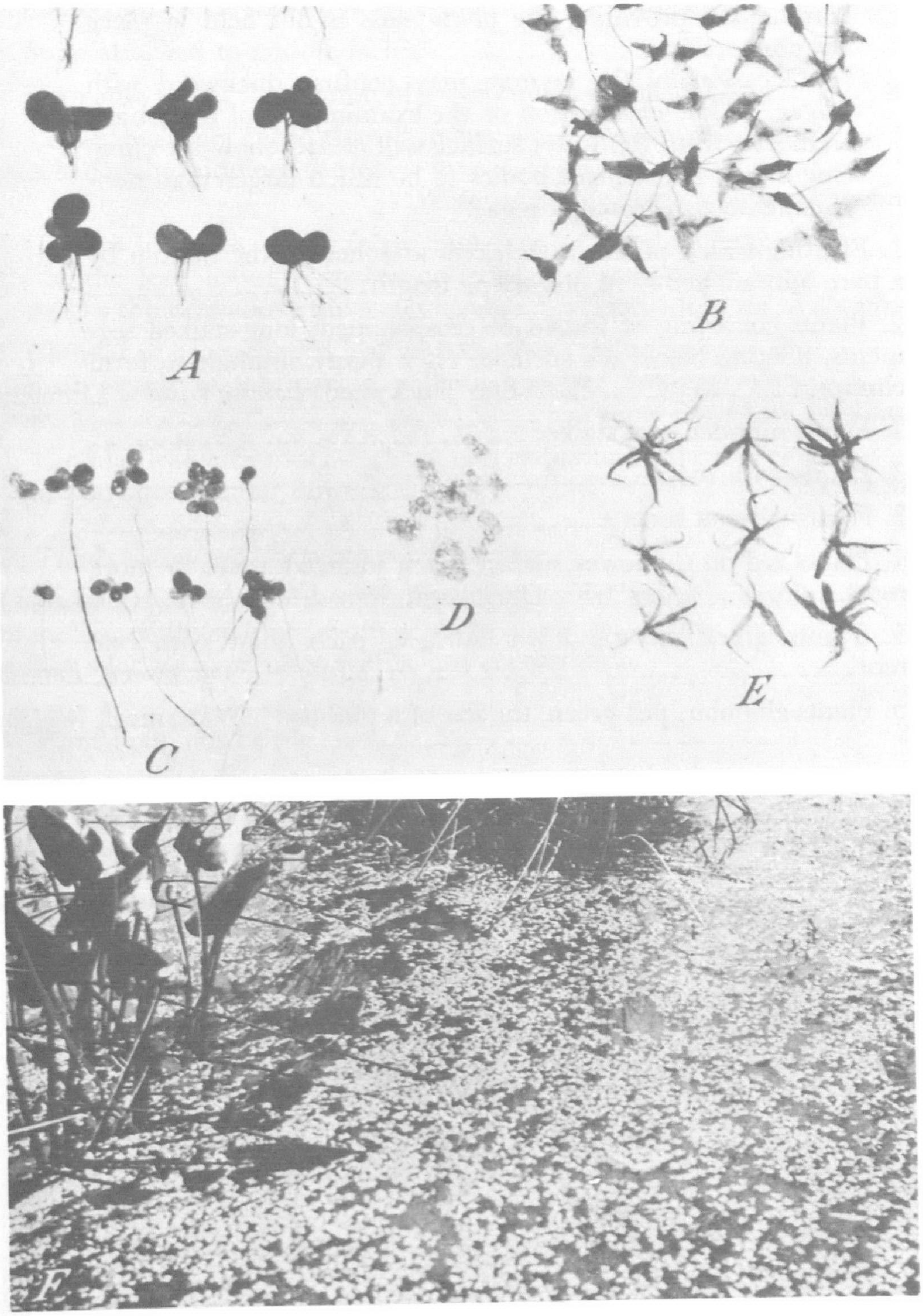

Plate 10. Duckweeds (Lemnaceae) A. Big duckweed [*Spirodela polyrhiza* (Linnaeus)]; B. star duckweed (*Lemna trisulca* Linnaeus); C. duckweed (*Lemna*); D. watermeal (*Wolffia*); E. *Wolffiella;* F. big duckweed on a Maryland pond.

production providing the plant mass is not held in place by obstructions.

Occasionally the layman may confuse duckweed with algae. Close observation or the examination of any object removed from the water surface will clearly show the clinging bright green plant bodies to be much larger than non-filamentous microscopic algae.

1. Floating-leafed plants with leaves attached to the bottom by a bare unbranched stem of varying length------------------ 6

2. Plants consisting of forked or cross-shaped, long-stalked segments, floating below the surface; often many entangle to form clumps------------------ Star Duckweed, *Lemna trisulca* Linnaeus

2. Plants rounded, not stalked------------------------------ 3

3. Plants with roots-- 4

3. Plants without roots------------------------------------- 5

4. Plants red on the lower surface, each joint with two or more roots--------------- Big Duckweed, *Spirodela polyrhiza* (Linnaeus)

4. Plants green on the lower surface, each joint with one root-------------------------------------- Duckweed, *Lemna*

5. Plants globular, pea green, the size of a pinhead--Watermeal, *Wolffia*

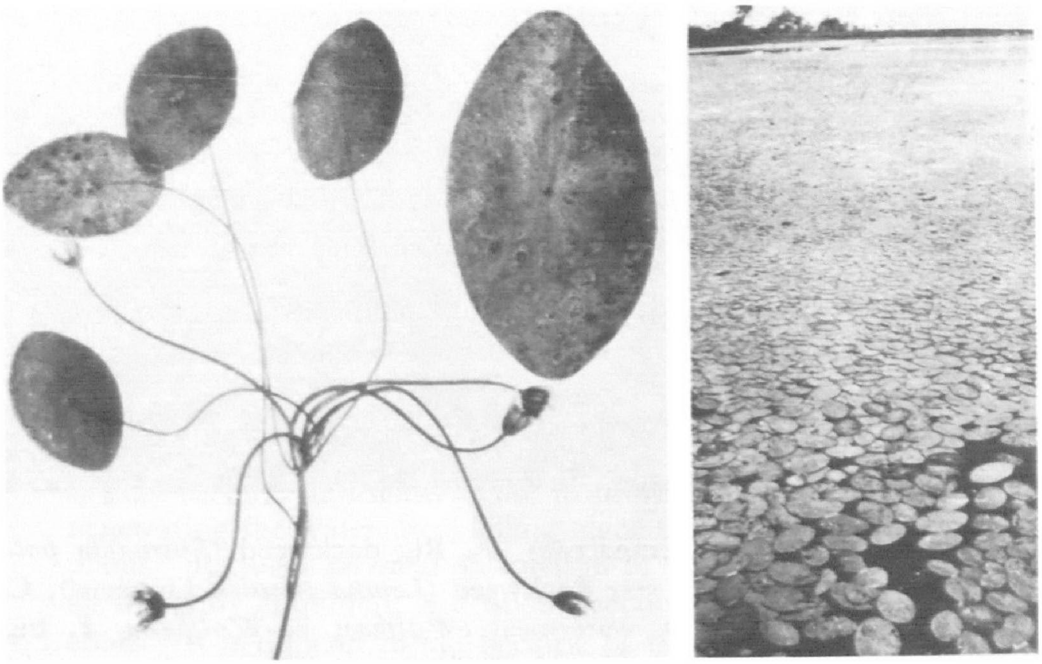

Plate 11. Watershield (*Brasenia schreberi* Gmelin) × 3/8.

5. Plants thin, sickle-shaped or elongated-------- Duckweed, *Wolffiella*

6. Stem attached to middle of leaf-------------------------- 7

6. Stem attached at the summit of a deep notch in the leaf------ 8

7. Leaves oval, not more than 3 inches wide, with supple stem attached to the middle of the leaf
Watershield, *Brasenia schreberi* Gmelin

7. Circular leaf with a long, fairly rigid stem attached to the middle of the leaf, leaves 6 inches or more wide sometimes supported by the stem above the water level---- American Lotus, *Nelumbo*

8. Circular or heart-shaped leaf with the veins radiating from the mid-rib nearly to the margin without forking; floating yellow flowers--------------------------------- Yellow Pond Lily, *Nuphar*

8. Circular leaf with much-forked veins radiating to the margin, white, or pink floating flowers-------- White Water Lily, *Nymphaea*

B. Plants submerged beneath water surface.

1. Plant body made up of stems bearing whorled, smooth, brittle branches, easily snapped with a slight pressure; plants with a musky odor, no roots, often with a limy encrustation
Green Algae, Muskgrass, *Chara*

1. Plant body not brittle---------------------------------- 2

Plate 12. American lotus (*Nelumbo*).

Plate 13. Muskgrass (*Chara*) × 4/5.

Plate 14. Bladderwort (*Utricularia*)

2. Submerged leaves bearing small bladders, leaves irregularly forked ---------------------------------- Bladderwort, *Utricularia*

2. Submerged leaves not bladder bearing ------------------ 3

3. Submerged leaves compound, made up of narrow segments or leaflets -- 4

3. Submerged leaves simple, made up of a single narrow blade-- 7

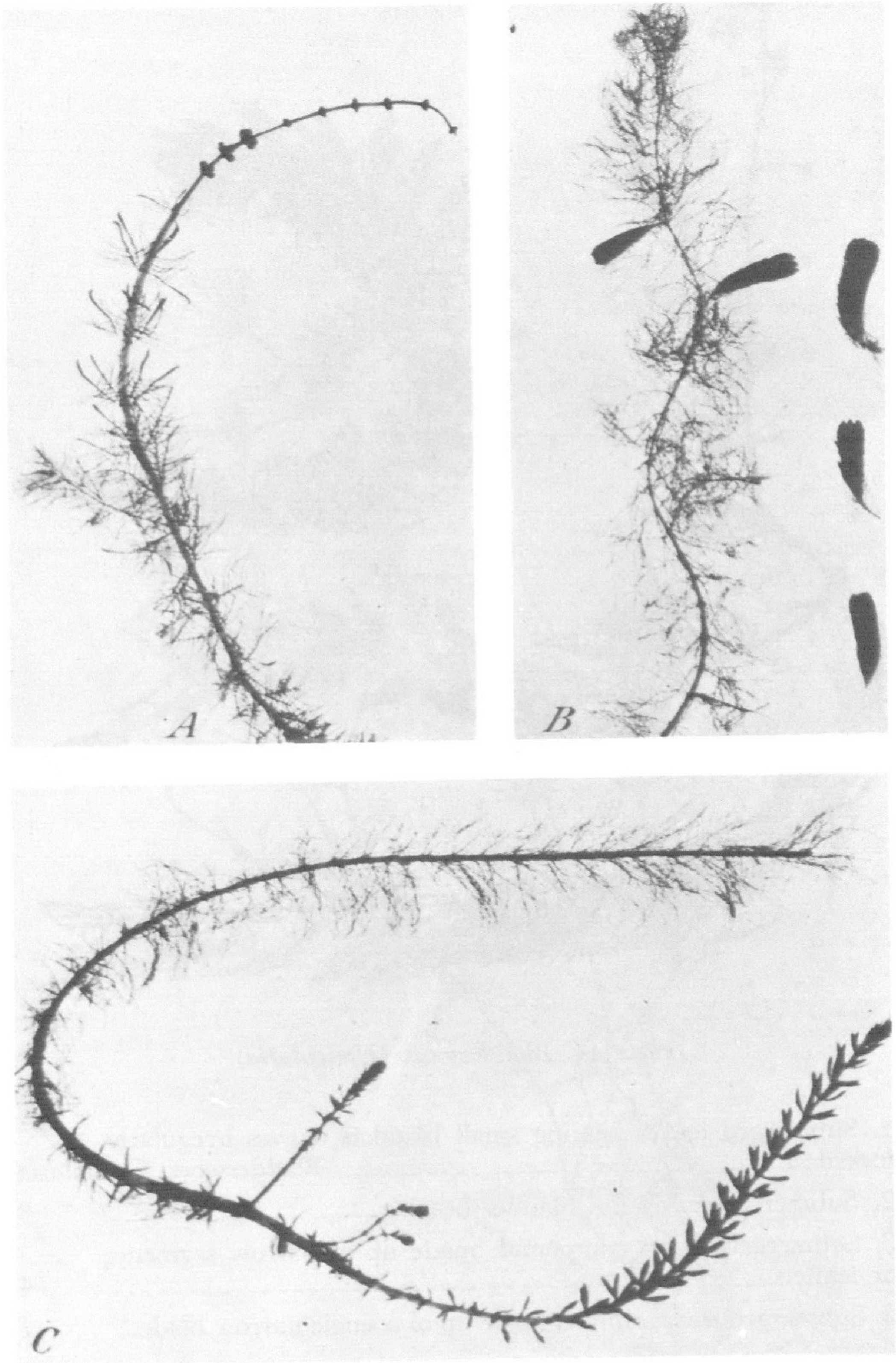

Plate 15. Water Milfoil × ⅓: A. *Myriophyllum spicatum* Linnaeus; B. *M. verticillatum* Linnaeus; C. *M. heterophyllum* Michaux.

Plate 16. Water Buttercup (*Ranunculus*) × ⅖.

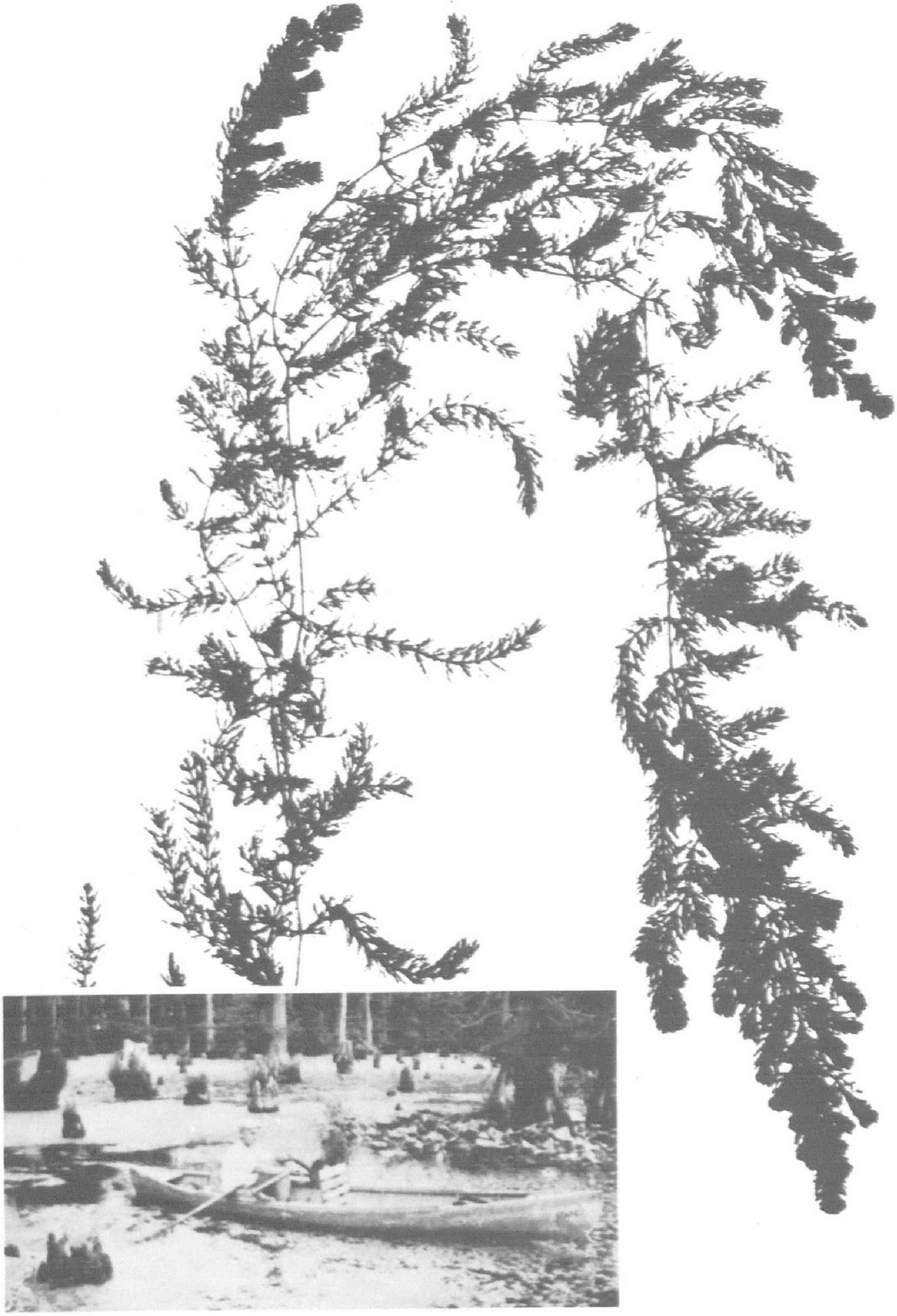

Plate 17. Coontail (*Ceratophyllum*) × 2/5.

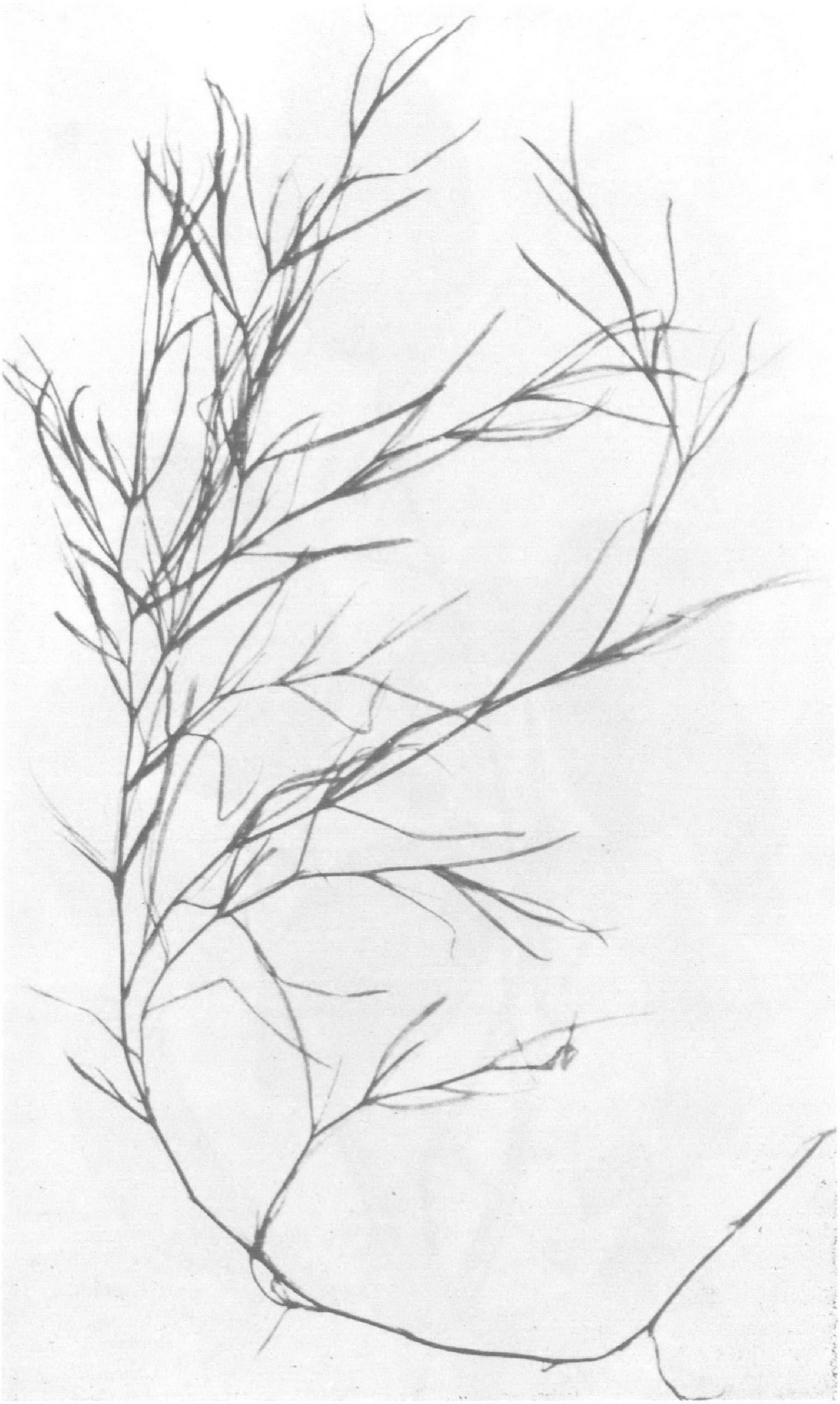

Plate 18. Water Star Grass (*Heteranthera*).

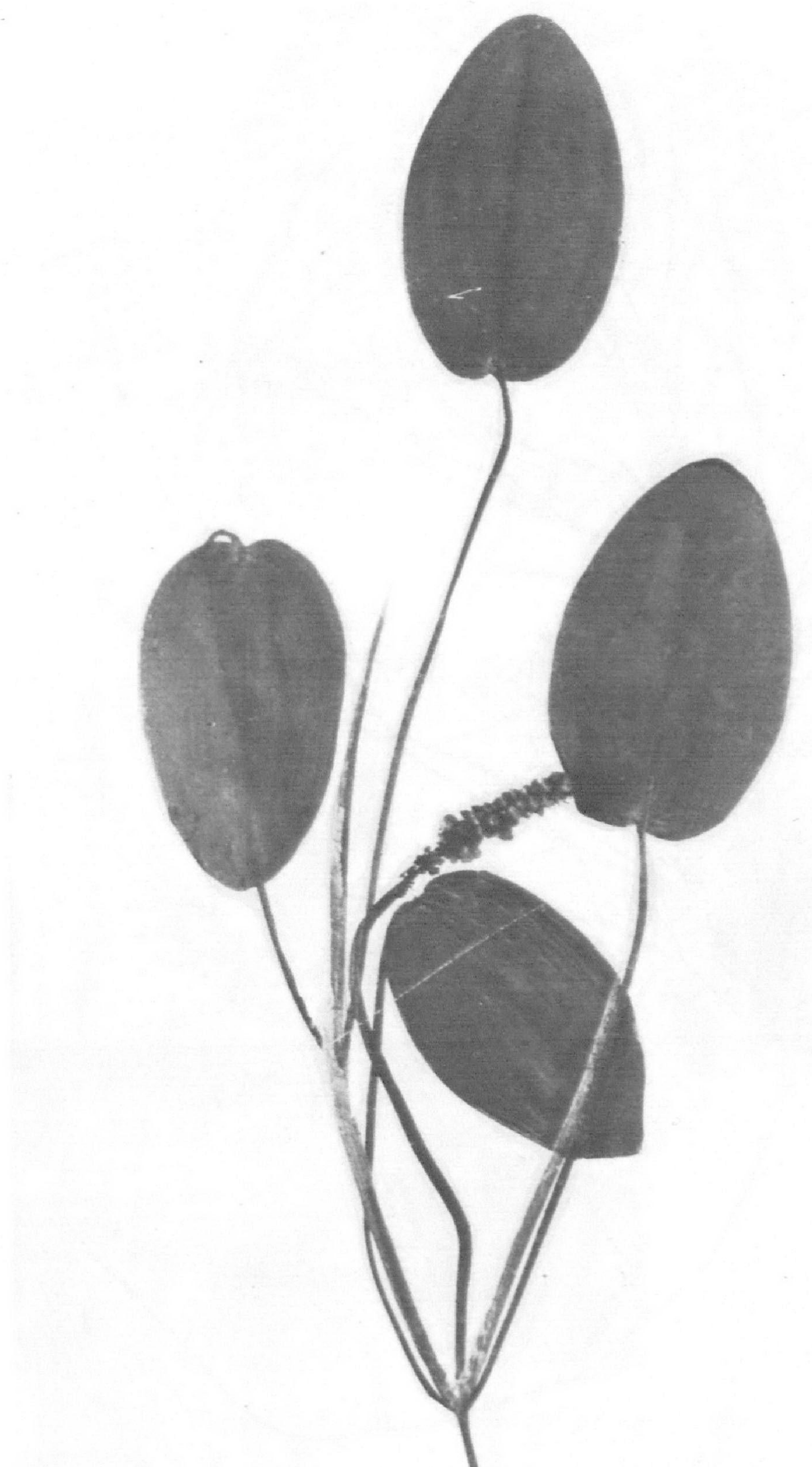

Plate 19. Floating-leafed Pondweed (*Potamogeton natans* Linnaeus

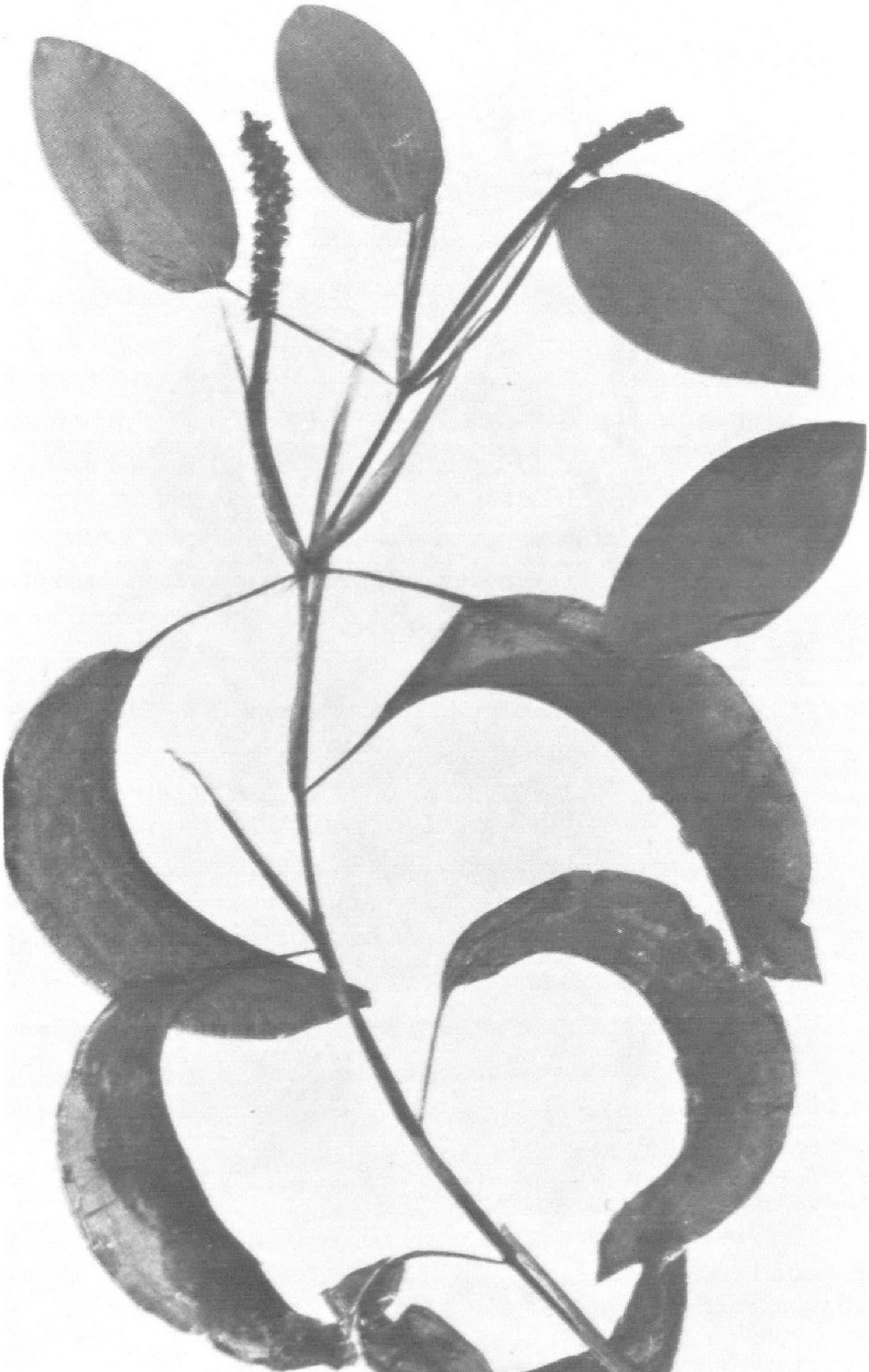

Plate 20. Large-leafed Pondweed (*Potamogeton amplifolius* Tuckerman) × ½.

