Biological Associated Problems in Freshwater Environments

Their Identification, Investigation and Control

UNITED STATES DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

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Kenneth M. Mackenthun
William Marcus Ingram

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Preface

THE authors of this book have used LIMNOLOGICAL ASPECTS OF RECREATIONAL LAKES (Public Health Service Publication No. 1167, (now out of print) by Mackenthun, Ingram, and Porges, as a base from which to expand the consideration and treatment of aquatic biota and the aquatic environment. The present work, however, is not a second edition. Rather, it discusses the identification, investigation, and control of problems associated with the biota in flowing stream, lake, reservoir, and pond.

This 12-chapter treatise first introduces the biological problems indicated in the title, reviews and gives examples of water uses, and cites briefly the history of the Federal legislation governing water pollution and the Federal role in coping with it. The effects on the aquatic environment of temperature, dissolved oxygen, and light are considered, as are the effects of streams on reservoirs and reservoirs on streams. The responses of algae, vascular plants, benthos, and fish to the aquatic environment under various influencing forces are itemized. Some of the problems associated with defining the aquatic environment are discussed. The why, what, how, where, and when of lake and stream data collecting and reporting are delineated. Nutrients that stimulate and characteristics that depress aquatic vegetation growths are detailed. Four chapters deal in series with water-associated pests and the multitude of problems they cause. Taxonomic keys are presented for some of the nuisance algae and common vascular plants; and, finally, information is given on how to control or alleviate excessive production of biological nuisances.

Physical or chemical changes in an aquatic environment can pose numerous problems, disrupting the life cycles and patterns of the things that live in water, and adversely affecting man in his use of the water resources. When the problems become severe—i.e., the water polluted—agricultural, industrial, and municipal water supply uses are handicapped, placing financial burdens on the water user. Whatever the time of year, it becomes "closed season" for most water sports.

Preventive measures and remedial controls for water pollution must be defined more clearly, instituted more enthusiastically, and enforced more vigorously than in the past. Recent legislation at the Federal level and, in many instances, at State level is clearly pointed in that direction.

Since the earth's supply of water grows no larger, accelerating human populations and economic growth have emphasized the divergent, often conflicting, interests and desires of water users. Competition in the recreation use alone subdivides among fishermen, waterfowl hunters, skin divers, water skiers, swimmers, and pleasure-boating enthusiasts. People who pursue these sports soon become aware of any biological problems in the waters they use. More often than other water-use groups, they are quick to demand remedial measures to alleviate developing nuisances or prevent pollution before it occurs.

Underlying demands by people may be nostalgic images of other days when many enjoyed favored old "swimming holes," firm-bedded and deep, whose jewel-like clarity mirrored overhanging trees. Once gone, the aquatic conditions that inspired such images will not return, even under the most rigid control of the factors disrupting the aquatic ecology. Water quality has suffered through increased use, abuse, and neglect of the resource. It can be greatly improved, but in most places water quality can never be returned to the primeval state.

This book is for the person who must identify, investigate, relate, interpret, and control biological problems as they may relate to recreational water quality. Its purpose is to aid the non-biologist's understanding of the aquatic environment and the associated phenomena. The book is intended also as a guide to the inexperienced aquatic biologist who may find the described field sampling techniques, data presentation, and data interpretation of very real help in meeting his day-to-day assignments.

Cincinnati, Ohio
July, 1967

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"The clear, fresh waters

that were our national heritage

have become dumping grounds

for garbage and filth.

They poison our fish,

they breed disease,

they despoil our landscapes."

President Johnson
at the signing of the Water Quality Act of 1965.

1

Introduction

"WHEN people hear someone say 'water' on a hot day, they usually think of a nice cool drink and a swim. At other times each person, hearing the spoken word, will more likely react on the basis of his occupation or avocation. It is

a travel route to the sailor
underground water to the geologist
moisture for his crops to the farmer
the habitat of fish and fowl to the sportsman
an essential basic commodity to the industrialist
a means of encouraging annexation to the city official
a natural resource to be used wisely to the conservationist

A chemist, on the other hand, is likely to think of water in the form of basic elements and a physicist in terms of physical factors" (Muegge, 1956).

To the biologist, water is a medium to support life in many forms; a challenge to the serious aquatic samplers and to the interpreting biologists who may be perfectionists; a purveyor of civilization's rejectamenta that affects adversely the health or welfare of man.

To the biologist the quality of water is manifested through the biotic community, in his comparison of one sampling station with another, one stream reach with another, one water quality with another. A station is chosen within a desired area by the investigator. The data collected on the characteristics of water quality from the selected station are compared with data collected from stations that do not receive man-caused pollution or are not associated with nuisances. From this comparison, an interpretation is made on the water quality in the selected study area.

"If at different times we stand on the same spot on the bank of a river, we find that the stream has changed in amount of sediment, the number and character of its fish, its rate of flow, color, temperature, and so on. Yet if we had been standing on that spot continuously, we could not have said, 'Now, it is beginning to get colder,' or 'Now it is beginning to flow faster.' It is only in retrospect and by comparison that we are conscious of these gradual changes, which begin at different times and merge imperceptibly one into the other" (Achorn, 1934, p. 7, as quoted by Carlander, 1954).

The investigation and study of waters require a knowledge and an understanding of the relationships between organisms and their environment. Knowledge initially is acquired through an individual's association with the professional literature; it is augmented and polished through detailed observations and field investigations of waters of varying quality; its acquisition is aided by the repeated use and manipulation of the tools of the profession.

The investigation and study of waters necessitate 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 basic problem is pollution, but there are many facets to this problem. An investigation must define the problem, assess the damages, and predict the changes that may be accomplished through abatement.

Pollution has been defined as a "resource out of place" (Anon., 1966). The Committee on Pollution, National Academy of Sciences, National Research Council, has broadly classified pollutants entering watercourses into eight categories. These are: (1) Domestic sewage and other oxygen-demanding wastes. (2) Infectious agents. (3) Plant nutrients. (4) Organic chemicals such as insecticides, pesticides, and detergents that are highly toxic at very low concentrations. (5) Other minerals and chemicals including chemical residues, petrochemicals, salts, acids, silts, and sludges. (6) Sediments from land erosion. (7) Radioactive substances. (8) Heat from power and industrial plants. All of these pollutants may be related to biological problems in the freshwater environment; many contribute to an overproduction of organisms that affect seriously the health or welfare of man.

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

The control of excessive production is of prime importance to those who use the water for recreation. Once biological nuisances develop, controls and maintenance are indicated; these 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.

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, picnicking, 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.* 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.

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

There are 29 major Tennessee Valley Authority (TVA) dams and reservoirs.* The total area of lake water at full pool is 619,460 acres; the total shoreline is 10,755 miles; at the top of gates elevation the capacity is 23,157,700 acre-feet. The largest single reservoir is Kentucky Reservoir near Paducah, Kentucky. Kentucky Reservoir drains 40,200 square miles; its length is 184.3 miles; its area is 158,300 acres; impoundment at top of gates elevation will total 6,002,600 acre-feet. Kentucky Reservoir led all TVA reservoirs in the number of recreational visits to its waters in 1965 with a total of 11,022,204. Recreational boats anchored on its waters numbered 11,518. In addition there were 205 houseboats in 1965. The value of water-based facilities and equipment on Kentucky Reservoir exceeds $10 million; land-based facilities and equipment, including privately owned summer cottages, picnic facilities, overnight rental units, restaurants, concession stands, and boat service buildings are valued in excess of $27-½ million. Water recreation is big business.

The average annual increase in recreational use of the TVA Reservoirs attests to the growing demands placed upon waters of suitable quality for various recreational pursuits (Table 1).

Table 1. Recreational Use of 25 TVA Lakes

	1965	Average annual increase since 1947
Number of inboard recreation boats	3178	106
Number of all other recreation boats	47,642	2,183
Total value of boats	$46,461,815	$2,283,453
Number of privately owned summer cottages	11,343	597
Number of person-day visits to reservoirs for recreational purposes	49,410,454	2,337,317

Yet another example of reservoir recreational usage is Chickamauga Reservoir near Chattanooga, Tennessee. The Chickamauga project was completed in 1940 to serve the purposes of flood control, navigation, and production of hydro-electric power. It drains

* Churchill, M. A. Chief, Water Quality Branch, TVA. Personal Communication.

Plate 2. Swimming is an outdoor recreational activity enjoyed by many.

20,790 square miles, has an 810-mile shoreline, and 34,500 acres of water. The recreational planning, site planning, development, and administration of land and land rights have been in accord with established procedures. Now along the shores of this lake are 2 state and 6 local parks, 75 public access points and thousands of acres in wildlife areas, 2 group camps and 30 club sites, 19 boat docks and resorts, 1,000 cabins, and 2,000 boats. In all, the value of recreation improvements and equipment on Chickamauga is $25 million, and the number of visits now made in a year to the lake for recreation totals 4.7 million.

A recent survey of boating in Wisconsin* indicated that more than 200,000 pleasure boats were licensed by the State of Wisconsin. Approximately 130,000 were registered by 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 recreational needs and demands will continue to increase as population pressures become greater.

Any single-purpose use of water may conflict seriously with other desired uses, affecting either the quality or quantity requirements of those uses. Reservoirs for flood control, for instance, lose

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

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 oxygen essential to support fish life, fish food organisms, 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 municipal 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 demonstrate clearly 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. Volume is often not the solution to pollution!

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 substances it contacts. 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, natural lakes and reservoirs. Drainage from lands, including residential yards and lawns, may carry substantial amounts of residuals of pesticides and chemical fertilizers.

Federal water-resource planning has been developing over the past sixty years. 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.* 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 provided for water pollution control activities in the Public Health Service then in the Federal Security 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

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

legislation was enacted by the 84th Congress, and was signed into law on July 9, 1956 as the Federal Water Pollution Control Act, Public Law 660. 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.

The Federal Water Pollution Control Act, Public Law 660, was further amended by the Water Quality Act of 1965 (PL 89–234), approved on October 2, 1965. The Act declares that it is ". . . the policy of Congress to recognize, preserve, and protect the primary responsibilities and rights of the States in preventing and controlling water pollution, to support and aid technical research relating to the prevention and control of water pollution, and to provide Federal technical services and financial aid to State and interstate agencies and to municipalities in connection with the prevention and control of water pollution." The Act requires that comprehensive programs shall be developed ". . . for eliminating or reducing the pollution of interstate waters and tributaries thereof" and retains the same wording as quoted above

Plate 3. A recreational pursuit of millions

from the Act of 1948 in connection with comprehensive programming. Research, investigations, experiments, demonstrations, and studies relating to the causes, control, and prevention of water pollution, as well as enforcement measures against pollution ". . . of interstate or naviable waters in or adjacent to any State or States . . . which endangers the health or welfare of any persons" are provided for in the Act.

One of the recommendations of the National Conference on Water Pollution held in Washington, D.C., December 12 to 14, 1960, related to comprehensive programming and defined this type of development as follows:

> "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, toxic algae, leeches, worms, insect pests, and parasites. All affect the use of waters for recreation. On the other hand, swimming, boating, and other water 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

Plate 4. Water skiing — an increasingly popular water contact sport.

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 on man 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 wates, (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.

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2

The Aquatic Environment

A COMPLEX interaction of many physical, chemical, and biological forces often influenced by meteorological phenomena occurs in the aquatic environment. 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 to the very surface. 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 for many months. In natural deep bodies of water three layers eventually form. The upper layer, or epilimnion, represents the warm, more

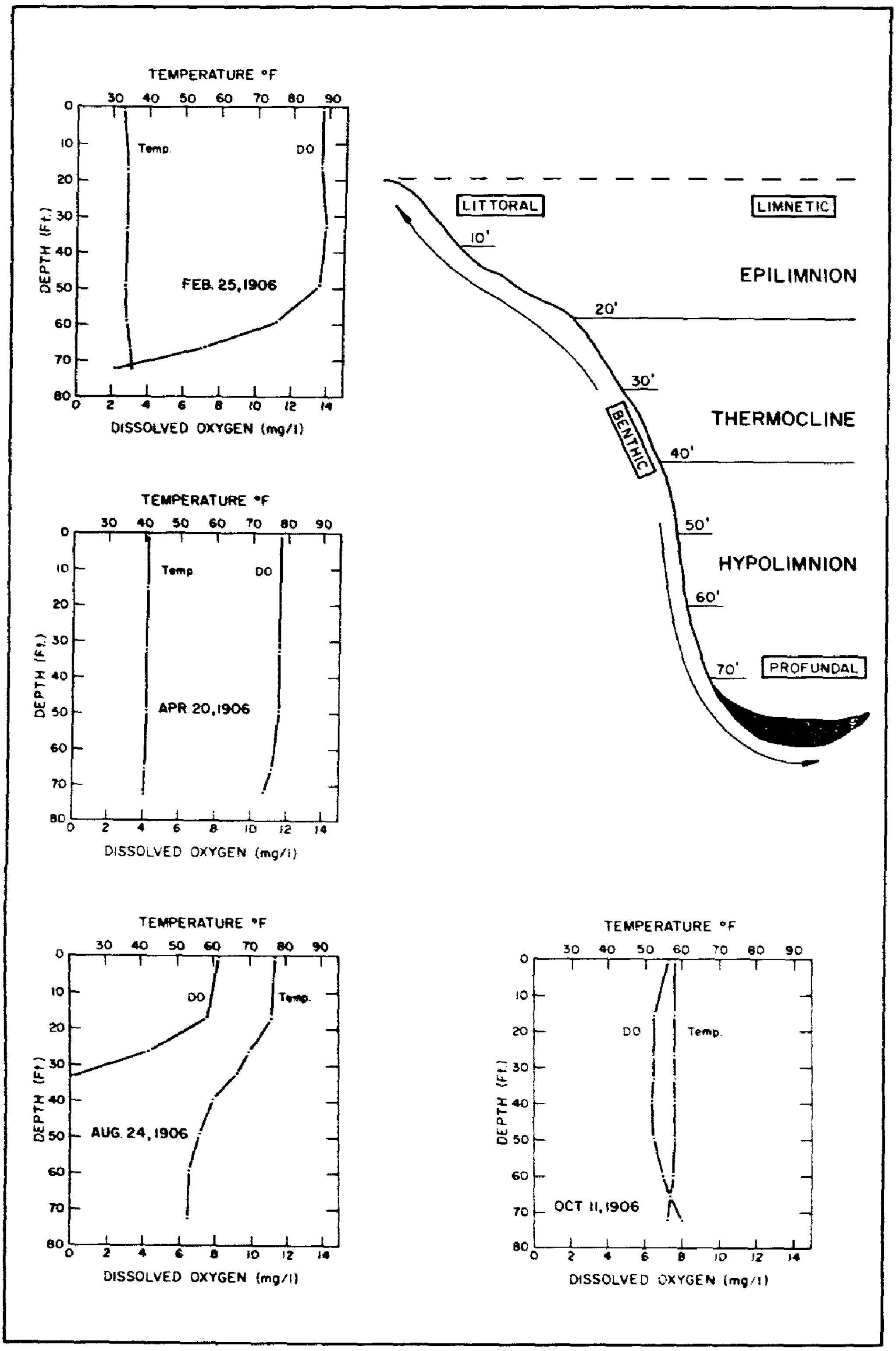

Figure 1. Diagram of lake zones with seasonal temperature and dissolved oxygen changes observed in Lake Mendota, Wisconsin (from Birge and Juday, 1911).

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 the upper waters and receives no 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, 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 day 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 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 in the reservoirs 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 as 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, 1941). The waters of Norris Reservoir, Tennessee, 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 populations 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.

Neel (1963) compares glaciated lakes with man-made reservoirs and notes a number of differences. Inlets and outlets of glaciated lakes are near the surface, but water may leave a reservoir at one of several depths or from two or three levels simultaneously. The lowest depression in a natural lake may occur anywhere in its basin, but maximum depth of a reservoir is always near the dam, unless a natural lake or deep canyon is included in the impoundment area. A reservoir bottom has a regular slope from head to tail that was established by the river before damming. A similar slope is found in natural lakes that are formed by earthquakes, but basins of glaciated lakes were scooped out below river level, and nonuniformity of bottom slope is to be expected. Glaciated lakes normally begin as oligotrophic bodies and increase in productivity with time. Reservoirs, on the other hand, often inundate rich bottom lands and fertile topsoils on river slopes and normally begin with high productivity potentials and tend to suffer productivity declines with the passage of time.

Sylvester (1963) notes that the impoundment of water will produce various temperature effects on the impounded water temperature and on the downstream water temperature, depending upon:

(1) Volume of water impounded in relation to mean streamflow. (2) Surface area of impounded water. (3) Depth of impounded water (4) Orientation with prevailing wind direction. (5) Shading afforded. (6) Elevation of impoundment. (7) Temperature of inflow water in relation to temperature of impounded water. (8) Depth of water withdrawal. (9) Downstream flow rates during critical temperature period, i.e., an increase or decrease in flow over that occurring naturally.

Sylvester (1963) states that in a natural stream flowing from an upland to a lowland environment, there will be a natural temperature increase or decrease that must be known before artificial causes of temperature change can be evaluated. In the 42-mile stretch of the Wenatchee River between Lake Wenatchee and Dryden, Washington, water temperature differences for 1956 were −1.2° F in February, +3.9° F in April, +2.1° F in June, +3.8° F in August, and −1.5° F in December. Raphael (1961, 1962) is quoted as calculating that, under natural conditions in August, the Columbia River temperature will rise about 1° F in a 72-mile stretch below Chief Joseph Dam and about 1° F in a 50-mile stretch below Rock Island. The Columbia River in the 450 miles between the Grand Coulee Dam and Bonneville rose 5.4° F, the sharpest rise occurring between Pasco and Umatilla because of the warm inflow of the Snake River.

Water, in passing through a municipal water system and subsequently through a sewerage system, experiences a rise in temperature that may or may not be significant, depending upon the size of the receiving water. The data from the Puget Sound area indicate that treatment plant effluents are warmer than the diverted water by about 14° F in the winter, 12° F in the spring, 9° F in the summer, and 13° F in the autumn.

In the Yakima Valley irrigation facility the water temperature increased, on the average, 3.5° F in 37 miles of main canal flow during August of 1959 and 1960. This is somewhat greater than would have been found in the river for the same distance if the water had not been diverted. However, in August, without irrigation flow augmentation, the normal river temperature rise in 37 miles of passage would closely approximate 3.5° F temperature rise. Water applied to the land had an average temperature increase of 3.3° F and water emerging from sub-surface drains, had an average temperature decrease of 5.3° F.

In general, Sylvester (1963) states that large and deep impoundments will decrease downstream water temperatures in the summer and increase them in winter, if withdrawal depths are low; that shallow impoundments with large surface areas will increase downstream water temperatures in the summer; that water drawn periodically from the surface of a reservoir will increase downstream water temperatures; that a reduction in normal stream flow downstream from an impoundment will cause marked temperature increases; and that "run-of-river" impoundments, when the surface area has not been increased markedly over the normal river area, will produce only small increases in downstream water temperatures.

Dissolved Oxygen

Interrelated with temperature and light, living and decaying organisms, decomposable man-produced wastes and deposited natural decomposable organics, is the dissolved oxygen in the water.

Oxygen enters the water by absorption directly from the atmosphere or by plant photosynthesis and is removed by respiration of organisms and by decomposition. That derived from the atmosphere may be by direct diffusion or by surface water agitation by wind and waves which may also release dissolved oxygen under conditions of supersaturation. In referring to the ineffectiveness of diffusion as a factor in the distribution of oxygen in a lake, Birge and Juday (1911) cite Hüffner.* According to his [Hüffner's] 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 dissolved and free-gaseous oxygen at times of supersaturation. Since energy is required in the form of light, photosynthesis is limited to the photic zone where light is sufficient to facilitate this process. According to Dice (1952), ". . . the ultimate limit of

* Arch. für Anat. und Physiol. (Physiol. Abteil.) 1897, p. 112.

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; based on computations of photosynthetic oxygen production, he found that the yields of several lakes were mostly between 42 and 57 pounds of dissolved oxygen per acre per day. A year-round study under completely natural conditions in western Lake Erie showed winter yields of about 11 lbs. of dissolved oxygen production per acre per day, and summer maxima of about 85 lbs. 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 dissolved 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 dissolved 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 oxgyen. 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 dissolved 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 dissolved 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.

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, detergent foams, dense mats of floating and suspended debris or a combination of these. The region in which light intensity is adequate for photosynthesis is often referred to as the trophogenic zone, the layer that encompasses 99 percent of the incident light. The depth of the trophogenic 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 bubbles or particulate matter reduces the transmission of light. Snow further reduces light penetration through ice. Greenbank (1945) found 84 percent light transmission through 7-½ inches of very clear ice, and 22 percent 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.

Beeton (1958) made 57 paired photometer and Secchi disc measurements at 18 stations in Saginaw Bay in Lake Huron. He found that the average percentage transmission of surface light intensity, at the Secchi disc depth, was 14.7 percent. Verduin (1956) made simultaneous determinations with the Secchi disc and submarine photometer during August, 1955, on Lake Erie. The Secchi disc readings in meters were plotted against the depth associated with one percent of the surface light. A line drawn by inspection through the scatter diagram, suggests that an approximate estimation of the depth of the euphotic zone can be obtained by multiplying the Secchi disc readings by 5. Riley (1941) used a factor of 3. Verduin (1956) computed a factor of 2.5 using the data of Bursche (1955). Rawson (1950) lists a factor of 4.3 when the Secchi disc reading is about 1 meter.

The maximum Secchi disc reading reported for Lake Tahoe, California–Nevada, was 136 feet at one station on April 4, 1962 (McGauhey et al., 1963). A minimum Secchi disc reading of 49 feet was recorded in Emerald Bay of Lake Tahoe on May 21, 1962. In contrast, the Secchi disc disappeared in 3-feet in Lake Sebasticook, Maine, during the July 1965 study. In areas with less dense algal growths, the readings were increased to 8 feet. Beeton (1965) records the average Secchi disc depth for Lake Superior as 32.5 feet; Lake Michigan, 19.6 feet; and Lake Erie, 14.6 feet.

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. "In general practice, pH values above 8.0 are assumed to denote the presence of carbonate; a level of 8.0 indicates bicarbonate alone; and values below 8.0 show the occurrence of free carbon dioxide. Carbon dioxide, usually produced by decomposition and respiration, will react with any carbonate present to form bicarbonate and water. Photosynthesis by aquatic plants utilizes carbon dioxide, removing it from bicarbonate and producing carbonate when no free CO_2 exists. Carbonates of calcium and magnesium are but weakly soluble and quantities of them leave solution. Decomposition and/or respiration thus tends to reduce pH and increase bicarbonates, whereas the tendency of photosynthesis is to raise pH and reduce 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, 1949). Moyle classified fish and plant productivity of natural lakes in Minnesota on the basis of total alkalinity as measured to the methyl

* Neel, J. K., H. P. Nicholson, and A. Hirsch. 1963. Main Stem Reservoir Effects on Water Quality in the Central Missouri River. U. S. Department of Health, Education, and Welfare, Public Health Service, Reg. VI, DWSPC, 112 pp. (Mimeo.)

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/l productivity of both fish and plants was medium to high; and above 90 mg/l productivity was high.

Two of the major nutrients, nitrogen and phosphorus, have become important analytical constituents to characterize water quality. Often nitrogen and phosphorus data are confusing to the reader because of the uncertainty of the type of analyses performed and the elemental form that the data represent. Preferably these data should be reported as the elements, N and P, with a modifier to indicate the form for which the analysis was made. Because phosphorus may cause the greater confusion between the two, the nomenclature and synonymy for phosphorus is presented in the following tabulation:

PHOSPHORUS (P) Nomenclature and Synonymy

Total phosphorus is obtained by digesting sample with persulfate, then filtering.

Soluble phosphorus is obtained by filtering sample, then digesting filtrate with persulfate.

Orthophosphate is obtained by filtering sample with no digestion.

Soluble orthophosphate plus hydrolyzable is obtained by filtering sample, then digesting with acid as stated in Standard Methods for the Examination of Water and Wastewater, 12th Edition.

Dissolved inorganic	= Orthophosphate
Dissolved organic plus poly-, meta-, and pyrophosphates	= Soluble minus ortho
Inorganic	= Orthophosphate
Insoluble	= Total minus soluble
Insoluble organic	= Total minus ortho
Organic	= [Soluble minus ortho] minus [(Soluble orthophosphate plus hydrolyzable) minus Orthophosphate] plus [total minus Orthophosphate]
Particulate	= Total minus soluble
Particulate organic	= Total minus ortho
Reactive	= Orthophosphate
Soluble orthophosphate	= Orthophosphate
Soluble organic plus poly-, meta-, and pyrophosphates	= Soluble minus ortho
Soluble organic	= [Soluble minus ortho] minus [(Soluble orthophosphate plus hydrolyzable) minus orthophosphate]
Total soluble	= Soluble
Total dissolved	= Soluble
Total insoluble	= Total minus soluble
Total hydrolyzable	= Soluble minus ortho

The Effect of Stream Inflows on the Water Body

The extensive use of organic phosphate and chlorinated hydrocarbon 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 lb. 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 inert and decomposable 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.

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. The destruction of ducks such as the canvasback, redhead, and scaup 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 water-logged, 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 man-made 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.

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. In addition, settleable solids may change heat radiation, retain organic materials and other substances which create unfavorable conditions on the bottom, interfere

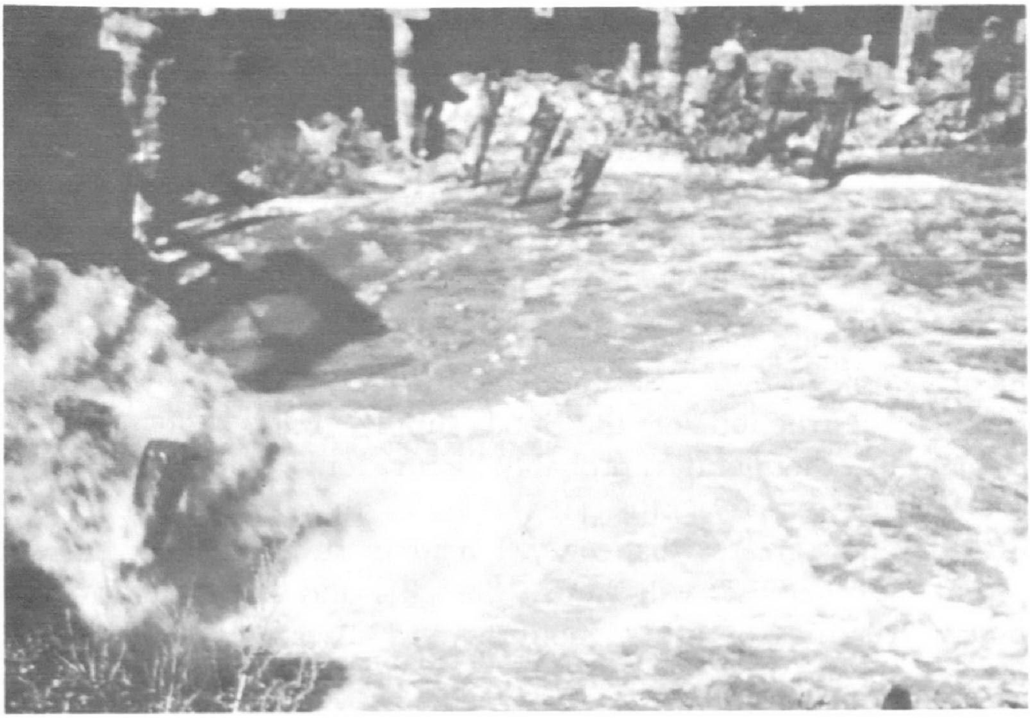

Plate 5. Industrial wastes degrade water for recreational use.

with fish feeding, smother fish eggs, and produce a grinding and crushing action deleterious to benthic forms.

The deposition of sediment in streams can and often does destroy insect and mussel populations. Ellis (1931), in studying the Mississippi, Tennessee, and Ohio Rivers, reported that erosion silt was destroying a large portion of the mussel population in various streams by directly smothering the animals in localities where a thick deposit of mud was formed, and by smothering young mussels whereas the adults could maintain themselves. Ziebell and Knox (1957) * investigated the effects of a gravel washing operation on the Wynooche River in Washington. The results of bottom samples indicated reductions in bottom associated organisms of 75 to 85 percent at distances exceeding one mile downstream from the operation. Silt from a gravel washing plant located on Cold Creek and the Truckee River, California, reduced bottom organisms over 75 percent for a distance of more than 10 miles downstream (Cordone and Pennoyer, 1960). Reports published by the Oregon State Game Commission et al., summarized the results of extensive collections of bottom organisms upstream and downstream from gold dredge operations on

* Ziebell, C. D. and S. K. Knox, 1957. Turbidity and Siltation Studies, Wynooche River. Report to Washington Poll. Control Comm., 7 pp. (Mimeo.)

the Powder River. During siltation, production of fish food organisms decreased to nearly zero in the zone of heaviest pollution and the effect of siltation extended for a distance of 20 miles (Cordone and Kelley, 1961). In about one year after the dredge closed operations, the silt was flushed from the pools and riffles by freshets and bottom organisms increased 8- to 10-fold in weight per unit of bottom area.

Few data are available regarding the direct harm of sediment to fish. In most cases indirect damage to the fish population through destruction of the food supply, redds and eggs, or changes in the habitat probably occur long before adult fish are harmed directly. Ellis (1944) states that particulate matter of a hardness greater than one, if held in suspension by current action or otherwise, will injure the gills and other delicate exposed structures of fishes, mollusks and insects, if the particles are large enough. Kemp (1949) stated that mud or silt in suspension will clog or cut the gills of many fish and mollusks; he considered 3,000 ppm dangerous if maintained for a period of 10 days. Stuart (1953) concludes that silt is not very dangerous in the stream if excess occurs only at intervals; however, the character of such normal streams can be drastically alter-

Plate 6. An esthetically unattractive stream reach polluted with waste wool and debris.

ed by allowing the washings of quarries, gravel pits, mines, etc. to flow into the streams untreated. In many cases the quantities allowed to enter the stream may be small and the material in suspension may in itself be of a non-toxic character, but continuous application of small quantities over the redds may be much more detrimental to the welfare of very young fish than sudden flushes of large quantities. Others who have noted detrimental effects of silt upon the eggs and developing fry of fish include Campbell (1954), Snyder (1959), and Shapovalov and Berrian (1940). Shapovalov and Taft (1954) in discussing mining silt, concluded that from a practical standpoint the damage to spawning beds would occur when mining silt enters a stream at times other than storm periods when the water velocity is insufficient to transport the sediment in suspension.

Turbidity reduces the enjoyment of fishing and may limit fishing success. This effect has been determined in expressable data for Fork Lake in Illinois where it was found that the fish caught per man-hour decreased from 6.53 to 2.04 when the transparency in feet as measured by the Secchi disc was likewise reduced from an average of 4.0 to 1.3 (Bennett, Thompson, and Parr, 1940).

Sediment is believed to destroy algae by molar action, by simply covering the bottom of the stream with a blanket of silt, or by shutting off the light needed for photosynthesis. Tarzwell and Gaufin (1953) found that turbid waters may transport for considerable distances the byproducts of bacterial action on organic wastes and the effluent from sewage treatment installations before they are utilized. When the water clears because of an impoundment, these fertilizing materials are utilized and may produce troublesome algal blooms, far from the source of pollution.

Following a study of the Howard A. Hanson multi-purpose reservoir near Tacoma, Washington, a number of suggestions were made by Sylvester and Seabloom (1965) to improve future water quality by careful site selection and by site preparation. The suggestions included the removal of all standing timber, brush, stumps, logs, and structures from the reservoir site; and the mowing and removal of grass and associated herbage from stream and pasture lands. Soil leaching and exchange studies will indicate whether a soil will impart undesirable properties to the overlying water. And the impoundment area should be flushed several times before use, whenever possible, to collect wood debris, to remove readily soluble soil mineral constituents, and to remove fine soil particles.

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. However, 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) dicusses the effect on downstream water quality of large storage reservoirs with discharge structures located deep within the reservoir. Because the reservoirs have been 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 often reduced over weekends and during other periods of off-peak power loads. The temperatures in the receiving stream may be 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 structures removes cold water from this level. As the supply of cold water at this elevation is exhausted from the pool, warmer water from above sinks down and is gradually discharged. By this process the discharged water may gradually warm 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 often 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

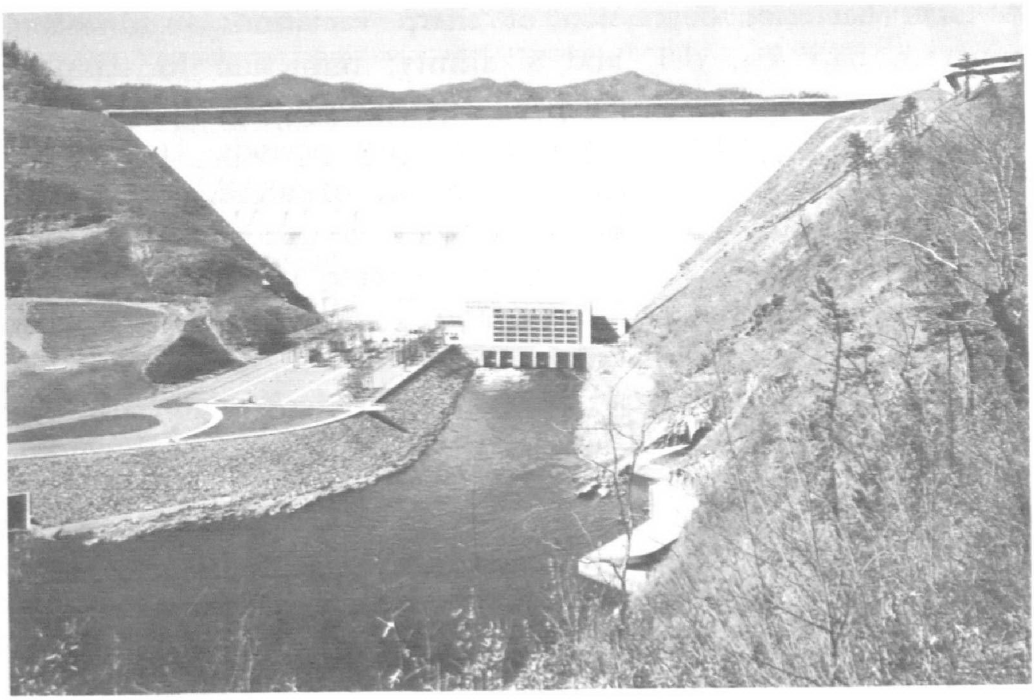

Plate 7. Fontana Project, Tennessee Valley Authority.

miles of open-channel flow before oxygen saturation is reached" (Churchill, 1958). As much as a 14 to 15° C decrease below "normal" summer stream temperatures was observed.

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 fishery below Fontana Reservoir, Tennessee, no longer exist. The highest water temperature recorded was 68.5° F and the lowest concentration of dissolved oxygen was 1.6 mg/l, 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.

Love (1961) lists important beneficial effects of impoundment on water quality as: reduction of turbidity, silica, color, and coliform bacteria; depression of sharp variations in dissolved minerals, hardness, pH, and alkalinity; reduction in temperature, which sometimes benefit fish life; entrapment of sediment; and storage of water for release in dry periods. Detrimental effects were given as: increased growth of algae, which may give rise to tastes and odors; reduction in dissolved oxygen in the deeper parts of the reservoirs; increase in carbon dioxide and frequently iron, manganese, and alkalinity, especially near the bottom; increases in dissolved solids and hardness resulting from evaporation and dissolution of rock materials; and reductions in temperature, which, although sometimes beneficial, may also be detrimental to fish.

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3

Biotic Responses to the Aquatic Environment

ORGANISMS repond to the aquatic environment by producing an aquatic crop that is suited best for the particular environment in which they exist. Organisms also respond to changes that may take place within their environment with shifts in species dominance in the aquatic community and with sometimes dramatic changes in the population numbers of a single species or a group of species with similar habitat requirements. Because of this response of the biota to the aquatic environment, biology has an important role in the characterization of water quality and the interpretation of population trends within the biota.

Algae

Following the spring overturn and throughout the warm summer period, algal populations often play a decisive role in the recreational use of fertile waters. Algal blooms 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 their transportation by water movement. Birge and Juday (1922) found that the largest crop of spring plankton in Lake Mendota, Wisconsin, was approximately 360 lbs. per acre on a dry weight basis (10 percent dry matter), and the largest crop of autumn plankton, 324 lbs. per acre. The summer and winter minimums were 124 and 98 lbs. per acre, respectively. Neil (1958) found that 1 ton or more per acre of the green filamentous alga, *Cladophora*, was produced on a suitable substrate in Lake Ontario. When the filaments of this alga are washed ashore or decompose in the shallow water, a typical pigpen odor is produced.

The wet weight algal standing crop in Lake Sebasticook, Maine, was calculated from a series of vertical plankton samples to be 534 lbs. per acre in February 1965; 631 lbs. per acre in May 1965; 1,019 lbs. per acre on July 30, 1965; 2,260 lbs. per acre on August 1, 1965; and 584 lbs. per acre in November 1965.

The response of algae to changes within the aquatic environment is most often observed in standing waters rather than in flowing streams. This response, observable by blooms of planktonic blue-green algae, floating scums or floating mats of filamentous green algae, or dense growths of weedlike *Chara* has been associated with abundant major nutrients, usually nitrogen and phosphorus. This response, also, may be observed in streams in increased populations of attached algae with the filamentous varities often producing 6- to 10-ft. long streamers that undulate lazily in the current. Shifts in populations of planktonic algae in flowing waters that are due to environmental change have not been demonstrated with similar ease. Large sluggish rivers that resemble lakes environmentally more closely than do swift flowing streams often produce noticeable changes in planktonic algal populations that may be associated with environmental changes. In the swift flowing streams the shifts in planktonic populations may be more difficult to isolate and interpret because the time of water passage would indicate that the algae collected by a particular sample were influenced environmentally at some distance upstream. In some instances the reach of stream studied may be too short to apply a meaningful interpretation.

Plankton are often introduced into the flowing water from impoundments, backwater areas or stagnant areas of the stream. The plankton that are developed in standing water within the river's basin are, however, frequently destroyed downstream (Butcher, 1940; Chandler, 1937; Reif, 1939). Blum (1956) cites Poretzkii (1926) as indicating that certain river plankters are unable to survive conditions of existence within an impoundment. Streams whose plankton are not dominated by species from upstream lakes or ponds are likely to exhibit a majority of forms that have been derived from the stream bottom directly (Butcher, 1940).

Factors influencing river algae are listed by Blum (1956) as: size of the stream, current rate, water level, depth, temperature, light, turbidity, and chemical conditions. Berg (1943) is quoted as discussing the possibility that the micro-environment of the stream bottom is surrounded with water that is not in motion. It is probable that massive filamentous algae on the stream bottom enclose between their filaments a volume of water that is essentially stationary, yet is in contact on all sides with constantly renewed water which brings fresh supplies of oxygen and essential nutrients.

Cairns (1956) states that in an unpolluted stream, diatoms generally grow best at 18° to 30° C; green algae at 30° to 35° C; and blue-green algae at 35° to 40° C, with some species growing at even higher temperatures. The work of Wallace (1955) was cited which shows a shift in the algal population with the introduction of heated water; as the temperature increases the diatoms decrease with a resultant rise in green algae and finally bluegreen algae.

Acid mine wastes discharged to a Pennsylvania-West Virginia stream reduced phytoplankton species from 12 and 13 in unaffected reaches to 3 and 4 in those reaches affected by acid mine discharges. Population numbers were also generally reduced in the affected reaches.

Lackey (1938) found that the most highly acid-polluted waters support a few species of microorganisms which occur in large numbers and are distinctive indicators of acid conditions. For example, *Euglena mutabilis* were so abundant that they were responsible for the green coating on sticks, leaves and stones. The organism is devoid of a flagellum and by a "conservative estimate," over 1,000,000 organisms were found per m^2

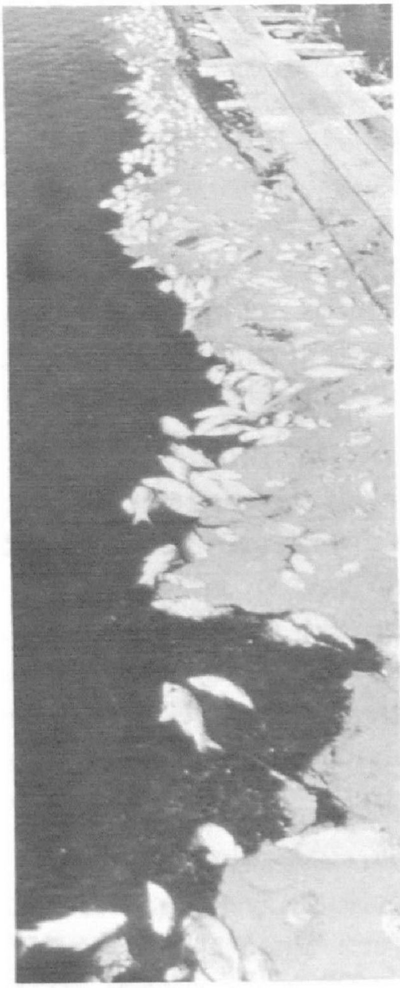

Plate 8. An overproduction of algae in a lake, when discharged to a river, sometimes causes fish kills (Yahara River, Wisconsin).

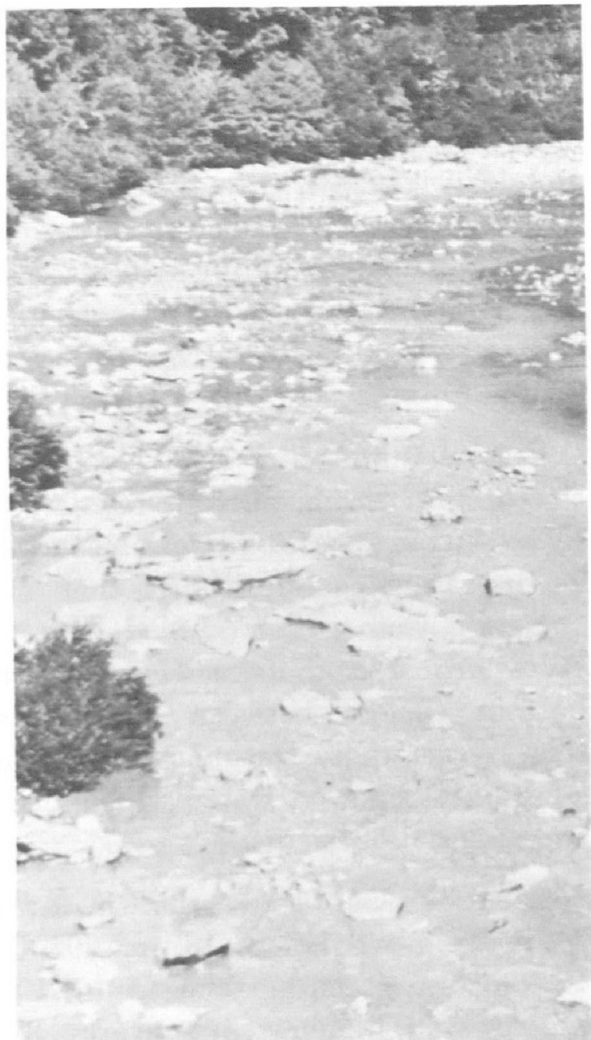

Plate 9. Acid mine discharges cleanse natural substrates of organisms.

of surface. Only one blue-green alga, *Oscillatoria sp.*, was noted below pH 7.0 *Ulothrix zonata* (Weber and Mohr) Kuetzing was common, *Stigeoclonium* was abundant, and *Cladophora* occurred occasionally. Naviculoid diatoms were numerous in many samples; one species of Tabellaria was noted. A total of 99 species of plants and animals were found living at or below pH 3.9; 76 were algae or protozoa. Commonly occurring microscopic forms included only 17 species (Lackey, 1939).

In studies on acid mine polluted waters with a pH of 3.5 and lower in Pennsylvania and West Virginia, *Ulothrix tenerrima* Kuetzing formed thick beds near the debouchment from mines.* *Euglena mutabilis* formed a green slime covering on rocks. *Microthamnion strictissimum* Rabenhorst was less abundant than

Ulothrix, but was very common, and two pennate diatoms (*Pinnularia sp.* and *Eunotia exigua* (Bréb) Rabenhorst) were extremely common and abundant.*

The adverse effects of silt on flowing-water algae were demonstrated in studies of a stream polluted with industrial silts in Georgia and Alabama. In a stream polluted with silt, algal populations totalled 126 and 422 cells per ml. Algal genera excluding diatoms did not exceed 2. In an unaffected associated stream sampled the same day, algal populations numbered 6,075 cells per ml and algal genera excluding diatoms numbered 10. The population was composed of all major algal groups.

Two miles downstream from the junction of the unaffected river with the turbid waters of the silt-polluted river, the algal data indicate reductions in both genera and numbers to form a population of less than half that in the unaffected stream. Thirteen miles downstream there was an additional reduction both in algal kinds and numbers, indicating a die-off of algae from the unaffected stream. In this reach only 2 genera of algae other than diatoms were noted.

