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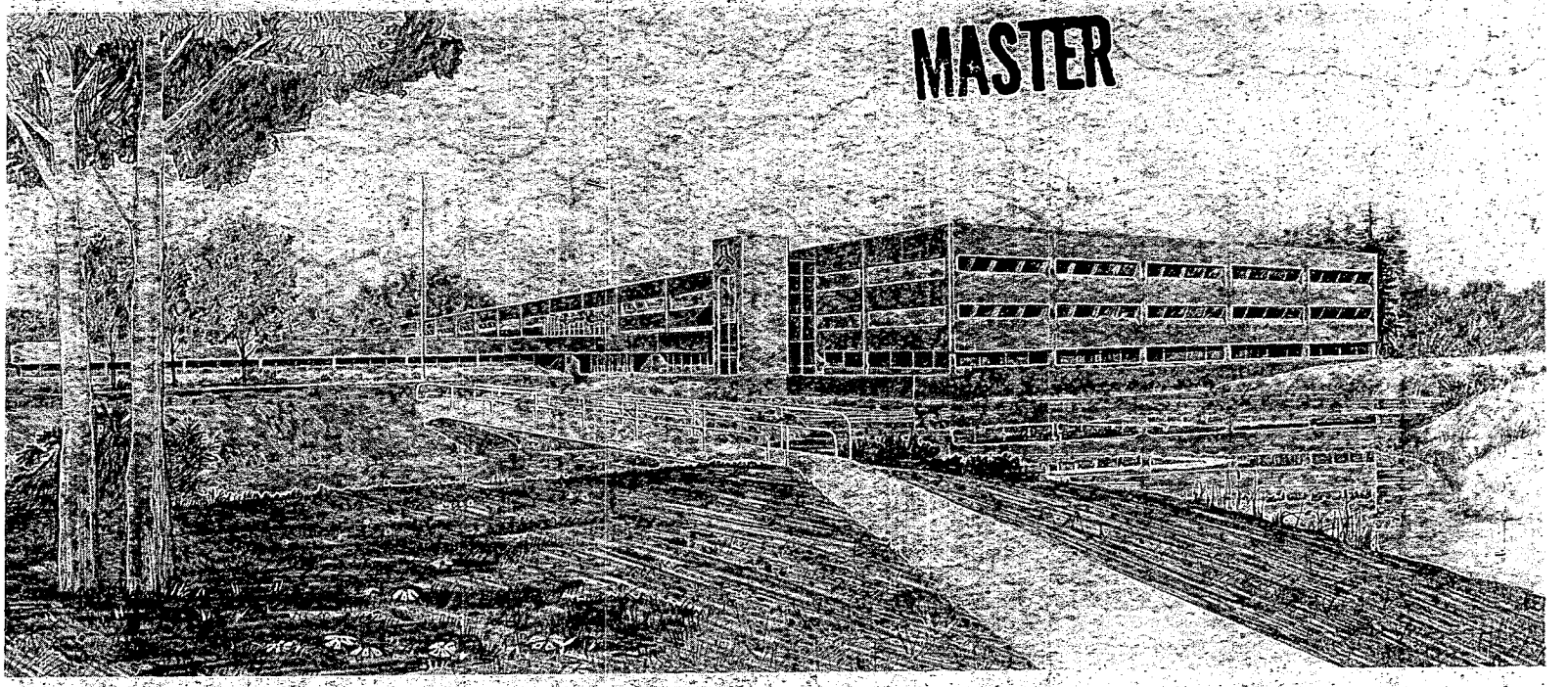



U.S. Department of Energy
Idaho Operations Office • Idaho National Engineering Laboratory

# Geothermal Wetlands: An Annotated Bibliography of Pertinent Literature

Norman E. Stanley
Thomas L. Thurow
Brent F. Russell
Jacquelyn F. Sullivan

May 1980



Prepared for the
U.S. Department of Energy
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EG&G Idaho

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# GEOTHERMAL WETLANDS: AN ANNOTATED BIBLIOGRAPHY OF PERTINENT LITERATURE



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## ABSTRACT

Literature providing information on natural and artificially created wetlands were reveiwed. The objective was to gather pertinent data that could be extrapolated to geothermal wetlands. Applicable studies are presented in the form of an annotated bibliography.

# CONTENTS

# GEOTHERMAL WETLANDS: AN ANNOTATED BIBLIOGRAPHY OF PERTINENT LITERATURE

## INTRODUCTION

Development of geothermal resources in the western United States, where water is in short supply and aquatic habitat is limited, has prompted an interest in the development of wetlands with geothermal fluids. Advantages associated with geothermal wetland development include: (a) development of a low cost biological alternative for treatment of geothermal water, (b) creation of valuable wildlife habitat mutually beneficial to fish, wildlife, and geothermal energy development, and (c) generation of biomass for potential conversion to liquid fuels.

Conventional disposal methods are limited primarily to surface disposal, evaporation, and injection; however, restrictions by state water protection agencies and the EPA often disallow surface disposal due to the high concentrations of dissolved solids inherent in most geothermal fluids. Injection is energy consumptive and cost prohibitive to many proposed developments. Development of an alternate disposal technology could reduce constraints imposed by these disposal barriers, and thus enhance the competitive economic position of geothermal direct use applications. In the arid western United States where many geothermal resources exist, water, even of marginal quality, is often limited and of preeminent value to terrestrial and aquatic ecosystems. If geothermal water in these areas were utilized for wetland habitat development, disposal costs would be reduced, water quality would be improved, and the wetland would provide significant benefits to fish and wildlife populations. An additional benefit could be realized from utilization of the primary and secondary crops produced in and on geothermal wetlands environments.

A review of the pertinent wetland literature was performed to gather information from natural and artificially created wetlands that could be extrapolated to those conditions anticipated for geothermal wetlands. Freshwater, brackish, and marine literature were reviewed as well as the effects of thermal discharges on aquatic environments. Emphasis was placed on (a) the characterization of water quality requirements; (b) tolerance limits of wetland flora and fauna; and (c) the potential effectiveness of aquatic vegetation at bioaccumulating solutes inherent in most geothermal waters. Biomass production in wetland ecosystems was also reviewed; literature topics reviewed include characteristics of:

(1) Algae

(2) Wetland ecosystems

(3) Institutional aspects

(4) Macrophytes—general

(5) Macrophytes—production rates

(6) Macrophytes—mineral absorption

(7) Trace metal absorption

(8) Wetland soils

(9) Water quality

(10) Other aspects of marsh ecosystems.[a]

Studies applicable to a geothermal wetland development are presented in the form of an annotated bibliography.

The annotated bibliography is a portion of an EG&G, Idaho, Inc., Technical Development Project (TDP) designed to research and develop the potential of utilizing wetlands in conjunction with geothermal developments. Ongoing research at the Department of Energy's Raft River Geothermal Site is designed to determine the bioaccumulative properties of selected plant species and their effectiveness at reducing the high solute concentrations associated with geothermal fluids.

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a. These numbers, (1) through (10), will be added, in parentheses, at the end of some of the bibliograhic annotations to indicate to which category or categories the reference pertains.

Anonymous, "Aquatic Biomass as an Energy Source," *Biomass Digest, 1*, 1979, p. 1.

Energy production from aquatic biomass requires development of high yield species and cost effective harvesting techniques. Present estimates for potential yields are 9200 to 11 000 kg/ha/year for marine biomass and perhaps as high as 66 500 ash free kg/ha/year for some land-based aquatic biomass. These figures compare favorably with 10 000 kg/ha/year yield for sugar cane, which is among the most efficient of terrestrial plants. A freshwater algae farm could produce about nine times as much energy per year as an equal area devoted to corn.

C. E. Boyd and J. M. Lawrence, "The Mineral Composition of Several Freshwater Algae," *Proceedings of the Twentieth Annual Conference Southeastern Association of Game and Fish Commissions, 1967*, pp. 413-424.

Samples of the following 14 genera of algae were collected from various geographical or geological areas during the period from April to November 1965 and subjected to mineral determinations: *Anabaena, Aphanizomenon, Chara, Cladophora, Euglena, Hydrodictyon, Lyngbya, Microcystis, Mougeotia, Nitella, Oedogonium, Pithophora, Rhizoclonium*, and *Spirogyra*. Considerable variation in the levels of most elements, both within and between genera, was found. Phytoplankton algae had low metal ion contents and high carbon (C), nitrogen (N), and phospherous (P) concentrations. Nonplankton algae generally contained more metallic ions and less C, N, and P. A marked mean accumulation of one or more elements above the usual levels by several genera was noted: N in Cyanophycean genera and *Euglena*; P in Cyanophycean genera; sulfur (S) in *Aphanizomenon, Hydrodictyon,* and *Pithophora*; potassium (K) in *Hydrodictyon* and *Nitella*; calcium (Ca) in *Chara* and *Pithophora*; magnesium (Mg) in *Chara*; sodium (Na) in *Spirogyra*; boron (B) in *Pithophora* and *Lyngbya*. Both *Chara* and *Pithophora* were extremely rich in most bases and low in Ca when compared to other genera. Almost all genera contained relatively high levels of copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn). Emission spectrographic analyses of *Chara, Euglena, Microcystis, Pithophora, Rizoclonium,* and *Spirogyra* revealed the presence of substantial quantities of aluminum (Al), barium (Ba), cobalt (Co), molybdenum (Mo), silicon (Si), and strontium (Sr). These compositional data indicate that algae play an important role in the mineral dynamics of aquatic ecosystems. (Author's abstract.)

C. E. Boyd, "Some Aspects of Aquatic Plant Ecology," *Reservoir Fishery Resources Symposium*, 1968, pp. 114-129.

Nonplankton algae and aquatic angiosperms contain large amounts of macronutrient cations while phytoplankton samples are lower in these elements. However, N and S levels in phytoplankton usually exceed values determined for macrophytes. Substantial levels of micronutrients are found in most aquatic species.

Productivity rates and vegetative yields in pure stands of macrophytes often equal or exceed those for nonaquatic herbaceous vegetation. Quantities of minerals contained in standing crops of aquatic plants represent a large drain on available nutrient supplies in many lakes.

Ecological data indicate that distribution and growth of many macrophytic species are related to characteristics of the substratum. Rooted angiosperms have the necessary morphological and physiological adaptations for mineral absorption via the roots; however, the role of hydrosoil nutrients in sustaining plant growth needs critical experimental evaluation.

Apparent shortcomings in techniques of estimating aquatic fertility with bottom-soil and water chemical analyses are discussed. (Author's abstract.)

C. E. Boyd, "Sources of $CO_2$ for Nuisance Blooms of Algae," *Journal of Weed Science, 20*, 1972, pp. 492-497.

Bacterial production of $CO_2$ from sucrose substrate increased growth of seven species of

NOTE: Numbers in parentheses at the end of the annotations refer to the category of the particular type of reference. The categories are identified in the introduction of this report.

algae in $CO_2$-limited laboratory cultures. Decomposition of organic matter in pond water also supplied enough $CO_2$ to support good algal growth in cultures deprived of other sources of $CO_2$. Estimates of $CO_2$ production from decay of dissolved organic matter in six pond waters ranged from 0.32 to 3.53 mg/l/24 hr. The carbonate-bicarbonate equilibrium system is a major source of $CO_2$ for algal photosynthesis. However, in waters of low or extremely high alkalinity, this system will not support high rates of photosynthesis. Decomposable organic compounds must be considered with N and P as factors responsible for accelerated eutrophication and nuisance algal blooms. (Author's abstract.)

C. E. Boyd, "Biotic Interactions Between Different Species of Algae," *Journal of Weed Science, 2l*, 1973, pp. 32-37.

Species of green algae seldom grow as well in two-species cultures with other green algae, or with blue-green algae, as when cultured alone. Several species of algae apparently excreted one or more substances into the medium which inhibited the growth of the second species. Inhibition of green algae growth was particularly great in two-species cultures with the blue-green algae, *Oscillatoria rubescens, Anabaena flos-aquae, Microcystis aeruginosa,* and *Coccochloris peniocystis*. Green algae also failed to grow at normal rates in media prepared from filtrates of water from ponds which contained blooms of blue-green algae. Inhibitory substances are apparently an important factor in the development and persistance of relatively unialgal blooms of various species. (Authors abstract.)

C. E. Boyd, "Summer Algal Communities and Primary Productivity in Fish Ponds," *Hydrobiologia, 4l*, 1973, pp. 357-390.

The types of algal communities and the magnitude of primary production in fish ponds receiving fish feeds and fertilizes was investigated.

Data are presented on phytoplankton communities in experimental ponds treated with the following: ammonium nitrate and triplesuperphosphate, triplesuperphosphate, cracked corn (10% crude protein), and Auburn No. 3 fish food (36% crude protein). Comparative data on algal communities were also obtained from production ponds which received feeds or fertilizers. All nutrient additions to experimental ponds resulted in higher levels of gross photosynthesis and greater concentrations of chlorophyll A than were found in the control treatments. Persistent blooms of blue-green algae occurred in ponds receiving nitrogen and phosphorus fertilization; blooms did not persist if only phosphorus was added. Control ponds where no nutrients were added were dominated by green algae. Data illustrating the competition of macro-algae with phytoplankton are presented.

J. S. Burlew, *Algal Culture—From Laboratory to Pilot Plant*, Washington, D.C.: Kirby Lithograph Co., Inc., 1964.

A collection of papers dealing with various topics relating to algal culture is presented. Subjects covered include conditions necessary for algae growth, possible uses of microscopic algae, growth of algae in mass culture, and pilot-plant experiments on algal mass culture. The current state-of-the-art of large-scale culture of algae is also assessed.

G. F. Combs, "Algae (Chlorella) as a Source of Nutrients for the Chick," *Science, ll6*, 1952, pp. 453-454.

The value of dried *Chlorella*, a green algae, as a nutrient source was tested for chicks raised for a 4 week period. Mortality, feed consumption, and body weights were recorded. An observed growth-depressing action resulted from the inclusion of 10% dried *Chlorella* in the supplemental diet and was believed to be due to the hygroscopic nature of the *Chlorella*. The mechanical impediment interferred with feed consumption and, consequently, resulted in a slightly lower total weight of the chicks at 4 weeks of age. Despite this mechanical difficulty, the results demonstrate clearly that dried *Chlorella* may serve as a source of certain dietary requirements and may be considered as a potential food source in areas of limited agricultural resources.

B. B. Cook, "The Nutritive Value of Waste-Grown Algae," *American Journal of Public Health, 52*, 1962, pp. 243-251.

The proximate analysis and concentrations of Ca, P, Fe, carotene, ascorbic acid, and eight B-vitamins were determined in single-cell algae grown in symbiosis with bacteria in open, outdoor ponds on both sewage and organic wastes. The two dried products were found to contain 40 to

50% protein and extremely high concentrations of minerals. Compared with beef on a weight basis, the algae contained more of all of the B-vitamins, except $B_{12}$. The unpleasant odor and flavor of algae-bacteria cultures would require combination of the algae with flavorful inexpensive protein foods to effectively mask that of the algae. This technique could supply amino acids in short supply in animal diets.

W. M. Dungstan, "Problems of Measuring and Predicting Influence of Effluents on Marine Phytoplankton," *Environmental Science and Technology, 9*, 1975, pp. 635-638.

Experiments were performed to determine if N and P concnetrations in municipal sewage effluents could be used to predict changes in production, seasonal patterns, and populations of coastal microalgae. A long-term subtle selection of species was noted, indicating that use of N and P to model ecological changes of marine phytoplankton in response to stimulation by sewage effluents may be misleading. Trace factors such as metals, chelation potential, organic load, and vitamins may ultimately be uniting or causing species selection.

L. J. M. Felfoldy, "Effect of Temperature on Photosynthesis in Three Unicellular Green Algae Strains" *Acta Biol. Hungary, 12*, 1961, pp. 153-159.

The photosynthetic potential of three pure algal strains (*Coelastrum microporum, Ankistrodesmus falcatus,* and *Scenedesmus obtusiusculus*) was investigated at different temperatures between 10 and 40°C. *Coelastrum* and *Scenedesmus* are high-temperature strains with optimal photosynthesis at 30 and 35°C, respectively. *Ankistrodesmus* maximal photosynthesis was observed at 25°C. Those strains which can endure high temperatures exhibit high productivity, an important consideration for mass culture of algae.

G. E. Fogg, *Algal Cultures and Phytoplankton Ecology*, Madison: University of Wisconsin Press, 1963.

Topics relating to algae and phytoplankton, such as metabolic and growth patterns, phytoplankton periodicity, and phytoplankton distribution and seasonal succession, are discussed in this general text.

J. L. Gallagher and F. C. Daiber, "Primary Production of Edaphic Algal Communities in a Delaware Salt Marsh," *Limnology and Oceanography, l9*, 1974, pp. 390-395.

Gross primary production of edaphic algae was estimated for five areas in a high salinity tidal marsh near Lewes, Delaware. Salt pan and bare bank (free of angiosperms) algal production did not vary significantly from one part of the year to another. Algal productivity in the tall *Spartina alterniflora* and *Distichlis spicata* areas was greatest from mid-January to mid-May. In the short *S. alterniflora* area algal productivity did not decrease in the warmest part of the year as it did in the two other grass areas. Annual cycles of light, temperature, and salinity were measured. Since much of the algal production occurs when angiosperms are dormant, it complements the pattern of angiosperm energy fixation. (Author's abstract.)

G. D. Johnson, A. W. McIntosh, G. J. Atchison, "The Use of Periphyton as a Monitor of Trace Metals in Two Contaminated Indiana Lakes," *Bulletin of Environmental Contamination Toxicology, l9*, pp. 733-740, 1978.

The feasibility of using periphyton as a monitor of trace metal contamination in two heavily polluted lakes was investigated; however, the results were inconclusive as to whether periphyton in lentic systems are reliable biological indicators of heavy metal pollution. A tolerance to metals on the part of certain periphyton species was suggested.

O. Holm-Hansen "Ecology, Physiology, and Biochemistry of Blue-Green Algae," *Annual Review of Microbiology, 22*, 1968, pp. 47-70.

All aspects of the life cycle and biology of blue-green algae are summarized in detail. Blue-green algae are widely distributed throughout practically all habitats which support life; they are of considerable ecological importance as a function of increasing the fertility of terrestrial and aquatic environments. Many of the ecologically important aspects of blue-green algae, together with physiological and biochemical considerations, are discussed.

B. Kok, "On the Efficiency of Chlorella Growth" *Acta Bot. Netherlands, 1*, 1952, pp. 445-467.

The efficiency of light conversion into organic matter by cultures of growing *Chlorella* cells was measured under various conditions. Incident light intensity, fractional absorption, photosynthetic rate, and respiratory rate were measured; the increase in dry weight and the chemical composition of the harvested algae were determined. Strong continuous illumination induced cells with low nitrogen content, whereas cycles of light and dark photoperiods favored the occurrence of algae rich in protein. A relatively small decrease in overall efficiency was caused by natural day and night photoperiods.

L. E. Kuentzel, "Bacteria, Carbon Dioxide, and Algal Blooms," *Journal of the Water Pollution Control Federation, 41*, 1969, pp. 1737-1747.

$CO_2$ is the major nutrient required for algal growth; 2 g of $CO_2$ produce approximately 1 g of algae. The atmosphere and/or dissolved carbonate salts cannot supply $CO_2$ in sufficient quantity for fast-growing massive algal blooms; however the action of bacteria on ample amounts of organic matter can supply as much as 20 mg/l $CO_2$ in a supersaturated state. While phosphorus is a necessary element for algal growth, the amount required to support massive blooms is quite low, $\leq 0.01$ mg/l.

A. M. Mayer, A. Eisenberg, M. Evenari, "Studies on Deep Mass Culture of Algae In Israel," *Scientific Monthly, 83*, 1956, pp. 198-203.

A deep unit with an inexpensive method of agitation for mass culture of algae is described. Yields as high as 21 g (dry weight)/$m^2$ of illuminated area per day were obtained. The yearly average for three species of *Chlorella* was 16 g/$m^2$/day. These results suggest that the mass culture of algae is economically feasible.

E. J. Middlebrooks et al., "Techniques For Algae Removal from Wastewater Stabilization Ponds," *Journal of the Water Pollution Control Federation, 46*, 1974, pp. 2676-2695.

Fourteen techniques for the removal of algae from stabilization pond effluent are discussed. These methods include: centrifugation, microstraining, coagulation-flocculation, in-pond removal of particulate matter, complete containment, biological disks, baffles and raceways, in-pond chemical precipitation of suspended materials, autoflocculation, biological harvesting, oxidation ditches, soil mantle disposal, dissolved air flotation, and granular media filtration and intermittent sand filtration. The criteria of ease of operation, low cost and maintenance, and dependability of operation cause many of the above methods to be impractical.

V. B. Myers, R. L. Iverson, R. C. Harriss, "The Effect of Salinity and Dissolved Organic Matter on Surface Charge Characteristics of Some Euryhaline Phytoplankton," *Journal of Environmental Marine Biology and Ecology, 17*, 1975, pp. 59-68.

The effects of salinity and dissolved organic matter on the surface charge characteristics of selected phytoplankton were investigated by means of microelectrophoresis. *Nannochloris oculata, Monochrysis lutheri,* and *Cyclotella meneghiniana* were negatively charged on diluted sea water. The magnitude of the electrophoretic mobility (EPM) of two of the phytoplankton species decreased as the salinity of the medium increased. Heat killing influenced the EPMs of the three phytoplankton species, suggesting the possibility that the surface charge of these phytoplankton organisms is influenced by surface biological processes. The EPM of *C. meneghiniana* decreased when the dissolved organic content of the medium was greater than 0.3 mg/l. Dissolved humic acids also inhibited the rate and magnitude of mercury (Hg) sorption by *C. meneghiniana*. (Author's abstract.)

J. Poltoracka, "Specific Composition of Phytoplankton in a Lake Warmed by Waste Water from a Thermoelectric Plant and Lakes with a Normal Temperature," *Acta Societatis Botanicorum, Poloniae, 37*, 1968, pp. 297-325.