Plate 21. Curly-leafed Pondweed (*Potamogeton crispus* Linnaeus).

4. Submerged leaves with one central axis, leaves feather-like, branches in whorls about the stem, stems usually very lax Water Milfoil, *Myriophyllum*

4. Submerged leaves irregularly forking ---------------------- 5

5. Submerged leaves singly and alternately or irregularly borne; leaves many branched, irregularly forked and appearing as tufts of numerous thread-like projections attached to the center stem ------------------------------ Water Buttercup, *Ranunculus*

5. Submerged leaves borne opposite each other on stem or whorled 6

6. Leaves stalked, fan-like, extending from opposite sides of the stem; leaflets not toothed ---------------------- Fanwort, *Cabomba*

6. Stems with whorls of stiff, forked leaves; leaflets with toothed or serrated margins (small barbs) on one side; plant without true roots ---------------------------------- Coontail, *Ceratophyllum*

7. Submerged leaves long and ribbon-like, at least 1/10 inch wide 8

7. Submerged leaves not ribbon-like; often thread-like but if wider than 1/10 inch, less than 1 inch long ---------------------- 18

8. Leaves scattered along the stem -------------------------- 9

8. Leaves all borne from one point ------------------------ 17

9. Leaves with mid-ribs evident when held against bright light, many species with great diversity in leaf forms Pondweed, *Potamogeton* 10

9. Leaves without mid-ribs evident when held against bright light ----------------------------- Water Star Grass, *Heteranthera*

10. Plants with both floating and submerged leaves, the floating leaves with expanded blades and differing from those submerged 11

10. Plants with all leaves alike and submerged -------------- 14

11. Floating leaves, heart-shaped at the base, 1 to 4 inches long, waxy in appearance ------------------- Floating-leafed Pondweed, *Potamogeton natans* Linnaeus

11.Floating leaves rounded at the base ---------------------- 12

12. Floating leaves with 30 to 50 nerves; submerged leaves about three times as long as broad ---------------- Large-leafed Pondweed, *Potamogeton amplifolius* Tuckerman

13. Floating leaves with less than 30 nerves ------------------ 13

13. Upper submerged leaves with long stalks ------------ Pondweed, *Potamogeton nodosus* Poiret

13. Submerged leaves not as above but with an abrupt awlshaped tip --------------- Pondweed, *Potamogeton angustifolius* Berchtold

14. Margins of the thin leaves crimpled and toothed, the marginal serrations visible to the naked eye---------- Curly-leafed Pondweed, *Potamogeton crispus* Linnaeus

14. Margins of leaves not visibly toothed-------------------- 15

15. Leaves minutely toothed on the margins, visible when magnified; leaves extending stiffly in opposite directions so that whole plant appears flat; only midvein prominent----- Robbins Pondweed, *Potamogeton robbinsii* Oakes

15. Not as above-- 16

16. Stems much flattened and winged, about as wide as the leaves; leaves 1/12 to 1/5 inch wide------- Flat-stemmed Pondweed, *Potamogeton zosteriformis* Fernald

16. Leaves threadlike, long, rounded, and slender, rarely exceeding 1/10 inch wide, oriented into a lax, diffuse, branched spray. The "bunched" appearance of the threadlike *rounded* leaves as they float in the water readily distinguishes sago pondweed from others of the group------------------------------ Sago Pondweed, *Potamogeton pectinatus* Linnaeus

17. Leaves very long and ribbonlike; when examined with hand lens, showing a central dense zone and a peripheral less dense zone; flowers borne on a long stem that forms a spiral after fertilization--------------------------- Wild Celery, *Vallisneria*

17. Leaf, when examined with hand lens, not showing zones as above--------------------------- Water Plantains, *Alismataceae*

18. Leaves opposite, all leaves elongated and narrow, many times longer than broad, and enlarged or dilated at base. Bunches of smaller leaves near the leaf base----------- Bushy Pondweed, *Najas*

18. Leaves whorled, usually 3 in each whorl, (sometimes 4) Waterweed, *Anacharis* (*Elodea*)

C. Plants erect and emergent; rooted to the substratum and extending upward out of the water.

1. Leaves more than 10 times as long as broad-------------- 2

1. Leaves less than 10 times as long as broad--------------- 9

2. Base of stem triangular in cross-section, the three angles in some cases so rounded as to make the stem appear almost round-- 3

2. Base of stem not triangular--------------------------- 5

3. Three cornered seeds, usually straw colored, enclosed within a loose elongated sac; a low-growing grass-like plant------ Sedge, *Carex*

3. Seeds not enclosed in a loose elongated sac--------------- 4

Plate 22. Robbins Pondweed (*Potamogeton robbinsii* Oakes).

Plate 23. Flat-stemmed Pondweed (*Potamogeton zosteriformis* Fernald) × ½.

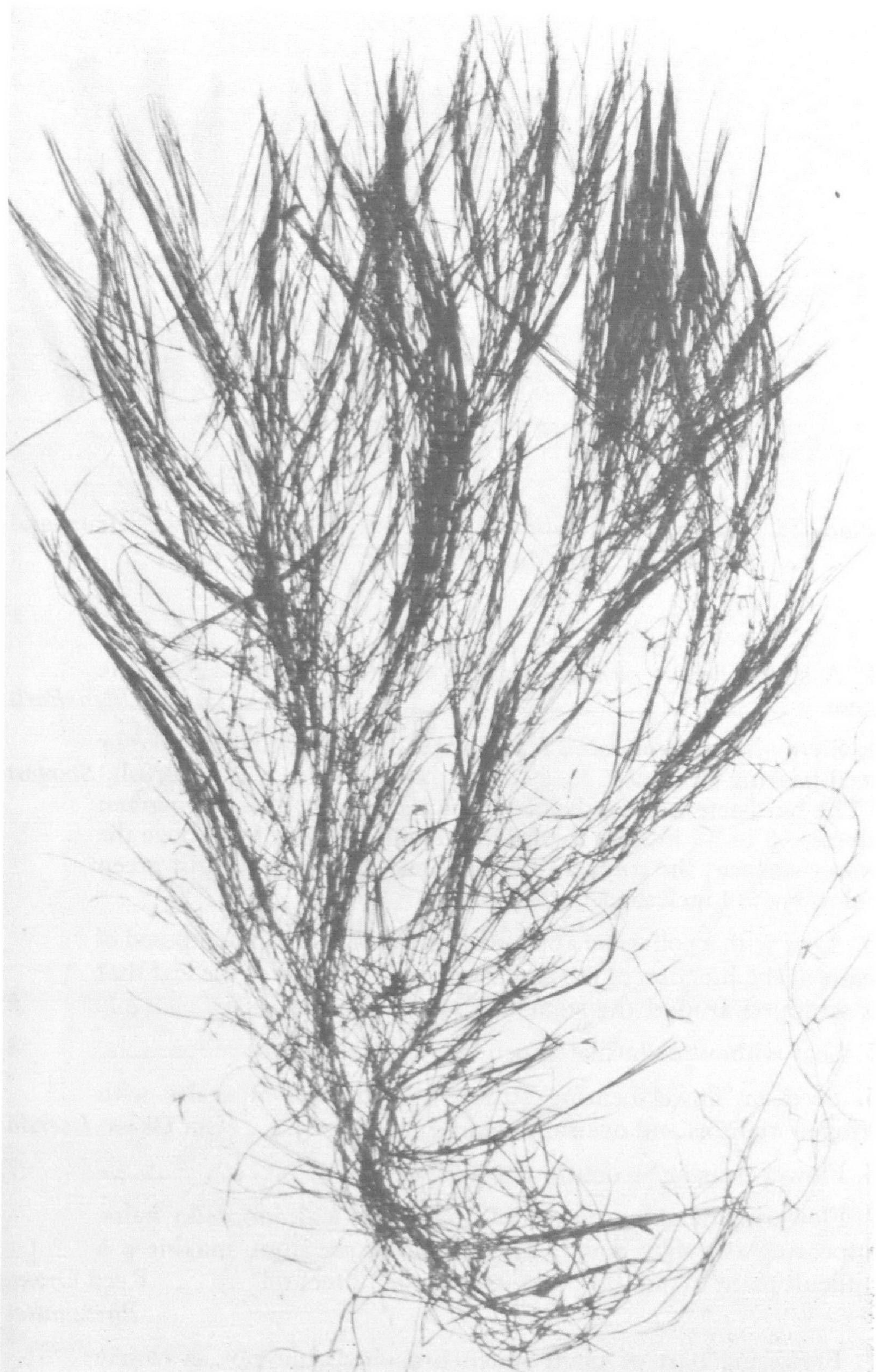

Plate 24.—Sago Pondweed (*Potamogeton pectinatus* Linnaeus).

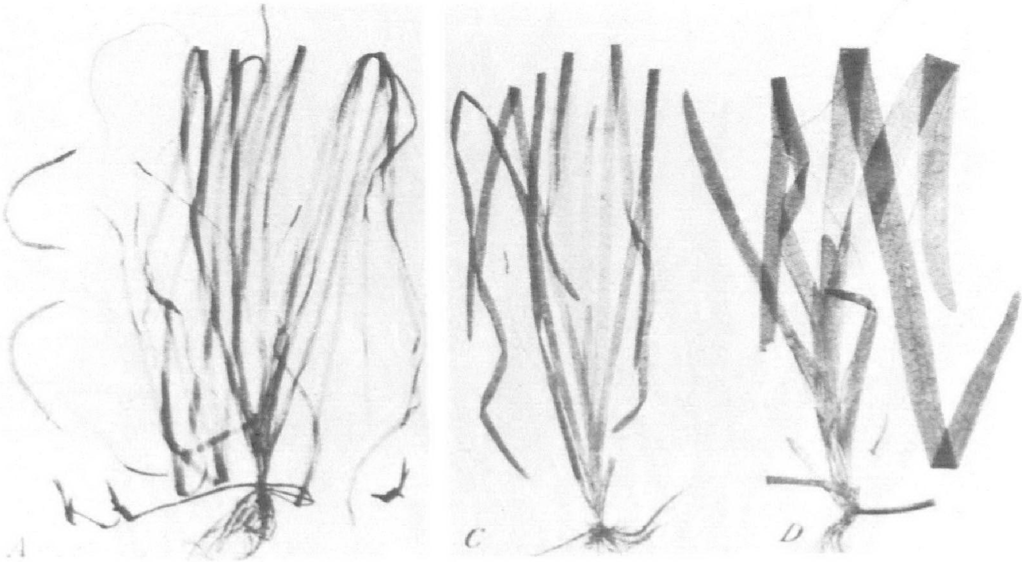

Plate 25. Wild Celery (*Vallisneria*) × ¼: A. Specimen with fruit and tubers; C. Northern form; D. Southern form.

4. A single flower or seed-bearing structure on the tip of the stem------------------------------------ Spike Rush, *Eleocharis*

4. Stem with one or more leaves extending beyond the spike or seed-bearing structure--------------------------- Bulrush, *Scirpus* (The hardstem bulrush has long, hard, slender, dark olive-green stems, ⅛ to ⅜ inch at the base, extending 3 to 5 feet above the water surface; the softstem bulrush has soft stems of light green color, $\frac{3}{10}$ to 1 inch thick at the base.)

5. Leaf with a collarlike appendage, membranous or composed of hairs at the junction of the leaf blade and that part of the leaf that is wrapped around the stem------------------------------ 6

5. Leaf without collarlike appendage mentioned above-------- 8

6. Seed or flower-bearing structure composed of scales with fringed margins and overlapping in a single row---- Cut Grass, *Leersia*

6. Flower-bearing structure not as above------------------ 7

7. Flowering heads composed of small seeds with long silky hairs, appearing as a silky mass. The rootstocks are stout, making it a difficult plant to pull up. Plants are 6 to 12 feet tall------ Reed Grass, *Phragmites*

7. Flowering part of plant much branched, but not as closely packed as in *Phragmites*. Seeds much larger, about ¾ of an inch long. Plants with short roots and easily pulled up-- Wild Rice, *Zizania*

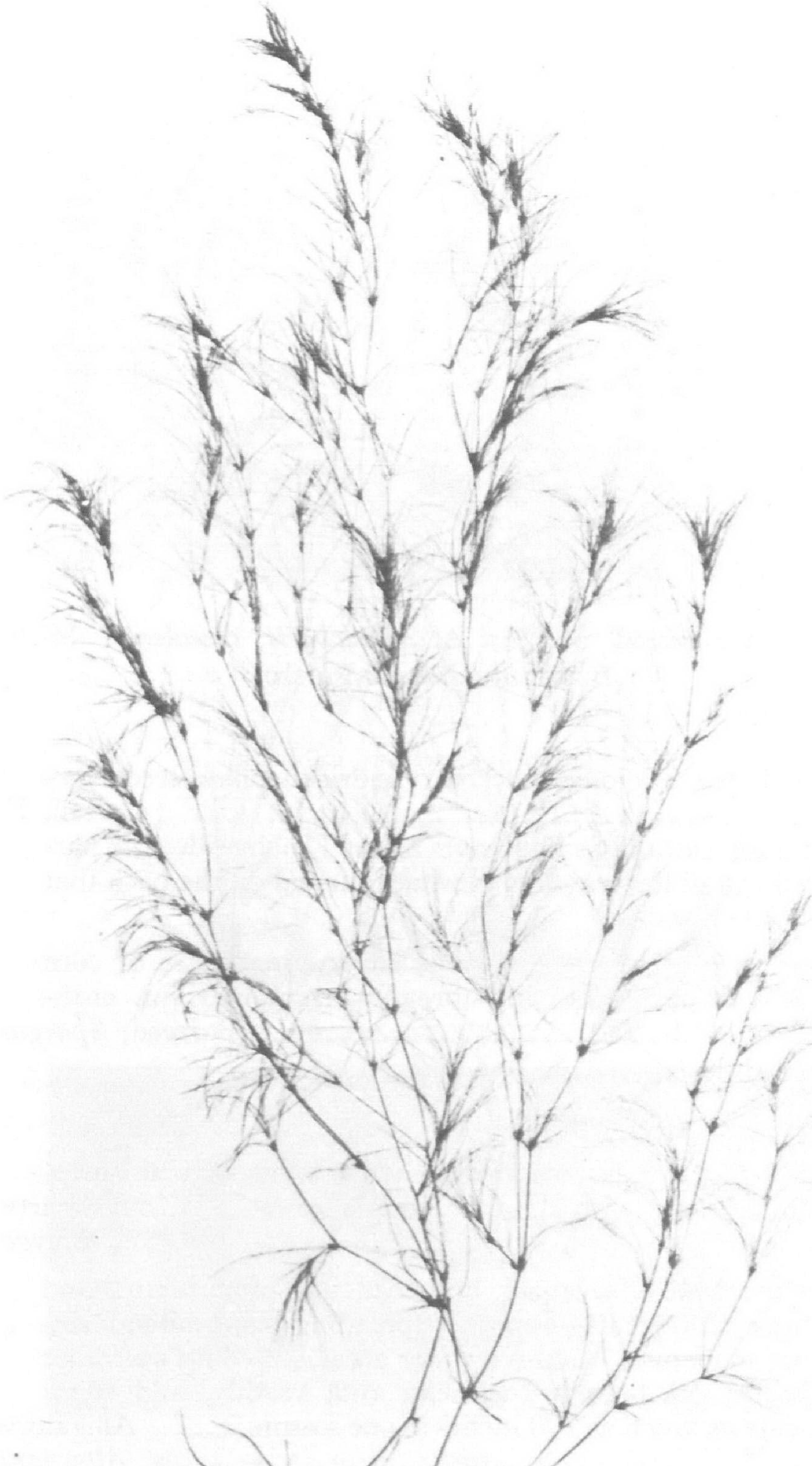

Plate 26. Bushy Pondweed (*Najas*) × ⅝.

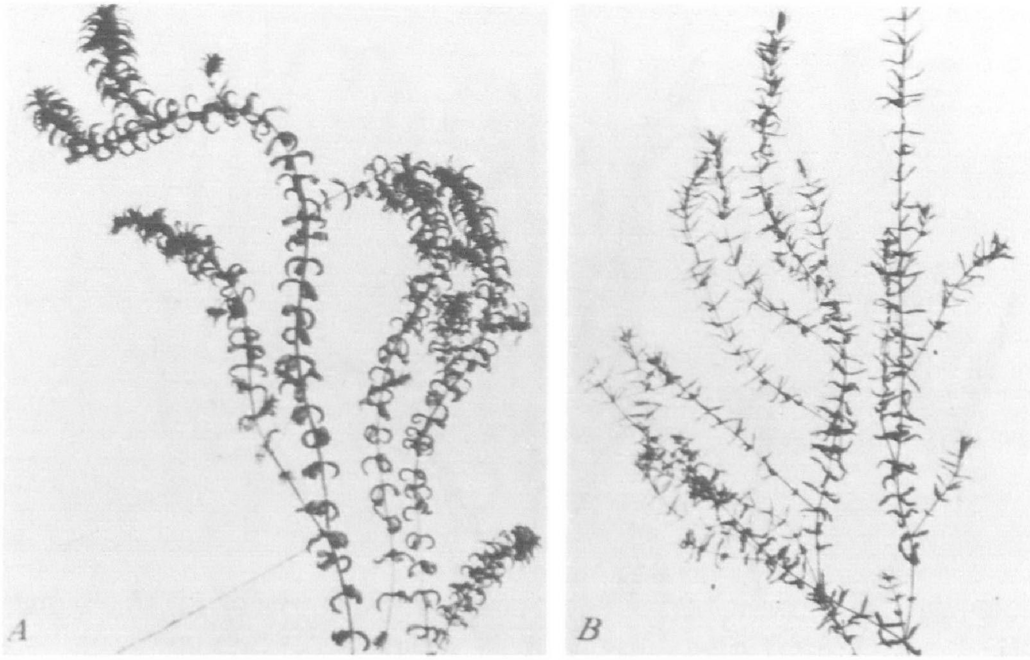

Plate 27. Waterweed × 3/5: A. (*Anacharis canadensis* Michaux), B. (*A. occidentalis* Pursh).

8. Flowers borne in closely packed cylindrical spikes, seeds very small-- Cattail, *Typha*
(The common cattail has flat leaves about 1 inch wide; the narrow-leaved cattail has leaves somewhat rounded on the back that are 1/8 to 7/8 inch wide.)

8. Flowers in spherical heads, seeds larger, up to size of corn kernel; leaves shallowly and broadly triangular in cross-section---------------------------------- Burreed, *Sparganium*

9. Leaves arising at intervals along the stem---------------- 10

9. Leaves arising at base of the plant----------------------- 11

10. Plants with jointed stems, swollen at the joints, or with creeping rootstocks; stems with alternate, simple leaves-------- Smartweed, *Polygonum*

10. Stems prostrate or creeping, branched, and often jointed and rooted at the joints; leaves opposite; spreading plant, often forming floating mats over extensive water areas crowding out other plants; broken-off branch fragments root readily, and stems may elongate as much as 200 inches in one season------ Alligatorweed, *Alternanthera*

11. Fleshy or tuber-bearing rootstocks and rosettes of sheathing basal leaves; leaves variable, some kinds arrowhead shaped----- Duck Potato, *Sagittaria*

Plate 28. Spike Rush (*Eleocharis*) × ½.

Plate 29. Bulrush (*Scirpus*) × ½.

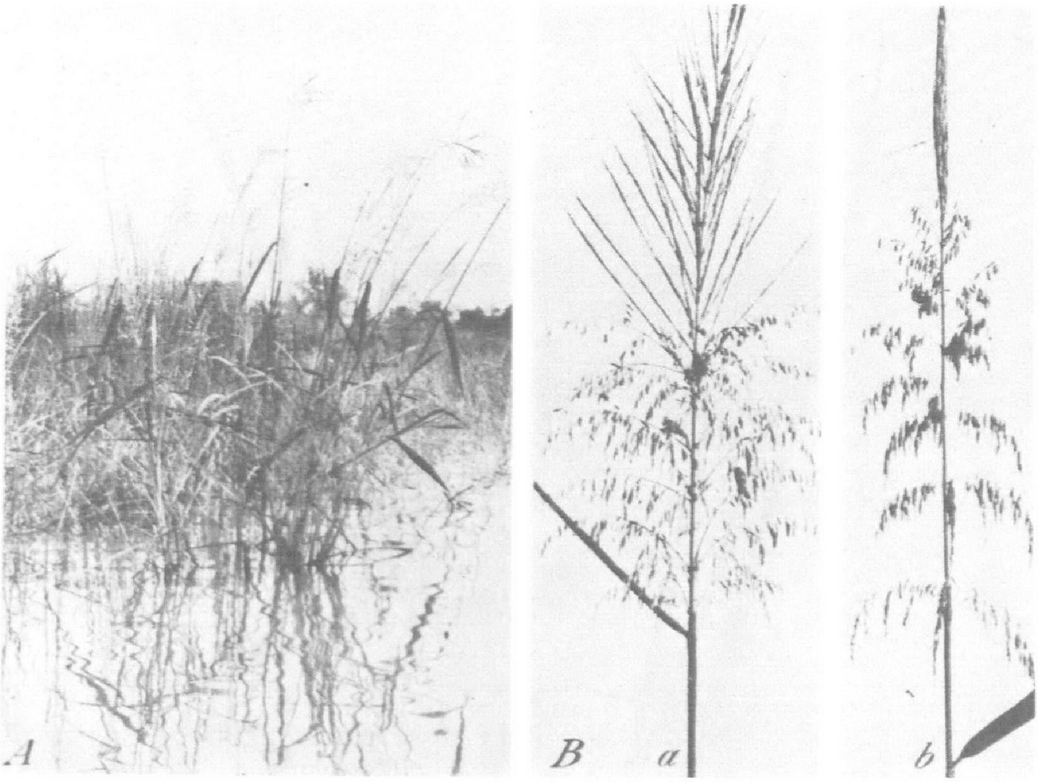

Plate 30. Wild Rice (*Zizania*): A. Stand of broad-leaved form; a. broad-leaved; b. narrow-leaved form.

