Nutrients And Their Relationship To Weed And Algal Growths

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Vegetational problems in water may derive from the masses of floating, attached, and rooted plants. These growths become problems only when conditions of existence promote excessive standing crops that interfere with a water use. The purpose of this presentation is to examine the assets, liabilities, interrelationships, and growth stimulators for aquatic plants. More appropriate control of excessive production can often be implemented through an understanding of these phenomena.

Aquatic plants, like most other living matter, are not all bad or all good. Their assets are many and their liabilities are most often associated with their degree of concentration within the water media. A group of aquatic weed control specialists may be inclined to think only of the undesirable aspects because of day-to-day association with problems caused by an overproduction of the aquatic crop.

Plants are a basic and extremely important component of the aquatic ecosystem. As the basis of the food chain they are the bread of life for the aquatic grazing animals. Such animals range in complexity from the thousands of different kinds of mostly microscopic zooplankton to ducks and diving birds and fur bearing animals as well. Serving not only as food in themselves, aquatic plants serve also as the high rise apartment homes for a myriad of different small animals that are a vital link in the aquatic food web that culminates in a fish population.

Aquatic plant apartment homes provide protection from predators to their inhabitants. Studies have indicated that the plants with the most finely divided leaves will harbor the greatest abundance of animals. All aquatic vegetation areas will support many times the animal populations that may be found in non-vegetational areas within the same ecosystem. Plants are collectors for fish and the fishing potential is increased in areas adjacent to standing crops of vascular plants. Many fish use these areas as foraging grounds and dine contentedly upon the apartment dwelling inhabitants of the vascular plant community.

These same plants serve as the substrate for the spawn of many organisms including snails and fish such as the yellow perch. Just forty years ago, Rudolfs and Huekelekian 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 could be decreased from supersaturation to 17 percent saturation by placing the water in darkness, and could also be increased to 282 percent saturation by subjecting it to diffused light (Rudolfs and Huekelekian, 1931). If the darkness experiments had been extended over a longer time period, these early researchers would have no doubt found the oxygen saturation decreasing into an oxygen deficit. By adding oxygen during the process of photosynthesis, plants decrease the problems associated with decomposition of organic materials that may be present.

Plants tend to purify their surrounding water by other means. Certain algal and vascular plant populations have been found to possess a bactericidal quality that reduces the concentration of coliform bacteria and presumably pathogenic bacteria that would otherwise be associated with the specific environment.

In photosynthesis, aquatic plants use 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. 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 or deeper waters. Thus, in stratified lakes, there is a gradual decrease of dissolved oxygen in this deep water zone. After the dissolved oxygen is depleted, anaerobic decomposition continues with evolution of methane and hydrogen sulfide.

Computations of net photosynthetic oxygen production for several lakes yield values lying mostly between 42 to 57 pounds of oxygen per acre per day. A year around study under completely natural conditions in western Lake Erie showed winter yields of about 11 pounds per acre per day and summer maxima of about 85 pounds per acre per day. The annual oxygen curve closely followed the solar radiation curve. Net oxygen photosynthesis in two Alaskan lakes ranged from 3.4 to 4.0 pounds per acre per day (Goldman, 1960).

When aquatic plants are stimulated in some manner to the production of a standing crop so abundant that it interferes with a water use, plant nuisances develop. It is at this point where citizens, whose normal use of the water has been restricted by an abundant plant growth, demand remedial measures and control of the nuisance. Plant nuisances 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; reduce the use potential of irrigation waters through evapo-transpiration; foul irrigation siphon tubes and trash racks; and cause skin rashes and hayfever-like symptoms in man.

Dispersal of water plants is accomplished by water transport, migratory birds, air transport of algae, and by 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 transported by animals 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 the water, it roots again on a suitable substrate. Most aquatic plants are perennials and are well adapted to withstand heavy cropping by animals.

Plant populations will develop in the aquatic environment wherever conditions are suitable. Plants have been found growing at a depth of 500 feet in Lake Tahoe (Frantz and Cordone, 1967). Providing the aquatic environment is non-toxic, light intensity and nutrients are the principal controlling factors for planktonic growths Temperature is an important factor with some of the nuisance forms such as blue-green algae. Light intensity, water temperature, wave action, flow velocity, nutrient abundance, water depth and type of substrate, all interact to govern the establishment of weed beds or weed sparsity. Both bottom sediments, as well as the water contribute nutrients to the plants (Martin et al., 1969; McRoy and Barsdate, 1967). Sediments supply inorganic nutrients through the plants relatively weak root system.