A study of the specific composition of phytoplankton in three Russian lakes characterized by different temperatures due to the addition of thermal effluents was conducted. One lake had "normal" temperature water (0.8 to 20.7°C), the second lake was only slightly influenced by thermal water and deviated in temperature from the uneffected lake at various periods from 0.2 to 2.2°C. The third lake was directly influenced by the addition of thermal water and ranged from 7.4 to 27.5°C. The highest phytoplankton species diversity (285) was found in the warmest lake and the lowest (197) in the coldest lake; the main difference consisted of lower numbers of *Chlorophyta*. The number of algae species in the

warm lake was relatively stable while the other two lakes showed marked seasonal variations. A positive correlation was found between the number of taxa of algae and increasing surface temperature of the water, with the most pronounced effects in the warm lake. This was most noticeable with respect to *Chlorophyta*.

L. R. Pomeroy, "Algal Productivity in Salt Marshes of Georgia," *Limnology and Oceanography, 4*, 1959,. pp. 386-397.

Gross primary production of algae in the intertidal marshes on the coast of Georgia was measured at various seasons. Measurements were made of light, temperature, pH, depth of flooding at high tide, and sedimentary chlorophyll. Migration of the algae in the sediments was observed along creek borders.

Production during low tide was 150 mg $C/m^2/hr$ (where C is carbon) in winter and 20 to 30 mg $C/m^2/hr$ in summer. Production under water, during high tide was 200 mg $C/m^2/hr$ in August and dropped to 50 mg $C/m^2/hr$ in winter. A relation between the changes in production and the regime of light, temperature, and tides was postulated. Changes in production during high and low tide alternated resulting in a nearly constant daily production throughout the year. The annual gross algal production was estimated to be 200 g $C/m^2$. Net production was not less than 90% of gross production. Photosynthetic efficiency varied from 3% to less than 0.1%. (Author's abstract.)

J. G. Stockner and N. J. Antia, "Phytoplankton Adaptation to Environmental Stress from Toxicants, Nutrients, and Pollutants - A Warning," *Journal of the Fisheries Research Board of Canada, 33*, 1976, pp. 2089-2096.

Studies investigating the impacts of pollutants and nutrients on phytoplankton species may overlook the potential for adaptation to the polluted environment and subsequent growth due to insufficient duration of algal bioassays. Literature examples are cited which support this concept. Evidence suggests that algal exposure to pollutants ranging from 20 to 40 days is required for successful adaptation, and that repeated exposure to increasing levels of pollutants induces successful adaptation to and tolerance of several-fold higher concentrations of the pollutants or nutrients. The importance of long-term bioassays aimed at assessing potential algal adaptation is stressed.

J. D. H. Strickland, "Measuring the Production of Marine Phytoplankton," *Journal of the Fisheries Research Board of Canada, 122*, 1960, pp. 1-172.

Methods of measuring marine phytoplankton production are discussed. Plankton, productivity, and plant pigment terminology are defined and conversion factors for standing crop production are presented. The elemental composition, major molecular constituents, and pigment chemical composition are described. Methods for measuring standing crop and rate of photosynthesis are provided.

H. Tamiya, "Mass Culture of Algae," *Annual Review of Plant Physiology, 8*, 1957, pp. 309-334.

Techniques used for culturing algae on a large scale, the potential yields that can be achieved with different strains or species of algae, and products that can be derived from mass cultures of algae are discussed in detail. The mass culture of nitrogen-fixing algae, algal culture in sewage, and an economic appraisal of the utilization of algal cells are discussed. Estimates for production costs of dry *Chlorella* ranged from 37 to 57 cents/kg in 1957. The potential for algal protein utilization as food supplements was high; the nutritive value of algal protein was found to be higher than that of dried skim milk or egg white. By adding dried algal powder to foods such as bread, noodles or soups, additional protein value of the foods was attained.

J. Verdiun and W. E. Schmid, "Evaluation of Algal Culture as a Source of Food Supply," *Developments in Industrial Microbiology, 7*, 1966, pp. 205-209.

Advantages and disadvantages of aquatic and terrestrial plants as energy fixing organisms are reviewed. The terrestrial environment is characterized by rapid $CO_2$ transport to photosynthesizing organisms and a highly transparent atmosphere; aquatic mediums limit light supply and transport of $CO_2$ and other nutrients. A disadvantage of terrestrial plant farming is extensive water consumption, which often limits yields in terrestrial habitats.

Algal culture has one large advantage over culture of terrestrial plants: algae are high in protein. It is estimated that algal culture under optimal conditions will yield 7000 g of protein/$m^2$/year compared to about 150 g for a good crop of wheat or maize. The disadvantage of low transparancy and low fluidity in the aquatic environment can be overcome by (a) stirring the water vigorously to improve transport within the medium, and (b) concentrating the algae in a small volume to reduce light absorption by the water layers.

# ECOSYSTEM

R. G. Bader, M. A. Roessler, A. Thorhaug, "Thermal Pollution of a Tropical Marine Estuary," *FAO Technical Conference on Marine Pollution, Rome, 1970*, pp. 425-428.

Sustained water temperature above 33°C resulted in extensive mortality of important macroalgae and sea grasses in a natural estuary, eliminating the major source of food and shelter for many herbivores and detritus feeders. Additionally, sediment erosion increased dramatically, resulting in increased turbidity of contiguous waters. Productivity may be detrimentally impacted by the increased turbidity, further deteriorating estuarine habitats.

Important green benthic macroalgae were shown to have abrupt thermal limits between 31 and 33°C. Shrimp and crabs were found to have upper thermal limits of 33 to 37°C, and their larval and egg stages exhibited thermal limits near 31°C. **(1,5,9)**

R. G. Bader and M. A. Roessler, *An Ecological Study of South Biscayne Bay and Card Sound*, University of Miami Progress Report to U.S. Atomic Energy Commission and Florida Power and Light Co., [AT(40-1)-3801-4], 1972.

The effects of thermal water upon the ecology of South Biscayne Bay and Card Sound, Florida, are reviewed. Aspects studied include water circulation, water chemistry, benthos, plankton, mangrove detritus, grasses, and algae. In general it was concluded that discharge temperature should not exceed a maximum of 32°C for Florida waters; however, the physical system of each area should be considered. **(1,9)**

J. A. Baker, "Wetlands Hydrology," *Proceedings of the First Wetlands Conference, University of Connecticut, June 20, 1978.*

Hydrologically, wetlands are defined as land areas covered with shallow water or subject to intermittant flooding and subsequent slow drainage, and are characterized by an accumulation of organic matter or swamp deposits. Wetlands are those in which the water is fresh and (a) the swamp deposits are directly underlain by glacial till and bedrock; (b) the swamp deposits are directly underlain by clay and silt; and/or (c) swamp deposits are directly underlain by glacial outwash or alluvium, consisting mostly of sand or sand and gravel. Organic compounds derived from organic material in swamp deposits may impact the color and odor of water and increase the concentration of iron in the water. With respect to the groundwater reservoir, wetlands serve as discharge areas for much of the year; however, they may receive recharge occasionally. The understanding of this role of wetlands in the larger hydrologic system is important with respect to management of wetlands. **(8,9)**

K. E. Biesinger and G. M. Christensen, "Effects of Various Metals on Survival, Growth, Reproduction, and Metabolism of *Daphnia Magna*," *Journal of the Fisheries Research Board of Canada, 29*, 1972, pp. 1691-1700.

The toxicities of various metals to *Daphnia magna* were evaluated on the basis of a 48-hr 50% lethal concentration (LC50), a 3-week LC50, and a 16% decrease in the number of young born (reproductive impairment). The 3-week 16% reproductive impairment concentrations (in μg/l) for the metal ions tested were: Na(I), 680 000; Ca(II), 116 000; Mg(II), 82 000; K(I), 53 000; Sr(II), 42 000; Ba(II), 5800; Fe(III), 4380; Mn(II), 4100; As(V), 520; Sn(II), 350; Cr(III), 330; Al(III), 320; Zn(II), 70; Au(III), 60; Ni(II), 30; Pb(II), 30; Cu(II), 22; Pt(IV), 14; Co(II), 10; Hg(II), 3.4; and Cd(II), 0.17. At metal concentrations permitting survival but impairing reproduction, daphnids weighed less than control animals. Amounts of total protein and glutamic oxalacetic transaminase activity varied with the different metals. The negative logarithm of the solubility product constant ($pK_{sp}$) of the metal sulfides, electronegativity, and the logarithm of the equilibrium constant (log $K_{eg}$) of the metal-ATP complex were positively correlated with toxicity to *D. magna*. Other physiochemical properties were considered, but no additional correlations were found. (Author's abstract.)

NOTE: Numbers in parentheses at the end of the annotations refer to the category of the particular type of reference. The categories are identified in the introduction of this report.

C. E. Boyd, "The Limnological Role of Aquatic Macrophytes and Their Relationship to Reservoir Management," *Reservoir Fisheries and Limnology, 8*, 1971, pp. 153-166.

Macrophyte communities often accumulate large quantities of inorganic nutrients early in the growing season and thus compete with phytoplankton for nutrients. Phosphorus concentrations are important in regulating macrophyte growth; the phosphorus cycle of the littoral zone is reviewed. In shallow, macrophyte-infested reservoirs, a considerable proportion of the phosphorus is cycled through pathways in which vascular plants are involved; harvest of macrophytes can therefore be used to reduce nutrient levels. **(6)**

C. E. Boyd and C. P. Goodyear, "Nutritive Quality of Food in Ecological Systems," *Archives of Hydrobiology, 69*, 1971, pp. 256-270.

The expression of net primary production in terms of dry matter, organic matter, carbon, or energy converts all units of plant production to an equivalent basis. However, net production differs in chemical composition, and nutritive quality of net primary production is very important in determining the efficiency of food utilization by herbivores. Nutrient content is equally important in determining the rate of decomposition of organic residues. Carnivores consume food of high nutrient content, especially with respect to protein, and adequate nutrition for these animals is likely determined by the amount of food consumption rather than by nutritive quality. Omnivores and detritivores fall somewhere between carnivores and herbivores with respect to the importance of food quality in regulating their growth and numbers in natural systems.

The use of energy flow or transfer in ecosystem analysis is a gross oversimplification of the relationships between organisms and their food. Energy utilization by consumers is regulated by nutritive quality of the food and all other factors regulating population sizes. (Author's abstract.)

J. S. Bradshaw, "Environmental Parameters and Marsh Foraminefera," *Limnology and Oceanography, 13*, 1968, pp. 26-38.

Continuous records of air and water temperature, light intensity, wind speed, oxygen concentration, pH, Eh, sodium ion, sulfide ion, salinity, and tide height were made in a marine marsh. Vertical changes in pH, Eh, oxygen, and sulfide were relatively large compared to other variations. Horizontal differences in pH and oxygen were due to varying amounts of vegetation. Variations due to tidal action affected all water parameters. At ebb tide, salinities increased from approximately 34% to as much as 50%, while pH decreased from approximately 9.2 at high water to as low as 6.8. Diurnal variations were large, with percent oxygen saturation values varying from approximately 10% to as high as 270%. Maximum and minimum values as well as the percent of time these values fall between a given set of conditions are presented, and various applications to seasonal occurrences of Foraminifera are discussed. (Author's abstract.) **(9)**

T. D. Brock, "Limits of Microbial Existance: Temperature and pH," *Science, 169*, 1970, pp. 1316-1318.

Bacteria are found in hot springs at temperatures up to the boiling point of water (92 to 100°C). In hot springs of increasing acidity, the upper temperature limit at which bacteria are found decreases; at a pH of 2 to 3, the upper temperature limit is 75 to 80°C. Bacteria have thus been able to grow at either high temperature or high acidity, but not at both.

B. J. Copeland, R. W. Laney, E. C. Pendleton, "Heat Influences in Estuarine Ecosystems," *Thermal Ecology*, 1974, pp. 423-437.

Studies were conducted in outdoor, artificial, and controlled estuaries and under controlled laboratory conditions to determine the response of ecosystems and individual organisms to heat loading. Temperature in the experimental artificial estuaries was maintained at 5°C above ambient (controls) during all seasons. Thermal treatment increased nutrient regeneration rates, yielding slightly higher algal biomass and photosynthesis/respiration ratios. Biomass of nekton and benthos was higher in the heated estuaries during spring but lower during summer. The relationship of temperature to growth, food conversion, and assimilation efficiency was investigated for the croaker (*Micropogon undulatus*) in the laboratory. Growth and feeding efficiency were directly related to increases in temperature. The critical thermal maximum (CTM) of penaeid shrimp was significantly related to acclimation temperature, with lesser effects

associated with salinity, size, and species. Similar responses were determined for the croaker except that acclimation temperature plays a more predominant role.

C. C. Coutant, "The Effect of a Heated Water Effluent Upon the Macroinvertebrate Riffle Fauna of the Deleware River," *Pennsylvania Academy of Science, 36*, 1962, pp. 58-71.

The macroinvertebrate bottom fauna of riffle areas in a one-mile stretch of a relatively unpolluted part of the Delaware River just below the point of discharge of condenser water from a steam electric generating plant was sampled, chiefly during the Summer of 1959. In the 487.7 m of river maximally heated on the Pennsylvania side to 11 to 14°C above normal river temperature, the summer fauna experienced drastic reduction both in numbers of taxa (24.5 to 5.0 for July through August average) and numbers of individuals (1763.8 to 186.0 for July through August average) for sampling areas of 1.5 $m^2$, as compared with a control station located above the discharge in the same riffle. The standing crop biomass was reduced from 11.2 g/$m^2$ to 0.09 g (July through August average). A slight increase in number and variety of organisms over the control was observed in a second riffle located 1463 m below the discharge, but this may have been unrelated to the 1 to 3°C elevation of normal river temperatures observed here. Midwinter and spring samplings indicated at least a partial repopulation of the maximally heated zone during the spring periods of high water. Traverse samplings extending from the maximally heated zone along the Pennsylvania shore into deeper and cooler water of the river indicate a tolerance limit for most of the fauna of 32 to 35°C. (Author's abstract.)

C. C. Coutant, "Thermal Pollution—Biological Effects," *Journal of the Water Pollution Control Federation, 41*, 1969, pp. 1036-1053.

The diverse biological effects of thermal additions to aquatic environments are reviewed. Impacts range from the direct lethal effects of high temperature on individual organisms to subtle changes in behavior, metabolism, performance responses, long-term genetic selection, alterations of community structure, and food chain relationships. Temperature effects, thermal resistance, heat discharges, synergism, reproduction, performance, temperature selection, growth, physiology, and waste stabilization are reviewed.

C. C. Coutant, "Biological Aspects of Thermal Pollution I. Entrainment and Discharge Canal Effects," *Critical Reviews in Environment Control, 1*, 1970, pp. 341-381.

Effects associated with entrainment and discharge canals at thermal power plants are discussed. Population changes among algal groups with changes in temperature, thermal tolerance of fish in relation to thermal acclimation, and the effects of thermal effluents on aquatic organisms are discussed. **(1)**

M. D. Dahlberg and J. C. Conyers, "Winter Fauna in a Thermal Discharge with Observations on a Macrobenthos Sampler," *Thermal Ecology*, 1974, pp. 414-422.

The influence of a thermal discharge on the fauna in the James River, Virginia, and the effectiveness of a benthic sampling device for monitoring freshwater macroinvertebrates was examined. Samplers were suspended in the water for 26 days during the winter and accumulated a greater variety and abundance of benthic organisms than were found in bottom samples at the same stations. Numbers of species and abundance of benthic macroinvertebrates increased as average water temperature increased regardless of the diurnal variation in discharge temperature resulting from the swing-load plant operations. The high production of benthic organisms could partially account for the observed aggregation of fish in the plume; 17 species of fish were found to be more abundant in the plume region than at the ambient-temperature stations.

J. J. Everett and R. G. Anthony, "Heavy Metal Accumulation in Muskrats in Relation to Water Quality," *Northeast Fish and Wildlife Conference Transactions, 33*, 1977, pp. 105-118.

Samples of plant and muskrat tissues were collected from four study sites in southeastern Pennsylvania and analyzed for Cd, Zn, Cu, Pb, and Hg. Differences in heavy metal concentrations in plants and muskrats were found; positive correlations between Cd, Zn, and Cu levels in muskrat tissues and plants indicate that the muskrat is a valid indicator of heavy metal pollution in semiaquatic ecosystems. Differences in physical condition parameters were not statistically significant; muskrat populations were apparently not affected by heavy metal pollution in the areas studied. **(6,7)**

J. L. Gallagher, "Sampling Macro-organic Matter Profiles in Salt Marsh Plant Root Zones," *Soil Science Society American Proceedings, 38*, 1974, pp. 154-155.

A device for sampling the root zones of marsh plants and a method for processing the resulting cores are described. Using these techniques, five stands of marsh plants were sampled and their macro-organic matter profiles compared. The least total macro-organic matter was found in the high vigor *Spartina alterniflora* and the *Distichlis spicata* root zones. Within *S. alterniflora* stands, the macro-organic matter in the soil profile increased as vigor of the aerial portions decreased. *Juncus roemerianus* and short form *S. alterniflora* profiles were similar in shape and had the highest macro-organic matter content. (Author's abstract.) **(6,8)**

J. L. Gallagher, F. G. Plumley, P. L. Wolf, *Underground Biomass Dynamics and Substrate Selective Properties of Atlantic Coastal Salt Marsh Plants*, Office, Chief of Engineers, U.S. Army, Technical Report D-77-28.

The dynamics of the underground portion of selected salt marsh plants provides information applicable to marsh development on dredged material. Methodologies to determine which marsh plants do well on various types of dredged materials are presented. Substrate characteristics to be considered include stability, pH, salinity, and nutrients. An investigation of underground biomass dynamics, characterization of soils supporting the plants, and experimentation on the substrate selective properties of the plants are presented. **(8,9)**

R. R. Grant and R. Patrick, "Tinicum Marsh as a Water Purifier," *Academy of Natural Sciences of Philadelphia*, Department of Limnology, 1969.

The general health of a marsh receiving water from a creek polluted by municipal sewage was studied in an attempt to assess the effectiveness of marshes in improving water quality. Results indicated that marsh vegetation and algae help reoxygenate water, reduce nitrates and phosphates, and generally enhance water quality. **(1,4)**

S. W. Harris and W. H. Marshall, "Ecology of Water Level Manipulations on a Northern Marsh," *Ecology, 44*, 1963, pp. 331-343.

Vegetation changes associated with marsh drawdowns in Minnesota indicated that establishment of vegetation on exposed mud flats was dependent upon seed availability, soil type and moisture, season and duration of drawdown, and standard algal debris. Reductions in emergent species and increases in upland species followed extended periods of drawdown. Shoreline and upland plants were replaced by aquatic species during the first season of reflooding. Willows persisted for two to five years following reflooding. It was found that one- to two-year drawdowns are required at 5to 10-year intervals to maintain optimum stands of emergent vegetation.

A. D. Hasler and E. Jones, "Demonstration of the Antagonistic Action of Large Aquatic Plants on Algae and Rotifers," *Ecology, 30*, 1949, pp. 359-364.

The competitive advantage of rooted aquatic macrophytes over phytoplankton and zooplankton populations was studied. Dense growths of large aquatic plants were found to have a statistically significant inhibiting effect upon phytoplankton and rotifer populations while Crustacea plankton were not affected.

T. L. Holzer, "Inland Wetlands and Groundwater in Eastern Connecticut," *Proceedings of the First Wetlands Conference, University of Connecticut, June 20, 1973.*

Climatic, geologic, and topographic conditions determine the relationship between inland wetlands and groundwater. Lowland wetlands are the result of depressions in topography which are sufficiently deep to intersect the water table. Upland wetlands in many cases are the result of low permeability of crystalline bedrock.

Lowland wetlands are considered to be a negligible component of the groundwater flow regime. Upland wetlands exhibit low permeability that renders the bedrock unable to transmit water which percolates through the overburden over long horizontal distances. **(8)**

W. J. Jewell, "Aquatic Weed Decay: Dissolved Oxygen Utilization and Nitrogen and Phosphorus Regeneration," *Journal of the Water Pollution Control Federeration, 43*, 1971, pp. 1457-1467.

Aquatic weeds were found to be composed of a measurable and consistent refractory fraction that

resisted decomposition over a 3 to 6 month period. During the 4 month experimental period, it was found that 76% of the aquatic plant biomass was readily available for decomposition. Aquatic weeds were found to decay more than twice as fast as phytoplankton; since their refractory fraction is half that of algae they use 20% more oxygen during aerobic stabilization. Because aquatic weeds decay faster and more completely than algae they have the potential for regenerating more nutrients. **(4)**

P. A. Kreukel and F. L. Parker, *Biological Aspects of Thermal Pollution*, Vanderbilt University Press, 1969.

A series of papers are presented on the biological effects of thermal pollution. Effects of thermal pollution on benthos, zooplankton, and fish are discussed.

B. J. Mathis and N. R. Kevern, "Distribution of Mercury, Cadmium, Lead and Thallium in a Eutrophic Lake," *Hydrobiologia, 46*, 1975, pp. 207-222.

Aquatic macrophytes, zooplankton, fish, water, and sediments from an eutrophic lake were analyzed for Hg, Cd, Pb, and Tl. Hg was detected in fish and sediments, while Cd and Pb were detected in all components. Tl was found only in sediments. Sediments in the lake acted as a "sink" for the four metals. Fallout of airborne particulate matter may be the primary method by which Hg and Tl enter the lake, although residual concentrations of the four metals in soil of the drainage basin were not determined. **(7)**

C. P. McRoy, R. J. Barsdate, M. Nebart, "Phosphorus Cycling in an Eelgrass Ecosystem," *Limnology and Oceanography, 17*, 1972, pp. 58-67.

Rates of uptake and excretion of P by both roots and leaves of eelgrass (*Zostera marina*) were found to be dependent on the orthophosphate concentration of the medium. In a typical shallow tidal pool dominated by eelgrass, the interstitial reactive P concentration of the sediments was as high as 75 μg-atom/l, while in the water, they were ca. 2. The plants absorbed 166 mg P/$m^2$-day from the sediments, assimilated 104 in the production of fresh eelgrass, and excreted 62 into the water. An amount equivalent to about 41% of the reactive P excreted, or 3 metric tons P/day, was exported from the lagoon into the Bering Sea. These results add a new pathway to the P cycle for estuaries containing vascular plants. (Author's abstract.) **(5,6)**

R. L. Meeks, "The Accumulation of $^{36}Cl$ Ring-Labeled DDT in a Freshwater Marsh," *Journal of Wildlife Management, 32*, 1968, pp. 376-398.