11. Not as above, floating plants------------------------- 12

12. Plants floating with fibrous, branched roots and rosettes of stalked leaves, the leaf stalks often inflated and bladder-like-------------------------------- Waterhyacinth, *Eichhornia*

12. Plants with floating rosettes of stalked leaves, commonly several rosettes produced on branches of the same plant at the end of flexible, cardlike, sparsely-branched submerged stems; plant thrives at depths of 2 to 5 feet and favors muddy bottoms with high organic content; leaf stalks inflated, but not as conspicuously as in waterhyacinth----------------------- Waterchestnut, *Trapa*

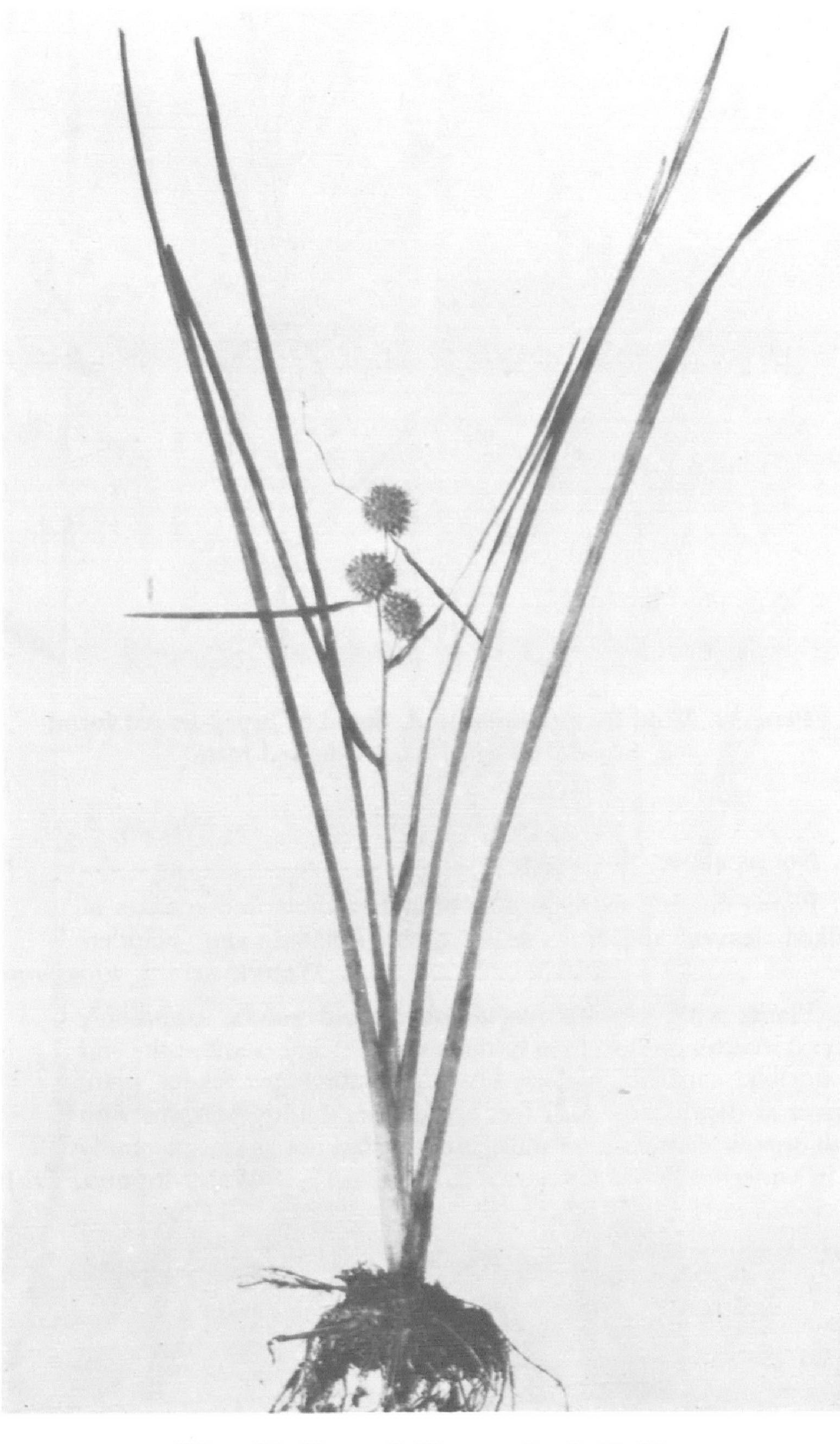

Plate 31. Burreed (*Sparganium*) × 3/8.

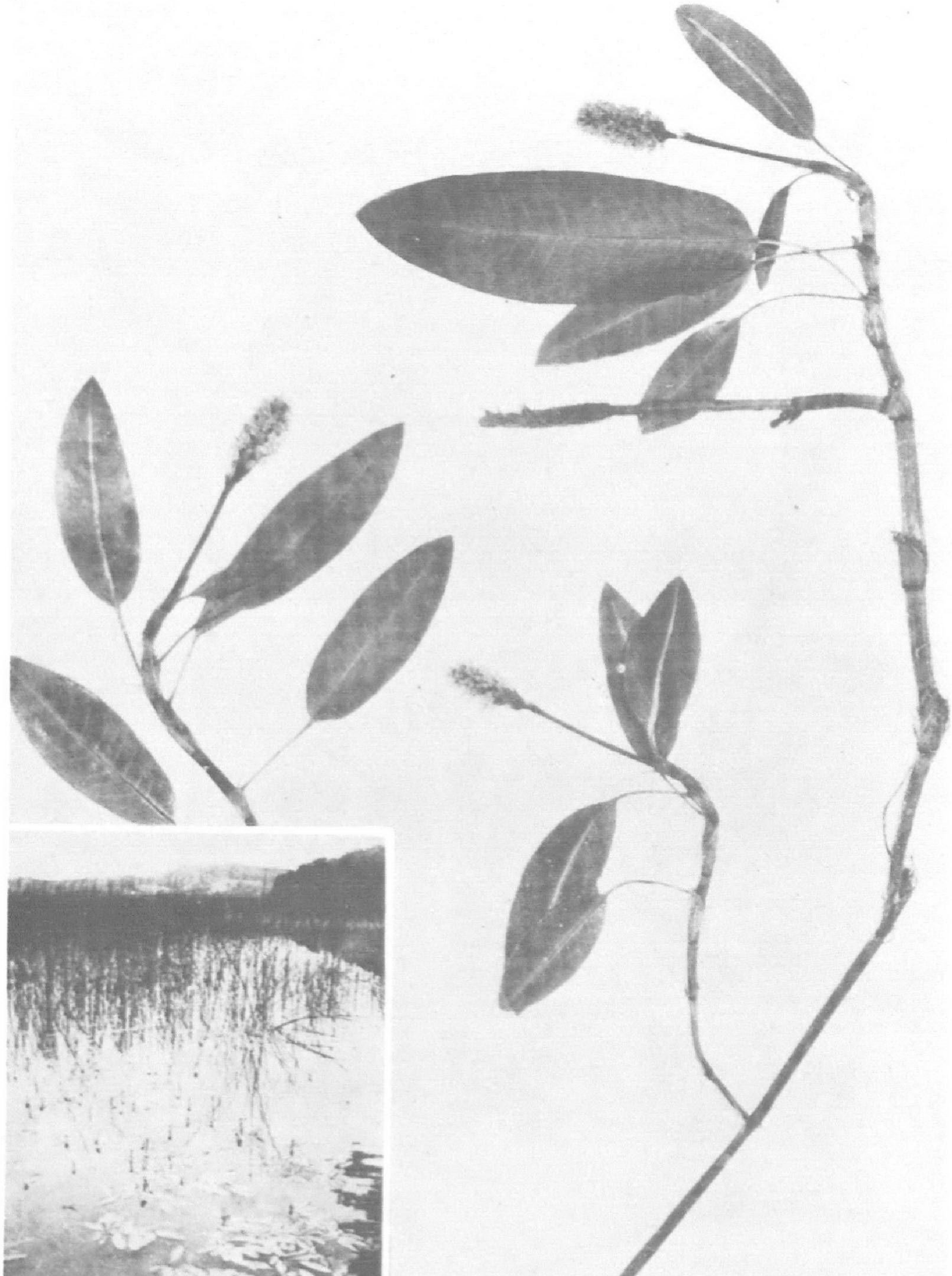

Plate 32. Smartweed (*Polygonum*) × ⅖.

Plate 33. Alligatorweed (*Alternanthera*) × ½.

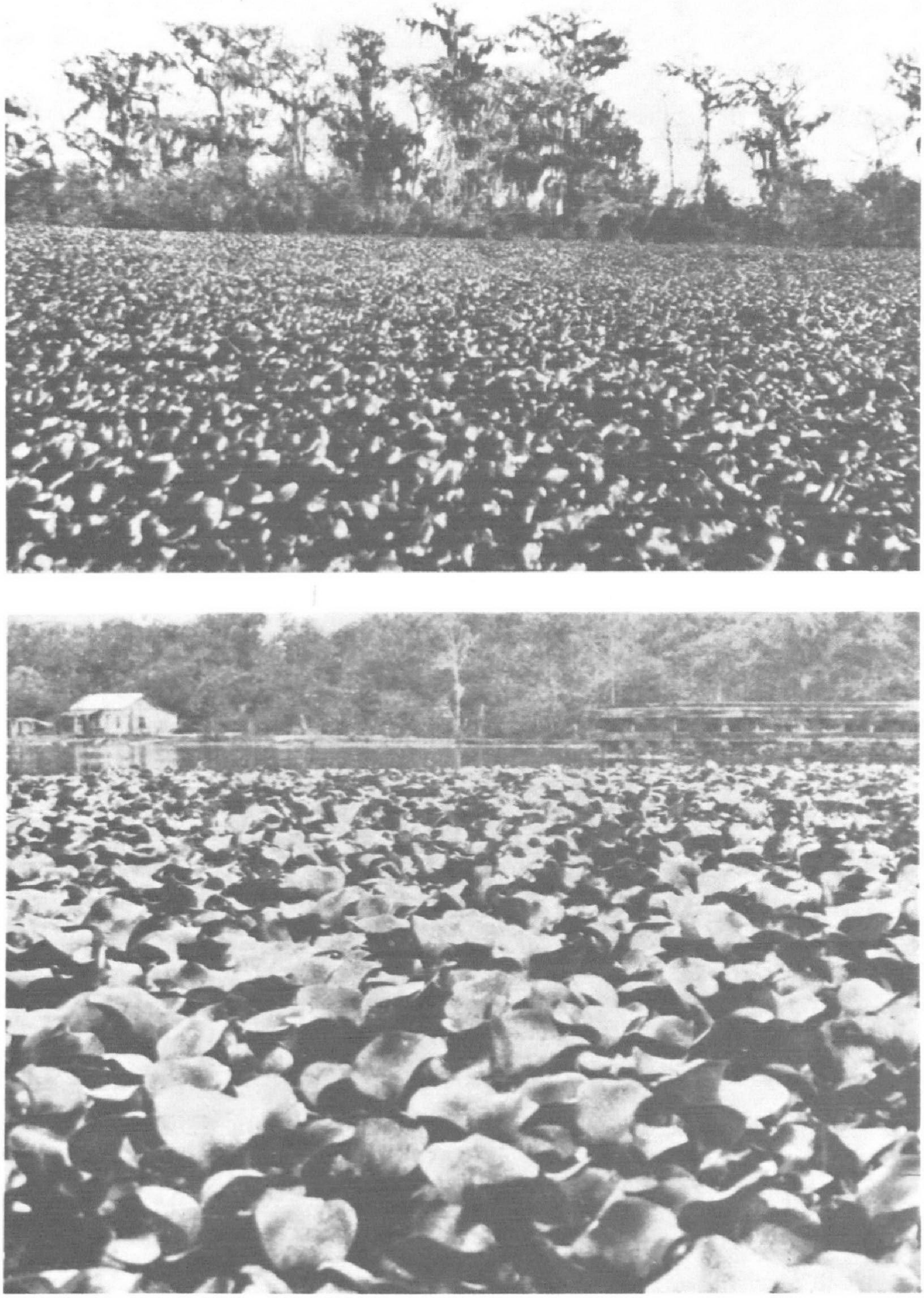

Plate 34. Waterhyacinth (*Eichhornia*).

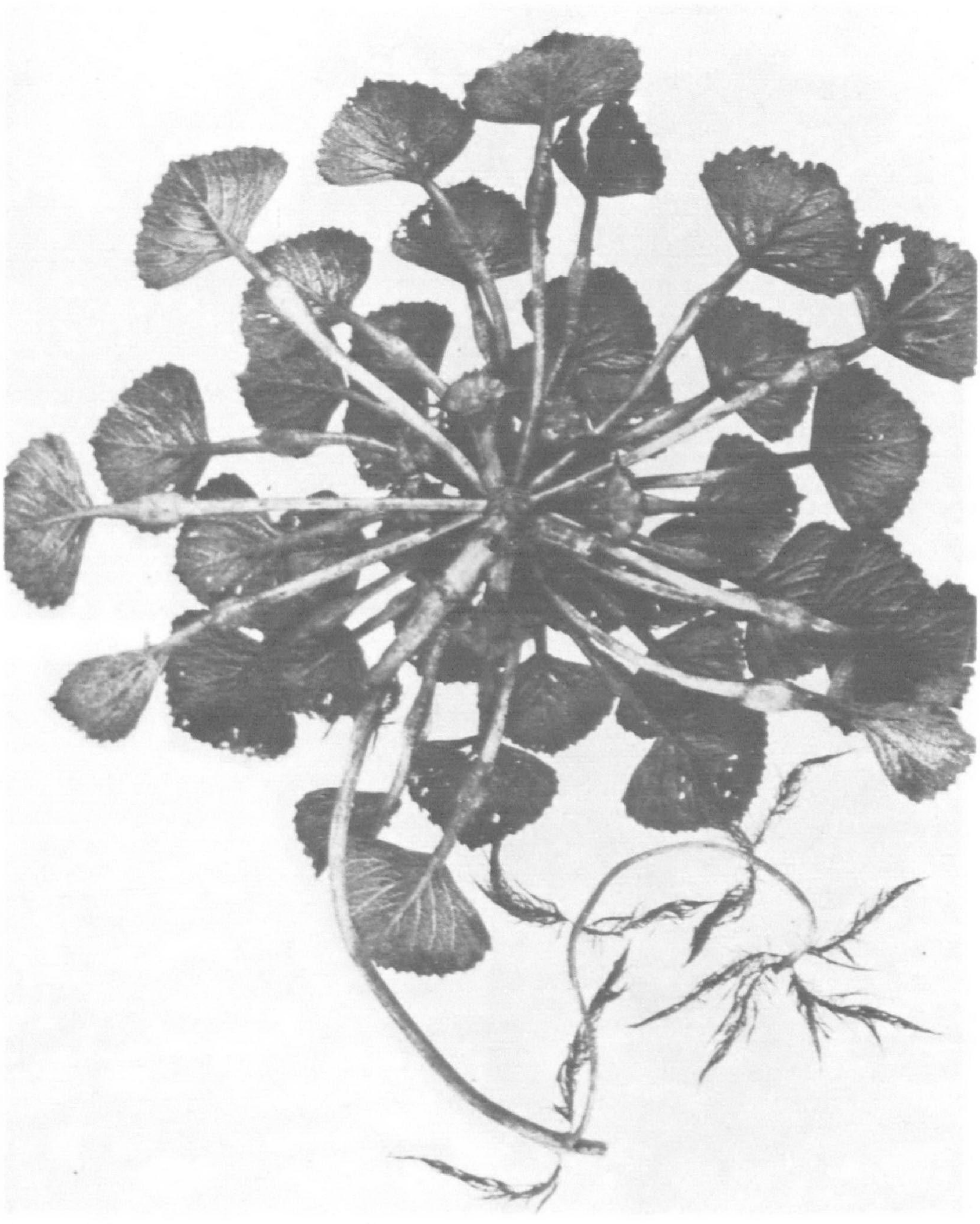

Plate 35. Waterchestnut (*Trapa*) × ¼.

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References are arranged in the order of their appearance in the table.

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CHAPTER V

Animal Pests Affecting Recreational Water Use

Great fleas have little fleas,
upon their backs to bite 'em,
And little fleas have lesser fleas,
and so AD INFINITUM.

—ANON.

MIDGES

Midges, or blind mosquitoes, have created nuisance problems around the shores of a number of lakes. The creation in New York City during 1936 and 1937 of Fountain and Willow Lakes, high in organic content, on what had previously been salt marsh meadow open to tidal action, apparently created optimal conditions for the breeding of a number of species of chironomids. As a result, midge adults were present in enormous numbers near the shores of these lakes within the World's Fair site during the summer of 1938 (Fellton, 1940). The waters apparently were very rich as the organic matter originally present on the bottom began decomposing as soon as flooding occurred. Raw sewage was added to the lakes, and much of the fertilizer applied on the shores was soon washed into the water. Laboratory experiments to guide control operations were performed with a number of chemicals, resulting in the use of rotenone as a control agent at concentrations of 6 and 10 ppm. Concurrently, copper sulfate was applied to control the algae.

For a number of years Winter Haven, Fla., has experienced blind mosquito problems from two adjacent lakes that receive raw sewage and treated effluent from the city. The midge involved was identified as *Glyptotendipes paripes* (Edwards) and Provost (1958) attributed its overproduction to excessively nutritious waters. Because midges feed almost exclusively on algae, lakes rich in algal production are likely also to be high in midge production.

Sadler (1935) found the breeding season of *Tendipes tentans* (Fabricius), another troublesome midge, extended from the last of April to about the first of October in the vicinity of Ithaca, N.Y. The immature stages of the midge are aquatic. The species overwinters in the larval stage, commonly called the bloodworm; the larvae or bloodworms develop from eggs and undergo several growth and development stages before they stop feeding and develop into pupae. Pupation and emergence of the adult are closely associated with the warming of the water in the spring and early summer.

Since emergence of the adults takes place from the entire surface of a lake at approximately the same time, nuisances result from the mass of numbers. Sadler (1935) describes the swarming of the adults, ". . . the adults appear on the wing in late afternoon and early evening for their mating flight. The swarm, which is composed almost entirely of males, begins with a few individuals, and increases in proportion as others join its ranks. Like a single unit, the mass moves forward for a short distance, and then drifts back with the wind, then forward again, and then back, and so on and on in endless repetition. There is much weaving in and out, up and down, among the individuals; also a somewhat regular rise and fall of the whole mass in the vertical plane, unless the wind is strong." The mass of adult midges gets into children's eyes and noses, turns houses black with insects, and literally stalls traffic along lake shore roads in the evening. Also, because of this abundant food supply, spiders increase in number and their webs drape the trees, bushes and buildings, and create an additional nuisance.

The periodic appearance of a large number of gnats, *Chaoborus astictopus* Dyar and Shannon, during the summer has presented a problem to residents of Clear Lake, Lake County, Calif., for many years and has adversely affected their large resort business (Hunt and Bischoff, 1960). Clear Lake has an area of over 41,600 acres. Walker [10] found that emergence took place from late April to early October with peak emergence in late July or early August. A series of tests over 2 years showed the average total seasonal emergence to exceed 500 gnats per square foot. Walker calculated that the total seasonal production on the upper arm of the lake, comprising 44 square miles, approximated 712 billion gnats or 356 tons of organisms. One night's emergence was estimated at 3½ billion, and bottom samples contained as many as 1,000 per square foot.

To control these gnats, Clear Lake was treated in September 1949, with a chlorinated hydrocarbon insecticide DDD (dichloro diphenyl dichloroethane) at a concentration of one part of active insecti-

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[10] Walker, J. R., 1949. The Clear Lake Gnat, *Chaoborus astictopus*—A Review of Investigations and the Proposed 1949 Clear Lake Treatment Program. Bureau of Vector Control, Department of Public Health, California, 12 pp. (mimeo.).

cide to 70 million parts of water. It was determined that a 99 percent kill of larvae resulted. A second chemical application was necessary in 1954, and a third in 1957. These latter applications were calculated to produce a concentration of one part in 50 million parts of water. Following both the 1954 and 1957 application, 75 to 100 western grebes were found dead along the shore. Results of chemical analysis of the fatty tissue from the grebes in 1958 indicated DDD was present at the unusually high concentration of 1,600 ppm (Hunt and Bischoff, 1960). The amount of DDD found during March 1958 in the visceral fat of the brown bullhead ranged from 40 to 2,500 ppm. To prevent the possibility of increasing the present hazard of DDD poisoning of wildlife, Clear Lake will receive no further treatment with DDD.

Serious outbreaks of the midge, *Tendipes plumosus* (Linnaeus), have plagued residents and industries in the Lake Winnebago area of Wisconsin for years. Lake Winnebago is a large (137,000 acres), shallow, fertile lake. Hilsenhoff (1959), in laboratory tests, screened 16 commercially available organophosphate insecticides to determine their relative toxicity to the bloodworm. Dipterex and malathion incorporated into granules produced an 80 percent mortality of the larvae at concentrations of 0.1 lb. per acre of the technical material. These insecticides have a low toxicity to both fishes and mammals. Field tests on Lake Winnebago with malathion granules, however, did not prove conclusive at low concentrations; the feasibility of chemical control on a large body of water with a nonaccumulative insecticide is questionable.

MOSQUITOES

Most mosquitoes breed in still water; small ponds and pools of many types, the shallow edges of lakes, and the still water in shallow, dense weed beds along the edges of streams serve as ideal habitats. They prefer areas with little wave action, an abundant cover in the form of at least moderate aquatic vegetation, an abundant food in the form of humus or other organic matter on the bottom, and floating particles of microorganisms at the surface. The mosquito production of a lake or reservoir appears to be directly proportional to the amount of intersection line between plants (or flotage) and the water surface. Likewise, the relative mosquito production potential of different plant types is in direct proportion to their relative amount of intersection line per unit area of water surface, other factors remaining equal. Situations with an abundance of intersection line provide mosquito larvae with food and protection from natural enemies and also furnish adult mosquitoes with an ideal environment for the deposition of eggs.

In a study of the effect of plants on mosquito production, Bishop and Hollis (1947) found a difference in the relative intersection values among the various types of aquatic vegetation. For a given plant species the intersection value, and therefore the mosquito production potential, varies according to the percentage of vegetation cover occurring at the water surface. The highest intersection values are usually produced with an intermediate cover; low intersection values may be associated with either low or high covers. When the cover at the water surface approaches 100 percent the intersection line is almost completely eliminated. Submerged species are not important except during periods of low water or flowering, when they may break the water surface and create high intersection values. Leafy erect species may have low production potentials when the water surface intersects the naked lower portions of the stems, but production of mosquitoes may be greatly increased when the water rises into the upper leafy portions of the plants. On impounded water, terrestrial species occur mainly in the upper portion of the zone of fluctuation; wetland species usually occur down to the lower limit of summer drawdown; aquatic species often overlap with wetland species and usually extend out into the reservoir below the lower limit of summer drawdown (figs. 4 and 5).

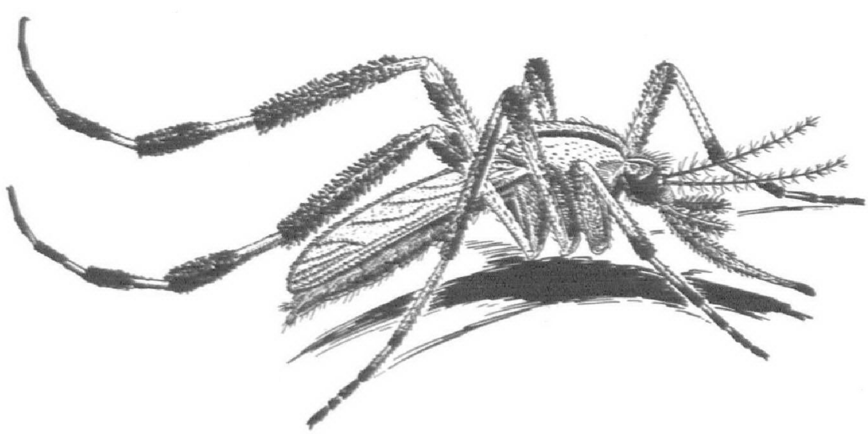


Plate 36. Mosquito (*Psorophora ciliata* (Fabricius)), one of the largest of Illinois mosquitoes.

LEECHES

Leeches abound in warm, protected shallow water where there is little wave action and where plants, stones, and debris offer concealment. They are chiefly nocturnal in their activities and remain hidden under stones and vegetation in daylight. The majority of specimens are found between the water's edge and at a depth of approximately 6 feet. Leeches require substrates to which they can adhere and consequently are rare on pure mud or clay bottoms. Some species persist in intermittent ponds by burrowing into the mud bottom where they construct a small mucous lined cell in which they live. Leeches are dormant in winter, burying themselves in the upper part of the bottom material just below the frost line.

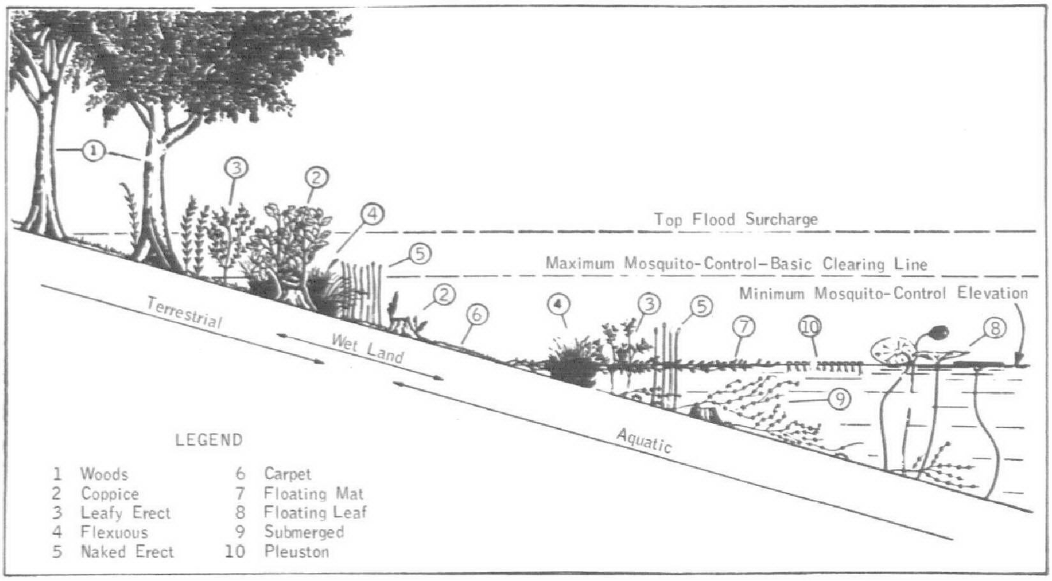


Figure 4.—Generalized contour distribution of basic plant types on the shore line of a main-river reservoir (from Bishop and Hollis, 1947).