Submerged Aquatic Plants

Studies of the standing crop of submerged aquatic plants in Lake Mendota and Green Lake, Wisconsin (Rickett, 1922, 1924), indicate a wet weight of 14,000 lbs. per acre and a dry weight of 1,800 lbs. per acre. In Lake Mendota, the 0- to 1-meter zone contained 1,600 lbs. per acre of submerged plants on a dry weight basis; the 1- to 3-meter zone, 2,400 lbs; and the 3- to 7-meter zone, 1,300 lbs. In Green Lake the 0- to 1-meter zone contained 600 lbs. per acre of submerged vegetation on a dry weight basis; the 1- to 3-meter zone, 1,960 lbs; and all deeper areas to the lower limit of plant growth, 1,580 lbs. per acre. Low and Bellrose (1944) found similar productions in the Illinois River Valley. Coontail growths approached 2,500 lbs. per acre (dry weight); sago pondweed, 1,700 lbs. per acre; and duckweed, 244 lbs. 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. Little has been demonstrated posi-

* Richard W. Warner, personal communication.

tively regarding the effects of pollution or adverse environmental changes on populations of higher aquatic plants. Generally, these plants respond to increased water fertility with increased production. The factors that trigger the development of dense higher aquatic plant populations instead of dense algal populations (and conversely) in fertile standing water bodies are presently unknown.

Bottom Associated Organisms

Much attention has been given to the bottom invertebrates in streams, lakes and ponds. Data in the literature pertain usually 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 differently with depth in each of the lakes and very differently during 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 and was composed predominately of *Corethra* and *Chironomid* larvae.

Cronk (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. Midges predominated. The average net weight of benthic organisms for 344-acre Blue Lake, California, was 134 lbs. per acre (Calhoun, 1944). There were an estimated 2,627 organisms per square meter of lake bottom.

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 as 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 area than a small lake.

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

Fremling (1960) reports on the large masses of mayflies, *Hexagenia bilineata* (Say), in the benthic sediments of the upper Mississippi River. He writes of a guard gate at Lock 19, Keokuk, Iowa that, when raised on July 9, 1958, contained 344 nymphs on 10.5 square feet of surface. The gate had been submerged at the river bottom in 18-feet of water for 3 months and was covered uniformly with about 3 inches of soft mud.

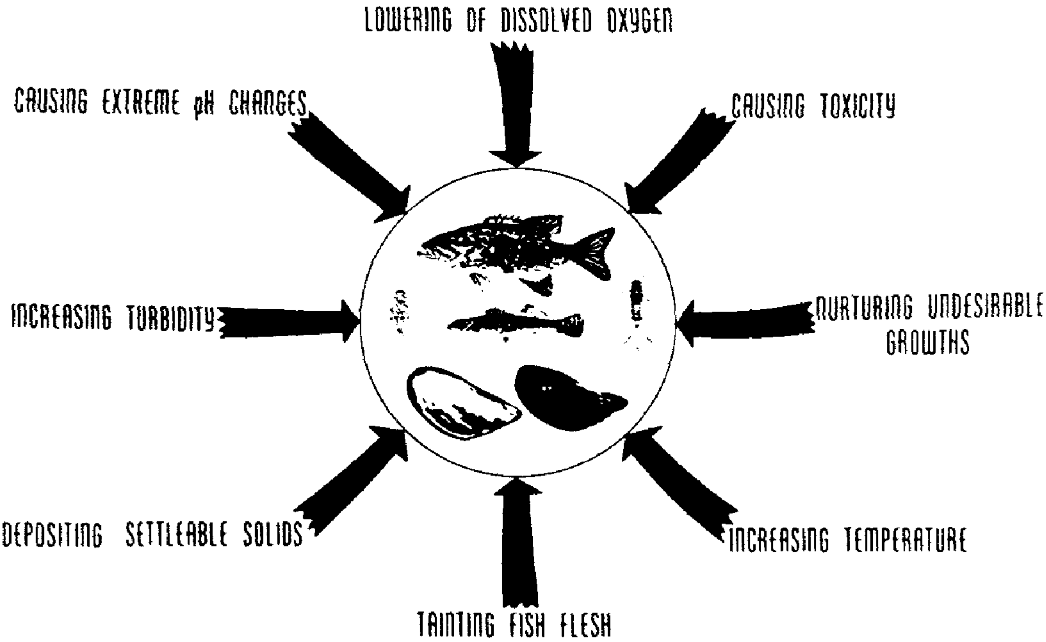

Figure 2. Ways in which pollution may affect aquatic life.

Burrowing mayfly nymphs in the vicinity of Green Bay, Wisconsin, are called the Green Bay fly. In a study on Green Bay conducted during 1938-39, these were found in bottom mud samples collected from 16 of the 51 stations examined. At some stations, burrowing mayfly nymphs were as numerous as 50 per square foot of bottom. In 1952, burrowing mayfly nymphs were found at 1 of 27 stations sampled with a population of 16 per square foot. In 1955, 93 stations were sampled in Green Bay. A single burrowing mayfly nymph was found at one of the near-shore stations. It was postulated that organic pollution was the cause of the mayfly population decline. Concurrent with the decline in mayfly nymphs there was an increase in the populations of sludgeworms and midges in the benthic deposits.

In the Milwaukee River at Milwaukee, Wisconsin, sludgeworms attained populations of 84,000 per square foot in 1952-53 by feeding on a seemingly inexhaustible organic food supply. Immature stages of mayflies, caddisfiies and hellgrammites were eliminated. The average live weight per sludgeworm was determined to be 6.3 milligrams and the calculated weight of the living sludgeworm population was 1.1 lbs. per square foot of river bottom. At Worcester, Massachusetts, in the organically enriched Blackstone River, 56,000 sludgeworms per square foot were found during August 1964. Purdy (1930) found that sludgeworms eat continuously. Observations during 21 hours of the 24 showed no perceptible decrease in the foraging activity. Evacuation of a string of fecal pellets about 68 inches in length in a 24-hour period was recorded for each worm. An incubation of 24-hours showed an oxygen demand of 2.8 mg/l by these pellets whereas the original mud beneath the surface showed a demand of 6.7 mg/l. Purdy's conclusion was that the large surface area exposed to the flowing water in the fecal pellets possessed a far greater purification potential than did the same mass of materials an inch or more beneath the mud-water interface.

In the Brule River bordering Michigan and Wisconsin, where man-associated organic wastes are not a problem, clean-water-associated larval caddisfly populations numbered 1,164 per square foot, and mayfiy nymphs were found to number 328 per square foot in riffles in 1963.

Silt has an adverse effect on benthic organisms, limiting both the variety and the total population. In a Georgia stream polluted heavily with industrial silts, only sludgeworms, midges, nematodes, and an occasional leech occurred in a combined population of less than 50 per square foot along the stream margins. In areas not affected adversely, immature stoneflies, burrowing mayflies and gill-breathing snails were found.

Coutant (1962) in studying the effect of a heated water effluent on the macroinvertebrate riffle fauna of the Delaware River found that the macroinvertebrate biomass was reduced from 1.04 to 0.09 grams per square foot throughout the summer in the area of maximally heated water as compared with a control station. A 95° F water temperature at the time of sampling was found to be causing a detrimental effect on many organisms, especially the caddisfly, *Hydropsyche*, many of which were dead while those alive were extremely sluggish. The data suggest that there is a tolerance limit close to 90° F for a variety of different kinds of animals in the population structure of benthos with extensive loss in numbers and diversity of organisms accompanying further temperature increase.

The highest 24-hour median tolerance limit lethal temperatures that could be obtained by raising acclimation temperatures from

10° C (50° F) to 20° C (68° F) were estimated to be 34.6° C (94.2° F) for the sowbug, *Asellus intermedius* Forks, and the scud, *Gammarus fasciatus* Say, 33.2° C (91.8° F) for the scud, *Hyallella azteca* (Saussure), and 29.6° C (85.3° F) for the scud, *Gammarus pseudolimnaeus* Bousfield (Sprague, 1963).

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 compact. 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 of 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 on bare pool bottoms. Needham (1938), in studying bottom fauna production associated with several kinds of aquatic plants in slow-flowing streams of New York, observed standing benthic crops of 3,500 lbs. per acre for *Chara*, and 300 lbs. per acre for sago pondweed, *Potamogeton crispus Linnaeus*. Shelford (1918), rated *Elodea* as excellent in the production of animals; *Myriophyllum* as good, and water lilies, *Nuphar*, 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 to reach down in the water as far as possible and to cut 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 plant was measured. He found the animal population on *Myriophyllum sp.* was about 2.5 times as great as on *Elodea*, and nearly 4 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.

Fish

Bennett (1962) states that the fish carrying capacity of a lake or pond may vary with (1) the fertility of water; (2) the age of the water, if this represents age in chemical composition; (3) changes 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 composition 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 (1956) 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 phosphorus content of fish lakes is 0.058 mg/l and the average fish capacity is estimated at about 150 lbs. 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 lbs. of rough fish per acre plus about 90 lbs. of other fishes, a total of 370 lbs. 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 lbs. of fish were recovered consisting of 304 lbs. of bluegills, 758 lbs. of gizzard shad, and 17 lbs. of bass. In 20 ponds

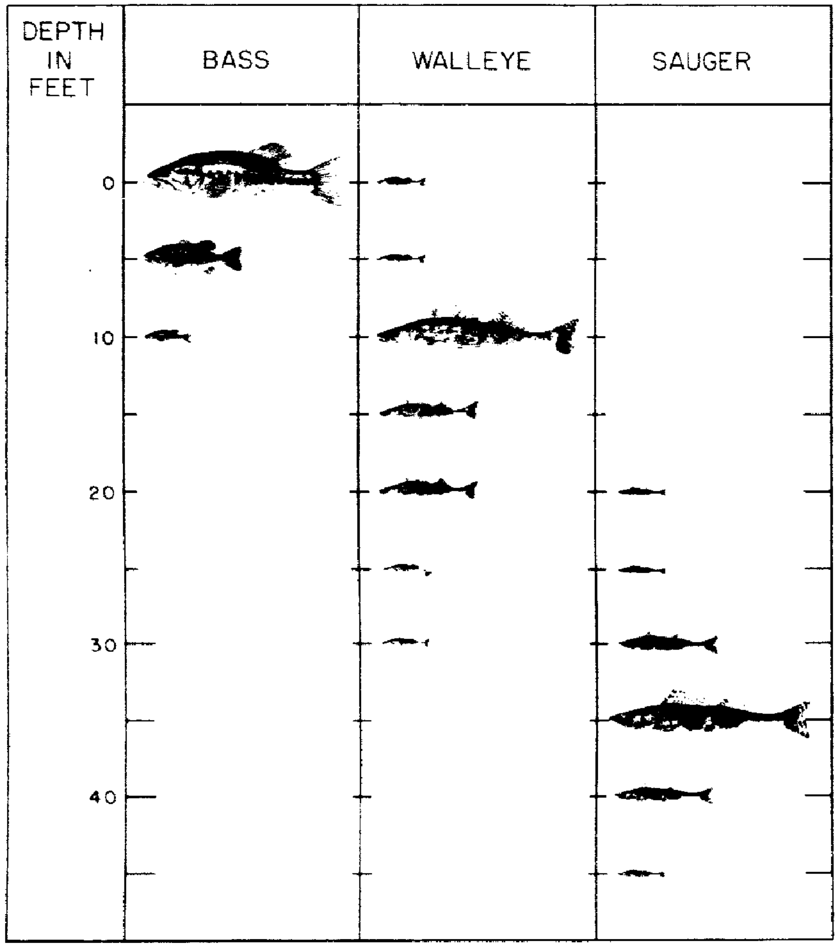

Figure 3. Approximate depths at which fish were found in TVA storage reservoirs, Cherokee, Douglas, and Norris on June 2, 1946. The figures refer to fish abundance at each level, not to fish size. Most largemouth bass were near the surface; walleye tended to be 10 feet or more deep; most sauger were over 30 feet deep (from Eschmeyer, 1950).

with a variety of fish forming the population, the pounds per acre 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 lbs. per acre in the soft-water ponds in the Ozark hills of southern Illinois, where the population was largemouth bass and green sunfish, to 1,100 lbs. per acre in the black-soil ponds in the flood plains of central Illinois, where the population was composed of crappies and big mouth buffalo.

The distribution of fish is influenced greatly by water temperature. Results of TVA netting studies (Eschmeyer, 1950)

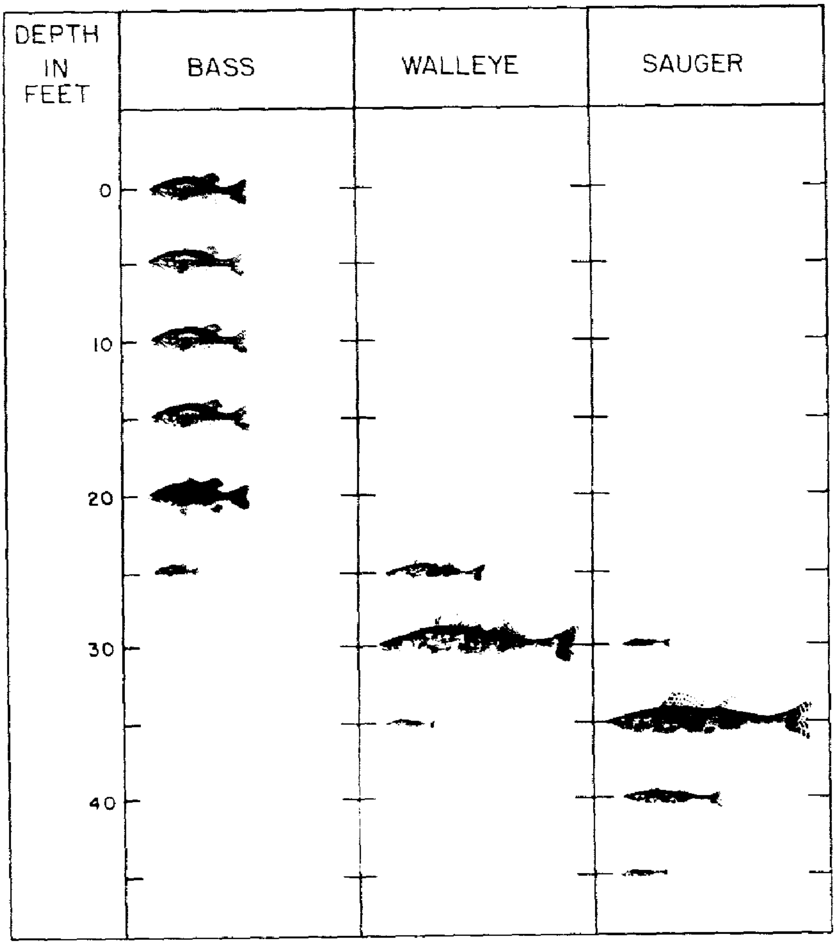

Figure 4. Approximate depths at which fish were distributed in Norris Reservoir, Tennessee, in late July 1946. Note the distribution differs from that of June 2 (fig. 3). Some bass were still near the surface, but the species was spread about evenly from the top to 20 feet or more in depth. Most walleye and sauger were in deeper water (from Eschmeyer, 1950).

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.

The response of fish to environmental adversities is well covered in a recent book (Jones, 1964); cognizance is given especially to the European literature. Agersborg (1930) studied the reaction of fish to temperature in a region of Lake Decatur, Illinois, where a cold stream, near 0° C joined a stream heated at times to between 24 and 29° C. No ill effects on the fish were noticed at the higher temperatures, except for an occasional shad which suffered from clotting of the gills and died; however, when the flow of the warm water stopped and the water suddenly cooled, or when fish moved out from the warmer water into the cold, they died, sometimes in large numbers. Effect of cold water was marked. Drops of 2° C brought about symptoms of unbalanced movements, fish surfaced and snapped at the surface as though gulping air. All fish that remained in the cold water, or swam into colder, died.

A review of the literature and other studies on heated discharges and their effects on streams has indicated the following (Anon., 1962):

"Studies made to date have demonstrated that:

1. As the water temperature rises it holds less DO.*
2. As the water temperature rises aquatic organisms require more DO in order to maintain a normal existence or to live at all.
3. The temperature requirements of a certain fish varies throughout its life history. The requirements differ for spawning and the development of eggs and fry. The sensitivity or tolerance of aquatic organisms to temperature changes or levels also varies with age, size, and season.
4. Lethal high and low temperatures vary widely for different species. The difference in upper lethal levels for different species varies as much as 32° F (e.g., 107.6° F for the goldfish and 75° F for the pink salmon).
5. Sudden changes in water temperature can be lethal to fishes and other aquatic organisms.
6. Within certain limits fish can acclimate to high or low water temperatures.
7. They become acclimated to higher temperatures much more rapidly than they do to lower temperatures.
8. A reduction in DO, an increase in CO_2, or the presence of toxic materials greatly reduce the upper temperatures which can be tolerated by fishes.
9. Water temperatures do not have to reach lethal levels in order to wipe out a species. Temperatures which favor competitors, predators, parasites, and diseases can destroy a species at levels far below those which are lethal.

* DO = dissolved oxygen.

10. As water temperatures increase, bacterial action and the so-called natural purification process are speeded up. This may result in the depletion of oxygen during the summer in certain areas in which DO conditions are satisfactory during fall, winter and spring.
11. Some fish will swim into hot water in which they are killed although they might as easily have swum into water which would have been harmless. Fish acclimated to warm water are rapidly killed when they swim into cold water.
12. Temperature influences physiologically all the vital processes including activity, feeding, growth and reproduction."

Studies on the relationship of fish to dissolved oxygen concentrations have been made by many; some of these studies include those by Burdick et al. (1954, 1957), Cooper (1960), Cooper and Washburn (1946), Davis et al. (1963), Davison et al. (1959), Ellis (1937), Jones (1952), Moore (1942), and Tarzwell (1958). Results of these studies have been discussed in several reviews, most recently by Jones (1964).

Floods and heavy silt loads were found by Starrett (1951) to be an important limiting factor to minnows and other species of fish. Continued low-water levels reduced space and successful spawning of many fish. The reduction of minnow populations through isolation following a high water period was thought to have a beneficial effect on subsequent spawning of two species of minnows.

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4

Collecting and Reporting Lake and Stream Data

FOUR basic and equally important interrelated components of a biological survey include: initial study organization, collecting and processing field samples, data analyses and interpretation, and report writing. Biological evaluation of an aquatic environment involves a comparison of the living community at one location with that in another. To accomplish this comparison satisfactorily entails the best possible manipulation of tools to sample adequately the organism associations, and an interpretation of existing water quality based on the professional analyses of collected samples, as well as on field observations.

Study Organization

The initial study organization involves a number of basic decisions.

Natural lakes, reservoir and stream sampling and data collection entail:

(1) a definition of the problem, (2) a determination of the types of samples necessary to delineate a solution, (3) a selection of sampling sites, (4) a judgment of the required number of samples, (5) a decision on the proper time, periodicity, and extent of sample collection, and (6) a knowledge and understanding of the science of limnology.

The location of the laboratory must be determined, whether it is a field unit or a permanent station. The method of handling, preserving, and transporting collected samples to the laboratory must be considered. Survey teams with duties assigned must be selected; these may include a biological team, sample collectors

DATE ____________________

DESIRED LABORATORY SERVICES

SURVEY ____________________ PROJECT CHIEF ____________________

LABORATORY LOCATION ____________________ PHONE ____________

FIELD CONTACT: NAME ______________________________________

ADDRESS ____________________________________

SAMPLING DATES ____________________ TO ____________________

ANALYSES REQUIRED

CHEMICAL	ESTIMATED SAMPLES/DAY	TOTAL SAMPLES
____________	________	______
____________	________	______
____________	________	______
____________	________	______
____________	________	______
____________	________	______
BACTERIOLOGICAL		
____________	________	______
____________	________	______
____________	________	______
____________	________	______
BIOLOGICAL	NO. OF LOCATIONS	
PLANKTON	________	______
BENTHIC	________	______
FISH	________	______
PERIPHYTON	________	______
____________	________	______

REMARKS

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Chart 5. Laboratory services used to plan field survey. Plan sheet should be submitted to laboratory chief well in advance of survey.

for routine chemical analyses, and perhaps a flow measurement team to evaluate streamflow as it pertains to quantitative volume and time of passage measurements. To ensure a well-organized survey laboratory operation, the total number of samples to be collected should be estimated for each phase of the study. When necessary, periodic adjustments will make the total estimate more realistic. Pre-planning will ensure systematic and coordinated data collection and analyses. Throughout the survey it is important to keep collected data current, understandable, and available to all survey participants.

In addition, a preliminary survey of pertinent literature is of extreme importance. Data that are already available may serve as guides to additional investigation. A study of the most complete maps of the study area will facilitate both organizational planning and initial field investigation.

Collecting and Processing Field Samples

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 and stream watercourses. Chemical factors include alkalinity, pH, dissolved oxygen, free carbon dioxide, hardness, nitrogen (organic, ammonia nitrogen, nitrite and nitrate), phosphate (soluble 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 associated organisms. Basically, the collecting of limnological data may be summarized by answering the questions why?, what?, how?, where?, and when? (Porges, 1960).

Why?

The purposes of a sampling program are to assemble data for 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. Too often the public is impatient with a 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 and disease vectors. 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 often greatly varied environments.

What?

Rawson (1958) considers lake and reservoir investigations 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	Latitude	Shore length, islands
Mean depth	Shore length	Drainage area
Maximum depth	Shore development	Rate of runoff
Area of depth zones	Littoral development	Average inflow
Volume of depth strata	Littoral slope	Average outflow
	Number of islands	Time of "flushing"
Altitude	Area of islands	Water levels

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

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

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 (1958) the plotting of the vertical dissolved oxygen curve and a knowledge of the nutrients inflows, outflows, and retention within the basins is indicated. The latter would involve nutrient measurements on influents and effluents, as well as vertical 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 when downstream domestic water supplies are involved.

Because nitrogen and phosphorus trace elements, and vitamins in man-associated wastes have been involved in nuisance algal blooms and developing aquatic vascular plant communities, a house to house survey of dwellings adjacent to the lake or reservoir should be made to determine methods of waste dispostal, number of residences, and time period of yearly occupancy. County agents should be contacted to determine the types and amounts of fertilizers applied to crops within the drainage basin, and the approximate application time. Nutrients contained in the annual precipitation, and in the ground water, should be evaluated.

The flowing stream necessitates flow measurements to assess the quantity of water quality constituents that pass a given point. The types of samples that may be related to the flowing stream are dependent upon the specific problem and will usually include a biological investigation.

Flow measurements should be made, and pertinent samples collected, on suspected municipal and industrial waste sources and irrigation return flows as they are discharged within the drainage basin. Where municipal water supplies or water-contact recreational sports such as swimming and skiing are involved, water samples for bacteriological determination may be collected from predetermined points.

Rawson (1958) 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 gill-net, 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 potential nuisance problem. Also base line data should be secured 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 accurately, both as to kinds present and relative abundance.

Biological considerations within the flowing stream also involve fish, bottom fauna and flora plankton and microbiological flora. The invertebrate bottom-organism community is most often investigated. Because the life histories of many bottom-dwelling organisms are 1-year or longer and because these organisms are not equipped to move great distances by their own efforts, they are valuable to indicate past and present water quality at fixed points, to identify conditions on the bottom of the stream and, by population comparison in point of time or distance, they suggest past "short-lived" inflows of toxic wastes.

Although fish may be transient, they are an important consideration in stream sampling. Fish represent one of the end products of the aquatic phase of the food chain. However, because of their mobility, they indicate water quality only at the particular time of capture. Bio-assays, in which fish in cages placed downstream and upstream from the pollution source are used as test animals, may increase the observer's ability to determine water quality for short-time periods. The fish population responds to adverse environmental changes in a manner similar to that of the bottom organism community.

Plankton, minute organisms that are suspended and/or float on the water surface, are basic to the aquatic food chain and often may be a significant part of a stream study. Because plankton are carried long distances by currents, they reflect water-quality conditions upstream rather than at the point of sampling.

Attached algae, slimes, and bottom dwelling animals indicate water quality over long-time periods. These organisms are fixed in a particular spot and are subject to whatever environmental adversities occur at that spot. Quantitative analyses may be made of samples of growths from artificial attachment surfaces placed in the water for predetermined time periods.

Sediments tend to accumulate in sluggish waters. A knowledge of the extent and composition of sludge deposits and the history of their deposition is important in any study of pollution in a stream reach. An important tool is the core sampler which secures a sediment core extending from the particulate matter making up the bottom at the water interface into the natural stream bed. Segments of cores can be analyzed microscopically and chemically to determine the composition of the layered sediments.

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 an idealized pond study to include analysis of pond soil; analyses 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 Federal Water Pollution Control Administration has established a Pollution Surveillance network currently involving 131 stations on the rivers of the United States. All network samples are examined for:[1 2 3 4]

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

Plankton populations (semimonthly).

[1] 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).

[2] 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).

[3] 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).

[4] 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).

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.

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. Instrumentation on them has kept pace with modern technological developments especially in the chemical discipline. The Federal Water Pollution Control Administration uses a 40-foot mobile trailer laboratory, and a 26-foot compact mobile laboratory. The 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.

How?

The techniques of sample collection and analyses have been well documented in the 13th, current edition, "Standard Methods for the Examination of Water and Wastewater" (Anon. 1965). This has been used for 61 years as a guide to the physical and chemical examination of water, sewage, and industrial wastes, the radiological and bacteriological examination of water, and the biological examination of water related to its pollution from municipal and industrial wastes. 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 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 pollution sources and water use draw-off points, which can be correlated with sampling dates, are of utmost importance. Such data permit, for example, a calculation of the amount of pollutants 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 examinations 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) described 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.

Innumerable 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 record precisely 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 any 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 rotifiers 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 Sedgewick-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

* Now the Federal Water Pollution Control Administration water quality lab.

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 represents 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 and a Kemmerer sampler were employed to obtain the sample, which was concentrated by a Foerst centrifuge, and counted in a Sedgwick-Rafter cell. 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 plankton number in all of the population densities than that obtained by his earlier method.

Some waters contain sufficient plankton (phyto- and/or zooplankton) so that samples must be diluted to obtain adequate numerical information; however, with a sparse plankton sample, concentration should be used. The phytoplankton in samples from many natural waters require neither dilution nor concentration and should be enumerated directly. Correspondingly, zooplankton often are not sufficiently abundant to be counted without concentration. Selection of methods and materials used in plankton enumeration depends on objectives of the study, density of plankters in the waters being investigated, equipment available, and experience of the investigator.

The Sedgwick-Rafter cell has been and continues to be the most commonly employed device for plankton enumeration because it is easily manipulated and provides reasonably reproducible information when used with a calibrated microscope equipped with an eyepiece measuring device, usually a Whipple ocular micrometer. It can be used to enumerate undiluted, concentrated, or diluted plankton samples. The biggest disadvantage associated with the cell is magnification. The cell cannot be used for enumerating very small plankton unless the microscope is equipped with special lenses that provide sufficient magnification (400X or greater) and clearance between objective lenses and the cell.

The Sedgwick-Rafter cell is 50 mm long by 20 mm wide by 1 mm deep. Since the total area is 1,000 mm^2, the total volume is 1×10^{12} cubic μ, 1,000 mm^3, or 1 ml. A "strip" the length of the cell thus constitutes a volume 50 mm long, 1 mm deep, and the width of the Whipple field. Two or four strips usually are counted, depending on the density of plankters. Counting more than four strips is not expedient when there are many samples to be enumerated; concentrating procedures then should be employed, and counts made of plankters in the concentrate.

$$\text{No. per ml} = \text{Actual Count} \times \frac{1{,}000}{\text{Volume of "strip" } (mm^3)}$$

If the sample has been concentrated, the concentration factor is divided into the actual count to derive the number of organisms per ml. For separate field counts (usually 10 or more fields):

$$\text{No. per ml} = \text{ave. count per field} \times \frac{1{,}000}{\text{Volume of field} \times \text{No. of fields}}$$

When special lenses are not used and there is a need to enumerate small plankton, unusually abundant, other procedures may be employed in conjunction with and related to counts obtained from the Sedgwick-Rafter cell.

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 is put on a glass slide and a cover glass added; 5 low-power fields and 10 high-power fields are examined, and number of each species is recorded at the magnifications used. Enumeration is repeated on 3 such mounts for a total of 15 low-power fields and 30 high-power fields.

No. per ml = ave. no. per field X no. of fields per drop or per cover slip X no. of drops per ml ÷ the concentration factor.

The concentration factor = ml of original sample ÷ ml of concentrate X (100 − percent of preservative in sample).

Lackey's method has the advantages of including 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. Certain disadvantages are inherent in the method: 1) because water normally is used as a mounting medium enumeration must be accomplished relatively rapidly to prevent dessication and subsequent distortion of organisms; 2) results are not sufficiently accurate when on 1 slide-mount is examined, thus necessitating preparation and enumeration of at least three or more slide-mounts; and 3) the investigator should be sufficiently familiar with plankton to rapidly identify and count the specimens encountered.

Application of the membrane filter method of plankton counting requires a vacuum pump, special filtering papers, and experience in determining the proper amount of sample to be filtered. Plankton in samples from waters containing substantial quantities of suspended matter such as silt may be difficult to enumerate by this method since, in the process of filtering, the suspended matter tends to crush the plankton or otherwise obscure them from view. However, the method has certain features that make it particularly adaptable for use on waters with a low phytoplankton and silt contents. Primary among these features, the method permits the use of conventional microscope lenses to achieve high magnification for enumeration of small plankton (the membrane filter retains very small organisms), provides relatively rapid processing of samples if the investigator is familiar with the procedure and the plankton, does not require counting of individual plankters to derive enumeration data, and increases the probability of observing the less abundant forms (McNabb, 1960).

The sample is filtered through a 1-inch membrane filter. The wet filter is removed and placed on top of 2 drops of immersion oil on a microscopic slide, 2 drops of immersion oil are placed on top of the filter. The filter is air-dried at room temperature until clear (approximately 48 hours). A cover slip is added prior to examination.

When examined, the magnification and sampling field or quadrat must be of such size that the most abundant species will appear in at least 70 but not more than 90 percent of the microscopic quadrats examined (80% is optimum). Otherwise the field size or the amount of sample concentrated must be altered. The occurrence of each species in 30 random microscopic fields is recorded.

Number of organisms per milliliter = density (d) from following table X number of quadrats or fields on membrane filter ÷ number of milliliters filtered X formalin dilution factor [0.96 for 4 percent formalin].

Conversion Table for Membrane Filter Technique

(Based on 30 Scored Fields)

Total Occurrence	F%	d
1	3.3	0.03
2	6.7	0.07
3	10.0	0.10
4	13.3	0.14
5	16.7	0.18
6	20.0	0.22
7	23.3	0.26
8	26.7	0.31
9	30.0	0.35
10	33.3	0.40
11	36.7	0.45
12	40.0	0.51
13	43.3	0.57
14	46.7	0.63
15	50.0	0.69
16	53.3	0.76
17	56.7	0.83
18	60.0	0.91
19	63.3	1.00
20	66.7	1.10
21	70.0	1.20
22	73.3	1.32
23	76.7	1.47
24	80.0	1.61
25	83.3	1.79
26	86.7	2.02
27	90.0	2.30
28	93.3	2.71
29	96.7	3.42
30	100.0	?

$$\text{Where F} = \frac{\text{total number of species occurrences X 100}}{\text{total number of quadrats examined}}$$

Plankton samples from the Madison, Wisconsin, 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. To concentrate the phytoplankton, 500 ml. of stream water were placed in 1-liter glass settling cylinders to which were added 20 ml. of commercial formalin to preserve the sample, and 10 ml. of a detergent to settle the sample. Sedimentation of the plankton was complete in 24 hours, after which the supernatant was carefully siphoned from the cylinder, and the concentrate was washed into 100 ml. centrifuge tubes. These were spun at 2,000 r.p.m. for 6 minutes. The supernatant in the tube was decanted and the concentrate was washed into screw-capped storage vials and brought to the nearest 5 ml. by the addition of 4% formalin and the use of a volume standard. In making the drop count, 5 low-power fields and 10 high-power fields were observed on this slide, and the magnification as well as number of each species of organisms was recorded. This procedure was repeated on 3 such mounts so that totals of 15 low-power fields and 30 high-power fields were observed. 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 average volume in cubic microns of each species was obtained by measuring 20 individuals. 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.

Mackenthun employed constable tubes to determine cell volume in a 1956 Wisconsin study. Concentrated algal samples were obtained on July 25, 1956 and again on August 8, 1956 from Station 1 in the Menasha Channel, Fox River, at mileage designation 38.5, at Station 2 from the Rapide Croche Dam at mileage designation 19.5, and Station 3 upstream from De Pere Dam at mileage designation 7.0. The concentrated algal samples were obtained by centrifuging 50 gallons of river water at 12,000 r.p.m. and suspending the residue in one gallon of algal-free water. A blender was employed in re-suspending the algae. An aliquot sample of this 50 to 1 concentration was used for biological analyses.

Ten ml. of the concentrated samples, equivalent to 500 ml. of raw water, were centrifuged at an approximate speed of 2,000 r.p.m. in a constable tube. The addition of a small amount of detergent to the constable tube will facilitate the packing of small blue-green algae. On August 8, 50 liters of river water were strained through a fine plankton net at the 3 stations for comparative purposes. The cell pack or cell volume as calculated on a raw-water basis was as follows:

Cell Pack (ml/l)

		August 8	
Station	July 25	Centrifuged	Net Plankton
1	.068	.086	.071
2	.058	.066	.038
3	.036	.045	.031

Both the centrifuged and net plankton samples taken on August 8 displayed color stratification in the constable tube. The upper white layer was composed principally of single blue-green algal cells and small fragments of blue-green algal colonies. The middle light green layer was principally blue-green colonies and many celled filaments or larger fragments of these filaments of *Aphanizomenon, Anabaena,* and *Gloeotrichia.* In addition, there were numerous single blue-green cells and some colonial greens with a few diatoms. The lower dark layer was predominately blue-green algae, because of their abundance in the sample, but diatoms were heavily concentrated. The large-celled *Lyngbya birgei* was most concentrated in this layer, as was the dinoflagellate, *Ceratium.*

The packed cells, or residue, from the constable tubes were washed in distilled water and were dried and ignited in a platinum dish. The following results were obtained:

	Mg. dry Wgt./L			*Mg. Ash/L*			*Mg. Vol. Sol./L*		
Sta.	*7–25C*	*8–8C*	*8–8N*	*7–25C*	*8–8C*	*8–8N*	*7–25C*	*8–8C*	*8–8N*
1	9.8	14.6	11.8	4.4	6.8	3.0	5.4	7.8	8.8
2	10.6	14.4	8.6	5.4	4.6	2.0	5.2	9.8	6.6
3	4.8	6.4	7.2	2.0	2.8	1.2	2.8	3.6	6.0

C—Centrifuged sample N—Net plankton Vol. Sol.—volatile solids

Some phytoplankton samples consist primarily of diatoms. These organisms generally are difficult to identify without special preparation since distinguishing markings on their frustules are obscured by protoplasm. Destruction of the protoplasm by heat or chemicals provides recognition of taxonomic features. Destruction by heat often is preferred to that by chemicals because the former requires no special glassware or reagents, reduces the risk of losing organisms during sample preparation, and shortens processing time. When there is obvious need to assemble diatom data, such organisms can be readily concentrated by settling-decanting or centrifuge-decanting techniques that employ a 2 to 4 percent solution of household detergent to free organisms lodged on the walls of sample containers and water-surface films.

A cover slip is placed on a hot plate that is warmed sufficiently to increase the evaporation rate, but does not boil the concentrated plankton sample. Several drops of concentrate are transferred to the cover slip by means of a large-pore calibrated dropper and allowed to evaporate to dryness. (This may be repeated on concentrates containing few diatoms until the entire sample has been transferred to the cover slip; precautions should always be taken to prevent a residue that is too dense to recognize the organisms.) Following evaporation, the residue on the cover slip is incinerated on the hot plate at temperatures ranging from 600-1,000° F, effecting adequate incineration in ¾ to ⅓ hour respectively. A drop of distilled water is placed on a clean slide. The cooled cover slip with its residue is carefully transferred to the slide thus forming a water mount for identification and enumeration of diatoms. Permanent and more easily handled mounts, especially for processing at high-dry and oil-immersion magnifications, are prepared by using Hyrax* instead of water as a mounting medium. When Hyrax is used, heating of the slide to near 200°F for 1 to 2 minutes prior to application of the cover slip

* Mention of commercial products does not constitute endorsement by the Federal Water Pollution Control Administration.

hastens evaporation of solvent in the Hyrax and reduces curing of the medium to about 20 seconds (solvent-free Hyrax is hard and brittle at room temperature). A firm but gentle pressure is applied to the cover glass by means of a forceps or other suitable instrument during cooling of the Hyrax mount (about 1 minute) to assure penetration of the medium into the diatom cells.

Enumeration and calculation to derive numbers of diatoms per ml are similar to those for the drop count. If examination reveals uneven distribution of diatoms in either the water or Hyrax mount, only proportionate counts of the species present are conducted and these are related to enumerations made by previously outlined methods.

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 2 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 6 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 must be corrected when dealing with polluted streams.

Periphyton include that assemblage of organisms that grow on free surfaces of submerged objects in water and cover them with a slimy coat. Cooke (1956) comprehensively reviews 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). Growths on such substrates may be analyzed qualitatively or quantitatively.

Chlorophyll, an enzyme present in green plants, in the presence of light converts carbon dioxide and water to basic sugar, a process that is termed photosynthesis. Chlorophyll increases in lakes as the lakes become more eutrophic; thus chlorophyll measurements provide comparative data on eutrophication (Deevey and Bishop, 1942; Kozminski, 1938; Manning and Juday, 1941; Anderson 1961).

The quantity of chlorophyll has also been used as a general index of the quantity of algae present (Harvey, 1934; Riley et al., 1949; Tucker, 1949). Chlorophyll is related closely to primary production or the conversion of organic materials to living plant tissue (Manning and Juday, 1941; Ryther and Yentsch, 1957; Odum et al., 1958). Because a large quantity of algae may be present, but not growing, and conversely a small population of algae may exhibit a substantial growth rate, the quantity of algae may not be related directly to primary production. Factors such as light intensity, nutrient availability, temperature, age or viability of algal cells, and size of the cells influence the quantity of chlorophyll per unit of algae present (Odum et al., 1958).

Chlorophyll-bearing cells may be filtered from the water with membrane filters (0.45 micron pore). Filters and cells are placed in vials of acetone for extraction of the pigments and for solution of the filters (Crietz and Richards, 1955). Samples are then centrifuged to remove particulate suspended materials. The clear supernatant pigment-bearing acetone is examined on a recording spectrophotometer. Spectrums are evaluated and the quantity of chlorophyll determined as outlined by Richards with Thompson (1952).

Segments of lake bottom core samples may be analyzed microscopically to determine the diatom composition of the layered segments. To examine diatomaceous sediments in lake bed core sediments, an aliquot solids sample based on a packed volume of a selected core segment is oven-dried, suspended in equal parts of water and concentrated nitric acid, gently boiled for 45 minutes, and allowed to cool. Potassium dichromate crystals (0.1 gram) are added, the mixture cooled, washed into a centrifuge tube, and water added. The sample is washed 3 times by alternately centrifuging, decanting, and adding water. The inorganic residue is then diluted to a specific volume of water (200 ml per gram of original sample), then 2 drops of liquid household detergent are added, the sample is stirred, and 2 drops of sample are withdrawn by a large bore pipette and placed on a cover slip. The sample on the cover slip is evaporated to dryness on a hot plate. Following drying the hot plate temperature is increased to 350°F, a clean microscopic slide is placed thereon, and a large drop of Hyrax mounting media is placed on the slide. After 10 minutes, with slight cooling, the cover slip with the dried sample is inverted onto the Hyrax drop and pressed firmly into place. The slide is then examined for diatom skeletons.

To facilitate an accurate appraisal of existing biological conditions within the flowing stream, observations are made on water depth; presence of riffles and pools; stream width; flow characteristics; bank cover; presence of slime growths, attached algae, scum algae, and other aquatic plants, as well as red sludgeworm masses; and unusual physical characteristics such as silt deposits, organic sludge deposits, iron precipitates, or various waste materials from manufacturing processes.

FIELD COLLECTION CARD

Date ____________ Hour ________ Collector ______________

Field Designation ________________________________

Station Location ________________________________

Sample No. ____________________ Stream Miles ____________

Weather ____

Bottom: _____ Rock: _____ C. Gravel F. _____: C. Sand F. _____

% : _____ Sandy Loam: _____ Silt Loam: _____ Silt:

: _____ C. Clay F. _____ : _____ Organic Sludge:

Sample Location ____________________ Sample Depth __________

River: Width __________ Depth __________ Current __________

: Temp __________ DO __________ pH __________

: Phth Alk __________ Tot Alk __________ Cond __________

Sampler : Ek : Pet : Sq Ft : Qual : :

No. of Samples: : : : : :

Fish: Gear : Shocker : Dip Net : Seine : :

Sample Time : : : : :

Sample Area : : : : :

Remarks:

Chart 6. Desired items for a field biological collection card may be arranged on a 5"x7" unlined card for convenience. Cards can be punched and carried in a field notebook; they may be filed after field and laboratory use. The back side of the card may be ruled to itemize the organisms observed in the laboratory examination of the collected sample.

The investigator should ask himself three basic questions: Based on a knowledge of preferred organism habitats, what bottom fauna should I expect to find at this station? Specifically, where would I expect to find these creatures? What is the appropriate gear with which to capture them? A close search of the respective areas should be made noting and collecting qualitatively the various types of organisms. A commercial 30-mesh sieve is a most handy exploratory tool. Attached forms should be collected and preserved for later identification by scraping rocks, submerged logs, and natural debris.

Following general observations, the investigator collects appropriate quantitative samples of the various kinds of organisms present in the aquatic area. He makes certain that: (1) the sampling area selected is representative of stream conditions, and (2) the sample is representative of and contains those forms predominant in the area and encountered during the qualitative search.

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

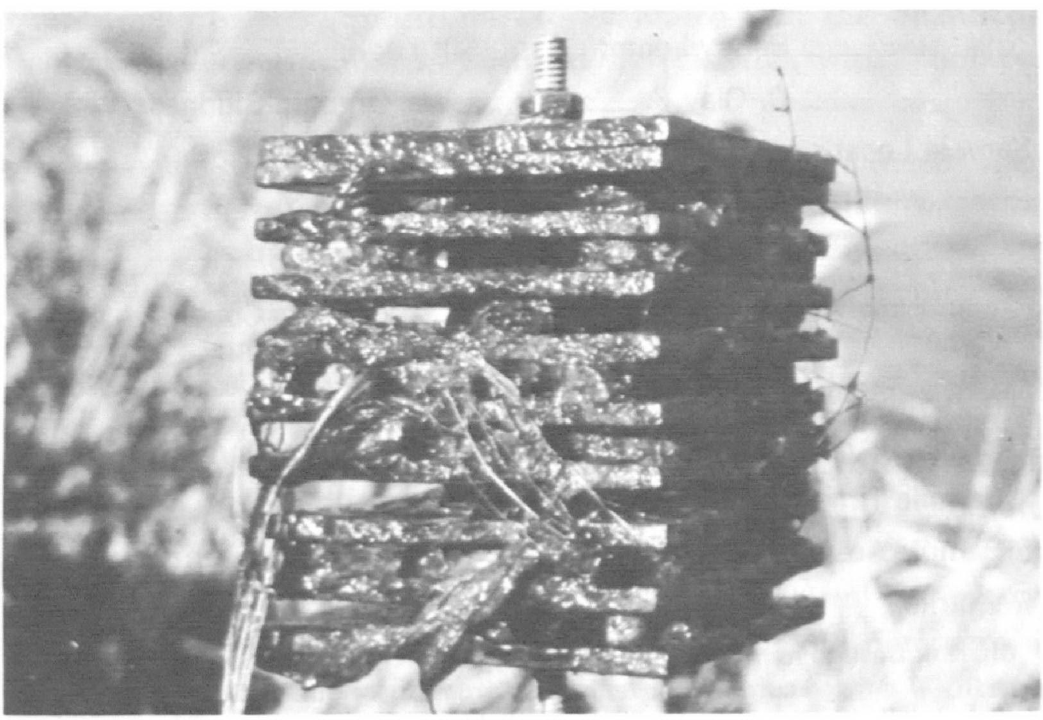

Plate 10. A multiple-plate artificial substrate colonized by aquatic organisms (Hester-Dendy type).

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 into 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 Ekman can also be mounted on a pipe for shallow stream sampling and tripped by a thrust-through rod.

The Petersen dredge (Petersen, 1911) is the most versatile stream-bed sampler for collecting bottom life. It is widely used for sampling hard bottoms such as sand, gravel, marl, clay, and similar materials. It is an iron, clam-type dredge, samples an area of 0.6 to 0.8 square foot, and weighs between 35 and 70 pounds depending on the rare use of additional weights that may be bolted to its sides. By means of a rope, the dredge is slowly lowered to the bottom to avoid disturbing and flushing away significant lighter materials. As 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. The operator controls the dredge by maintaining tension on the rope until the dredge is placed. This is helpful in sampling gravel or rubble, as the operator can determine through sound and touch the type of bottom and by carefully manipulating the dredge, can secure a better

* Ekmans are made in 8″ x 8″ and 12″ x 12″ sizes, but because of size of grabs, these are almost impossible to operate effectively on many occasions. Through long experience the authors recommend only the 6″ x 6″ size.

sample than would otherwise be possible. In streams with gravel and rubble beds that permit wading, another technique is for the investigator to place the dredge and then stand on the jaws working them into the stream bed with his weight, thus gradually closing them. When the dredge is surfaced, careful and rapid placement and subsequent discharge, endwise, of the dredge into a bucket whose lip is placed at the water's surface prevents loss of material.