An enclosed 1.6-ha marsh at the southwestern edge of Lake Erie was treated by helicopter with 3.9 millicuries of chlorine-36 ring-labeled DDT at a rate of 0.25 kg technical DDT/ha. Radiolabeled DDT residues were traced until 15 months after the application. Whole body residues were of major concern, although tissues were assayed from vertebrates too large to assay entirely. DDT residues were detected in sago pondweed (*Potamogeton pectinatus*), duckweed (*Lemna minor*), bladderwort (*Utricularia vulgaris*), crayfish (*Orconectes immunis*), tadpoles (*Rana pipiens*), and carp (*Cyprinus carpio*) when first assayed 4 hours after the application. The alga Cladophora averaged 96 mg/l DDT, or 3125 times the environmental level, 3 days after the application. A northern water snake (*Natrix sipedon*) accumulated 36 mg/l 13 months after the application. The maximum level in carp was 19 mg/l in the soft palate, also after 13 months. Plants and most invertebrates accumulated their highest residues during the first week; vertebrates required longer periods. Algae, the pondweeds (*Potamogeton spp.*), duckweed, crayfish, and small carp should make good indicator species of environmental DDT residues. (Author's abstract.)

R. D. Misra, "Edaphic Factors in the Distribution of Aquatic Plants in the English Lakes," *Journal of Ecology, 26*, 1938, pp. 411-451.

The distribution of aquatic plants in English lakes, with particular emphasis on the nature of the substratum are reviewed. The physical and chemical characteristics of the lake muds were found to be closely correlated with vegetation. A relationship between the quantity of organic matter in the substratum and plant succession was identified. Decomposition of organic matter in submerged muds was shown to be chiefly anaerobic; during this process, $CO_2$ was abundant and $O_2$ was rapidly absorbed. Sulphides were present in appreciable amounts in submerged muds containing more than 5 to 10% organic matter. Nitrates were absent from the substratum;

ammonia was the only form of nitrogen available for aquatic plant utilization. As the substratum became more organic, there was an increased availability of calcium and nitrogen. **(3)**

F. Parker and P. Krenkel, *Physical and Engineering Aspects of Thermal Pollution*, Cleveland: CRC Press, 1970, p. 100.

Substantial changes in the mode of heated condenser cooling water discharge are required to reduce thermal pollution as electrical demand increases. Physical, biological, and chemical effects in relation to thermal discharge are discussed in a theoretical manner.

M. A. Proffitt and R. S. Benda, *Growth and Movement of Fishes, and Distribution of Invertebrates Related to a Heated Discharge into the White River at Petersburg, Indiana*, Indiana University Water Resources Research Center, 1971 pp. 1-94.

A heated discharge rate of 191 $m^3/s$ and a temperature elevation of 11°C resulted in a 1.6°C rise in the average temperature of the White River of Petersburg, Indiana. Data on fish movements failed to disclose a thermal barrier to upstream or downstream passage. No relationship was found between the discharge of heated water and the incidence of external parasites. The research indicated that the heated discharge was not a major factor in the density of invertebrates in the river.

R. Rehwoldt et al., "The Effect of Increased Temperature Upon the Acute Toxicity of Some Heavy Metal Ions," *Bulletin of Environmental Contamination and Toxicology, 8*, 1972, pp. 91-95.

Heat input within the tolerance range of an organism increases the metabolic rate; in fish this increases the oxygen demand and simulataneously decreases the solubility of oxygen in water. In addition to direct effects upon metabolism, indirect effects such as increased solubility and diffusion rates of substances that control water quality are observed. The mean toxicity limit for 50% survival of representative Hudson River fish species at 28°C was estalished and compared to limits established at 15°C. The data are expressed in analytical concentration of metal ion as well as multiples of background concentrations. Metal ions tested were Cu, Zn, Ni, Hg, Cd, and Cr. The toxicity limit data at 28°C and 15°C are not significantly different for the ions studied with the exception of the mercurous ion.

G. Rohde, "The Effects of Trace Elements on the Exhaustion of Sewage-Irrigated Land," *Journal Institute of Sewage Purification, 6*, 1962, pp. 581-585.

Berlin and Paris utilized cropland irrigation for sewage disposal, increasing crop yields. After many years of disposal decreased yields were observed. Soil samples collected from disposal and control land areas were analyzed for trace elements; it was concluded that high accumulation of copper and zinc in the soil was primarily responsible for the observed exhaustion of the sewage-irrigated land. **(8)**

N. M. Saks et al., "Growth of Salt-Marsh Microcosms Subjected to Thermal Stress," *Thermal Ecology*, 1974, pp. 391-398.

Preliminary laboratory studies on the effects of temperature on interspecific competition among represtative New York salt-marsh microflora and meiofauna showed that as temperature increased from 10 to 25°C competitive effects were enhanced and blooms of particular species became conspicuous. The effect of temperature on 12 species of algae that serve as food for the animals *Euplotes vannus, Allogromia latecollaris*, and *Chromadorina germanica* was studied. Tolerance to acute thermal stress at 40°C by axenic populations of various species of logarithmically growing algae ranged from 15 to 195 minutes. Optimum temperatures for the species of algae tested ranged from 25 to 29°C. **(1)**

W. H. Schlesinger and B. F. Chalot, "The Use of Water and Minerals by Evergreen and Deciduous Shrubs in Okefenokee Swamp," *Botanical Gazette, 138*, 1977, pp. 490-497.

Shoot water potential, leaf diffusion resistance, and foliar concentration of Ca, K, N, and P were measured in an evergreen and deciduous shrub (*Clethra inifolia*). The deciduous shrub generally had the highest mineral content and water loss in transpiration in the warm-temperate swamp; evergreen species were found to have the greatest potential for efficiency of mineral use and productivity, largely due to their leaf longevity. **(6)**

J. B. Sills, "A Review of Herbivorous Fish for Weed Control," *The Progressive Fish—Culturist*, 1970, pp. 158-161.

The potential for utilizing fish as a means for controlling aquatic weeds is examined. The species investigated were *Tilapia niclotica, T. mossambica, T. melanspleura, Cyprinus carpo*, and the Chinese grass carp *Ctenopharyngodon idellus*. All tests where tilapia were stocked in ponds resulted in overcrowded populations and unsatisfactory control of weeds. *Cyprinus carpo* controlled aquatic plants in an indirect way; when rooting about the pond bottom for insects algal mats were broken up, allowing them to float and collect on the surface. The shading from these mats, and the silt stirred into the water by their feeding action, reduced light penetration to a level that retarded plant growth. All observations on the grass carp were most favorable. They fed on aquatic vegetation and exhibited definite plant preferences: filamentous algae, pondweed, and naiad were first eaten. Sixteen-inch fish, stocked at a rate of 100/ha completely eliminated a stand of pondweed and chara.

H. F. Thut, "The Movement of Water Through Some Submerged Plants," *American Journal of Botany, l9,* , 1932, pp. 693-709.

Water flow through selected aquatic plants was measured. An average flow rate through the plant of 0.0086 $cm^3$/plant/hr was obtained for *Elodea densa* and 0.0ll $cm^3$/plant/hr for *Potamogeton lucens*. Water rates moving through plants ranged from 0.0026 to 0.0l3 $cm^3$/plant/hr, depending on the type of species tested. In comparing the amount of water flow from the basal part of the plant with the amount of water entering the upper stem and submerged leaves, it was found that the former exceeded the latter from seven to twenty times. The "transpiration stream" of the plants studied thus appears to be caused primarily by the forces in the basal part of the plant. The water-moving forces of the upper stem and submerged leaves appear to have but a slight effect on the flow. The flow of water through the submerged plants studied thus seems to be due primarily to root pressure. **(4)**

F. J. Trembley, *Research Project on Effects of Condenser Discharge Water on Aquatic Life Progress Report, 1956-1959*, The Institute of Research, Lehigh University, Bethlehem, Pennsylvania, 1960.

Effects of the addition of thermal water on the upper Delaware River were investigated. Water temperature ranged from 0 to 30°C over the study area. A summary of the conclusions according to general catagories of the report are as follows: *Chemistry*—The addition of heated water to the river has little influence upon the water chemistry except for the dissolved oxygen concentration. *Microorganisms*—Addition of heated water changed the species composition of the population of these organisms. The more heat-tolerant organisms, such as blue-green algae and some diatoms, increase in heated water with corresponding decline or loss of less heat-tolerant forms such as green algae and many species of protozoa. *Macroinvertebrates*—Heated water caused a decrease and alteration in species composition during the summer months, however a reinvasion occurred during the cold weather period. *River Fish*—Warm water attracted fish in cold periods but did not seem to otherwise affect them. *Rooted Aquatic Plants*—Plants in some parts of the river initially decreased, but seemed to acclimate to the warmer temperatures. **(1,4,9)**

K. K. Turekian, A. Katz, L. Chan, "Trace Element Trapping in Pteropod Tests," *Limnology and Oceanography, 189*, 1973, pp. 240-249.

Pteropod tests from the South Atlantic Ocean and "bulk" plankton samples from Long Island Sound were analyzed for 11 trace metals (Fe, Ce, La, Sm, Eu, Th, Sc, Cr, Co, Sb, and Se) to study the trapping and transport mechanisms for these metals in oceans and the capability of pteropods to modify the composition of seawater during this process. The data suggest that a fine particulate authigenic iron-rich phase is trapped by both the soft and hard tissues of plankton, and carries several trace metals. The iron and associated trace elements appear to have residence times in the deep water of the same order of magnitude as that of the deep water itself.

R. Wagemann et al., "Arsenic in Sediments, Water and Aquatic Biota from Lakes in the Vicinity of Yellowknife, Northwest Territories, Canada," *Archives of Environmental Contamination and Toxicology, 7*, 1978, pp. 169-191.

Arsenic concentrations were measured in aquatic invertebrates, macrophytes, sediments, and water of lakes in the vicinity of Yellowknife, Canada. In arsenic-contaminated lakes, the arsenic concentration ranged from 0.70 to

5.5 mg/l in water, 6 to 3500 mg/l in bottom sediments, 150 to 3700 mg/l in macrophytes, 700 to 2400 mg/l in zooplankton, and 1 to 1300 mg/l in other invertebrates. The arsenic concentration in invertebrates varied with sampling time, location, and taxon. Arsenic concentration factors are discussed.

WAPORA, Inc., *The Effect of Temperature on Aquatic Life in the Ohio River—Summary*, WAPORA, July—December 1970.

Three main concerns are generally expressed relevant to thermal discharges in aquatic ecosystems:

1. Game fish populations may be threatened either directly or indirectly by heated effluents

2. Entrainment of plankton in power plant condensers

3. Heated effluents may change algal populations enough to limit the abundance and availability of basic food chain organisms.

This report states that none of these concerns is warranted in the case of the portion of the Ohio River studied. In this study, thermal water was not found to have a major effect on the total fish population, except in rare cases. When fish were killed, the mortality was felt to be insignificant when compared to the total fish population. The destruction of plankton by entrainment in power plant condensers appeared to have little impact on the total ecosystem. Significant changes in algal populations sufficient to limit the availability and abundance of basic food chain organisms was not apparent.

R. Wenstel, A. McIntosh, G. Atchison, "Evidence of Resistance to Metals in Larvae of the Midge *Chironomus tentans* in a Metal Contaminated Lake," *Bulletin on Environmental Contamination and Toxicology, 20*, 1978,pp. 451-455.

Tests on survival, growth, and avoidance behavior of Chironomid larvae demonstrated that larvae developed resistance to heavy metal pollution in Palestine Lake, Indiana.

# INSTITUTIONAL

D. R. Allen, "Legal and Policy Aspects of Geothermal Resource Development," *Water Resources Bulletin, 8*, American Water Resources Association, 1972, pp. 250-256.

Geothermal reservoirs may be divided into three distinct categories: vapor-dominated, hot water dominated, and hot dry rock. The fundamental legal and policy problems associated with geothermal resources arise primarily because of the inability to identify exactly what geothermal resources are. Geothermal resources may end up being governed by a legal regime which has been determined primarily by categorizing the resource rather than by attempting to select the regime which is most appropriate to the resource itself. The legal and policy problems surrounding development of the nation's geothermal resources stem from the unique and as yet undetermined nature of the resource itself.

*Comptroller General Report to the Congress of the U.S., PAD-79-10*, "Better Understanding of Wetland Benefits Will Help Water Bank and Other Federal Programs Achieve Wetland Preservation Objectives," Washington: U.S. Government Printing Office, February 8, 1979.

Issues impacting the effectiveness of the Water Bank Program (WBP) in preserving, restoring, and improving the nation's wetlands were discussed. A general appraisal of the WBP was presented, including a description of the program, benefits, and program participants. Concepts related to preservation of wetlands were discussed, ranging from regulatory programs and policies to ecological benefits. An interagency task force including USDA, USDI, EPA, and the Army COE under the leadership of Water Resources Council was recommended to develop a coordinated approach to wetland preservation.

Bureau of National Affairs, "Environmental Protection Agency Statement of Policy on Protection of the Nation's Wetlands," *Environmental Reporter, 2l*, 1974.

The EPA policy on wetland ecosystems was designed to preserve and protect them from destruction through waste water or nonpoint source discharges and their treatment or control. The EPA policy also governs the development and construction of waste water treatment facilities or treatment by other physical, chemical, or biological means. Wetlands represent an ecosystem of unique and major importance and, as a result, they require protection. Protection of wetland areas requires the proper placement and management of any construction activities and also requires controls of nonpoint sources to prevent disturbing the terrain and quality of the wetland area. EPA's policy minimizes alterations in the quantity or quality of the natural flow of water that nourishes wetlands and protects wetlands from adverse dredging or filling practices. The EPA advises those applicants who install waste treatment facilities under a Federal grant program or as a result of a Federal permit that the selection of the most environmentally protective alternative should be made.

W. M. Eichbaum, "Legal and Political Restraints to Implementation of Noval Systems," *Biological Control of Water Pollution*, University of Pennsylvania Press, 1976, pp. 317-322.

There are three characteristics of environmental regulatory organizations which pose barriers to innovative technology that should be specifically addressed. In the first instance, the normal structure of an agency is to have a central office with a number of regional offices, sometimes resulting in intra-agency competition. Second, most pollution control agencies do not have an adequate number of personnel available with the level of sophisticated training that permits evaluation and understanding of the concepts and opportunities inherent in an innovative pollution control technology. Third, the techniques that the government uses in its decision making process were felt to sometimes become an obstacle to an application of innovative technology.

M. Gravitz, "EPA's Response to the Need for Encouragement of Alternative Waste Treatment Techniques," *Biological Control of Water Pollution*, University of Pennsylvania Press, 1976, pp. 303-312.

NOTE: Numbers in parentheses at the end of the annotations refer to the category of the particular type of reference. The categories are identified in the introduction of this report.

One obstacle in getting more widespread use of resource recycling/reclaiming systems is the lack of expertise with these treatment techniques in Federal, state, and local governments and in the private engineering sector. The need for multidisciplinary design teams and the complexity of design for these, as opposed to conventional tank systems, may be reason for the reluctance to employ alternatives more widely. The largest institutional obstacle that prevents widespread use of resource recycling/reclaiming systems is the lack of incentives in the grant program.

J. Hammack and G. Brown, Jr., *Waterfowl and Wetlands: Toward Bioeconomic Analysis*, Baltimore: Johns Hopkins University Press, 1974.

Topics of discussion include: methods of valuing outdoor recreation and waterfowl; empirical results reviewed; biometric relationships and data for mallards; cost-benefit analyses; and limitations, conclusions, and recommendations for future study.

# MACROPHYTES

## General

M. Abou-El-Fadl et al., "Utilization of Water Hyacinth as an Organic Manure with Special Reference to Water-Borne Helminths," *Journal of Microbiology, U.A.R., 3*, 1968, pp. 27-34.

Conventional methods of dealing with the excessive growth of water hyacinth (Eichhornia Crassipes) in the UAR have usually involved removal of the plants from waterways with deposition on the streambanks. This approach often resulted in eutrophication and reinvasion of waterways. Hyacinth may be used as an organic fertilizer on agricultural fields following composting. Composting is necessary to eliminate the potential threat of water-borne parasitic helminths.

R. G. Anderson and R. C. Lommasson, "Some Effects of Temperature on THG Growth of *Chara Zeylanica*," *Butler University Botanical Studies, 13*, 2, 1958, pp. 113-120.

Clonal members of *Chara Zeylanica* were grown at five different constant temperatures (16, 20, 24, 28, and 32°C). Growth of main shoots, lateral branches, number of nodes produced, length of the rhizodal mass, and the number of reproductive structures was monitored for each treatment. The most abundant growth of main shoots and rhizodal mass occurred at 24°C. Growth at 16°C was restricted. Reproductive structures developed on plants growing at all temperatures, except 20°C.

R. R. Anderson, R. G. Brown, R. O. Rappleye, "The Mineral Content of *Myriophyllum spicatum* in Relation to its Aquatic Environment," *Ecology, 47*, 1966, pp. 844-846.

The mineral composition of *Myriophyllum spicatum* (Eurasian water-milfoil) and its aquatic environment were investigated to determine the relationship between ionic contents in the plant and in the water. Systematic samplings were made in several estuarine and fresh water areas.

NOTE: Numbers in parentheses at the end of the annotations refer to the category of the particular type of reference. The categories are identified in the introduction of this report.

The species was growing in a wide range of environmental situations. Normal-appearing specimens were collected at water temperatures ranging from 0.2 to 30°C. Salinities varied from 0.05 to 16.4 ppt. Each of the estuarine collecting sites fluctuated about 7 ppt during the experimental period. The fresh-water pond varied between 0.05 and 0.20 ppt. The pH values ranged from 5.8 to 9.5, with alkaline water predominating at four of the five collecting stations.

*M. spicatum* was capable of regulating salt intake independent of concentrations in the aquatic environment. (Author's abstract.)

R. R. Anderson, "Temperature and Rooted Aquatic Plants," *Chesapeake Science, 10*, 1969, pp. 157-164.

In relation to the disappearance of a *Ruppia maritima* population near the effluent of an electrical generating station on the Patuxent River, Maryland, a broad study of temperature effects on respiration and photosynthesis of aquatic plants was performed.

A Gilson differential respirometer was used to investigate respiratory variation in leaves of *Potamogeton perfoliatus* at 25, 30, 40 and 45°C. This species grows with *Ruppia maritima*, appears to be more tolerant of high temperatures, and plant material was readily available. Plants growing in heated and nonheated water were compared. The data indicate that *P. perfoliatus* is capable of physiological adjustment to higher temperatures as the leaf matures, since only older leaves tended to respire less at the elevated temperatures. Death of plant material occurred at 45°C. (Author's abstract.)

L. O. Bagnall, R. L. Shirley, J. F. Hentges, *Processing, Chemical Composition and Nutritive Value of Aquatic Weeds*, Florida Water Resources Research Center, 25, 1973, p. 55.

As an alternative to chemical control, water hyacinth (*Eichhornia crassipes*) and hydrilla (*Hydrilla verticillata*) can be converted to agriculturally useful products. Whole or chopped plants can be composted to create an organic

material for potting plants. The processed plants can also be ensiled or dried for animal feed. Protein contents range from 12 to 18%, and ash free crude fiber contents range from 25 to 35%. Nitrate, oxalate, and cyanide levels in the aquatic plants were considered safe. Calcium and phosphorus ratios were satisfactory. Animal acceptability of properly made hyacinth silage was very good. Animal utilization of protein was poor.

T. D. Beard, *Overwinter Drawdown—Impact on the Aquatic Vegetation in Murphy Flowage, Wisconsin*, Technical Bulletin No. 61, Department of Natural Resources, 1973, pp. 2-16.

Lowering the water level on Murphy Flowage during the winters of 1967-68 and 1968-69 resulted in significant reductions in the relative abundance and area of aquatic vegetation. Before the drawdown approximately 30 ha (42% of the flowage) were covered by dense plant growth which restricted fishing during the summer. After two overwinter drawdowns, 24 of the 30 ha were open to fishing. **(2)**

J. W. Bedish, "Cattail Moisture Requirements and Their Significance to Marsh Management," *The American Midland Naturalist, 78*, 1967, pp. 288-300.

A hybrid cattail resulting from a natural cross of *Typha latifolia* and *Typha angustifolia* was studied under greenhouse and field conditions to determine optimum soil moisture and water depth for germination and vegetative reproduction. Seeds in greenhouse tests required flooding for germination, but no differences in percent germination were detected between water depths of 2.5 and 15 cm. Germination was reduced 50% by storage of seed for 1 year at room temperature and humidity.

The fastest growth rate and production was recorded for plants in 2.5 cm of water. Plants in saturated soil and 15 cm of water grew nearly as well as plants in 1.5 cm of water. Vegetative reproduction was similar in saturated soil and in soil flooded with depths of 2.5 cm of water and 15 cm of water. Management recommendations include water manipulation and artificial propagation. (Author's abstract.) **(2)**

J. H. Bock, "Productivity of the Water Hyacinth *Eichhornia crassipes* Solms," *Ecology, 50*, 1969, pp. 460-464.

The tropical water hyacinth, *Eichhornia crassipes*, occurs in some of the sloughs and rivers of northern California's Central Valley, a possible northern limit for its weedy distribution. The growth rates and reproductive rates of these water hyacinths, at least for brief periods each year, were comparable to those of water hyacinths growing in the tropics. Their rapid reproduction and high productivity in the summer months enable the populations to be maintained from year to year despite a high death rate in winter. (Author's abstract.) **(2)**

C. E. Boyd, "Freshwater Plants: A Potential Source of Protein," *Economic Botany, 22*, 1968, pp. 359-368.

Several species of aquatic plants could be used as high protein animal feeds. Dried aquatic plants contain large quantities of trace minerals and could possibly be used as mineral supplements. Leaf protein (which might be used as a supplement source) is readily extractable from a few species. Large monospecific stands are necessary for harvesting economy and to ensure product quality. Standing crop values for submerged plants and algae usually ranged from 1000 to 4000 kg dry wt/ha, while emergent plants equaled or exceeded that many agricultural crop plants. Aquatic plant forages require partial drying, whereas a high moisture content will enhance protein extraction processes. **(5,6)**

C. E. Boyd, "Production, Mineral Nutrient Absorption and Biochemical Assimilation by *Justicia americana* and *Alternanthera philoxeroides*," *Archives of Hydrobiology, 66*, 1969, pp. 139-160.