According to Pennak (1953), *Macrobdella,* the northern bloodsuckers, and *Philobdella,* the southern bloodsuckers, are the only common American leeches that regularly take human blood. Like all other bloodsuckers, they attach to the host with the caudal sucker and explore with the anterior end until a suitable spot is located, especially where the skin is thin. The oral sucker is then attached tightly and three fine painless incisions are made by back-and-forth rotary motions of the jaws. Sufficient blood is taken to distend the stomach so that the leech may be five times as heavy as it was when it began feeding. When the leech has filled its digesitve tract it leaves the host voluntarily, but the incisions keep on bleeding for a variable time because of the persistence of the salivary anticoagulant, hirudin, which the leech injects into the incision and which causes a more or less intense and prolonged itching. If the leech is permitted to complete its meal, this substance is largely or entirely withdrawn from the wound; but if the meal is curtailed, it acts as an

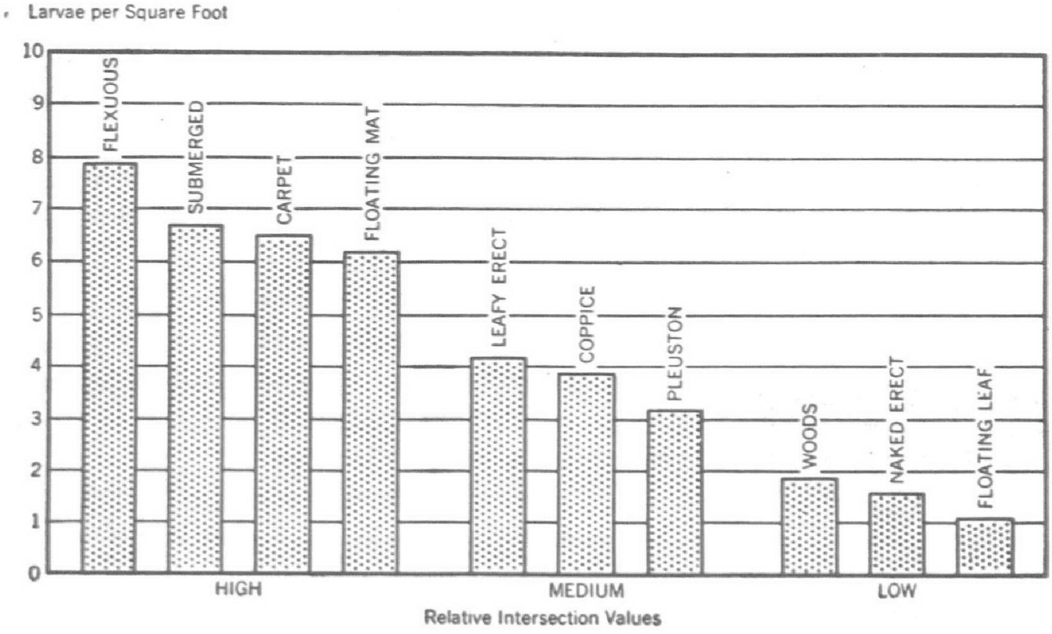


Figure 5. *Anopheles quadrimaculatus* Say production potentials of basic plant types (from Bishop and Hollis, 1947).

irritant. Some persons are much more sensitive to the irritant qualities of leech bites than others, just as some are more sensitive to the poison of mosquitoes or other insects. True bloodsucking leeches require only an occasional full meal. Specimens have been kept for more than 2 years without feeding.

Pennak (1953) records species of the following genera as ones that take blood from man: *Helobdella, Placobdella, Erpobdella, Macrobdella, Philobdella,* and *Haemopis.* Distinguishing characteristics are as follows:

HELOBDELLA STAGNALIS (Linnaeus) (Pond or Common Snail Leech)

This species is identifiable by the small brown or yellow cuticular plate on the anterior dorsal surface. The color is brownish, greenish-gray or pale pink; it is translucent or nearly transparent. The leech has one pair of eyes that are simple and close together. Its size is small; the body is elongate oval, very narrow at the anterior end, and moderately depressed. Maximum length is three-fourths inch, although the usual extended length varies between three-eighths and one-half inch. It is predaceous, feeding on small aquatic snails, bloodworms, aquatic annelid worms, and insect larvae. It will also take blood and flesh from excoriated surfaces of all kinds of living and dead animals if the opportunity arises. *Helobdella stagnalis* (Linnaeus) inhabits ponds, lakes and sluggish streams, attaching to undersides of rocks, logs, boards, and other objects submerged in the shallow waters. It sometimes attaches itself to small snails.

PLACOBDELLA RUGOSA (Verrill) (Rough Turtle Leech)

Placobdella rugosa (Verrill) may be readily recognized by its numerous rough and high papillae, and dull color; it is opaque to translucent, dark greenish-brown, and spotted with yellow and green. It has one pair of compound eyes. The leech is medium to large; the body firm, broad, thin, and flat, and is much depressed. The maximum length is 3 inches when extended, although the usual extended length is 1½ to 2 inches. These leeches are temporary parasites clinging to the legs and necks of water turtles, snapping turtles and western painted turtles, but are generally predaceous and freeliving, feeding on aquatic worms, snails and insect larvae. If the leech is living a parasitic life on a turtle, it will leave its host during periods of reproduction and live a free life in ponds, lakes and streams. It will take a meal of human blood if the opportunity arises. It is found attached to the undersides of rocks, logs and boards submersed in the shallows of lakes, ponds, and streams.

ERPOBDELLA PUNCTATA (Leidy) (Common Worm Leech)

The large forms are distinguished by the two to four dorsal longitudinal rows of black, irregular spots. These are separated by paler bands; the medium two are very pronounced, and the outer two are often lacking in mature forms and are generally absent in immature forms. *Erpobdella punctata* (Leidy) has a firm, moderately contractile body. It is opaque, dark olive-green, or light chocolate brown to black dorsally and paler ventrally; the color tone varies considerably. It has three pair of eyes; the first pair on somite II are largest, and the other two pair are at the sides of the mouth on somite IV. The body is slender, elongated, moderately firm, and moderately contractile. The maximum extended length is 4 inches, whereas the usual extended length is 2 to 3 inches. The leech feeds on small worms, smaller leeches, aquatic snails and eggs, aquatic insect larvae, and nymphs. It will take human blood when the opportunity arises. It is found in lakes, ponds, and streams, atached to rocks, logs, old tree stumps, plants, and other objects submerged in the shallow waters.

MACROBDELLA DECORA (Say) (American Medicinal Leech)

Macrobdella decora (Say) may be identified by its bright striking color pattern, large size and soft slimy, very contractile body. It has a

Plate 37. Blood Sucking Leeches (from Moore, 1923)

A. *Helobdella stagnalis,*
B. *Glossiphonia complanata,*
C. *Macrobdella decora,*
D. *Placobdella parasitica,*
E. *Haemopis grandis,*
F. *Erpobdella punctata,*
G. *Haemopis marmoratis.*

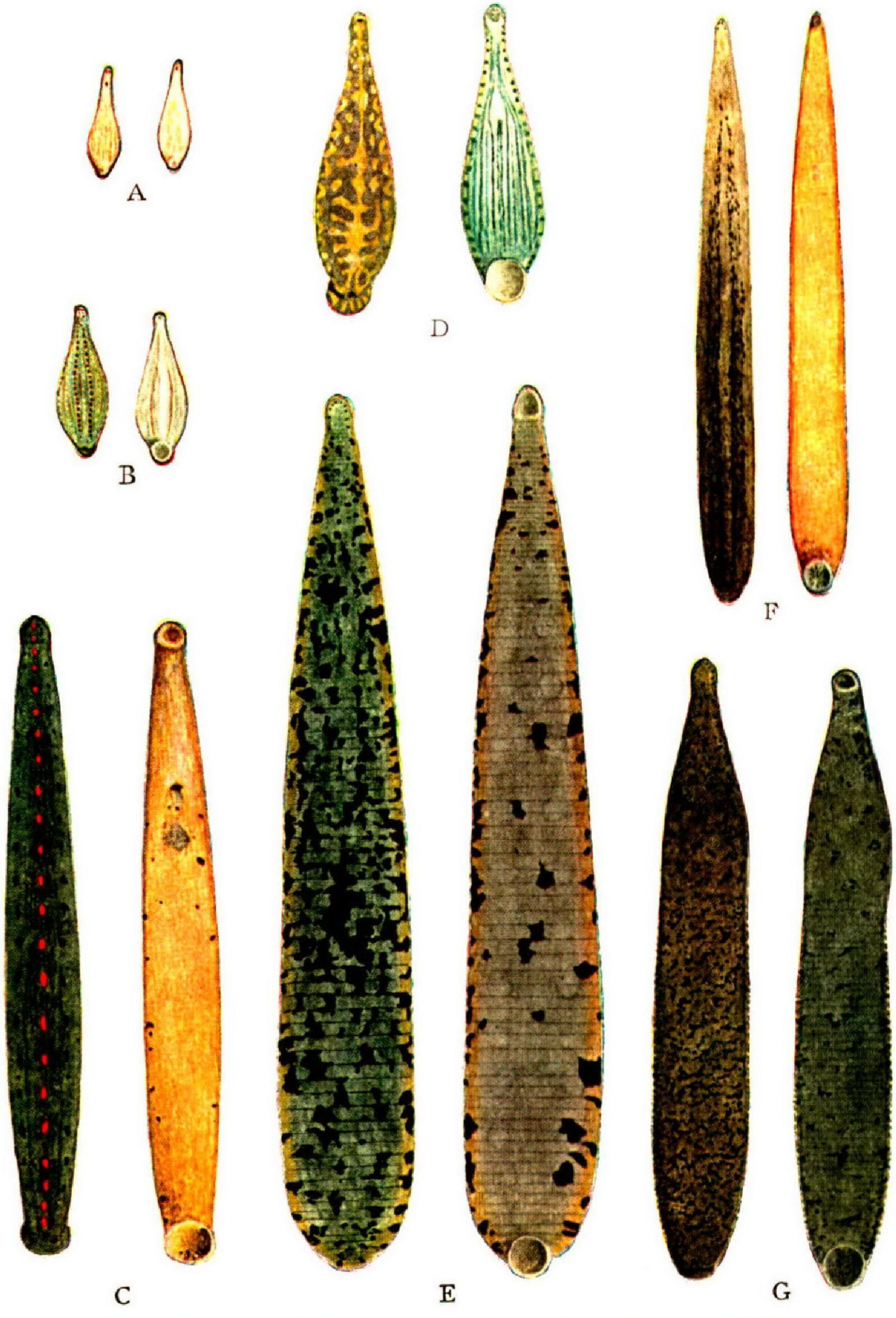


Plate 37. Blood Sucking Leeches (from Moore, 1923)

A. *Helobdella stagnalis,*
B. *Glossiphonia complanata,*
C. *Macrobdella decora,*
D. *Placobdella parasitica,*
E. *Haemopis grandis,*
F. *Erpobdella punctata,*
G. *Haemopis marmoratis.*

median longitudinal row of 20 to 22 orange or light red spots, a similarly arranged series of small black spots on each side close to the margins, and a rich orange ventral surface sometimes plain but usually spotted with black. Five pairs of eyes are arranged in a regular arch near the anterior dorsal margin; the last two are especially difficult to see in pigmented specimens. The body is elongated, flattened, smooth, very soft and slimy, and very contractile. The maximum extended length is 7 to 8 inches, whereas the usual extended length is 4 to 6 inches. It is voraciously predaceous, feeding on earthworms, aquatic worms, snails, insect larvae, and frog eggs; it is even cannibalistic. At times it is a fierce bloodsucker, attacking wading birds, fishes, frogs, and tadpoles, turtles, wading animals and humans. Normally it inhabits the shallows and areas along the muddy shoreline where land and water meet. Often the leech is found attached to floating logs, boards and limbs, and is in abundance on the moist, wave-washed shores, hidden beneath algae, pondweeds, logs, limbs, and other debris.

HAEMOPIS MARMORATIS (Say) (Mottled Horse Leech)

The color of *Haemopis marmoratis* (Say) is variable and usually blotched. Sometimes the dark blotching is barely distinct, blackish-green, dark olive-green or brown, and paler ventrally; sometimes light blotching is very distinct, olive-green, yellow-green blotched with irregular darker brown or black spots that are often confluent (marbled mottled), and paler ventrally. Sometimes the color is plain dark green or yellow. Dorsally, little conelike elevations (sensillae) or sensory annuli are noticeable, even to the naked eye in larger specimens. Eye arrangement is the same as in *Macrobdella decora* (Say). The maximum extended length is 6 inches, and the usual extended length varies between 2 and 5 inches. The leech is usually predaceous, feeding upon earthworms, aquatic worms, snails, insect larvae, and even its own species. It will occasionally take a meal of blood from the legs of wading animals, from frogs, tadpoles, aquatic birds, and humans. It is less active than *Macrobdella decora* (Say). It abounds in the mud at the side of pools, lakes, streams and ditches and also occasionally on land. It is found attached to floating logs, boards and limbs near the shoreline, also in abundance on the moist, wave-washed shores, hidden beneath algae, pondweeds, limbs, twigs, and other debris. *Haemopis marmoratis* (Say) and *Macrobdella decora* (Say) are often found in close association.

The leech of greatest concern to bathers is *Macrobdella decora* (Say). It is principally a swamp animal and normally inhabits the shallows in the vicinity of the shoreline where land and water meet. It may be found concealed under stones and logs where, when well fed, it rests quietly or, when hungry, lies in wait for frogs or warm-blooded animals.

Any disturbance of the water, such as is caused by a wading animal, attracts the leeches partly because of the mechanical disturbance that stimulates the tactile organs and partly because of the animal emanations that stimulate the organs of chemical sense. Thus, leeches are attracted by bathers and tend to congregate and remain about the docks and stones of the bathing area. They are strong and rapid swimmers and can invade a particular area from other sections of the lake. They are most active at maximum water temperatures, and the period of greatest prevalence in the bathing area corresponds with that of maximum water temperature in August.

Moore (1923) describes methods of leech control through freezing in their winter quarters. As the temperature of the water falls with the onset of winter, leeches become more and more sluggish and finally bury themselves in the mud or beneath stones on the bottom of shallow water. Leeches are readily killed by exposure to a temperature of 20° F for a few hours. When the first thin ice starts to form and it is certain that the water temperature has attained its minimum, Moore recommends that the water be drawn off as rapidly as possible until the water level is lowered 4 feet, and that this level be maintained for at least 5 or 6 weeks during the coldest part of the winter. He reasoned that under these circumstances the exposed flats would be frozen hard to a considerable depth, and temperatures would be well below the fatal minimum for the imprisoned leeches. This method of control was effective in Carr Pond, Palisades Interstate Park near New York City.

Pennak (1953) states that leeches may be temporarily controlled in localized bathing beach areas by applying 100 lb. of powdered lime per acre per day in the shallows. In general, chemical controls have not proven successful, although chemicals such as copper sulfate will kill leeches that are exposed to it. The measures employed in snail control have been used with some success in leech control. Weekly distribution of a slurry composed of 10 pounds of copper sulfate and 5 pounds of copper carbonate or lime per acre of bathing area has shown some success. Chelated copper compounds applied marginally as a spray at concentrations sublethal to fish have also been of value.

SWIMMER'S ITCH

Cort (1928) first demonstrated that certain larval trematode worms (schistosome cercariae) of birds and mammals can penetrate the skin of man and produce a dermatitis characterized by papular eruptions.

"Swimmer's itch," schistosome dermatitis, or "water rash" has attracted increasing attention since 1928, particularly in the lake regions of the North-Central part of the United States where tourist trade has been affected.

The cercariae causing swimmer's itch are free-swimming, colorless, and about 0.7 mm in length. With proper illumination they are just visible to the unaided eye as they swim rapidly in an irregular manner or hang suspended in water (Brackett, 1941). The adults are parasitic in the hepatic, portal, and mesenteric veins of birds or mammals. The fertilized female migrates to the smaller intestinal veins and deposits eggs that work their way through the intestinal wall into the lumen, from which they are passed with the feces. Each egg contains an embryo which, upon hatching, develops into a ciliated free-swimming organism termed a miracidium. If a suitable snail is located, the miracidium penetrates into its soft tissues, and a further type of development and reproduction takes place in which cercariae are produced. Following this period of development, the cercariae emerge from the snail host and swim about in search of the proper vertebrate host to penetrate in which they can develop to maturity in the blood vessels to complete the cycle.

This cycle is accidentally interrupted by the occasional penetration of cercariae into the epithelial layer of the skin of bathers, resulting in swimmer's itch. Following such penetration, the cercariae are soon destroyed, perhaps by unsuitability of human body fluids, and their bodies remain as the site and stimulus of acute inflammatory reactions. Apparently the cercariae do not penetrate completely until the bather has emerged from the water, but a few minutes later the victim experiences a tingling sensation in exposed parts of the body. Soon, minute red spots can be seen at the points where the organisms have penetrated the skin. The tingling sensation may then disappear, and it may be a number of hours before a distinct itching is felt, and the minute spots enlarge to form discrete red elevations of the skin one-sixteenth to one-fourth inch in diameter. Occasionally the elevations become pustular. The degree of discomfort and bodily reaction resulting from infestation varies with the sensitivity of the individual and the degree of infestation. In certain persons, considerable pain, fever, and severe itching may occur along with noticeable swelling of the affected areas; in others the discomfort may be only minor and transitory, and some bathers appear immune to infestation. The skin elevations typically disappear within a week, but the redness may persist for some time longer.

Several characteristics of swimmer's itch are constant: ". . . it is always associated with bathing or wading in natural waters; it is found less commonly on parts of the body protected by bathing suits or clothing and almost never on the face; each lesion is discrete and does not spread;

Figure 6. Life cycle of swimmer's itch cercariae. E, egg; M, miracidium; S, sporocyst; R, redia; and C, cercariae.

and the condition clears up within a few days if there is no further contact with the cercariae. Thus schistosome dermatitis can usually be differentiated from other common skin afflictions such as poison ivy, which continues to spread after contact, chigger bites, which characteristically occur where clothing constricts the body, and bites of other insects, which often occur on the head and face" (Brackett, 1941).

Cercariae may live in the water from 24 to 60 hours or more after emerging from the snail host (Brackett, 1941). It is probably safe to assume that under natural conditions the life span is only 24 hours or less, and in wind-agitated water it may be considerably shorter. The types of cercariae capable of producing swimmer's itch typically emerge from the snail host quite regularly at a definite and more or less restricted period each day. The majority of forms emerge about 4:30 a.m., and one type emerges at about 9:30 p.m. Because cercariae probably survive at least 24 hours under conditions in nature, it appears during an outbreak that the causative organisms may be present in water at all times of the day. The typical emergence activity of the cercariae may be influenced to some extent by factors existing in the water. A sudden rise in temperature may be followed by sudden emergence of many cercariae irrespective of the time of day. On the other hand, natural starvation of the snail host may delay or prevent the shedding of cercariae.

There is evidence that submerged aquatic plants promote infections of swimmer's itch. Some of the species of snails capable of harboring the causative organism live in and upon stands of submerged aquatics that often grow adjacent to or in the vicinity of bathing areas. Also, at least two species of cercariae attach themselves to objects and may cling to such vegetation. Under these circumstances, the removal of the submerged vegetation will usually eliminate infections to bathers by the parasite.

Cercariae emerge in greatest numbers during the warmest weather. Infected snails kept at low temperatures cease to shed cercariae; however, if these snails are brought into a warmer environment, cercariae emerge suddenly in large numbers regardless of light conditions. Cercariae are also attracted by light and swim actively in the direction of the greatest light intensity. Although active swimming by the cercariae may be limited to 50 feet or less, it is thought that they may be carried distances of one-fourth mile or more by the movement of surface water. In many places bathers are troubled only when there is an inshore wind of not too great intensity, and only those who bathe in the shallow water close to shore are affected. Those who swim in the deeper water farther from the shore are scarcely bothered even though they may swim directly over an infected bed of snails.

Olivier (1949) presented clear evidence that schistosome dermatitis is essentially a sensitization reaction. He found that primary exposure to the cercariae produced only mild reactions; with repeated exposures, the reactions became progressively stronger. There is some evidence that sensitization may persist for several years, since three persons who had their last exposure 8, 10, and 12 years previously developed severe dermatitis following exposure to very small numbers of cercariae.

Cort (1950) lists 18 species of schistosome cercariae, excluding those that develop to maturity in man, that have been reported to cause dermatitis. Brackett (1941) states that "one of the most striking and clear-cut features of schistosome dermatitis outbreaks is the fact that probably over 90 percent of the more severe outbreaks are caused by *Cercaria stagnicolae* in varieties of the snail *Stagnicola emarginata*." The relationship between this snail and the most severe outbreaks of swimmer's itch is promoted by (1) clean, sandy beaches ideal for swimming and preferred by the snail; (2) peak populations of the snail host that develop in sandy-bottomed lakes of glacial origin; (3) the greatest development of adult snails that do not die off until toward the end of the bathing season; and (4) the cycle of cercarial infection so timed that the greatest numbers of cercariae emerge during the hot weather in the middle of the summer when the greatest amount of bathing is done.

According to Cort (1950), the dermatitis-producing schistosome cercariae have been shown to develop either under natural or experimental conditions from the following intermediate snail hosts in the United States:

Lymnaea (*Lymnaea*) *stagnalis* (Linnaeus)
Lymnaea (*Radix*) *auricularia* (Linnaeus)
Lymnaea (*Stagnicola*) *palustris elodes* (Say)
Lymnaea (*Stagnicola*) *emarginata* (Say)
Physa parkeri Currier
Physa ampullacea Gould
Gyraulus parvus (Say)

In the Lake States region the seasonal cycle of the parasite in relation to the life cycle of the intermediate host snail determines the seasonal variation in the dermatitis infections. The first case on the bathing beaches usually occurs in late June or early July when the snails infected in the fall begin to give off cercariae in appreciable numbers. Exact dates may vary somewhat with the season and with water temperature. During July, the peak of cercarial production is reached, and the infections come to maturity. Production is especially influenced by hot spells that speed up the development of the cercariae and increase the numbers that escape. Later in the summer the dermatitis infection becomes less, chiefly because of the death of infected snails, and in many places it disappears before the end of the swimming season. Where the adult snails die early the dermatitis season is shortened since there is practically no infection in the juvenile snails during the summer.

Schistosome dermatitis is widespread. As summarized by Cort (1950), it has been reported from the United States, Asia, Japan, Australia, Wales, France, Switzerland, Cuba, Mexico, and Canada. In the United States, schistosome dermatitis is principally endemic in the North Central lake region. In addition to Wisconsin, Minnesota, and Michigan, schistosome dermatitis has been reported from North Dakota, Illinois, Nebraska, Texas, Florida, Washington, Oregon, Nevada, Oklahoma, California, Connecticut, Rhode Island, New York, and Iowa.

The simplest method of control for the individual bather is the rubbing of the body with a rough towel before the water film dries on the surface. Such action will crush the cercariae before they have an opportunity to penetrate the skin. A fresh-water shower taken immediately after leaving the water is also effective. The common practice of alternately swimming and sun bathing provides an excellent opportunity for a bather to receive a severe infection if infective cercariae are abundant in the water.

Knowledge of the relationship between schistosome cercariae and snails indicates the point in the cycle at which extensive control measures should be aimed. Since the developmental cycle is interrupted unless these larvae find the proper type of snail and penetrate its tissues, the elimination of snails from bathing areas will result in the immediate disappearance of swimmer's itch. The problem, therefore, reduces itself to one of destroying all snails capable of harboring cercariae in and around the bathing beach. Such destruction, with chemicals, is one of the most severe controls in lake ecology; some of the other fish food organisms as well as the snails are killed as a result of the toxicity of the chemicals used. The general ecology of the area is disrupted and the "balance of nature" is destroyed with a successful treatment. Treatment, therefore, should be confined to areas extensively used by man for swimming and the size of the area should be kept to the minimum that will provide adequate control of the snails.

The area treated is usually very small in relation to the total area of the lake; thus the loss of fish food organisms in the treated area and the resulting effect upon the fishery is negligible when compared with the lake as a whole. Generally, most treatments are accomplished on sandy beaches that are good for swimming, but are very low in the production of fish food organisms.