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, and the sample is mixed into a slurry with the slurry finally being 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 retained in the sieve. The organisms and coarser debris are then removed from the sieve and are preserved. 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 square-foot bottom sampler, originally described by Surber (1936), is widely used. It consists of two 1-foot-square brass frames hinged together at right angles; one frame supports the net which is held extended downstream by current velocities, 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. In stagnant or in slowly moving water, it often is not practical to employ this square-foot sampler.

Hess (1941) described another form of circular square-foot sampler suitable for gravel and rubble stream bottoms. It consists of a cylinder 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 with the dislodged organisms being captured in a downstream net in much the same manner as in the Surber sampler.

Needham and Usinger (1956) studied the variability in the organisms of a single riffle in Prosser Creek, California, as collected 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 current 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 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 commonly 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

Plate 11. Biological sampling equipment. From left, Kemmerer sampler, Ekman dredge, U.S. Standard No. 30 sieve, washing bucket, and Petersen dredge.

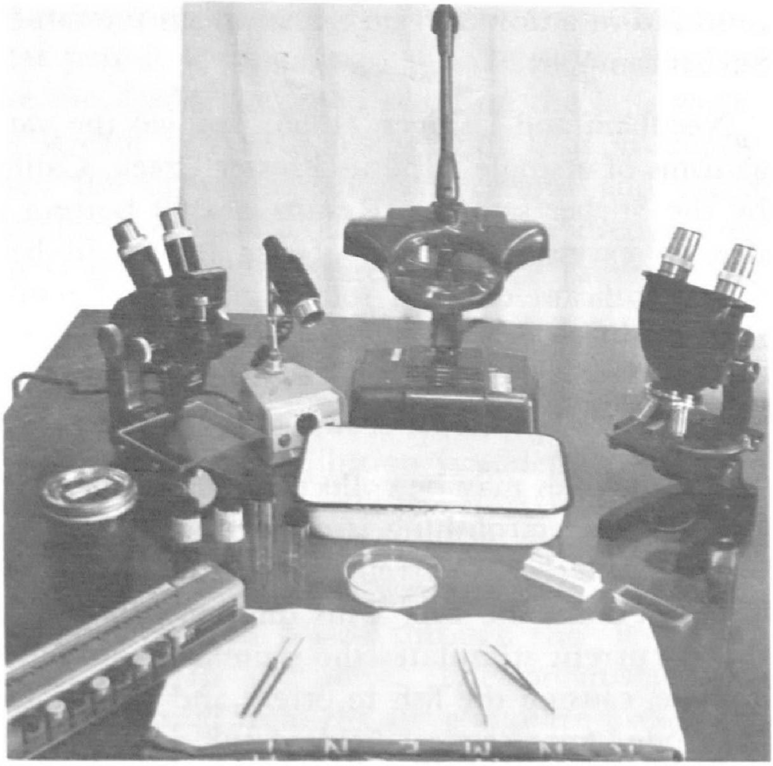

Plate 12. Sorting, enumeration, and identification equipment used in analyzing benthic samples

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.

Excluding regular plankton collections, a biologist should always collect his own samples. Much of the value of an experienced biologist lies in his observation of stream conditions in the field and his ability to recognize signs of change within the growth patterns of those organisms that are subject to adversities within the environment.

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.

Routinely, biological stations should be located close to or at those sampling stations selected for chemical and microbiological analyses to assure correlation of findings among the varied disciplines involved with comprehensive surveys. Samples for chemical analyses often are taken from road bridges that cross the stream; however, because these structures sometimes create an atypical habitat within the stream environment, samples of bottom dwelling organisms should be taken from an area of the stream uninfluenced by man-made structures.

Sampling stations should be located upstream and downstream from suspected pollution sources and from major tributary streams, and at appropriate intervals throughout the reach under investigation. When water in tributary streams is found to be polluted, these streams should be similarly investigated. Because the biologist seeks to determine the damage pollution causes to aquatic life, he must compare observations for each station with his findings from an unpolluted area. Thus, he may choose a number of stations in addition to those selected for chemical or bacteriological sampling.

A lake or reservoir is the base-level receiving basin of its inflowing waters. It is thus greatly influenced by influent streams, which must be critically studied to measure the input to the water body. Sampling stations should be established on major influent steams, at points where they are not influenced by the back water from the lake, 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 often 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 five points across the stream (mid and 2 quarter points and at near zero water level with banks) ; a minimum of 3 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.

Likewise, the receiving waters from the lake or reservoir should be studied in the same manner as the influent streams. The effluent of a natural lake will usually give a better than average 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 often 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. Maximum 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 to 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 in the fore-bay area or discharge, constrictions within the 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.

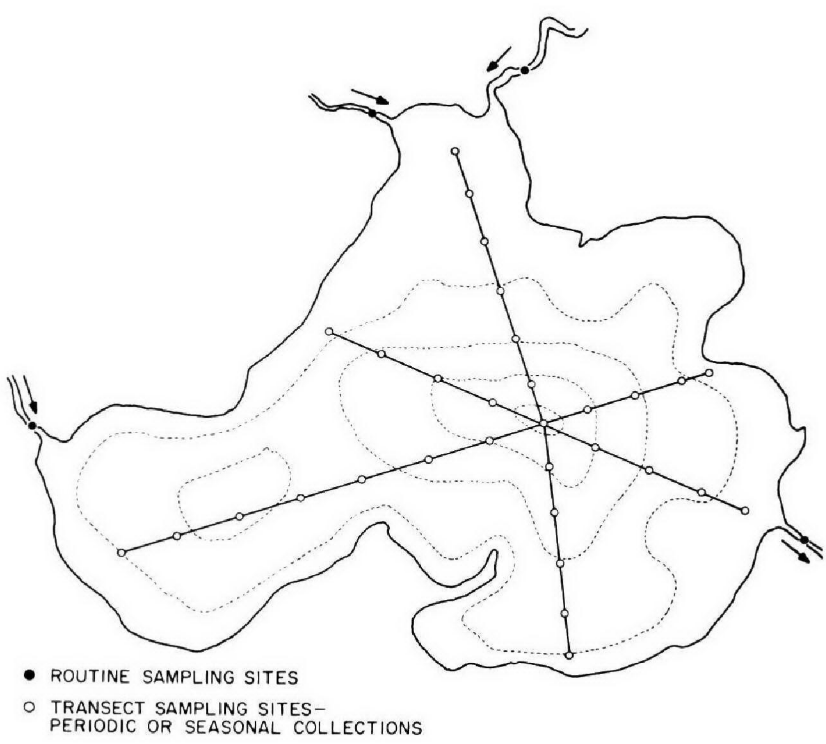

Figure 7. Diagram of a natural lake basin showing suggested sampling sites. Inlet and outlet samples give valuable data. Samples taken from points on transection lines on a periodic or seasonal basis are valuable in determining vertical water characteristics and the benthic standing crop.

When?

The periodicity with which samples are collected during a particular season will depend on the time, weather conditions 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 done during maximum vegetation growth, usually in midsummer. Bottom fauna should be sampled during the annaul seasons; the standing crop will be highest, however, during the fall and winter periods when insect emergence is minimal and one of the sampling dates should reflect this period.

Data Analyses and Interpretation

Data analyses and interpretation must be preceded by logical, systematic organization. Seasonal studies should be examined closely for seasonal trends at the same location. Understandable, accurate graphs that depict trends among study sectors should then be developed. It may be necessary to graph a number of facets of the investigation to determine the most suitable way of analyzing and presenting the data. Narrative description should

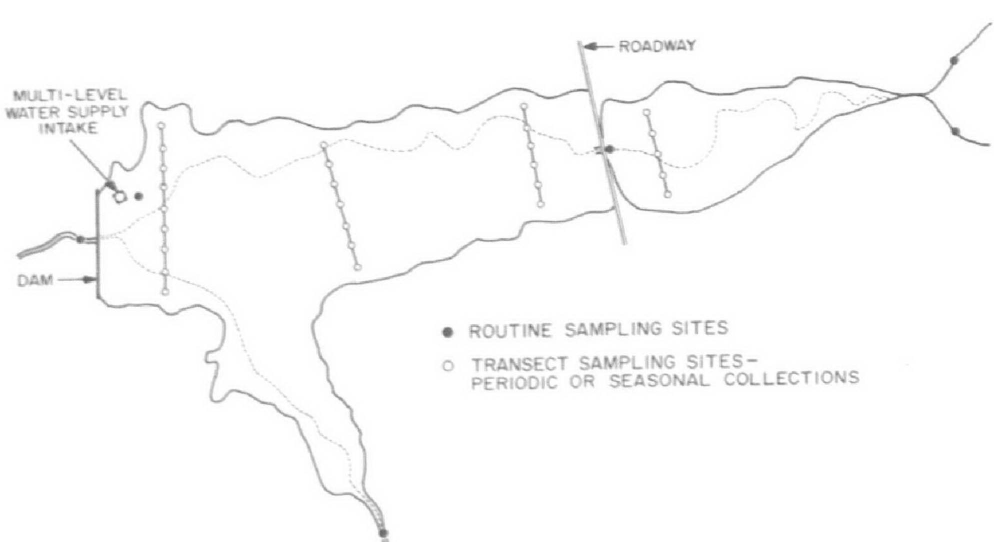

Figure 8. Diagram of a long, narrow, shallow water reservoir showing suggested sampling stations.

begin only after the data have been analyzed sufficiently to permit their arrangement into meaningful graphs.

The "classical" benthic organism responses to organic wastes in the flowing stream have been detailed frequently in the literature (Hynes, 1960; Biglane and Lafleur, 1954; Hirsch, 1958; Dymond and Delaporte, 1952; Pentelow, 1949; Van Horn, 1949, 1952; Bartsch and Ingram, 1959; and Gaufin, 1958). Benthic organisms are directly subjected to adverse conditions of existence in their preferred habitat and their general inability to move great distances by self-motion. Different types of organisms respond in various ways to changes that may occur in their environments. Some species cannot tolerate any appreciable water quality changes, whereas others can tolerate a wide range of water quality, and some very tolerant ones are able to live and multiply under extremely adverse environmental conditions. Generally, a natural, unpolluted stream reach will support many different kinds of organisms but relatively few individuals of a given species because of predation and competition for food and living space. The converse most often exists in a stream reach polluted with organic wastes. In such a reach, most predators are eliminated by water quality or substrate changes, living space presents no problem because remaining organisms must be well adapted to live in organic sludge, and food is seemingly inexhaustible. Sludgeworm populations have, on occasion, been calculated to exceed 50,000 pounds per acre of stream bottom.

A toxic substance will eliminate aquatic biota until dilution, dissipation, precipitation, and volatilization reduce the concentration below the toxic threshold. Downstream from the source of the toxic substance there is no sharp increase in certain organisms, such as occurs with organic wastes; rather, there is an abrupt decline in both the number of species and the total population. Gradually the "normal" stream inhabitants reappear at some point farther downstream. Since severely toxic wastes eliminate all animal life, the recovery of an area so affected depends upon many factors, including the proximity of similar habitats for seeding, the migratory tendencies and ranges of the animals, and the number of generations per year.

Inert silts affect bottom-associated animals in a manner similar to toxic wastes, but usually not so severely. Following silt pollution the number of bottom-associated-organism species, as well as the total organism population generally decreases. The algal population often is much reduced. Because the food supply is not increased by inert silt pollution, organism populations return gradually to the levels encountered in unpolluted stream reaches when the silt load is dissipated. On occasions the physical effects of inert inorganic solids can reduce animal populations by their "ball-mill" grinding action more severely than do organic solids by settling.

Heat is a pollutant that alters the chemical properties of water, as well as directly affects the biota. Thermal pollution can cause fish deaths, alter drastically stream-bed-associated-organism populations, and stimulate biological slimes and nuisance organism growths.

Lakes and other standing waters do not usually support the variety of benthos found in streams. As with streams, however, organic pollution eliminates many benthic forms and results in population increases among the more tolerant varieties (Surber, 1953). Surber (1957) stated, "A survey of the lake reports showed that an abundance of tubificids in excess of 100 per square foot apparently truly represented polluted habitats." Changes in the benthic population structure are especially evident in the alluvial fans produced in lakes by polluted influent streams. Along with changes in the benthos, the nutrients contributed by organic pollution may stimulate aquatic growths that will have a severe impact on recreational use of the water. Resultant algal blooms concomitant with recycling and reuse of nutrients within the lake basin contribute to and hasten inevitable eutrophication.

Reporting the Results

A report represents the end result of all the efforts put forth to accomplish the study. A poor report frequently negates a meticulous field program while a good report does much to enhance the study. The report should be equally 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 actions 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, representatives of varied vested interests who may be for or against the conclusions and recommendations, and the public.

In all instances the report adds to the existing record, often through "endless" time. Ideally field notes, observations, and laboratory data should be included in the report for a permanent record. Such information will always provide 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 report objectives; however, most reports of water studies will contain the following major items:

- Introduction
- Summary and conclusions
- Recommendations
- Acknowledgement
- Historical background of study
- Physical description of study area
  - Geography
  - Topography
  - Climate
  - Hydrology
- Use of water resources
  - Water resources conservation program
  - Municipal and industrial needs
  - Navigation
  - Irrigation
  - Fish and wildlife
  - Flood control
  - Recreation
- Survey methods
  - Field investigation
  - Laboratory operations
  - Results of study (data presentation)
  - Discussion
  - Bibliography
  - Appendicies

The discussion should evaluate the data. There is opportunity in this section for aggressive and imaginative thinking. The analyses 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.

Too often the vital message that biology can bring in defining pollution problems is lost in the vague generalities and difficult to understand language used in the biologist's presentation. Often basic facts become mired in technical explanation. Today's biologist must travel more than halfway if he is to sell the products of his science to the public. Good, concise, assertive reporting supported by uncluttered, pertinent graphical material pleases and stimulates the reader to greater comprehension of the findings of fact. The biologist has a challenge to present information that is understandable, meaningful, and helpful to associated disciplines, to administrators, and to the general public who are the financial supporters as well as the benefactors of a pollution abatement program.

Recently several methods have been proposed for the presentation of biological stream data. Beck (1954, 1955) grouped benthic organisms into five classes based on their sensitivity to environmental change and proposed a numerical biotic index that represented a summation of those species that tolerate no appreciable pollution and those that tolerate only a moderate amount. Beak (1963) modified Beck's reporting method to include three groups in which all occurring species are placed: those very tolerant of pollution, those occurring in both polluted and unpolluted situations, and those intolerant of pollution. Points are arbitrarily assigned to each group, and a biological score results from adding the points at a given station.

Wurtz (1955) developed for each station a four-column histogram in which the columns represent basic life forms: burrow-

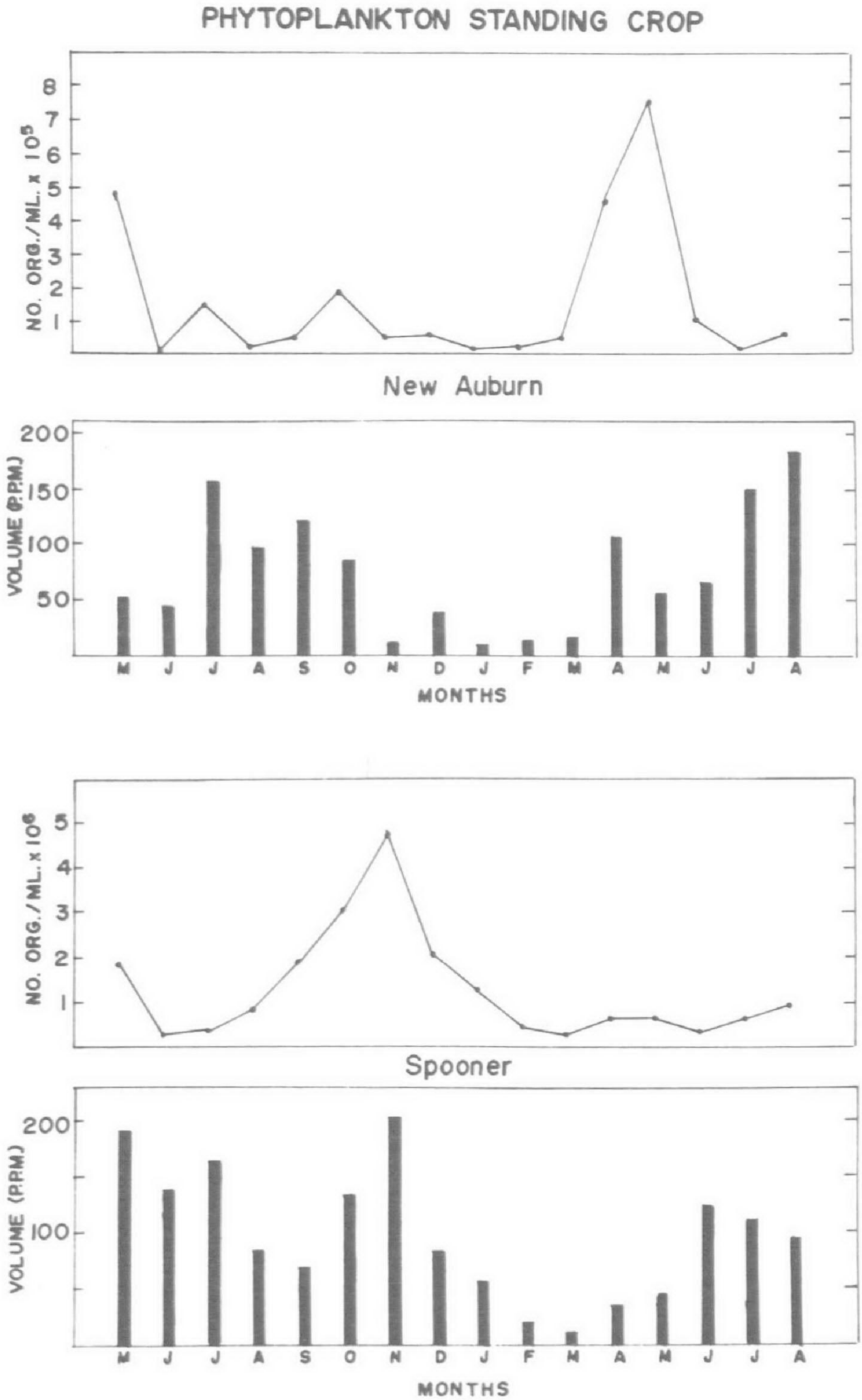

Figure 9. Phytoplankton standing crops in Wisconsin stabilization ponds May 1957 to August 1958, reported as No./ml and as ppm by volume. Note the dissimilar trends of the two approaches.

ing organisms, sessile organisms, foraging organisms, and pelagic organisms. Columns are plotted as a frequency index in which the total number of species found at any station represents a frequency of 100 percent for that station.

Beak et al. (1959) used bivariate control charts to describe changes in benthos adjacent to the site of a large chemical plant. Burlington (1962) statistically calculated a "coefficient of similarity" among stations; for each specific group of organisms, he used "prominence values" that take into account both density and frequency of observation. Patrick and Strawbridge (1963) stated that it is relatively easy to determine the presence of large amounts of pollution, but that the determination of definite but borderline deterioration of water quality is in some cases difficult. They presented a mathematical method whereby the limits in variation of natural populations, especially diatoms, can be defined.

Ingram and Bartsch (1960) pleaded for the use of common, understandable terms in presentations on biology. They pointed out the value of photographs to depict unusual environmental conditions and showed a number of different graphical presentations used in investigational reports.

Serious thought should be given the methods and techniques of reporting data to ensure that the final report meets the needs of the study and provides answers to questions originally responsible for the initiation of the study. Often less thought and consideration are given to reporting data than to collecting and analyzing the data. Each is equally important.

The first step in building a report is to arrange the data in a systematic and logical manner. From the data, simple understandable graphs that depict general trends of biological activity should be developed. Lastly, the narrative is molded to the graphical and tabular material.

Statements in the narrative report should be related to point sources of pollution. What do the biological findings indicate the water quality to be in a given reach of water? If some facet of the ecosystem indicates a degraded water quality, how severely is it degraded? What is the cause of the degradation? Where is the source located in relation to the reach degraded? It is not enough to describe findings of fact related to biological activity; these findings of fact must be interpreted to relate the biotic condition of the study area, the problems involved, the cause of the problems, and suggested measures that would alleviate the problems.

The narrative report should be built around the graphs, tabular material, and photographs or drawings and the trends they indicate; it should interpret the trends and relate them to pollution sources. The writer should strive constantly to answer the basic questions what, how, when, where, and why. The ABC's of reporting data or information caution the writer to be:

Accurate
Brief
Consistent
Definite
Effective
Factual
Grammatical
Hostile to indefinite, nondescriptive terminology.

Specific Studies

Specific studies that have been made on lakes, reservoirs, and streams are presented to exemplify the type of information that may be collected in field studies and the use that is made of these data in formulating an interpretation of water quality. Several graphic presentations are included to illustrate methods of selling the product of biological investigations.

Geist Reservoir near Indianapolis, Indiana is 7.5 miles long; it has a surface area of 1,800 acres, a shoreline of 35 miles, and stores 6.9 billion gallons of water. It has a maximum depth of 30 feet and is divided into three unequal basins by two causeways. The watershed draining to the impoundment is 215 square miles; the surrounding land is used primarily for farming and is gently rolling to flat "Wisconsin" glacial-drift. During the spring runoff period (March through May), the average turbidity was 155 units for the influent and upper causeway stations (Figure 10). A large portion of the particulate matter settled out in the reservoir; the mean turbidity was 30 units at the dam station. During the spring period, maximum turbidity readings were 950 units at the inlet and upper causeway stations and 75 units at the dam station. The decrease in turbidity with both time and distance from the influent is shown in Figure 10.

During the spring, Geist Reservoir supported 458 pounds per acre (wet weight) of phytoplankton; and in summer, 960 pounds per acre. The fall and winter standing crops were (on the average) very similar to the spring phytoplankton standing crop, namely, 484 and 213 pounds per acre respectively. Volumetrically, the lower causeway station was richest in phytoplankton with the exception of the fall period (Figure 11). Phytoplankton volume was least at the inlet station and greatest in the shallower pools formed by the two causeways. In these areas turbidities are reduced and nutrients are readily available.

The biology of the Menominee River was investigated in relation to organic wastes arising from sulfite and groundwood pulp and paper mill wastes discharged at Niagara, Wisconsin (Figure 12). Clean water associated organisms such as stonefly, caddisfly and mayfly larvae that are sensitive to organic wastes were reduced for a distance of 22 stream miles downstream from the source of these wastes. Tolerant and

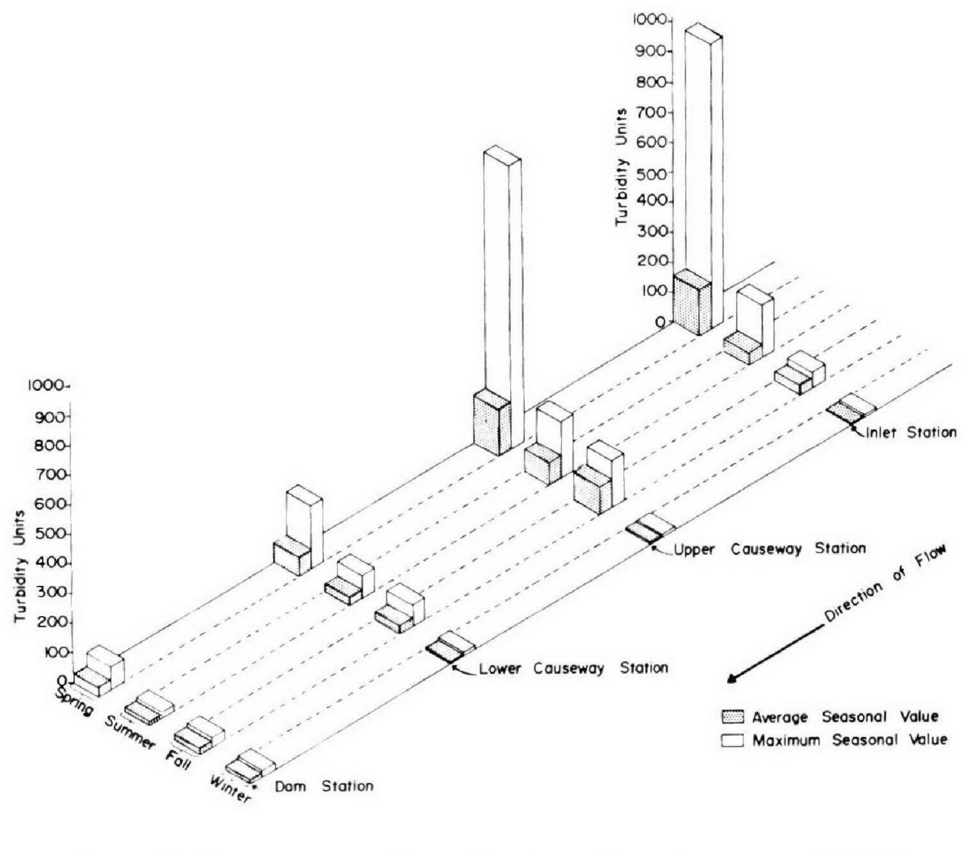

Figure 10. Seasonal turbidity unit values, Geist Reservoir, 1963-1964.

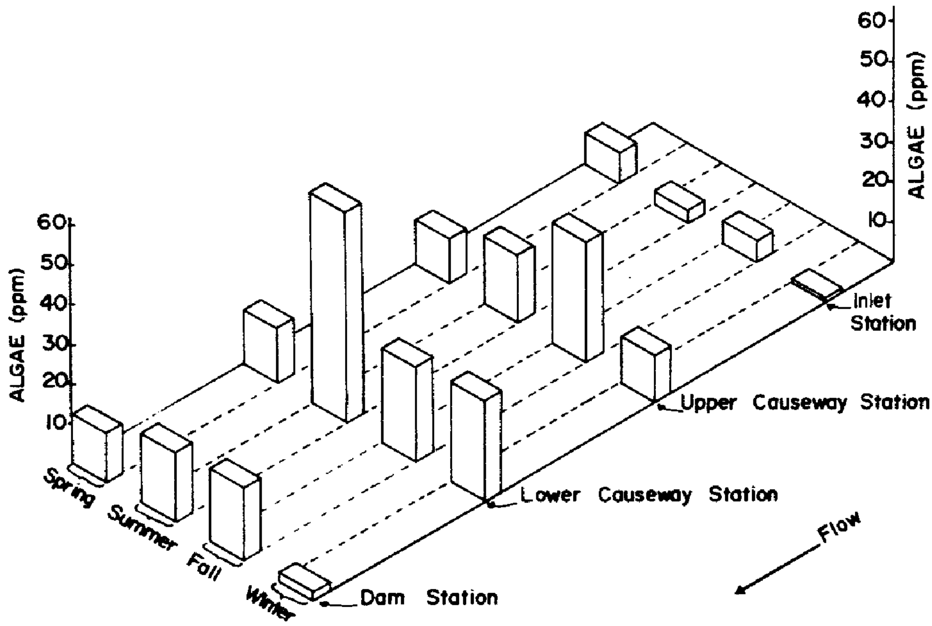

Figure 11. Concentration of phytoplankton (ppm), Geist Reservoir, 1963-64.

very tolerant organisms such as many different kinds of midge larvae and sludgeworms were increased markedly in the downstream reach. Stream recovery was noted some 25 stream miles downstream from the waste source. In the reach just downstream from the waste source, the bed was coated with slime bacteria and wood fibers, and small balls of sludgeworms entwined themselves in this mass. Fish food and fish spawning areas had been destroyed; the reach was degraded severely by pollution. Farther downstream, where settleable solids were reduced and nutrients could exert a greater impact on aquatic growths, algal streamers reached lengths of 15 to 20 feet. The discharge of wood chips from pulp mill operations interferes greatly with the normal use of the bottom substratum by bottom associated organisms, fish, and other aquatic life. These chips, that eventually become water-logged and sink, destroy natural homes for bottom associated organisms, and also serve as a substrate for the development of slime bacteria which mat together masses of wood chips, fibers, and other debris. The stream bed is blanketed with these materials and fish spawning areas are destroyed. As the slime mats become more extensive they collect gasses of decomposition which, on occasions, bring a mass of such material to the water surface. Here it breaks up, disperses, and often is carried to new locations downstream to decompose. Such solids as fibers, slimes, and floating sludge patches degrade the appearance of the stream and reduce its esthetic appeal for general recreational use. This, then, is the effect of one type of organic waste upon the aquatic biota in one type of stream environment.

What are the effects of wastes in the reservoir habitat? Bottom samples were collected from Little Quinnesec Reservoir upstream from Niagara, Wisconsin, and from Sturgeon Falls Reservoir downstream from the waste source (Figure 13). The lake bed associated organism population found in the upstream reservoir was considered descriptive for a clean water environment; a great diversity of organisms was found. In the Sturgeon Falls Reservoir, sensitive organisms were eliminated and the sludgeworm population was increased tremendously, indicating degraded benthic conditions (Figure 13). The water was turbid; sludge and wood chips were found in areas of reduced current. Wood fibers and limited quantities of slime bacteria were present.

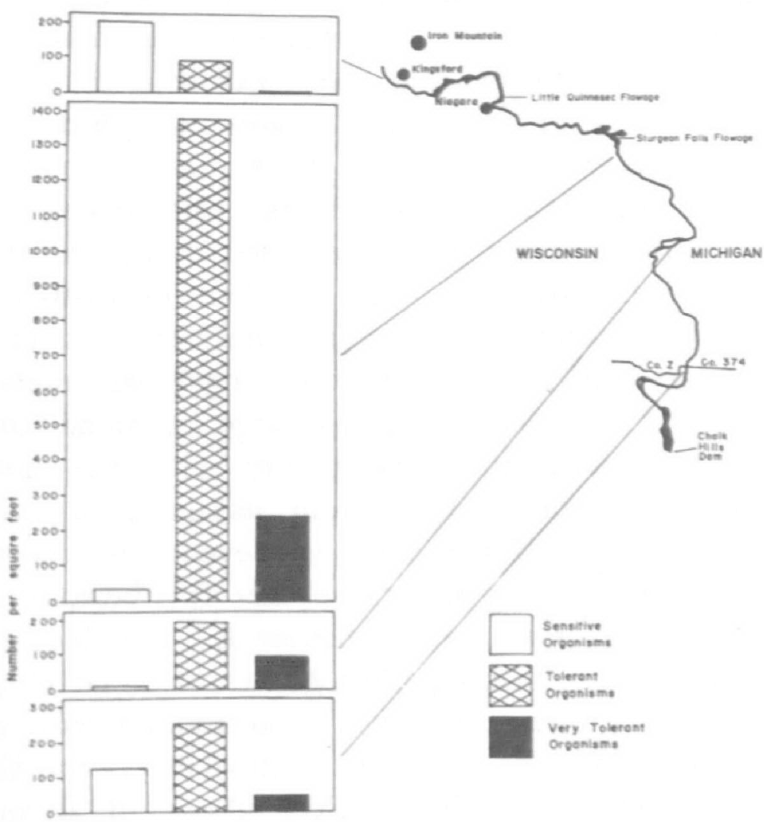

Figure 12. Bottom associated organism populations in upper Menominee River near Niagara, Wisconsin, August 1963.

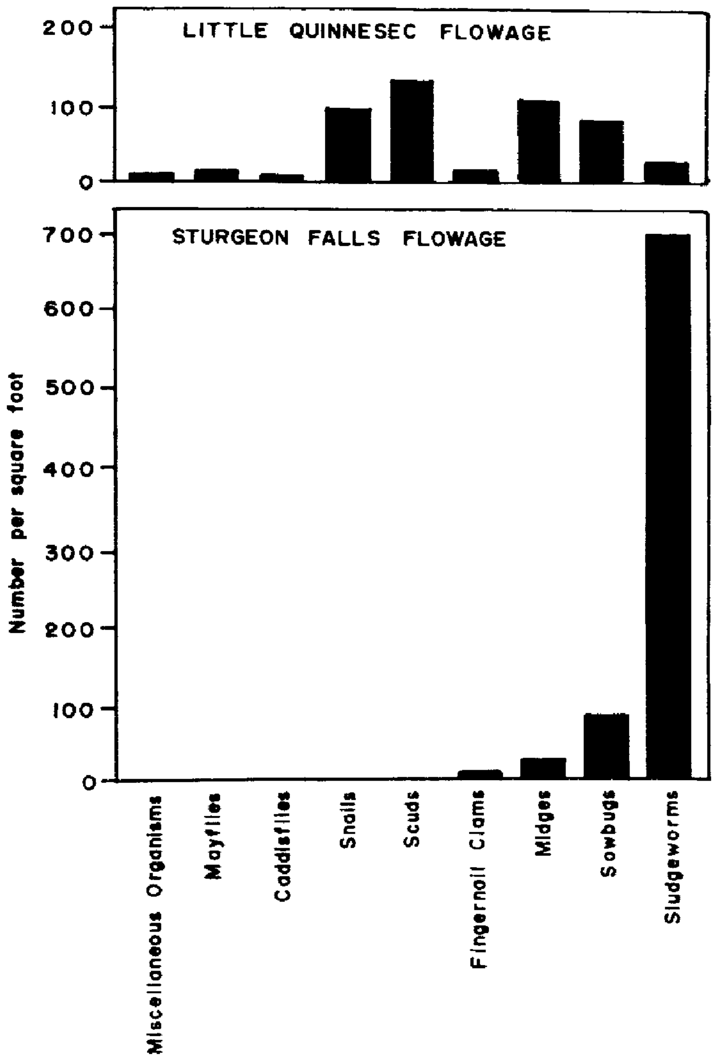

Figure 13. Benthic population in Upper Menominee River Reservoirs, August 1963

The Chattooga River near Summerville, Georgia received untreated sewage, and textile and other industrial wastes. The stream bed was excellent, however, for the production of many associated organisms; it was composed of rock and coarse gravel with sand occasionally intermingled. The upstream biological station was in an area that supported 20 species of benthos, predominantly clean water associated immature insects (Figure 14). Because of predation and competition for available food among these insects in this tree-lined stream, the total population was less than 50 organisms per square foot of stream bed. Five miles downstream, alkaline textile wastes increased the stream's pH to 9.7 and was toxic to the benthos. Benthic organisms were eliminated. A layer of black sludge composed of the settlings from raw sewage and industrial wastes covered the stream bed. Because of the wastes' toxic properties, sludgeworms could not develop to begin stabilizing the sludge. Slight improvement only was noted three miles downstream. Five miles downstream a filamentous blue-green alga was attached to the rocks and the only benthic organisms encountered were sludgeworms; these had reached a density of 680 per square foot. The toxic properties of the environment had become reduced sufficiently at this point to permit sludgeworms to develop and consume the organic food. Clean water associated insect species did not occur in 50 miles of stream downstream from the intermingled toxic and organic wastes. When insect species did occur, they were found sparingly for another 5 miles. Accompanying a decrease in total numbers of organisms and an increase in species present, these immature insects heralded the beginning of stream recovery. Two additional stations located at 5 mile intervals downstream were in areas in which the water quality was further improved, although populations were higher than at the farthest upstream station which reflected a carry-over of the enrichment from upstream organic wastes.

The Bear River near Lewiston, Utah was sampled in a 47.7 mile reach that encompassed a variety of habitats (Figure 15). The

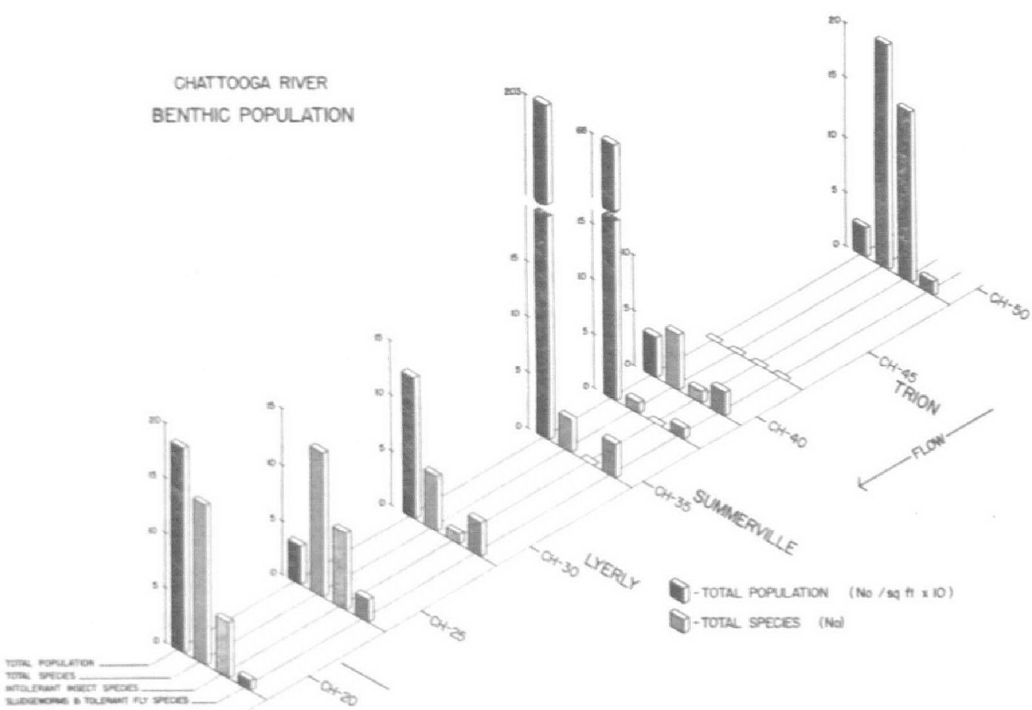

Figure 14. Bottom associated organism population in Chattooga River near Summerville, Georgia, August 1962.

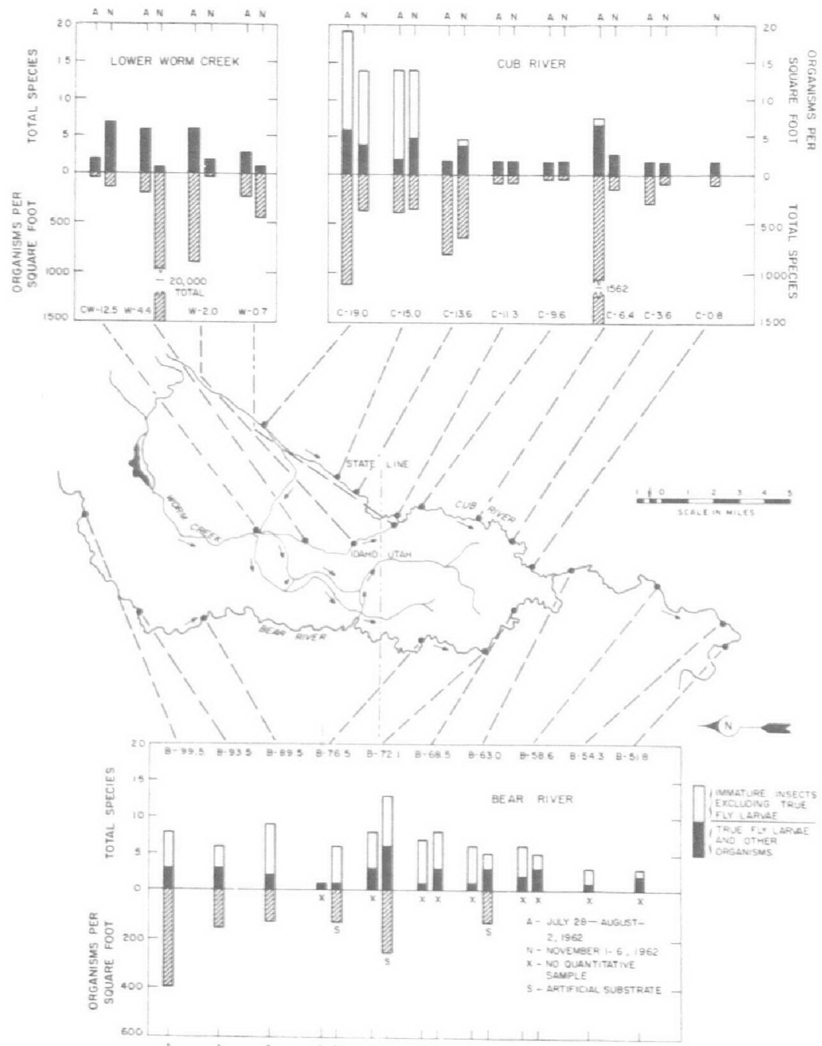

Figure 15. Benthos Data — Bear River System, 1962.

two upstream stations, located in a series of riffles unaffected by man's activities, supported several species of mayflies, caddisflies, and other clean water associated fishfood organisms that numbered 400 per square foot of stream bed. Downstream from station B 89.5 the bed had become covered with silt and sand. It has been estimated that between 1910 and 1950 the natural gravels, clays, and silts on the stream bed were covered with five to six feet of sand from gullies developed as a result of improper agricultural practices and poor land management. This change in the physical environment had a dramatic effect on the aquatic biota. Siltation reduces both the numbers and kinds of organisms that a given stream reach will support. This stream was devoid of most aquatic vegetation. Organisms were associated only with rocks around bridge abutments and roadways that sand had not covered. Careful search revealed six species of mayflies and caddisflies making their homes on rocks.

Artificial substrates of the Hester Dendy type (Hester and Dendy, 1962) were placed in the silt-laden reach of the Bear River for 19 days; these collected a maximum 250 organisms per square foot indicating that a more suitable stream bed would be much more productive of fishfood organisms. Drifting organisms principally from upstream riffles and occasional rocks were the source of the biota inhabiting the artificial substrates. Drifting organisms supply a limited fishfood source also. Stomach analyses of captured green sunfish, carp, suckers, yellow perch, bullheads, and bass showed that fish in this reach were feeding primarily on caddisfly larvae, mayfly naiads, and midge larvae; some of the stomachs contained up to 15 immature caddisflies and mayflies. The fish population within the reach was limited primarily by the available food supply that originated in an upstream productive zone.

Concurrent with the Bear River study, 18 miles of the Cub River were sampled (Figure 15). At river miles C–19.0 and C–15.0, large numbers of intolerant species such as immature stonefly naiads, mayfly naiads, caddisfly larvae and aquatic beetle larvae were found; relatively few individuals were represented in any one species. Such an organism assemblage is representative of an unpolluted aquatic environment. During the fall survey, trout eggs were found in this reach. Downstream, wastes from a canning plant packaging peas, green beans, and sauerkraut, were discharged. Downstream from these wastes, pollution tolerant organisms predominated. Intolerant species were eliminated, and the numbers of the more tolerant forms had increased greatly. The stream bed was covered with sludge, and mats of blue-green algae (*Oscillatoria sp.*, *Lyngbya sp.*, and *Spirulina sp.*) were growing on the sludge. The filamentous bacterium, *Sphaerotilus natans*, was observed on sticks and rocks in the stream. The Cub River was degraded seriously. In the course of a few miles it had changed from a trout stream to one that supported only the most tolerant benthic organisms. The stream did not recover.

Wastes from a plant processing sugar beets were discharged to Lower Worm Creek in Idaho during October and November (Figure 15). Resulting sludgeworm populations reached 20,000 per

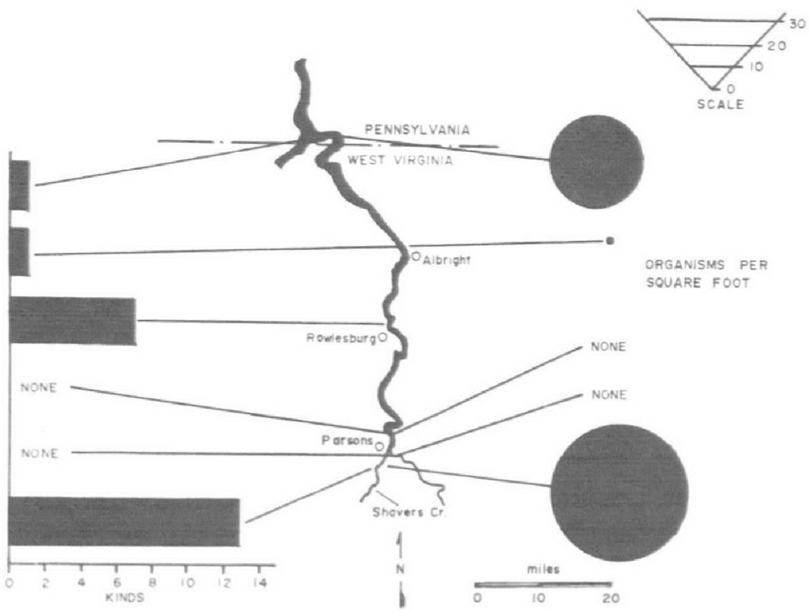

Figure 16. Bottom associated organism data, Cheat River near Albright, West Virginia, 1963.

square foot. Sludge beds on the stream bottom consisting of beet tops and beet pulp reached depths of 3 feet or more. Oxygen demand by the decomposing sludge restricted the sludgeworms to the canal banks where limited oxygen was present. The biota of Worm Creek, consisting of such pollution tolerant kinds of organisms as sludgeworms, leeches, and *Physa* snails, remained essentially unchanged at Worm Creek's confluence with the Cub River.