Net dry matter production in a *Justicia americana* stand was complete by mid-July. Maximum rate of net productivity occurred during late May and early June. Percentage composition of most chemical constituents declined steadily as the growing season progressed. The maximum rate of absorption of mobile mineral nutrients occurred prior to the time of maximum growth. The greatest quantity of these nutrients was absorbed early and then utilized for subsequent growth. Net production of several biochemical constituents was complete by mid-June. A similar pattern of events was noted for an *Alternanthera philoxeroides* stand.

Lentic *J. americana* stands had higher dry matter standing crops than lotic stands. The chemical composition of various stands was apparently related to water hardness. Several nutrients were absorbed and stored in early spring before the period of rapid growth and were utilized later. A similar relationship was observed between the assimilation of organic constituents and net productivity. (Author's abstract.) **(5,6)**

C. E. Boyd, "The Nutritive Value of Three Species of Water Weeds," *Economic Botany, 23*, 1969, pp. 123-127.

Three of the most serious aquatic pest plants, water hyacinth, water lettuce, and *Hydrilla* were studied for their quality as foodstuffs. Analyses of hydrated samples indicated that all three species contained rather large amounts of crude protein and had rather satisfactory levels of essential amino acids. The chemical composition of aquatic plants changes appreciably as the plants age. Another possible use of these plants is as green manure. Fertilizer units for nitrogen and potash were rather high on a dry weight basis, but on a fresh weight basis all units were extremely low.

C. E. Boyd, "Production, Mineral Accumulation and Pigment Concentrations in *Typha latifolia* and *Scirpus americanus*," *Ecology, 51*, 1970, pp. 285-290.

Shoot productivity and composition were determined for *T. latifolia* and *S. americanus*. Tissue concentrations of chlorophyll, carotenoids, and most macronutrients declined as the plants aged. Uptake rates for macronutrients were generally not proportional to productivity rates. The most rapid uptake of several nutrients occurred earlier than maximum growth rates.

C. E. Boyd, "Amino Acid, Protein, and Caloric Content of Vascular Aquatic Macrophytes," *Ecology, 51*, 1970, pp. 902-906.

A remarkable similarity exists between the relative amounts of each amino acid in the total proteins of eleven species of vascular aquatic plants, as well as the same species from different sites, and the same species at different stages of maturity. However, total protein concentrations in the various samples differed greatly. Aquatic plant amino acids were synthesized or utilized, or both, in about the same ratios throughout the sampling period. Caloric values for all samples were relatively uniform.

C. E. Boyd, "A Bibliography of Interest in the Utilization of Vascular Aquatic Plants," *Economic Botany, 26*, 1972, pp. 74-84.

A bibliography of vascular aquatic plant utilization containing 233 references categorized into the following seven topics is presented: chemical composition and nutritive value, nutrient removal, productivity and standing crops, ecology and life history, identification, aquatic plant nutrition and physiology, and nutrient relationships in aquatic environments.

C. E. Boyd, "Utilization of Aquatic Plants," *Aquatic Vegetation and Its Use and Control*, D. S. Mitchell, (ed.), Paris: UNESCO, 1974.

Potential and actual uses of aquatic macrophytes are: compost, mulches, fertilizers, human food, livestock feeds, sources of fiber for paper making, sources of various chemical substances, and for the purification of polluted effluents and water bodies. Rice is the only vascular hydrophyte which is a major agronomic species. The use of aquatic plants as livestock feed in technologically advanced nations will require the product to be competitive in quality and cost with conventional feeds. Pilot studies in the United States demonstrated that high quality feeds can be made from several species of aquatic plants. However, the cost of harvesting and processing the plants by mechanical techniques prohibited commercial exploitation. Schemes for cultivating aquatic plants in eutrophic waters to remove nutrients and control the growth of phytoplankton have promise.

C. E. Boyd and R. D. Blackburn, "Seasonal Changes in the Proximate Composition of Some Common Aquatic Weeds," *Hyacinth Control Journal, 8*, 1970, pp. 42-44.

The nutritive value and chemical composition of aquatic plants are contingent upon the nutrient concentration of the water and the stage of maturity of the plants. Further data are needed to determine optimum timing for harvesting aquatic weeds for fodder. Nitrogen (N) content of emersed aquatic plants declines with age, while the N levels of submerged plants may increase, decrease, or remain constant as the season progresses.

J. R. Bray, "Estimates of Energy Budgets for a *Typha* (Cattail) Marsh," *Science, 136*, 1962, pp. 1119-1120.

Yearly utilization of total solar radiation by a *Typha* marsh shows approximately equal allotment to reflection (albedo), evapotranspiration, and conduction-convection. Reflection declines as the growing season progresses in response to increased light absorption by the vegetation. Photosynthesis is a negligible quantity, although in relation to visible radiation during the growing season it nearly equals reflection.

J. M. Bristow and M. Whitcombe, "The Role of Roots in the Nutrition of Aquatic Vascular Plants," *American Journal of Botany, 58,* 1971, pp. 8-13.

Rooted stems of three aquatic species were cultured in a two-compartment apparatus which allowed the upper and lower portions of the stem to be kept in different nutrient solutions. $P^{32}$ was supplied to either the upper or lower compartment. At the end of a 10-day growth period, the specific activity of phosphate was determined in axillary shoots which developed during the course of the experiment from buds in the upper compartment. The results indicated that most of the phosphate in these shoots was not absorbed from the ambient medium but was derived from the rooted stem base in the lower compartment (over 90% in *Myriophyllum brasiliense*, 59% in *M. spicatum*, and 74% in *Elodea densa*). These results give a very different but probably more accurate picture of phosphate absorption in rooted aquatic vascular plants than short-term experiments, in which phosphate is readily taken up from the ambient medium by leaves of *M. spicatum* and *E. densa*. In *M. brasiliense* the amount of phosphate translocated is related to the mass of roots present. Evidence is presented that normal growth of axillary shoots occurs even when all mineral ions have to be obtained by translocation from the lower compartment.

Roots of amphibious species appear to be more efficient in ion absorption and translocation than true aquatic species. (Author's abstract.) **(6)**

E. H. Daubs, "A Monograph of Lemnaceae," *Illinois Biological Monographs,* 34, 1965, pp. 1-118.

This text provides a comprehensive review of the natural history and systematics of the duckweed (Lemnaceae) family. A detailed taxonomic description of the 4 genera and 28 species found throughout the world is included.

J. de Jong, "The Purification of Wastewater with the Aid of Rush and Reed Ponds," *Biological Control of Water Pollution Conference, Philadelphia, 1976.*

An elongated ditch stalked with *Phragmites australis* and *Scirpus lecustris* provided an effective mechanism for purifying low volume, seasonal sewage effluent.

Biochemcial oxygen demand (BOD), chemical oxygen demand (COD), N, P, and most probable number (MPN) were all reduced 93 to 98% with a 10-day residence time. Costs for biological elongated-ditch treatment were approximately 75% less than required for an activated sludge system. **(9)**

J. de Jong, "The Purification of Wastewater with the Aid of Rush or Reed Ponds," *Biological Control of Water Pollution Conference, Philadelphia, 1976.*

Biological methods of secondary treatment of municipal wastewater using *Scirpus lacustris, Phragmites australis*, and soil infiltration techniques were evaluated. Suspended solids, N, P, BOD, and coliform were reduced by wetland treatment. A residence time of 12 days produced near 100% reductions. The biological systems were more effective than trickling filter or activated sludge systems at 16% of the capital cost and 18% of the annual operating expense.

Soil infiltration studies using sand, med. texture and clay soils produced reductions in P, BOD, COD, and MPN. N was not reduced by infiltration. **(9)**

A. A. De La Cruz, "The Production of Pulp from Marsh Grass," *Economic Botany, 31,* 1977, pp. 46-50.

The Romanian government mechanically harvests 113,400 metric tons of dry marsh grass (*Phragmites communis*) annually. The young tender shoots are fed to cattle and are the favorite food of pelt marsh animals. *Phragmites*, a hardy plant, is among the most productive vascular plants in brackish and freshwater marshes. Shoot production yields about 2.5 $kg/m^2/yr$. *Phragmites* marshes are also good assimilators of waste effluents suggesting that they may also have economic potential as a natural tertiary treatment facility for domestic sewage. Currently the major

use of Phragmites is in production of cellulose for manufacture of paper and other cellulose biproducts. (5)

C. Forsberg, "Quantitative Sampling of Subaquatic Vegetation," *Oikos, 10*, 1959, pp. 233-240.

A new method of sampling subaquatic vegetation for investigations on standing crops and productivity was developed. A sampler was designed and constructed for luxuriant subaquatic meadows on soft bottoms. Studies performed using this sampling method established productivity rates of 2.8 $g/m^2$/day for *Myriophyllum verticillatum* and 2.5 for *Nitella mucronata*. In the autumn the data are negative: *M. verticillatum* is -1.3 and *N. mucronata* -0.9 $g/m^2$/day, indicating that decomposition and dissimilation are greater than assimilation. (5)

J. L. Gallagher, "Growth and Element Compositional Responses of *Sporobolus virginicus* to Substrate Salinity and Nitrogen," *American Midland Naturalist, 102*, 1979, pp. 68-75.

Observations on plant biomass, substrate salinity, and soil fertility from natural stands of *Sporobolus virginicus* indicated a reduction in growth as soil salinity increased and a possible limitation of growth due to lack of available forms of N. The field observations on salinity were tested with a controlled environment experiment where seedlings were grown in a range of NaCl concentrations from 0 to 80°/oo (ppt) in Hoagland's solution in a growth chamber. Survival rates were high in all treatments, although growth was greatly reduced in the more saline media. Plants grown in the higher salinity media had 3.9% of the biomass of those not stressed by NaCl. Culms, rhizomes, and leaves were shorter, and culms were less numerous in the salt-stressed plants. There was no evidence of an enhancement in growth due to the presence of NaCl. The N and Mn concentrations in the plants sustained in saline media were high compared to the controls, while those for Fe and K were low. There was no increase in biomass due to the nitrogen pulse, although the nitrogen content of the tissue was significantly increased. The change in composition of the live and dead plants would change the quality of food entering both the grazing and detrital food webs in these areas. (Author's abstract.) (5,6)

J. J. Gaudet, "Growth of a Floating Aquatic Weed, *Salvinia*, Under Standard Conditions," *Hydrobiologia, 41*, 1973, pp. 77-106.

Increases in light intensity or $CO_2$ enrichment resulted in increases in growth rate of *Salvinia*. In culture, *Salvinia* exhibited excessive consumption of N and P and also discriminated against calcium relative to strontium. Use of *Salvinia* as an animal food may not be favorable because of high C to N ratios, but might be useful in nutrient removal schemes. *S. molesta* produced fewer leaves than *S. minima* but leaf area and dry weight was greater in *S. Molesta*.

R. W. Haag, "The Ecological Significance of Dormancy in Some Rooted Aquatic Plants," *Journal of Ecology, 67*, 1979, pp. 727-738.

*Elodea canadensis* is uncommon in lakes of central Canada, but it was abundant in the permanently ice-free region of Lake Wabamun, which was heated by power-plant thermal effluent. The hypothesis that local abundance results from differences in dormancy between *Elodea* and more common aquatic macrophytes was tested. *E. Canadensis* showed little seasonal variation in readiness to grow, whereas *Myriophyllum exalbescens* exhibited weak dormancy, and *Potomageton zosteriformis* maintains a strong dormancy throughout the winter. Differences between species in dormancy response, and resultant differences in winter survival, were the principal factors determining the initial successional changes in the lake in response to cessation of thermal effluent discharge.

W. T. Haller, D. L. Sutton, W. C. Barlowe, "Effects of Salinity on Growth of Several Aquatic Macrophytes," *Ecology, 55*, 1974, pp. 891-894.

Growth rates of 10 aquatic macrophytes in various salinities under greenhouse conditions varied widely. Salt concentrations of 1.66 and 2.50% were toxic to *Pistia stratiotes* and *Eichhornia crassipes*, respectively. Salinities of 16.65% or higher were toxic to *Lemna minor*, but growth of *L. minor* was increased by salt concentrations of 0.83%, 1.66%, 2.50%, and 3.33%, as compared to other *L. minor* plants grown in fertilized pondwater. Other species studied, *Hydrilla verticillata, Myriophyllum spicatum, Najas quadalupensis, Vallisneria americana, Azolla caroliniana*, and *Salvinia rotundifolia* gradually declined in growth

as salinity increased. Transpiration of the emersed growth form of *Myriophyllum brasiliense* decreased with increasing levels of salinity, but root growth was stimulated by salt concentrations of 0.83 to 3.33%, presumably a response of the plant to overcome an internal water deficit resulting from the saline solutions. (Author's abstract.) **(5)**

H. H. Hannon and T. C. Dorris, "Succession of a Macrophyte Community in a Constant Temperature River," *Limnology and Oceanography, 15*, 1970, pp. 442-453.

The relationship of community metabolism to community structure in a 567-m stretch of the spring-fed San Marcos River, Texas, was studied during a period of autotrophic succession after a dredging operation. In general, plant biomass increased throughout the study period. Species diversity of submersed macrophytes increased sharply in the immature community, but there was a general decrease in diversity in the older community. Light intensity limited gross photosynthesis. An inverse relationship existed between photosynthetic efficiency and light intensity. The observed 29:1 ratio of plant surface area to stream bed may be about optimum for maximum use of solar energy by the plant community. Community metabolism in the immature community fluctuated as differences in light intensity acted on low biomass and few species. As succession developed in the ecosystem with increase in species and biomass, ecological stability increased until only autotrophic conditions existed even under low light intensity. (Author's abstract.)

R. M. Harvey and J. L. Fox, "Nutrient Removal Using *Lemna minor*," *Journal Water Pollution Control Federation, 45*, 1973, pp. 1928-1938.

Wastewater nutrient removal capabilities and economic resource potential of *Lemna minor* are investigated and discussed. *L. minor* was selected over *Woffia Columbiana* and *Salvinia rotundiflora* as the principal subject of the investigation because it was the only one of the three species screened that was both easy to harvest and has a high forage potential. *Lemna* removed substantial quantities of nitrogen ad phosphorus from secondary effluent under batch laboratory conditions. Dried *Lemna* plants contained 4.59% nitrogen and 0.80% phosphorus. *Lemna*was found to double its area every 4 days and is as good or better than common pasture grass as a cattle feed based on digestibility testing. Furthermore, harvesting costs are low because of its small size and free floating nature. **(5,6)**

J. F. Hentges, "Processed Aquatic Plants for Cattle Nutrition," *Proceedings of the Aquatic Plant Research Conference, Gainsville, Florida: University of Florida, 1970*, pp. 62-67.

Cattle nutrition research with diets containing aquatic forage from water hyacinths (*Eichhormia crassipes*), and Florida elodea (*Hydrilla verticillata*) was conducted. It was found that: (a) cattle will graze floating water hyacinths when the supply of nutrients from land forages are limited; (b) full-fed cattle have voluntarily consumed up to 10% of their ration as chopped fresh water hyacinths sprayed with cane molasses; (c) the substitution of sun-dried, chopped water hyacinths for 5.5% of the roughage in a mixed diet for feedlot cattle did not alter their feed intake although they did refuse to eat the roots; (d) dehydrated, aquatic forage meal (milfoil, coontail, and *Elodea*) was not equal in nutritive value to dehydrated alfalfa and; (e) during a year's cycle, the chemical and apparent nutrient composition, especially crude protein content, of aquatic plants varied widely from location to location apparently due to stage of maturity, fertility of water, and processing method.

W. S. Hillman, "The *Lemnaceae*, or Duckweeds—A Review of the Descriptive and Experimental Literature," *The Botanical Review, 27*, 1965, pp. 221-287.

This study summarizes the biology of the *Lemnaceae*, with special emphasis on their characteristics as organisms for developmental, physiological, and biochemical investigations. The paper reviews the following topics in depth: systematics, morphology and anatomy, natural history, normal vegetative growth, growth cycles, and developmental physiology.

L. G. Holm, L. W. Weldon, R. D. Blackburn, "Aquatic Weeds," *Science, 166*, 1969, pp. 699-709.

Several aquatic weeds can become problems in water systems. The plants studied include water hyacinth, *Salvinia*, water lettuce, submerged weeds, emersed weeds, Phreatophytes, and

floating island weeds. The biology, past and potential uses, and governing environmental factors for growth are reviewed.

R. G. Koegel, D. F. Livermore, H. D. Bruhn, "Harvesting Aquatic Plants," *Agricultural Engineering*, 1975, pp. 20-21.

Aquatic plant harvesting trials were performed in central Wisconsin during 1972 and 1974 to determine the relative costs. Eurasian watermilfoil and associated filamentous algae are the major types of plants harvested. Two different harvesters were tested: the *Aquamarine Harvester* and the *Modified Grinwald-Thomas Harvester*. Harvesting costs ranged from $68 to $94 per acre. Harvesting costs per hour of actual operating time were $58 to $65. **(5)**

J. G. Linn et al., "Nutritive Value of Dried or Ensiled Aquatic Plants II Digestability by Sheep," *Journal of Animal Science, 41*, 1975, pp. 610-615.

*Potamogeton pectinatus and Myriophyllum exalbescens* were tested to determine the digestability by lambs. Both were unpalatable. However, these plant species were partially digestable when mixed with dehydrated alfalfa. The palatability of aquatic plants may be a limiting factor in their use as a forage for rumenants. Drying or ensiling did not appear to be satisfactory procedures for improving palatability.

J. J. Lynch et al., "Effects of Aquatic Weed Infestations on the Fish and Wildlife of the Gulf States," *USDI Fish and Wildlife Special Scientific Report, 39*, 1947, pp. 1-71.

Lynch evaluated the nature and extent of damage to wildlife and fisheries caused by water hyacinth and alligatorweed, the amount of economic damage caused, and the effect of weed control programs on fisheries and wildlife. Water hyacinth and alligatorweed provide a serious threat because once the species colonize an area they alter the habitat, diminish the value of wildlife, and restrict access of recreationalists. In Louisiana alone the fish and wildlife resource affected annually by the encroachment of these species is estimated to be worth $368,000,000. In all cases, water under mats of hyacinth plants exhibited an oxygen deficit and was unsuitable for fish life. Hyacinth mats also interfere with the normal interchange of gases between the water surface and atmosphere preventing the release of $CO_2$ and $H_2S$. It was concluded that a concentrated effort needs to be developed to control the further spread of exotic weed species in the south.

C. MacFarlane, "A Survey of Certain Seaweeds of Commercial Importance in Southwest Nova Scotia," *Canadian Journal of Botany, 30*, 1952, pp. 78-97.

Of 523 km of Nova Scotia coastline surveyed for rockweed, 225 km contained harvestable stands representing a total potential yield of $1.8 \times 10^8$ kg. 255 stations, examined in detail, showed the average density to be 20.01 kg/m$^2$. The width of the harvest zone ranges from 3 to 274 m, the average being 46 m. *Ascophyllum nodosum* forms the greatest percentage of rockweed, *Fucus vesiculosus* ranking next. *Laminaria* beds totaling 4800 ha in extent and bearing 816 426 000 kg = were charted. Mortality among *Laminaria* sporophytes in the beds is generally high, and varies from year to year. Succession of algal cover and recolonization of denuded areas is described. In 1950, $3.6 \times 10^6$ kg of *Chondrus* were harvested from beds varying in density from 4.88 to 12.21 kg/m$^2$. *Chondrus* ecology is discussed. **(1)**

C. McMillan, "Salt Tolerance Within a *Typha* Population," *American Journal of Botany, 46*, 1959, pp. 521-526.

*Typha* in a disturbed salt flat near Lincoln, Nebraska, provided material for an examination of population dynamics. Within the population, clones of *T. angustifolia* tended to occupy the drier sites and those of *T. latifolia* occupied the sites of greater moisture probability. Clones of intermediate morphological characteristics were distributed with both *T. angustifolia* and *T. latifolia*. Rhizomes taken from the clones were grown in various NaCl solutions in the greenhouse. Results indicated greatest salt tolerance by *T. angustifolia* and least salt tolerance by *T. latifolia*. The intermediate, probably hybrid, clones were intermediate in salt tolerance. Seeds of the 3 clone-types germinated over the same range of salt concentration. The seeds of all 3 types withstood 4 months submergence in a 2% salt solution and germinated upon being returned to tap water. In the salt flat habitat, the clones of *T. latifolia* were not vigorous during the years 1956-1957 and many died or were reduced considerably in area of

occupancy. The clones of *T. angustifolia* remained vigorous and flowered over the same period. The intermediate clones were vigorous and increased their coverage, primarily in areas that were occupied prior to 1956 by *T. latifolia*. The spatial adjustments within the population probably resulted from the selective action of increased salt concentration accompanying the drier conditions of 1956 and 1957. (Author's abstract.) **(2,8)**

C. D. McNabb, Jr. and D. P. Tierney, *Growth and Mineral Accumulation of Submersed Vascular Hydrophytes in Pleioeutrophic Environs*, Department of Fisheries and Wildlife, Michigan State University, Technical Report No. 26, May 1972.

Submersed vascular hydrophytes invade ponds designed for stabilizing municipal waste. The adaptability of several species for vegetative growth in pleioeutrophic environments was compared by measuring growth rates. Coontail has a range of tolerance that includes the extremes in water quality that are observed in wastewater ponds. The tissue concentration of phosphorus in submersed plants tended to increase linearly with concentrations of soluble phosphorus in the ambient water. A similar relationship regarding nitrogen was not found. Heavy metals were not discussed or studied.

S. J. McNaughton, "Ecotype Function in the *Typha* Community Type," *Ecological Menographs, 36*, 1966, pp. 297-325.

Typha communites were observed and sampled at 33 sites in the United States. Rhizomes were collected from each site for controlled environment studies. Three native species (T. domingensis, T. latifolia, and T. augustifolia) were included.

*Typha domingensis* from saline habitats was more tolerant of salinity than plants of the same species from inland habitats. There is no cold requirement for germination. *T. latifolia* was more rhizomatous than other species, and rhizome proliferation was stimulated by short days and cool temperatures. Temperatures which force dormancy of northern plant samples were ineffective for southern samples under controlled conditions. Concentrations of major chemical constituents were higher in northern community samples and were stimulated by short days and cool temperatures with the magnitude of the stimulation being greatest in the northern samples. Plants from northern communities are more responsive to modification by the environment. Interlocking adaptions occur in potentially competative species that intigrate their energy requirements resulting in asynchronous energy demands. **(2,5,6)**

C. McVea and C. E. Boyd, "Effects of Water Hyacinth Cover on Water Chemistry, Phytoplankton, and Fish in Ponds," *Journal of Environmental Quality, 4*, 1975, pp. 375-378.