The time of year that chemical treatment is undertaken is im-

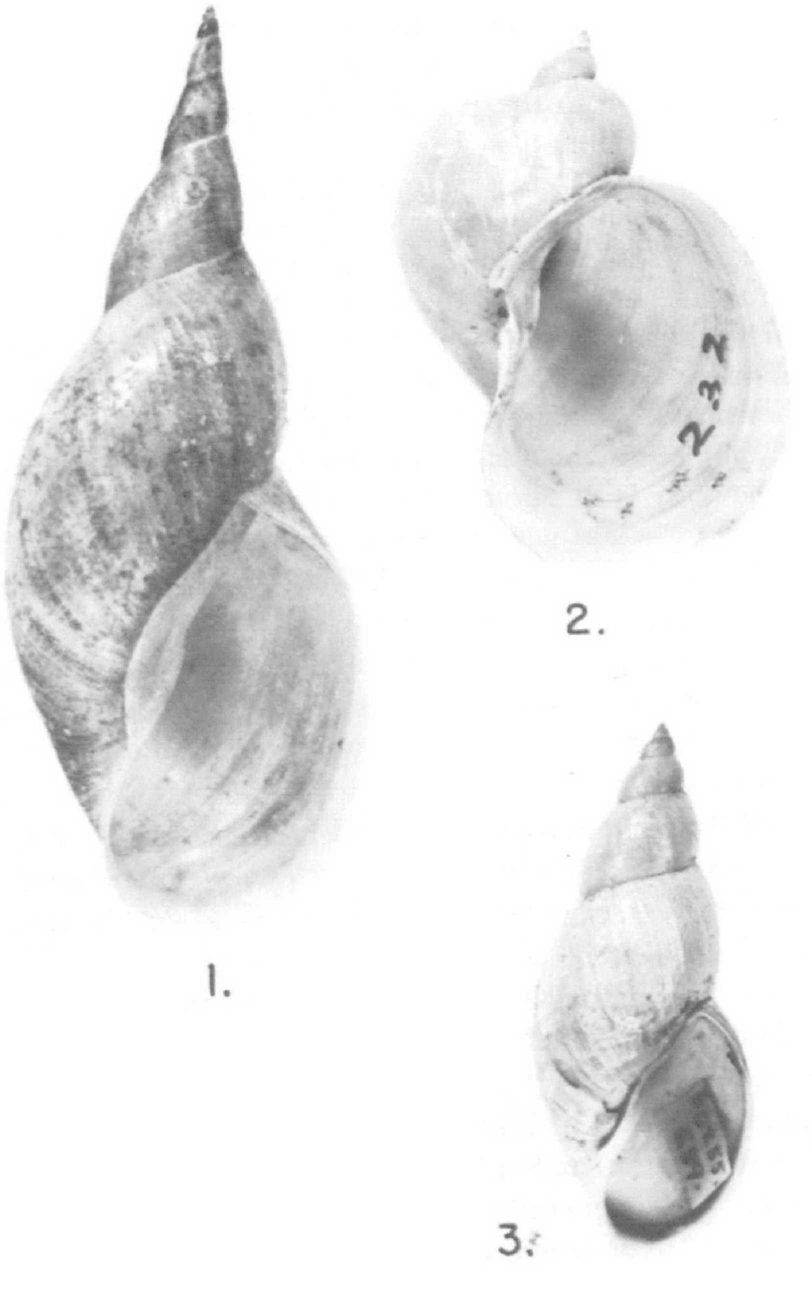
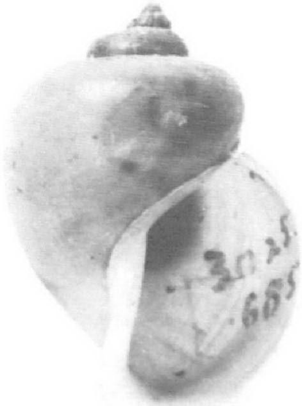


Plate 38. Snails known to harbor swimmer's itch cercariae

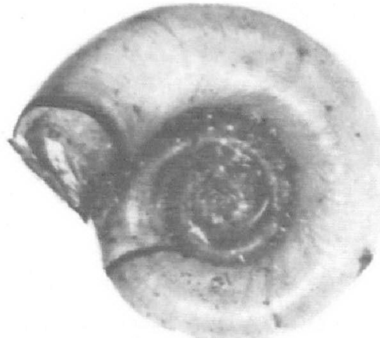
U.S.N.M. No.	*Snail*	*Collector*	*Location*
1. 28448	*Lymnaea* (*Lymnaea*) *stagnalis* (Linnaeus).	Bryant Walker.	Detroit, Mich.
2. 569286	*Lymnaea* (*Radix*) *auricularia* (Linnaeus).	F. C. Baker....	Greenhouse, Lincoln Park, Chicago, Ill.
3. 30255	*Lymnaea* (*Stagnicola*) *palustris elodes* (Say).	L. H. Streng...	Grand Rapids, Mich.



4.

5.

6.



7.

Plate 39. Snails known to harbor swimmer's itch cercariae

U.S.N.M. No.	*Snail*	*Collector*	*Location*
4. 30252	*Lymnaea* (*Stagnicola*) *emarginata* (Say).	L. H. Streng...	Lake Houghton, Mich.
5. 251214	*Physa parkeri* Currier.	H. B. Baker....	Douglas Lake, Mich.
6. 334392	*Physa ampullacea* Gould.	W. Westgate...	Klamath Falls, Oreg.
7. 432259	*Gyraulus parvus* (Say).	J. P. E.Morrison	Boulder Junction, Wis.

portant, since it involves the life cycle and habits of the snails and fish. Studies indicate that very few young snails are infected. Early in the summer, numerous immature infections are present in the adult snails that have survived the winter. The majority of the cercariae complete their development and first begin to emerge in late June and early July. The infected snails in most cases continue to give off certain cercariae until their death in late summer or early fall. In the North Central lake States, the optimum time to apply controls occurs between mid-June and July 4.

In 1937 Cort and his coworkers experimented by treating with copper sulfate a small area on a large lake to kill the snails and prevent further cases of water itch (McMullen, 1941). Early experiments centered around broadcasting copper sulfate crystals of pea size, and spreading a solution of copper sulfate along the bottom with a T-shaped pipe. Later it was found that a copper sulfate-copper carbonate mixture precipitated more copper on the bottom where the snails could get it, and that this treatment was effective longer than any other treatment tried. To reduce cost, fresh hydrated lime has since been substituted for copper carbonate and has been found to be effective.

Lake waters with a total methyl orange alkalinity of 50 mg/1 or greater have been successfully treated with the following mixture: 2 pounds of copper sulfate (snow grade) plus 1 pound of copper carbonate for each 1,000 square feet of bottom. Lake waters with a methyl orange alkalinity of less than 50 mg/1 have been successfully treated with 2 pounds of copper carbonate per 1,000 square feet of bottom. For example, an area 1,000 feet long and 200 feet wide would require 400 pounds of copper sulfate and 200 pounds of copper carbonate in a hard water lake, or 400 pounds of copper carbonate in a soft water lake (Mackenthun, 1958).

For small-scale operations, very simple equipment will suffice to distribute the chemical mixture. An open end, 50-gallon drum is half filled with lake water and placed in a suitable boat. Fifty pounds of copper sulfate "snow" is added and stirred until dissolved. To this solution, 25 pounds of copper carbonate is added slowly and stirred in to make a suspension of the carbonate in the sulfate solution. A vigorous reaction takes place inside the drum and froth is caused by the carbon dioxide produced. When all of the copper carbonate has been added and the chemical action has subsided, the drum is filled with water and it is ready for use. It should be borne in mind that these chemicals are irritating to the mucous membranes of the eyes, nose, and throat. Prolonged exposure of the skin to this concentrated mixture should be avoided.

The chemical solution is allowed to flow by gravity through a

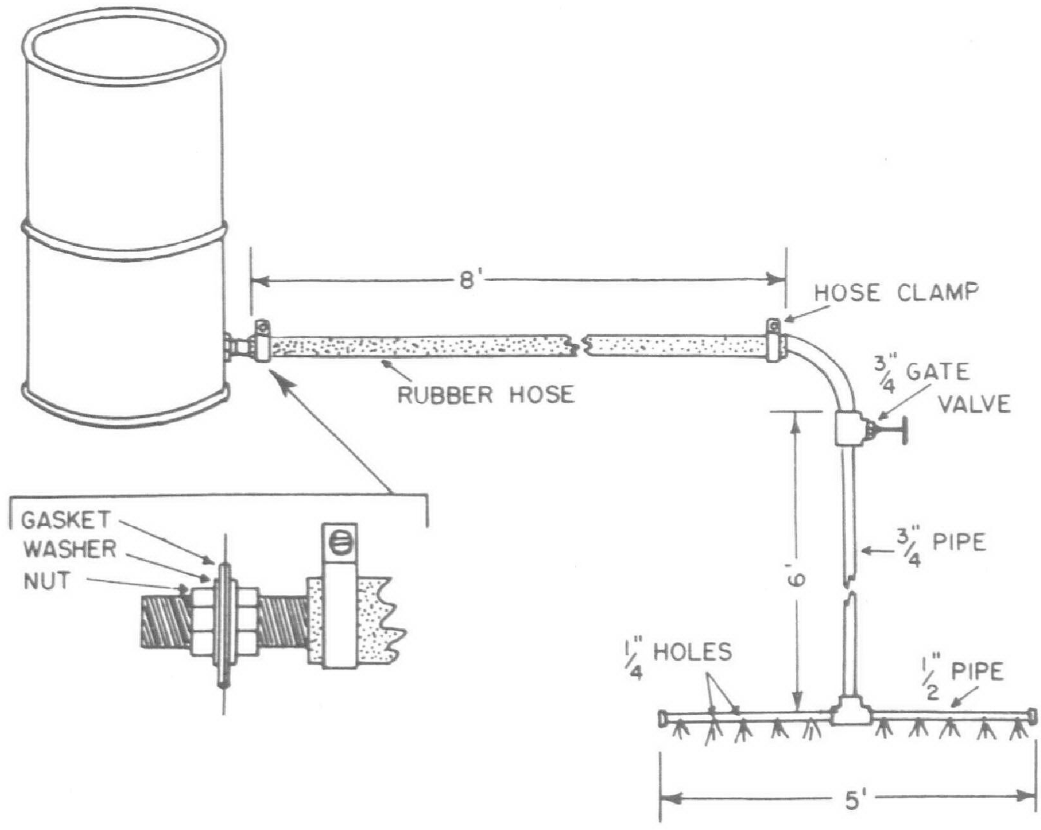


Figure 7. Diagram of gravity flow equipment used in distributing chemical mixture for snail control.

"T" pipe and is distributed evenly over the bottom of the areas to be treated. The boat is propelled slowly back and forth so that the mixture is distributed as evenly as possible. The speed of the boat must be regulated so that the calculated quantity of chemicals covers the area. A drum filled as described is sufficient to treat 25,000 square feet. To insure the proper distribution it is advantageous to stake out the area to be covered by each barrel of the mixture. For large-scale operations, minor adjustments may be made to the equipment used for algal control and a pump and motor may be successfully used in distributing the chemical solution.

Over many years, swimmer's itch has been controlled successfully in Michigan with motor-powered units that distribute a mixture of copper sulfate and fresh hydrated lime. The units are mounted in ordinary flat-bottom row boats. Dilution water is taken from the lake by a pump and into this water is injected a mixture of dry chemicals that consists of 8 parts of copper sulfate (snow grade) to 1 part of fresh hydrated lime. The mixture passes through a discharge pipe from the pump over the

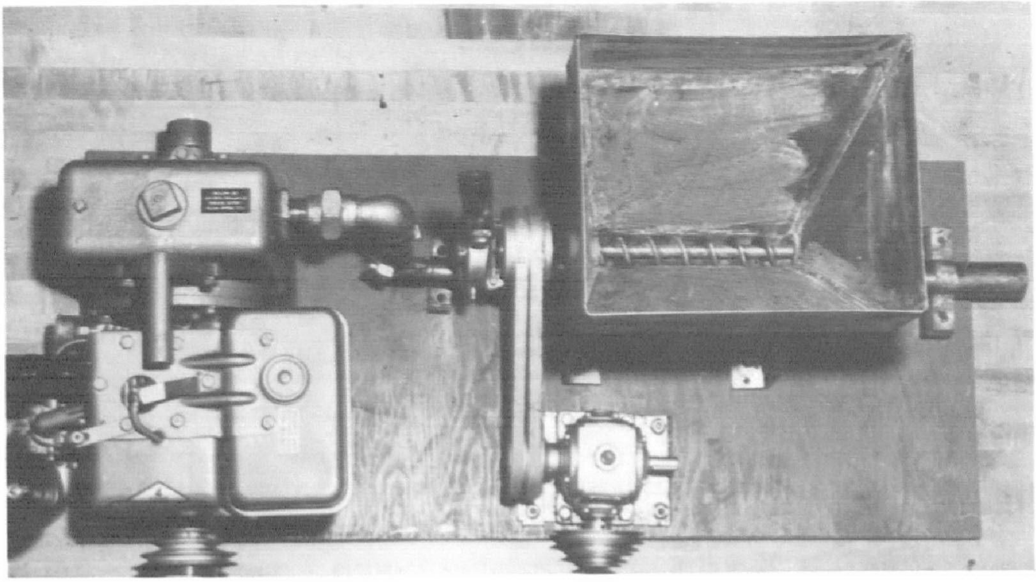


Plate 40. Combination mixer-distributor unit for underwater chemical application, top view. The dry chemical is injected into water stream on suction side of pump.

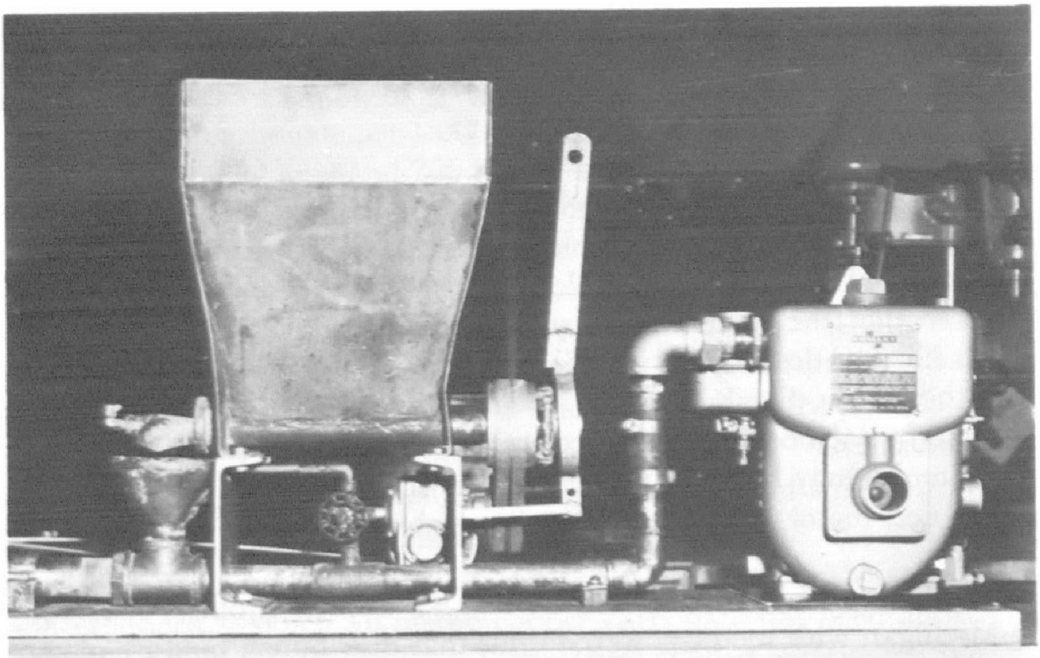


Plate 41. Combination mixer-distributor unit for underwater chemical application, side view.

stern of the boat and is fed from a pipe "header" attached to the stern onto a strip of lake bottom 10 to 12 feet wide. A number of lengths of hose attached to the header and trailing from the rear of the boat are weighted at the outlet end so as to introduce the chemical solution directly onto the sand bottom (Adams, 1945).

On some shallow bottom shelves it may be difficult to float a loaded boat over the snail beds near the shore. Here, the sowing of copper sulfate crystals by hand, at the same rate of 2 pounds of copper sulfate per 1,000 square feet of area, has been successful in killing snails in water up to 2 feet deep.

The chemicals should be applied beneath the surface of the water directly over the snail beds when the water is very calm. Even slight ripples on the surface indicate sufficient water movement to decrease the efficiency of the treatment. Applying the chemical beneath the surface of the water concentrates the chemical within the treatment area and reduces the adverse effects upon the ecology of the surrounding area.

Areas to be treated should be carefully marked and subdivided into small enough sections to insure even distribution of the calculated amount of chemical.

Swimming should be prohibited for at least 2 hours after treatment to prevent undue dispersion of the chemical; since snails are on the bottom of the lake, the longer the chemical remains undisturbed on the bottom the more effective the treatment will be. Any fish trapped within the treated area will be killed. It is wise to remove all minnow boxes and traps from the general area before treatment is begun. If there are no underwater currents within the area, there will be little "drift"; however, if currents are present, chemical "drift" will occur.

Bottom organisms are very much affected by chemical treatment; crayfish, leeches, tubificids, and some of the insect larvae are usually killed. Most of the bottom organisms killed are fish food, but the area treated usually is an insignificant portion of the total shoreline of a body of water or of the total bottom area capable of supporting a population of fish food organisms, and the killing of leeches on beaches where they cause considerable trouble is distinctly advantageous.

To reduce dermatitis appreciably it has been found necessary to apply chemicals to at least 300 to 400 feet of lake frontage to a width of 200 feet or to the dropoff; it is desirable to treat up to 1,000 uninterrupted shoreline feet. Treatment should be conducted from the shoreline outward until the entire area is covered. One treatment is effective during a season and often throughout a subsequent season. Control experience in Wisconsin indicates that treatment every other year successfully reduces the snail population within the bathing area and thus controls swimmer's itch.

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CHAPTER VI

Sampling and Data Evaluation

Nothing useless is, or low;
each thing in its place is best;
and what seems but idle show
strengthens and supports the rest.

—HENRY WADSWORTH LONGFELLOW.

Sampling and data collection are governed by physical features, chemical factors, and biological communities. Physical features include water temperature, turbidity, color, water movement, light penetration, wind velocity and direction, bottom deposits, and the size, shape and slope of the lake basin. Chemical factors include alkalinity, pH, dissolved oxygen, free carbon dioxide, hardness, nitrogen (organic, ammonia nitrogen, nitrite and nitrate), phosphate (ortho and total), as well as other specific elements that may be of interest in a particular problem. Biological communities include the littoral community composed of rooted vegetation, attached algae, fish, and a host of invertebrates; the limnetic community, principally fish and plankton; and the benthic community of midge larvae, sludgeworms, fingernail clams, and other bottom dwelling organisms.

Lake sampling and data collection entail:

a definition of the problem,

a determination of the types of samples necessary to delineate a solution,

a selection of sampling sites,

a judgment of the necessary number of samples,

a decision on the proper time, periodicity, and extent of sample collection, and

a knowledge and understanding of the science of limnology.

Basically, this discussion may be summarized in the questions why?, what?, how?, where?, and when? (Porges, 1960).

WHY?

The purposes of a sampling program are to point toward a logical and satisfactory solution to a specific problem, to correlate physical, chemical, and biological phenomena, to understand the interrelationships of the biota with the environment, and to evaluate biological productivity. Predictions of productivity yet are as but crude estimates because of the variability among lakes and reservoirs, the present limited knowledge of lake ecology, and the physical magnitude of a comprehensive sampling program. Too often the public is impatient with a study program designed to investigate the water body as an entity, since paramount interest usually centers in certain kinds of desirable fish and in the control of oppressive aquatic nuisances. Authors who contribute an insight into problems associated with productivity include Coker (1954), Hutchinson (1957), Needham and Lloyd (1937), Reid (1961), Ruttner (1953), and Welch (1952).

Odum (1959) describes the pond complex in four basic units: abiotic substances such as basic inorganic and organic compounds including water, carbon dioxide, oxygen, calcium, nitrogen and phosphorus salts, etc.; producer organisms such as rooted plants and algae; consumer organisms such as animal plankton, bottom-dwelling insect larvae, crustacea, and fish; and decomposer organisms such as aquatic bacteria and fungi. Odum quotes Hayes and Coffin (1951) who said that a pond or lake "is not, as one might think, a body of water containing nutrients, but an equilibrated system of water and solids, and under ordinary conditions nearly all of the nutrients are in a solid stage." Odum emphasizes that the rate of release of nutrients from solids is one of the most important processes that regulate the rate of function of the entire ecological system.

Complicated food chains are established that transfer energy from one organism to another. Odum (1959) describes three types of food chains: the predator chain that starts from a plant base and goes from smaller to larger animals; the parasite chain that goes from larger to smaller organisms; and the saprophytic chain that goes from dead matter into microorganisms.

The primary purpose of a sampling program is, then, to shed light on the physical-chemical-biological complex within a body of water or within a particular segment of that water body, and to understand the meteorological phenomena that are interrelated. To achieve this aim, cognizance must be given to the environment and the ecology of the organisms within that environment.

WHAT?

Rawson (1958) considers lake and reservoir (measurement) in three broad groups: a morphometric group, a group of physical and chemical determinations, and a unit on biological conditions. A reference list for the morphometric group includes the following:

- Area
- Mean depth
- Maximum depth
- Area of depth zones
- Volume of depth strata
- Altitude
- Latitude
- Shore length
- Shore development
- Littoral development
- Littoral slope
- Number of islands
- Area of islands
- Shore length, islands
- Drainage area
- Rate of runoff
- Average inflow
- Average outflow
- Time of "flushing"
- Water levels

Rawson's somewhat conservative list of physical and chemical determinations includes:

- Weekly temperature series
- Highest mean temperature
- Highest bottom temperature
- Mean temperature 0 to 10 meters
- Degree of stratification
- Duration of stratification
- Summer heat income
- Duration of ice cover
- Average bottom DO
- Lowest percent saturation DO
- Average pH surface
- Average pH bottom
- Color
- Secchi disk average
- Secchi disk range
- Total dissolved solids
- Total alkalinity
- Calcium
- Magnesium
- Bicarbonates
- Sulfates
- Chlorides

He states, "It would seem desirable to reduce the number of determinations to the minimum which would provide a general grasp of the physical and chemical conditions in the lake. Bimonthly or preferably weekly temperature series, secchi disk, surface and bottom pH and dissolved oxygen, and mineral analysis once or twice during the summer should provide most of this information."

To augment the list of tests proposed by Rawson, the plotting of the vertical dissolved oxygen curve and a knowledge of the nutrient inflows, outflows, and retention within the basins is indicated. The latter would involve flow measurements of influents and effluents, as well as determinations for organic nitrogen, ammonia, nitrate, and nitrite nitrogen, total phosphorus, and soluble phosphorus. In deep reservoirs and lakes, iron and manganese are important considerations especially if downstream domestic water supplies are involved.

Rawson considers the biological conditions with the following reference list:

Plankton	*Bottom Fauna*	*Fish*
Average standing crop (dry wt. basis); qualitative data such as water blooms, percent predominant species composition, etc.	Average standing crop (dry wt. per unit area); percent composition of major benthic forms.	Average catch per standard net-number and weight; relative growth rates; sustained commercial yields.

"Looking back now over the three groups of 'factors,' which do we regard as most significant, to be included in our minimum required list? No doubt each limnologist will have some special preferences and will assign different importance to the various measures. Nevertheless, a solid core of information can be selected. Let us assume that for any lake you can cite the following 10 items; area, mean depth, shore development, highest mean temperature, average near bottom oxygen at midsummer, average depth for secchi disk, total dissolved solids, average standing crop of plankton and bottom fauna per unit area, average catch of fish in a standard gillnet, and a list of a few dominant plankters, bottom organisms and fish. An experienced limnologist would feel that he had a considerable grasp of what was going on in such a lake and would probably make some definite suggestions concerning the level of fish production to be expected." (Rawson, 1958)

Submerged aquatic vegetation has become a problem in many standing bodies of water used for recreation. It is important, therefore, to conduct a reconnaissance of the standing crop of submerged aquatics during the period of maximum growth to determine the immediate

Plate 42. Interior of 26-foot U.S. Public Health Service Mobile Laboratory—facing forward.

potential nuisance problem, as well as secure base line data against which future observations can be compared to determine relative changes in the standing crop and predict future potential nuisances. This is done best by mapping the standing crop as accurately as possible, both as to kinds present and relative abundance.

Dobie and Moyle (1956) state that ". . . . there have been many attempts to evaluate fish-rearing ponds on the basis of fish populations and production. Too often basic limnology and chemistry of pond water and soil have been neglected by fisheries workers . . . knowledge of the aquatic habitat is essential for understanding the mechanics of fish production." Based on 10 years of experience in Minnesota, they set up a typical pond study to include analysis of pond soil; analysis of pond water including total alkalinity, sulfates, chlorides, ammonia, organic, nitrate and nitrite nitrogen, total nitrogen, and total and soluble phosphorus; the protein nitrogen and phosphorus; and a measure of plankton production.

The Public Health Service has established a National Water Quality Network currently involving 128 stations on the rivers of the United States. All Network samples are examined for:[11, 12, 13, 14]

Radioactivity (weekly): (1) Gross alpha; (2) Gross beta; (3) Strontium 90.

Plankton populations (semimonthly).

Coliform organisms (weekly).

Organic chemicals (monthly).

Biochemical, chemical, and physical measurements, including biochemical oxygen demand, dissolved oxygen, chemical oxygen demand, chlorine demand, ammonia nitrogen, pH, color turbidity, temperature, alkalinity, hardness, chloride, sulfate, phosphates, and total dissolved solids (weekly).

Trace elements.

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[11] National Water Quality Network, Annual Compilation of Data, Oct. 1, 1957–Sept. 30, 1958. U.S. Public Health Service Publication No. 663 (1958 Edition), 239 pp. (1958).

[12] National Water Quality Network, Supplement 1, Statistical Summary of Selected Data, Oct. 1, 1957–Sept. 30, 1958. U.S. Public Health Service Publication No. 663, Supplement I, 164 pp. (1959).

[13] National Water Quality Network, Annual Compilation of Data, Oct. 1, 1958–Sept. 30, 1959. U.S. Public Health Service Publication No. 663 (1959 Edition), 323 pp. (1959).

[14] National Water Quality Network, Annual Compilation of Data, Oct. 1, 1959–Sept. 30, 1960. U.S. Public Health Service Publication No. 663 (1960 Edition), 424 pp. (1960).

A survey that measures many water characteristics necessitates planning and organization of equipment (Hoskins, 1938; Carnahan, 1941). DeMartini (1941) described one of the first mobile laboratory units used in a survey of the Ohio River. Since that time, mobile laboratories have increased in size and in instrumentation. The U.S. Public Health Service uses a 40-foot mobile trailer laboratory, a 26-foot compact mobile laboratory, and a smaller unit designed especially for biological studies. The larger units contain a hot water heater, BOD incubator, air conditioner, electric muffle furnace, hot air sterilizer, electric water still, bacteriological incubators and water baths, refrigerator, steam sterilizer, fume hood, ice machine, glassware washer, exhaust fan, and a 110-volt generator. The small mobile biological laboratory contains a sink, counter space, cupboard and shelves for holding sampling cases, electrofishing unit, dredges, nets, and miscellaneous equipment.

HOW?

The techniques of sample collection and analysis have been well documented in the "Standard Methods for the Examination of Water and Wastewater" (Anon., 1960). This has been used for many years as a guide to the physical and chemical examination of water, sewage, and industrial wastes, the radiologic and bacteriologic examination of water, and the biologic examination of water, sludges, and bottom materials. The first edition of "Standard Methods" was published in 1905. In its letter of transmittal, the committee developing the first edition stated: "The methods of analysis presented in this report as 'Standard

Plate 43. Interior of 26-foot U.S. Public Health Service Mobile Laboratory—facing the rear.