The Cheat River in West Virginia is formed by Shavers Fork and Black Water River upstream from Parsons (Figure 16). Thirteen kinds of benthic organisms were found in Shavers Fork including those commonly found only in clean, healthy streams. Black Water River, on the other hand, receives pollution from acid mine drainage; it contained no benthic organisms and the rocks were coated with red silt, iron flocks and bacterial slimes, and an alga tolerant of acid waters. Downstream from Parsons, West Virginia, acid pollution was so severe that no benthos were found. Some stream recovery was shown by the bottom associated organism population at Rowlesburg, but additional acid discharges severely degraded bottom conditions in the Albright, West Virginia reach so that only an occasional benthic organism could exist in the stream. Similar conditions persisted generally to the confluence of the Cheat River with the Monongahela River.

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5

Nutrients And Biological Growths

Introduction

EUTROPHICATION is a term that is used increasingly to mean enrichment of waters by nutrients through either man-created or natural means. Natural enrichment produces a rate of lake aging that may be measured only by the clock of geologic time. Additional fertilization will accelerate this rate of lake aging, making changes in water quality noticeable within a few decades or even less. It is obvious, for example, that growing cities and expanding industries are pouring nutrients into the nation's waterways at an accelerating rate; aquatic weed and algal nuisances have increased in areas where before they did not exist and have become magnified in areas where before there was a tolerable growth.

The scope of accelerated eutrophication or water enrichment is broad. The most perceptible characteristics to the layman on the scene are those readily noted through visual inspection including a change in water color and an increase in turbidity, nuisance growths of small suspended plants or algal scums, developing areas of rooted water plants, and odors associated with decaying dead vegetation and possibly fish. More subtle changes can be found by the investigator as indicated by decreased light penetration; decreased dissolved oxygen in deeper waters; increased nitrogen and phosphorus concentrations especially in the deeper waters; significant changes in the algal population, in the kinds and numbers of bottom dwelling organisms, and in the fishery; and increased rooted aquatic weed beds.

Present knowledge indicates that the fertilizing elements contributing most to lake eutrophication are nitrogen and phophorus. Iron and certain "trace" elements are also important. Vitamins such as B_{12}, many micronutrients, and extracellular products from existing plant populations play a role in the developing aquatic plant growths but this role is not presently well understood. Sewage and sewage effluents contain a generous amount of those nutrients necessary for abundant algal development.

It is well documented that many lakes throughout the country, and the world, have been fertile reservoirs for algal development for many years and have been called eutrophic. Notable among these for their algal growths in the United States are Lake Zoar in Connecticut, Lake Sebatiscook in Maine, the Madison Lakes in Wisconsin, Lake Erie, the Detroit Lakes in Minnesota, Green Lake and Lake Washington in Washington, and Klamath Lake in Oregon.

As nutrient concentrations increase the numbers of algal cells increase. Nuisance conditions occur such as surface scums and algal-littered beaches. The water may become foul smelling. Filter-clogging problems may occur at municipal water treatment installations. Filamentous algae, especially *Cladophora*, grow profusely on any suitable subsurface; these can cause nuisances when they break loose and wash ashore to form windrows of stinking vegetation. The abnormal acceleration of a process that is considered as normal often is not in the best interests of man.

To properly assess a nutrient problem, consideration should be given to all of those sources that may contribute nutrients to the watercourse. These sources could include sewage, sewage effluents, industrial wastes, land drainage, applied fertilizers, precipitation, urban runoff, soils, and nutrients released from bottom sediments and from decomposing plankton. Transient waterfowl, falling tree leaves, and ground water may contribute important additions to the nutrient budget. Flow measurements are paramount in a study to quantitatively assess the respective amounts contributed by these various sources during different seasons and at different flow characteristics. In the receiving lake or stream the quantity of nutrients contained by the standing crops of algae, aquatic vascular plants, fish, and other aquatic organisms are important considerations. A knowledge of those nutrients that are harvested annually through the fish catch, or that may be removed from the system through the emergence of insects will contribute to an understanding of the nutrient budget.

For comparative purposes it is valuable to know nutrient concentrations that have been found in various lakes and streams, the loadings to specific lakes under varying situations, and the retention in lakes and ponds. The interaction of specific chemical components in water, prescribed fertilizer application rates to land and to water, minimal nutrient values required for algal blooms, vitamins required, other limiting factors, and the intercellular nitrogen and phosphorus concentrations are likewise important. Usually, it is necessary to determine that portion of the nutritive input attributable to man-made or man-induced pollution that may be corrected as opposed to that input that is natural in origin, and therefore, usually not correctable. A nutrient budget is used to determine the annual input to a system, the annual outflow, and that which is retained within the water mass to recycle with the biomass or become combined with the solidified bottom sediments.

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.

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.

The four principal sources of nitrogen today are the atmosphere, coal, natural nitrates, and organic materials. Since the 1920's the chemical industry, by nitrogen fixation, has supplied the major part of the world's nitrogen requirements. The only commercially important large nitrate deposits in the world are in Chile, in an area 10 to 50 miles wide and 450 miles long between the Coast Range and the Andes Mountains in northern Chile.

The mass of the atmosphere has been estimated at more than 5 quadrillion tons containing about 4 quadrillion tons of nitrogen, or about 148,000 tons for each acre of land area. Each day, lightning fixes about 60,000 tons of nitrogen which reaches the earth in the form of nitric or nitrous acids; however, most of this tonnage falls on nonagricultural areas. The quantity of nitrogen in coal ranges from less than 1 to 3 percent (Anon. 1965).

Phosphate rock have been reported in 23 states including Arkansas, Florida, Tennessee, Idaho, Montana, Utah, and Wyoming (Anon. 1965). Of the 19.8 million long tons of phosphate rock produced in the United States in 1963, 74 percent came from Florida, 14 percent from the Western states and 12 percent from Tennessee.

SEWAGE

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 (P) 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 the Madison, Wisconsin 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 (P). By diverting its treated sewage effluent around downstream 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). Following diversion, in the receiving stream, long streamers of filamentous green algae (*Stigeoclonium* and *Rhizoclonium*), some of which were estimated to be 50 feet in length, were attached to bottom materials at numerous locations. *Oscillatoria* covered the bottom in the upper area. Severe stream degradation following diversion was indicated by the community of stream biota.

Engelbrecht and Morgan (1959) found that the mean orthophosphate concentration among 3 trickling filter sewage treatment plant effluents and 1 activated sludge plant effluent in Illinois in 1956 ranged from 5.1 to 10.6 mg/l P and the annual per capita contributions from 1.5 to 3.9 pounds. In addition, the maximum inorganic condensed P concentration ranged from 0.4 to 0.9 mg/l and the annual per capita contribution from 0.3 to 3.6 pounds.

McGauhey et al. (1963) stipulated the unit design factors suggested for domestic wastes in the Lake Tahoe area as follows:

Average sewage flow, gallons per capita per day:	
Residential and commercial areas	90
Recreational areas	30
BOD, mg/l	250
Phosphate, mg/l P	8
Total Nitrogen, mg/l N	45

Bush and Mulford (1954) report the nitrogen and phosphorus range of domestic sewage for 15 California communities as 20 to 40 mg/l N and 5.3 to 10.6 mg/l P. The annual per capita contribution ranged from 6 to 12 pounds N and 2 to 4 pounds P. Mackenthun (1965) cites Metzler et al. (1958) who reported the annual per capita nitrogen and phosphorus contributions at Chanute, Kansas, as 6 pounds N and 2.3 pounds P.

Analysis of samples of domestic sewage from communities in Minnesota, with populations varying from 1,200 to 940,000, showed that the raw sewage of these communities contained 1.5 to 3.7 grams, with a median of 2.3 grams of phosphorus per capita per day; 1.9 pounds per year (Owen, 1953).

Stumm and Morgan (1962) state that the P-content of domestic sewage is about 3 to 4 times what it was before the advent of synthetic detergents, and it is not unlikely that the P-content of sewage may continue to rise. Since the ability to assimilate elementary nitrogen by certain blue-green algae has been demonstrated to be of importance in fresh water, phosphorus is a key element in the fertilization of natural bodies of water. If phosphorus (as P) is the predominant limiting factor, 1 mg of phosphate (as P) released to the surface water in one single pass of the phosphorus cycle is capable of stimulating the production of about 75 mg of organic material. Oswald (1960) gives the elementary chemical composition of an average domestic sewage as 61.3 mg/l total nitrogen (N) and 10.7 mg/l phosphorus.

Van Vuran (1948) states that the average human inhabitant of a European city excretes 107 pounds per year solids and 964 pounds per year liquids for a total of 1,071 pounds. This contains 75.8 pounds of dry matter, 11.4 pounds of nitrogen and 1.1 pounds of phosphorus (P). Sawyer (1965) states that the average citizen of the United States excretes about 1 pound of phosphorus per year. Synthetic and other detergents should increase the per capita phosphorus content of domestic sewage by a factor of nearly 2.5 over that caused by human excreta.

WATERFOWL

Lakes and reservoirs located on heavily used duck flyways receive "flying" or "bombed in" nutrients from transient duck populations. 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, Illinois from the wild duck population was 12.8 pounds of total nitrogen and 5.6 pounds of total phosphorus per acre. Samples of fresh and aged wild fowl excrement adjacent to Green Lake in Seattle, Washington were found to average 1.43 milligrams of nitrates, 10.3 milligrams of organic nitrogen, and 0.91 milligram total phosphorus (Sylvester and Anderson, 1964).

RUNOFF

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;[1] on an 8-percent slope, this was reduced to 18 pounds of nitrogen and 0.5 pound of phosphorus. In a study of the lower Madison lakes, Sawyer et al.,[2] and Lackey and Sawyer (1945) found that the annual contribution of inorganic nitrogen per acre of drain-

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[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.).

[2] 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).

age 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, Washington, 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/l 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, Washington, 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.

In the process of becoming soluble, nitrogen is converted into nitric acid which combines with important elements in the soil, such as calcium and potassium, among other elements, to form soluble compounds which are subject to leaching, thus causing the loss of these mineral elements as well as nitrogen. In Kentucky, the pounds of nitrogen leached per acre ranged from 0 to 10 for alfalfa, and 0.3 to 12.2 for bluegrass to 29 to 165 where no crop was grown (Andrews, 1947). The average loss of plant nutrients per acre of row crops in the Tennessee River System for the year 1939 was: 84.6 pounds of calcium, 97.9 pounds of magnesium, 212.2 pounds of potassium, 13.0 pounds of phosphorus (all expressed as oxides) and 23.8 pounds of nitrogen (Fippin, 1945).

In recent years about 50,000 tons of commercial fertilizer of various formulae have been applied annually to Prince Edward Island, Canada farms, mostly to potato fields (Smith, 1959). These commercial fertilizers made substantial contributions of phosphorus to the drainage water. It was estimated that about 10 percent of the phosphorus put on the land was lost through drainage during the year of its application. At Coshocton, Ohio, two storms with 2.21 to 5.09 inches of rainfall per storm produced a runoff of 6,600 to 76,300 gallons per acre; phosphorus (P) in the runoff water ranged from 0.016 to 0.14 pound per acre and total nitrogen (N) ranged from 0.20 to 6.12 pounds per acre (Anon., 1964).

Phosphorus carried to surface waters may be in the simple orthophosphate form or as a soluble hydrolyzable phosphate, or it may be absorbed on clay particles. As absorbed forms of phosphate increase in amount, their solubility in water increases rapidly. The amount of agricultural phosphate transported to streams undoubtedly depends upon such factors as: (1) nature and amount of phosphates in the soil, (2) mode of drainage, (3) topography, (4) intensity and distribution of rainfall, (5) rates of infiltration and percolation, etc. Results are reported for 100 samples from the Kaskaskia River basin in Illinois that has farmlands containing 40 to 50 pounds of available P_2O_5 per acre, and are drained by tile. High rainfalls and high rates of percolation exist. At one station that receives no domestic sewage but receives runoff from a cultivated drainage area of 11 square miles ortho plus hydrolyzable P_2O_5 averaged 225 pounds of phosphorus (P) per year per square mile of drainage area (Engelbrecht and Morgan, 1961).

Sawyer (1947) found that agricultural drainage in the Madison, Wisconsin area contributed approximately 4,500 pounds of nitrogen and 255 pounds of phosphorus per square mile of drainage area per year. Weibel (1965) determined that the loss of phosphorus (P) was about 256 pounds per square mile of agricultural drainage per year to Ohio streams.

Lake Sebasticook in Maine with a non-agricultural drainage basin of 106 square miles, a runoff of 0.43 cfs per square mile, and a total phosphorus (P) concentration of 20 $\mu g/l$, received 17 pounds of phosphorus per square mile of drainage basin per year. Similarly, Geist Reservoir in Indiana with a drainage basin of 215 square miles, a runoff of 0.90 cfs per square mile, and an influent total phosphorus (P) concentration of 140 $\mu g/l$, received 248 pounds of phosphorus per square mile of drainage basin per year. The Ross R. Barnett Reservoir near Jackson, Mississippi, with a drainage basin of 3,100 square miles is currently receiving 226 pounds of phosphorus per square mile of drainage basin.

A study was made of irrigation return flow in the Yakima River Basin, Washington, from a 375,280 acre area during an irrigation season whose principal months extend from April through September (Sylvester and Seabloom, 1963). Average water diversion was

6.6 acre-feet per acre per year of which approximately 4.25 acre-feet per acre was applied to land, the remainder being lost in canal seepage, canal evaporation, and wastage. The evapo-transpiration loss in itelf would result in a salt concentration increase of 1.7 times in the irrigation return water. Chemical constituent increases occurring in the sub-surface drainage water because of evapo-transpiration, leaching and ion exchange, expressed as number of times greater than in the applied water were as follows: bicarbonate alkalinity, 4.8; chlorides, 12; nitrate, 10; and soluble phosphate, 3.2. During the irrigation and non-irrigation seasons, the approximate contribution of ions or salts in pounds per acre resulting from irrigation were, respectively, bicarbonate, 575 and 715; chloride, 37 and 63; nitrate, 33 and 35; and soluble phosphate, 1 and 1.2.

Nutrient data are presented by Sylvester (1961) for major highways, arterial and residential streets in the State of Washington anywhere from 30 minutes to several hours after a rainstorm had commenced; from three streams containing large reservoirs, roads and some logging but no human habitation as they emerge from forested areas, from the Yakima River Basin irrigation return flow drains, and from Green Lake in Washington.

Table 2. Mean nutrient concentrations (μg/1)

	Total phosphorus (P)	Soluble phosphorus (P)	Nitrates (N)	Total kjeldahl nitrogen (N)
Urban street drainage	208	76	527	2,010
Urban street drainage (median)	154	22	420	410
Streams from forested areas	69	7	130	74
Subsurface irrigation drains	216	184	2,690	172
Surface irrigation drains	251	162	1,250	205
Green Lake	76	16	84	340

GROUND WATER

Juday and Birge (1931) sampled 19 wells located on the shores of 13 widely distributed lakes in northeastern Wisconsin and found total phosphorus (P) values of 2.0 μg/1 to 197 μg/1 with a mean of 29 μg/1. Eight shallow wells and one spring located on the shores of Sebasticook Lake, Maine were analyzed for nitrate-nitrogen and total phosphorus. With one exception (a 38-foot artesian well with 3.45 mg/1) the nitrate-nitrogen in these well samples did not exceed 0.05 mg/1. The total phosphorus (P) in one well was 70 μg/1, in one 18-foot deep well and one 2-foot deep spring was 20 μg/1, and in the remaining wells was 10 μg/1 or less.

NITROGEN FIXATION

Dugdale and Neess (1961) cite necessary conditions for intense nitrogen fixation. These conditions specify that:

1. the general physical and nutritional characteristics of the body of water must be such as to encourage the growth of blue-green algae,
2. some factor (s) must operate to reduce the concentrations of the various forms of combined nitrogen to very low levels,
3. an adequate supply of phosphorus would appear to be critical,
4. certain elements (calcium, boron, and molybdenum) in trace amounts are known to be specifically necessary to permit nitrogen fixation by particular species of blue-green algae.

Dilute sea-water is a reasonably good medium for nitrogen-fixing blue-green algae, perhaps because it contains favorable amounts of trace elements. It is possible that some of these elements are concentrated in sewage, resulting under certain circumstances in the stimulation of nitrogen fixation by this material.

Nitrogen fixation, demonstrated among the algae only in the *Nostocaceae, Oscillatoriaceae, Scytonemataceae, Stigonemataceae,* and *Rivulariaceae* (Fogg, 1951; Wilding, 1941), has been studied from economic as well as scientific points of view. Watanabe (1956) showed that, in four years after inoculation with *Tolypothrix tenuis,* fields of rice yielded 128 percent more than uninoculated controls. The plants in the inoculated paddies contained 7.5 pounds more N per acre than the controls (Watanabe, 1951). De and Mandal (1956) were able to obtain from 13 to 44 pounds of fixed nitrogen per acre from unfertilized, waterlogged rice soils. Fogg (1951) found that *Mastigocladus laminosus* can fix 12.88 mg N per liter in 20 days. Atmospheric nitrogen, however, is not generally as efficient as a source for growth as NH_3 or nitrate. Kratz and Myers (1955) showed that N fixation in *Nostoc* supported only 75 percent of the growth obtained on nitrate.

Rates of biological nitrogen fixation in Lake Wingra and Lake Mendota, at Madison, Wisconsin varied with light intensity (Goering and Neess, 1964). In Lake Mendota, rates were erratic and did not follow a regular seasonal pattern. Through the ice-free season, the rate of fixation was usually zero; however, positive rates did occur without obvious relation to the concentrations of various forms of combined nitrogen. Significant fixation rates were found in Lake Wingra from mid-February to late October. The highest rate observed was 14.85 μg of nitrogen fixed per liter per 24 hours at a depth of 1 meter on July 26, 1961. Although the rates were significant throughout the ice-free season, they often fluctuated widely from date to date. Fixation occurred at times when nitrate and ammonia were present; however, maximum rates did not develop until nitrate and ammonia concentrations were low or undetectable. *Microcystis* and *Anabaena* were predominant genera present, and *Anabaena* probably was the significant nitrogen fixer.

PRECIPITATION

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 fallout of atmospheric nitrogen to be 5.8 pounds per acre. Sixty-one percent of the total nitrogen fell on 25 percent of the days when precipitation occurred; the balance was attributed solely to the sedimentation of dust.

McKee (1962) found that the total atmospheric nitrogen reaching the soil per unit area tends to increase with the annual rainfall. The amount of nitrogen reaching the soil as nitrate and ammonium lies usually between 1.8 and 9 pounds per acre per year in certain regions of Europe. Several observers have found appreciable amounts of organically combined nitrogen (usually cited as albuminoid N) in rain. Much of the organic nitrogen of the atmosphere is in small particles such as pollen, spores, bacteria, and dust carried from the earth's surface by ascending currents. Voigt (1960) studied the composition of rainfall in an open area in southern Connecticut which receives about 45 inches of precipitation per year. Water samples collected from two storms, one in May and one in September, contained total nitrogen concentrations of 0.05 and 0.07 mg/l and total phosphorus of 10 μg/l.

RELEASE FROM BOTTOM SEDIMENTS

Hasler (1957) found that in an undisturbed mud-water system, the percentage as well as the amount of phosphorus that is released to the superimposed water is very small. In laboratory experiments, when P^{32} is placed at various depths in the mud the diffusion into the overlying non-circulating water is negligible if placed greater than 1 centimeter in the mud. Application of lime to the water, or to the mud, reduces the amount of soluble phosphorus available. Acidification of previously alkalized mud will, upon agitation, increase the amount of phosphorus entering solution. In an aquarium experiment, circulation of the water above phosphorus-rich mud with the aid of air bubbles increases the phosphorus in solution.

Experiments on the fertilization of Scottish lochs, and laboratory experiments on the loss of dissolved phosphate from water overlying mud deposits, showed that aerobic bottom deposits can take up large amounts of phosphate although the rate of absorption is slow (Holden 1961). When phosphate is added as a fertilizer, the rate of removal by the deposits may be slower than the uptake by macrophytic and attached flora. Most of the phosphate absorbed remains in the upper aerobic zone of the mud, most of it being converted to organic forms so that only a small proportion is available for release during periods of temporary anaerobic conditions in the mud. In unfertilized lakes, the quantity of phosphorus in the mud surface is very high compared with the equilibrium concentration in the overlying water. In shallow fertilized lakes, where the upper 15 cm of the bottom deposit may be involved in phosphate uptake, very large quantities can be removed from solution and much of that removed may be converted to forms which are unavailable for subsequent release to the water.

Phosphorus may be removed from solution by a number of mechanisms which do not act independently of one another. In alkaline waters where there is an excess of calcium, phosphorus may precipitate as tricalcium phosphate [$Ca_3(PO_4)_2$]. This salt eventually may be converted to the more soluble di- and mono-calcium phosphates if the pH of the water is reduced. In the presence of iron, insoluble ferric phosphate may be formed. In addition, it may be absorbed directly on organic soil colloids (humus), where the nature of the reaction is not clearly understood. Under these circumstances, phosphorus will tend to accumulate in the bottom in insoluble forms where it is not available to the phytoplankton in general, although some algae may be able to use absorbed phosphorus directly. Bacteria can use particulate phosphorus in a microzone surrounding the cell and thus the element may be passed on through food chains. Increased solubility of strongly basic phosphates may be the result of local acidity from base-exchange. Beneath the surface of the soil where oxidation-reduction potentials are lowered, colloidal complexes of ferric iron are made soluble by reduction and phosphorus absorbed on them is released.

Zicher et al. (1956) found that in laboratory experiments the percentage as well as the amount of phosphorus released to the water from radioactive superphosphate fertilizer placed at various depths below the mud surface in an undisturbed mud-water system was indicated to be very small. There was virtually no release of phosphorus from fertilizer placed at depths greater than one-fourth inch below the mud surface. There was a higher percentage of soluble phosphorus contained in the water samples taken near the mud surface than in water samples taken at greater distances above the mud surface. The radiophosphorus placed one-half inch below the mud surface showed only a very slight tendency to diffuse into the water, while the radiophosphorus placed at the 1-inch depth did not diffuse into the water at all.

Although the consideration of the release of major nutrients from the bottom sediments into the superimposed water remains an important one, the specific contribution to the ecosystem of any particular water body remains unknown.

MINOR CONSIDERATIONS

Donahue (1961) states that sawdust contains 4 pounds of nitrogen (N) and 0.8 pound of phosphorus (P) per ton of dry material and wheat straw contains 10 and 1.2 pounds respectively. McGauhey et al. (1963) state that the amount of nitrogen from pollen may be as high as 1.8 to 4.5 pounds nitrogen per acre per year in a forested area. The pollen contains chloride and phosphate in addition to nitrogen, but since a significant amount of pollen is often found intact in the benthic sediments it cannot be assumed that these materials are released to water.

The nutrients returned annually to the soil by forest tree leaves have been cited as follows (Chandler 1941 and 1943):

	Pounds per acre returned annually	
	Nitrogen	Phosphorus
Conifer	23.6	1.8
Hardwood	16.6	3.3

Utilization By Aquatic Crops

The literatures indicate that all marine algae capable of utilizing inorganic nitrogen can use ammonia, and most of the common forms attain comparable rates of growth with ammonia, nitrate, or nitrite. With all three nitrogen sources available simultaneously, ammonia is often used preferentially.

The activity of phytoplankton in Sanctuary Lake, Pennsylvania was found by Dugdale and Dugdale (1965) to fall into three clearly defined periods: (1) a spring bloom when ammonia nitrogen, nitrate nitrogen, and elemental nitrogen are assimilated strongly and in that order of importance; (2) a midsummer period when weak assimilation of ammonia nitrogen and elemental nitrogen,

Plate 13. An August algal bloom in Lake Sebasticook, Maine.

but not nitrate nitrogen, occurred; and (3) a fall bloom with intense nitrogen fixation and some ammonia nitrogen uptake but characterized by low nitrate nitrogen activity. Nitrogen fixation and ammonia nitrogen uptake appear to proceed concurrently, although ammonia uptake dominates in spring and nitrogen fixation dominates in fall.

Flaigg and Reid (1954) found that in concentrations up to about 15 milligrams per liter there was no significant difference in the utilization of nitrite nitrogen, nitrate nitrogen, and ammonia nitrogen. Webster (1959) states that certain bacteria and certain algae can assimilate all the forms of nitrogen including molecular N and organic N. Provasoli and Pinter (1960) state that Euglenoids prefer ammonia nitrogen or amino acids.

The senior author, following a 1965 limnological study of Lake Sebatsticook in Maine, calculated that the lake contained 220,000 pounds of organic nitrogen and 109,000 pounds of inorganic nitrogen in mid-May. The lake, at this time, contained an estimated 270,000 pounds of algae on a dry weight basis which contained, in turn, 6.1 percent nitrogen. Thus only 7.5 percent of the organic nitrogen in the lake was accountable in the algal mass. Sixty-two percent of the total nitrogen was not accounted in either the inorganic nitrogen fraction or combined in the algal mass. Lake Sebasticook in late July contained 197,000 pounds of organic nitrogen and 88,000 pounds of inorganic nitrogen. Concurrently 1,000,000 pounds of algae on a dry weight basis were present. Thus 25 percent of the organic nitrogen was accountable in the algal mass and 52 percent of the total nitrogen was unaccountable in either the inorganic fraction or combined in algal cells.

Phosphorus is taken up by phytoplankton from the uppermost waters and is concentrated by these plants by a factor of 10^7 to 10^8. Phosphorus is returned to the water possible well distant from the place and depth at which it was abstracted, on the death and decomposition of the plants or by the organisms which have eaten them.

Watt and Hayes (1963) found experimentally that organic phosphorus compounds were released into solution from dead or dying organisms. Rapidly growing populations of bacteria or green plants did not release organic phosophorus compounds. Dissolved organic phosphorus compounds were absorbed by bacteria, broken down, and inorganic phosphorus was released.

In laboratory experiments Phillips (1964) found that bacteria retained much of the phosphorus in the water, but higher plants were more efficient than bottom sediments in removing phosphorus from the water in the presence of bacteria. When bacteria were inactivated, there was a much more rapid loss of P to the mud. Also, water plants assimilate phosphorus more readily in the absence of bacteria. Bacteria convert inorganic phosphates to organic phosphorus which may be released to the water in an unavailable form; this appears to be a reversible process. Phosphorus uptake in zooplankton was negligible in the absence of bacteria, confirming that zooplankton organisms obtain their food by digestion of particulate matter rather than by absorption of dissolved compounds.

Harvey (1960) states that although most of the phosphorus is absorbed by phytoplankton as orthophosphate ions, there is reason to believe that some may be absorbed as molecules of dissolved organic phosphate. Moore (1958) found evidence that some organic phosphorus compounds can be utilized by algae, but most of it is broken down to phosphate by bacterial action and then utilized as such by algae.

Rice (1953) points out that algae absorb more phosphorus when grown in a medium containing high phosphate concentrations. Since the amount of phosphorus entering the cell is proportional to the concentration in the medium, it necessarily follows that any phosphorus entering the cell in excess of that which the cell can convert into the organic state, will persist as the inorganic salts.

Hutchinson (1957) writes that at the height of summer there may be a great increase in total phosphorus in the surface water at times of algal blooms although soluble phosphate is undetectable. This may occur as a result of rapid decomposition and subsequent liberation of phosphate in the littoral sediments during very warm weather. The phosphate would be taken up by the growing algae so fast that it never would be detected.

In Lake Sebasticook in mid-May, 1965, floating blue-green algae contained 0.64 percent phosphorus (P) on a dry weight basis. Thus, 1,700 or 15 percent of the 11,400 pounds of the total phosphorus in the lake was combined in the algal mass. This 1700 pounds plus the 900 pounds of soluble phosphorus in the lake left 75 percent of the total phosphorus unaccountable for but presumed to be bound in bacteria, zooplankton, seston, and fecal pellets. On July 25 it was determined that 0.5 percent of the algae on a dry weight basis was total phosphorus (P). At this time, nearly 1,000,000 pounds of algae (dry weight) were present in the lake. The phosphorus bound within the algal mass was 33 percent of the total phosphorus contained in the lake. This bound phosphorus plus the soluble phosphorus present at this time left 54 percent unaccountable for as either soluble phosphorus or as phosphorus bound within the algal mass.

Occurrence in the Ecosystem

INTRODUCTION

As fixed nitrogen enters the water, 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 (Hutchinson, 1957):

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 phososphorus 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.

STREAMS

Concentrations of nitrogen and phosphorus in streams depend upon the kinds and amounts of man-associated pollution and the geology of the area. Results from 9 samples collected at 8 lake and reservoir sources in Illinois, believed to be relatively free of domestic pollution, showed a mean orthophosphate concentration of 16 $\mu g/l$ P and a mean value of orthophosphate plus the maximum inorganic condensed (hydrolyzable) P of 35 $\mu g/l$ (Engelbrecht and Morgan, 1959). The analytical results from 27 samples from streams in the major Illinois River basin, suspected to contain significant amounts of treated and untreated wastes, gave an average orthophosphate concentration of 179 $\mu g/l$ P and an average orthophosphate plus maximum inorganic condensed P of 286 $\mu g/l$.

Total phosphorus levels in streams entering Western Lake Superior were higher than those observed in the lake (Putnam and Olson, 1959). In August the concentration of phosphorus (P) in the streams along the north shore varied from 31 $\mu g/l$ in the Poplar River to 47 in the Baptism River. In the south shore streams, the Brule River contained 53 $\mu g/l$ P which was the maximum for August. The following year the nitrate nitrogen in all streams except one was lower than that observed in the lake (Putnam and Olson, 1960). In August, the range was 0.01 to 0.44 mg/l. The overall mean total phosphorus (P) concentration for north shore streams was 22 μg/1 while that for the south shore tributaries was 42 μg/1. Inorganic phosphorus constituted 38.5 percent of the total phosphorus (48 μg/1) in the St. Louis River, and 67.0 percent of the total phosphorus (93 μg/1) in the Black River.

Total phosphorus (P) concentrations in unpolluted area streams in the Lake Sebasticook, Maine, study were 20 μg/1. In reaches polluted with domestic and industrial wastes, total phosphorus (P) concentrations were 340 μg/1.

LAKES

Lake Washington near Seattle, Washington began exhibiting phenomena characteristic of eutrophication about 1955. The maximum hypolimnetic concentration of phosphate (PO_4–P) reached in the deepest waters was 23 μg/1 in 1950, 89 μg/1 in 1957, and 74 μg/1 in 1958 (Anderson, 1961).

Juday and Birge (1931) reported a mean of 23 μg/1 total phosphorus for 479 lakes of northeastern Wisconsin, and Hutchinson (1941) reported a mean of 21 μg/1 total phosphorus for 23 analyses of the surface water of Linsley Pond, North Branford, Connecticut. About 183 pounds per day of phosphorus (P) enter Lake Zoar in Connecticut giving rise to a concentration of 12 to 41 μg/1 in the water mass with an average of 25 μg/1 (Benoit and Curry, 1961).

In western Lake Erie organic nitrogen varied from a high of 26 μg/1 on August 26 to a low of 2 μg/1 on September 18; these extremes coincided with a high and low level of phytoplankton, respectively. Soluble phosphate phosphorus values varied from 1 to 8 μg/1 with the high point occurring at three times: (1) at the time of greatest organic phosphorus concentration, (2) during a period of increased turbidity which apparently resulted from increased river discharge, and (3) two weeks following the cessation of the autumn phytoplankton pulse. Lowest values occurred when the phytoplankton population was decreasing. Twenty-nine percent of the total phosphorus content was in the soluble phosphate phosphorus state (Chandler and Weeks, 1945).

Lake Mendota, Wisconsin was found to contain more than 9 times as much soluble nitrogen as it did total plankton nitrogen (Domogalla et al., 1925). Ammonia nitrogen varied from 11.6 to 39.2 μg/1 N during a 1-year period. Most of the soluble nitrogen was formed at the bottom of the lake, spreading upward toward the surface. At the spring and fall overturns, the soluble nitrogen content of the lake was uniform. As soon as stratification occurs, the concentration of soluble nitrogen in the hypolimnion exceeds that in the epilimnion. Hutchinson (1957) states that most relatively uncontaminated lake districts have surface waters containing 10 to 30 $\mu g/l$ P, but in some waters that are not obviously grossly polluted, higher values appear to be normal. The soluble phosphate usually is of the order of 10 percent of the total.

On the basis of surveys in Minnesota it was estimated that the summer surface waters of Mississippi River headwater lakes in Minnesota have a mean total phosphorus (P) content of about 34 $\mu g/l$ (Moyle, 1956). In central Minnesota the mean total phosphorus content of studied lakes was 58 $\mu g/l$ and in southern Minnesota, the total phosphorus content was 126 $\mu g/l$.

A 16-month investigation at Douglas Lake, Michigan, with water samples collected and phosphorus determinations made every two weeks, showed that at the surface total phosphorus (P) fluctuated between 7 and 14 $\mu g/l$, and at the 12-meter depth (lower limit of the epilimnion), between 7 and 15 $\mu g/l$ (Tucker, 1957). At the 20-meter depth, between July 3 and September 16, the total

Plate 14. Algal scums often result from warm temperature, abundant sunshine, and nutrients.

phosphorus increased from 10 to 641 μg/l. Seasonal variation in inorganic phosphorus (soluble) followed closely the variation in total phosphorus, although it was smaller in amount. Analysis of a vertical series of samples showed that the most constant fraction of phosphorus was the soluble organic phosphorus, never exceeding 9 μg/l regardless of the depth at which the sample was taken.

A year's investigation of Geist Reservoir at Indianapolis, Indiana showed mean inorganic nitrogen (N) concentrations in the reservoir of 1.2 μg/l, total phosphorus (P) values of 110 μg/l and soluble phosphorus of 60 μg/l. At the Ross R. Barnett Reservoir near Jackson, Mississippi the mean inflowing total phosphorus (P) concentration was 100 μg/l and the outflow from the reservoir, 50 μg/l. Seasonal studies on Lake Sebasticook, Maine, in which the total phosphorus (P) concentration is a statistic weighted to the total water volume, showed concentrations of 40 μg/l in winter, 49 μg/l in spring, 64 μg/l in summer and 40 μg/l in fall.

Total to soluble phosphorus ratios in lakes often range from 2 to 17. Total to soluble phosphorus ratios vary from water to water and seasonally within the same water body:

Table 3. TOTAL TO SOLUBLE PHOSPHORUS RATIOS IN WATER

Water	Total P: Sol. P	Reference
Western Lake Erie	3.5	Chandler and Weeks, 1945
Detroit River mouth	5 to 7	PHS Detroit Project
Linsley Pond, Connecticut	10.0	Hutchinson, 1957
Northern Wisconsin Lakes	7.0	Juday and Birge, 1931
Northeast Wisconsin Lakes	2 to 10	Juday et al., 1927
Ontario Lakes (8)	17	Rigler, 1964
Southeast Wisconsin Lakes (17)	9	Mackenthun, unpublished
Rock River, Wisconsin	2 to 15	Mackenthun, unpublished
Sebasticook Lake, Maine	2.8 winter	Mackenthun, unpublished
"	12.7 spring	"
"	7.0 summer	"
"	4.1 fall	"

The nutrient loading to the lake on a unit basis gives some measure of comparability among various water bodies. Likewise, a lake or reservoir usually retains a portion of those nutrients that it receives from its various sources. The amount or percentage of the nutrients that may be retained by a lake or reservoir is variable and will depend upon:

1. the nutrient loading to the lake or reservoir,
2. the volume of the euphotic zone,
3. the extent of biological activity,
4. the detention time within the basin or time allotted for biological activity, and
5. the level of the penstock or discharge from the basin.

Some nitrogen and phosphorus loadings and retentions have been reported as follows:

NUTRIENT POPULATION EQUIVALENTS

Nutrient population equivalents are one way to summarize data using a common denominator. In presenting the population equivalents suggested in Table 5 it is recognized that variability occurs in both the base (domestic contribution in sewage) and the selected contributions.

PLANTS

Birge and Juday (1922) report the percentages of total nitrogen (N) and phosphorus (P) on a dry weight basis for a number of plants as follows:

Organism	Percentage of the dry weight	
	N	P
Microcystis	9.27	0.52
Anabaena	8.27	.53
Volvox	7.61	1.10
Cladophora	2.77	.14
Myriophyllum	3.23	.52

Schuette (1918) made analyses of composite plankton samples obtained by pumping water from different levels of Lake Mendota, Wisconsin, and straining it through a plankton net. In 7 samples, total nitrogen ranged from 4.51 to 9.94 percent dry weight and averaged 7.55 percent, while the available protein nitrogen ranged

Table 4. LAKE NUTRIENT LOADINGS AND RETENTIONS

Lake	State	Nitrogen (N)		Phosphorus (P)		
		Loading lb./yr./acre	Retention (Percent)	Loading lb./yr./acre	Retention (Percent)	Reference
Washington	Wash.	280	—	12	—	Anderson, 1961
Mendota	Wis.	20 I	—	0.6 S	—	Anon., 1949
Monona	Wis.	81 I	48 to 70	7.5 S	64 to 88	Lackey and Sawyer, 1945
Waubesa	Wis.	435 I	50 to 64	62.8 S	–26 to 25	"
Kegonsa	Wis.	162 I	44 to 61	35.9 S	–21 to 12	"
Tahoe	Calif.	2	89	0.4	93	Ludwig et al., 1964
Koshkonong	Wis.	90	80	40	30 to 70	Mackenthun, unpubl.
Green	Wash.	—	—	4.8	55	Sylvester & Anderson, 1964
Geist	Ind.	440 I	44	28	25	F.W.P.C.A. Data
Sebasticook	Maine	—	—	2	48	"
Ross R. Barnett	Miss.	—	—	32	—	"

I — inorganic nitrogen only.
S — soluble phosphorus only.

Table 5. Nutrient Population Equivalents

Nutrient source	Basic reference	Contribution		Population equiavlent (PE per year)	
		N	P	N	P
Treated domestic contribution in sewage.	Bush and Mulford, 1954.	6-12* (9 lb/yr)	2-4 (3 lb/yr)	1	1.
	Metzler et al., 1958.	6**lb/yr	2.25 lb/yr.		
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.	15 lb/A	1.5 lb/A	1.7 to 2.5/A	0.5/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.

from 2.82 to 8.67 percent and averaged 4.55 percent. Forty to 87 percent of the total nitrogen was in the available form. Total phosphorus ranged from 0.92 to 1.57 percent and averaged 1.26 percent.

Gerloff and Skoog (1954) found the total phosphorus (P) and mean total nitrogen (N) of 7 samples of *Microcystis aeruginosa,* collected from heavy algal blooms in three lakes in the vicinity of Madison, Wisonsin, to be 6.83 and 0.69 percent dry weight, respectively.

In Upper Klamath Lake, Phinney and Peek (1961) found that partial analysis of freshly dried algae contained 61.1 percent crude protein, 5.73 percent ash, and 0.60 percent phosphorus. Floating blue-green algae collected on May 16, 1965 from Lake Sebasticook, Maine, contained 39 percent carbon, 6.1 percent organic nitrogen and 0.64 percent total phosphorus on a dry weight basis. A floating mass of blue-green algae collected on July 25, 1965, contained 0.50 percent phosphorus on a dry weight basis.

Submerged aquatic weeds were found by Harper and Daniel (1939) to be 12 percent dry matter and to contain an average of 1.8 percent total nitrogen (dry weight) and 0.18 percent total phosphorus. Plants that were hand-picked, air-dried, and desiccated at 60°C were found to contain the following percentages of nitrogen and phosphorus by Schuette and Alder (1928 and 1929).

	Sand-free basis (Units expressed as percent)			
	Vallisneria	Potamogeton	Castalia	Najas
Ash	25.19	11.42	11.21	19.16
Total nitrogen (N).....	1.88	1.28	2.78	1.86
Total phosphorus (P)...	.23	.13	.27	.30

In an examination of the chemical composition of Eurasian water milfoil, Anderson et al. (1965), determined that the percentage of the dry weight for nitrogen (N) was 3.0 in freshwater and 2.2 in brackish water; the percentage for phosphorus (P) was 0.5 in freshwater and 0.35 in brackish water.

ANIMALS

Birge and Juday (1922) determined the percentages of total nitrogen (N) and phosphorus (P) on a dry weight basis for a number of aquatic animals as follows:

Organism	Percentage of the dry weight	
	N	P
Cyclops	9.57	1.02
Limnocalanus	7.18	.78
Daphnia pulex	6.55	1.60
Daphnia pulex	8.61	1.54
Daphnia pulex	7.55	1.48
Leptodora	9.28	1.56
Cambarus	6.60	1.16
Hyalella	7.37	1.20
Hirudinea	11.13	.76
Zygoptera	10.62	.66
Sialis	8.07	.64
Chironomus tentans	7.36	.93

To determine the amounts of nitrogen and phosphorus removed from lakes by aquatic insects which leave the water in the adult stage, Vallentyne (1952) made a study of the concentration of total nitrogen and phosphorus in adult insects trapped as they emerged from the water in Lake Opinicon, Ontario. On an average, 136 insects emerged per day per square meter of surface; they had a fresh weight of 69.2 mg and contained 2.26 mg of total nitrogen and 0.15 mg of total phosphorus. It was calculated that in Winona Lake, Indiana, where the amount of organic sediment has been determined, the loss of organic matter by emergence of insects was less than 1 percent of the amount of organic sediment deposited annually.

Animal excretions are a major source of plant nutrients in the sea and contribute to the nutrients in freshwater. According to Johannes (1964), the rate of excretion of dissolved phosphorus per unit weight increases as body weight decreases. As a result microzooplankton may play a major role in planktonic nutrient regeneration. Although data are not available on quantitative nutrient excretions from these organisms in the freshwater ecosystem, the importance of this as a continuing nutrient source should be considered.

The phosphorus (P) content of fish flesh on a wet weight basis has been given by various authors as follows:

Percent Phosphorus (P)	Reference
0.20	Beard, 1926
0.18 to 0.49	Borgstrom, 1961
0.19	Love et al., 1959
0.20	McGauhey et al., 1963
0.292	Sylvester and Anderson, 1964
0.18 to 0.24	Ingalls et al., 1950

Based on selected data on standing crops of various organisms and values of nitrogen and phosphorus within the crop selected from the literature, the following tabulation (Table 6) may be made, and an estimate may be made of that amount that is harvestable.

NUTRIENTS IN BOTTOM DEPOSITS

McGauhey et al. (1963) report the results of 14 samples of the sediments of Lake Tahoe indicating total carbon of 0.6 to 19.8 percent, organic nitrogen of 0.6 to 1.6 percent, and carbon-nitrogen ratios from 3.7 to 28.4. Black (1929) and Juday et al. (1941) report on samples collected from 39 lakes in Wisconsin and Alaska. The organic carbon ranged from 4.4 to 40.5 percent, organic nitrogen from 0.55 to 3.58 percent, and carbon-nitrogen ratios from 7.5 to 14.4. The total phosphorus (P) ranged from 0.12 to 0.61 percent of the dry weight. The authors could not explain their high organic carbon concentrations in the bottom sediments because many of the lakes sampled would not be considered fertile lakes. Sawyer et al. (1945) found the nitrogen and phosphorus content of the Madison, Wisconsin eutrophic lakes to be 0.7 to 0.9 percent nitrogen dry weight, and 0.1 to 0.12 percent phosphorus. The N–P ratio was 6 to 9. Sylvester and Anderson (1964) found the uppermost layer of bottom mud of Green Lake in Seattle to be 0.6 percent nitrogen dry weight and 0.167 percent phosphorus. The N–P ratio was 4.2.

The dry weight carbon in Lake Sebasticook, Maine, benthic sediments ranged from 10.1 to 34 percent and the dry weight organic nitrogen ranged from 0.3 to 1.8 percent. Carbon-nitrogen ratios ranged from 8 to 44. The dry weight phosphorus (P) in Lake Sebasticook bottom sediments ranged from 0.06 to 0.16 percent. The nitrogen-phosphorus ratio was 5.0 to 15.8. A 19-inch

Table 6. THE STANDING CROP PER LAKE WATER ACRE

	PHYTOPLANKTON	ATTACHED ALGAE	SUBMERGED VASCULAR PLANTS	FISH	MIDGES
Wet Weight (lbs)	1,000 to 3,600[1]	2,000[2]	14,000[3]	150 to 600[4]	200 to 400[5]
Dry Weight (lbs)	100 to 360	200	1,800	—	40 to 80
Percentage N (dry wgt)	6.8[6]	2.8[1]	1.8[7]	2.5[8]	7.4[9]
Percentage P (dry wgt)	0.69	0.14	0.18	0.2	0.9
N in crop (lbs)	7 to 25	6	32	3.8 to 15	3 to 6
P in crop (lbs)	0.7 to 2.5	0.3	3.2	0.3 to 1.2	0.4 to 0.7
Harvestable N (lbs)	—	—	16	1.0 to 3.8	0.2 to 0.4
Harvestable P (lbs)	—	—	1.6	0.1 to 0.3	0.02 to 0.04

[1] Birge and Juday, 1922
[2] Neil, 1958
[3] Rickett, 1922, 1924
[4] Swingle, 1950
[5] Dineen, 1953 and Moyle, 1940
[6] Gerloff and Skoog, 1954
[7] Harper and Daniel, 1939
[8] Beard, 1926 (wet wgt)
[9] Borutsky, 1939

sediment core was collected from a depth of 53 feet in Lake Sebasticook. Segments of the core were oven dried and analyzed for the percentage of carbon, nitrogen and phosphorus. The 0–1 inch segment of the core contained 11 percent carbon dry weight, 0.6 percent nitrogen, and 0.15 percent phosphorus. At greater depths in the core, the percentage of carbon gradually decreased until at 7 inches it was 1.0 percent or approximately 10% of the surface value. There was little change in the organic carbon percentages from 7 inches to the 19-inch stratum. The greatest carbon change in the sediment core occurred between the 0- to 2-inch stratum and between the 6- to 8-inch stratum. Likewise, the percentage of nitrogen decreased from 0.6 percent in the 0–1 inch segment to about 0.1 percent in the deeper strata. The demarcation zone of greatest change in nitrogen coincided roughly with the carbon and occurred between the 8- and 9-inch strata (from 0.3 percent to 0.1 or 0.2 percent). The dry weight phosphorus (P) in the 0–1 inch stratum was 0.15 percent. The 1–2 stratum contained 0.09 percent phosphorus. Beneath the 1–2 inch stratum the phosphorus content ranged from 0.06 to 0.09 percent on a dry weight basis.