Water hyacinth (*Eichhornia crassipes*) cover of 0, 5, 10, or 25% surface was established in fertilized ponds stocked with the fish, *Tilapia aurea*, at Auburn, Alabama. Measurements of water chemistry, phytoplankton density, and fish production were made during the 1973 growing season.

Phytoplankton production was less in ponds with 10 to 25% cover by water hyacinth than in ponds with 0 to 5% cover. Competition of water hyacinth with phytoplankton involved shading and removal of P from the water. Concentrations of dissolved oxygen were lowest in ponds with 25% cover, but oxygen tensions in all ponds were adequate for survival and growth of fish. Reduction in phytoplankton growth in ponds with 10 and 25% cover resulted in much lower fish production. The presence of 5% cover by water hyacinth did not significantly affect fish production. Water hyacinth in enclosures absorbed large amounts of N and P corraborates claims that this species could be cultivated to remove N and P from excessively eutrophic water. (Author's abstract.) **(6)**

National Academy of Sciences, *Making Aquatic Weeds Useful: Some Perspectives for Developing Countries*, Washington D.C.: National Academy of Sciences, 1976.

Aquatic weeds are becoming a menace at alarming rates in many parts of the world. Several methods for controlling these aquatic macrophytes are presented and discussed in semi-detail, i.e., utilization of herbivorous animals, harvesting techniques, and other uses such as wastewater treatment and aquatic plants for food. Each section includes a bibliography and a listing of research contacts. **(2)**

W. T. Penfound and T. T. Earle, "The Biology of Water Hyacinth," *Ecological Monographs, 18*, 1948, pp. 447-472.

In the New Orleans area, growth of the water hyacinth is continuous from March 15 to November 15 and discontinues during the winter. Water hyacinth is intolerant to brackish or salt water. The species cannot tolerate water temperatures higher than 34°C (93°F) for extended periods. Leaves are killed by freezing temperatures but entire plants are not destroyed until the rhizome tip (29 cm below surface) is frozen. The water content of this species averages about 95%. Total transpiration from water hyacinth averages 3 times that of evaporation from a free water surface. Vegetative propagation is more important than sexual reproduction in colonization. Ten plants have a potential to produce 265 218 plants per ha in one growing season.

R. E. Perdue, "*Arundo donax*—Source of Musical Reeds and Industrial Cellulose," *Economic Botany, 12*, 1958, pp. 368-404.

*Arundo donax* is a tall, erect, perennial, cane-like grass 2 to 8 m high. It is one of the largest of the herbaceous grasses. Cane grows very rapidly (a growth rate of 0.3 to 0.7 m/week over a period of several months is not unusual) when conditions are favorable. The plant is native to the Mediterranean area, and tolerates excessive salinity and will survive extended periods of drought. The plant produces the most vigorous growth in well-drained soils where abundant moisture is available; its favored environment is along the border of lakes or along ditches and canals. When dormant, it is able to survive very low temperatures but is subject to serious damage by frosts that occur after the initiation of spring growth. The reeds are used for woodwind musical instruments. A considerable quantity of the grass has been used as a source of cellulose for rayon manufacture, and the plant has received consideration as a source of paper pulp. Among nonwoody plants this species is one of the highest producers of cellulose. Increases in the cost of wood pulp will create a better competitive position for *A. donax* and other nonwoody plants.

M. A. Profitt, *Effects of Heated Discharge Upon Aquatic Resources of White River at Petersburg, Indiana*, Indiana University Water Resources Research Center, 1969, pp. 1-101.

Research was initiated 2 years prior to the scheduled start-up of a power generating plant and was concluded about 2 years after the initial thermal discharges into the river. Thermal water discharged into the White River, Indiana, was 10 to 11°C above ambient river temperature, and, when the river is very low, represents as much as one fourth of the total river flow. Mixing of the discharge was essentially complete with in 1.6 km downstream, and temperature at this point was never more than 3°C above upstream temperatures. Monitoring programs included temperature, oxygen, turbidity, fish, and macroscopic invertebrate animals. Occasional low oxygen levels were observed in the heated water. Negative effects of the heated discharge on aquatic life were largely confined to the effluent canal. Some species of fish and invertebrates were more abundant in the heated water than elsewhere. **(2)**

C. D. Sculthorpe, *The Biology of Aquatic Vascular Plants*, London: Edward Arnold Publishers, 1967.

This text discusses the biological and physiological aspects of aquatic vascular plants. Some topics discussed include the influence temperature, salinity, and light transmission on aquatic plant growth.

B. Seddon, "Aquatic Macrophyte as Limnological Indicators," *Freshwater Biology, 2*, pp. 107-130.

Lake plant communities were surveyed in Britain to correlate the composition of aquatic macrophyte communities with the water chemistry. At given solute concentrations, higher values of hardness are correlated with greater diversity of aquatic macrophytes and with the presence of more exacting species. Five species groups were identified. First there was a highly eutrophic group comprising those species whose occurrence is generally limited to waters with a hardness ratio $>5.0$ and conductivity $>200$ μmhos. The lowest class occurs in dystrophic waters, which occurs where the hardness ratio is below 1.5 and conductivity is less than 50 μmhos. Among emergent aquatic species there are many which seem to be indifferent to water quality. The author concludes that water composition exerts a controlling influence, determining in any lake which species may occur, whatever their substrate preferences and the niches available. **(9)**

A. Sharma, "Eradication and Utilization of Water Hyacinth—A Review," *Current Science, 40*, 1975, pp. 51-55.

There are 4 major uses of water hyacinth that show potential.

1. *Use as a fertilizer and soil conditioner.* Plant yield per acre in India averages about 40 tons/ha or about 4 tons of compost. This is equivalent to 205 kg nitrogen, 110 kg $P_2O5$, and 250 kg of $K_2O$. The dry weight composition of water hyacinth is 75.8% organic matter, 1.5% nitrogen, 24.2% ash. The ash has 28.7% $K_2O$, 1.8% $Na_2O$, 12.8% CaO, 21.0% Cl, and 7.0% $P_2O5$. The potash content increases with the size of the plants.

2. *Use as food for animals.* As fodder, hyacinth is inferior to other agricultural feeds but it compares favorably in nitrogen content. It can be used as a supplemental fodder with good results especially in hog production.

3. *Use as a raw material for industry.* Water hyacinth has been used in paper manufacture and for wicker and basket work, however, none of these uses are feasible for large scale manufacture.

4. *Use as a source for gases, proteins, and other chemicals.* Utilization of the dried plants in the production of methane and alcohol has been achieved through saccharification, gasification, and bacterial fermentation. The high costs of drying and transporting have made this use currently unprofitable.

S. G. Smith, "Experimental and Natural Hybrids in North American Typha (Typhaceae)," *The American Naturalist, 78,* 1967, pp. 257-287.

*Typha latifolia, T. angustifolia,* and *T. domingens* occupy distinct but overlapping ecological and geographic ranges. The plants are protogynous, self-compatible, and rhizomatous. Leaf mucilage glands and gynophore hair apices provide useful new taxonomic characters. Three interspecific hybrids synthesized in the field in California are intermediate between their parents and similar to numerous putative hybrids. The species remain distinct due to either hybrid sterility or relatively narrow zones of sympatry. Hybridization and introgression have probably allowed the evolution of ecotypic races. The hybrids appear to be better adapted than the parents to habitats with rapidly fluctuating water levels.

L. E. Squires, *A Review of Algal and Vascular Aquatic Plant Applications in Aquaculture,* Aquatic Ecology Laboratory, Brigham Young University, Provo, Utah, 1979.

A review of the literature regarding the culture of algae and aquatic macrophytes with emphasis on the utilization of thermal effluent is presented. Algal cultures may provide useful organic materials for food or feed, may possess nitrogen fixing (fertilization) abilities, and may be functional in biological wastewater treatment. Algal productivity varies with species and environmental conditions and ranges from 4 to 330 kg/ha/day. Feeding trials showed algae to be inferior to soybeans as a feedstuff. The facility, temperature, light, nutrient, harvesting, and other requirements and considerations for algal culture are addressed.

Vascular aquatic plants are being cultured for fiber, pulp, wastewater treatment, animal feeds, and methane generation. High productivity and protein contents (dry weight) are reported for many species. Reviews of the characteristics, culture and uses of duckweeds, water hyacinth, cattail, bullrush, and chinese water chestnut are presented. A limited annotated bibliography and references regarding aquaculture and waste heat utilization are also presented.

R. Stalter and W. T. Batson, "Transplantation of Salt Marsh Vegetation, Georgetown, South Carolina," *Ecology, 50,* 1969, pp. 1087-1089.

A salt marsh located at Georgetown, South Carolina includes four vegetation zones (high high marsh, low high marsh, high low marsh, and low low marsh). Thirty plants of each of the dominant species in each zone were transplanted into the other three vegetation zones, and thirty plants of each of the dominant species in each zone were dug up and replanted in the same zone to serve as controls. Survival and growth rates of the transplants suggest that several species can tolerate conditions not found in their usual zones such as *Salicornia virginica* and *Limonium carolinianum.* Also some species such as *Borrichia frutescens* were found not to do well after transplanting under any circumstances. (Author's abstract.)

D. L. Sutton and S. W. Bingham, "Absorption and Translocation of Simazine in Parrotfeather," *Weed Science, 17*, 1969, pp. 431-435.

Root applications of simazine at concentrations greater than $1.0 \times 10^{-7}$ m inhibited growth of parrotfeather (*Myriophyllum brasiliense*).

C. E. Timmer and L. W. Weldon, "Evapotranspiration and Pollution of Water by Water Hyacinth," *Hyacinth Control Journal, 6*, 1967, pp. 34-37.

Water loss through evapotranspiration from water hyacinth was 3.7 times that from open water. Solar radiation can be measured to give an accurate prediction of the amount of water lost through evapotranspiration. Natural growths of water hyacinth added plant debris and allowed water coloring chemicals to leach into the water. The clarity of the water was greatly influenced by the growth of water hyacinth. (Author's abstract.)

F. T. Walker, "Sublittoral Seaweed Survey," *Journal of Ecology, 35*, 1947, pp. 166-185.

Sublittoral seaweed beds were quantitatively surveyed using a view box for preliminary assessment, and a calibrated spring grab and a modified rangefinder for the detailed survey. By this method it has been found possible to survey the sublittoral zone with reasonable accuracy. In ten sublittoral subareas situated in and around Scapa Flow on the Scottish coast, nearly 324 ha were surveyed in detail using the above method. The results indicate that approximately 12.36 E+06 kg of seaweed grew in that area. The average weed density/sampling operation was found to be 4.61 kg/$m^2$. The average weed density for the ten subareas sampled was 3.81 kg/$m^2$.

R. P. H. Welch and P. Denny, "The Translocation of $^{32}P$ in Two Submerged Aquatic Angiosperm Species," *New Phytologist, 82*, 1979, pp. 645-656.

The translocation of phosphorus as $^{32}P$ was investigated in two species of rooted, submerged aquatic angiosperms, *Potamogeton pectinatus* and *Potomogeton crispus*. Autoradiography and radioactive counting indicate the circulation of $^{32}P$ in these plants is similar to that described for terrestrial plants but with slower rates of movement. Directions and rates of phosphorus transport appear to be dependent upon the morphology, age, and physiological condition of the individual plants. *P. crispus* typically retains three groups of vascular bundles within the stem, while *P. pectinatus* stems have only a single xylem element surrounded by a ring of phloem. Translocation was much more rapid both up and down the stem of *P. crispus*. **(5)**

B. C. Wolverton and R. C. McDonald, "Don't Waste Waterweeds," *New Scientist*, 1976, pp. 318-320.

Water hyacinth is an extremely prolific species, which reproduces vegetatively and can double in number every 8 to 10 days. Grown in warm, enriched domestic sewage, the species produces over 16 148 kg/ha of wet biomass per day, or approximately 1270 kg of dry plant material per day. Dried plants contain approximately 20% crude protein, 16% fibre, and 18% ash. Water hyacinth has a high capability to absorb toxic heavy metals and organic nutrients and could be useful in treating polluted effluents. Water hyacinths show some promise for use as cattle fodder and as an organic fertilizer and soil conditioner. The plants can also be used to produce biogass containing 60 to 80% methane. The organic sludge byproduct can then be used as a high nutrient fertilizer.

R. R. Yeo, "Life History of Common Cattail," *Weed Science, 12*, 1964, pp. 284-288.

Seed of common cattail (*Typha latifolia*) germinated 100% when the blunt ends were ruptured. Seedlings developed primarily while submersed in water. Growth of the seedlings was rapid. A single plant in 6 months developed a network of rhizomes covering an area greater than 3 m in diameter. Pistillate spikes 18 cm long produced an average of over 222 000 seeds.

# Production Rates

T. A. Bailey, "Commercial Possibilities of Dehydrated Aquatic Plants," *Proceedings of the Eighth Weed Control Conference, 18*, 1965, pp. 543-551.

Xanthophyll concentrations of *Myriophyllum sp., Ceratophyllum sp.*, and *Elodea sp.* were assayed and found to average 838 mg/kg dry weight as compared to 13 to 397 mg/kg for yellow corn and alfalfa meal, characteristic suppliers of Xanthophyll. Upon successive recuttings, milfoil was not found to increase in either protein or Xanthophyll content. Average protein content of dehydrated aquatic macrophytes was found to be 19% based on dry weight.

C. E. Boyd, "Evaluation of Some Common Aquatic Weeds as Possible Feedstuffs," *Hyacinth Control Journal, 7*, 1968, pp. 26-27.

Crude protein analysis of 43 species of aquatic macrophytes revealed that 11 (or 26%) had a protein content of greater than 18%, while 18 (42%) ranged between 12 to 18% protein, which is considered good as a feed source. The plants were also evaluated for tannin content because large quantities of tannin (> 6%) decreases the digestibility of protein. Eleven of the 43 species contained >6% tannin. The maximum crude protein content of aquatic plants occurs in relatively young plants, an important consideration in harvesting for feedstuffs. Harvesting of aquatic plants can slow eutrophication by balancing the nutrient inflow and outflow at a steady state. Pilot studies are recommended to evaluate the feasibility of drying aquatic plants for animal feed.

C. E. Boyd and L. W. Hess, "Factors Influencing Shoot Production and Mineral Nutrient Levels in *Typha latifolia*," *Ecology, 51*, 1970, pp. 296-300.

Shoot standing crops for *Typha latifolia* ranged from 428 to 2252 g dry wt/$m^2$. Standing crops were positively correlated with concentrations of dilute acid soluble phosphorus in hydrosoils and dissolved phosphorus in the waters. Except for a weak correlation for dissolved calcium, additional site fertility parameters were not correlated with standing crop.

Tissue nutrient levels varied considerably, maximum values for most minerals being three or four times as great as the smallest values. Correlations between environmental levels of several nutrients and tissue concentrations were significant, but not very strong. Tissue concentrations of most nutrients were positively correlated with nitrogen content. Despite variations in tissue levels of nutrients, standing crop was the decisive factor determining quantities of nutrients per unit area of stand. (Author's abstract.)

J. L. Gallagher, "Effect of an Ammonium Nitrate Pulse on the Growth and Elemental Composition of Natural Stands of *Spartina alterniflora* and *Juncus roemerianus*," *American Journal of Botany, 62*, 1975, pp. 644-648.

A nitrogen (ammonium nitrate) pulse of 200 kg $ha^{-1}$ was added to stands of tall (1.0 to 1.5 m) *Spartina alterniflora*, short (< 0.5 m) *Spartina alterniflora*, and *Juncus roemerianus* in a Georgia salt marsh in July. The major response ten weeks later was an increase in the aerial biomass and a sharp reduction in the C/N ratio in short *S. alterniflora*. One year after the treatment the difference between the biomass in enriched and control plots was greater than ten weeks after treatment, but the C/N ratio in the plants in the treated plots had risen to that of the controls. The availability of N appears to limit growth in the middle elevation Georgia salt marsh (short *S. alterniflora*), but not in the lower (tall *S. alterniflora*) or higher (*J. roemerianus*) portions.

The greatest response to N occurred in the middle marsh where *S. alterniflora* was growing. The major effect was to increase aerial biomass and to decrease the C/N ratio, which likely increased the quantity of detritus in the salt marsh ecosystem and the rate at which it decayed.

J. L. Gallagher and F. G. Plumley, "Underground Biomass Profiles and Productivity in Atlantic Coastal Marshes," *American Journal of Botany, 66*, 1979, pp. 156-161.

Underground biomass profiles and productivity were evaluated in 18 stands of salt marsh plants in Georgia, Delaware, and Maine. Three types of underground biomass profiles were found. In the first, the concentration of macro-organic matter (MOM) was uniform with depth. A second type

had a high MOM concentration at the surface which decreased with depth; this was the most common type of profile. The third type of profile was seen where a large rhizome mat developed 15 to 20 cm below the surface.

R. A. Gortner, "Lake Vegetation as a Possible Source of Forage," *Science, 80*, 1934, pp. 531-533.

Aquatic vegetation from several Minnesota lakes was analyzed for proximate analysis and found to be characterized by high ash and protein content and low crude fiber. The potential for developing aquatic macrophytes in shallow lake areas for use as a high quality animal feedstuff is suggested.

R. A. Hough, "Photorespiration and Productivity in Submersed Aquatic Vascular Plants," *Limnology and Oceanography, 19*, 1974, pp. 912-927.

Laboratory studies with axenic cultures of *Najas flexilis* indicated that respired carbon dioxide is refixed extensively in the light and that the $^{14}C$ assay used in the study is a measure of net, rather than gross photorespiration. Respiration in the light in axenic *N. flexilis* increased with increasing dissolved oxygen concentration, which indicated the presence and enhancement of photorespiration, and that net photosynthesis would decrease with increasing oxygen concentration. In situ experiments with *N. flexilis* and *Scirpus subterminalis* demonstrated variations in photorespiration and dark respiration within a 1-day photosynthetic period and seasonally.

C. W. Keefe, "Marsh Production: A Summary of the Literature," *Contributions in Marine Science, 16*, 1972, pp. 163-181.

The markedly high productivity of marshes is discussed and attributed to such factors as longer growing season, vertical orientation of plants, abundant soil water, high nutrient content, and concentration of organic content in marsh soils.

The literature pertaining to net primary production of marsh communities is reviewed for both fresh and salt water ecosystems.

R. A. Linthurst and R. J. Reimold, "An Evaluation of Methods for Estimating the Net Aerial Primary Productivity of Esturine Angiosperms," *Journal of Applied Ecology, 15*, 1978, pp. 919-931.

Five harvest methods were used to estimate the net aerial primary production (NAPP) of angiosperm species in coastal salt marshes. Differences as great as ten fold were found between the five methods. Most methods underestimated production. It was concluded that the morphology of the species, the location, and the general environmental conditions affect the results of any single method and that these factors must be considered before selecting a particular harvest method.

C. D. McNabb, Jr., "The Potential of Submersed Vascular Plants for Reclamation of Wastewater in Temperate Zone Ponds," *Biological Control of Water Pollution*, J. Toubier and R. W. Pierson, (eds.), 1976, pp. 123-132.

The productivity of submersed vascular plants in a series of wastewater treatment ponds was assessed. In the temperate climate of Michigan, submersed plants demonstrated a doubling time of 11 days during the summer season ($> 10^{o}C$) until light became a limiting factor due to dense algal blooms. The submersed vascular species flourished best in an environment where *Daphnia magna* and *D. pulex* decreased algal densities through grazing and thus increased light penetration and clarity. Nutrients were accumulated primarily from the water through foliage rather than from the sediments through the roots. Strategies for harvesting submersed aquatic macrophytes for maximum yield are discussed.

W. T. Penfound, "Primary Production of Vascular Aquatic Plants," *Limnology and Oceanography, 1*, 1956, pp. 92-101.

Data are presented on the productivity of four hay crops, five prairie plots, one floodplain community, one cultivated aquatic crop, two emergent plant populations, and two floating mat communities. The productivity (production rate) of the communities investigated varied with the amount of light, water, and nutrients available. The average productivity, in grams of $C/m^2/day$, based on the terminal crop, was moderate (1.5) in hay crops tall grass prairie, and rice, relatively high (3.6) in giant ragweed, and presumably still higher in certain aquatic plants. The terminal

standing crop was found to be less than the sum of periodic measurements of the developing crop. It was noted also that the magnitude of productivity values depended upon the time of harvest. The productivity of vascular aquatic plants was usually highest in spring and autumn and lowest during the summer. Low summer productivity was due primarily to the relatively low rate of photosynthesis, compared with that of respiration, during hot summer weather. On the basis of present data, it appears that productivity in the terrestrial habitat was greatest along shorelines of water bodies and did not increase continuously in the hydrarch succession toward the regional climax. (Author's abstract.)

W. E. Sopper and L. T. Kardos, "Vegetation Responses to Irrigation with Treated Municiple Wastewater," *Recycling Treated Municipal Wastewater and Sludge through Forest and Cropland*, Harrisburg: Pennsylvania State University Press, 1973, pp. 271-294.

Crop yields and tree growth increased significantly following irrigation with sewage effluent. The value of the vegetation as a water renovating agent was also demonstrated. For year-round operations, a combination of cropland and forestland will provide the greatest flexibility in operating a system using the living filter concept. **(2)**

C. H. Stoddard, "Wild Rice Production from New Wetlands," *Twenty-Fifth North American Wildlife Conference*, p. 144-153.

The ideal planting depth for wild rice is under 30 to 90 cm of water. The following physical and chemical conditions appear necessary for wild rice growth:

1. Water should be slowly flowing or circulating
2. Water depths above the seed beds must be in the range of 15 to 137 cm
3. Nearly constant or slightly declining water levels are necessary
4. Water with a total alkalinity of 40 to 200 ppm contains the best rice stands
5. Soil pH should be as nearly neutral as possible
6. Water pH from 6.8 to 8.8 seems to support the best stands
7. Sulfate-ion concentration below 10 ppm is required for best growth.

Yields in most cases were found to be lower than the potential because of the effect of damage due to insects, diseases, predators, or unfavorable weather conditions.