Plate 44. Mobile biological laboratory with electrofishing unit, Petersen dredge, Ekman dredge, and other equipment in interior.

Methods' are believed to represent the best current practice of American water analysts, and to be generally applicable in connection with the ordinary problems of water purification, sewage disposal and sanitary investigations. Analysts working on widely different problems manifestly cannot use methods which are identical, and special problems obviously require the methods best adapted to them; but, while recognizing these facts, it yet remains true that sound progress in analytical work will advance in proportion to the general adoption of methods which are reliable, uniform and adequate." The foresight of the original committee is evident in comparing its statement with our present beliefs.

Another book, "Limnological Methods" (Welch, 1948) is worthy of special mention since it ". . . presents the essentials of those basic methods necessary for (a) entry into the subject of limnology, (b) limnological surveys of lakes and streams, and (c) fundamental information upon which specialized researches depend."

Water samples for chemical analyses are obtained from a particular location within the water body. The location will depend upon the problem under investigation, but the sample should represent the water volume from which it was obtained and for which the sampling program was devised. Sampling equipment designed especially for lakes or streams aids in sampling; a Kemmerer water bottle is widely used in limnological investigations.

Flow data for the inlets, outlets, and contributing sources, which can be correlated with sampling dates, are of utmost importance. Such data permit, for example, a calculation of the amount of nutrients entering, remaining, and being discharged from a body of water. These data are necessary to the full understanding of a particular problem and permit a better evaluation of feasible remedial measures.

Samples of water for plankton examination are secured in much the same fashion as samples for chemical analyses. In most cases, a volume of water from a particular location is sufficient; in special studies it may be advantageous to use one of the specialized plankton samplers described in "Standard Methods for the Examination of Water and Wastewater" and "Limnological Methods." Again, the sample must be representative of the ecological niche for which the sampling program was planned. Unless the samples are examined soon after collection they must be preserved with either 4-percent formalin or one of the special plankton preservatives.

Williams (1961) describes the method used by the Public Health Service Water Quality Laboratory, Cincinnati, Ohio. Each sample is taken directly from the river or lake, or from a continuously flowing intake (as at a water treatment plant) receiving the river or lake water. The sample, consisting of 3 liters of untreated water, is added to 100 ml. of preservative (thimerosal, 0.16 percent, plus Lugol's solution, 1 percent) in a polyethylene bottle. The Lugol's solution stains parts of the cells making identification easier. It also aids in settling the plankton since the iodine causes some of them to lose gas and, therefore, their buoyancy. This preservative has been found to be effective for approximately 1 month during the warm seasons and longer during cool weather. One gram of sodium borate is added for each gram of thimerosal to help keep the thimerosal in solution.

Various laboratory methods have been employed to estimate plankton populations within a sample and simplified procedures have been presented (Ingram and Palmer, 1952). Calibration of plankton counting equipment is essential at the start of any counting program and methods for calibration and calculation of results have been recorded (Jackson and Williams, 1962). Statistical precision of the results reported have also been given thoughtful treatment (Moore, 1952; Kutkuhn, 1958). Researchers recognize the many errors inherent in determining a theoretical plankton population. The investigator should precisely record the procedure he has followed in both sample collection and sample examination to permit the reader to judge the report against past literature on the subject and to repeat a method if an area may someday be restudied.

Three analyses, each requiring 1 liter, are made per sample at Cincinnati, Ohio (Williams, 1961):

(1) the genera of phytoplankters are identified and enumerated with the Sedgwick-Rafter slide technique; (2) the genera of microinvertebrates, mostly rotifers and crustaceans, are settled, identified to genus, and counted in a special microslide; and (3) the diatoms are settled, washed, and made into a permanent hyrax slide from which are made proportional counts of the species and some of the varieties. These determinations are also used to qualitate to genus the diatoms recorded in the Sedgwick-Rafter (step one) procedure and to make the proportional counts in step three. Phytoplankters counted in the Sedgwick-Rafter slide include forms measuring 4 microns or more. Clump counts are made of fungi and sheathed bacteria. The Sedgwick-Rafter counts for total algae that were alive when collected are made as clump counts in which each single-celled individual or natural clump or colony of cells is enumerated as one. The count is made in a Sedgwick-Rafter slide from unconcentrated or undiluted raw water samples, with 20-power objectives and 10-power oculars, and is accomplished by counting two lengthwise strips (about 500 microns) the width of the Whipple square. These two strips represent a volume of about 0.05 ml. To obtain the number of plankters per ml., a factor of 20 to 22 is used, varying with the correction for preservative dilution and differences in calibration of the microscopes. Diatom shells without chromatophores are tallied separately from preserved diatoms with chromatophores.

In a survey of the Delaware-Susquehanna watershed (Tressler and Bere, 1935), a 10-liter plankton trap, a Kemmerer water sampler, a Foerst centrifuge, and a Sedgwick-Rafter counting cell were used. The results of the counts were correlated with depth and with the amount of organic matter in the water.

Damann (1941) described results of quantitative studies of the phytoplankton of Lake Michigan in which water samples were filtered through sand supported upon 200-mesh bolting cloth discs and the number of organisms from the concentrate calculated. Later Damann (1950), found that a direct count without concentration in a Sedgwick-Rafter counting cell yielded a considerably higher average plankton number in all of the population densities than that obtained by the standard concentration method.

Lackey (1938) used a drop counting method in his examination of Scioto River, Ohio, phytoplankton. In this method, the sample is first centrifuged and "... after thorough agitation by alternately sucking it in and spurting it out of the pipette, the exact number of drops was counted and a sufficient number of drops of the decanted portion was added, so that one drop of catch bore a definite relationship to the amount centrifuged." One drop of sample was put on a glass slide and a cover glass added. Advantages of the method include inclusion of all organisms in the catch, simplicity and ease of manipulation, and instant use of the high power magnification where identification with the low power is questionable. Use of the high power objective is also possible when phytoplankton are concentrated on the membrane filter (McNabb, 1960). McNabb developed a method in which a 1-inch membrane filter was used to concentrate the sample and the frequency of occurrence of specific organisms in a specified number of microscopic fields was noted. The frequency-percentage was converted to a theoretical average number of individuals per quadrat through the use of a frequency-density table.

Plankton samples from the Madison, Wis., sewage treatment plant effluent diversion study (Mackenthun et al., 1960) were concentrated by settling with a liquid detergent and were counted by the drop technique. The number of a particular type of organism in 1 liter of water was determined by the following formula:

$$\text{No./l} = \frac{(\text{Avg No./field})\ (\text{No. fields/coverslip})\ (\text{No. drops/ml}) \times 1{,}000}{\text{Concentration factor}}$$

$$\text{The concentration factor} = \frac{\text{ml of original sample}}{(\text{ml of concentrate})\ (0.94)},$$

where 0.94 accounts for the dilution of the sample by the addition of formalin and the detergent.

The volume contributed by each species was expressed in parts per million by use of the following formula:

$$\text{Volume (ppm)} = (\text{No. org/l})\ (\text{avg species vol in } \mu^3) \times 10^{-9}.$$

Palmer (Palmer and Maloney, 1954), developed a new counting slide for nannoplankton.

Patrick et al. (1954) developed a slide-carrying device, termed the Catherwood diatometer, to sample the diatom populations of streams. It consists of a plastic base mounted on a lead bar shaped like a boat. On the plastic base are mounted two floats designed so that the depth to which the diatometer is sunk can be varied. Between the floats, behind a plastic V-shaped vane, the plastic slide holder slotted to hold six slides vertically is mounted edgewise to the current. The vane prevents excess washing of the slides. It was stated that 1 week was sufficient to expose the slides and that the population of an unpolluted stream could be estimated as adequately with this method as with the usual methods of collecting diatoms. Calculations upon which these estimates are based have to be corrected when dealing with polluted streams.

Periphyton include that assemblage of organisms that grow upon free surfaces of submerged objects in water and cover them with a slimy coat. Cooke (1956) gives a comprehensive review of the literature on the subject. Periphyton play an important role in flowing waters because these organisms are the major primary producers in that environment. Thus, they are an important part of a lake or reservoir study of both the influent and receiving streams. A number of substrates have been proposed with which to study attached organisms including glass slides, cement blocks, wooden shingles, and plexiglass plates (Grzenda and Brehmer, 1960).

Artificial substrates have been successfully employed in studying bottom fauna in the flowing stream. One multiple-plate sampler constructed of tempered hardboard (Hester and Dendy, 1962) has been especially suitable for studying stream inhabitants in those streams that do not possess a natural substrate suitable for the attachment of benthic forms. A sampler constructed of eight 3-inch squares separated by seven 1-inch squares and held in place by a bolt or threaded rod exposes slightly more than 1 square foot of surface to which organisms can attach.

Bottom samples in lakes usually may be collected with an Ekman dredge, although the physical composition of the bottom determines to a great extent the type of sampler that must be used to collect an adequate sample. The Ekman dredge (Ekman, 1911) consists of a square box of sheet brass 6 x 6 inches in cross section. The lower opening of this box is closed by a pair of strong jaws so made and installed that they oppose each other. When open, the jaws are pulled apart so that the whole bottom of the box is open; the jaws are held open by chains attached to trip pins. To close the dredge, the trip pins are released by a brass messenger sent down the attachment rope and the jaws snap shut by two strong external springs. The hinged top of the box is equipped with a permanent 30-mesh screen to prevent loss of organisms if the sampler sinks in to mud deeper than its own height. The sampler is especially adapted for use in soft, finely divided mud and muck; it does not function properly on sand bottoms or hard substrates.

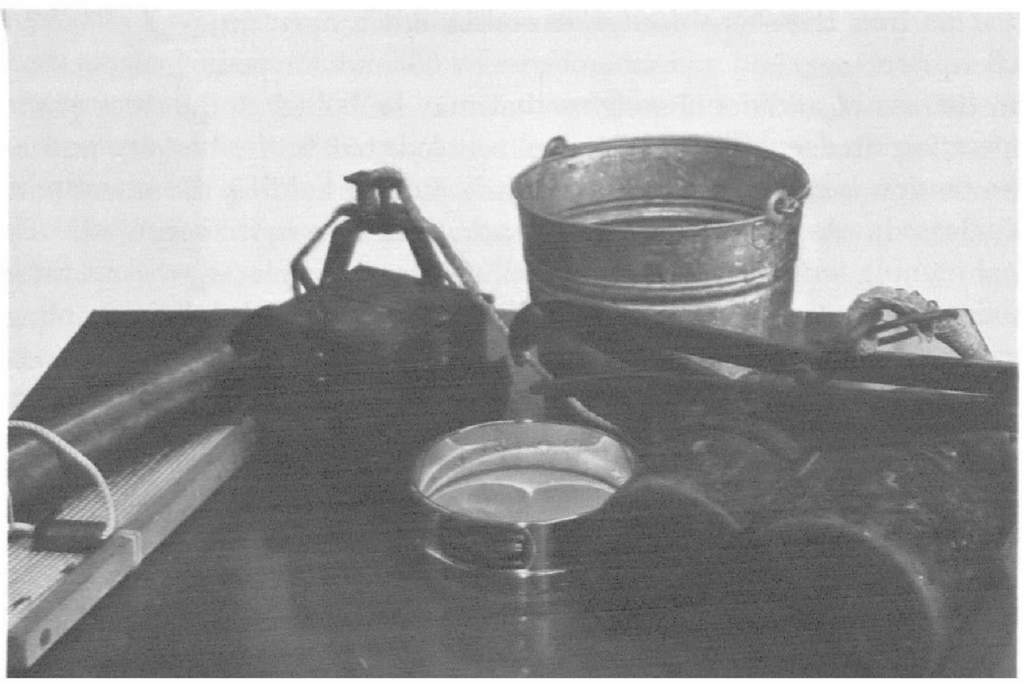
The Petersen dredge (Petersen, 1911) is widely used for sampling hard bottoms such as sand, gravel, marl, clay, and similar materials. It is an iron clam-type dredge, sampling when open an area of 0.6 to 0.8 square foot, and weighing between 35 and 70 pounds depending on the use of additional weights that may be bolted to the sides of the operating dredge. The dredge is slowly lowered to the bottom, and as the tension is eased on the rope the mechanism holding the jaws apart is released. As the rope is again made taut, a sample is secured. By maintaining tension on the rope until the dredge is placed, the operator maintains control of the dredge. This is especially helpful in sampling gravel or rubble, as the operator can determine through sound and touch the type of bottom and can, through careful manipulation of the dredge, secure a better sample than would otherwise be possible. After the dredge is "set", alternate application and release of tension on the rope aid in working the dredge into the bottom substratum.

After the bottom sample is collected by one of the deepwater sampling devices, it is brought to the surface and placed in a large pail or tub. Water for sample dilution is added to the pail, the sample is mixed into a slurry, and the slurry passed through a U.S. Standard No. 30 mesh sieve while the sieve is being rotated in the water. The washing operation is repeated until all fine material has passed through the sieve, and all organisms are washed from the sample and are trapped in the sieve. The organisms and coarser debris from the sieve are then removed and may be preserved. The sand and rubble in the original sample from which the organisms have been removed are discarded. It is often easier to sort the organisms from the debris when the organisms are alive. Time schedules and extensive field operations, however, often dictate that sample collection and examination take place at different times during the year. Thus, after the samples are preserved in the field they are returned to the laboratory where the organisms are separated from the debris, placed in respective groups, identified, and enumerated.

To sample riffle areas in streams, a stream-bottom sampler, originally described by Surber (1936), is widely used. It consists of two 1-foot-square frames hinged together at right angles; one frame supports the net, the other encloses the sampling area. In field operation, the sampler is so placed that organisms dislodged by hand from the substratum within the sampling frame will be carried into the net by the current.

Hess (1941) described another form of circular square-foot sampler suitable for gravel and rubble stream bottoms. It consists of a cylin-

Plate 45. Biological sampling equipment. From left to right, a Kemmerer water sampler, Ekman dredge, U.S. Standard No. 30 sieve, washing bucket, and Petersen dredge.

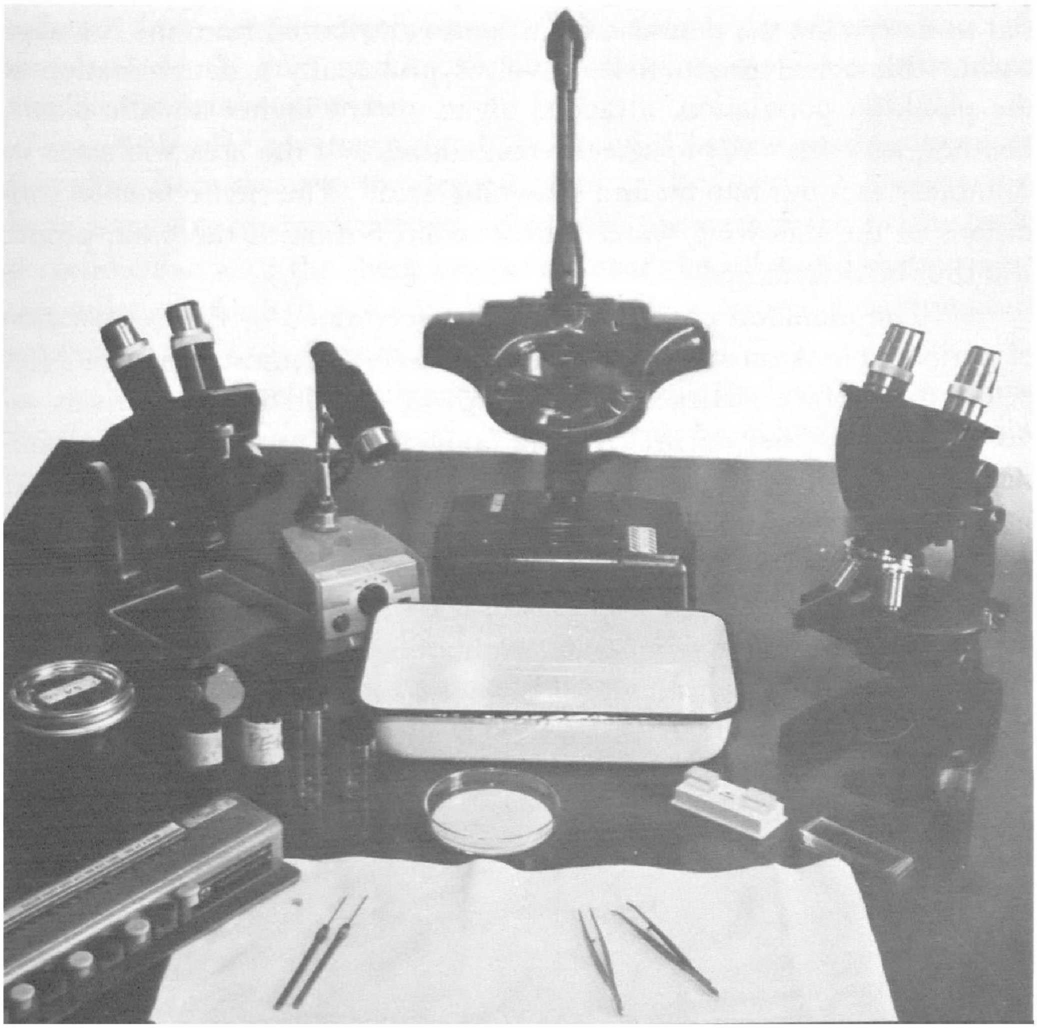


der about 18 inches tall, streamlined in cross section and tapered to a bottom hoop whose inside diameter encloses exactly 1 square foot of area. The sampler is so constructed that it may be thrust into the bottom and the organisms dislodged and captured in a downstream net in much the same manner as in the Surber square-foot stream-bottom sampler.

Needham and Usinger (1956) studied the variability in the organisms of a single riffle in Prosser Creek, Calif., as indicated by the Surber sampler. Results of 100 bottom samples indicated that an excessive number of samples would be required to provide significant data on total weights and total numbers of bottom organisms. The data showed, however, that only 2 square-foot samples are necessary to be reasonably certain of obtaining representatives of principal groups of organisms present.

Fish samples may be collected by nets, seines, poisons, and electrofishing. Electrofishing is conducted by means of an alternating or direct electrical potential applied to water that has a resistance different from the fish. This difference in resistance to pulsating direct current stimulates the swimming muscles for short periods of time, causing the fish to orient and be attracted to the positive electrode. An electrical field of

Plate 46. Sorting, enumeration, and identification equipment used in analyzing benthic samples.



sufficient potential to demobilize the fish is present near the positive electrode, but decreases in intensity with distance. After the fish are identified, weighed, and measured, they can be returned to the water uninjured.

The electrofishing unit may consist of a 110 volt, 60 cycle, heavy duty generator, an electrical control section, which is a modified commercially-sold variable voltage pulsator, and electrodes. The electrical control section provides selection of voltages from 50 to 700 volts AC and 25 to 350 volts DC. The AC current acts as a standby for the DC current and is used in cases of extremely low water resistance. The variable voltage allows control of field size in various types of water.

WHERE?

Proper location of sampling points depends primarily upon the particular problem under investigation. Sampling may be also closely correlated with the particular niche of the environment that appears to contribute most to the study problem.

A lake or reservoir is the receiving basin of its inflowing waters. It is thus greatly influenced by influent streams, which must be critically studied to measure the input of the water body. Sampling stations should be established on major influent streams, at points where they are not influenced by the lake's basin, to determine nutrient loadings, biological productivity, and other pertinent water properties. Flow data are essential to determine the pounds of nutrients contributed from the drainage basin. Biological productivity involves principally a determination of the plankton population, attached algae, rooted higher aquatic plants, benthos, and fish. A biological reconnaissance of the area will assess its suitability as a fish habitat and spawning area. The environmental conditions of the inflowing water and its contribution to the basin proper will thus be determined.

The plankton population can be ascertained by the examination of periodic plankton samples normally collected at midstream 1 to 2 feet below the surface. Attached algal growths should be qualitatively assessed wherever they occur. Bottom fauna should be collected at a minimum of three points across the stream (mid and two quarter points); a minimum of three individual samples should be collected from each point and retained separately. An attempt should be made to determine the fish population within a specified area. Points at which samples are collected for routine chemical determinations or stream monitoring for chemicals should match those for biological samplings.

Likewise, the receiving waters from the lake or reservoir should be studied in a fashion similar to that of the influent streams. The effluent of a natural lake will usually give a good composite of the epilimnionic waters of the lake. The discharge from a penstock located below the thermocline, however, will not give a representative sample of the productive zone of the reservoir but shows water quality in a portion of the hypolimnion instead. A study would be indicated to show the effect of the low-level discharge on the receiving waters.

Within the lake or reservoir, a number of sampling sites may be chosen depending on the problem under investigation and the conditions to be studied. An investigation of the kinds and relative abundance of aquatic vegetation would naturally be limited to the littoral area. A mapping of aquatic plants often proves useful for future comparisons. Fish sampling also is usually more profitable in shallow water areas, although gill nets set in the region of the thermocline and below may sample a fish population not usually observed in shallow water.

The use of transections in sampling a lake bottom is of particular value because there are changes in depth and because benthos concentration zones usually occur. Unless sampling is done systematically and at relatively close intervals along transections, especially those that extend across the zone between the weed beds and the upper extent of the hypolimnion, concentration zones may be missed entirely or inadequately represented. High benthic productivity may occur in the profundal region. Because depth is an important factor in the distribution of bottom organisms, productivity is often compared on the basis of samples collected from similar depth zones. Collections from a transection will sample all depth zones, and a sufficient number of samples must be taken to make the data meaningful.

A circular lake basin should be sampled from several transections extending from shore to the deepest point in the basin. A long narrow basin is suitable for regularly spaced parallel transects that cross the basin perpendicular with the shore beginning near the inlet and ending near the outlet. A large bay should be bisected by a transection originating near shore and extending to the lake proper.

There are definite advantages in sampling the benthic population in winter beneath the ice cover. Samples can be collected at definite, spaced intervals on a transection, and the exact location of sampling points can be determined. Also, collections are at a time of peak benthic population when emerging insects do not alter the benthic population.

Transections also aid in sampling the plankton population. Because of the number of analyses necessary to appraise the plankton population, however, more strategic points are usually sampled, such as water intakes, a site near the dam or discharge, constrictions within the

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water body, and major bays that may influence the main basin. Because of significant population variation, plankton samples must be taken vertically at periodic depths, and at different times over the 24-hour day.

Samples of bottom muds are useful to determine the concentration of specific elements within the bottom deposits. Heavy metals, for example, are known to be concentrated in the deeper portions of the lake, and copper and arsenic used in aquatic vegetation control have been found in significant quantities in such deposits. Core samples from the bottom present a historical background of bottom sediments, from which determinations can be made of the relative rate of deposition for a period of time.

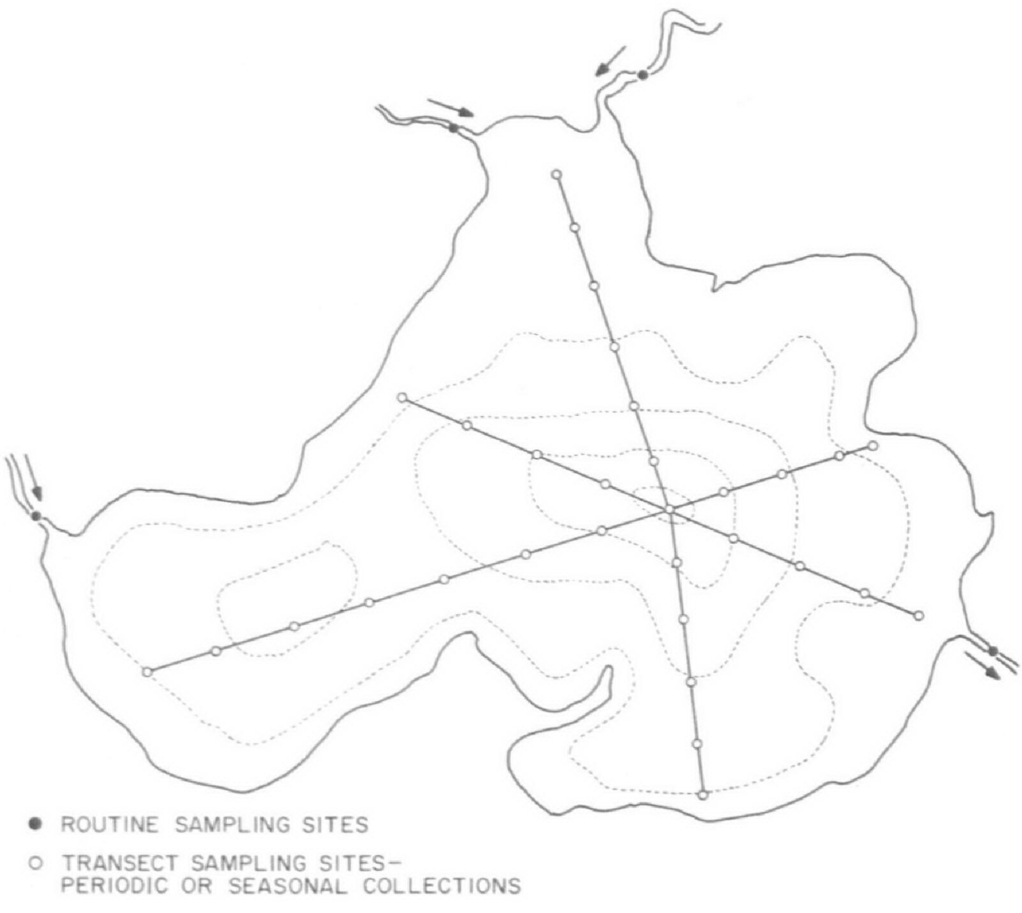

Figure 8. Diagrammatic sketch of a natural lake basin showing suggested sampling sites. Inlet and outlet samples give valuable data. Samples taken from points on transection lines on a periodic or seasonal basis are valuable in determining vertical water characteristics and the benthic standing crop.