Critical Factors for Aquatic Plant Production

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 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 may be 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 a considerable lag is imposed by the slow rate of the involved reaction, which is comparable to sludge digestion at low temperatures (Sawyer, 1954).

Sawyer (1954) dicusses various factors that influence the development of nuisance algal growths in lakes. The surface area is important since the accummulations 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, under equal fertilization per acre. The shape of the lake determines to some degree the amount of fertilizing matter the lake can assimilate without algal nuisances 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 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.

Lund (1965) in his thorough literature review states that "Nitrogen and phosphorus can still be considered as two of the major elements limiting primary production. In some tropical and highly eutrophic temperate lakes, nitrogen may be a more important limiting factor than phosphorus. In many other lakes phosphorus is present in very low concentrations and seems to be the major factor limiting production. Evidence from the addition of fertilizers to fish ponds and from what is known about the eutrophication of lakes by sewage supports the view that phosphorus plays a major role in production."

Chu (1943) found that optimum growth of all organisms studied in cultures can be obtained in nitrate-nitrogen concentrations from 0.9 to 3.5 mg/l and phosphorus concentrations from 0.09 to 1.8 mg/l, while a limiting effect on all organisms will occur in nitrogen concentrations from 0.1 mg/l downward and in phosphorus concentrations from 0.009 mg/l downward. The lower limit of optimum range of phosphorus concentration varies from about 0.018 to about 0.09 mg/l; and the upper limit from 8.9 to 17.8 mg/l when nitrate is the source of nitrogen, while it lies at about 17.8 for all the planktons studied when ammonium is the source of nitrogen. Low phosphorus concentrations may, therefore, like low nitrogen concentrations, exert a selective limiting influence on a phytoplankton population. The nitrogen concentration determines to a large extent the amount of chlorophyll formed. Nitrogen concentrations beyond the optimum range inhibit the formation of chlorophyll in green algae.

Experiments by Ketchum (1939) with the diatom, *Phaeodactylum*, show a reduction in rate of cell division when phosphate present in the medium is less than 17 μg/l P. Strickland (1965) states that the limiting phosphorus concentration in some cultures has been found to be less than 5 μg/l. The problem is complicated because auxiliary compounds may affect the availability of phosphate to a plant cell. Sylvester (1961) found that nuisance algal blooms were observed to commence in Seattle's Green Lake (a very soft-water lake) when nitrate nitrogen (N) levels were generally above 200 μg/l and soluble phosphorus (P) was greater than 10 μg/l.

Müller (1953) concludes that excessive growths of plants and algae in polluted waters can be avoided if the concentration of nitrate nitrogen is kept below about 0.3 mg/l and the concentration of total nitrogen is not allowed to rise much above 0.6 mg/l.

The question is sometimes asked, how much algae can be grown from a given amount of phosphorus? Allen (1955) found that the maximum that could be grown in the laboratory on sewage was 1 to 2 g/l (dry weight) and in the field in sewage oxidation ponds the maximum was 0.5 g/l. Thus, assuming optimum growth conditions and maximum phosphate utilization, the maximum algal crop that could be grown from 1 pound of phosphorus would be 1,000 pounds of wet algae under laboratory conditions or 250 pounds of wet algae under field conditions. Considering a phosphorus (P) content of 0.7 percent, 1 pound of phosphorus could be distributed among 1,450 pounds of algae on a wet weight basis.

Micronutrients, Growth Stimulators and Depressants

It is generally conceded that abundant major nutrients in the form of available nitrogen and phosphorus are an important and a necessary component of an environment in which excessive aquatic growths arise. Algae, however, are influenced by many and varied factors. Vitamins, trace metals, hormones and auxins, extracellular metabolites, autointoxicants, viruses, and predation and grazing by aquatic animals are factors that stimulate or reduce algal growths. Some of these may be of equal importance to the major nutrients in influencing nuisance algal bloom production.

Several vitamins in small quantities are known to be required as growth factors by certain species of algae. In the fresh water environment this requirement is variously considered to be met by the vitamin supply contained in soil runoff, in lake and stream bed sediments, as solutes in the water, and as produced by actinomycetes, certain fungi, many bacteria, several algae, and domestic sewage.

Harder, in 1917, is credited with first connecting growth inhibiting substances with algae. As early as 1931, autoinhibiting substances were recognized (Akehurst, 1931). These papers gave rise to a common belief that a plant can create its self-destruction through the production of growth inhibiting substances that it cannot tolerate but which may, in turn, stimulate other growths. Natural waters contain these acive agents that are secreted and excreted by fresh-water algae. The toxicity of these agents to other algae and bacteria and to fish varies constantly and is not well understood in the natural aquatic environment. It has been postulated that algae secrete not just one substance but several, some antibiotic, others stimulating. The amount secreted and the net result of the secretions would be determined by the prevalence of one group of substances over the other. Thus, sequences of algal blooms may be expected to occur under conditions of a nutrient supply far in excess of critical values.

In man's quest to reduce major nutrients enriching waters, such as nitrogen and phosphorus, and thereby restore such waters to a greater water use potential without attendant algal pests, other algal population-influencing factors will have a role in the ultimate success of the restoration efforts. This role is presently neither clearly defined nor understood. It does seem clear that the constant progression of the geologic clock cannot be substantially altered. Despite man's most ardent dreams, lakes now fertile and abundantly productive of algae will never again attain their crystal-clear, pristine appearance so well imprinted in the minds of long-time local residents. The old swimmin'-hole lingers on in local folklore. Recently defiled waters can be improved substantially, however, by reducing or removing the varying causes of algal productivity. By placing all known algal population influencing factors in their proper perspective and by intensifying investigative efforts directed towards the interrelationships of factors most likely to effect population controls, knowledge and nuisance reducing efforts will be enhanced. Lakes, reservoirs, ponds, flowing streams, estuaries, and bays will be improved, and the using public will be benefited.

Eyster (1964) divides the elements required by green plants into macronutrients and micronutrients. Macronutrients include carbon, hydrogen, oxygen, nitrogen, phosphorus, sulfur, potassium, magnesium, calcium (except for algae where it is a micronutrient), and sodium. Micronutrients include iron, manganese, copper, zinc, molybdenum, vanadium, boron, chlorine, cobalt, and silicon.

Manganese is one of the key elements in photosynthesis and manganese-deficient cells have a reduced level of photosynthesis and a reduction in chlorophyll. Iron is associated with nitrogen metabolism. Arnon (1958) confirmed that chloride is a coenzyme of photosynthesis specifically concerned with oxygen evolution. Vanadium and zinc appear to be involved in photosynthesis. Calcium and boron are involved in nitrogen fixation. Molybdenum is necessary for nitrate utilization and nitrogen fixation. Cobalt is associated with the nutritional functions of vitamin B_{12}.

Fitzgerald (1964) discusses the sequences of algal blooms that occur under conditions of nutrient supply in sewage stabilization ponds far in excess of those found in natural lakes. He also reviews some of the factors other than nutrition that might influence the algal population. These factors include grazing and the production of inhibiting extracellular products. It is pointed out that there is evidence that an inverse relationship frequently exists between the density of phytoplankton and zooplankton. This might be the result of over-grazing in specific areas and a lack of grazing in adjoining areas, or it may be due to an "exclusion" effect on zooplankton produced by extracellular plant metabolites. Gibor (1957) has shown evidence that algae can at times pass through the zooplankton without being affected by digestive processes.

In situations where the algae are so abundant that their control may be required by chemical means, it appears that animal predation or attacks by microorganisms are not enough to cause a shift in the dominant species. Once the dominant species is eliminated, however, other species increase in numbers and become dominant. Factors thought to contribute to species dominance include secreted or excreted inhibiting extracellular products (Rice, 1954).

Léfevre (1964) states that when an algal species develops extensively in standing waters causing waterblooms, it eventually become intoxicated by its own accumulated excretion products and dies. When the water is renewed slowly, this phenomenon does not occur because the extracellular products are constantly removed. Also, when one species of algae predominates in standing water, other species appear only sporadically and the number of bacterial species decreases. Léfevre et al. (1952) suggest that this phenomenon is due to antagonistic substances produced by the predominant species. Léfevre (1964) states that the production of extracellular active agents is conditioned by: (1) nature of strain; (2) composition of culture medium; (3) nature and size of inoculum; (4) temperature; (5) illumination; (6) agitation of medium; (7) duration of culture; and (8) season of the year.

Of 154 algal species, 56 require no vitamins and 98 species require vitamin B_{12}, thiamin and biotin, alone or in various combinations (Provasoli, 1961). Those blue-green algae not requiring B_{12} employ it readily as a cobalt source; since cobalt is generally scarce in water, even organisms not requiring B_{12} may compete for it. A great part of the vitamins in freshwaters and in the littoral zone of the sea can be assumed to come from any soil run-off especially during the spring floods. Muds are another source of vitamins. A third source is the vitamins present as solutes in water.

Vitamins are synthesized by several organisms. *Chlorella* has been found to produce as much as 6.3 μg B_{12} per 100 g of dry algae and *Anabaena* as much as 63 to 110 per 100 g of dry algae (Brown et al., 1955). Burkholder (1959) studied the production of B vitamins by 344 bacteria isolated from waters and muds from Long Island Sound and found that 27 percent of these gave off vitamin B_{12}, 50 percent gave off biotin, 60 percent thiamine, and 11 percent nicotinic acid. Sixty-five percent of the actinomycetes studied were found by Burton and Lockhead (1951) to produce vitamin B_{12}. Robbins et al. (1950) reported that fungi and many bacteria, isolated from the water and mud of a pond in which *Euglena* blooms, produced B_{12}; they demonstrated also that these bacteria, grown with *Euglena* on agar plates of a medium deprived of B_{12}, diffused sufficient vitamin to support growths of *Euglena*. And Robbins and Kavanagh (1942) state that the ability of a fungus to synthesize vitamins essential for their metabolic processes may be complete, incomplete, or absent.

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 diffused 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). The production of Chlorella to many controlled growth factors in the laboratory and in a pilot plant is detailed by Burlew (1953).

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 mid-morning at Lemmon, South Dakota (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 autotropic organisms under optimum light was 35×10^{-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 and 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

Lackey (1958) lists benefits, at least from sewage fertilization that arise because of algal growths. These include (a) reoxygenation, (b) mineralization, and (c) production of a food chain. Three well recognized ills are: (a) algal toxicity, (b) aesthetic harm, and (c) buildup of biochemical oxygen demand (BOD). Green algae (*Micractinum*) growing in sewage in an experimental lagoon at the University of Florida had a BOD of 77.8 mg/l in five days. These algae, harvested from 500 ml of water produced a dry weight of 0.0848 gram representing protoplasm, cellulose, and starch. Lackey et al. (1949) are cited to the effect that, after the oyster industry was well established in Great South Bay, the Long Island duck industry located around the Bay. The duck excreta at once began to fertilize the Bay. A heavy algal bloom resulted but the algae were not suitable food, or they produced external metabolites that adversely affected the oysters; thus, an annual four million dollar industry was destroyed. Letts and Adeney (1908) were cited as reporting on the pollution of estuaries and tidal waters by sewage and trade wastes in Ireland and Great Britain and relating the destruction of salmon and sea trout fisheries to the growth of vast beds of macroscopic green alga, *Ulva*, and its subsequent decay. That decay produced intolerable odors, blackened paint and silver in homes, and generally was damaging to real estate values.

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 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.*

Enrichment often results in domination of the algal mass by a relatively small group of blue-green algae that become well established. Most of the adverse effects resulting from an algal mass occur when one species of alga dominates the population.

Fish kills have been reported as attributable to 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/l) in the surface water. Gas emboli were reported to be present in the gill capillaries and gas bubbles 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). For example, in October 1946, tremendous quantities of the blue-green alga, *Aphanizomenon flos-aquae* (Linnaeus), entered the Yahara River from Lake Kegonsa near Madison, Wisconsin, decomposed in passing downstream, and caused oxygen depletion resulting in the death of tons of fish.

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* 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).

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 California; Lake Winnebago, Wisconsin; 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. When 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 shore-line 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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6

Aquatic Plant Pests

PLANT nuisances affecting recreational waters may curtail or eliminate bathing, boating, water skiing, and sometimes fishing; perpetrate psychosomatic illness in man by emitting vile stenches; 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; on occasion become toxic to certain warm-blooded animals that ingest the water; and cause skin rashes and hay-fever-like symptoms in man. 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, brown or even brilliant red 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 3 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." Some of the American freshwater trouble-forming 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 (agal) 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 (a) blue-green algae; (b) green algae; (c) yellow-green algae; (d) golden-brown algae and diatoms; (e) red algae; (f) euglenoids and (g) 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. Then 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 "pig-pen" 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 to 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 (parasitism) and those in which an exchange of benefits apparently occurs between the attached alga and a host plant (symbiosis).

TASTES AND ODORS

From a nationwide survey reported in 1957 (Sigworth, 1957), it was indicated that algae were considered by 241 waterworks officials to be the most frequent causes of tastes and odors in water supplies, with other types of decaying vegetation second in importance. Decay or decomposition is brought about by fungi and bacteria, including the actinomycetales. Often a considerable proportion of the decaying vegetation is composed of dead algal cells. The odors that are produced through the activities of fungi and bacteria may be either from the intermediate products formed during the decomposition or from special substances that are synthesized within the cells of the microorganisms. The latter appears to be true in the case of actinomycetales. Algae were listed as the causative agent in 82 percent of the reports, decaying vegetation in 67 percent, industrial wastes in 38 percent, and other causes in 23 percent.

A few algae are well known for the production of specific distinctive tastes and odors, while a larger number of others are associated with tastes, and odors that vary in type according to local conditions. Often certain diatoms, blue-green algae, and pigmented flagellates are the principal offenders but green algae may also be involved. Thirty-nine species have been selected by Palmer (1959) as representative of the more important taste and odor algae. They are listed alphabetically under their respective groups in Table 7. Other genera and species, in addition to the ones selected, must be considered also as potential offenders.

Silvey (1963) noted a relationship between summer blooms of blue-green algae and rapid growths of actinomycetes three to four weeks later. Most concentrated tastes and odors appear associated with the latter. Silvey and Roach (1964) state that " . . . it has been observed for many years in the literature that the degradation of algal remains may result in a multitude of types and intensities of odors and tastes in the water supply. Some odors are contributed directly by the algal degradation products dissolved in the water, whereas others are merely described as decaying vegetation." Disintegrating algae are associated with increases in gram-negative heterotrophic bacterial populations following which there is generally a new growth of algae, either diatoms or blue-green algae. When blue-green algae predominate and algal mats form on the surface or in protected water areas, actinomycetes attack the remains of the algae thus reducing the gram negative heterotrophic bacteria. Various odors are released, depending upon the predominant organism, its degradation products or metabolites. Silvey and Roach (1964) point out that when a stream or reservoir is highly polluted, one cycle may impinge upon another to the extent that total confusion results if attempts are made to determine what stage of the microbiotic cycle is operating in a particular water supply at a specific time.

Symons (1956) states that 500 to 1,000 areal standard units of odor-producing organisms are generally conceded to cause trouble in water supplies but the range varies widely for different organisms. The Metropolitan Water Commission of Boston was quoted by Symons as setting maximum allowable limits of troublesome algae before control treatment was instigated. For some genera (e.g., *Chlamydomonas*) the level was as low as 10 standards units per ml. For other flagellates such as *Cryptomonas*, *Synura*, and *Uroglenopsis* it was 200; for the blue-green alga, *Aphanizomenon*, the level was 1,000 areal standard units per ml.

FILTER CLOGGING PROBLEMS

As water passes through a sand filter in the water treatment plant the spaces between the grains of sand become filled

Table 7. ODORS, TASTES, AND TONGUE SENSATIONS ASSOCIATED WITH ALGAE IN WATER

Algal genus	Odor when algae are —		Taste	Tongue sensation
	Moderate	Abundant		
Actinastrum		Grassy, musty		
Anabaena	Grassy, nasturtium, musty.	Septic		
Anabaenopsis		Grassy		
Anacystis	Grassy	Septic	Sweet	
Aphanizomenon	Grassy, nasturtium, musty.	Septic	Sweet	Dry.
Asterionella	Geranium, spicy	Fishy		
Ceratium	Fishy	Septic	Bitter	
Chara	Skunk, garlic	Spoiled, garlic		
Chlamydomonas	Musty, grassy	Fishy, septic	Sweet	Slick.
Chlorella		Musty		
Chrysosphaerella		Fishy		
Cladophora		Septic		
(Clathrocystis)				
Closterium		Grassy		
(Coelosphaerium)				
Cosmarium		Grassy		
Cryptomonas	Violet	Violet	Sweet	
Cyclotella	Geranium	Fishy		
Cylindrospermum	Grassy	Septic		
Diatoma		Aromatic		
Dictyosphaerium	Grassy, nasturtium	Fishy		
Dinobryon	Violet	Fishy		Slick.
Eudorina		Fishy		
Euglena		Fishy	Sweet	
Fragilaria	Geranium	Musty		

Glenodinium		Fishy		Slick.
(Gloeocapsa)				
Gloeocystis		Septic		
Gloeotrichia		Grassy		
Gomphosphaeria	Grassy	Grassy	Sweet	
Gonium		Fishy		
Hydrodictyon		Septic		
Mallomonas	Violet	Fishy		
Melosira	Geranium	Musty		Slick.
Meridion		Spicy		
(Microcystis)				
Nitella	Grassy	Grassy, septic	Bitter	
Nostoc	Musty	Septic		
Oscillatoria	Grassy	Musty, spicy		
Pandorina		Fishy		
Pediastrum		Grassy		
Peridinium	Cucumber	Fishy		
Pleurosigma		Fishy		
Rivularia	Grassy	Musty		
Scenedesmus		Grassy		
Spirogyra		Grassy		
Staurastrum		Grassy		
Stephanodiscus	Geranium	Fishy		Slick.
Synedra	Grassy	Musty		Slick.
Synura	Cucumber, muskmelon, spicy.	Fishy	Bitter	Dry, metallic, slick.
Tabellaria	Geranium	Fishy		
Tribonema		Fishy		
(Uroglena)				
Uroglenopsis	Cucumber	Fishy		Slick.
Ulothrix		Grassy		
Volvox	Fishy	Fishy		

with colloidal and solid particles which have been dispersed in the water. When the raw water comes from a surface supply such as a reservoir, lake, or stream, the algae that are invariably present will be well represented in the material collected by the sand filter. They are frequently the primary causes of filter clogging.

Efficient coagulation and sedimentation may remove 90 to 95 percent of the algae from the water. The algae remaining in the water may still be sufficient to cause gradual or even rapid loss of head in the sand filter. The clogged filter must then be backwashed. Filter runs may often extend for 30 to 100 hours before backwashing is required, or may be shortened to less than 10 hours when algae are present (Tarlton, 1949). In Chicago, when the water to be filtered contained approximately 700 microorganisms per ml., principally two diatoms *Tabellaria* and *Fragilaria*, the filter runs were 4.5 hours. Three days later, when the count was down to approximately 100 per ml., the filter run increased to 41 hours (Baylis, 1955). In Washington, D.C. filter runs were reduced from an average of 50 hours to less than 1 hour because of a sudden influx of the diatom *Synedra*, which occurred in the raw water, reaching 4,800 cells per ml (Lauter, 1937).

At Kenosha, Wisconsin microstraining equipment was installed at the water plant at an initial cost of $330,000 primarily to reduce microorganisms prior to filtration (Nelson, 1965). The output of finished water from this plant has been increased by up to 25 percent, thereby providing 5 mgd of extra water for sale to the public during peak demand periods which otherwise would have been used to backwash filters. Algal removals by microstraining have ranged from 46 to 97 percent.

CORROSION PROBLEMS

Algae sometimes contribute to corrosion either directly in localized places where they may be growing or through their modification of the water by physical or chemical changes. Green and blue-green algae, growing on the surface of submerged concrete, have caused the concrete to become pitted and friable. The effect has been most pronounced when the percentage of SO_3 in the mortar was 0.6 or higher. It has been assumed that the gelatin present in the living plants, together with the carbonic, oxalic, and silicic acids produced by them, are adequate to corrode the cement (Oborn and Higginson, 1954).

Algae have been reported to cause corrosion in metal tanks and basins open to sunlight. *Oscillatoria* growing in abundance in water in an open steel tank has caused serious pitting of the metal. The pits were bright and clean, the iron apparently going into solution and not producing any covering compound such as an oxide or sulfide. The algal growth permitted the pitting to take place by releasing oxygen which combined with the protecting film of oxide over the steel. When the steel tank was covered to prevent entrance of light, the algae disappeared and the corrosion stopped (Myers, 1947).

Indirectly, algae may affect the rate of corrosion in a number of ways. Increases in organic deposits in the pipe, increases in the dissolved oxygen in the water through photosynthesis in the raw water supply, and changes in the pH, CO_2 content, and calcium carbonate content of the water can all be stimulated by algae. Such changes can, in turn, affect the rate of corrosion.

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 of gastroenteritis 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 humans 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 occured after the animals had drunk from lakes or ponds containing heavy algal growths, usually during successive days of hot weather. The reported symptoms of algae intoxications vary but the most striking clinically are the involvements of neuromuscular and respiratory systems in cattle. 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 have also been incriminated in human reactions resulting in dysenterial disorders, systemic allergic reactions, and local allergic eruptions (Tables 8, 9 and 10). 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 raw water supply sources.

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 papulovesicular 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.

Fitch et al. (1934) observed that when samples of toxic algae were fed in the fresh state to guinea pigs, rabbits, and chickens, death occurred in a very short time. When toxic algae were stored for a brief period at ice box temperature, or dried, it was further observed that it was almost impossible to produce death by feeding, but with a similar dose, animals could be killed quickly by inoculating intraperitoneally. The specific alga or algae used are not listed.

The syndrome of symptoms described by Fitch et al. (1934) exhibited by guinea pigs from the feeding or from the inoculation intraperitoneally of a fatal dose of toxic algae was: (1) restlessness; (2) urination; (3) defecation; (4) deep breathing; (5) weakness in the hind quarters; (6) sneezing; (7) coughing; (8) salivation; (9) lachrymation; (10) clonic spasms and death.

In studying experimental deaths of guinea pigs, it was noted that they occasionally show symptoms of intoxication and then

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* 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 8. 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, epigastic 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.
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 gastrointestinal upset.
1959	Govan, Long Lake, Saskatchewan, Canada (Dillenberg, 1959; Senior, 1960).	Ten children at a camp..	*Anabaena*	Diarrhea and vomiting.
1959	Fort Qu'Apelle, 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 10.

Table 9. 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, coughing, chest tighteness, 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, Wis., 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 of throat, nostrils and eyes, sneezing and coughing.

1946-1947	West Coast of Florida, U.S.A. (Hunter 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 10.

Table 10. 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.

recover. The syndrome of symptoms in pigeons observed by Fitch et al. (1934) was: (1) immediate restlessness; (2) immediate blinking of eyes; (3) immediate repeated swallowing, at times accompanied by regurgitation; (4) in from 9 to 10 minutes loss of balance; falling on breast; head drawn back; (5) clonic spasms and death.

Wheeler et al. (1942) working with animals and fresh *Microcystis aeruginosa* filtered from sample water and resuspended in just enough water to flow through a 16 gauge hypodermic needle, made the following observations: (1) mice were invariably killed when either a subcutaneous or intraperitoneal dose was more than 0.25 ml, death occurring rarely in less than 16 hours or more than 36 hours; (2) a guinea pig given a 2 ml intraperitoneal dose died in 24 hours; (3) a rabbit given a 5 ml intraperitoneal dose showed no ill effects; (4) guinea pigs given 4 ml oral doses showed no ill effects; (5) mice given algae orally by a blunt needle or by adding algae to drinking water nearly always survived; and (6) injections of pond water after the alga was filtered off did not affect animals.

Olson (1952) points out that the toxicity of unpurified algal material from field collections varies a great deal. For example, 0.02 ml injected into mice intraperitoneally may kill a 20-gram individual in an hour, whereas of another sample it may require 2.0 to 3.0 ml to produce death in 18 hours. Certain samples of toxic algae (0.1 ml fatal dose) taken from a lake 1 day may kill mice in 20 minutes, whereas 9 days later, samples from the same lake with a greatly increased dosage (2.0 ml) may require 5 hours to produce death.

The poisoning of wild and domestic animals by a toxic waterbloom of *Nostoc rivulare* Kuetz from a pond in central Texas has been described by Davidson (1959). Cattle, fish, frogs, and fowl that drank the water containing a heavy growth of the alga became acutely ill, and many died within a short period of time. Most of the accompanying symptoms were similar to those described for a number of other toxic waterblooms. Intraperitoneal injections of albino mice with fresh algal material or with extracts prepared from preserved material produced symptoms that were uniform. The characteristic symptoms were restlessness, increased respiratory rate, renal and intestinal disorders, decrease in blood sugar, decrease in blood coagulation time, decrease in red blood cell count, increase in the rate of heart beat, and paralysis of the hindquarters. Subcutaneous injections resulted in complete necrosis of the abdominal wall, including the skin. The mice that survived developed tumors on the shoulders; two experienced evisceration; and the eye of one completely atrophied.

The minimal lethal dosage of the fresh alga was found to be 0.0933 mg/g of body weight in mice. The toxic factor was soluble in ethanol or water and was rendered inactive when autoclaved at 15 psi pressure for 20 minutes. It affects the neuromuscular and respiratory systems of albino mice.

Toxic algae as a public health hazard are reviewed by Gorham (1964). He concludes that the fish and livestock poisons produced by waterblooms are nuisances and economic hazards rather than public health hazards. It was estimated that the oral minimum lethal dose of decomposing toxic *Microcystis* bloom for a 150-pound man would be 1- to 2-quarts of thick, paint-like suspension. Gorham states that this amount would not be ingested voluntarily; however, in the case of an accident, such a quantity might be ingested involuntarily.

Aquatic Vascular Plants

In the long-term cycle of the change in the aquatic terrain there is a continuing tendency for the land to encroach upon shallow ponds and shallow areas of lakes, decrease their size, make them more shallow, and eventually return them to dry land. Rooted aquatic vegetation plays a prominent role in this gradual process by invading shallow water areas through entrapment of particulate silt that is carried into lakes and ponds. The rooted vegetation will continue to spread as water areas become more shallow and the bottom mud provides suitable anchorage for roots. Plants contribute also to the filling in of lakes through both the precipitation of calcium carbonate and the accumulation of their remains upon death and decay.

While these lake invasion and encroachment activities by higher aquatic plants may sometimes be sufficiently rapid to be recognized by those who habitually use the lake, the common objections to rooted vegetation stem from their immediate interference with recreational use such as outboard motor propeller clogging, and encroachment on navigation channels and swimming beaches. The depth of water determines the adjustment of aquatic seed plants into three principal categories. Emergent weeds are those that occupy shallow water, are rooted in bottom mud, and support foliage, seeds and mature fruit one or more feet above the water surface. Cattails and rushes are familiar examples. Surface or floating weeds generally grow in deeper water at the front of (and oftentimes commingling with) the emergent weeds. The larger floating weeds are waterlilies that may be rooted in the mud of the bottom and bear large leaves that float upon the surface. Smaller types such as the duckweeds are free-floating. Submerged aquatic growths often form a belt or zone of herbage farthest from shore. Except for those forms that dwell in quiet waters, they are rooted to the bottom. Depth varies considerably within this zone and may extend down to the limits of effective light penetration. Submerged varieties are those which often create the most severe nuisance.

Physical factors, such as light intensity, water temperature, wave action, flow velocity, water depth and type of substrate, all interact to govern establishment of weed beds or weed sparsity, and determine the rate at which they grow. Many submerged plants continue active in winter, provided ice and snow cover are not sufficiently opaque to reduce light penetration so that growth is impeded. Once established in an area, rooted aquatic plants exhibit a high degree of persistence and efficiency of propagation. Some reproduce only by means of seeds formed in insect-pollinated flowers borne at or above the water surface; others may propagate by buds, tubers, roots, and node fragments in addition to producing viable seeds. 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.

Higher aquatic plants are most abundant in old lakes or those fertile water bodies in which there has been thick deposition of soil from land erosion. Higher plants provide food, shelter and attachment surfaces for other organisms, and dissolved oxygen to the water under favorable light conditions (from their underwater green portions), remove and temporarily store nutrients, and serve as spawning or as schooling areas for some fish. Plant populations may become sufficiently dense to limit or restrict water use by physical obstruction, to remove large quantities of water through transpiration, and to contribute to the stunting of fish populations. Upon death and decay, stored nutrients are released for the development of new generations of aquatic biota.

Dispersal of water plants is accomplished largely by water transport, 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, when, in settling out of water, it roots again on a suitable substrate. Most aquatic plants are perennials and are well adapted to withstand 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 foilage 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 6 of the States and in 1 Canadian province reported that nearly half the food consumed was derived from the higher freshwater plants (table 11).

For many years, aquatic and bank weeds in irrigation and drainage systems in the western States have caused serious financial losses annually (Timmons, 1960). Submerged waterweeds such as pondweeds (*Potamogeton* spp.) reduce the flow in channels, causing higher water levels, breakage in canal banks, increased seepage into adjoining croplands, greater losses of water by evaporation and inadequate delivery of irrigation water to farms or inadequate drainage of water from croplands. Decreased flow velocity causes increased sedimentation;

Table 11. 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		

this reduces capacity and makes more frequent mechanical cleaning necessary. Algae and weed fragments clog sprinklers, pumps, screens, valves, and pipes, and create problems at pumping plants in irrigation and drainage systems. Emergent aquatic weeds such as cattails (*Typha* spp.) and bank weeds, and phreatophytes like willows (*Salix* spp.) and salt cedar (*Tamarix pentandra*) transpire tremendous quantities of water from canals and reservoirs into the dry air. Weeds prevent proper inspection and maintaince of irrigation and drain canals.

A survey conducted in 1948 by the Bureau of Reclamation of the U. S. Department of the Interior (Balcom, 1950) showed that nearly 150,000 acre-feet of water was lost each year by evapotranspiration in the Bureau's 14,075 miles of canals and laterals because of weeds. By assigning a productive value of $20 per acre-foot to this lost water and adding the cost for ditch-bank repairs and damage to flooded crops attributed to weeds, the loss in irrigation systems built by the Bureau of Reclamation was estimated at nearly $3 million annually. When these losses were projected to all irrigation systems in the 17 Western States, by using the 1940 Census figures of 120,386 miles of unlined canals, an estimate of $25.5 million loss annually because of weeds was obtained.

In 1957 these figures were updated (Timmons, 1960). The total annual water loss from transpiration, increased evaporation, and overflows because of aquatic weeds in the 17 Western States was estimated at 1,966,068 acre-feet; this would have been sufficient to irrigate 330,000 to 780,000 acres of cropland depending upon the length of the growing season, evaporation losses, and other factors. The total cost of losses caused by weeds for the 17 Western States was estimated at $5,739,164.

The total cost of weed control in the 17 Western States was $8,113,297. The expenditure for control of ditchbank weeds was more than three times the expenditure for aquatic weed control. The average cost per mile of treating aquatic weeds ranged from $11.08 in one region to $121.42 in another averaging $42.36 for all regions. The cost per mile also varied greatly for different species of aquatic weeds and methods of control. The methods used included drying, handcutting and cleaning, and chaining, draglining, and treating with chemicals. The cost of ditchbank weed control averaged $21.45 per acre for all regions. Methods of controlling ditchbank weeds included hand cutting, mowing, burning, and spraying. When losses from weeds of $5,739,164, are added to the cost of weed control, $8,113,297, the total expenditure related to weed pests was $13,852,461 in the 17 Western States for 1957. This is the actual cost to the water user of water lost and other direct costs caused by weeds and expenses involved with weed control in irrigation systems.

Infestations of Eurasian watermilfoil have become a serious threat to ponds, lakes, and tidewater areas by reducing their use for recreation, as well as hampering navigation, diminishing the size of open waterfowl feeding areas and reducing the value of waterfront real estate (Anon., 1966). Since 1961, watermilfoil has doubled its water surface coverage in the Maryland tidewater area and now inhabits an estimated 100,000 acres. Heavy concentrations of this weed also have been found in the waters of New Jersey, New York, North Carolina, Alabama, Indiana, Ohio, California, and Texas. In the Tennessee Valley Authority watershed, reservoir infestations have demanded major control programs. Eurasian watermilfoil was first found in this country in 1902. It can sprout from seeds, creeping rhizomes, or from a stem having a single joint or node. Seeds have been found to remain viable even after passing through the digestive tracts of migratory waterfowl.

A summary of aquatic nuisance control activities on Wisconsin Lakes for 1965* indicates the use of 101,947 pounds of arsenic

* Lloyd A. Lueschow, personal correspondence.

trioxide and 71,279 pounds of commercial copper sulfate on 130 water bodies. Thus, minimal control of aquatic nuisances to protect recreational use of water in this one State can be estimated to approach $70,000 annually.

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7

Recognizing some Aquatic Nuisance Algae

AN ARTIFICIAL key is presented for some of the algal genera commonly encountered in recreational waters. Because of a preponderance of genera associated with the fresh-water environment, other English-language publications useful in supplying descriptive details and pictures for identification are listed. These include Forest (1954), Palmer (1959), Patrick and Reimer (1966), 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. Choosing the one that best fits the specimen, 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 per-

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

mitting 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

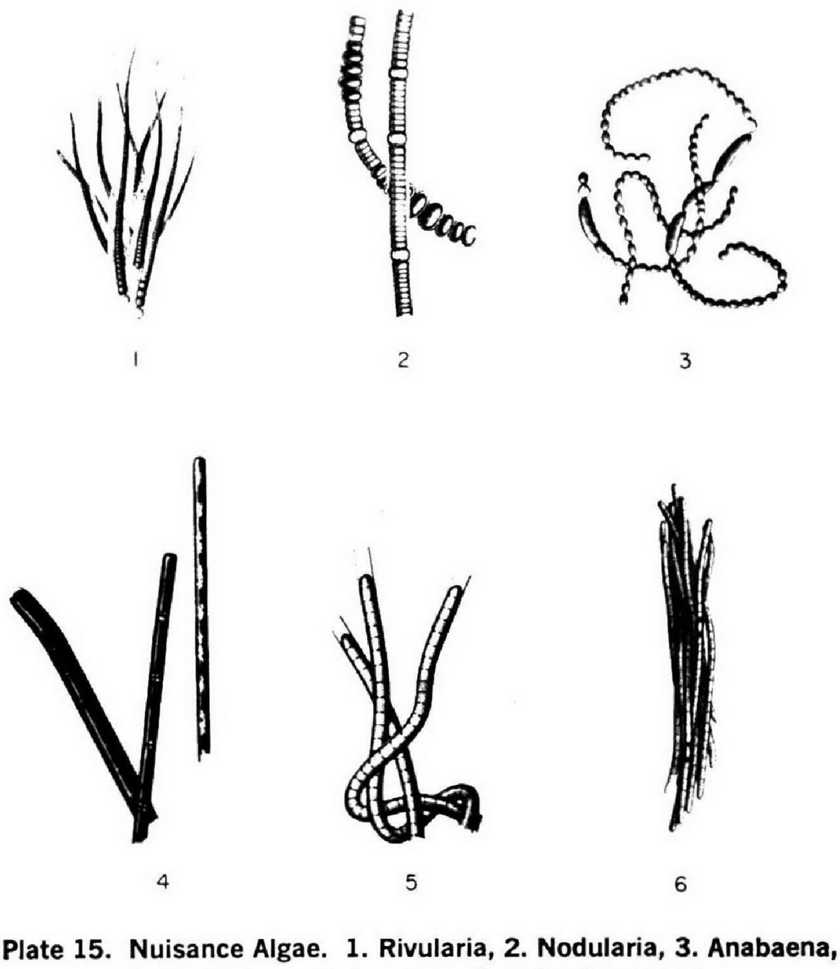

Plate 15. Nuisance Algae. 1. Rivularia, 2. Nodularia, 3. Anabaena, 4. Oscillatoria, 5. Lyngbya, 6. Aphanizomenon.

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

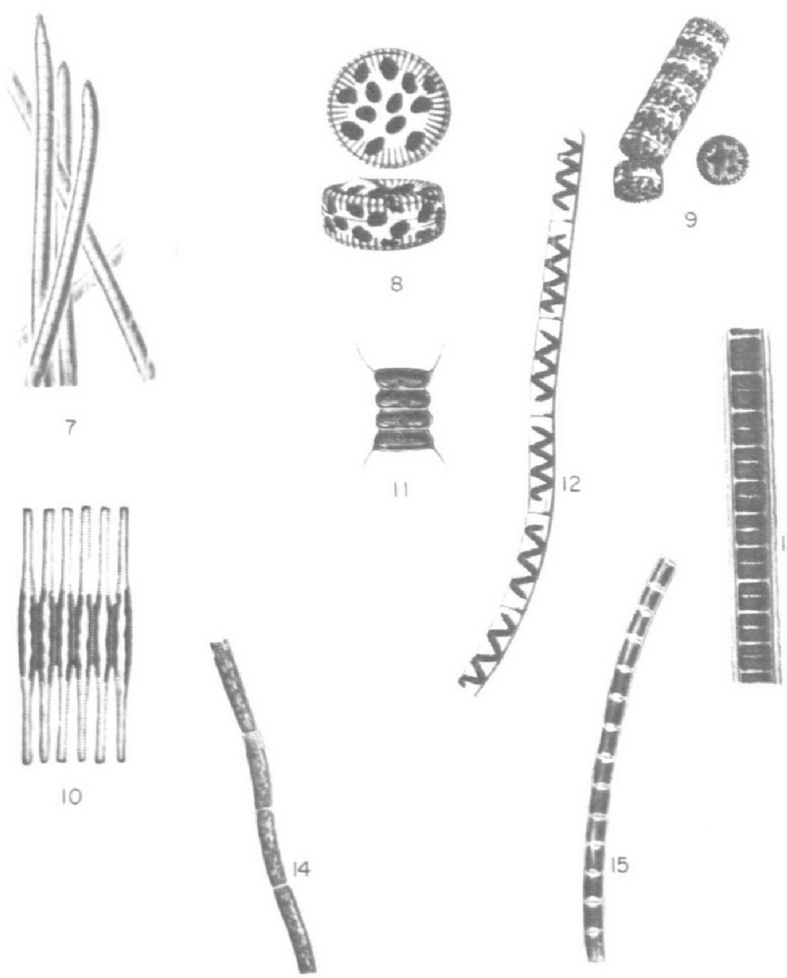

Plate 16. Nuisance Algae. 7. Phormidium, 8. Cyclotella, 9. Stephanodiscus, 10. Fragilaria, 11. Scenedesmus, 12. Spirogyra, 13. Zygnema, 14. Oedogonium, 15. Ulothrix.

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*

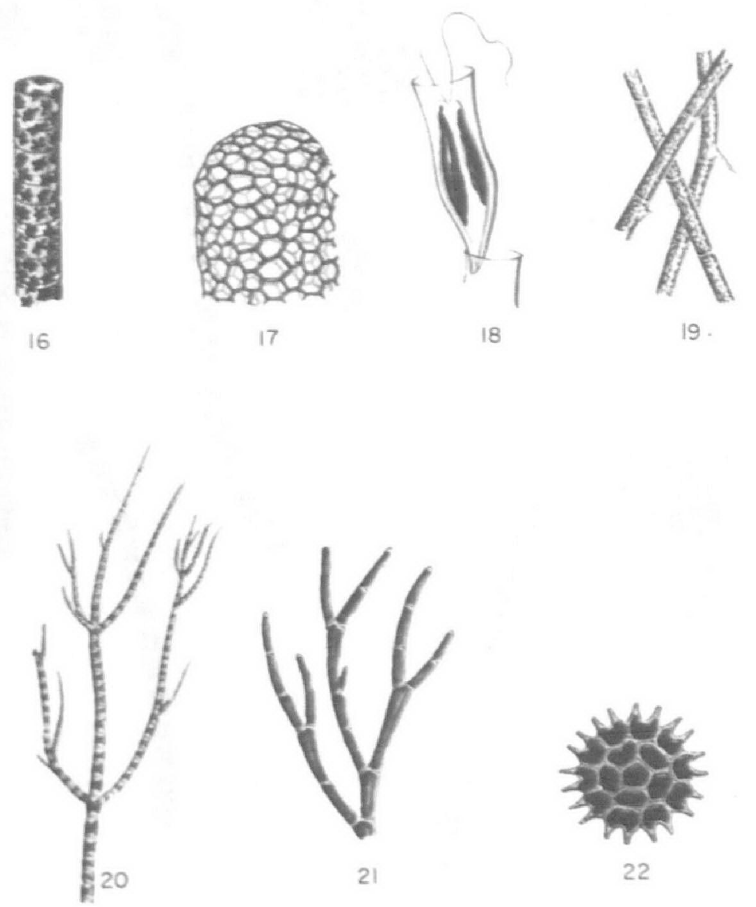

Plate 17. Nuisance Algae. 16. Melosira, 17. Hydrodictyon, 18. Dinobryon, 19. Rhizoclonium, 20. Stigeoclonium, 21. Cladophora, 22. Pediastrum.

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*)

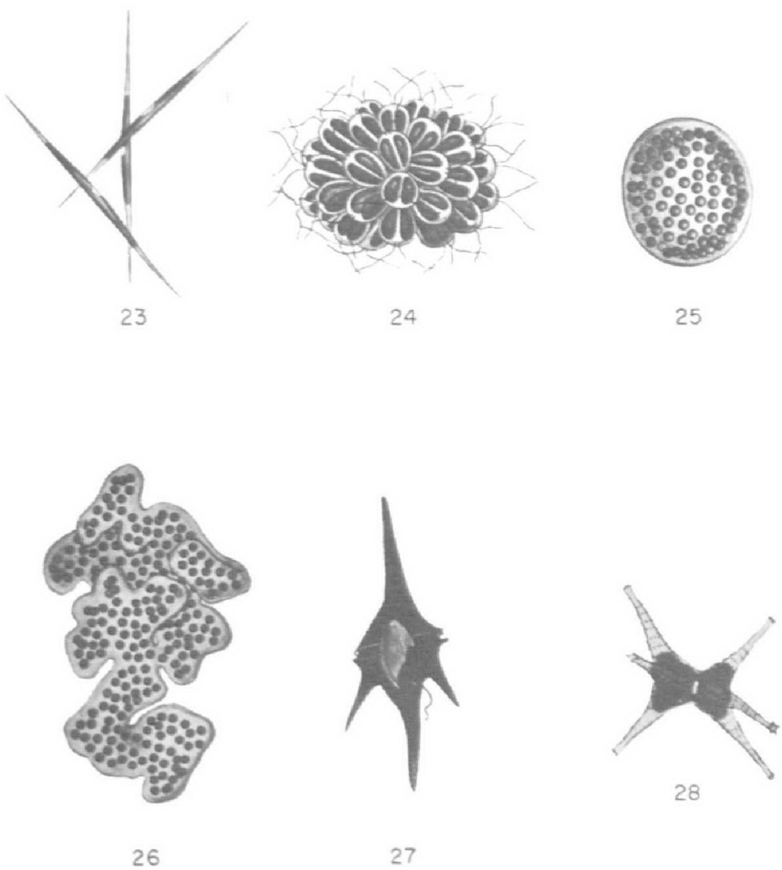

Plate 18. Nuisance Algae. 23. Ankistrodesmus, 24. Synura, 25. Coelosphaerium, 26. Microcystis, 27. Ceratium, 28. Staurastrum.

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8

Recognizing Some Common Higher Aquatic Plants

SPECIFIC identification of aquatic plants is possible sometimes only through the examination of minute plant parts by specialists.

A key is presented that will aid the non-systematist 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), Mason (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 unidentified specimen.