D. F. Westlake, "Comparisons of Plant Productivity," *Biological Review, 38*, 1963, pp. 385-425.

The principles of comparative productivity and the net primary productivity of different types of plant communities are discussed. The most productive temperate communities appear to be fertile reedswamps which may produce 30 to 45 metric tons (mt) per ha in a year. Coniferous forests, and perennial plants under intensive cultivation, may produce 25 to 40 mt. Deciduous forests, uncultivated herbs, and cultivated annual plants are less productive (10 to 25 mt/ha). Rain forests and perennial plants under intensive cultivation may produce 50 to 80 mt/ha in a year, and it is probable that swamps are similar. The phytoplankton of lakes and oceans are relatively poorly productive even on fertile sites, with an annual production of only 1 to 9 mt/ha. Values greater than 3 mt/ha are only achieved in waters enriched by man's activities. Freshwater macrophytes may attain 13 to 21 mt/ha. Benthic marine plants produce 25 to 40 mt/ha. Algae cultivated in sewage can produce 45 mt/ha. Annual productivity of up to 150 mt/ha year might someday be attained in cultivated stands of *Eichhornia crassipes*. **(1,2)**

J. L. Yount and R. A. Crossman, "Eutrophication Control by Plant Harvesting," *Journal of the Water Pollution Control Federation, 42,* 1970, pp. 173-183.

Harvesting organisms grown in hypertrophic ponds to remove nutrients reduces the ponds primary productivity. This is shown by the fact that plant productivity became much reduced in time over the early measures in the test ponds, while in the control ponds where nutrients were returned to the ponds, productivity remained relatively high. Therefore, large-scale harvesting from natural waters can be expected to reduce the productivity of those waters, and probably reverse the trend toward hypertrophy, especially in polluted waters. Furthermore, it is evident that the present method of controlling the water hyacinth and other plants by chemical sprays is returning their contained nutrients to the lakes and exacerbating hypertrophy of these lakes. **(2)**

# Mineral Absorption

I. L. Bayley and T. A. O'Neill, "Seasonal Ionic Fluctuations in a *Phragmites communis* Community," *Canadian Journal of Botany, 50*, 1972, pp. 2103-2109.

Ca, Mg, K, Na, and P concentrations were measured in the shoots of a *Phragmites communis* community and its natural substrates. Shoot length and shoot moisture were determined as indicators of physiological age. Following decomposition of annual plant production, the organic matter content and cation exchange capacity of the soil were determined. Ca increased in the shoot tissue, and Mg, K, and P decreased during the course of the growing season.

I. L. Bayley and T. A. O'Neill, "Seasonal Ionic Fluctuations in a *Typha glauca* Community," *Ecology, 53*, 1972, pp. 714-719.

Ca, Mg, K, Na, Fe, and P concentrations were measured in rhizomes, leaves, and floral stalks of a *Typha glauca* community during the 1968 growth season. Leaf length and plant-organ moisture contents were determined and used as indicators of physiological aging. Seasonal fluctuation was found in all ions examined in the soil and all plant parts analyzed. The ions studied were grouped into three categories with reference to apparent seasonal fluctuations of ionic concentrations. Concentration changes of Ca and possibly Mg in plant tissue were inversely related to apparent changes in substrate concentration. Changes in concentration of K and P in floral stalks and leaves were inversely related to apparent changes in ion concentration in the rhizome, although not related to changes in the substrates. Changes in concentration of Na and Fe in all plant parts sampled were directly related, but no relationship was detected between the apparent changes in concentration in plant tissue and those in the substrates. (Author's abstract.)

I. L. Bayley and M. F. Shibley, "Seasonal Nutrient and Sodium Accumulation in the Macrophyte *Pontederia cordata*," *Canadian Journal of Botany, 56*, 1978, pp. 417-425.

A seasonal study of accumulation of Ca, Mg, Na, K, and P was made on Pickerelweed (*Pontederia cordata*), an important plant of wetlands in North America. Samples of soil and plant material were taken twice weekly from May 23, 1975 to September 23, 1975. Positive correlations between seasonal growth events of *P. cordata* and accumulation of individual ions were obtained from the analysis. Also, a positive correlation between accummulation of ions and changes of ion concentration in the upper horizon of the soil was detected for K and Mg.

C. E. Boyd, "Chemical Analysis of Some Vascular Aquatic Plants," *Archives of Hydrobiology, 67*, 1970, pp. 78-85.

The mineral nutrient and pigment content of vascular plants from a soft water impoundment were determined. Large interspecific variations in most constituents were noted even among species with similar ecological growth habits. Concentrations of nutrients in aquatic macrophytes are apparently regulated by both physiological and environmental factors. Active uptake and accumulation of nutrients against a concentration gradient is obvious. Submersed plants were highest in all pigments, and floating leafed plants usually had higher pigment concentrations than emergent species.

C. E. Boyd, "Losses of Mineral Nutrients During Decomposition of *Typha latifolia*," *Archives of Hydrobiology, 66*, 1970, pp. 511-517.

Rates of dry matter and mineral nutrient losses from decaying *Typha latifolia* were determined by the net bag technique. Dry matter and nutrient losses from bags submerged in water were generally much greater than for bags suspended in the air. Rates for bags suspended in the air were similar to those for typical terrestrial decomposition. These results indicate that aquatic macrophytes decompose more rapidly than terrestrial plants during the initial stages of decay. Apparently a large quantity of the nutrients in aquatic vegetation is returned to the environment during the first few days of decay. (Author's abstract.)

C. E. Boyd, "Vascular Aquatic Plants for Mineral Nutrient Removal from Polluted Waters," *Economic Botany*, 1970, pp. 95-103.

Wastewater treatment systems based on the harvest of aquatic plants have potential application in removing nutrients from effluents and

natural waters. Large quantities of all elements essential for plant growth would be removed in proportion to their compositional ratios in the particular species. Plants could be subsequently used as forage to partially offset the cost of nutrient removal. **(9)**

D. D. Culley and E. A. Epps, "Use of Duckweed for Waste Treatment and Animal Feed," *Journal of the Water Pollution Control Federation, 45*, February 1973.

Duckweed samples from several Louisiana and Arkansas effluent receiving water bodies were collected and analyzed for protein, fat, fiber, ash, Ca, K, P, Mg, Fe, Ma, $H_2O$, Cu, and Zn. Constituent levels varied depending upon location and time (season) of sample collection. Duckweed grows well on eutrophic water and accumulates relatively high levels of nutrients and metals. They grow rapidly, are easy to harvest, have a high nutritional value/dry wt., lack serious pests and diseases, and are not toxic to herbivores. High water content is a major deterrent to utilization of plant material.

J. A. De Marte and R. T. Hartman, "Studies on absorption of $^{32}P$, $^{59}Fe$, and $^{45}Ca$ by Water-Milfoil (*Myriophyllum exalbescens*)," *Ecology, 55*, 1974, pp. 188-194.

A method was developed for determining uptake and translocation of mineral elements by intact submersed aquatic vascular plants in laboratory and field studies. Autoradiographs and radioactivity measurements provided direct evidence that $^{32}P$, $^{59}Fe$, and $^{45}Ca$ were absorbed by the roots of *Myriophyllum exalbescens* and translocated to the shoot tissues. Similar evidence was obtained for absorption of $^{32}P$ by the shoots and translocation to the roots. Data from experiments designed to compare the effect of substrate type (sand or muck) and the presence or absence of light showed no significant difference in the amounts of $^{32}P$ absorbed by roots. Translocation of $^{59}Fe$ from root to shoots was greatest for plants rooted in sand and maintained in the light.

$^{32}P$ was generally distributed throughout *Myriophyllum* as revealed by autoradiography, with some accumulation occurring at the nodal and budding regions. $^{59}Fe$ and $^{45}Ca$ were not translocated as readily, but some accumulation of each occurred in the stem.

$^{32}P$ absorbed by the roots of *Myriophyllum* was translocated to the shoot system and released to the surrounding water. Experimental evidence showed that injury to submersed hydrophytes can result in additional release of phosphate to the water. The rate of release is increased as a result of physical damage to the shoot. This provides an additional pathway for the cycling of phosphorus in freshwater environments. (Author's abstract.)

P. Denny, "Sites of Nutrient Absorption in Aquatic Macrophytes," *Journal of Ecology, 60*, 1972, pp. 819-829.

Six species of floating leaved and submerged leaved aquatic plants were cultured on nutrient-rich mud and nutrient-poor sand in artificial ponds. Waters were homogenously mesotrophic. Growth rates were calculated for roots and shoots of each species on each substrate. Totally submerged species were least affected by substrate whereas floating leaved species showed a 4-fold growth increase on the mud. **(5)**

W. R. Duffer and J. E. Moyer, *Municipal Wastewater Aquaculture*, EPA-600/2-78-110, U. S. Environmental Protection Agency, 1978.

Literature regarding natural and artificial wetlands, macrophytes, intervertebrates, and fish systems are reviewed as alternative methods for municipal wastewater treatment. Exploratory wastewater treatment research is recommended for several aquatic macrophytes, including cattails, waterweeds, duckweeds, and bullrushes. Additionally, investigation is recommended for developing artificial wetlands for wastewater treatment, as well as evaluating the value of natural wetland systems for municipal wastewater treatment. While numerous exploratory studies have been conducted to demonstrate the potential of wastewater aquaculture treatment, information remains limited with respect to design of operational aquaculture systems. Research progress in municipal wastewater aquaculture is reviewed through mid-1977.

C. T. Garten, J. B. Gentry, R. R. Sharitz, "An Analysis of Elemental Concentrations in Vegetation Bordering a Southeastern United States Coastal Plain Stream," *Ecology, 58*, 1977, pp. 979-992.

Mineral element concentrations were measured in the component parts of different species of

plants from a floodplain community along a coastal plain stream in South Carolina. Frequency distributions of concentrations of mineral elements were positively skewed, although distributions of P, K, Ca, and B concentrations tended to be less skewed than those of some trace elements (Na, Al, and Cs-137). Sources of variation in the elemental compositions of the major natural plant species of the floodplain were examined statistically. In herbaceous species (*Scirpus cyperinus* and *Andropogon sp.*) 52 to 56% of the variation in P, Mg, Mo, and Na concentrations was accounted for by differences in the chemical composition of stems, leaves, roots, and seeds. Seasonal variation in the mineral element composition of leaves from woody species was greater than that in stems. Concentrations of K, P, Al, Mo, and Sr in leaves were significantly different among seasons in 3 woody species (*Alnus serrulata, Myrica cerifera*, and *Salix nigra*). Mean concentrations of Ca, Na, Al, B, Mo, and Sr in leaves tended to increase from spring to autumn; while K, Mg, M, P, Cu, Zn, and Cs-137 concentrations declined. For macroelements (P, Mg, K, Ca, and N) and some trace elements (B, Sr, Na, and Mo), 50% of the variation in concentrations was accounted for by differences among 4 species (*Polygonum punctatum, Scirpus cyperinus, Salix nigra*, and *Sagittatia latifolia*) while 12% was explained by differences among 7 locations along the creek. Discriminant function analysis showed that K concentrations, which are low in the floodplain soils, contributed more than did concentrations of 11 other elements to species differences. Concentrations of elements were significantly correlated across species and locations from the floodplain community. A principal components analysis of elemental concentrations in leaves produced 2 components after varimax rotation. Principal component I was most highly correlated with concentrations of Ca and Sr, but many other elements were loaded on this component. (Author's abstract.)

C. G. Golueke, "Aquaculture in Resource Recovery," *Compost Science, 20*, 3, 1979, pp. 16-23.

A general overview of the use of aquaculture systems for municipal wastewater treatment is presented and the "Solar Aqua Cell System," is described. A list of research personnel studying aquaculture systems for wastewater treatment is presented. Abstracts of the following wastewater aquaculture reports are included:


1. W. R. Duffer and J. E. Moyer, *Municipal Wastewater Aquaculture*, EPA-60012-78-110. Robert S. Kerr Environmental Research Laboratory, Office of Research and Development: U. S. E.P.A.: Ada, Oklahoma, June 1978.

2. P. Tortell, *The Utilization of Waste Nutrients of Aquaculture*, Paper Presented at the International Conference on Developments in Land Methods of Wastewater Treatment and Utilization, Melborne, Australia, October 23-27, 1978.

3. R. Dinges, "Upgrading Stabilization Pond Effluent by Water Hyacinth Culture," *Journal of the Water Pollution Control Federation, 50*, 1978, pp. 833-845.

4. S. A. Serfling and C. Alsten, "An Integrated, Controlled Environment Aquaculture Lagoon Process for Secondary or Advanced Wastewater Treatment," *Paper Presented at the Conference on Performance and Upgrading of Water Stabilization Ponds, Utah State University, Logan, Utah, August 23-25, 1978.*

5. "Some Prospects for Aquatic Weed Management in Guyana," Workshop on Aquatic Weed Management and Utilization, National Science Research Council of Guyana and National Academy of Sciences, U.S.A. Georgetown, Guyana, March 15-17, 1973.

6. W. S. Hillman and D. D. Culley, Jr., "The Use of Duckweed," *American Scientist*, 1978, pp. 442-451.



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7. National Academy of Sciences, *Making Aquatic Weeds Useful: Some Perspectives for Developing Countries*, National Academy of Sciences, Washington, D. C., 1976.

H. J. Harper and H. A. Daniel, "Chemical Composition of Certain Aquatic Plants," *Botanical Gazette, 96*, 1934, pp. 186-189.

Concentrations of N, P, and Ca in 12 species of aquatic plants and 8 species of some common weeds and mature grasses were reviewed.

W. S. Hillman and D. D. Culley, Jr., "The Uses of Duckweed," *American Scientist, 66*, 1978, pp. 442-451.

Duckweed is capable of removing organic and inorganic materials from wastewater. It is particularly effective for reducing nitrogen and phosphorus concentrations and less effective with toxic chemicals or heavy metals. Duckweed will tolerate micronutrients such as Cu, Zn, and B. It will grow in the presence of high concentrations of sodium and will survive in high concentrations of potassium, phenols, or other organic substances.

J. P. Law and R. S. Kerr, "Nutrient Removal from Enriched Waste Effluent by the Hydroponic Culture of Cool Season Grasses," Federal Water Quality Administration, Department of the Interior, Program 16080, 1969, pp. 1-33.

Grasses were grown in hydroponic culture tanks to evaluate their nutrient removal capabilities when supplied with secondary-treated sewage effluent as the sole source of plant nutrients. Fescue produced over 9071 kg/4046 $m^2$dry weight yield, and ryegrass yield was about 6350 kg/4046 $m^2$ for one year. The quantities actually removed by the grasses were rather small compared to the total quantity supplied. About 4 to 8% of the N supplied was accounted for in the grass harvested, while about 2 to 5% of P, and 6 to 22% of the K were removed in the harvests.

E. B. Knipling, S. H. West, W. T. Haller, "Growth Characteristics, Yield Potential, and Nutritive Content of Water Hyacinths," *Soil and Crop Science Society of Florida Proceedings, 30*, 1970, pp. 51-63.

Physiological and growth characteristics of water hyacinth were studied to provide a basis for evaluating the plants' productivity and potential agricultural value. Plants grown in water containing 0.05 ppm P had larger root-to-shoot ratios than plants growing in water containing 0.5 ppm P. The optimum water temperature for hyacinth growth is 28 to 30°C but growth rate is relatively high over the range of 22 to 35°C. Exposure of hyacinth leaves to 10°C at night reduces photosynthesis on following warm days. Hyacinth leaves exhibit extremely high transpiration rates, up to 2400 mg/$dm^2$/hr. In comparison to grass and alfalfa forage, water hyacinths have a high nutrient content. As a percent of dry weight N was 1.75, Ca at 3.06, P at 0.63, K at 3.07, and Mg at 0.63. The high nutrient content of water hyacinths favors their use as a livestock forage supplement and as a means of removing nutrients from water.

C. P. McRoy and R. J. Barsdate, "Phosphate Absorption in Eelgrass," *Limnology and Oceanography, 15*, 1970, pp. 6-13.

The absorption of phosphate by eelgrass (*Zostera marina*) was studied using $^{32}P$ in a partitioned container where leaves were separated from roots and rhizomes. Absorption, which was greatest in the light, occurred through both leaves and roots, and the absorbed phosphorus was transported rapidly to all parts of the plant. It therefore appears that eelgrass can use phosphate from sediments and from water. P removed from solution by the roots and rhizomes was returned in part to the surrounding water through the leaves, suggesting that in nature seagrass may act either as a sink or as a source for dissolved P in estuarine waters. (Author's abstract.)

J. M. Polisini and C. E. Boyd, "Relationship Between Cell-Wall Fractions, Nitrogen and Standing Crop in Aquatic Macrophytes," *Ecology, 53*, 1972, pp. 484-488.

Shoot samples of 21 species of aquatic macrophytes were separated into cell-wall and noncell-wall fractions by digestion in a neutral detergent solution. This method is useful for estimating digestibility by herbivores. Nitrogen content was also used as an indication of restrictive quality. Amounts of noncell-wall material and nitrogen in the dry matter decreased as shoot standing crops of the different species increased.

D. N. Riemer and S. J. Toth, "A Survey of the Chemical Composition of *Potamogeton and Myriophyllum* in New Jersey," *Weed Science, 17*, 1969, pp. 219-223.

Several species of *Potamogeton* and *Myriophyllum* from New Jersey were collected and analyzed for 11 elements. Wide variations

were observed in the inorganic composition of the plants, both within species and among species. In some instances, there appeared to be a relationship between the content of a specific element in a plant sample and the content of that element in the water in which the plants were growing. The N content of the plants was sufficiently high so that no extra N would be required to prepare composts from them. (Author's abstract.)

D. N. Riemer and S. J. Toth, "Chemical Composition of Five Species of *Nymphaeaceae*," *Weed Science, 18*, 1970, pp. 4-6.

Five species of *Nymphaeaceae*, representing four genera, were collected from various sites in New Jersey and their tissues analyzed for 12 elements. Three species were separated into leaf blades and petioles before the mineral analyses were made. Variations in the concentrations of many elements were noted between these two structures. Except for the petioles of these three species, the N content of the plants appeared to be sufficiently high so that no extra N would be required to prepare composts from them. (Author's abstract.)

D. W. Schults and K. W. Malueg, "Uptake of Radiophosphorus by Rooted Aquatic Plants," *Proceedings of the Third National Symposium on Radiology, Oak Ridge, Tennessee*, 1971, pp. 1-21.

Laboratory experiments were conducted to compare the uptake of P by roots and foilage of *Elodea canadensis, Potamogeton amplifolius*, and *Vallisneria americana* to evaluate the cycling of radiophosphorus between the sediment and the water medium with the plant as the exchange agent. All three species exhibited a higher uptake by the foilage than by the roots. For *Potamogeton* and *Vallisneria* uptake by the foilage was greatest for plants rooted in sediments, less for those rooted in sandy substrate and least for those rooted in lake water. For *Elodea*, uptake by the foilage was not statistically different for the three rooting media.

S. A. Serfling and C. Alsten, "An Integrated, Controlled Environment Aquaculture Lagoon Process for Secondary or Advanced Wastewater Treatment," *Proceedings of the Conference on Performance and Upgrading of Waste Stablilization Ponds, Utah State University, Logan, Utah, August 23-25, 1978*, pp. 124-145.

A system designed for dealing with wastewater as a valuable resource to be managed for controlled harvesting of nutrients, and planned reuse of the water is presented. Intentional stocking of aquatic species for subsequent harvest for a variety of beneficial uses is discussed. The advantages of utilizing floating aquatic macrophytes, specifically water hyacinth and duckweed for treating wastewater include: (a) stability and hardiness of selected species; (b) providing shade to prevent excessive algal growth; (c) rapid growth and high productivity; (d) ease of harvest; (e) high reuse potential such as animal feeds and conversion to liquid fuels; and (f) potential to economically achieve tertiary—quality effluent. Disadvantages include climatic requirements, predation, and evaporation losses in water short areas. The Solar Aquacell process is discussed in detail as a reliable, short retention time, lagoon process rendering high quality effluent suitable for multiple reuse options.

U. H. Shepherd and D. I. F. Bowling, "Active Accumulation of Sodium by Roots of Five Aquatic Species," *New Phytology, 72*, 1973, pp. 1075-1080.

The accumulation of several major nutrient ions by the roots of some aquatic plants was investigated. Five species growing in freshwater lochs on the north coast of Scotland were studied. Electrical potential differences between root epidermal cells and the surrounding loch water were measured using micro-electrodes. From these measurements, electrochemical potential gradients between the roots and the loch water were calculated, and also the driving forces on each ion. For each species investigated, the results indicate that Na is actively accumulated by the roots. This contrasts with results of studies which provide evidence for a sodium efflux pump in plant cells. It is suggested that active accumulation of Na is evident in plant roots when the external Na concentration is low. The results showed that $K^+$, $Cl^-$, and $NO_3$ are actively accumulated; $Ca^{++}$ and $Mg^{++}$ appear to be in electrochemical equilibrium with the external medium. (Author's abstract.)

F. Spangler, W. Sloey, C. W. Fetter, "Experimental Use of Emergent Vegetation for the Biological Treatment of Municipal Wastewater in Wisconsin," *Biological Control of Water Pollution*, J. Toubier and R. W. Pierson, (eds.), 1976, pp. 161-171.

Native Wisconsin marsh plants were assessed for their ability to provide secondary or tertiary sewage treatment. A 258-ha natural cattail marsh that receives both municipal and industrial waste was investigated; a striking water quality improvement due to movement through the marsh was recorded relative to BOD, COD, ORTHO-$PO_4$, total-P, coliform bacteria, and turbidity. The highest concentrations of nutrients were found to occur in young plant tissue of emergent species; therefore the effects of harvesting were investigated. *Scirpus acutus* (hardstem bullrush) and *S. validus* (softstem bullrush) recovered well post harvest while cattails (*Typha spp.*) did not. Additionally most P was associated with the root rhizomes, and little was harvested in the shoots.

K. K. Steward, "Nutrient Removal Potentials of Various Aquatic Plants," *Hyacinth Control Journal, 8*, 1970, pp. 34-35.

Harvesting aquatic plants has potential as a method of reducing nutrient pollution and of bringing eutrophic waters into proper nutrient balance. Floating plants such as water hyacinth have a greater potential than submersed plants because of higher productivities. The problems of harvesting plants with high water content and their utilization or disposal need to be weighed against the possible advantages of regaining the intended uses of the waters.