Many submersed plants, as well as algae, continue active in winter, providing 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's surface. Others propagate by buds, tubers, roots and node fragments in addition to producing viable seeds. Factors that limit growth include insufficient 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. Considering that the physical properties of the environ-

The Standing Crop Per Lake Water Acre

	Phyto-plankton	Attached Algae	Submersed Vascular Plants	Fish	Midges
Wet Weight (lbs.)	1,000 to 3,600[1]	2,000[2]	14,000[3]	100 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

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

ment are favorable, the nutrients become the prime stimulators and controllers of aquatic plant production. The most important required nutrients are carbon, nitrogen, phosphorus, certain trace elements, organic growth factors, and, in the case of diatoms, silica.

Of the required nutrients, one will become limiting for future growth if other physical and chemical features of the aquatic environment are suitable. The term, "limiting", is one that has caused much misunderstanding among many of those who attempt to evaluate limiting factors. Something is always limiting to the further growth of a biological population. That which is limiting at one level of production may not limit at another. The term, "limit- is one that has caused much misunderstanding among many of those who attempt to evaluate limiting factors. Something is always limiting to the further growth of a biological population. That which is limiting at one level of production may not limit at another. The term "limiting", when associated with eutrophication and its control should refer to that substance which when added will stimulate a biological population to increase and become restrictive, or more detrimental, to a given water use.

Hutchinson (1957) states, "Of all elements present in living organisms, phosphorus is likely to be the most important ecologically, because the ratio of phosphorus to other elements in organisms tend to be greater than the ratio in primary sources of the biological elements. A deficiency of phosphorus is, therefore, more likely to limit productivity." Research over the succeeding years has not produced evidence that would discredit this basic observation. Evidence indicates that: (1) High phosphorus concentrations are associated with accelerated eutrophication of waters, when other growth promoting factors are present; (2) aquatic plant problems develop in reservoirs or other standing waters at phosphorus values lower than those critical in flowing streams; (3) reservoirs and other standing waters collect phosphates from influent streams and store a portion of these within consolidated sediments; and (4) phosphorus concentrations critical to noxious plant growths vary, and they produce such growths in one geographical area, at a given concentration but not in another. Basic sources of nutrients to waterways are (1) tributary streams carrying land runoff and domestic and industrial wastes, (2) the biological and chemical interchange between bottom sediments and superimposed water, and (3) precipitation from the atmosphere. Tributary streams have been reported to carry 21 pounds of phosphorus per square mile of drainage area in sparsely settled forested areas, 225 pounds of phosphorus per square mile of drainage area in agricultural areas, and more than 6,000 pounds in densely populated urban areas (Keup, 1968). The phosphorus contribution by domestic sewage is about 3 pounds per capita per year (Mackenthun, 1969). The upper 1-inch stratum of bottom sediments in Lake Sebasticook, Maine, contained a calculated 50 pounds of phosphorus per acre (Mackenthun, 1969).

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, an excellent growth media for algae, was 1 to 2 g/1 (dry weight) and in the field in sewage oxidation pounds the maximum was 0.5 g/1. Thus, assuming optimal 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 wet algae under field conditions. Considering a cellular phosphorus content of 0.7 percent in algae, 1 pound of phosphorus could be distributed among 1,450 pounds of algae on a wet weight basis. A considered judgment suggests that to prevent biological nuisances, total phosphorus should not exceed $100\mu g/1$ P at any point within the flowing stream, nor should $50\mu g/1$ be exceeded where waters enter a lake, reservoir, or other standing water body. To enhance the quality of this Nation's lakes, reservoirs and estuaries, we must pursue a major effort with diligence and speed to reduce to the ultimate phosphates, and all other nutrients where feasible, from all controllable sources.

With suitable environmental conditions, plants will develop and avail themselves of the space and available nutrients. With the application of chemicals to a segment of the aquatic environment, it is possible to change the predominant growth from vascular plants to planktonic algae or attached algae and visa versa almost at will.

There are over 17,000 species of algae and fresh water forms which are grouped into blue-green algae, green algae, yellow-green algae, golden-brown algae and diatoms, red algae, euglenoids and dinoflagellates. Some of these are capable of producing physiologically active metabolites that may function as toxins, growth inhibitors, or growth stimulators to themselves or to associated algae. Some algae are born to self-destruct. After a growth period when extracellular products have accumulated, it is thought that these act as deterrents and that the plant, in a sense, manufactures its own algicide (Prescott, 1960). The extracellular substances (possibly of a toxic nature) have prevented the growth of certain other species, and thereby the plant that begins its development first in a body of water quickly assumes a dominance, depending upon its inherent cell division rate. With auto-destruction comes a reduction in the inhibitor, thus permitting another species or group of species to develop.

Natural waters contain these active 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 aquatic environment. It has been postulated that algae secrete not just one substance but several, some antibiotic, other 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 in excess of critical values.

It should be of interest to those engaged in the control of aquatic plants to have information on the relative standing crops of some of the life within water and their relative nitrogen and phosphorus contents. The following table presents some of the pertinent information.