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

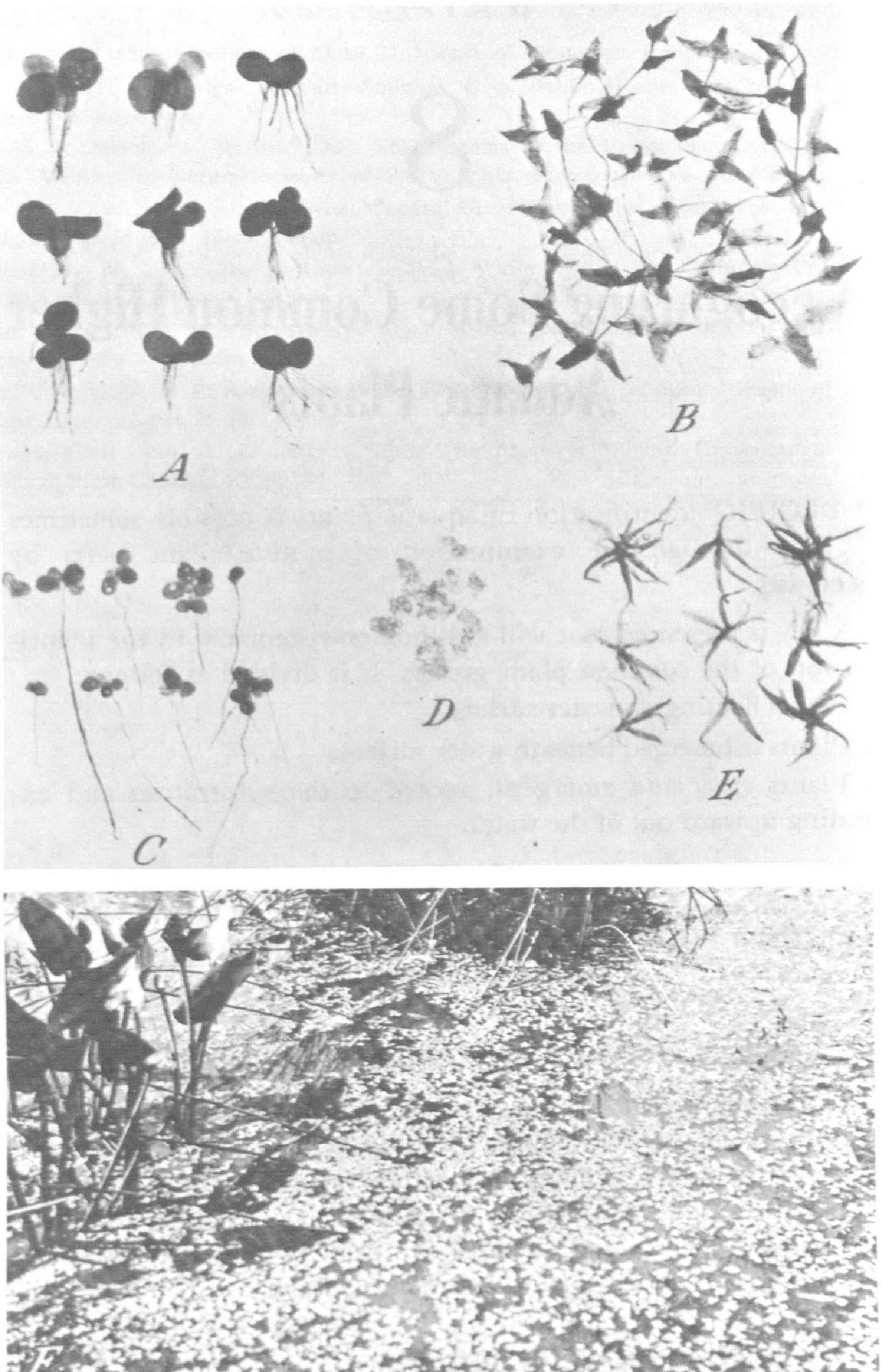

Plate 19. Duckweeds (Lemnaceae) A. Big duckweed [Spirodela polyrhiza (Linnaeus)]; B. Star duckweed (Lemna trisulca Linnaeus); C. Duckweed (Lemna); D. Watermeal (Wolffia); E. Wolffiella; F. Big duckweed on a Maryland pond.

The duckweed group includes the smallest of the aquatic flowering plants. They have neither 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 such streams 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 physically obstructs 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" of one plant upon another. Wind or currents aid greatly in dispersing 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 nonfilamentous miscroscopic 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 triscula* 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*
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*

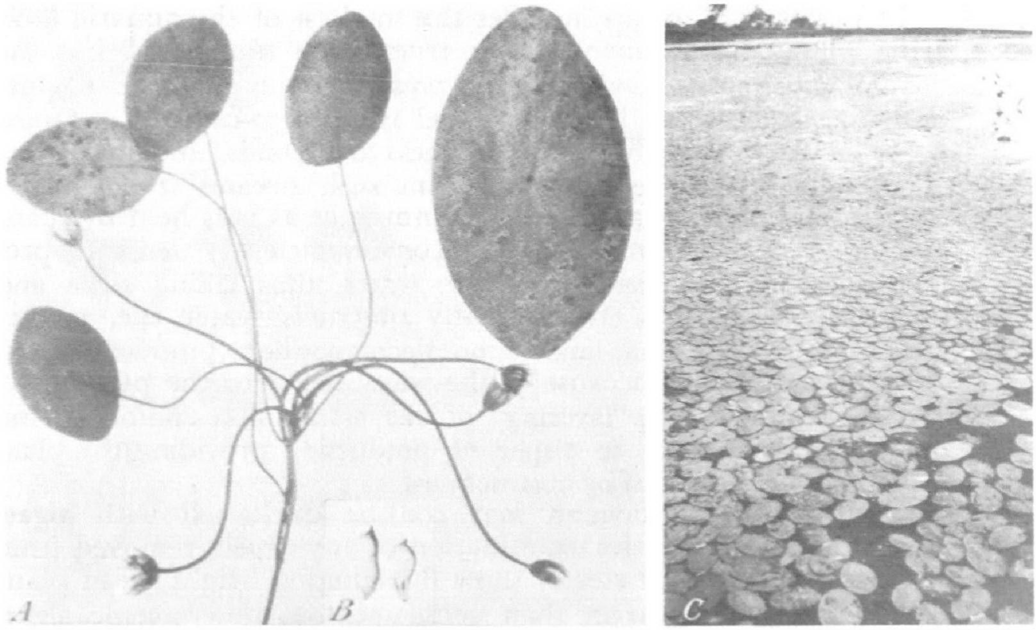

Plate 20. Watershield (Brasenia schreberi Gmelin) X ⅜.

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*

Plate 21. American Lotus (Nelumbo).

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
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
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*

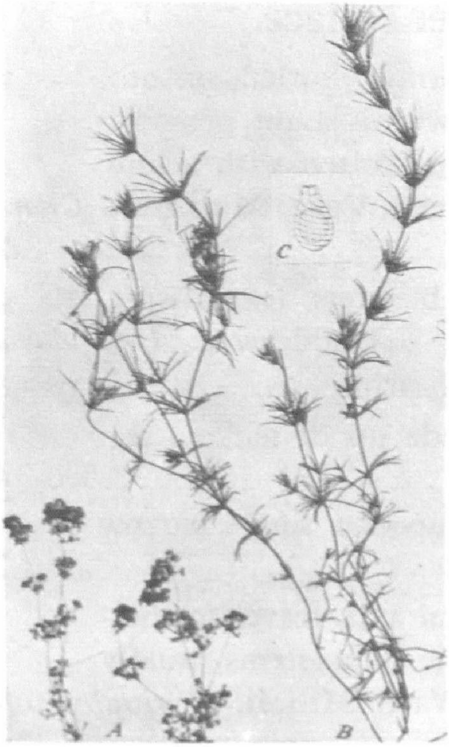

Plate 22. Muskgrass (Chara) (An Alga)

Plate 23. Bladderwort (Utricularia)

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
12. 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 awl-shaped tip ..Pondweed, *Potamogeton angustifolius* Berchtold
14. Margins of the thin leaves crimped and toothed, the marginal serrations visible to the naked eye
Curly-leafed Pondweed, *Potamogeton crispus* Linnaeus
14. Margins of leaves not visibly toothed 15

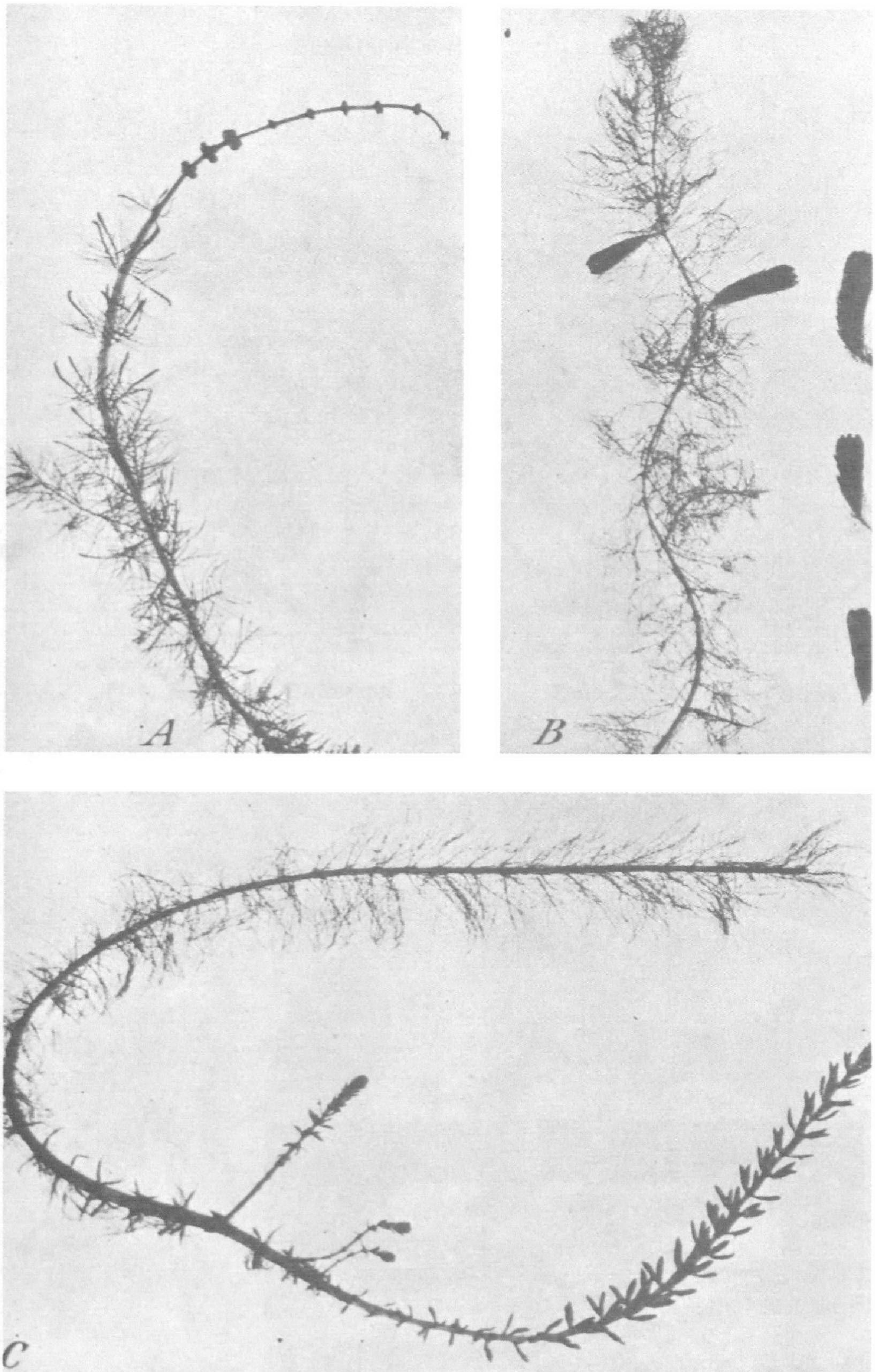

Plate 24. Water Milfoil X ⅓: A. *Myriophyllum spicatum* Linnaeus; B. *M. verticillatum* Linnaeus; C. *M. heterophyllum* Michaux.

Plate 25. Coontail (Ceratophyllum) X ⅖.

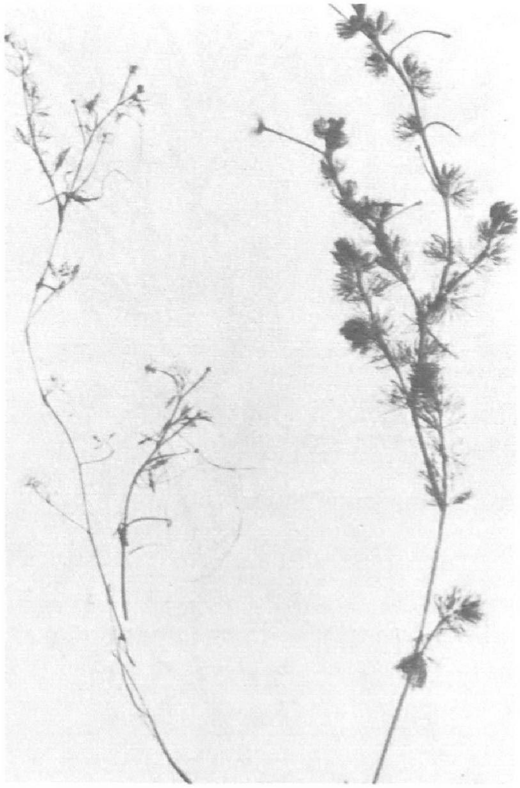

Plate 26. Water Buttercup
(Ranunculus)

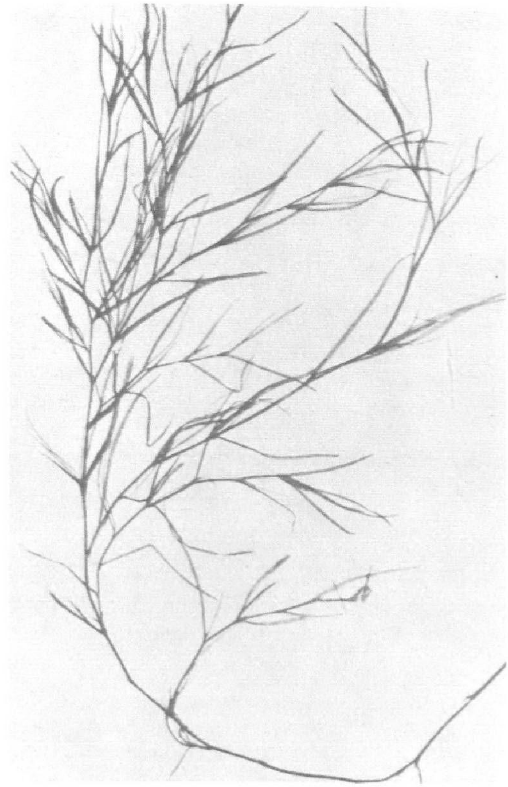

Plate 27. Water Star Grass
(Heteranthera).

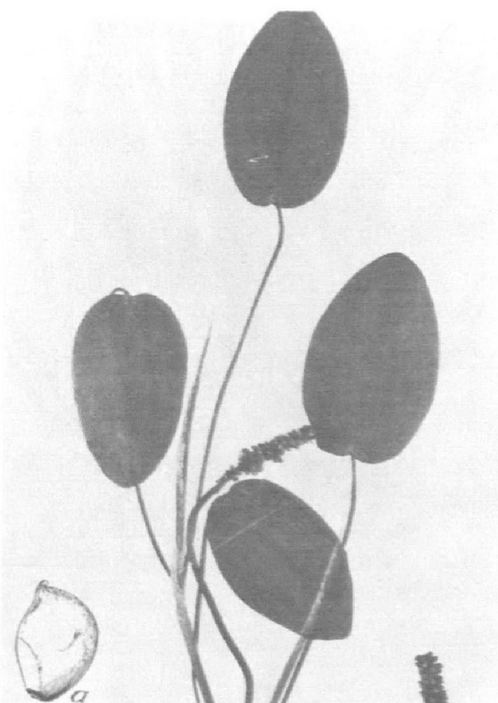

Plate 28. Floating-leafed Pondweed
(Potamogeton natans Linnaeus).

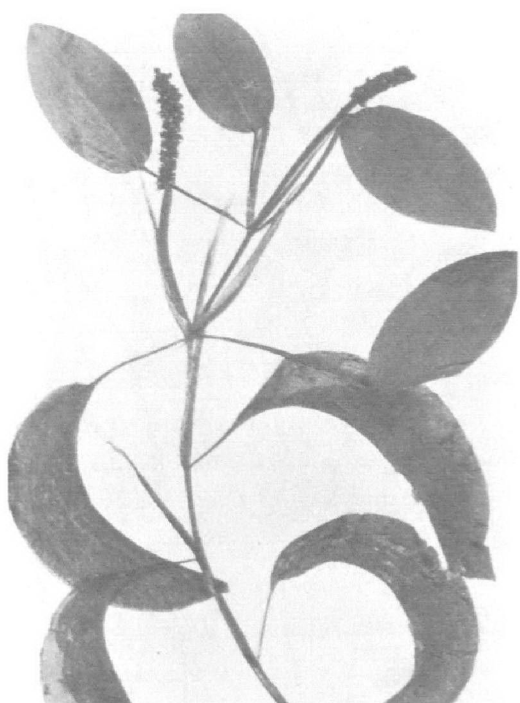

Plate 29. Large-leafed Pondweed
(Potamogeton amplifolius Tuckerman)

Plate 30. Curly-leafed Pondweed (Potamogeton crispus Linnaeus).

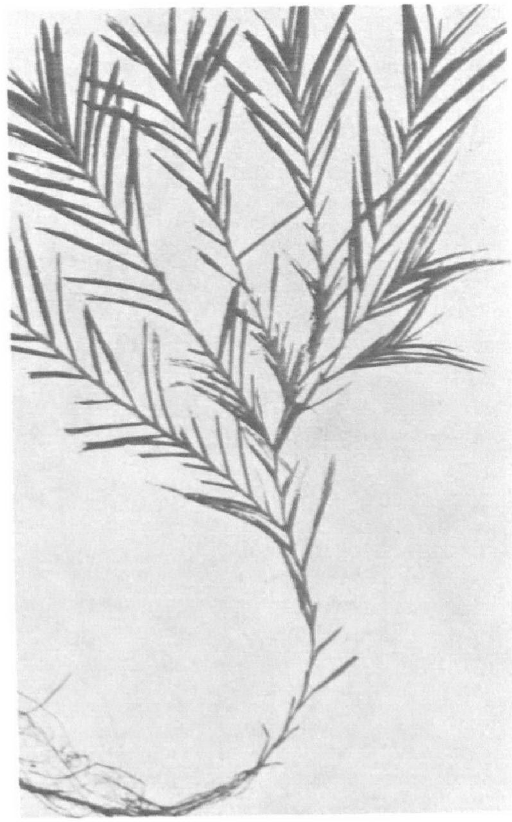

Plate 31. Robbins Pondweed (Potamogeton robbinsii Oakes).

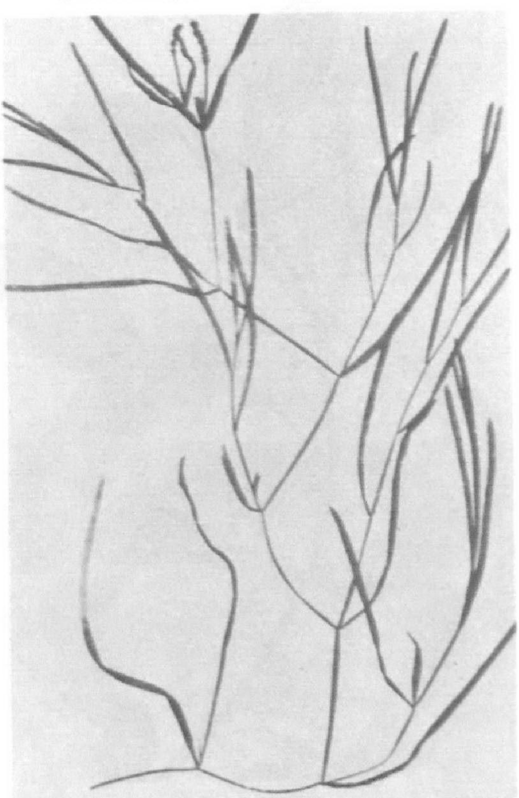

Plate 32. Flat-stemmed Pondweed (Potamogeton zosteriformis Fernald)

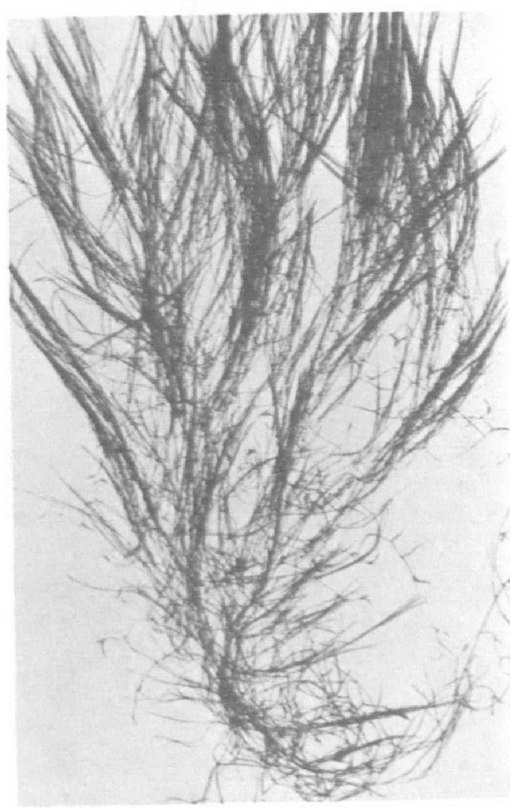

Plate 33. Sago Pondweed (Potamogeton pectinatus Linnaeus).

Plate 34. Wild Celery (Vallisneria) X ¼: A. Specimen with fruit and tubers; C. Northern form; D. Southern form.

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 distinguished sago pondweed from others of 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*)

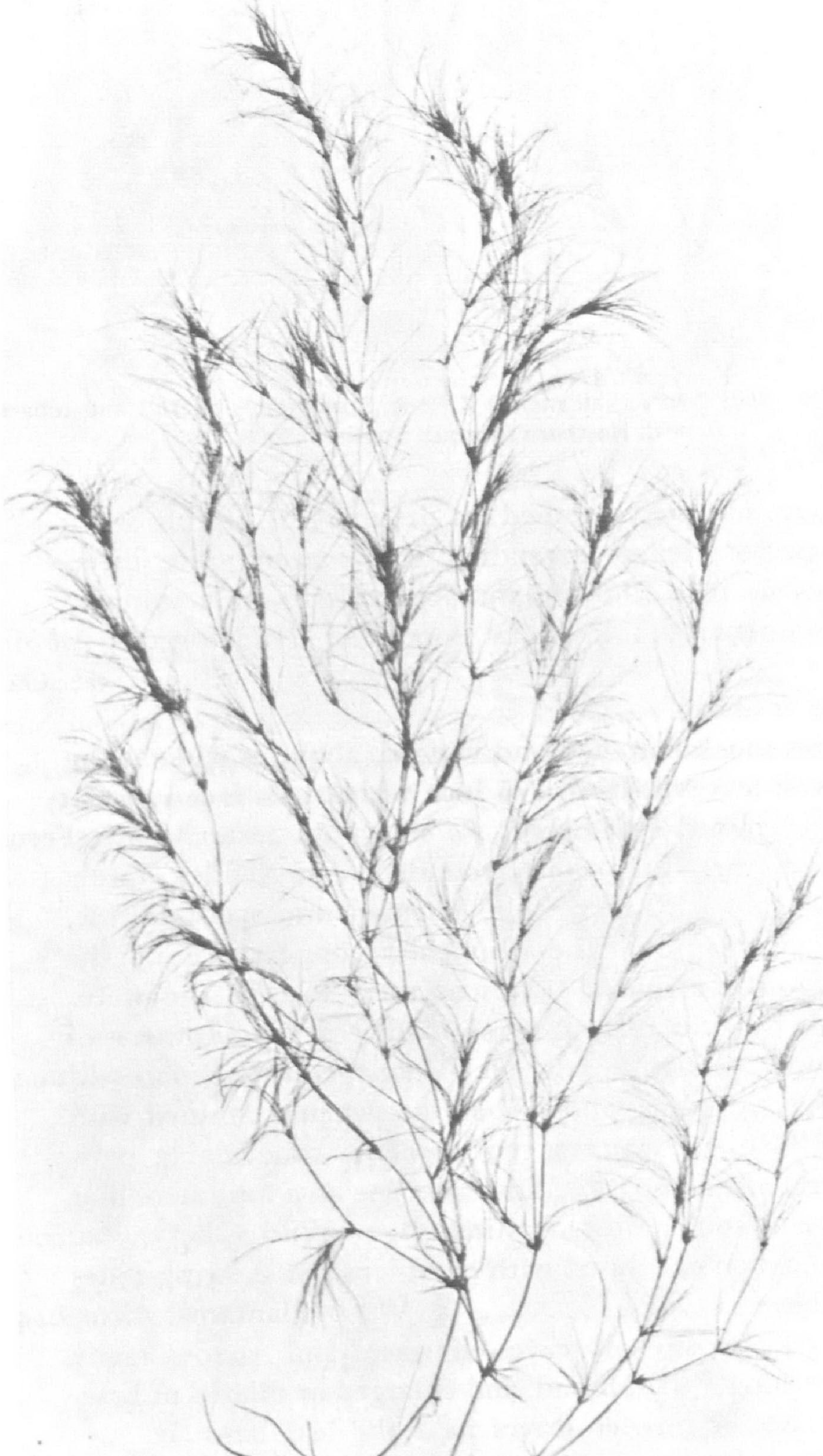

Plate 35. Bushy Pondweed (Najas) X ⅝.

Plate 36. Waterweed X ⅗: A. Anacharis canadensis Michaux, B. A. occidentalis Pursh.

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 grasslike plant ....Sedge, *Carex*
3. Seeds not enclosed in a loose elongated sac 4
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, 1/8 to 3/8 inch at the base, extending 3 to 5 feet above the water surface; the softstem bulrush has soft stems of light green color, 3/10 to 1 inch thick at the base.)

Plate 37. Spike Rush (Eleocharis).

Plate 38. Bulrush (Scirpus)

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*

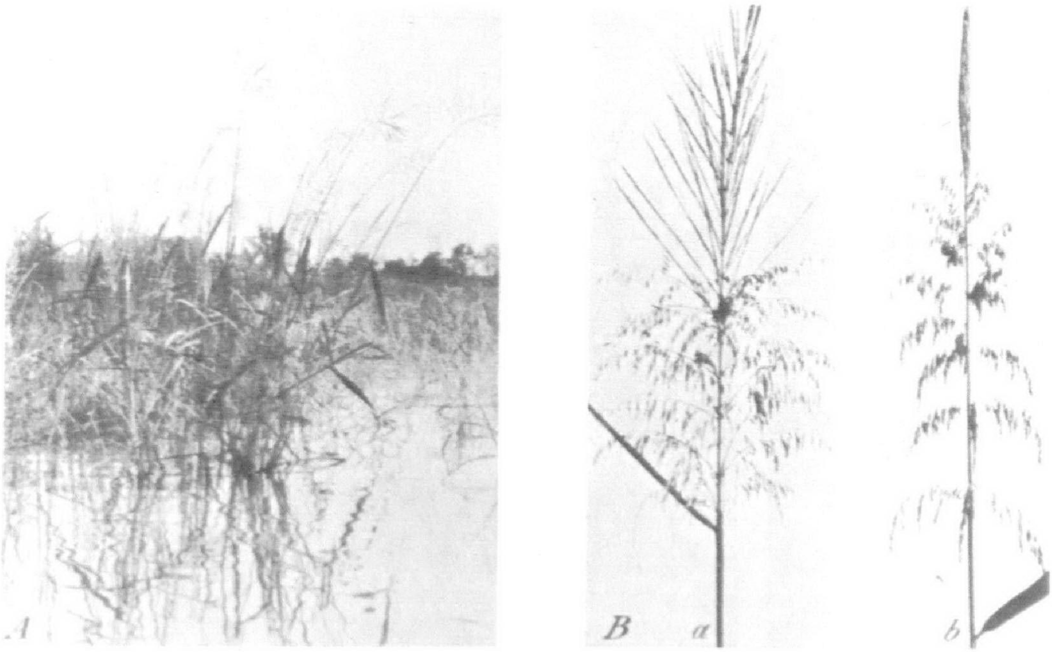

Plate 39. Wild Rice (Zizania): A. Stand of Broad-leaved form; a. broad-leaved; b. narrow-leaved form.

7. Flowering part of plant much branched, but not as closely packed as in *Phragmites.* Seeds much larger, about 3/4 inch long. Plants with short roots and easily pulled up .... Wild Rice, *Zizania*
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*
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 bladderlike .... Waterhyacinth, *Eichhornia*
12. Plants with floating rosettes of stalked leaves, commonly several rossettes 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*

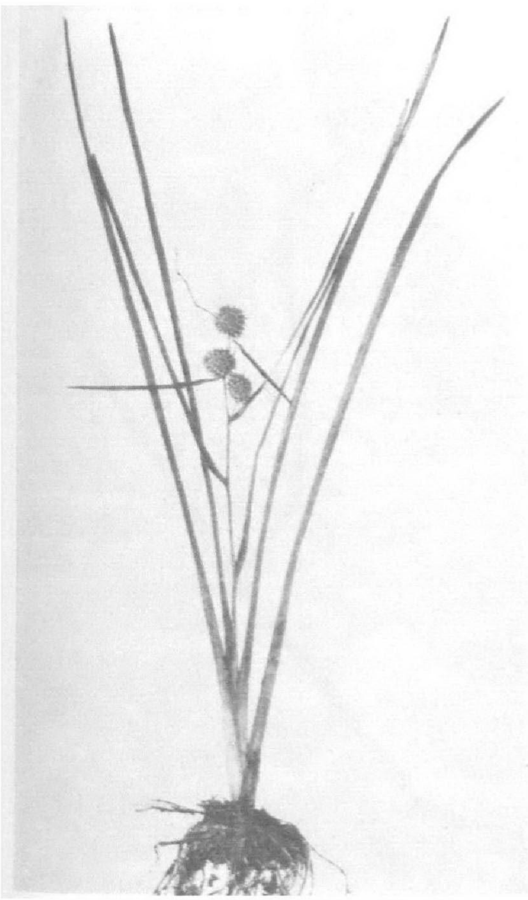

Plate 40. Burreed (Sparganium).

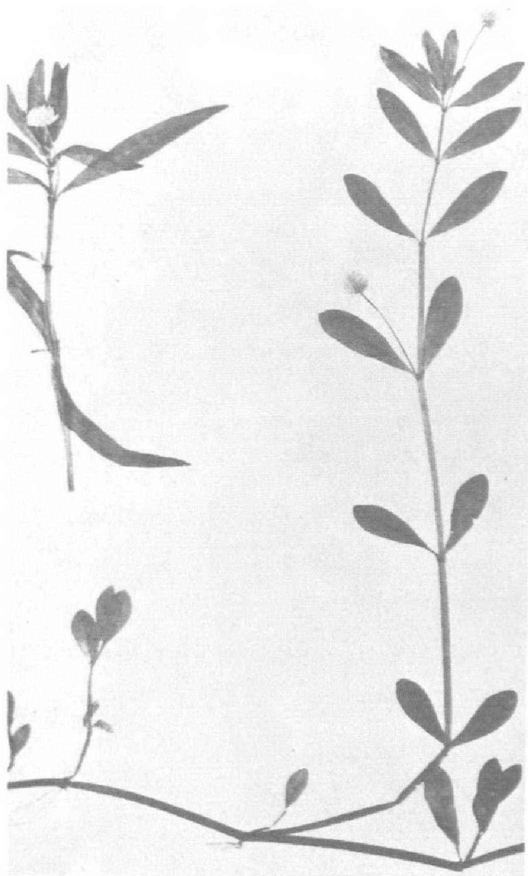

Plate 41. Alligatorweed (Alternanthera).

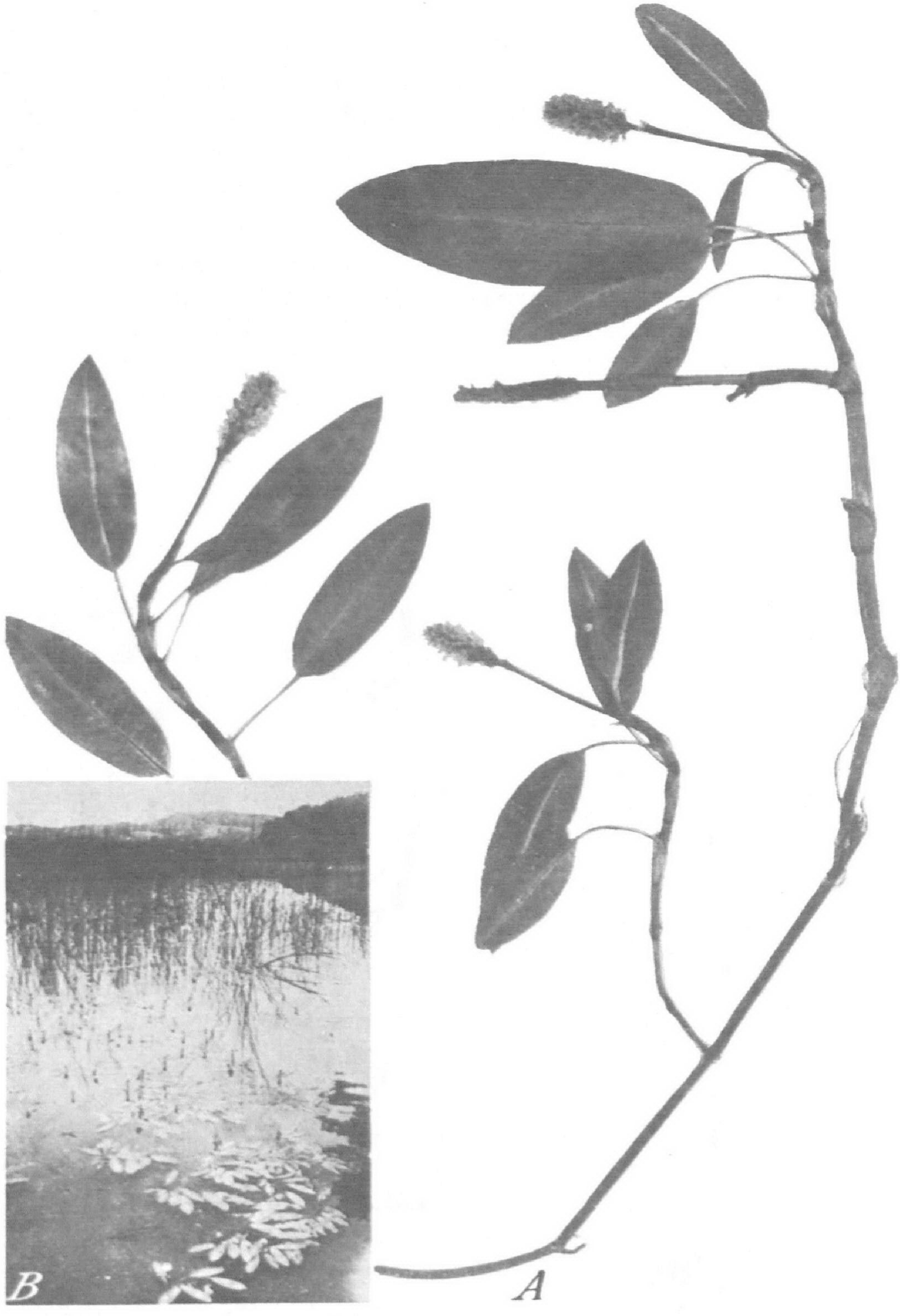

Plate 42. Smartweed (Polygonum) X ⅖.

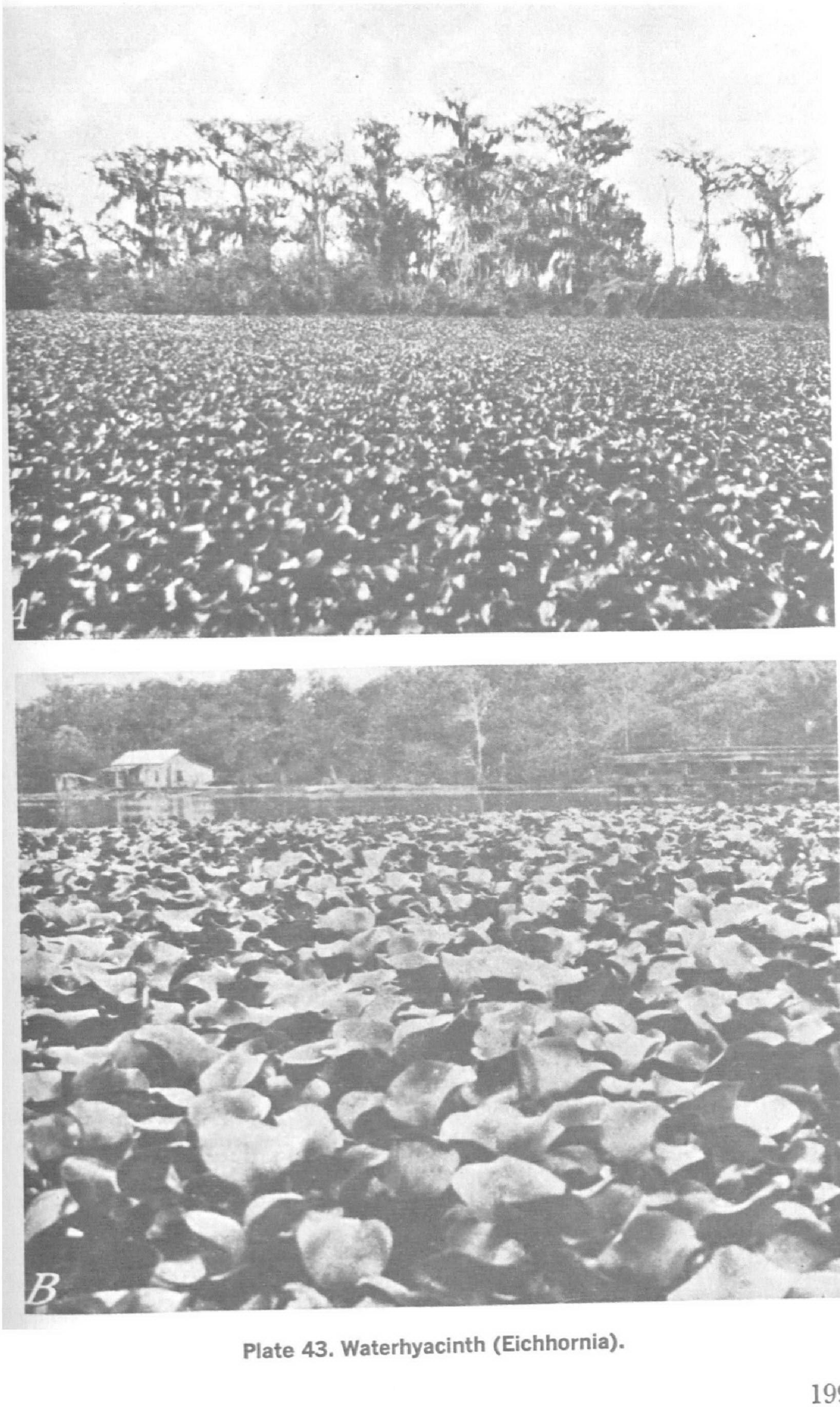

Plate 43. Waterhyacinth (Eichhornia).

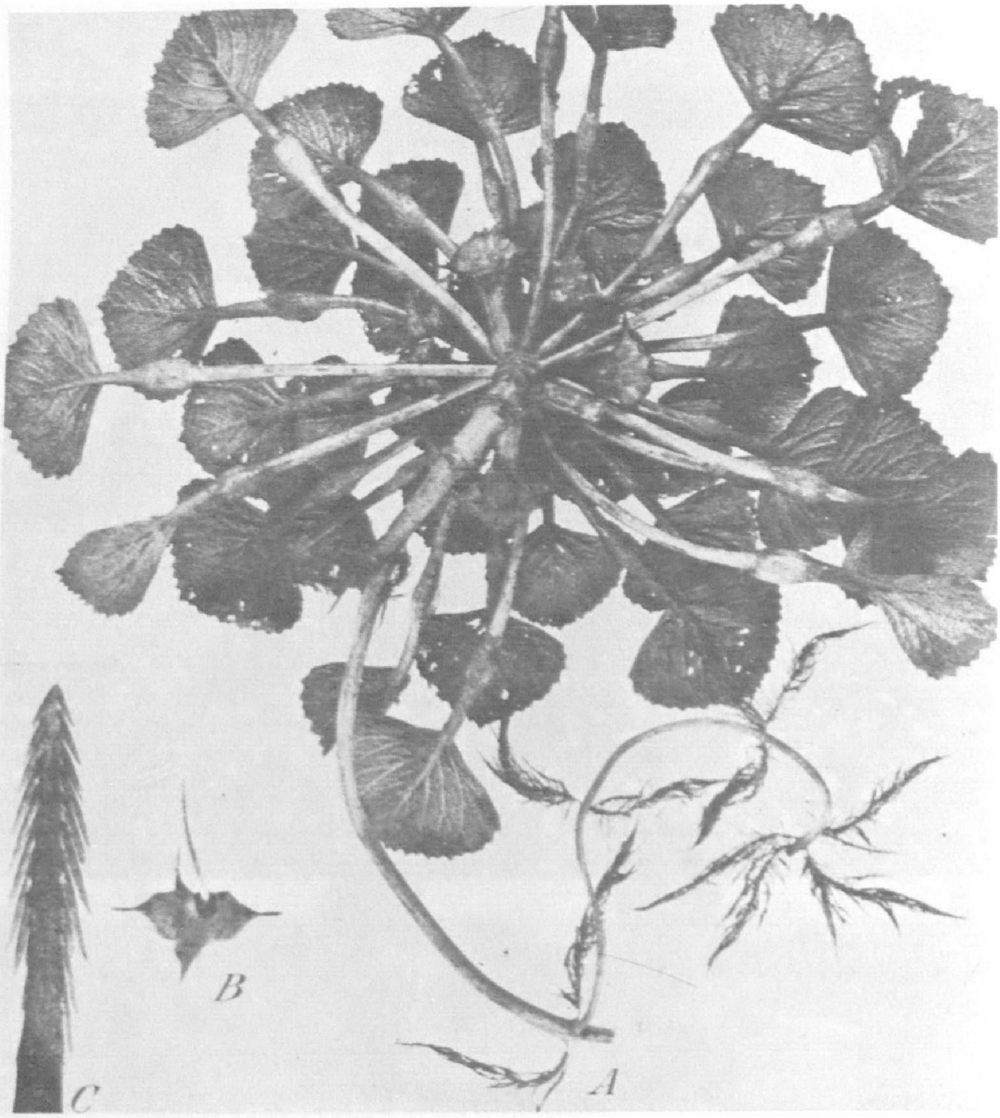

Plate 44. Waterchestnut (Trapa) X ¼.

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9

Some Aquatic Animal Pests

WHEN aquatic animals become abundant, they become pests and nuisances to men because of their biting habits and their sheer mass of numbers. Some aquatic animals serve as intermediate hosts for parasites that may attack man directly and some service as vectors of diseases that affect the health of man. The more important oganisms and the associated problems that they cause are discussed in this and the following chapter.

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 because 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 grass and ornamental plants near their 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, Florida, 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); Provost

(1958) attributed its overproduction to excessively fertilized 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 *Chironomus tentans* (Fabricius), another troublesome midge, extended from the last of April to about the first of October in the vicinity of Ithaca, New York. 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 hordes of adult midges have been known to get into children's eyes and noses, turn houses black with insects, and literally stall 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, California, for many years and has adversely affected a large resort business (Hunt and Bischoff, 1960). Clear Lake has an area of over 41,600 acres. Walker* 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 3-½ 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 (dichlorodiphenyl dichloroethane) at a concentration of 1 part of active insecticide 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, *Chironomus plumosus* (Linnaeus), have plagued residents and industries in the Lake Winnebago area of Wisconsin for years. Winnebago is a large, shallow, fertile lake of 137,000 acres. 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 fishes, water fowl 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.

Various species of midges have become established as significant nuisance problems in San Mateo County and many other suburban areas throughout California (Whitsel et al., 1963).

• 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).

Midge production at all stations in a study of the problem area, was preceded by a pronounced increase in accumulated organic matter. Water known to be polluted with sewage wastes was found to have over 1100 larvae per square foot of substrate. Man-made drainageways were found to produce greater midge infestations than natural drainage creeks. Localized chemical applications were reported to be successful in control practices. "Chemical control by granular Baytex 0.1 and 0.2 lb. per acre provided fairly effective reduction of *Chironomus* larvae in impounded and slowly-moving waters, with no harm to mosquito fish, *Gambusia affinis.* Granular dieldrin showed promising control in slowly-moving waters, with little harm to Gambusia and aquatic invertebrates at 0.5 lb. per acre."

The use of carp and goldfish stocked at rates of 150 to 500 pounds of fish per acre for midge control in water-spreading basins was found to be of only short-term advantage (Bay and Anderson, 1965). Other factors, including pond siltation, filamentous algae, and natural enemies tended to maintain the larval populations at the same level as did the carp.

Mayflies And Caddisflies

Mayflies and caddisflies are among those organisms to which water pollution biologists apply the term "clean-water-associated" animal assemblages. Because of biological or climatic phenomena, or both, these organisms may cause nuisances.