D. L. Sutton and W. H. Ornes, "Phosphorus Removal from Static Sewage Effluent Using Duckweed," *Journal of Environmental Quality, 4*, 3, 1967.

Two experiments were conducted in containers to evaluate the influence of various concentrations of static sewage effluent on the growth of duckweed and to determine the rate of P removal and harvesting effects on growth rates. Several replicates were provided to ensure data validity. Maximum growth rates were achieved at 25% effluent plus 75% pond water. Increased effluent concentration did not increase the growth rate but did affect an increase in P uptake and protein content of plant tissues. There is a positive correlation between P concentration in the water and duckweed uptake rate up to 2.1 μg/ml. With continued nutrient input, half of the duckweed could be harvested every 4 days.

## Trace Metal Absorption

M. F. Baudouin and P. Scoppa, "Acute Toxicity of Various Metals to Freshwater Zooplankton," *Bulletin of Environmental Contamination and Toxicology, 12*, 1974, pp. 745-751.

Some zooplanktonic species are more susceptable to heavy metal cations than fish. Since zooplankton is the main source of food for several species of fish, its destruction by heavy metals may result in the disappearance of some fish species even though the fish may not be directly affected. This investigation determines the degree of toxicity of various metal salts to three species of freshwater zooplankton. The species tested were *Cyclops, Eudiaptomus*, and *Daphnia*. Acute toxicity levels were determined for Ca, Mg, St, Ce, Cr, Co, Ni, Pb, Hg, An, Cd, and Cu.

J. A. Bently-Mowat and S. M. Reid, "Survival of Marine Phytoplankton in High Concentrations of Heavy Metals, and Uptake of Copper," *Journal of Exal Marine Biology and Ecology, 26*, 1977, pp. 249-264.

The growth of *Phaeodactylum tricornutum, Tetraselmis spp., Dunaliella primolecta*, and *Cricosphaera elongata* (renamed *Hymenomonas elongata*) in batch culture in S88 medium is not arrested on addition of Cu, Cd, or Pb below a concentration of $10^{-4}$ M. In contrast, *Ditylum brightwelli* undergoes osmotic disturbances in $10^{-5}$ M and $10^{-4}$ M Cu, with swelling of the cell contents.

*Phaeodactylum* grown in continuous culture survives single doses of up to $10^{-3}$ M Cu with no diminution in growth and with considerable uptake of Cu. *Cricosphaera* in continuous culture survives up to $10^{-4}$ M Cu with no long-term diminution in growth, but takes up between ten and a hundred times less Cu than *Phaeodactylum*. (Author's abstract.) **(4)**

C. Boyd and W. Walley, "Studies of the Biogeochemistry of Boron 1 Concentrations in Surface Waters, Rainfall and Aquatic Plants," *American Wildlife and Nature, 88*, 1972, pp. 1-14.

Boron (B) concentrations in streams, swamps, ponds, and reservoirs of the southeastern United States were usually below 100 g/l. Levels of B in rainfall varied greatly between different periods of precipitation, but the highest concentrations were observed during winter. However, most rainfall samples contained less than 10 g/l B. The annual input of B in rainfall at two Mississippi sites and one station in South Carolina ranged from 62.7 to 74.2 g/ha.

Boron levels in 22 species of aquatic macrophytes from a reservoir ranged from 1.2 to 11.3 mg/l dry weight. The plant populations accrued from 0.5 to 6.8 mg boron/$m^2$. Boron uptake studies on *Typha latifolia* populations indicated a maximum rate of uptake during early spring growth. Boron concentrations in *T. latifolia* and *Juncus effusus* samples from different sites varied considerably. There is no significant correlation between concentrations of B in soils and in plant tissues. Standing crops of *T. latifolia* increased with increasing levels of soil B. (Author's abstract.) **(2,4)**

R. R. Brooks and M. G. Rumsby, "The Biochemistry of Trace Elements Uptake by Some New Zealand Bivalves," *Limnology and Oceanography, 10*, 1965, pp. 521-527.

Spectrographic determinations of Ag, Cd, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Sb, V, and Zn were conducted on three species of New Zealand bivalves. Analyses were performed on the sediment, on the whole animal excluding shells, on the shells, and on the individual disected organs. All the elements were more concentrated in the shellfish than in the marine environment. The biochemical and geochemical processes involved in trace metal uptake were also examined.

B. Brown and M. Ahsanullah, "Effect of Heavy Metals on Mortality and Growth," *Marine Pollution Bulletin, 2*, 1971, pp. 182-187.

The acute toxicity of six metal salts on *Artemia salina* and *Ophryotrocha labronica* were determined. The data showed that the two species had different susceptibilities to the heavy metal salts. In *A. Salina*, the sequence of toxicity at a concentration of 1 ppm of test metal was Hg, Cu, Cd, Fe, Zn, and Pb; and in *O. labronica*, the sequence was Hg, Cu, Zn, Cd, Fe, and Pb. The only difference in the sequence of toxicities was the position of Zn, which was more toxic than Cd and Fe for *O. labronica*. As the concentrations of the heavy metal salts increased from 1 to 10 mg/l a significant suppression of growth rate was usually noted.

T. Fujiyama and M. Maeda, "Content and Uptake of Trace Metals in Benthic Algae, *Enteromorpha* and *Porhyra*. Measurement and Variation of Trace Metal Content of *Porphyra* Grown in Natural Environment," *J. Fac. Fish and Animal Husbandry, 16*, 1977, pp. 23-32.

Trace metals were recovered at more than 95% by the treatment of the alga with $HNO_3$-$HC10_4$-HCl. Standard deviations of 10 to 20% were tained by the analysis of the alga. The trace metals in *Porphyra* could be divided into two groups according to their tendencies of seasonal and regional variations. The recovery rate of trace metals from algae treated with $HNO^3$-$HClO^4$-HCl was over 95%. Standard deviation of the algae's metal content ranged from 10 to 20%; probably a function of the differences in algae size and maturity. Seasonal and regional variations in *Porphyra* trace metal content could be divided into two groups. One group was composed of Fe, Zn, Mn, and Cu and the other group was Pb and Cd. The variation of chlorophyll content was quite similar to that of Fe; showing very high content during the growing season while the period of maturity yielded a rapid decrease.

J. D. Gaynor and R. L. Halstead, "Chemical and Plant Extractability of Metals and Plant Extractability of Metals and Plant Growth on Soils Amended with Sludge," *Canadian Journal of Soil Science, 56*, 1976, pp. 1-8.

Sludge applied to several soil types increased Cd 2 to 5 times, Pb 2 to 3 times, Cu 3 to 7 times, and Zn 7 to 31 times. Metal extractability in sandy loam soils was not greatly changed after 11 months incubation, but extractable Zn, Cu, Pb, and Cd were reduced in the clay soils following incubation. Planting lettuce reduced the quantity of metal extracted from some of the sandy loam and clay soils tested. Lettuce yields were significantly reduced for the first crop grown on sludge and fertilizer treated soils. Saturation extract conductivities for all sludge treatments were higher for incubated than for cropped soils. Generally Zn, Cu, and Pb tissue concentrations in lettuce harvested from sludge and fertilizer treated soils were significantly increased, but total uptake was only increased for Zn. To a lesser extent, similar trends were observed with the tomato. **(8)**

J. P. Giesy and D. Paine, "Uptake of Americium-241 by Algae and Bacteria," *Progressive Water Technology, 9*, 1977, pp. 845-857.

Algae and bacteria concentrate $^{241}Am$ to a high degree, which makes them important links in the biomagnification phenomenon which may ultimately lead to a human hazard. The ability of algae and bacteria to highly concentrated $^{241}Am$ makes them potentially important in cycling $^{241}Am$ in the water column and mobilization from the sediments.

Chemical fixation of algal cells caused an increased uptake of $^{241}Am$, which indicates that uptake is by passive diffusion. Increased uptake after fixation is probably due to chemical alteration of surface binding sites. This problem may be eliminated by killing algal cells, used in uptake studies by ultraviolet light. (Author's abstract.) **(1,2)**

L. N. Gryzhankova et al., "Concentration of Some Metals in the Algae of the Sea of Japan," *Oceanology, 13*, 1973, pp. 206-210.

The concentration of polyvalent metals Fe, Mn, Cu, Ni, Co, Ti, V, and Cr in twelve types of algae of the Sea of Japan were investigated. The strongest concentrator of polyvalent metals among the brown algae studied was *Agarum cribrosum*, and among the green algae, *Enteromorpha sp.* The swim bladders of *Sargassum palidum* were the richest in metals as compared with other parts of the algae. **(1)**

L. H. P. Jones, C. R. Clement, and M. J. Hopper, "Lead Uptake from Solution by Perennial Ryegrass and its Transport from Roots to Shoots," *Plant and Soil, 38*, 1973, pp. 403-414.

The uptake of Pb by roots and its transport to the shoots in perennial ryegrass was rapid, almost complete, and unaffected by removing the shoots or killing the roots. Pb bound in the roots was not released by exchange with Ca or Ba ions. The total uptake, or Pb burden, increased with increasing rates of addition. Transport of Pb to the shoots continued throughout the experimental periods of 21 to 28 days but did not exceed 28.9% of total uptake. It was concluded that roots of actively growing ryegrass provide a barrier which restricts the movement of Pb to the aboveground parts of plants. **(4)**

L. Karbe, N. Antonacopoulos, C. Schnier, "The Influence of Water Quality on Accumulation of Heavy Metals in Aquatic Organisms," *Vech. International Verein Limnology, 19*, 1975, pp. 2094-2101.

Accumulation of metals by aquatic organisms was strongly influenced by the trophic and saprobic condition of the water. A correlation was shown between heavy metal accumulation in mussels and oxygen saturation. **(9)**

R. A. Khalid et al., *Transformation of Heavy Metals and Plant Nutrients in Dredged Sediments as Affected by Oxidation Reduction Potential and pH*, U.S. Army Engineer Waterways Experiment Station, Contract Report D-77-4.

The occurrence and chemistry of selected trace metals and plant nutrients in sediment-water systems were studied. The toxic and nutrient elements included in the study were Pb, Cd, Hg, As, Se, Cu, Zn, Mn, Fe, N, P, and S. Effects of pH and oxidation-reduction conditions on metal and nutrient chemistry were stressed.

T. J. Kneip and G. J. Lauer, "Trace Metal Concentration Factors in Aquatic Ecosystems," *Chemical Analysis of the Environment and Other Modern Techniques*, New York: Plenum Press, 1973.

The basis for understanding bioconcentration and concentration factors, were discussed. A series of examples were presented which demonstrate the variations in the bioconcentration of trace metals. Examples included elements known or thought to be essential as well as those known to be adventitious. The differences in the behavior of the metals demonstrate the problems inherent in general statements regarding concentration factors, and the reasons that many misuses have occurred. (Author's abstract.)

Laboratory of Algal Physiology, *Biological Accumulation of Inorganic Materials by Algae*, U.S. Atomic Energy Commission, AT(40-1)-1039, October 1953.

Maintaining a culture collection of different types of algae, conditions which affect their growth, methods of growing uniform experimental material, and determining the amount and rate of uptake of various radioactive ions were

described. The objective of the study was to test the ability for algal uptake of radioactive wastes. The elements which were studied included Cs, St, Yt, Zr, and Nb. The order or algal preference with regard to alkali metal ions was K and Rb > Cs > Na. Sr uptake decreased with increasing concentrations of Mg and K. Uptake of Yt, Zr, and Nb fell off sharply with pH ranging from 5.5 to 6.0. Below a pH of 5.5, sorption was very high.

R. J. Lancaster, M. R. Coup, J. W. Hughes, "Toxicity of Arsenic Present in Lakeweed," *New Zealand Veterinary Journal, 19*, 1971.

Effects of sheep feeding on lakeweed containing As was determined, the amount of As stored in sheep tissues after a period of lakeweed ingestion was measured, and the fate of As within the animals that survived lakeweed feeding and subsequently received no feed containing As for a period was determined. A pilot experiment was conducted to observe the reaction of a lamb when it was given lakeweed containing approximately the amount of As in a toxic dose of NaAs. The toxicity of As was found to be extremely variable, depending on the valency state of the element, the type of the element, and the type of chemical combination in which it is ingested.

C. R. Lee, T. C. Sturgis, M. C. Landin, *A Hydrodynamic Study of Heavy Metal Uptake by Selected Marsh Plant Species*, U.S. Army Engineer Waterways Experimental Station, Technical Report D-76-5.

Eight marsh plants were grown in chemically controlled hydroponic solutions containing three concentrations of heavy metals to evaluate the ability of each plant species to take up and accumulate heavy metals. The marsh plants studied were *Cyperus esculentus, Scirpus validus, Spartina patens, Scirpus robustus, Distichlis spicata, Triglochin maritima, Spartina alterniflora*, and *Spartina foliosa*. The heavy metals studied were Zn, Cd, Ni, Pb, and Cr, each at a concentration of 0.0, 0.5, and 1.0 mg/l. Marsh plants were exposed to heavy metals for six weeks and harvested. Plants were separated into tops, lower stems, rhizomes, tubers, and roots, and analyzed for heavy metals to locate plant parts where heavy metals may accumulate.

Exposure to heavy metals adversely affected the growth of *S. validus, S. patens, D. spicata,* and *S. alterniflora* more than the other plant species evaluated. The species that appeared to have more potential in taking up Zn, Cd, and Ni were *C. esculentus, S. patens, D. spicata*, and to some extent *S. alterniflora*. Pb and Cr accumulated in the roots of all species with very little translocation into plant tops. P and Fe content in the roots appeared to be a major factor in determining the ability of a marsh plant to translocate heavy metals from the roots into other plant parts. (Author's abstract.) **(4)**

A. G. Lewis, P. H. Whitfield, A. Ramnarine, "Some Particulate and Soluble Agents Affecting the Relationships Between Metal Toxicity and Organism Survival in the Calanoid Copepod *Euchaeta japonica*," *Marine Biology, 17*, 1972, pp. 215-221.

Particulate and water-soluble agents were tested to determine their ability to affect the relationship between metal toxicity and the survival of *Euchaeta japonica* (Copepoda and Calanoida). Clay minerals and diatoms were two types of particles capable of affecting this relationship. Ascorbic acid, sewage effluent, water extracts of humic acid, and two types of soils exhibited the same capability. The ability of the water-soluble agents were compared with that of a known chelating agent in an attempt to quantify the activity of the agents. (Author's abstract.)

A. J. Maclean, "Cadmium in Different Plant Species and its Availability in Soils as Influenced by Organic Matter and Additions of Lime, P, Cd, and Zn," *Canadian Journal of Soil Science, 56*, 1976, pp. 129-138.

The Cd concentration in 10 plant species grown in a neutral surface soil (0.65 mg/l Cd) varied from 0.18 mg/l to 0.99 mg/l on a dry matter basis. Addition of 5 mg/l Cd increased the concentrations in the plants markedly. Added Cd decreased yields in only a few instances. The Cd content could be reduced by liming some of the acid soils. Addition of Cd increased the concentration of Zn in the plants appreciably. In comparisons of two sandy loam soils and of surface and subsoil layers of a sand, extractable Cd increased with higher amounts of soil organic matter. **(8)**

M. Maeda, T. Fujiyama, "Content and Uptake of Trace Metals in Benthic Algae, *Enteromorpha* and *Porphyra*. Studies on the Algae Cultured in Sea

Water Supplemented with Various Metals," *J. Fac. Fish and Animal Husbandry, 16*, 1977, pp. 33-44.

Uptake of Mn and Cd by *Porphyra* were relatively high and increased in proportion to culture time when metal concentrations in water were high. In general the uptake was highest in the middle front layer of the algae. The uptake of Mn varied depending upon the light intensity. Mn was absorbed only during light periods while Cd was absorbed regardless of light and dark periods.

R. A. Mayes, A. W. McIntosh, V. L. Anderson, "Uptake of Cadmium and Lead by a Rooted Aquatic Macrophyte (*Elodea canadensus*)," *Ecology, 58*, 1977, pp. 1176-1180.

The role of roots in the uptake of nonessential trace metals by aquatic macrophytes was investigated. Plants were grown in two lakes in which metal concentrations in the water differed. Specimens were placed in either control sediment or in sediment contaminated with Cd or Pb. Plants grown in the same water but in different sediment had significantly different concentrations of the two metals. *E. canadensis* samples rooted in sediments from the same source but grown in water with different levels of metals also accumulated significantly different amounts of Cd and Pb. **(4)**

A. W. McIntosh et al., "Some Aspects of Sediment Distribution and Macrophyte Cycling of Heavy Metals in a Contaminated Lake," *Journal of Environmental Quality, 2*, 1978, pp. 301-305.

Distribution and forms of Cd and Zn in sediment and the possible significance of a die-off of *Potamogeton crispus* in a Cd contaminated lake were studied. Metal levels in the upper 5 cm of lake sediment ranged from 2.54 mg/l Cd and 115 mg/l Zn, to 805 mg/l Cd and 6120 mg/l of Zn. Dominant forms present in the sediment were carbonate Cd and carbonate and organic Zn. Analysis indicated Cd levels in *P. crispus* as high as 89.6 mg/l. **(8)**

R. O. McLean and A. K. Jones, "Studies of Tolerance to Heavy Metals in the Flora of the Rivers Ystwyth and Clarach, Wales," *Freshwater Biology, 5*, 1975, pp. 431-444.

It was found that *Hormidium spp.* were the most tolerant filamentous green algae present in the heavy metal polluted rivers that were studied. *S. undulata* was found in greater abundance on polluted sites. This bryophyte's metal extracts were correlated with the variation in metal concentrations of the environment. Lower levels of Fe, Pb, and Mn were generally found in *S. undulata* compared with the less tolerant *F. squamosa*. When *F. squamosa* was transplanted to polluted sites, an increase in Pb, Cu, Zn, and Mn content occurred within 6 weeks, and the plants began to die within 18 weeks. **(1,4)**

S. J. McNaughton et al., "Heavy Metal Tolerance in *Typha latifolia* without the Evolution of Tolerant Races," *Ecology, 55*, 1974, pp. 1163-1165.

Clones of *Typha latifolia* and soil samples were obtained from near a Zn smelter and from a control location. At the smelter location, soil Zn concentration was 385 times higher, Cd content 37 times higher, and Pb content 16 times higher than the control location. No evidence for the evolution of heavy metal tolerance could be detected in 2 x 2 experiments in which genotypes from both locations were grown on both soils. Growth of genotypes from both locations was inhibited on the heavy metal soil. This is the first case described in which a species has been able to colonize heavy metal soils in the absence of the evolution of tolerant races. (Author's abstract.)

D. C. Mortimer and A. Kudo, "Interaction Between Aquatic Plants and Bed Sediments in Mercury Uptake from Flowing Water," *Journal of Environmental Quality, 4*, 4, 1975, pp. 491-495.

Elodea densa was exposed to 0.2, 2, and 10 g/l concentrations of mercuric chloride and methyl mercuric chloride. There was no significant difference in the uptake rate between the two forms of Hg. Uptake was proportional to water concentration over the entire 17-day exposure period in both plants and sediment. Methyl mercury was more toxic to plant growth in this time interval than inorganic Hg. *E. densa* growing in sediment absorbed significantly less Hg than *E. densa* growing in glass beads. Sediment from which the plants had been removed contained about twice as much Hg as plant-free sediment. **(4)**

A. Netzer, P. Wilkinson, S. Beszedits, "Removal of Trace Metals from Wastewater by Treatment with Lime and Discarded Automotive Tires," *Water Research, 8*, 1974, pp. 813-817.

Experiments were conducted to evaluate the feasibility of using discarded automotive tires in conjunction with lime to remove Al, Cd, Cr, Co, Cu, Fe, Pb, Mg, Hg, Ni, Ag, and Zn from aqueous solutions. Continuous bench-scale studies showed that removals in excess of 99.5% for most of the metals can be achieved by treatment with lime and discarded automobile tires. Rubber is as effective as activated carbon, and cheaper and easier to dispose of. (Author's abstract.)

J. Overnell, "The Effect of Some Heavy Metal Ions on Photosynthesis in a Freshwater Alga," *Pesticide Biochemistry and Physiology, 5*, 1975, pp. 19-26.

The effect of Cu, Cd, Pb, Hg, methyl mercury, and Tl, and the herbicide 3 (3,4-dichlorophenyl) 1, on the freshwater alga *Chlamydomonas reinhardii* was studied. The light-induced oxygen evolution of whole cells was found to be very sensitive to the Cd ion. The light-induced oxygen evolution was also very sensitive to methyl mercury and Pb. **(1)**

O. Pettersson, "Heavy-Metal Ion Uptake by Plants from Nutrient Solutions with Metal Ion, Plant Species and Growth Period Variations," *Plant and Soil, 45*, 1976, pp. 445-459.

Rape, cucumber, wheat, oats, and tomato were grown for one to two weeks in nutrient solutions with heavy metals added. Of the metal ions tested ($CR^{3+}$, $Cu^{2+}$, $Co^{2+}$, $CrO_4$2-, $Ni^{2+}$, $Cd^{2+}$, $Pb^{2+}$, $Mn^{2+}$, $Zn^{2+}$ and $Ag^{+}$), Mg, Ni, and Pb exhibited the greatest mobility in cucumber plants, which resulted in the highest shoot/root concentration ratio. When the plants were grown with 1.0, 10, and 100 M Cd or Ni in solution, the shoot and root concentration increased 5 to 10 times if the metal ion concentration of the solution was increased 10 times. The Ni and Cd concentration in roots and shoots increased with the age of the plant. **(4)**

R. Ray and W. White, "Selected Aquatic Plants as Indicator Species for Heavy Metal Pollution," *Journal of Environmental Science and Health, 12*, 1976, pp. 717-725.

Heavy metal pollution of the aquatic environment is often responsible for depletion of fishery resources and sudden fish kills. Some aquatic plants do selectively accumulate specific metals and can serve as biological monitors. Two vascular plants, *Potamogeton* and *Equisetum* and a blue algae *Oscillatoria* have proven useful for monitoring metal pollution. (Author's abstract.) **(2)**

P. F. Reay, "The Accumulation of Arsenic from Arsenic Rich Natural Waters by Aquatic Plants," *Journal of Applied Ecology, 9*, 1972, pp. 557-565.