WHEN?

The periodicity with which samples are collected during a particular season will depend on the time and personnel available. In special studies, samples are often collected daily or even periodically during a 24-hour day.

To measure plankton populations and chemical constituents that may change rapidly, weekly collections, as a minimum, are desirable throughout the season of active biological growth. A reconnaissance and mapping of the aquatic vegetation should be accomplished during maximum vegetation growth, usually in midsummer. Bottom fauna should be sampled during the annual seasons; the standing crop will be highest, however, during the fall and winter periods when there is no insect emergence and one of the sampling dates should reflect this period.

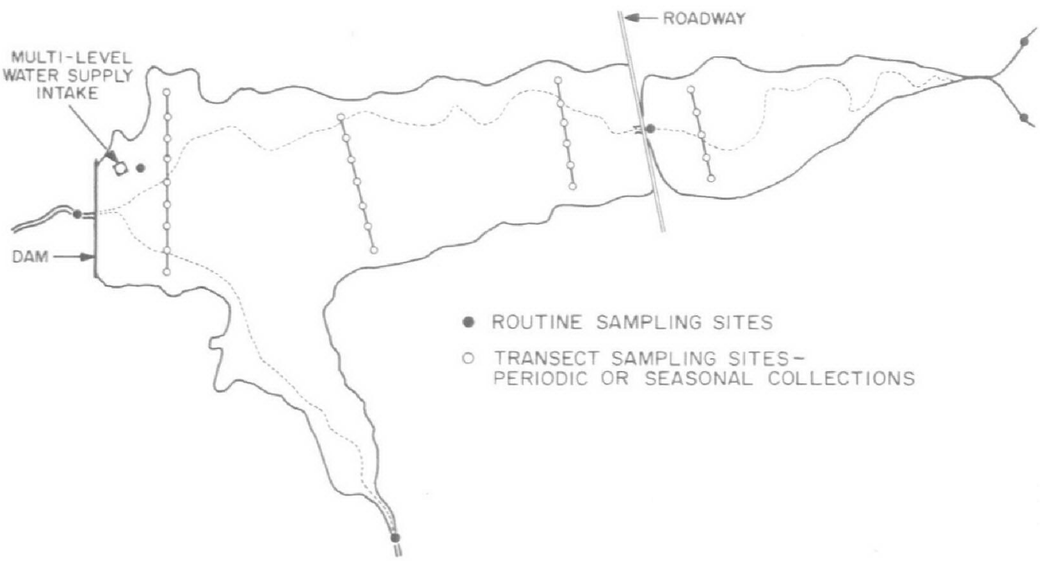

Figure 9. Diagrammatic sketch of a long, narrow, shallow water reservoir showing suggested sampling stations.

REPORTING THE RESULTS

A report represents the end result of all the efforts put forth to accomplish the study. A poor report frequently negates the results of a meticulous field program while a good report does much to enhance the study. The report should be as carefully planned as the field operations. The type of report will depend upon two basic considerations: (1) the purpose of the report, and (2) who will use it. The report may be only a record of the findings. It may be an exposition of existing causes and effects and projections to other considerations that may reasonably occur, or predictions of conditions that might occur and recommendations for action to be taken. The report should be considered as a document permanently recording all essential facts in the study to meet the needs of all concerned including technical agencies, political representatives who may be for or against the conclusions and recommendations, and the public.

In all instances the report adds to the existing record. All field notes, observations, and laboratory data should be included in the report for permanent recording. This information provides valuable baseline data for future studies of an area.

The first step in the development of the report is an outline. It should be thought out very carefully and cover all necessary items in logical continuity. A good outline will prevent omission of necessary material and save considerable time in report writing. Outlines vary with objectives of the reports; however, most reports of water studies will contain the following major items:

Introduction

Acknowledgment

Summary and conclusions

Recommendations

Historical background of study

Physical description of study area

- Geography
- Topography
- Climate
- Hydrology

Use of water resources

- Water resource conservation program
- Municipal and industrial needs
- Navigation
- Fish and wildlife
- Recreation

Survey methods

- Field investigation
- Laboratory operations
- Results of study (data presentation)
- Discussion
- Bibliography
- Appendixes

The discussion should be used for the evaluation of the data. There is room in this section for aggressive and imaginative thinking. The analysis and interpretation of results, including methods of attack and validity of data, should be discussed. Detailed description of any statistical method used should be placed in an appendix. Wherever possible, references should substantiate reports of contradicting results; an effort should be made to explain discrepancies (Porges, 1960).

Graphic expression of biological data has been used to advantage (Bartsch, 1948; Bartsch and Ingram, 1959; and Greenberg, 1962) and has been summarized by Ingram and Bartsch (1960). Graphics add impact to the findings and give the reader a broad picture in clear, concise form. Pertinent biological information has little value or utility to the general reader unless presented in a form that is readily visualized and understood. Information from a great many reports is disseminated to the general public since the public decides, in a broad sense, the monies allocated for particular studies. Thus, reports should be so written that they can be understood by the public, and still contain sufficient scientific terminology to accurately define the results of the study.

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CHAPTER VII

Control of Excessive Production

Man cannot change a single law of nature, but can put himself into such relations to natural laws that he can profit by them.

—EDWIN GRANT CONKLIN.

The control of aquatic nuisances unquestionably should be directed to the basic cause. Uncontrolled drainage from heavily fertilized farmland, the discharge of untreated or partially and inadequately treated domestic wastes from shoreline cottages, the discharge of effluents from municipal and industrial treatment plants, drainage from garbage dumps, or the discharge of untreated industrial and municipal wastes each contributes its share of fertility and thus accelerates the aging of a body of water.

The process of growing old limits the life span of some lakes to a comparatively short time in the geological calendar. As the aging process advances, the water becomes enriched and the lake gets shallower because of accumulated sediment from erosion and organic debris, and the anchoring of it by rooted aquatic plants. The enriched water gives rise to offensive weed and algal growths that in turn hinder or reduce the potential or multiple utilization of the water. Enrichment of the water under primitive conditions would be a slow process when measured against the life span of man, but natural enrichment augmented by man-made enrichment may increase the fertility of the water to such an extent that the process can be observed over a period of an average life span. Most of our lakes are affected by some form of manmade enrichment.

To control developing nuisances by correcting the basic causes, each individual connected with a given watershed must practice pollution abatement. The discharge of effluents from sewage treatment operations, and of industrial wastes or effluents into the watercourse must be curtailed, unless research can produce processes that will tie up nutrients that serve as fertilizers. Over the years, progressive strides have been made by many of the States in water pollution abatement and prevention. The problem, however, is of great magnitude, and the solution will be slow in coming. Great harm has been and is being done to many waters, and nature's repair process is slow even after the underlying cause is partially or completely corrected. Controls, even though temporary, are necessary if man is to enjoy and utilize this great natural resource to the fullest extent.

The concept of maintenance must be considered by all users of lakes or reservoirs. Controls developed to cure water ills are not singular operations. The triggering mechanism responsible for nuisance development is usually such that it probably will reestablish itself another year. Thus, continuous surveillance as well as maintenance are necessary items of lake or reservoir management.

Methods have been developed and perfected that effect an adequate temporary reduction and control of the nuisance under a number of circumstances. Controls may be either mechanical or chemical, and their selection and use depend upon the nature and scope of the problem, the type and extent of the control desired, and comparative costs. Mechanical controls are limited principally to rooted aquatic vegetation, whereas chemical controls have been developed for algae, rooted aquatic vegetation, and other nuisance organisms. Every control has limitations based upon the dimensions of a proposed area to be treated; however, the limitations are broad and do not exclude overall utilization of the water. Controls that are most generally recommended have not been shown to seriously disrupt general lake ecology.

Of the various algal control methods, chemical treatment has proven most rapid, economical, and effective. Selection of an algicide depends on its effectiveness to kill the majority of the organisms responsible for the nuisance; control materials must not, however, seriously affect the production of zooplankton, the production of fish and the existing fish population, or the benthic invertebrates.

Aquatic vegetation has a definite role in the development and maintenance of a balanced aquatic community. A certain amount of aquatic vegetation in a given body of water is of value to the fishery and waterfowl, although no one has determined the proportion of plant area to water area that is necessary for optimum fish production.

Bennett (1948) studied a pond in which the area of open water was reduced by more than 50 percent of the total surface area by a dense stand of pondweed. Concurrently, the fish harvest was reduced to 58.1 percent of the yield taken during the year that aquatic vegetation was largely absent, although fishing intensity by nets was increased 359 percent and the angling intensity was increased 157 percent at the time of the low harvest of fish.

Control should be confined to a nuisance area, and should not involve an attempt at complete elimination of aquatic vegetation from a given body of water. The primary aim is to control organisms that relate to water-use nuisances, and to leave areas in the natural state that have not been proven to interfere with varied uses. It is important, therefore, to know the ecology of aquatic vegetation and to use it to the best advantage in maintaining the water environment for fishing, hunting, and other recreational pursuits.

STATE CONTROL PROGRAMS

The problem of algal and weed nuisances varies considerably from State to State. Most States receive requests for aquatic nuisance control and generally carry out some type of control program. The program may be limited to field experiments with various chemicals or to the limited control of a nuisance in State-owned water. Some States report that no problem exists; some report a much reduced problem and cite as reasons the general high turbidities of the water and fluctuating water levels. Many States are conducting research and field trials with newer chemicals to find better control measures in anticipation of the developing problem.

About 40 percent of the States regulate the introduction of chemicals for the control of aquatic nuisances by statute or executive order.[15] Another 40 percent regulate by informal supervision, and about 20 percent report no regulation of any type. Many in the latter group also report the nonexistence of a problem. The Wisconsin legislature in 1941 was the first State legislature to pass an act authorizing the Committee on Water Pollution to supervise chemical treatment of waters to suppress algae, aquatic weeds, swimmer's itch, and other nuisance-producing plants and organisms (Mackenthun, 1958). A State permit is required for the introduction of chemicals in 40 percent of the States; approximately 60 percent require no permit. About 57 percent of the States, however, report complete supervision of field application of chemicals, 21 percent report spot checks on the application of chemicals, about 7 percent report supervision principally by a control over commercial spraying operators, and the remaining 15 percent report that no supervision is provided. Many of the States that report complete supervision of field chemical application are also included in the group reporting no required permit. Presumably, notification of control measures is based principally on cooperation between those applying the chemical and the governmental agency. Nearly 45 percent of the States report that com-

[15] Moyle, J. B. and B. R. Jones, 1957. Summary of Aquatic Nuisance Control Activities in the United States in 1956. pp. 1–9 (mimeo.).

plete cost of the treatment is paid by the State; however, these are generally small-control operations, many of which are experimental, performed on State-owned waters.

A questionnaire to all States in 1960 revealed that over 2,000 aquatic vegetation control projects were conducted annually and that most States consider aquatic vegetation control to be a serious and growing problem.[16] Currently 78 percent of aquatic weed control is performed by chemicals and 18 percent by mechanical harvesting. Principal advantages of chemical control include ease in application, relatively low cost, lasting effect, and the covering of a large area in a short time. Mechanical harvesting will not usually endanger fish, animals, and humans, and can be used in water supply reservoirs. Main disadvantages of mechanical control methods are the temporary benefit and the high cost of labor and equipment; removal of cut vegetation poses a problem since there is little or no commercial value for vegetation removed from the water.

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[16] McCarthy, H., 1961. Survey Study on Methods of Controlling Aquatic Weeds and their Effectiveness. FWD Corp., Clintonville, Wis., pp. 1–27 (mimeo.).

Plate 47. Mechanical Weed Cutting and Removal

HARVESTING THE CROPS

From the standpoint of nutrient removal, harvesting the aquatic crops annually would be advantageous. The economics of present methods of harvesting and the scope of the problem, however, necessitate a critical appraisal of the benefits versus the costs. The expected standing crop of algae approaches 2 tons per acre (wet weight) containing 15 pounds of nitrogen and 1.5 pounds of phosphorus. Submerged aquatic plants would be expected to approach at least 7 tons per acre (wet weight) containing 32 pounds of nitrogen and 3.2 pounds of phosphorus. Values may be higher under severe nuisance conditions.

Bottom-dwelling bloodworms (midge larvae) might be expected to occur in population densities of 300 pounds per acre (wet weight). If 6 percent of this population is annually lost as emerged insects outside the lake basin (Borutsky, 1939), this removes only ¼ pound per acre of nitrogen and possibly 1/10 as much phosphorus.

The nitrogen content of fish flesh is 2.5 percent (wet weight) and the phosphorus content 0.2 percent (Beard, 1926). Thus, it would be necessary to harvest 1 ton of fish to remove 50 pounds of nitrogen and 4 pounds of phosphorus.

The inorganic nitrogen and phosphorus concentrations occurring during the period of early spring growth that are believed to cause algal nuisance are 0.8 and 0.04 pound respectively per acre foot of water. Thus, if a mean water depth of 15 feet is assumed, 12 pounds per acre of inorganic nitrogen and 0.6 pound per acre of soluble phosphorus available for organism utilization in early spring might be expected to stimulate troublesome nuisances. Harvesting an aquatic crop would be expected to remove a portion of the nutrients in a body of water. It, therefore, is an important consideration in reservoir or lake management. Ultimately, harvesting techniques that are effective, feasible, and financially practical must be perfected.

Some methods and equipment used for the physical and mechanical removal of water weeds are reservoir drawdown and drying, burning, hand-pulling, hand-cutting, hand-raking, chain-dragging, hand-operated underwater weed saws, and power-driven underwater weed cutting and weed removal units. The type of control employed depends on the field situation, the extent of control desired, and the labor and cost involved. Mechanical controls are especially valuable in the reclamation of shallow nuisance areas by dredging and filling.

CHEMICAL CONTROL

Chemical control measures are dependent upon the type of nuisance and local conditions. A good algicide or herbicide must: (1)

be reasonably safe for the applier to use, (2) kill the specific nuisance plant or plants, (3) be nontoxic to fish and fish-food organisms at the plant-killing concentration, (4) not prove seriously harmful to the ecology of the general aquatic area, (5) be safe for water contact by humans or animals, or provide suitable safeguards during the unsafe period, and (6) be of reasonable cost. Some of these factors assume added significance, based primarily on the physical aspects of a particular control operation. What might be suitable from both a cost and toxicity standpoint in a control program for a pond might not be feasible in a control program for specific areas on a large body of water. Certainly more scientific information is needed on the use of algicides and herbicides as fish management tools; on the physiological activities and habitat limitations of aquatic plants; on the effect of presently known chemical formulations on a wider variety of plant species; and on the development, use, and effectiveness of soil sterilants in an aquatic environment.

For many years, recommended chemicals have included copper sulfate or blue vitriol for algal control, and sodium arsenite for submerged aquatic vegetation control. Within the past 5 years, additional chemicals have been used with varying success in the control of aquatic plants. Specialization of chemicals is developing to the extent that some are more effective on specific plant species. Recommendations usually should be directed to the specific problem within a specific body of water.

For algal control it is usually necessary only to know the acreage of water requiring treatment and for weed control, the volume of water. To ascertain the volume of water, the surface area is multiplied by the average depth. The latter is determined by frequent soundings at regular intervals across the area to be treated. Accurate soundings are best made in the winter through ice cover when it is a simple matter to determine exact positions. The volume of water in cubic feet is used to determine the quantity of chemical needed:

$$\frac{\text{Length (ft.)} \times \text{Width (ft.)} \times \text{Average Depth (ft.)} \times 62.4 \text{ (wgt. of a cu. ft. of water)}}{1{,}000{,}000} =$$

pounds of chemical (active ingredient) needed to give a concentration of 1 mg/l. This, multiplied by the required chemical concentration in milligrams per liter required for treatment equals the pounds of chemical needed for the measured area. Various formulations may be purchased. For example, a formulation containing 2 pounds of active ingredient per gallon would necessitate dividing the pounds of chemical by two to arrive at the gallons of commercial formulation required to control the nuisance.

ALGAL CONTROL

From 1904 (Moore and Kellerman, 1904) and up to the present, the chemical that has most nearly met specifications for the control of algae has been copper sulfate (blue vitriol). Despite its extensive usage, copper sulfate has shortcomings in that it may in excessive concentrations poison fish and other aquatic life, it may accumulate in bottom muds as an insoluble compound following extensive usage, and it is corrosive to paint and equipment (Bartsch, 1954).

Definite dosages of copper sulfate for the control of various types of algae were first prescribed by Moore and Kellerman (1905); these have been extensively reprinted in tabular form with specific dosages for some 70 organisms (Hale, 1954). The practical application of such a table is limited, however, because of the many variables encountered in nature. Because the solubility of copper in water is influenced by pH and alkalinity as well as temperature, the dosage required for control depends upon the chemistry of the water itself, as well as on the susceptibility of particular organisms to the copper. Thus, rather arbitrary dosage rates have been successfully used, especially in the midwestern States, for a number of years (Bartsch, 1954; Mackenthun, 1958). Since a total alkalinity of 40.0 mg/l seems to be a natural separation point between soft and hard waters (Moyle, 1949a), those lakes that have a total methyl orange alkalinity of 40 mg/l or greater are treated with blue vitriol (commercial copper sulfate) at a rate of 1 mg/l for the upper 2 feet of water regardless of actual depth. On an acreage basis, this concentration would amount to 5.4 pounds of commercial copper sulfate per surface acre. The 2-foot depth has been determined to be about the maximum effective range of a surface application of copper sulfate in such water, since algae will be killed with increasing depth only if the rate of downward diffusion exceeds the rate of copper precipitation. The algae killed by such a treatment are those that are suspended near the water surface and commonly occur as blooms in calm weather. For lakes with a total methyl orange alkalinity below 40 mg/l, a concentration of 0.3 mg/l commercial copper sulfate for the total volume of water has been recommended. This is comparable to 0.9 pound of copper sulfate per acre foot of water. It is obvious that if a low-alkalinity lake has an average depth of about 6 feet, the dosage would be about the same as in a high-alkalinity lake having the same area. When lesser average depths are involved, a greater concentration of chemical results in the high-alkalinity lakes. This apparent paradox would be even more striking were it not for the fact that in low-alkalinity lakes the algae frequently are of the filamentous types that may lie at the bottom and, therefore, the entire volume of water must be calculated to insure that a sufficient concentration of the chemical reaches the algae to effect

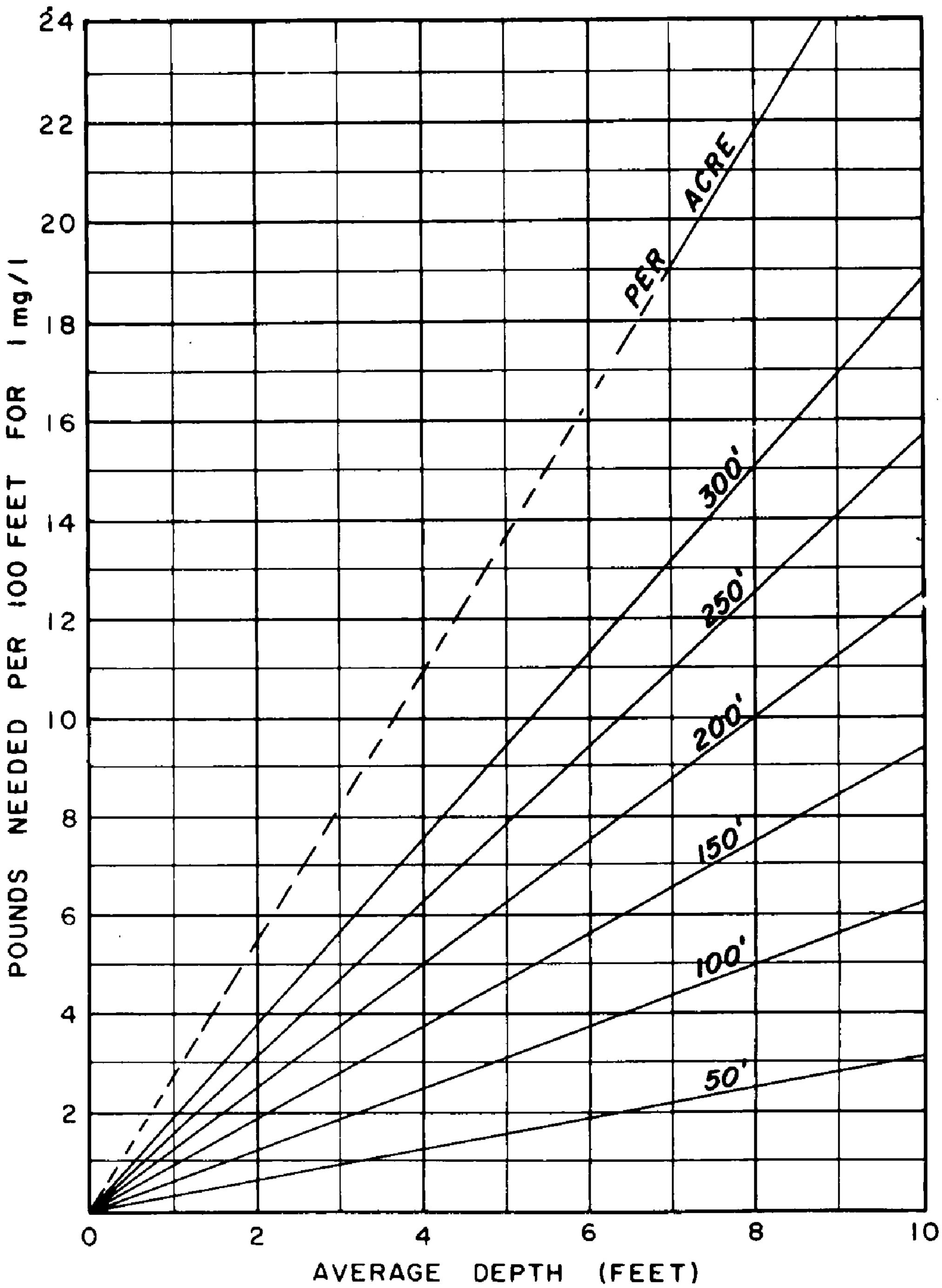

Figure 10. Chemical Dosage Chart. To achieve a chemical concentration of 1 mg/l in water having an average depth of 8 feet requires 10 pounds of the active chemical for an area 200 feet by 100 feet, or 21.8 pounds per acre.

a kill. In high-alkalinity lakes, algae frequently are planktonic and tend to concentrate near the surface, which is the only stratum in which ap preciable concentrations of soluble copper can be produced. Certainly, when copper sulfate is used as the algicide, the best and most lasting control will result if the lake water has a total alkalinity around 50 mg/l or less.

Algal control treatments can be marginal or complete; the type applied to a given body of water must be determined by the size, shape, and relative fertility of the water, and the estimated cost of the project. Complete treatment in which the calculated amount of copper sulfate is systematically applied over the entire surface area is the most satisfactory. It insures that a major portion of the total algal population is eliminated at one time, so that a longer recovery period is required before an algal bloom condition recurs. The interval between necessary treatments will be directly correlated with climatological conditions and the available nutrients utilized by the remaining algal cells that are not killed as a result of chemical application. One to three complete treatments per season may be sufficient to give reasonable control.

Marginal treatment, on the other hand, is a method designed to obtain temporary relief in a restricted area where more extensive activity is not feasible or financially possible. In this procedure a strip, 200 to 400 feet wide lying parallel with the shore, and all protected bays are sprayed in the same manner as in complete treatment. No other part of the area is treated even though many algae may be present. As a result of treatment, the algal population and the intensity of odors along the periphery of the lake are reduced. The duration of freedom from the algal nuisance following marginal treatment is dependent upon the density of the algal population in the center of the lake and its ability to infiltrate the treated area through the action of wind, waves, and currents. Any marginal control operation should definitely be considered on a periodic repeat basis. If fertility is not excessive, large bodies of water might gain enough relief from marginal treatment to warrant this type of control; however, it probably would be a waste of money for a large, fertile lake that is long and narrow and subject to considerable wind and wave action. In the latter case, complete treatment might be the only present answer, the cost of which might be prohibitive.

Copper sulfate may be applied in a variety of ways: bag-dragging, dry feeding (Monie, 1956), liquid spray (Mackenthun, 1958), and airplane application of either dry or wet material.[17] Because rapid and

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[17] Great Lakes Newsletter. Great Lakes Commission, Rackham Bldg., Ann Arbor, Mich., *3*(6): 1–10, July 1959.

uniform distribution of the algicide is essential, the size and scope of the problem determine to some extent the method employed. In general, liquid spraying systems operated from a boat or barge have been most widely used. Because copper sulfate is a highly corrosive chemical, materials that are used in the construction of spraying equipment should be resistant to its corrosive nature.

The effect of copper sulfate on an algal population can be noted soon after treatment. Within a few minutes, the color of the water changes from dark green to grayish-white. Although at no time are all the algae in the lake entirely eliminated (Domogalla, 1926), the water should be visibly free of cells 2 or 3 days following a complete application. Treatment has proven beneficial both in large bodies of water (Domogalla, 1935; and Domogalla, 1941) and in small fish-rearing ponds (O'Donnell, 1945). Both in Wisconsin and Minnesota (Moyle, 1949b) there is an indication that certain algae, particularly *Aphanizomenon*, seem to have acquired an increased tolerance to copper as a result of many years of treatment; two to five times as much copper sulfate must now be used as was necessary some 26 years ago to achieve similar control.