There are over 550 species of mayflies known from North America north of Mexico (Burks, 1953). Occasionally, reports Burks, over a period of years, adult mayflies have caused damage in certain local areas. Unusual hordes of these insects may leave the water on the first suitable day after adverse weather conditions. The adults are fragile insects that die within a few hours; when occurring in hordes their dead bodies may clog ventilator ducts and sewers and may also cause temporary traffic difficulties. On July 23, 1940, at Sterling, Illinois, mayflies piled as high as 4 feet blocked traffic over the Fulton-Clinton highway bridge for nearly 2 hours. Fifteen men in hip boots used shovels and a snow plow to clear a path.

Fremling (1960) reports on mayfly problems caused by the large burrowing mayfly [*Hexagenia bilineata* (Say)] in some areas of the Mississippi River. Upon emerging ". . . the mayflies rest on terrestrial objects during the day, and under their weight tree limbs become pendulous and even break. Residents of summer homes along the river find their houses covered and their yards littered by the insects. A constant rustle is heard as the insects are disturbed and fly up from their resting places. The dead insects and their cast nymphal exuviae form foul-smelling drifts where they are washed up along the shore. . . . Crews of the towboats which transport freight on the Upper Mississippi River find mayflies to be a navigation hazard. . . . Visibility is greatly reduced by the mass of insects in the searchlight beams. The crushed insects render the decks, ladders and equipment of the boats slippery and dangerous. The towboats must of necessity be completely hosed off with water after each encounter with a large swarm of mayflies."

Caddisflies have created serious nuisance and health problems at Keokuk, Iowa (Fremling, 1960). They swarm around the city lights during most of the summer and often blanket store windows. Masses of the insects dart into the faces of passersby, flutter under their eye glasses and fly down open-necked clothing. The minute setae that are dislodged from the wings and bodies of the caddisflies cause swelling and soreness in the eyes of hypersensitive individuals. Many Keokuk residents have become hypersensitive to caddisfly emanations and have developed typical hay fever symptoms. Fremling goes on to say that it is inadvisable to paint houses along the river bluff during the caddisfly season, and outdoor lighting is impractical. Spider webs become pendulous with captured caddisflies, making the riverside homes unsightly. Allergic reactions to caddisflies in the Fort Erie area have been reported by Parlato (1929, 1930, 1932, 1934), Parlato et al. (1934) and by Osgood (1934, 1957a, 1957b).

Wilson (1913) was first to cite mayflies as a cause of allergic distress. Allergies caused by mayflies have also been reported by Figley (1929 and 1940) and by Parlato (1938). In 1929, the first report was made of allergic distress caused by caddisflies (Parlato, 1929). Osgood (1957b) tested 623 allergic patients for sensitivity to caddisflies and found that 12 percent showed a strong reaction. Most allergic patients are not sensitive to caddisflies alone; some showed a stronger reaction to caddisflies than to mayflies, and vice versa. Parlato found the incidence of allergic reaction to caddisflies sufficiently high as to state that this insect was not a rare cause of allergy (Parlato, 1934).

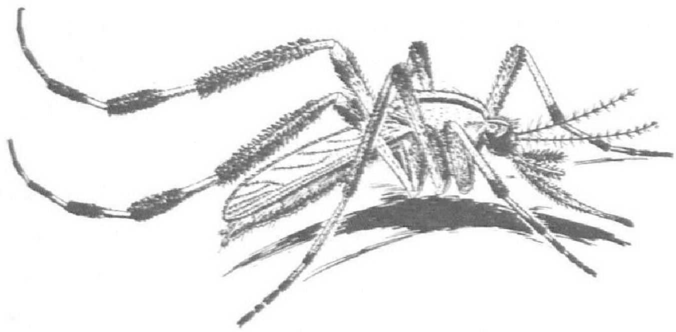

Plate 45. Mosquito [Psorophora ciliata (Fabricius)], one of the largest of Illinois mosquitoes.

Mosquitoes

Ross (1947) estimates the nation's annual "mosquito bill" at $100 million because of mosquito-borne diseases, and close to $50 million for screening, pest control programs, and depressed real estate values. Mosquitoes cause an economic loss both as nuisances and as disease carriers.

Mosquitoes in the nuisance group inflict financial loss in various ways. In some sections they restrict the vacation season by inflicting painful bites, with subsequent loss of patronage to resort establishments. They attack domestic animals and fowl and, when bites are inflicted in large numbers, cause loss of weight and health. It has been estimated that 500 mosquitoes will draw 1/20 of a pint of blood per day from an exposed animal (Ross, 1947). Sometimes mosquitoes become so abundant as to interfere with or stop work by man, with a consequent loss of labor and accomplishments. Mosquitoes are among the worst nuisances of the out-of-doors and prevent enjoyment of recreational facilities by many people seeking exercise and relaxation.

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 and lakes, and in accumulated algal masses, serve as ideal habitats. They prefer areas with little wave action, an abundant cover in the form of aquatic vegetation, an abundant food in the form of humus or other organic matter on the bottom, and surface floating particles of microorganisms. 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 being 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

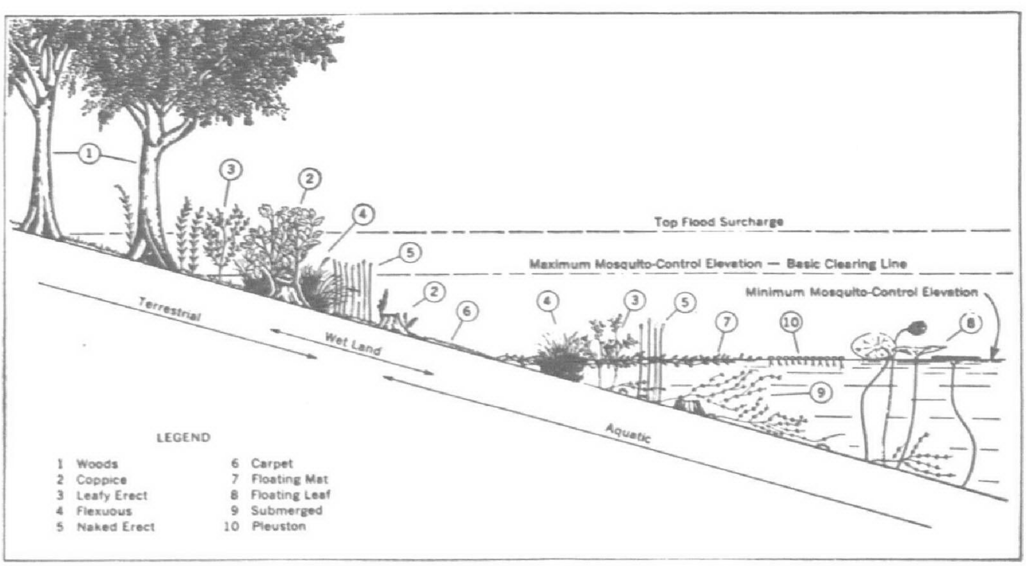

Figure 17. Generalized contour distribution of basic plant types on the shore line of a main-river reservoir (from Bishop and Hollis, 1947).

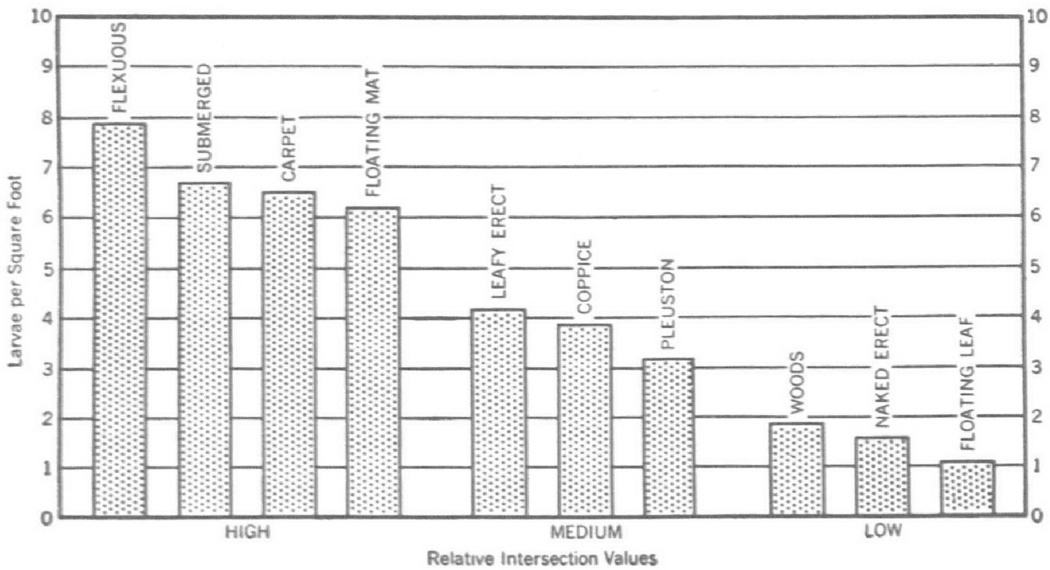

Figure 18. Anopheles quadrimaculatus Say production potentials of basic plant types (from Bishop and Hollis, 1947).

drawdown; aquatic species often overlap with wetland species and usually extend out into the reservoir below the lower limit of summer drawdown (figs. 17 and 18).

The three principal arthropod-borne viruses in the United States are western equine, eastern equine and St. Louis encephalitis (Hess and Holden, 1958). Western equine and St. Louis encephalitis occur primarily in the 22 western States, whereas eastern equine encephalitis occurs primarily in the Atlantic and Gulf coast States. Birds serve as natural hosts, and mosquitoes as vectors, for all three viruses. Man is an accidental host, but clinical disease in man is produced by all three viruses.

Mosquitoes are implicated in the transmission of parasitic diseases. Elephantiasis, characterized by massive glandular swelling, is a disease that occurs commonly among the people of Puerto Rico (Faust, 1939). The disease is caused by filarial worms, *Wuchereria bancrofti* which are slender nematode parasites that invade the circulatory and lymphatic systems, muscles, connective tissues or serous cavities of vertebrates. *Wuchereria bancrofti* are carried by 41 species of mosquitoes.

Other Insects

The attacks on man and other animals by blackflies, *Simulium spp.*, are described by Belding (1942). The bite, at first painless except for a slight prickling sensation, later produces an ulcer-like sore that is due to the salivary toxin. In susceptible individuals there may be marked inflammation, local swelling, and general incapacity. Exposed portions of the body such as head, neck and legs are most frequently attacked. The flies also have the habit of crawling beneath the clothing. They are a pest to fishermen and woodsmen and may incapacitate both man and animals. Large numbers of cattle, horses and other domestic animals have perished from the depredations of these flies in Europe and America. As carriers of human diseases, blackflies are not serious in this country, although many persons get severe dermatitis or allergic reactions from the bites (Anon., 1952).

Deer flies and horse flies, *Chrysops spp.* are of medical importance not only as aggressive bloodsucking pests, but also because certain species transmit diseases to man and animals. As mechanical vectors they may carry pathogenic organisms on their mouth parts and bodies. *Chrysops discalis* Williston, the western deer fly, can transfer tularemia, *Pasteurella turalenses,* to both man and animals and remains infective for at least 2 weeks (Belding, 1942). Occasionally anthrax germs also are carried on the beaks of horse flies and deer flies between diseased and healthy animals and sometimes to man. Deer flies often attack man. In the summer of 1935, 170 men of the Civilian Conservation Corps were preparing a game refuge on salt marshes near Bear Lake, Utah. The deer flies were very annoying; 30 men contracted tularemia in 2 weeks, and the camp had to be closed (Anon., 1952).

Anthrax, an acute disease caused by *Bacillus anthracis,* is highly infective to all classes of mammals including man. Infections in livestock are acquired generally during grazing. Incidence is especially high during the fly season, and outbreaks in cattle have been ascribed to fly transmission. The vectors of this disease are the horseflies, the stable fly, mosquitoes, and several nonbiting insect species (Anon., 1952).

The stable fly, *Stomoxys calcitrans* (Linnaeus), resembles a housefly in appearance; its mouthparts are adapted for piercing and for sucking blood (Comstock, 1936). It attacks man viciously. In some of the TVA impoundments, extensive breeding areas have been created for this organism by the aquatic weeds and algae that reach or concentrate on the water's surface in dense mats of decomposing vegetation.* In some waterways in Kentucky this

* Dr. Gordon Smith, Aquatic Biologist, TVA, Wilson Dam, Alabama.

pest breeds prolifically in flotage created by the bodies of dead mayflies and aquatic vegetation. Stableflies threaten the recreational resource. One 180,000-acre recreational area had to be closed in 1965 because of this pest.

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 from the water's edge to 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.

According to Pennak (1953), *Macrobdella,* the northern bloodsucker, and *Philobdella,* the southern bloodsucker, 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 3 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 digestive 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 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 ¾ inch, although the usual extended length varies between ⅜ and ½ 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 1 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 1-½ 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 2 to 4 dorsal longitudinal rows of black, irregular spots. These are separated by paler bands; the medium 2 are very pronounced, and the outer 2 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 3 pair of eyes; the first pair on somite II are largest, and the other 2 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, attached 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 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 2 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 ele-

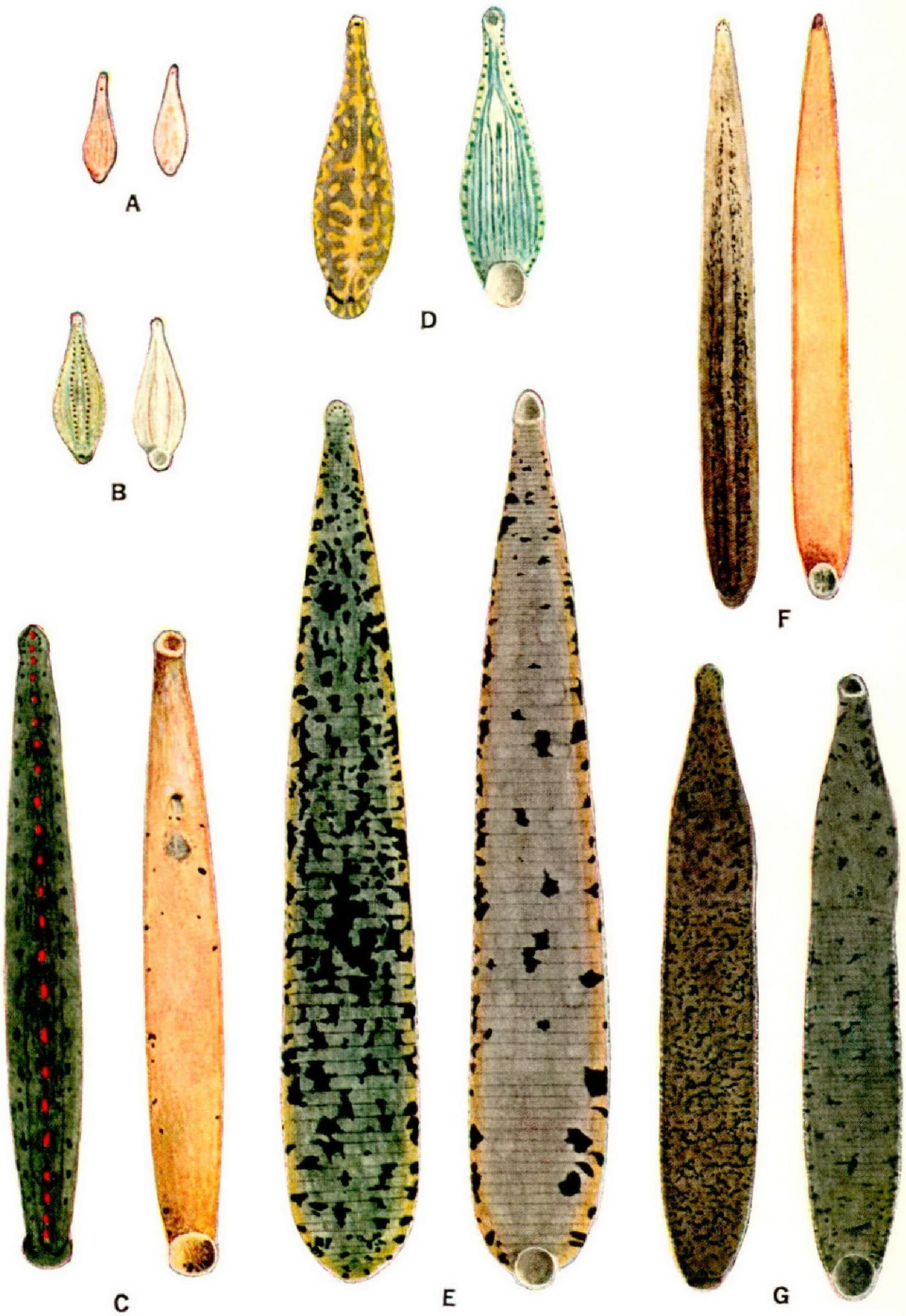

Plate 46. Blood Sucking Leeches (from Moore, 1923)

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

vations (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; 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 water temperatures fall 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 reasons 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 lbs. of powdered lime per acre per day in the shallows. In general, chemical controls have not proved 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 lbs. of copper sulfate and 5 lbs. 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.

CLAMS

Ingram (1959) discussed nuisances caused by the Asiatic clam, *Corbicula fluminea* (Müller) in California. He states: "In 1953 C. S. Hale, general manager of the Coachella Valley County Water District, Coachella, California, stated in correspondence that an apparently serious infestation of *Corbicula fluminea* had developed in the water district's underground distribution system. Irrigation water is taken from the Colorado River at Imperial Dam, transported through 123 mi. of open canal, and distributed through approximately 500 mi. of underground pipe. Accumulation of live clams and clam shells causes serious impairment of water delivery at farmers' turnout valves, at ends of laterals, and in irrigation sprinkler systems. Clams were appearing in irrigation water in Riverside County and Imperial Valley distribution systems."

"In January 1958, correspondence from Lowell O. Weeks, general manager and chief engineer of the Coachella Valley County Water District, reviewed the troubles cited in Hale's letters and brought the clam situation up to date. Weeks stated that an 8-ft. diameter lateral is opened each January at its distribution point. In 1953, perhaps 100-200 clams were found in this structure. In 1954 about 3 cu. yd. of clams were removed, but during the summer the clam nuisance to farmers greatly subsided. In January 1955 only about ½ cu. yd. had accumulated in the lateral. Succeeding seasons have revealed only slight accumulations in this structure and no farmers have complained. Weeks commented that 86 mi. of unlined canal, which brings water into the Coachella Valley from the All-American Canal, was emptied of water in November 1957 after approximately 10 years of continuous flow. It was noted that various sections were heavily infested with clams, and that for a distance of ½ mi. the bottom appeared to be heavily graveled with clams. This observation led him to believe that recurrence of the 1953 summer clam infestation was entirely possible if and when the correct conditions occurred."

In the Tennessee Valley, the economic problem posed by *Corbicula* has been centered chiefly in the sand and gravel industry (Sinclair, 1964). Approximately 12 such plants operate on the Cumberland and Tennessee Rivers. The Asiatic clam has been a nuisance to these companies. Clams present in river gravel deposits are naturally introduced into the aggregate. Mechanical separation is almost impossible. Their number does not exceed the 1 percent limit specified for such gravel; the problem lies, rather, in the clams' response to being poured with concrete aggregate. The live clams move toward the surface, leaving a void. Sinclair quotes one sand and gravel company executive as stating that, "seeing moving concrete can be unnerving." In addition, the clam is troublesome because it gets past the intake screens in steam plants, grows to larger size inside the pipes and necessitates expensive periodic boiler-cleaning procedures.

Animals in Drinking Water Supplies

Organisms in potable water supplies in which interest has been expressed are as follows (Ingram and Bartsch, 1960):

Single-celled animals (Protozoa)
- Ciliates: *Paramecium*, *Didinium*
- Amebas: *Arcella*, *Difflugia*

Sponges (Porifera)
- *Meyenia*

Hydras and jellyfish (Coelenterata)
- *Hydra*
- *Craspedacusta sowerbii* Lankester

Segmented worms (Annelida)
- *Nais*

Water fleas (Cladocera)
- *Daphnia*
- *Bosmina*

Copepods (Copepoda)
- *Cyclops*

Aquatic sow bugs (Isopoda)
- *Asellus*

Insects (Insecta)
- Bloodworm, *Chironomus* (Diptera)

Rotifers (Rotatoria)
Philodina
Brachionus

Roundworms (Nematoda)
Diplogaster nudicapitatus Steiner

Moss animals (Bryozoa)
Paludicella
Fredericella
Plumatella
Pectinatella

Predacious diving beetle, *Dytiscus* (Coleoptera)
Whirligig beetle, *Gyrinus* (Coleoptera)
Water strider, *Gerris* (Hemiptera)

Faucet snails and Asiatic clams (Mollusca)
Bythinia tentaculata Linnaeus
Corbicula fluminea Muller

Bahlman's papers (1931, 1932) are among the early ones that report bloodworms from finished water that had been thoroughly treated in a filtration plant. He first discovered these organisms in an uncovered clear well on the grounds of the Cincinnati, Ohio plant and concluded that they multiplied by feeding on algal growths and decaying leaves that had accumulated, forming a bottom sludge. He noted that " . . . a complete covering of the clear-well reservoir is the only means of maintaining an aesthetic supply." Bloodworms were eventually reported emerging from bathtub faucets and in toilet bowls in a suburban family hotel.

Hechmer (1932) reported that *Chironomous plumosus* was found in finished-water tanks in the filtration plant of the Washington, D.C.–Maryland Suburban Sanitary District. He states that they did not pass through the sand filters, but developed in the finished water from eggs that were deposited directly on the finished-water tanks. Larvae discharged from faucets caused consumer complaints. The bloodworm problem was eliminated for the householder by covering the filtered finished-water tanks.

Brown (1933) discussed a bloodworm infestation of a distribution system and found the point of development to be a reservoir of the Stockton, California potable supply. The reservoir had a collapsed roof.

Clam nuisances have not yet been reported in distribution systems in the United States (Ingram and Mackenthun, 1963); however, one species, *Corbicula fluminea,* introduced from Asia and bordering Pacific Islands, has been recorded as causing trouble in raw drinking water supplies and in the canal transportation system of the LaVerne water softening plant of the Metropolitan Water District of Southern California (Ingram, 1956, 1959). This clam has a life cycle that, in prognostication, should eventually cause it to be listed as a nuisance in treated supplies. It is established as a pest in pipes of irrigation systems in California. Since the time of the first published record of its distribution in the United States as an inhabitant of certain streams in California and Washington (Ingram, 1948), it has spread to waterways in Arizona, Oregon, Idaho, Tennessee, and Ohio.

The snail, *Bythinia tentaculata,* as the mollusk invader of bathtubs and kitchen sinks, has been named the faucet snail. Baker (1902), while studying drinking water from Lake Michigan, first collected this snail in the United States in 1898 as an intermittent household guest. The snails were pumped into the distribution system of the Chicago area, which was supplied by the Lake View crib intake. During this infestation they were found occluding small water pipes in residences; in a number of instances tumblerfuls of snails issued from faucets.

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10

Swimmer's Itch and Human Blood Flukes

CORT (1928) first demonstrated that certain larval trematode worms peculiar to the United States (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 United States where tourist trade has been affected.

Life Cycle of Swimmer's Itch Organism

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 and 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 takes place in which a sporocyst stage and then 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 life-cycle.

This cycle is interrupted accidentally 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, with their bodies remaining at the penetration site to cause acute inflammatory reactions. Apparently the cercariae do not penetrate completely until the bather has emerged from the water; however, a few minutes after emergence 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 $\frac{1}{16}$ to $\frac{1}{4}$ inch in diameter. Ocassionally the elevations become pustular. The

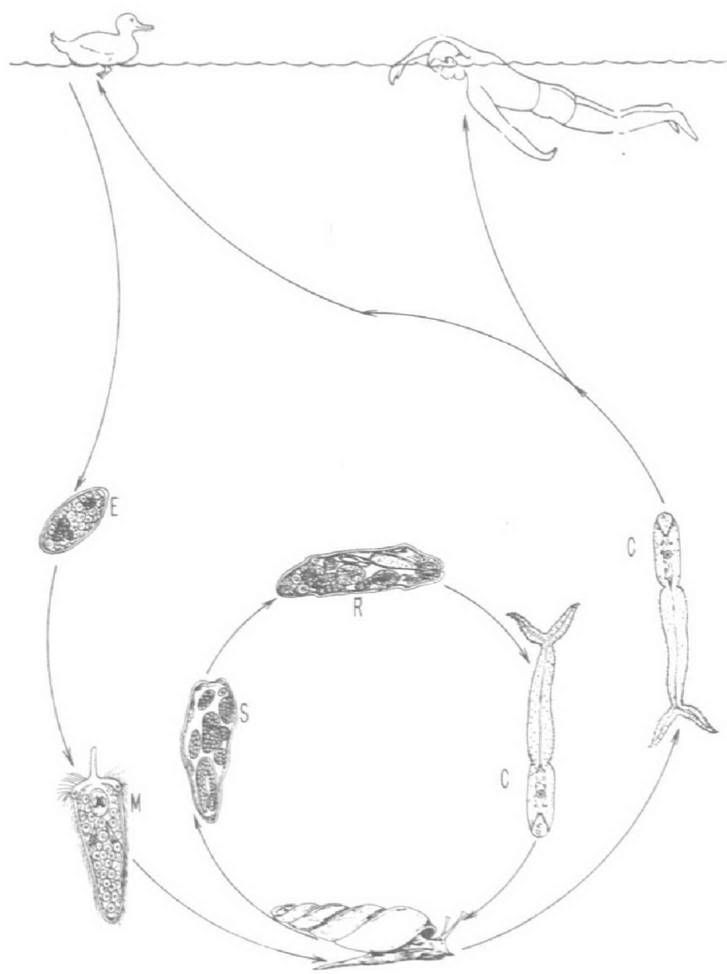

Figure 19. Life cycle of swimmer's itch cercariae. E. Egg; M. Miracidium; S. Sporocyst; R. Redia; and C. Cercariae.

degree of discomfort and bodily reaction resulting from infestation varies with the sensitivity of the individual and the degree of infestation. With particularly sensitive 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; 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 1 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 2 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 ¼ 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 shore are scarcely bothered even though they 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 3 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 in other areas of the world, 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 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 reach their highest intensities. 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 cases lessen, chiefly because of the death of infected snails; in many places there is a complete cessation before the end of the swimming season. Where the adult snails die early the dermatitis season is shortened since there is practically no infection of 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 has caused greatest problems 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.

In Nevada, Oklahoma, Alabama, Tennessee, Texas and Florida, cases of dermatitis have been reported in which the diagnoses were based on clinical evidence without laboratory confirmation (Jarcho and Van Burkalow, 1952). The existence of these outlying areas and the crossing over of birds from one flyway to another in addition to the creation of new impoundments suggests that the dermatitis may spread to still other areas where it has not so far been known. This is what appears to have happened among the TVA Reservoirs which have attracted birds from the Mississippi flyway. These authors conclude by saying, "Thus the silent zone of cercarial dermatitis seems to be spreading into man-made lakes farther south. And in the endemic areas, where the lakes are being made increasingly accessible, larger and larger numbers of summer visitors are entering the silent zone. More often, therefore, and in more localities, man is being added to the worm-snail-bird association to form the four-factor pathogenic complex called 'cercarial dermatitis'."

CONTROL

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 sunbathing 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 on the 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 applied only to areas extensively used by man for swimming and confined to the minimum area 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,

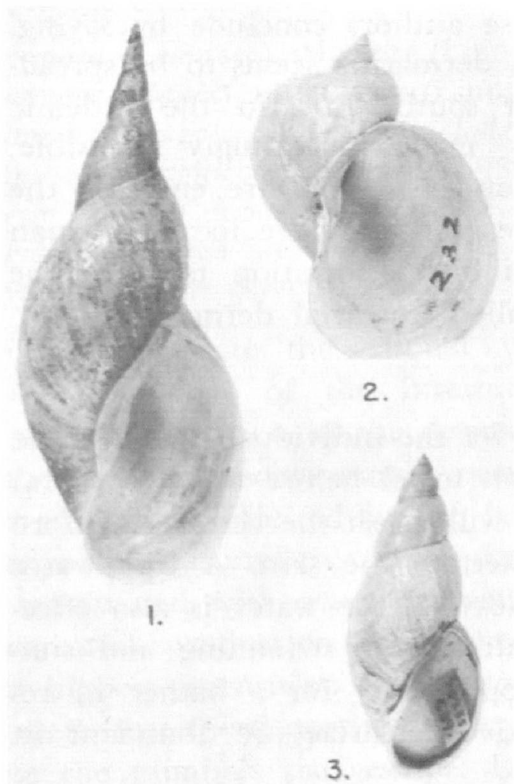

Plate 47. Snails known to harbor swimmer's itch cercariae.

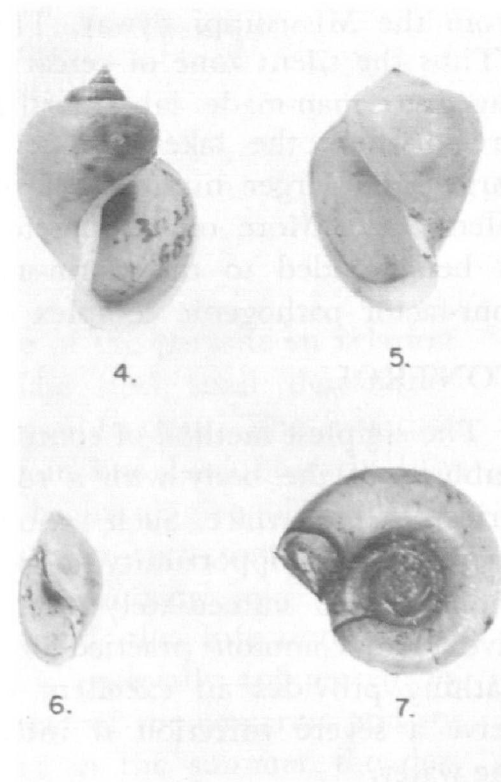

Plate 48. Snails known to harbor swimmer's itch cercariae.

*U.S.N.M.** *No.*	*Snail*	*Collector*	*Location*
1. 284448	*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. 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.

*United States National Museum

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 important, 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 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 a small area on a large lake with copper sulfate 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 it would make direct contact with the snails, 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 lbs 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 lbs 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 lbs of copper sulfate and 200 lbs 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 the solution 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 "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 pump and motor may be successfully used in distributing the chemical solution.

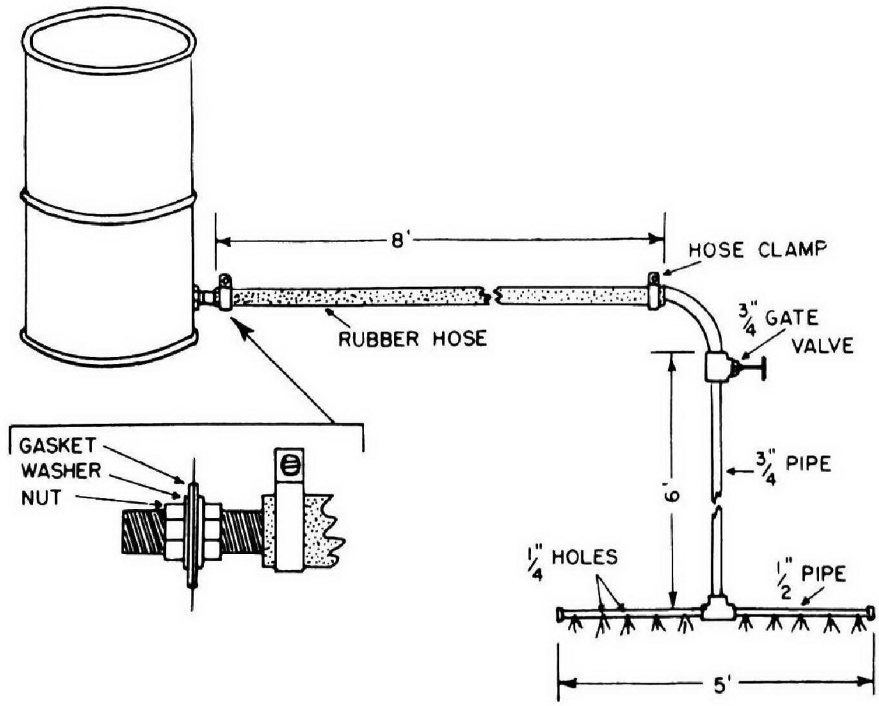

Figure 20. Diagram of gravity flow equipment used in distributing chemical mixture for snail control.

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 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 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

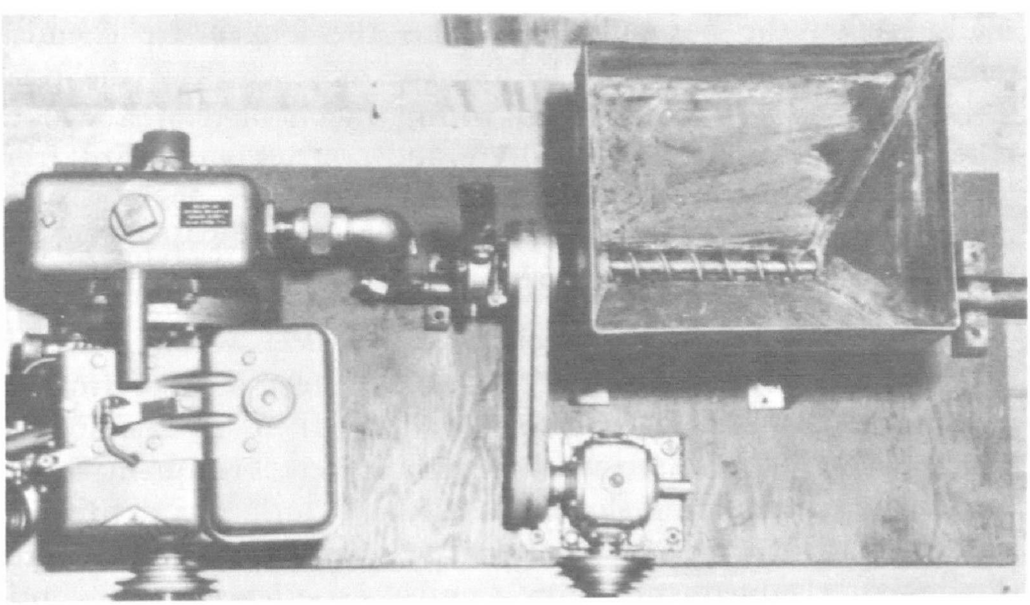

Plate 49. Combination mixer-distributor unit for underwater chemical application, top view. The dry chemical is injected into water stream on suction side of pump.

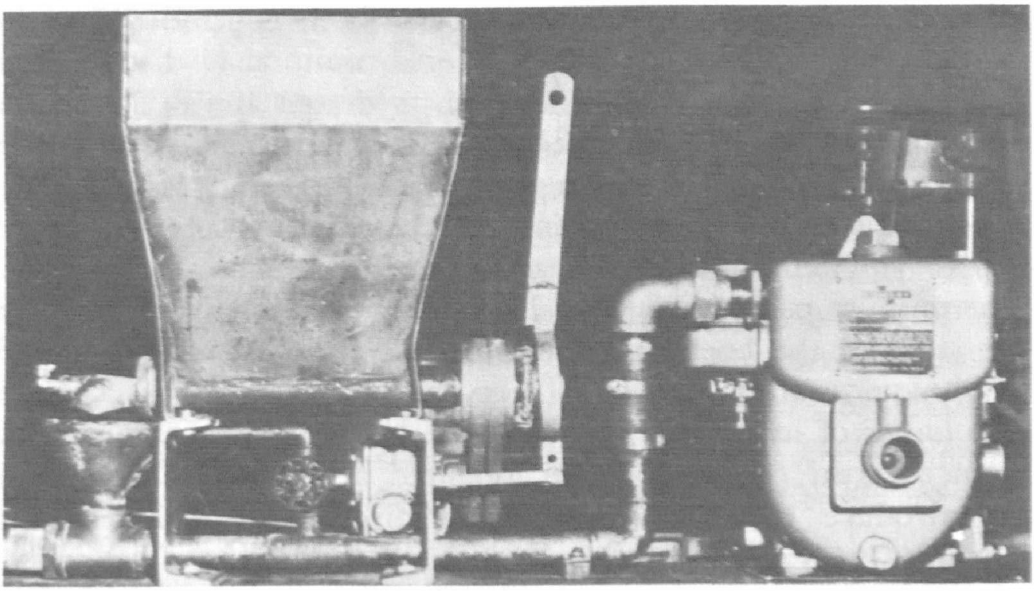

Plate 50. Combination mixer-distributor unit for underwater chemical application, side view.

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.

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.

Howard*, following research in British Columbia, reports that commercial copper sulfate used alone at a rate of 2 lbs per 1,000 square feet of treated bottom area may be optimal for the control of snails in lakes with > 50 mg/1 of bicarbonate. Little advantage was noted in the use of lime as an additive. Howard et al. (1964) state that in lake waters where hardness is 10 to 50 mg/l bicarbonate, cupric sulfate dissolves yielding ionic copper concentrations of 0.3 to 6.8 mg/l. Excess copper forms the bicarbonate, which can remain colloidally dispersed as a suspension. Under these conditions ionic copper concentrations are high enough to kill in relatively short periods of time. In hard waters, granular cupric carbonate is too insoluable to kill snails. In softer waters cupric carbonate does go into solution slowly, producing toxic levels of ionic copper.

Dermatitis Causing Organisms Attacking Man

Four species of animal schistosomes have been associated with cercarial dermatitis in man (Belding, 1942): (1) *Cercaria elvae* (Miller) whose intermediate hosts are *Lymnaea stagnalis* vars. *appressa, perampla, lillianae, sanctaemariae* and *jugularis* and *Stagnicola palustris elodes*; (2) *Cercaria stagnicolae* (Talbot) whose intermediate hosts are *Stagnicola emarginata* vars. *angulata, emarginata, vilasensis, wisconsinensis* and *canadensis*; (3) *Cercaria physellae* (Talbot) whose intermediate hosts are *Physella parkeri* and *P. magnalacustris*; and (4) *Schistosoma douthitti* (Cort) whose intermediate hosts are *Lymnaea stagnalis* vars, *appressa, jugularis, lillianae, sanctaemariae* and *perampla, L. palustris, L. reflexa* and *Physa ancillaria parkeri.*

The pathology and symptomatology of schistosome dermitis is described by Belding (1942): "The resistance of man, an abnormal host, to these cercariae explains the severe reaction. Its nature indicates that the cercariae are walled off by the host and destroyed in the epithelial layers of the skin. Penetration of the skin occurs when the film of water evaporates. The cercariae adhere with the ventral suckers and enter in about 5 minutes through the action of their anterior spines and lytic secretions, either between or through the pores. After 29 hours no cer-

* T. E. Howard, Division of Applied Biology, British Columbia Research Council, University of British Columbia, Vancouver, personal correspondence, May 5, 1965.

cariae remain but the reaction persists around the burrows. They evoke an acute inflammatory response with edema, early infiltration of neutrophils and lymphocytes, and later invasion of eosinophils. As the water evaporates a prickling sensation is followed by the rapid development of urticarial wheals, which subside in about half an hour leaving a few minute macules. After some hours severe itching, edema and the transformation of the macules into papules and occasional pustules occurs, reaching maximal intensity in 2 to 3 days. The papular and sometimes hemorrhagic rash heals in a week or more, but may be complicated by scratching and secondary infection. Individuals vary in susceptibility and show slight or severe reactions."

Schistosomiasis, the Blood Fluke Disease of Man

Schistosomiasis caused by *Schistosoma mansoni*, is widely distributed throughout Puerto Rico and is an important health problem there. It has been estimated that up to 12 percent of the population are infected (Anon. 1946). The 2 types of environments responsible are the streams and pools used for bathing and other domestic purposes, and the irrigation systems. The intermediate host, *Australorbis glabratus*, prefers the quiet waters of stream pools, irrigation ditches, and reservoirs. The habits of the people play an all important role in the spread of the infection. The natives commonly use the snail-infested waters for bathing and washing and there is excessive human pollution of the water and diversion of untreated sewage into streams.

In the human, cercarial penetration may give rise to a more or less intense local reaction. The immature worms then find their way to the veins and are carried to the lungs; this requires 2 or 3 weeks. From the lungs the developing worms find their way to the liver lobules. Nausea, vomiting, headache, and abdominal pain may be the systemic complaints. After becoming nearly mature in the liver the worms migrate against the blood stream to the small veins in the mesenteric venules draining the colon and the terminal section of the small intestine. The adults of themselves seem to produce virtually no pathologic process in the mesenteric venules. They feed on serum and cells but not so gluttonously as to create any noticeable effect. Egg deposition is initiated within an average of 10 weeks following infection. Abdominal pain, tenesmus, dysentery, bloodflecked stools, and remittent fever are results of the intestinal egg deposition process. The eggs are equipped with a lateral spine that aids in tissue penetration. Severe liver damage is typical. The liver becomes involved and enlarged because of the drift of the eggs back through the portal blood stream into the liver. Enlargement of the liver results in abscesses around infiltrated eggs. Tissue damage in unarrested and progressive cases is severe, and in all moderately heavy infections would be enough alone to cause death. The liver becomes a gigantic mass of scar tissue. Accompanying symptoms are daily fever, extreme weakness, diarrhea, loss of appetite and weight, emaciation, and, in untreated cases, death from exhaustion.

The density of *Schistosoma mansoni* cercariae in Puerto Rican waters undergoes marked daily fluctuation (Rowan, 1958). The peak of cercarial abundance occurs between 11:00 a.m. and 1:00 p.m. Few cercariae were present in the water before 9:00 a.m. or after 4:00 p.m.

The destruction of snails theoretically offers the best method of attack, but the practical application of control measures is far from satisfactory (Belding, 1942). Snails may be destroyed by chemicals, desiccation, collection, removal of vegetation, and natural enemies. Periodic clearance of plants and snails in Egyptian irrigation canals was effective in reducing the snail population over a period of 3 years. Desiccation is ineffective unless the snails are kept dry over 3 months, but reduces their parasitic infestation. Agricultural workers may be protected by clothing and boots from exposure to water, but economic considerations, convenience of working, and ignorance tend to make such efforts impractical. Likewise prohibition of bathing in infected waters cannot be enforced.

When copper sulfate or sodium pentachlorophenate is applied for prolonged periods and in relatively high concentrations (30 and 10 ppm respectively), snail populations are at least markedly reduced (McMullen and Harry, 1958). However, the snails that survive or are introduced into the habitat have little difficulty in repopulating it in 3 to 5 months. Repopulation is usually slower when sodium pentachlorophenate is employed, because of its greater efficiency. With both chemicals the "knockdown" value is high; they also cause drastic temporary reductions in other biota in the habitat. The population recovery made by these organisms depends on their vagility and capacity for reproduction. In an irrigation system snails can be brought in from upstream and, because of their reproductive capacity, may repopulate an area within 3 months. If the molluscicide is not applied for 2 years the snails repopulate the area. It has been demonstrated that the introduction of sodium pentachlorophenate into irrigation systems in Egypt 3 times a year at 10 ppm is very effective in controlling the snail population and preventing transmission. Although snails and eggs are introduced from upstream, there is insufficient time for young snails to develop and acquire mature infections. The introduction of previously infected snails would be the only source of cercariae. Under such conditions it would be expected that transmission would be prevented as long as the control measures were continued.

Goodnight (1942) points out the toxicity of sodium pentachlorophenate and pentachlorophenol to fish, stating that the more sensitive species are killed in concentrations above 0.2 mg/l although hardier species will survive 0.4 and 0.6 mg/l. Invertebrates such as those used by fish as food are relatively insensitive to these compounds; the most sensitive invertebrates will live at concentrations at which fish will survive. There are dangers involved to those who use and handle sodium pentachlorophenate (Blair, 1961). In 1959 when the chemical became more easily available through commercial channels and when it was used as a molluscicide by farmers using their own laborers in Southern Rhodesia, fatalities occurred.

Another chemical, acrolein, has been found to have a dual purpose in that it eliminates both submersed weeds and snails. At the concentration of acrolein required for destroying submersed weeds (20 to 25 ppm), the resurgence of snails to pretreatment levels was delayed by 8 to 12 months, and submersed weeds did not reappear until 8 months after treatment (Unrau et al., 1965). The chemical is toxic to fish and invertebrates. Acrolein has been used successfully in Puerto Rico against *Australorbis glabratus* (Ferguson et al., 1961).

Jobin and Ippen (1964) point out that it may be possible to devise a control method based on engineering the snail's microenvironment. For *Australorbis glabratus*, a velocity exceeding 33 cm per sec at shell height produces a hydrodynamic drag force sufficient to dislodge the snail from its position on the solid boundary of a canal.

Abbott (1948) notes that one species of Tropicorbid snail capable of acting as an intermediate host of the human blood fluke has been found in Louisiana and Texas. To date, the disease has not been able to establish itself in the United States. Abbott postulates that the disease was introduced into Puerto Rico during the era of the slave trade.