Chemical plant control measures to be employed depend 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 essentially nontoxic to fish, fishfood organisms and terrestrial animals that may use the water 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 be amenable to safeguards during the unsafe period; and (6) be of reasonable cost.

Ultimate control of nuisance aquatic organisms can be accomplished only by drastic alteration of the basic cause (s) of the problem. The maintenance concept must be considered by all users of streams, lakes, or reservoirs. The water front is an aquatic extension of the surrounding land. To achieve the most lasting beauty, it must be maintained in a fashion similar to that of the adjoining lawn or the abuting parkway; otherwise nuisances and unsightliness will prevail. Controls developed to cure water ills are not singular operations. The mechanisms triggering nuisance development are usually such that it will reestablish itself another year. Continuous surveillance and appropriate maintenance are necessary in water management to ensure maximum multiple use.

REFERENCES CITED

Allen, M. B., 1955. General Features of Algae Growth in Sewage Oxidation Ponds. California State Water Pollution Control Board, Sacramento, Publication No. 13, pp. 11-34.

Beard, H. R. 1926. Nutritive Value of Fish and Shellfish. Report U. S. Commissioner of Fisheries for 1925, pp. 501-552.

Birge, E. A. and C. Juday, 1922. The Inland Lakes of Wisconsin. The Plankton. I. Its Quantity and Chemical Composition. Wisconsin Geological and Natural History Survey. Bull. No. 64, Scientific Series, No. 13, pp. 1-222.

Borutsky, E. V., 1939. Dynamics of the Total Benthic Biomass in the Profundal of Lake Beloie. Proc. Kossino Limn. Sta. of the Hydrometeorological Service, USSR, 22: 196-218. Trans. by M. Ovchynnyk, edited by R. C. Ball and F. F. Hooper.

Dineen, C. F., 1953. An Ecological Study of a Minnesota Pond. Am. Midl. Nat., 50 (2): 349-356.

Frantz, T. C. and A. J. Cordone, 1967. Observations on Deepwater Plants in Lake Tahoe, California and Nevada. Ecology 48 (5): 709-714.

Gerloff, G. C. and F. Skoog, 1957. Nitrogen as a Limiting Factor for the Growth of *Microcystis aeruginosa* in Southern Wisconsin Lakes. Ecology, 38, (4): 556-561.

Goldman, C. R., 1960. Primary Productivity and Limiting Factors in Three Lakes of the Alaska Peninsula. Ecological Monographs 30: 207-230.

Harper, H. J. and H. R. Daniel, 1939. Chemical Composition of Certain Aquatic Plants. Botanical Gazette, 96, p. 186.

Hutchinson, G. E., 1957. A Treatise on Limnology. John Wiley and Sons, New York, 1015 pp.

Keup, L. E., 1968. Phosphorus in Flowing Waters. Water Research, Pergamon Press, 2: 373-386.

Mackenthun, K. M., 1969. The Practice of Water Pollution Biology. United States Department of the Interior, Federal Water Pollution Control Administration, 281 pp.

Martin, J. B., Jr., B. N. Bradford, and H. G. Kennedy, 1969. Factors Affecting the Growth of *Najas* in Pickwick Reservoir, National Fertilizer Development Center, Tennessee Valley Authority, Muscle Shoals, Alabama, Doc. No. F70 ACD 2.

McRoy, C. P. and R. J. Barsdate, 1970. Phosphate Absorption in Eelgrass. Limnology and Oceanography 15 (1): 6-13.

Moyle, J. B., 1940. A Biological Survey of the Upper Mississippi River System (in Minnesota). Minn. Dept. Cons. Fish. Inv. Rept. No. 10, 69 pp.

Neil, J. H., 1958. Nature of Growth in a Report on Algae, *Cladophora*. Report of Ontario Water Resources Commission, pp. 3-7.

Prescott, G. W., 1960. Biological Disturbances Resulting from Algal Populations in Standing Waters. The Ecology of Algae, Spec. Pub. No. 2, Pymatuning Laboratory of Field Biology, University of Pittsburgh, pp. 22-37 (1959).

Rickett, H. W., 1922. A Quantitative Study of the Larger Aquatic Plants of Lake Mendota. Trans. Wisconsin Acad. Sci., Arts, Letters, 20, pp. 501-522.

Rickett, H. W., 1924. A Quantitative Study of the Larger Aquatic Plants of Green Lake, Wisconsin. Trans. Wisconsin Acad. Sci., Arts, Letters, 21, pp. 381-414.

Rudolfs, W., and H. Heukelekian, 1931. Effect of Sunlight and Green Organisms on Reaeration of Streams. Industrial and Engineering Chemistry, 23, pp. 75-78.

Swingle, H. W., 1950. Relationships and Dynamics of Balanced and Unbalanced Fish Populations. Agricultural Experiment Sta., Alabama Polytechnic Institute, Auburn, Bull. No. 274, pp. 1-74.