Much has been recorded on the toxicity of copper sulfate to various forms of aquatic life (Doudoroff and Katz, 1953; Ellis, 1937; Marsh and Robinson, 1910; Prescott, 1948; Rushton, 1924; and Schaut, 1939). Extensive field and laboratory studies have shown that fish

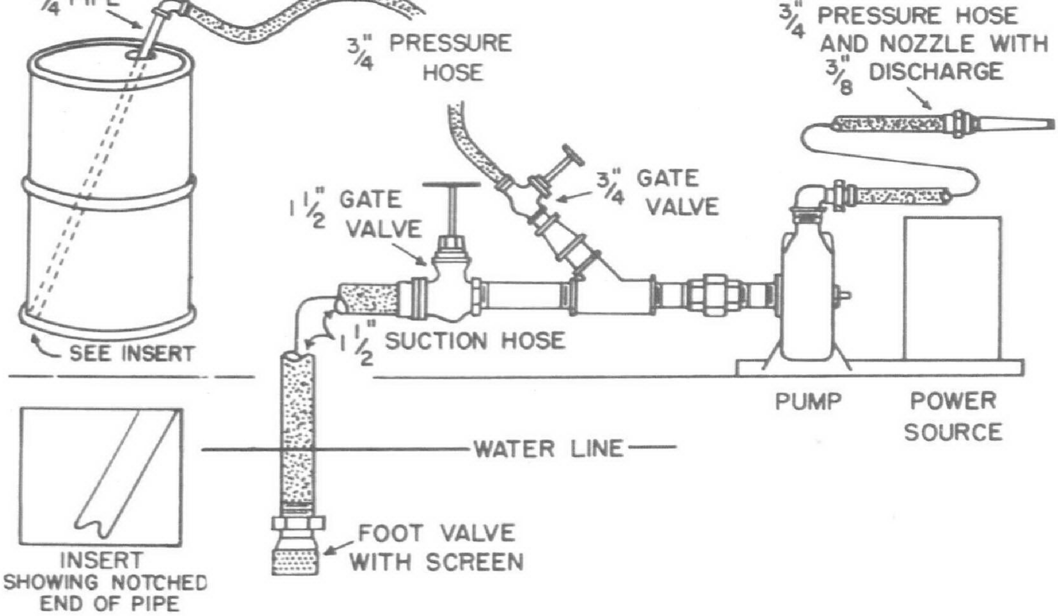


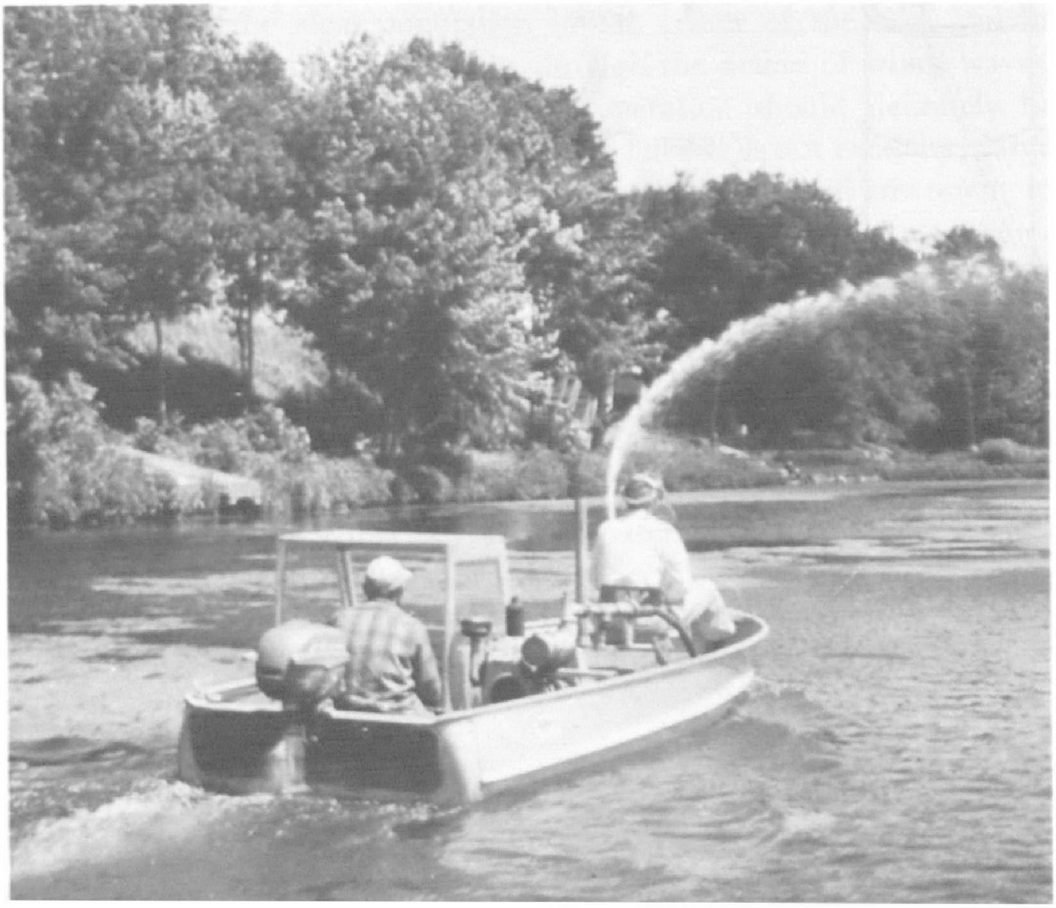
Figure 11. Diagrammatic sketch of equipment suitable for liquid spray distribution of chemical.

are not killed by copper sulfate at the minimum concentrations used for algal control, and that fishing and fish yields have not deteriorated in lakes that have been treated over a long period of time (Moyle, 1949b). It is well known that copper salts accumulate upon the lake bottom following repeated treatments and that the greatest accumulation is found in the profundal region (Nichols, Henkel, and McNall, 1946). Attention has also been directed to the possible deleterious effect of this accumulation on lake ecology (Hasler, 1947). It has been shown experimentally, however that the concentration of copper salts in bottom muds as a result of the use of nearly 2 million pounds of copper sulfate to control algae in a hard-water lake over a 26-year period was considerably lower than the concentration determined to have a deleterious effect on profundal bottom-dwelling organisms (Mackenthun and Cooley, 1952).

In recent years, there has been a constant search for a chemical to replace copper sulfate that would be more effective, nonaccumulative, and perhaps even less costly over an extended period of time. Some newer algicides are just now entering the field-testing phases following preliminary work. These will require many tests and observations under varying conditions found in nature before their future potential can be determined.

Algal control measures should be undertaken before the maximum development of the algal bloom. If, for some reason, a given area

Plate 48. Liquid spray distribution of herbicide by small boat.



is not treated until the algal population has become dense, judgment must be used in determining the area that should receive treatment at a given time lest sufficient organic matter is killed to result in decomposition and oxygen removal. It is good practice to subdivide the total area into sections and control the nuisance in one section at a time. Other sections may be treated after an interval of 7 to 10 days to ensure that sufficient dissolved oxygen is present to satisfy the demand of the decomposing algae.

CONTROL OF SUBMERGED AQUATIC WEEDS

In the control of submerged aquatic plants, it is often desirable to chemically treat localized areas along the shoreline, such as bathing beaches and around piers, and to develop channels through weed beds so that boats will have access to deeper water. Sometimes it is advantageous to treat an extensive area in an effort to curtail an advancing population of a weed species, such as Eurasian watermilfoil (*Myriophyllum spicatum* Linnaeus). Best results are obtained when the shoreline areas are treated because currents and wave action are usually minimized, and the diffusion of the chemical can only take place in one direction—into the lake. There are minimum limitations below which it is usually not feasible to attempt chemical weed control. The recommended minimum dimensions of an area to be treated are 200 feet by 200 feet. The treatment of very small areas permits the diffusion of the chemical on three sides, thus reducing the concentration of the chemical within the area to a point below the toxic level for rooted plants. An exception to this recommendation might be a small slough, bay, or stagnant channel with an area of less than 40,000 square feet.

For many years, arsenic trioxide in a sodium arsenite solution has been effectively used to control submerged aquatic weeds. Domogalla (1926) used it first in 1926 in the Madison, Wis. lakes to control a nuisance and to enhance the recreational value of the area. Surber (1931) was the first to adopt this means of control in fish management work, stating that preliminary experiments with sodium arsenite during the summer of 1929 indicated that this chemical can be used effectively at low cost in controlling submerged aquatic plants without doing apparent injury to either large or small fish and without exterminating or seriously diminishing the supply of natural foods.

Surber (1949) found that dosages of 1.7 to 4.0 mg/1 white arsenic equivalent were effective in controlling practically all submerged flowering plants in fishponds, but did not affect the fish. Because the water bodies treated in Wisconsin were larger lakes, somewhat higher arsenic concentrations were used (Mackenthun, 1950). To treat a small body of water a dosage of 5 mg/1 white arsenic equivalent was used. In treating fish management ponds containing walleye fry a two-part treatment was found to be effective; one-half of the pond was treated 1 week later than the other half. In the treatment of the shoreline area of a large body of water protected from wind and wave action and having an average depth not exceeding 5 feet and a maximum depth not exceeding 8 feet, a dosage of 7.5 mg/1 white arsenic equivalent was recommended; a dosage of 10 mg/1 was found effective against submerged vegetation in the treatment of a shoreline area of a large body of water unprotected from wind and wave action and having an average depth not exceeding 5 feet and a maximum depth not exceeding 8 feet. The majority of the projects in Wisconsin required the higher dosage in order to ensure effective control.

Because arsenical compounds are recognized poisons, their use necessitates a number of handling precautions. In the hands of untrained and irresponsible individuals they could become extremely dangerous to the appliers, to the water users, and to all forms of aquatic life. With proper precautions, however, there is no danger either to humans or animals. Children and animals should not have access either to the chemical or empty containers. Containers should be thoroughly washed and rinsed with water when emptied. As a safety measure, for two days following treatment no bathing is allowed in a treated area and the water is not used for watering lawns, for livestock, or for any other purpose; also, pets of all kinds are kept from the water. At the

Plate 49. An air boat serves as a steady transport vehicle for spraying equipment.

end of that time, the chemical should be sufficiently dissipated by dilution and absorption to make these precautions unnecessary. Cattle and other grazing animals should be excluded from the treated area until rains have washed the shore vegetation. Although domestic animals probably would not drink enough of the treated water to be injured, it is almost impossible to spray a pond or similar area thoroughly and not leave a certain amount of poison on the shore plants. Stock may be attracted by the salty taste and eat enough of the treated shoreline vegetation to be poisoned.

Arsenicals accumulate in lake bottom muds, plankton, unkilled submerged vegetation, and to some extent fish. Analyses of bottom muds from a 2,500-acre lake that had received 195,548 pounds of arsenic (As) over a 12-year period indicated an arsenic concentration in excess 180 μg As (dry weight)/g mud in some samples. Plankton analyses in another lake revealed a concentration of 965 μg As (dry weight)/g plankton 2 weeks after treatment. Those weeds or portions of weeds that remained alive after the initial shock of treatment appeared to be able to take from the surrounding water substantial quantities of arsenic without suffering severe ill effects. Weeds that appeared to be normal and healthy adjacent to a treated area contained 660 μg As/g on a dry weight basis. Ullman et al. (1961) reported that the arsenic concentration in fish fillets ranged from 0.22 to 0.47 μg/g while that in the viscera ranged from 0.10 to 0.78 in a treated lake compared to 0.10 to 0.12 μg As/g in a control lake.

In recent years, the number of herbicides available for aquatic weed control has increased. These include some 25 compounds, many of which are specific in their herbicidal action (Surber, 1961).[18, 19] Many of the compounds are available in liquid and granular formulations, the latter being suitable for broadcasting on the water surface. Many of these compounds are in the experimental and developmental stage, and problems of specific toxicity to other aquatic life have not been clarified.

A few details should be kept in mind in the application of a chemical. It has been found advantageous, for example, to divide a large area to be treated into a convenient number of small subareas and to accurately determine the volume of water each contains. Since the quantity of the chemical used is proportional to the water volume to be treated, it is a simple matter to properly adjust the chemical application

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[18] Mackenthun, K. M., 1959. Summary of Aquatic Weed and Algae Control Research and Related Activities in the United States. Committee on Water Pollution, Madison, Wis., pp. 1–14 (mimeo.).

[19] Ecology Is Keynote to Successful Waterweed Control. Delegates to 3d Aquatic Weed Society Meeting Told. Weeds and Turf (April), pp. 14–16 (1963).

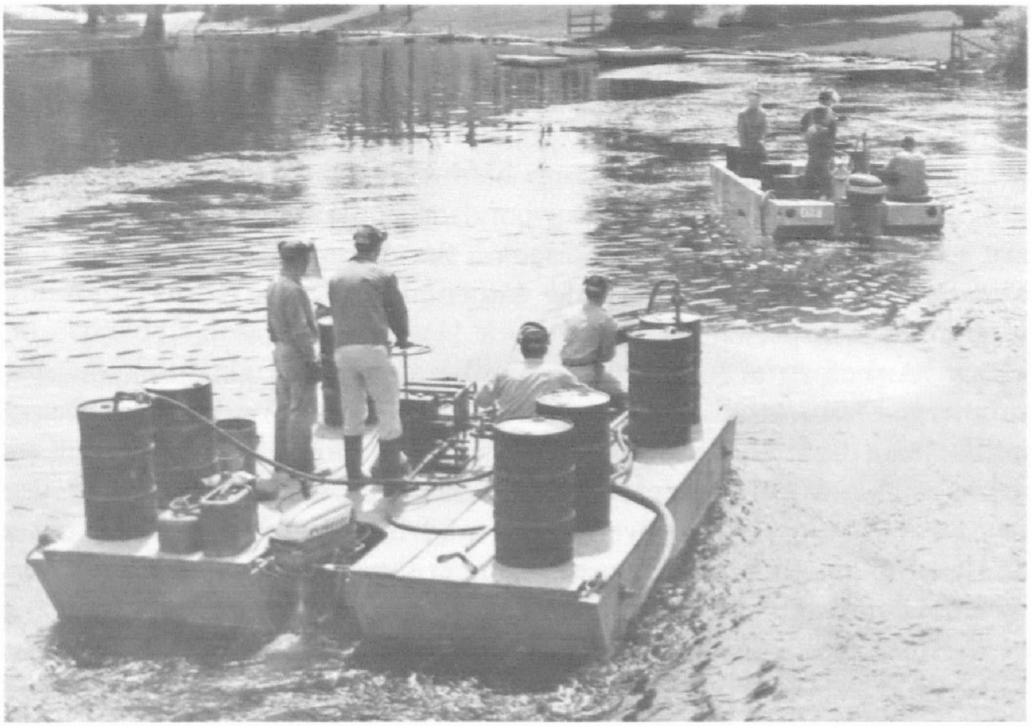

Plate 50. Chemical distribution through pressure spraying from a barge.

and evenly distribute the correct amount of chemical into the subarea. This procedure is then repeated in successive subareas.

Chemical control of aquatic vegetation must currently be regarded as a temporary remedy although it should last for the season in which it is applied. Under certain conditions, the removal of a vascular plant population may promote the growth of a bottom dwelling alga such as *Chara*. The alga must then be attacked with a suitable algicide. Since *Chara* grows on the bottom, the algicide usually must be dispersed just above the bottom so that it can come immediately in contact with the plant. It is most important not to disrupt too much of the lake ecology at one time lest another nuisance develop in place of the one being treated.

CONTROL OF EMERGENT WEEDS

Rapid advances are also being made in research on the control of marsh weeds and other aquatic forms that project above the surface of the water. Two factors explain the growing interest in the control of these weeds: one is the advent of new and better herbicides for the purpose; the other is the increasingly critical situation facing the Nation's waterfowl hunting resource—a sport on which 2 million Americans spend 89 million dollars annually.[20] Already more than half of the country's original 125 million acres of wetlands have been spoiled for waterfowl use. As the national census continues climbing toward the predicted 200-million mark, more and more of the places where ducks feed, breed, and are hunted will have to be converted to the needs of advancing civilization. In other words, prospects are for fewer hunting places and fewer ducks for a large number of hunters.

To help offset this trend, it is important to make the best use of available waterfowl habitat. Thousands of poor or fair areas in the United States can be made more attractive for ducks and duck hunters by replacing marsh weeds with plants that furnish food or cover for waterfowl. Commonly, the costs involved are not prohibitive (Martin et al., 1957).

In Florida recently, water hyacinths and other pest plants were cleared away from 20,000 acres of ponds and lakes by the Game and Fresh Water Fish Commission. Numerous other programs, both large and small, are being waged against phragmites, cattails, waterchestnut, and other marsh weeds in various States. In the Federal refuge system, more than 2,000 acres of marshlands are treated with herbicides annually to make them more productive for waterfowl. All this is small, however, compared with what can be done.

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[20] National Survey of Fishing and Hunting. U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife, Circular 120, 73 pp. (1960).

Plate 51. Barge distribution of granular herbicide.

CHEMICAL USAGE

Slightly over 1 million pounds of arsenic trioxide (As_2O_3) in a sodium arsenite solution have been applied to lakes in Wisconsin for the control of submerged aquatic vegetation from 1950 through 1962. About 50 lakes involving about 1,500 surface acres of recreational water annually receive treatment. Other chemicals are applied, but on a much smaller scale. Approximately 1,100,000 pounds of commercial copper sulfate for algal control were applied to 6,000 acres of recreational water over the same period of time.

The results of a questionnaire circulated in 1959 indicated that many States do not keep accurate records on the extent of use of chemicals for aquatic weed and algal control. The most complete records were kept by Wisconsin and Minnesota, the States that, along with Michigan, accomplished the greatest amount of large-scale control of submerged aquatics at that time. Of some 32 States reporting control activities on aquatic weeds, Minnesota reported the use of 94,570 pounds of arsenic trioxide in 1958. Michigan reported that 31 lakes receive sodium arsenite, and 30 additional lakes receive either 2,4-D or Kuron for the control of submerged aquatic weeds. Several States (Colorado, Georgia, New Jersey, North Carolina, Ohio, and Pennsylvania) reported an extensive number of small acreage operations, the majority of which presumably were confined to control in ponds. The reported amount of arsenic trioxide (As_2O_3) used by Minnesota and Wisconsin comprise 92 percent of the reported total amount used by all States. Many States undoubtedly do much more control work than was indicated on the questionnaires, but do not have available the specific chemical application figures.

This questionnaire indicated that at that time sodium arsenite was by far the most common herbicide used in the control of submerged aquatics. The concentrations used varied from 4 to 12 mg/1 As_2O_3; the lower concentrations were used in pond control, and the higher concentrations for area treatment in large bodies of water. Eighteen States reported the use of 2,4-D granules, generally on a limited scale at a concentration of approximately 20 pounds of active ingredient per acre. Florida reported the control of 150 acres of cattails with 2,400 pounds of Dalapon along with the use of 48,000 pounds of 2,4-D on 21,750 acres for water hyacinth control.

Twenty-one States reported the use of copper sulfate for the control of algae. Minnesota in 1958 used 167,464 pounds of copper sulfate in the treatment of 12,579 acres of water on 41 lakes. In Wisconsin in 1959, 6,270 acres on 29 lakes received 54,765 pounds of copper sulfate for algal control. Other States reported the use of lesser amounts.

Snail control was reported by Alabama, Michigan, Minnesota, and Wisconsin. The two latter States also reported some attempts at leech control. Generally, a heavy, localized concentration of copper sulfate and lime or copper carbonate is applied for this purpose.

The explosive spread of Eurasian watermilfoil in two Tennessee Valley Authority reservoirs during 1960 and 1961 and its real and potential threat to mosquito control, recreation, and other interests dictated that an immediate all-out effort be made to stop its further spread (Smith, 1963). Efforts were made to treat all known colonies of milfoil in both Watts Bar and Chickamauga Reservoirs. In 1962, 175,000 pounds (87.5 tons) of 20-percent 2,4-D granular herbicide, at a rate of 20 pounds acid equivalent per acre, was applied by helicopter to approximately 2,075 acres in the two reservoirs. The treatment was ". . . highly successful . . ." Smith states that ". . . under certain TVA reservoir conditions, our experience indicates that either delivery of an adequate dose of granular 2,4-D herbicides to the plant or dewatering of the plant [winter drawdown] will be effective in controlling watermilfoil. Furthermore, the chemical appears to be effective at the water temperatures which exist during the winter and spring drawdown period."

The application of a chemical to water involves certain hazards which must be understood and against which public rights must be protected. Factors that must be considered are the short- and long-range toxicity to all aquatic life; the deposition and possible accumulation of

Plate 52. Helicopter application of a granular herbicide.

the chemical upon the lake bottom, and the subsequent reaction upon the community of bottom organisms; the impact resulting from the destruction of too much biological growth at one time; and the possible disturbance of the general aquatic environment.

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Glossary

Aerobic organism—An organism that thrives in the presence of oxygen.

Anaerobic organism—A microorganism that thrives best, or only, when deprived of oxygen.

Autotrophic—Self-nourishing; denoting the green plants and those forms of bacteria that do not require organic carbon or nitrogen, but can form their own food out of inorganic salts and carbon dioxide.

Benthic region—The bottom of all waters; the substratum that supports the benthos.

Benthos—Bottom-dwelling organisms; the benthos comprise: (1) sessile animals such as the sponges, barnacles, mussels, and oysters, some of the worms, and many attached algae; (2) creeping forms, such as snails and flatworms; and (3) burrowing forms which include most clams and worms.

Biomass—The weight of all life in a specified unit of environment, for example, a square foot of stream bottom. An expression dealing with the total mass or weight of a given population, both plant and animal.

Cercariae—The tailed, immature stage of a parasitic flatworm.

Cuticular plate—A hard chitinous or calcareous plate on the epidermis or outer horny layer of the skin.

Ecology—The branch of biology that deals with the mutual relations of living organisms and their environments, and the relations of organisms to each other.

Ecosystem—The functioning together of the biological community and the nonliving environment.

Epilimnion—That region of a body of water that extends from the surface to the thermocline and does not have a permanent temperature stratification.

Epithelial layer—The purely cellular, nonvascular layer covering all free body surfaces.

Eutrophic waters—Waters with a good supply of nutrients; they may support rich organic production, such as algal blooms.

Eutrophication—The intentional or unintentional enrichment of water.

Floc—A small, light, loose mass, as of a fine precipitate.

Flocculent—Reassembling tufts of cotton or wool; denoting a fluid containing numerous shreds of fluffy, gray-white particles; containing or consisting of flocs.

Gelatinous matrix—Jellylike intercellular substance of a tissue; a semisolid material surrounding the cell wall of some algae.

Globular—Having a round or spherical shape.

Hepatic vein—The vein leading from the liver.

Heterocyst—A specialized vegetative cell in certain filamentous blue-green algae; larger, clearer, and thicker-walled than the regular vegetative cells.

Hirudin—A substance extracted from the salivary glands of the leech that has the property of preventing coagulation of the blood.

Homothermous—Having the same temperature throughout.

Hypolimnion—The region of a body of water that extends from the thermocline to the bottom of the lake and is removed from surface influence.

Invertebrates—Animals without a backbone.

Larva—The wormlike form on an insect on issuing from the egg.

Limnology—The study of the physical, chemical, and biological aspects of inland waters.

Low Flow Augmentation—Increasing of an existing flow. The total flow of a stream can seldom be increased but its ability to assimilate waste can generally be improved by storage of floodflows and their subsequent release when natural flows are low and water quality conditions are poor.

Lumen—The space in the interior of a tubular structure such as an artery or the intestine.

Mesenteric vein—The large vein leading from the intestines in the abdominal cavity.

Miracidium—The ciliated free-swimming larva of a trematode worm.

Oligotrophic waters—Waters with a small supply of nutrients; hence, they support little organic production.

Papilla—Any small nipplelike process.

Peaking—The use of hydropower to meet maximum or rapid changes in power demands.

Penstock—A sluice for regulating flow of water, a conduit for conducting water.

Photosynthesis—The process by which simple sugars are manufactured from carbon dioxide and water by living plant cells with the aid of chlorophyll in the presence of light.

Phytoplankton—Plant microorganisms, such as certain algae, living unattached in the water.

Plankton—Organisms of relatively small size, mostly microscopic, that either have relatively small powers of locomotion or drift in the water subject to the action of waves and currents.

Plastids—A body in a plant cell that contains photosynthetic pigments.

Portal vein—The large vein carrying the blood from the digestive organs and spleen to the liver.

Pupa—An intermediate, usually quiescent, form assumed by insects after the larval stage, and maintained until the beginning of the adult stage.

Secchi disk—A circular metal plate, 20 cm in diameter, the upper surface of which is divided into 4 equal quadrants and so painted that 2 quadrants directly opposite each other are black and the intervening ones white.

Sickle-shaped—Curved or crescent shaped.

Seston—The living and nonliving bodies of plants or animals that float or swim in the water.

Snail—An organism that typically possesses a coiled shell and crawls on a single muscular foot. Air breathing snails, called pulmonates, do not have gills but typically obtain oxygen through a "lung" or pulmonary cavity. At variable intervals most pulmonate snails come to the surface of the water for a fresh supply of air. Gill breathing snails possess an internal gill through which dissolved oxygen is removed from the surrounding water.

Species (both singular and plural)—An organism or organisms forming a natural population or group of populations that transmit specific characteristics from parent to offspring. They are reproductively isolated from other populations with which they might breed. Populations usually exhibit a loss of fertility when hybridizing.

Spore—A reproductive cell of a protozoan, fungus, or alga. In bacteria, spores are specialized resting cells.

Trematode—The common name for a parasitic worm of the class Trematoda, a fluke.

Thermocline—The layer in a body of water in which the drop in temperature equals or exceeds 1 degree centigrade for each meter or approximately 3 feet of water depth.

Trophogenic Region—The superficial layer of a lake in which organic production from mineral substances takes place on the basis of light energy.

Tropholytic Region—The deep layer of the lake where organic dissimilation predominates because of light deficiency.

Tubificids—Aquatic segmented worms that exhibit marked population increases in aquatic environments containing organic decomposable wastes.

Ventral—Relating to the belly or the abdomen; opposed to dorsal.

Zooplankton—Animal microorganisms living unattached in water. They include small crustacea, such as daphnia and cyclops, and single-celled animals as protozoa, etc.

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