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11

Slimes

The Problem

UPON the introduction into water courses of waste nutritive materials, biological slimes may develop to the extent that visible masses appear. These are woolly coatings on submerged objects or tufts and strands, sometimes 15 inches or more long, streaming in the current from point of attachment. They vary in color from milky white in fresh new growth to dull grey-white, brown or rusty-red, depending on age, nutrition, and type and amount of solids they entrap from the passing water. In many cases, a rather heterogenous population makes up what is commonly called the slime floc. For example, Tiegs (1938) described the "sewage fungus"* community as including the following organisms: *Sphaerotilus natans, Beggiotoa alba, Thiothrix nivea, Fusarium aquaeductum, Leptomitus lacteus* and *Mueor* sp. The two organisms that have been described repeatedly as ecologically dominant are *Sphaerotilus natans* and *Laptomitus lacteus.* Butcher's (1932) description of his "sewage fungus" community also included the fungus *Shenospora* and the protozoan *Carchesium.*

Numerous problems arise from the presence of slime growths in streams. Where commercial or game fishing exists, drifting *Sphaerotilus* may foul gill nets rendering them ineffective (Lincoln and Foster, 1943**; Ingram and Towne, 1960; Wilson et al., 1960), interfere with fish hatching by coating fish eggs (Lincoln and Foster, 1943**), and smother aquatic fauna that serve

* *Sphaerotilus* is not a genus of a fungus, but is a filamentous bacterium; for years in the literature of sanitary science it has been referred to incorrectly as a fungus.

** Lincoln, J. H. and R. F. Foster, 1943. Report on the Investigation of Pollution in the Lower Columbia River. Washington State Pollution Commission and the Oregon State Sanitary Authority.

Plate 51. Slimes in the Columbia River render gill nets useless as fishing tools.

as food for fish. Biological slimes and the materials they entrap, such as plant fibers, wood chips, and debris, blanket the stream bed destroying the homes of clean water associated organisms. Because organic food is usually abundant where slime growths occur, pollution tolerant organisms such as sludgeworms may become abundant in association with the slime growth. These organisms do not offer the fish food potential that clean water associated species do. Conditions may become so severe that all benthos are eliminated.

Kramer and Smith (1965) found that suspended conifer groundwood fibers had no effect upon egg survival, respiration rate of embryos, or growth rates of alevins and juveniles from eggs incubated in fiber but hatched and grown in clean water. When alevins were held in wood-fiber suspensions, survival was reduced from 98 to 100 percent in controls to 0 to 72 percent in 250-ppm fiber. Walleye (*Stizostedion vitreum vitreum*) eggs were incubated in a temporary jar hatchery using Rainy River water taken downstream from paper mills discharging sulfite, kraft, insulating board, and groundwood wastes (Smith and Kramer, 1963). Eggs were also incubated in trays held on and off the bottom in the river downstream from the mills, upstream from the mills, and in tributary streams. In two years, survival of eggs in jar controls was 31.2 to 73.5 percent. Survival to hatching of eggs jar-incubated in polluted water was 0.02 to 6.0 percent. At river stations down stream from the mills survival of tray eggs on the bottom did not exceed 1.2 percent; and off-bottom, 3.5 percent. Eggs held on the bottom upstream from the mills had maximum survivals of 37.6 percent; and off the bottom, 49.1 percent. In most experiments in polluted Rainy River water the principal cause of mortality was *Sphaerotilus* growths on the eggs which prevented successful emergence of fry. Prior to hatching, egg survival rate in jars was similar in controls and in experiments. Chemical treatment to remove slime increased the hatch of eggs. *Sphaerotilus*-covered eggs removed to fresh water lost the bacterium and hatched at a high rate.

Biological slimes bring about an aesthetically unpleasant stream. To the public, they are an obvious sign of stream pollution. Prolific slime growths destroy the recreational potential of the water, thus interfering with one of the major public-associated uses of water.

Slimes may develop from well waters, particularly those from deep wells that contain dissolved iron and carbon dioxide, and may accumulate in pipes and distribution systems. Complaints of "red water" are a consequence of rust clogging, associated with iron bacteria, which reduces the carrying capacity of pipes. Masses of rust and bacteria break off and are carried in the water to the consumer. Growths sometimes occur in sewer pipes and break loose and descend on the treatment plant, clogging screens and choking filter nozzles and stone filter beds (DeMartini, 1934).

The filamentous sewage bacterium, *Sphaerotilus natans*, has been implicated in the bulking of activated sludge (Lackey and Wattie, 1940). Ruchhoft and Kachmar (1941) concluded that *Sphaerotilus* was a delicate indicator of disturbances of the biological equilibrium of activated sludge but not a primary cause of bulking. It has been found in paper machine wet felts, and clogging of the felts with *Sphaerotilus* was experimentally produced (Drescher, 1957). It has created problems by clogging intake screens and cooling water lines in power plants.

The secondary effects of biological slimes in streams may be even more serious. The stream slime community is composed of a variety of microorganisms that are held together as a mat prin-

Plate 52. Slimes form as waving masses in polluted streams destroying the habitat for animals.

cipally by *Sphaerotilus*. Such interwoven mats entrap silt, sand, fibers, and chips. The filamentous masses offer shelter and support for other organisms such as bacteria, protozoans, nematodes, rotifers, and occasionally midge larvae. During the process of decomposition, or because of physical disturbances, mats sometimes as large as 3-feet in diameter "boil" to the water's surface in an unsightly foul-smelling eruption. These "boils" may settle at or near the point of origin or be carried downstream to areas where the flow velocity permits settling. Here sludge banks are formed that give rise to anaerobic conditions with subsequent offensive effects. These sludge banks may be formed many miles downstream from the initiating pollution source, thus increasing the stream reach of pollution.

Because most bacteria respond directly to the introduction of organic materials to the water course, they may be considered the major factor in the self-purification processes occurring in most natural waters. Slime growths in natural waters function similarly to those in treatment plants in the stabilization of organic materials. In simulated stream studies, biochemical oxygen demand (BOD) reductions as high as 87 percent were obtained at waste retentions as low as 33 minutes after extensive slime growths had developed. In one experiment, 11.5 mg/l BOD were removed during this short time interval. Similar high purification rates have also been observed in many shallow, turbulent streams in which slime growths were the major force in the self-purification process (Amberg and Cormack, 1960).

SPHAEROTILUS

Dondero (1961) cites a number of quantitative measurements that have been made on *Sphaerotilus* infestation of streams. Although the productivity of polluted streams is difficult to estimate, some measurements on detached masses of floating *Sphaerotilus* have been made from which the amount of material passing the river cross section has been calculated, for example: (a) in the Danube and Main Rivers, about 64 tons wet weight per day of drifting *Sphaerotilus* (Demoll and Liebmann, 1952); (b) in the Main 325 tons, wet weight per day (Liebmann, 1953); and (c) in the Oker River, 12.5-100 gm. dry weight per cubic meter of water (Popp and Bahr, 1954). By using the factor 7 percent (Popp and Bahr, 1954; Liebmann, 1952, used 8 percent), the wet weight values can be converted to 4.5 and 22.7 tons dry weight, respectively. Such values indicate the potential for the deposition

Plate 53. Slimes growing on stream animals makes them less effective to compete for existence in the environment.

of large amounts of decomposing *Sphaerotilus*. Popp and Bahr (1954) measured deposition in layers 1 to 2 meters thick in areas of high oxygen deficiency. There was a high degree of secondary pollution resulting from the decomposition of the *Sphaerotilus* sludge for months after heavy pollution with sugar waste. The oxygen demand of dead *Sphaerotilus* sludge was about 11 times that of the same amount of living *Sphaerotilus*.

There are at least 3 kinds of slime or biological masses affecting gill nets in the Columbia River: (a) slimes composed mostly of wood fibers, stuck together by *Sphaerotilus* which is very difficult to remove from nets when wet and nearly impossible to remove when dry because it hardens to a substance resembling plastic wood; (b) biological masses, principally plant trash and leaf and grass fragments, which adhere to nets when wet, but crumble away when dry; (c) masses composed almost entirely of *Sphaerotilus*.

The appearance of *Sphaerotilus* in streams as the dominant organism has repeatedly been correlated with the entry of industrial wastes (Harrison and Heukelekian, 1958). Butcher (1932) states that it is associated with effluents from the following industries: beet sugar, paper, rayon, glue, and flour mills. Other observers have noted its occurrence following waste discharges such as textile bleach, by-product coke, dairy wastes, and spent sulfite liquors. Wuhrmann (1949) asserts that the organism does not grow in undiluted sewage. DeMartini (1934) reports the organism in sewers carrying very dilute sewage, and Agersborg and Hatfield (1929) note that it is present in raw sewage, Imhoff tanks, and aeration tanks. Amberg and Cormack (1960) state that *Sphaerotilus* grows on kraft effluents as well as on spent sulphite liquor. No slime growth was obtained from the kraft bleach plant effluents. They state further that slime growths may be expected in discharges of weak wash waters and evaporator condensate from evaporation and burning of spent sulphite liquor. Amberg and Cormack cite Scheuring and Höhnl (1956) to the effect that *Sphaerotilus natans* will grow at sulphite waste liquor dilutions of 1:700,000 or at BOD levels in the range of 0.05 to 0.10 mg/l. The ability of slime growths to extract nutrients from large volumes of flowing water at extremely low waste concentrations presents a difficult problem in obtaining adequate control.

Sphaerotilus can assume a variety of different appearances that are correlated with different nutrient conditions. The organisms giving rise to the *Sphaerotilus* slime growths must be present in the flowing stream at all times because of the sudden appearance of slimes following the introduction of pollution.

Naumann (1933) is quoted by Harrison and Heukelekian (1958) as early investigating the possibility of *Cladothrix dichotoma* being transformed into *Sphaerotilus natans* under certain conditions. These organisms are similar, except that *Cladothrix dichotoma* exhibits regular dichotomous branching of the filaments and does not have the slimy sheath of *Sphaerotilus.* Pringsheim (1949) showed that *Sphaerotilus natans, Cladothrix dichotoma,* and the ecologically distinct *Leptothrix ochracea* could give rise to similar cultures by appropriate treatments.

Factors that Stimulate Sphaerotilus Growths

Under laboratory conditions the most important food requirements necessary for heavy growth seem to be sugars and organic nitrogen (Lackey and Wattie, 1940). These authors and others (Ruchhoft and Kachmar, 1941) describe a culture method with a medium that was found to contain ample quantities of all the nutrient materials for the growth of *Sphaerotilus natans.* This medium contained the following materials:

	mg
Dextrose	1,000
Peptone	600
Meat extract	200
Urea	50
Na_2HPO_4	50
NaCl	15
$CaCl_2$	7
$MgSO_4$	5
KCl	7
Distilled water to make 1 liter	

The media was sterilized, seeded with *Sphaerotilus* and aerated continuously through a ball diffuser. Growth occurred in 24 hours.

There is general agreement that the luxurious growths similar to those found under stream conditions cannot be reproduced in the laboratory with inorganic sources of nitrogen. There are many references in the literature to the necessity of a supply of amino acids by *Sphaerotilus.* The organism does not require accessory growth factors such as vitamins (Wuhrmann and Koestler, 1950). Harrison and Heukelekian (1958) state that cultural experiments show growth of *Sphaerotilus* when nitrate is the nitrogen supply. There is some evidence that the utilization of ammonium compounds depends on the carbon supply. For luxurious growth, an organic nitrogen supply is necessary.

Höhnl (1955) concludes that visible *Sphaerotilus* growths do not occur as long as the pH is below 5.5. A pH of 6 to 7 is favorable for growth. Optimum temperature is 10 to 15° C. Amberg and Cormack (1960) observed excellent slime growths in the Columbia River where stream velocities ranged from 0.4 to 2.0 feet per second. Increases in velocity at constant concentrations increase the amount of food passing a unit growing surface. These authors stress the importance of both phosphorus and nitrogen for optimum growth. Working on the Columbia River, they observed active competition between filamentous and planktonic algae and *Sphaerotilus* for available phosphorus.

Plate 54. Dried wastes from pulp and paper making operations. These fibers are often held together by Sphaerotilus and other slimes, forming a blanket over the stream bed.

Control of Sphaerotilus

Lackey and Wattie (1940) tested substances for toxicity for *Sphaerotilus* in activated sludge or in heavy cultures and found that the following were toxic at the doses indicated (mg/l): chlorine (0.5 residual), silver nitrate (0.5–2.0), phenol (5.0), acetic acid (50), brilliant green (5.0), malachite green (5.0), Janus green (20), methylene blue (20), and gentian violet (10). Chlorine was considered to be the most feasible substance for large scale use, as in water and sewage treatment plants.

In water treatment plants, high initial doses of chlorine are required to remove established slimes. Repeated dosing to 50 to 100 mg/l residual chlorine followed by high-pressure air and flushing has been used (Alexander, 1944). After dislodgment of the slimes, 0.75 to 1.0 mg/l residual chlorine was maintained in the effluent water. DeMartini (1934) recommended 2 mg/l in wastes for *Sphaerotilus* control in sewers.

Amberg and Cormack (1960) found, in laboratory studies, that intermittent discharge of spent sulphite liquor for 24 hours followed by 5 days of storage was very effective in reducing slime growth by more than 80 percent. Field studies showed that by discharging 24 hours every 6 days, growth was lower than growth obtained from ⅕ the total liquor discharged continuously.

Sphaerotilus infestations were controlled downstream from a southern Kraft pulp mill by retaining all black liquor from entering the river during optimum conditions for slime growth. The liquor was held for a period of 5 to 6 days and released over a 1- to 2-day period, which was insufficient time for an infestation to materialize (McKeown, 1962).

Leptomitus

Leptomitus lacteus is a member of the most abundant order of aquatic fungi, the Saprolegniales. No cells are visible in the organism, although characteristic constrictions give it a pseudoseptate appearance. The constrictions are a result of the presence of cellulin plugs, whose function is unknown. Harrison and Heukelekian (1958) state that *Leptomitus* requires high molecular weight compounds of nitrogen to supply its needs for this element. Schade (1940) has confirmed that no growth occurs with ammonium, nitrate, or nitrite compounds, even in the presence of available carbon compounds. The optimum pH for luxuriant growth is 5.4 to 6.0 and the suitable pH range is 4.3 to 7.5.

Fouling Bacteria

Iron bacteria are typically aerobic organisms, widely distributed in nature, and commonly observed in most water habitats. They are generally considered fouling organisms and not agents of corrosion, but they may indirectly contribute to the latter. Energy is derived from the oxidation of ferrous iron to the ferric state and in the process, ferric hydrate is accumulated on the sheaths and cells of the organisms.

The occurrence of iron bacteria was observed in northern Wisconsin drainage waters in which deposits had accumulated to a depth of 2 ft throughout several miles of drainage ditch. Control was effected with a 3-ppm copper sulfate application. Also, springs often have reddish-brown deposits produced by the activity of iron bacteria, and stagnant marshes may produce a reddish scum resulting from this activity. As early as the middle of the nineteenth century, iron bacteria in potable water supplies were reported to be the causative organisms of taste and odor problems, and the condition was called a "water calamity."

Starkey (1945) reviews the transformation of iron by bacteria in water and states that iron bacteria are some of the most important fouling organisms because they not only produce troublesome accumulations of cell material but also produce still greater quantities of ferric hydrate. In addition to the iron bacteria there are various other bacteria, including sulfur bacteria and sulfate-reducing bacteria, which are responsible for various transformations of iron. Some bring iron into solution, others cause its precipitation and some are responsible for corrosion.

The development of iron bacteria may manifest itself in several ways. There may be hard deposits that tend to fill up pipes and reduce their water-carrying capacity. Slimes and accumulations of filamentous bacteria may form on the walls of pipes and water holders and scums may be produced on the water surface. These bacteria may cause turbidity and discoloration of water and be responsible for some of the unpleasant tastes and odors that are produced either directly or indirectly as the dead bacterial cells are decomposed by other micro-organisms. Water color may be used as a very rough criterion of abundance because very clear water may reveal only 1 or 2 organisms per milliliter, whereas the number of organisms in reddish and turbid waters may exceed 10,000,000 per milliliter (Lueschow and Mackenthun, 1962). From the examination of 76 municipal wells in Wisconsin, 53 percent revealed iron bacteria at various concentrations. Generally, *Gallionella* sp. occurred more regularly than *Leptothrix* sp., and usually in greater numbers. Iron concentrations did not appear to be related to the occurrence of iron bacteria, but very high concentrations of iron bacteria revealed substantially higher concentrations of iron than the general mean. The occurrence of iron bacteria in the distribution systems was considered independently from the occurrence in wells. Generally, the occurrence was under 100 organisms per milliliter, but two outlets revealed concentrations as high as 10,000,000 organisms per milliliter. These two samples were from a fire hydrant and a relatively unused tap. Under circumstances of high organism population, the water contains a dense red sediment, and settling indicated that ¼ to ⅓ of the sample volume were iron or iron bacteria.

Harder (1919) reports active development of iron bacteria in pipes carrying water with 1.3 mg/l iron. Halvorson (1931) found them in springs having 1 to 10 mg/l. Schorler (1906) records incrustation of 3 centimeters thickness in pipes carrying water with from 0.2 to 0.3 mg/l iron during 30 years of usage. The amounts of nitrogen required by the iron bacteria are very small compared to the requirements for iron and it is probably that the nitrogen content of most waters meets their needs.

Chlorination of water appears to be the most satisfactory method of controlling the development of iron bacteria (Clark, 1963). Duchon and Miller (1948) found that chlorine and hypochlorite were the most effective chemical agents for controlling growths of *Crenothrix*. Blair (1954) stated that maintaining free residual chlorine throughout the distribution system was an effective means of combating infestation. He warned that even though the kill was effective, tastes and odors were still possible.

Some of the sulfur bacteria are encountered occasionally in water, particularly in water containing sulfide or elemental sulfur. One of the typical sulfur bacteria, *Thiobacillus thiooxidans,* may bring large amounts of iron into solution under conditions favorable for its development. It is an aerobic bacterium that has the capacity to oxidize sulfur, and has been linked to the corrosion of iron pipelines.

Sulfate-reducing bacteria are of importance in water distribution systems because they produce sulfide which is dissolved in the water and makes the water objectionable by reason of the odor, the presence of suspended black particles, and the corrosive effect of the sulfide on steel and other metals. In cases where the water in iron pipes and concrete conduits contains sulfide or where sulfide is produced as in sewage, and the pipe is only partly filled so that there is an air blanket over the water, some of the sulfide becomes dissolved in the moisture film on the upper walls of the pipe. Here it undergoes oxidation, caused principally by sulfur bacteria, and the sulfuric acid that is formed attacks the pipe, causing its disintegration (Starkey, 1945).

Alexander (1944) stresses that in controlling slime-forming iron and sulfur organisms in a water supply, control is only partly attained when the plant effluent is made sterile. It is equally important to clean up and maintain a distribution system free from iron and sulfur organisms, a system in which chlorine residuals will be carried to the remotest part of the distribution system.

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12

Control of Excessive Production

UNQUESTIONABLY the control of aquatic nuisances should be directed to the basic cause. Uncontrolled drainage from heavily fertilized farmland, from forest soils, and natural soils varied in mineral wealth, the discharges 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 water body.

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 sediments from upstream sediment transport, bank erosion and from in situ organic and inorganic 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 for multiple use of the water. Enrichment of the water under primeval conditions would be a slow process when measured against man's life span, but natural enrichment augmented by man-associated enrichment may increase the fertility of the water to such an extent that the aging process can be observed over such a period. 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 sewage and effluents from sewage treatment operations, industrial wastes or effluents, and land erosion into the watercourse must be curtailed unless research can produce processes that will tie up nutrients that serve as fertilizers. Prodigious advancements must be made in the handling of street and storm drainages, runoff from fertilized croplands, other agricultural wastes, and municipal and private refuse dumps; these, also, contribute to the fertilization of receiving waters. Over the years, progressive accomplishments have been made by a number of States in water pollution abatement and prevention. The problem, however, is of great magnitude, and solutions may 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. Nuisance controls, even though temporary, are necessary if man is to enjoy and utilize the great aqueous natural resource to the fullest extent.

The maintenance concept must be considered by all users of streams, lakes, or reservoirs. The waterfront is an aquatic extension of the surrounding land. To achieve the most lasting beauty, it must be maintained periodically in a fashion similar to that of the adjoining lawn or the abutting parkway; otherwise nuisances and unsightliness will prevail. Controls developed to cure water ills are not singular operations. The mechanism triggering nuisance development is usually such that it 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 plant nuisances 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 its limitations, based upon the dimensions of the area to be treated; these limitations are broad and do not exclude over-all utilization of the water. Controls that are recommended most generally have not been shown to seriously disrupt general lake ecology.

Of the various algal control methods, chemical treatment has proved 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 affect seriously the production of zooplankton, the production of fish and the existing fish population or the benthic invertebrates, or pose a health hazard.

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.

An overproduction of aquatic vegetation has been shown to inhibit 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.

Controls should be confined to nuisance areas, and should not attempt complete elimination of aquatic vegetation from a water body. The primary aim is to control organisms that relate to water-use nuisances, and to leave areas in the natural state that do not interfere with varied uses. It is important, therefore, to understand the ecology of aquatic vegetation and to use this 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. Many State agencies receive requests from laymen 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 nuisances in State-owned waters. 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 developing problems.

In 1956, about 40 percent of the States regulated the introduction of chemicals for the control of aquatic nuisances by statute or executive order.* Another 40 percent regulated by informal supervision, and about 20 percent reported no regulation of any type. Many in the latter group also reported the nonexistence of a problem. The Wisconsin State legislature in 1941 was the first to pass an act authorizing the State 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 complete costs 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.** 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 of the vegetation will not usually endanger fish, animals, and humans,

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

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

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.

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 benefits versus costs. The expected standing crop of algae approaches 2 tons per acre (wet weight) containing 15 lbs of nitrogen and 1.5 lbs of phosphorus. Submerged aquatic plants would be expected to approach at least 7 tons per acre (wet weight) containing 32 lbs of nitrogen and 3.2 lbs of phosphorus. Values may be higher under severe nuisance conditions. The efficacy of removing nutrients by harvesting the aquatic crops is discussed in the chapter, NUTRIENTS AND BIOLOGICAL GROWTHS.

Some methods and equipment used for the physical and mechanical removal of water weeds are reservoir drawdown and

Plate 55. Mechanical weed cutting and removal.

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. The mechanical harvesting of aquatic weeds involves equipment capable of handling large tonnages of materials (Livermore, 1954). Mechanical controls are especially valuable in the reclaiming of shallow nuisance areas by dredging and filling.

Microstrainers have been employed to remove algae from raw water at water treatment installations. Kenosha, Wisconsin, which receives its water from Lake Michigan, employs a microstrainer with apertures of 35 microns; algal removals have ranged from 46 to 97 percent (Nelson, 1965).

On 29 sampling dates extending from July 22 through September 6, 1961, water pumping rates varied from 10 to 27 mgd and from 1½ to 10 hours of sustained pumping.* The efficiency of the microstrainer depends on the number, size, and shape of the algal cell, and whether or not the cells occur singly or in chains. Rate of pumpage did not appear to affect efficiency in this study. The microstrainer was very efficient in removing those algal cells occurring in chains, since the water following the strainers contained only single cells or chains of 2- or 3-cells in length. The algal mass was reduced from 141 ± 10 to 11 ± 3 lbs per day (wet weight) in passing through the microstrainers for an overall volumetric efficiency of 91.9 percent. The number of individual algal cells was reduced from 47 ± 11 trillion per day to 5 ± 1 trillion in passing through the microstrainers for an average reduction of 88.8 percent. The efficiency of the microstrainer varies from one species of alga to another. For example, there was little reduction in *Stephanodiscus spp.* with the passage of water through the microstrainer, because the species occurring in these waters were small enough to pass with ease through the 35-micron mesh of the microstrainer.

In testing a pilot microstrainer of 35 micron aperature on Lake Winnebago, Wisconsin raw water in 1957, it was found that the poorest reduction performance by the fabric was experienced on the dates when the plankton counts were the highest. Blooms of

* Nelson, O. F., K. M. Mackenthun, and L. A. Lueschow, 1961. Microstraining at Kenosha. Paper Presented at Wisconsin Section, American Water Works Association, Milwaukee, Wisconsin (September 28) 15 pp. (mimeo.).

Anabaena and *Microcystis* were occurring. Five algal genera consistently passed through the microstraining fabric. These were the blue-greens *Anabaena* and *Aphanizomenon*, the diatoms *Cyclotella* and *Navicula*, and the green flagellate, *Phacotus*. On July 25, 1957, the algal count on the intake water to the microstrainer was 10,030 organisms per ml and the reduction through the microstrainer was 41 percent; on August 21, the raw water count was 47,270 organisms per ml and the reduction was 25 percent; on August 22 with a raw water count of 30,350 the reduction was 16 percent (26,600 *Anabaena spp.* per ml) ; and on August 28 the reduction was 37 percent with 4,740 organisms per ml in the intake water.

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 to use, (2) kill the specific nuisance plant or plants, (3) be nontoxic to fish, fish-food organisms and terrestrial animals 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 pesticides 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 to know only 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 lbs of active ingredient per gallon would necessitate dividing the pounds of chemical by 2 to arrive at the gallons of commercial formulation required to control the nuisance.

Algal Control

From 1904 (Moore and Kellerman, 1904) 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 reprinted extensively 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, the concentration would amount to 5.4 lbs of commercial copper sulfate per surface acre. The 2-foot depth has been determined to be about the maximum

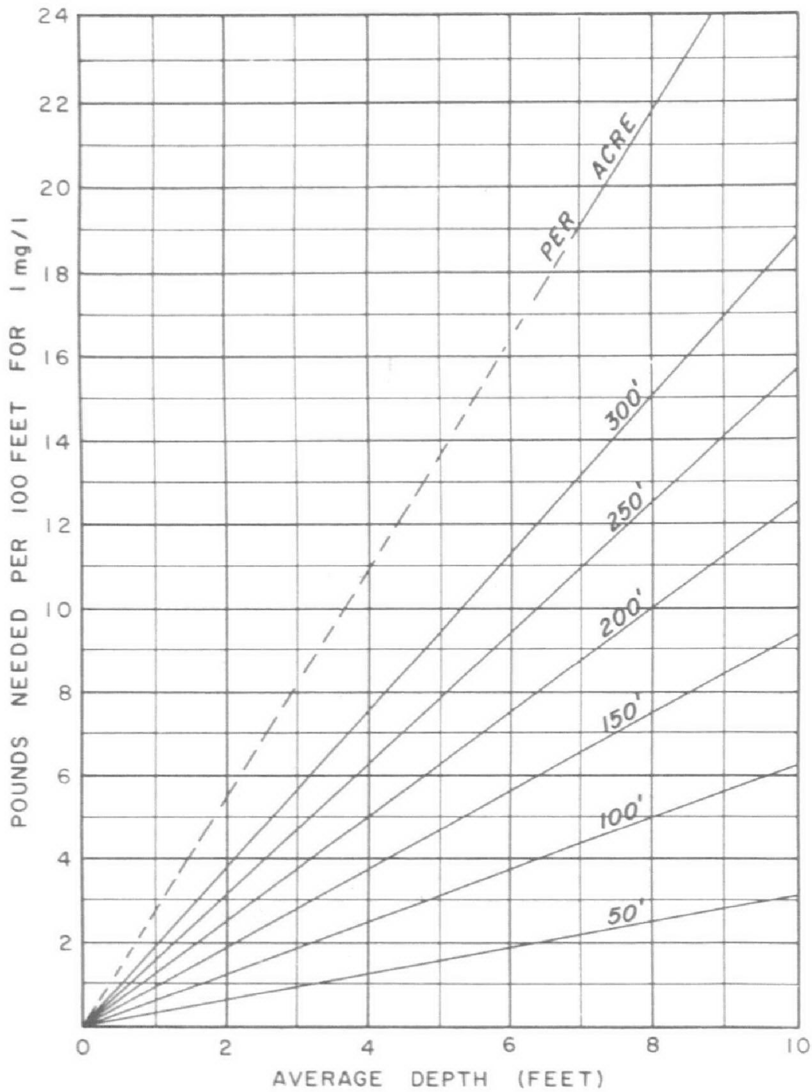

Figure 21. Chemical Dosage Chart. To achieve a chemical concentration of 1 mg/1 in water having an average depth of 8 feet requires 10 pounds of the active chemical for an area 200 feet by 100 feet, or 21.8 pounds per acre.

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 occur commonly 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 lb 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 a kill. In high-alkalinity lakes, algae frequently are planktonic and tend to concentrate near the surface, which is the only stratum in which appreciable 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

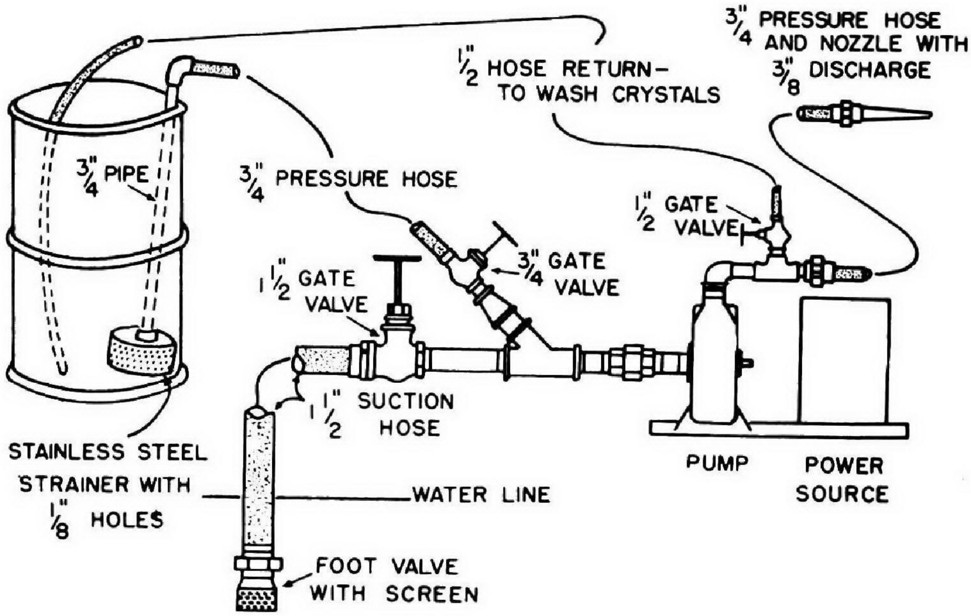

Figure 22. Equipment design for algal control. Small blue vitriol crystals are placed over perforated drum in chemical solution tank.

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.* Because rapid and uniform distribution of the algicide is essential,

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

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 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; 2 to 5 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 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).

Algal control measures should be undertaken before the maximum development of the algal bloom. If, for some reason, a given area 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 1 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.

Other methods of distributing copper sulfate have been devised; one of these is to blow a chemical dust rather than use a slurry or solution (Anon., 1965). The principal advantage of the blower-type machine is the ability to treat large surface areas rapidly with a light dosing of material.

The blower operates at 3,000 to 3,500 rpm, which has the tendency to grind the commercial-grade $CuSO_4$ snow into smaller particles. These small particles are blown into the air, and wind currents assist in spreading them over the surface of the water.

Certain disadvantages are found in the blower-type machines. For example, the larger machines are heavy enough to reduce the permissive load of chemical in the boat; and two or more men are required to transport the units in and out of the watercraft. The

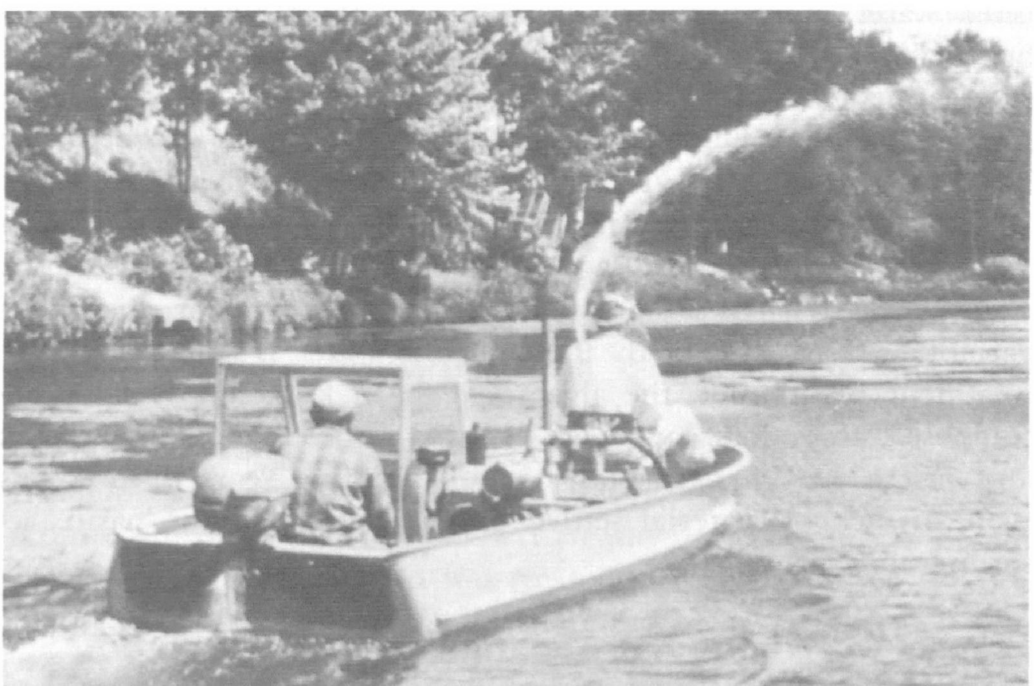

Plate 56. Liquid spray distribution of herbicide by small boat.

machines also need continual adjustment by a trainer operator, such as a contract applicator, to maintain a constant feed and to obtain an even distribution of copper. An excessive rate of feed may clog the discharge spout. Use of these blower-type machines is dependent upon the wind for distribution of chemical, and with shifting winds the boat crew as well as the reservoir may be dusted with the material. There is always the loss of varying amounts of copper sulfate dust that is carried away by the wind and then settles upon the above-water shoreline of the reservoir.

Helicopters have also been used in chemical distribution (Rosenberg, 1964). The East Bay Water Company, Oakland, California, found that a more efficient treatment could be obtained with a helicopter and that, as a result, fewer treatments were required per season for a particular reservoir. The cost of chemical distribution was slightly more by helicopter than by boat.

Menasha, Wisconsin draws its water from Lake Winnebago, an algal-laden surface supply. Taste and odor problems were severe in 1939 based upon Marx's (1951) statement, ". . . as an example of how bad the water can get, during August of 1939 the water temperature was 85, the algae count reached 50,000 units per ml., turbidity was 200 ppm and the odor reached 300. A treatment of over 100 ppm of carbon and 9 grains of alum, cut the odor down to about 15 and the turbidity down to about 10, in the finished water. This water was obviously not satisfactory for use, but nothing could be done about it." In 1946, a 25-million gallon pretreatment basin, giving a detention period of 7 or 8 days, with concrete baffles to ". . . force the water from one shore of the basin to the other five times as it travels from the inlet to the outlet" was placed in operation. As the water flows into the basin it is given a dosage of 2 mg/l of copper sulfate throughout the algal season regardless of type of algae, pumpage, or any other variable (Marx, 1951). By the time the water reaches the water treatment plant inlet, the algae have been killed, they have decomposed, the odors have been reduced an average of 67 percent and just a very fine turbidity is left. In five years of use, less than an inch of material settled on the bottom of the basin, according to Marx.

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 take place only in one direction—into the lake. There are limitations below which it is usually not feasible to attempt chemical weed control. The recommended minimum area to be treated is 200 feet by 200 feet. The treatment of very small areas permits the diffusion of the chemical on 3 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 as a sodium arsenite solution has been effectively used to control submerged aquatic weeds. Domogalla (1926) used it first in 1926 in the Madison, Wisconsin 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/l white arsenic equivalent were effective in controlling practically all submerged flowering plants in fish ponds, 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/l 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/l white arsenic equivalent was rec-

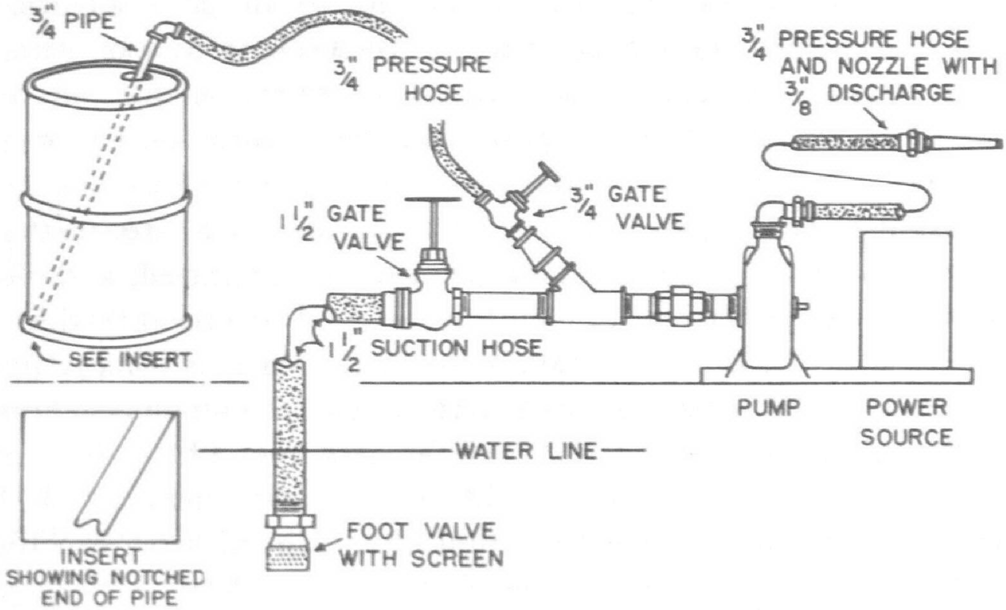

Figure 23. Diagram of equipment suitable for liquid spray distribution of chemical.

ommended; a dosage of 10 mg/l 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 ft. The majority of the projects in Wisconsin required the higher dosage 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 2 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 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, in 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 of 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. Ullmann 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,

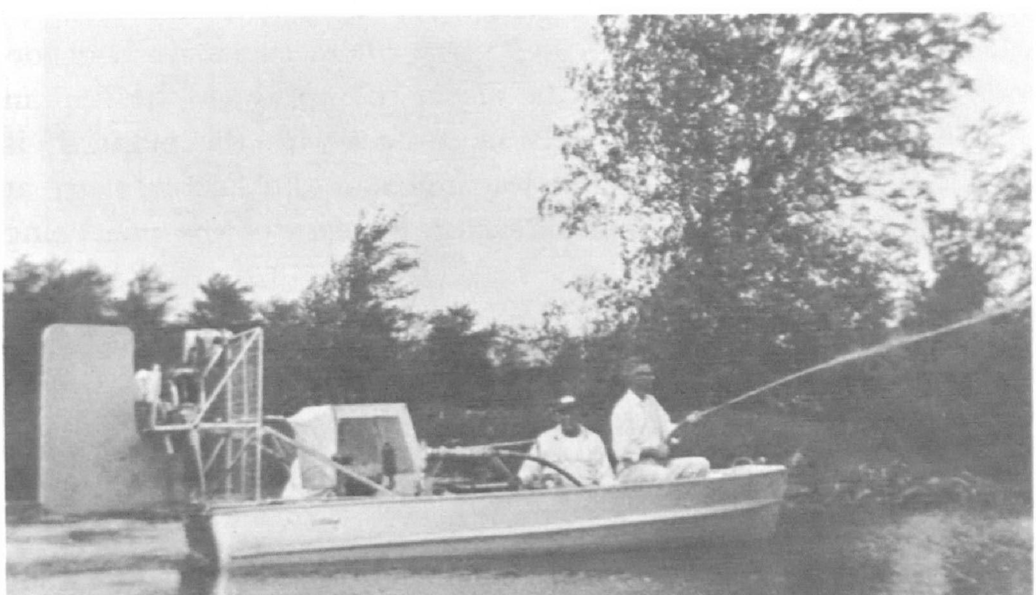

Plate 57. An air boat serves as a steady transport vehicle for spraying equipment.

many of which are specific in their herbicidal action (Surber, 1964).* 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. Data on the effects of many aquatic herbicides on algae, on various aquatic weeds, and on fish and other aquatic organisms have been reviewed in great detail by Lawrence (1962).

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 and evenly distribute the correct amount of chemical into the subarea. This procedure is then repeated in successive subareas. Spraying should be intiated at the shoreline so that fish will not be trapped in shallow water.

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.

Biological controls are currently being tested in the control of aquatic weeds. Preliminary studies on use of grass carp, *Ctenopharyngodon idellus*. (Cuvier and Vallenciennes), for aquatic weed control have recently been completed at Auburn University Agricultural Experiment Station. When stocked at a rate of 685

* Mackenthun, K. M., 1959. Summary of Aquatic Weed and Algae Control Research and Related Activities in the United States. Committee on Water Pollution, Madison, Wisconsin, pp. 1-14 (mimeo.).

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

per acre, the fish eliminated 12 species of weeds growing in plastic-lined pools within 6 weeks. In ponds, 3 species of rooted weeds were significantly reduced or eliminated in 1 month after being stocked with 20 to 40 grass carp per acre (Avault, 1965).

Stevenson (1965) reports that early growth of the grass carp (*Ctenopharyngodon idellus*) at the Fish Farming Experimental Station, Stuttgart, Arkansas, compared favorably with that reported in semi-tropical countries. The average weight at 18 months was 1,816 grams; the length, 50 centimeters. The fish were given a supplemental ration of commercial fish pellets and cut grass. Observations of the feeding habits indicate that this carp may not be a strict herbivore; it is recommended that a thorough study be made before the fish is released in natural waters. Stevenson calls it the most efficient aquatic plant-eating fish, but cautions that it might become another carp problem if introduced.

The destructiveness of aquatic vegetation by the German carp has long been recognized (Black, 1946; Cahn, 1929; Threinen and Helm, 1954; and Tryon, 1954); Grizzell and Neely (1962) recommend six or more muscovy ducks per acre to control duckweed in ponds.

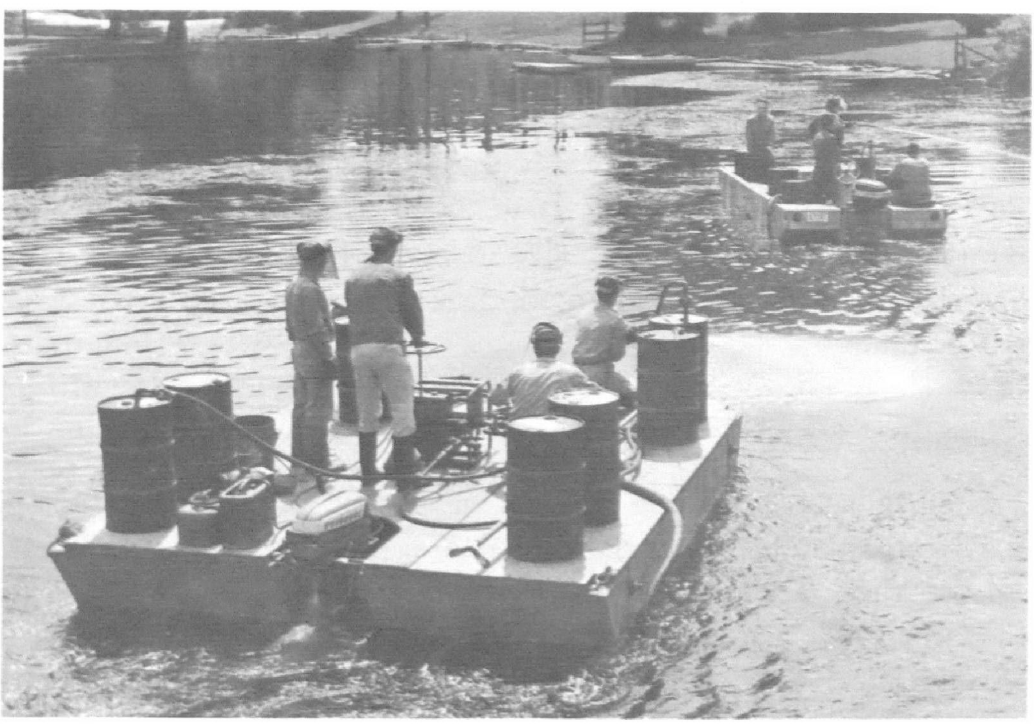

Plate 58. Chemical distribution through pressure spraying from a barge.

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 water surface. 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.* Already more than half of the country's original 125 million acres of wetlands have been spoiled for waterfowl use. As the national population approaches the 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 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.

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 chemi-

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

Plate 59. Barge distribution of granular herbicide.

cals are applied, but on a much smaller scale. Approximately 1.1 million 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 (Colorada, 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.

Plate 60. Helicopter application of a granular herbicide.

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/l 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 lbs of active ingredient per acre. Florida reported the control of 150 acres of cattails with 2,400 lbs of Dalapon along with the use of 48,000 lbs 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 lbs 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. Smith reported the treatment as ". . . highly successful . . ." and stated further 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 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 non-living 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, non-vascular 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—Resembling tufts of cotton or wool; denoting a fluid containing numerous shreds of fluffy, gray-white particles; containing or consisting of flocs.

GELATINOUS MATRIX—Jelly-like 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 filamenous 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 worm-like form of 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 flood flows 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 nipple-like 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 DISC—A circular metal plate, 20 cm in diameter, the upper surface of which is divided into four equal quadrants and so painted that two 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 one degree centigrade for each meter or approximately three 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.

TUBIFICIDAE—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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