Several aquatic plants were found to accumulate As at levels well above those associated with toxicity of this element. The species differed in the amounts of As they accumulated, ranging from 30 to 650 mg/kg dry weight. Accumulation was influenced by the amount of As in the water but not by the amount of As in the sediment. The withdrawal of As from the water by aquatic plants did not markedly affect the river's discharge of As. **(4)**

J. A. Ruthven and J. Cairns, "Response of Fresh-Water Protozoan Artificial Communities to Metals," *Journal Protozoology, 20*, 1973, pp. 127-135.

An artificial fresh-water protozoan community was subjected to different concentrations of Zn and Cu. Although the percentage survival of colonizing species exposed to Cu or Zn fluctuated greatly at each concentration, the range of toxicity for each compound allowed comparison of protozoa with other organisms with respect to resistance to heavy metal toxicity. Individual protozoan species also were exposed for 3 hr to Zn, Cu, Cr, phenol, Pb, Mn, Co, $HNO_3$, acetic acid, Al, Sn, and HCl to derive time to death curves. Protozoa tested appeared to be more resistant than *Daphnia* to phenol, $K_2Cr_2O_7$, and Cu; however, some species were more sensitive than *Daphnia* to Zn, $HNO_3$, and HCl. This suggests that the sensitivity of protozoa to toxicants may be either more or less than that of macroinvertebrates and that information does not suffice to predict sensitivity. Moreover, the relative sensitivity of protozoa to various toxicants will not always be the same, i.e., species X may be twice as tolerant to a toxicant as species Y but its relative sensitivity may be quite different for another toxicant. (Author's abstract.) **(2)**

E. Small and J. D. Gaynor, "Comparative Concentrations of Twelve Elements in Substrates and Leaves of *Scirpus validus* and Other Aquatic Plant

Species in a Sewage Lagoon and in Unpolluted Habitats," *The Canadian Field Naturalist, 88*, 1975, pp. 44-45.

Concentrations of 12 elements were examined in vegetation and associated soils and water of 12 rooted aquatic plant species growing in the lagoon of a sewage treatment plant, and elsewhere in unpolluted habitats. Near the point of discharge of effluent into the lagoon, the substrate accumulated sludge, with very high concentrations of Cl, Zn, and Cu, and also notably high concentrations of P, Fe, and Ca. The only rooted aquatic plant species successfully colonizing this area was *Scirpus validus* which accumulated significantly higher concentrations in the leaves of P, Fe, Cl, N, Na, and Mg compared with the same species in nonsludge areas of the lagoon, and in unpolluted habitats. Eleven additional aquatic plant species were found in the lagoon, rooted in sandy sediment adjacent to the sludge area. These species appeared excluded from the sludge area. Concentrations of the 12 elements examined in substrates and leaves of these species growing just outside the sludge area did not differ notably in comparison with concentrations in unpolluted habitats. (Author's abstract.) **(4,8,9)**

L. A. Smock and M. S. Shuman, "Influence of Organism Size, Species and Sediment on Metal Accumulation by Benthic Macroinvertebrates," *ASB Bulletin, 24*, 1977, p. 87.

Neutron activation analysis was used to determine Co, Cr, Fe, Mn, Sb, Sc and Zn concentrations in benthic macroinvertebrates collected from eight locations on the Haw and New Hope river systems in North Carolina. Concentrations were determined for approximately forty species collected from both clean and polluted areas. Sediment, filtrable (< 0.45μ) and suspended particulate metal concentrations were also determined for the same sampling sites and periods. Concentrations of Cr and Sb reflect industrial inputs of these metals into the Haw River. Organism metal concentrations generally increased with decreasing median organism size, possibly indicating the importance of the surface to volume ratio on metal accumulation. The degree of association a species has with the sediment was shown to influence its accumulation of metals, strict detritivores generally having higher concentrations than carnivores, filter feeders or sediment associated species. Sediment particle size was also shown to influence metal concentrations in these organisms. (Author's abstract.)

G. A. Smout and G. T. Weaver, "Heavy Metal Accumulation in Selected Tree Species Grown on Sewage-Sludge Amended Strip Mine Spoils," *ASB Bulletin, 24*, 1977, p. 87.

Anaerobically digested sewage-sludge was applied to a 126-ha test plot. The accumulation patterns of six heavy metals (Cd, Cr, Cu, Ni, Pb, and Zn) were observed in green ash (*F. pennsylvania*), and river birch (*B. nigra*). Tissue concentrations of these metals were compared with nursery stock withheld from treatment and trees planted on site and harvested after one growing season.

J. B. Sprague, "Promising Anti-Pollutant: Chelating Agent NTA Protects Fish from Copper and Zinc," *Nature, 220*, 1968, pp. 1345-1346.

The trisodium salt of nitrilotriacetic acid (NTA) seems to be a promising "antipollutant" for preventing fish kills in case of short-term breakdown of normal pollution controls. It is generally accepted that one molecule of NTA chelates one ion of metal. Although NTA chelates a number of cations, including desirable constituents of natural waters, it shows selectivity toward metal ions. The NTA complex biodegrades in a few days in natural waters at which time metals would be released back into solution.

R. A. Stanley, "Toxicity of Heavy Metals and Salts to Eurasian Watermilfoil," *Archives of Environmental Contamination and Toxicology, 2*, 4, 1974.

Controlled growth experiments were conducted to determine the levels of $Cu^{++}$, $Cr_2O_73$, $Hg^{++}$, $AsO_2$, $Cd^{++}$, $Al^{+++}$, $Ba^{++}$, $Cr^{++}$, $Zn^{++}$, $NH_4+$, $CN^-$, $B_4O_7{}^{-2}$, $Pb^{++}$, $Na_2SO_4$, and NaU which caused a 50% inhibition in root growth of Eurasian Milfoil. The threshold of toxicity was determined for heavy metal salts and other less toxic salts.

D. L. Sutton and R. D. Blackburn, "Uptake of Copper in Hydrilla," *Weed Research, 11*, 1971, pp. 47-53.

A linear increase from 933 to 15 943 ppmw of Cu occurred in *Hydrilla verticillata* four days after treatment with copper sulphate pentahydrate (CSP) at 0.5 to 4.0 ppmw of Cu. Neither increase in Ca levels to 0.8 mm in the ambient solution, nor aeration, affected the amount of Cu in excised

hydrilla tissue during a 24-hr treatment period with CSP at 1.0 ppmw of Cu. Part of the accumulated Cu appeared to be bound in hydrilla. A higher accumulation of Cu occurred after treatment with an organic Cu complex (cutrine) than with either CSP or copper chloride ($CuCl_2$, $2H_2O$) at 1.0 ppmw of Cu. This high accumulation with cutrine appeared to be related principally to the amount of Cu remaining in the treatment solution. (Author's abstract.)

I. Valiela, M. D. Banus, J. M. Teal, "Response of Salt Marsh Bivalves to Enrichment with Metal-Containing Sewage Sludge and Retention of Lead, Zinc, and Cadmium by Marsh Sediments," *Environmental Pollution, 7*, 1974, pp. 149-157.

Growth in the bivalves *Mercenaria mercenaria* and *Crassostrea virginica* was not affected by experimental additions of metal-containing sewage sludge and fertilizers to salt marsh plots. *Nodiolus demissus*, a mussel inhabiting the marsh surface, did grow better under the same fertilizer treatments. Input-output budgets show that Pb was trapped in the sediments with virtually no loss to deeper waters. Zn and Cd also accumulated in the sediments but there was some transport away from the salt marsh surface. Increases in Zn and Cd, but not Pb, were detected in the creek bottom detritus downstream. All three species of shellfish showed no increases in Pb or Zn contents, but all showed increases in Cd.

D. M. Victor and D. F. Martin, "Effect of Chelators on the Suitability of Natural Waters for Hydrilla Growth," *Water Research, 11*, 1977, pp. 447-452.

The role of chelators in affecting the suitability of natural water for growth of a submersed nuisance aquatic plant, *Hydrilla verticillata*, was investigated. The growth characteristic, defined as the percent dissolved oxygen increase in the presence of hydrilla, was found to be associated with the amount of Fe present. The availability of Ca ion and the availability of inorganic C with which Ca is known to form ion pair complexes, play a role in making a medium suitable for hydrilla growth. The behavior of natural chelators is complicated, but they could act as Fe transport agents or as Ca-sequestering agents, and their presence in a lake may alter the suitability of the lake for hydrilla growth. The limitations and significance of these points with reference to potential control of hydrilla were discussed. **(9)**

A. Wallace, "Effect of Concentration on Uptake of Some Trace Metals by Plants," *Communications in Soil Science and Plant Analysis, 8*, 1977, pp. 689-691.

The uptake by plants of some trace metals at different concentrations was related closely to the decay constant, In2. This means that for a 10-fold increase in applied concentration, the increase in uptake was close to 4.93 ($10^{0.693} = 4.93$). With some trace metals the value of Y ($10^Y$ = ratio) of uptake for 10-fold increase in metal concentration was around 1. For generalized conditions the value of Y in the expression, $(C_1/C_2)^Y$ = uptake ratio, for different concentrations $C_1$ and $C_2$ varied around In2. Some values of Y for whole plants were Ni, 0.699 with C.V. (coefficient of variation) 12.2%, Cu, 0.468 with C.V. 12.1%, Zn, 0.606 with C.V. 31.5%, and Cd, 0.903 with C.V. 10.9%. From soil the values for shoots for Co were 0.855 (C.V. = 14.8%) without EDTA (ethylenediamine tetraacctic acid) and 0.941 (C.V. = 20.8%) with EDTA; for Cu, it was 0.562 (C.V. = 25.8%) with EDTA. (Author's abstract.) **(4)**

S. L. Warnick and H. L. Bell, "The Acute Toxicity of Some Heavy Metals to Different Species of Aquatic Insects," *Journal of the Water Pollution Control Federation, 41*, 1969, pp. 280-284.

Relative toxicity of heavy metals to aquatic insects varied widely with the test species. In general, insects were less sensitive to heavy metals than many fish that have been tested. Toxicity values of some metals are provided that could be expected to cause mortality under most environmental conditions. **(2)**

B. A. Whitton, "Toxicity of Heavy Metals to Freshwater Algae: A Review," *Phykos, 9*, 1971, pp. 116-125.

This text provides a literature review on toxicity of heavy metals to freshwater algae. Emphasis was put on effects of exposure to heavy metals over long periods and adaptation potential of algae to heavy metals. **(1)**

L. G. Williams, "Uptake of Cesium$^{137}$ by Cells and Detritus of *Euglena* and *Chlorella*," *Limnology and Oceanography, 5*, 1960, pp. 301-311.

Mass culturing demonstrated that uptake of $Cs^{137}$ by *Euglena* and *Chlorella* is linear with concentrations at all levels that might be encountered

in natural aquatic habitats. The rate of Cs uptake during population growth was greatest in cells of *Euglena* during the stationary period following the exponential growth phase. At this stage the Cs taken in is mostly unbound. Following this it is released so that in old cells and detritus it is largely bound Cs. Cs and P behave independently in killed cells of *Chlorella*. Alkali ions, known to be chemically similar, were selected or rejected discriminately by these algae. The presence of antibiotics significantly depresses the uptake of Cs by *Chlorella* and *Euglena*. (Author's abstract.) **(1)**

B. C. Wolverton, R. M. Barlow, R. C. McDonald, "Application of Vascular Aquatic Plants for Pollution Removal Energy, and Food Production in a Biological System," *Biological Control of Water Pollution*, J. Toubier and R. W. Pierson, (eds.), 1976, pp. 141-149.

An efficient, inexpensive filtration/disposal system utilizing water hyacinth (*Eichhornia crassipes*) and alligator weed (*Alternanthera philoxeroides*) was assessed for pollution removal capabilities. It was estimated that a 0.4-ha pond could produce 240 kg of dry water hyacinth material/day and could remove 120 g of toxic heavy metal containments (including Cd, Pb, Hg, Ni, Ag, Co, and Sr) every 24 hr. A conceptual illustration of a biological system for pollutant removal was presented. **(4)**

B. C. Wolverton and M. M. McKown, "Water Hyacinths for Removal of Phenols from Polluted Waters," *Aquatic Botany, 2*, 1976, pp. 191-201.

A quantity of 2.75 g dry weight of water hyacinth demonstrated the ability to absorb 100 mg. of phenol/72 hr from distilled water, river water, and bayou water. One ha of water hyacinth is potentially capable of removing 395 kg of phenol/72 hr from water polluted with this chemical. **(4,6)**

P. T. S. Wong, Y. K. Chau, P. L. Luxon, "Toxicity of a Mixture of Metals on Freshwater Algae," *Journal of the Fisheries Research Board of Canada, 35*, 1978, pp. 479-481.

The International Joint Commission on Water Quality set the following objectives for metal concentrations in the great lakes (μg/l): As 50; Cd 0.2; Cr 50; Cu 5; Fe 300; Pb 20; Hg 0.2; Ni 25; Se 10; and Zn 30. This study found that these recommended levels of a number of metals were very toxic to freshwater algae when present simultaneously. The diatom tested was more sensitive to metal toxicity than the blue-green and green algae. **(1)**

C. E. Boyd, "Influence of Organic Matter on Some Characteristics of Aquatic Soils," *Hydrobiologia, 36*, 1970, pp. 17-21.

Analysis of hydrosoils from 29 Alabama lakes revealed that relationships between soil organic matter and organic nitrogen, sulfur, and cation exchange capacity were similar to those exhibited by agricultural soils.

R. E. Brown, "Significance of Trace Metals and Nitrates in Sludge Soils," *Journal of the Water Pollution Control Federation, 47*, 1975, pp. 2863-2875.

The ability of macrophytes to absorb metal from a compound depends on factors other than the solubility of the metal compound in water. Plant uptake of metals from soils depends on the portion of soil metal called plant-available metal rather than on the total metal content of soils. Recommended sludge application rates, based upon maintaining a balance between crop nitrogen requirements and plant available nitrogen in sludge amended soils, are often lower than the minimum cost effective application rate from a sludge disposal perspective.

The potential for nitrate pollution of water in a given year is proportional to the accumulated organic nitrogen in the soil. A balance should be maintained between plant-available nitrogen in sludge-amended soils, and the sum of nitrogen re-quirement of the crop. Denitification losses and volatization losses should eliminate the potential for serious nitrate pollution of surface waters. The accumulated organic nitrogen in sludge-amended soils will become a major source of plant available nitrogen providing the sludge application rate is reduced accordingly over a period of 5 to 20 years. **(7)**

J. Chapin and C. Cooper, *Feasibility of Using Plants to Decontaminate Radioactive Soils*, EG&G Idaho Inc., TREE-1366, 1979, p. 95.

The feasibility of using aquatic plants to remove radionuclides from soils was reviewed. The technique appears most feasible using aquatic plants such as water hyacinths, alligator weeds, water willows, or common cattail which can be grown in a greenhouse environment. Aquatic plants can absorb heavy metals such as Hg, Cd, and Pb, and may indicate a method for decontamination of mill tailings that contain other heavy metals, such as U, Am, and Ra. **(4)**

B. G. Ellis, "The Soil as a Chemical Filter," *Recycling Treated Municipal Wastewater and Sludge through Forest and Cropland*, W. E. Sopper and L. T. Kardos (eds.), The Pennsylvania State University Press, 1973, pp. 46-70.

The soil acts as a chemical filter by: (a) ion exchange, (b) absorption and precipitation, and (c) chemical alteration. A literature review and example are presented to detail each method. $PO_4$, B, $SO_4$, and heavy metal absorption reactions are discussed individually, and the effects of wastewater applications upon $PO_4$ and heavy metals are delineated.

M. Fireman and H. E. Haywood, "Irrigation Water and Saline and Alkali Soils," *Yearbook of Agriculture*, U.S. Department of Agriculture, 1955, pp. 321-327.

Saline-Alkali soils contain excessive quantities of both soluble salts and sodium, so distributed that the growth of most crop plants is reduced. If the excess soluble salts are leached out, the soil properties may change markedly and become similar to those of alkali soils. To manage the soil, the soluble salts and exchangeable sodium must be removed by the addition of amendments followed by leaching. Water with a moderate degree of salinity can be used for irrigation if drainage is adequate and enough irrigation water is applied. Salinization of soil affects the growth of crop plants in two ways

1. A reduction in the amount of water absorbed by the roots

2. Sodium may be absorbed on the soil particles and result in an unfavorable physical condition.

NOTE: Numbers in parentheses at the end of the annotations refer to the category of the particular type of reference. The categories are identified in the introduction of this report.

J. L. Gallagher et al., "Distribution and Movement of Toxaphene in Anaerobic Saline Marsh Soils," *Hydrobiologiea, 63*, 1979, pp. 3-9.

The distribution and method of movement of a hydrophobic pesticide through anaerobic saline marsh soil profiles was investigated. In the study area, the flooding tidal water contained low concentrations of toxaphene. The compound accumulated only slightly in the marsh soils not flooded daily by the tides. Pesticide concentrations in the marsh soils generally decreased with depth. Dissection of the soil horizons revealed many micro-habitats with differing toxaphene concentrations. In all of the soil profiles, the toxaphene concentrations was greater in the macro-organic matter (MOM) than in the MOM-free soil. Highest pesticide concentrations were associated with the dead roots.

Toxaphene added below the soil surface was absorbed into the plant tissue from both sandy and silty clay loam marshes. Bidirectional translocation occurred, with toxaphene moving down to the roots, as well as upward into the stems. The highest concentrations were in the underground plant parts. Translocation in *Spartina alterniflora* roots represents a rapid method of moving toxaphene through these waterlogged anaerobic soils.

Accumulation of toxaphene in the soil is significant only where the substrates are frequently subjected to tidal flooding by contaminated water. Toxaphene distribution is the function of basipetal and acropetal plant translocation, as well as leaching, degradation, and the pesticide concentration at the time of substrate deposition. (Author's abstract.)

S. K. Jorgensen, "Do Heavy Metals Prevent the Agricultural Use of Municipal Sludge?" *Water Research, 9*, 1975, pp. 163-170.

The chemical binding of heavy metals on different samples of soil was investigated. The distribution between undissolved metals and metals in solution was dependent upon soil pH, clay, and humus content. A method was developed to calculate allowable sludge application rates based upon the standard for metals in potable water. It was shown that Pb in most cases is the metal limiting the amount of sludge, which can be used.

R. H. Miller, "The Soil as a Biological Filter," *Recycling Treated Municipal Wastewater and Sludge Through Forest and Cropland*, W. E. Sopper and L. T. Kardos, (eds.), Pennsylvania State University Press, 1973, pp. 71-94.

Microbial reactions which influence the success of soil as a filter for renovating municipal wastewater and sludge is reviewed. Most of these activities are essential for maintaining the integrity and effectiveness of the soil filter. Only one reaction (nitrification) can be considered detrimental to the success of the soil filter when the disposal method maintains adequate soil aeration. Prolonged periods of anaerobiosis must be avoided for the proper functioning of the microbial component of the soil filter.

R. R. Parizek, "Site Selection Criteria for Wastewater Disposal—Soils and Hydroeologic Considerations," *Recycling Treated Municipal Wastewater and Sludge Through Forest and Cropland*, W. E. Sopper and L. T. Kardos, (eds.), Pennsylvania State University Press, 1973, pp. 71-94.

Knowledge of the soils, geology, and hydrology are essential for proper selection of a wastewater disposal site. As the size of irrigation projects increase, the likelihood for major failures will increase. The concentration of harmful trace elements and toxic substances not likely to be removed in the renovation media may well have to be controlled in irrigation waters or reduced or eliminated prior to land disposal. Extensive soil water and groundwater pollution is a much more difficult condition to correct than surface water pollution, and pollutants can persist for generations within the subsurface.

J. Phillips, *Wisconsin's Wetland Soils: A Review*, Department of Natural Resources, Madison Wisconsin, Research Report 57, 1970.

Wetland soils consist of porous materials usually saturated with and overlain by water. The soils are either mineral, organic, or both. Mineral materials comprise the land form in which the wetland is located. Organic soils tend to form on top of mineral materials. Organic soils of wetlands are classified as either aquatic or terrestrial. Aquatic deposits are sedimentary, composed mostly of material formerly in solution, suspension, or floating in overlying waters. Terrestrial

organic soils are composed of the remains of rooted plant species. Organic soil in wetland communities nourishes nonrooted plants by contributing to the fertility of the overlying water. Plants rooted in the soil derive nutrients directly from it.

The plants involved in early succession are the hydrophytic emergents such as cattail. By invading open water areas, they tend to reduce wave turbulence, favoring peat deposition, and initiating the soil building process.

The organic soils are either peat or muck, depending on the water table fluctuation and location. Mucks are more common in southern Wisconsin, and peats are more common in northern Wisconsin.

Wetland properties have not always been considered when determining their use, and this oversight has created problems. Characteristics of the wetland soils which should be considered when they are used for farming are soil composition, erodibility, hydrology, and presence of harmful chemical substances. Filling of wetlands in order to use them results in their destruction. (Author's abstract.)

A. F. Regenthal, *Mechnical Methods of Accelerate Soil Leaching*, Utah State Division of Wildlife Resources Internal Report, 1975.

A six-year study was conducted to investigate the effects of mechanical disturbance upon the leaching rates of alkaline marsh soils. Several implements were used to disturb study plot soils to various degrees from moderate to severe. Measured amounts of water were then passed over the plots to leach salts. Leaching effectiveness increased with the severity of disturbance and water quality improvement.

I. F. Schneider and A. E. Erickson, "Soil Limitations for Disposal of Municipal Waste Waters," *Michigan State University Agricultural Experiment Station Farm Science Research Report No. 195,*, 1972.

Suitability of a soil for disposing of municipal waste waters depends upon nutrient sorption capacity, infiltration, and permeability rate of the soil profile. For this study, physical and chemical characteristics of the soil series were considered to a depth of 152.4 cm. The major soil properties which should be considered prior to wastewater applications include soil management groups, profiles, textural classes, natural drainage, percent slope, permeability, water holding capacity, phosphorus adsorption capacity, and hydrologic limitations.

R. E. Thomas, "The Soil as a Physical Filter," *Recylcing Treated Municipal Wastewater and Sludge Through Forest and Cropland*, W. E. Sopper and L. T. Kardos, (eds.), Pennsylvania State University Press.

Several approaches to utilize the filtering capability of the soil for disposal or renovation of municipal effluents and industrial wastewaters are discussed. These approaches include septic tank-soil absorption systems, cropland irrigation systems, surface disposal systems, and groundwater recharge systems. Septic tank-soil absorption systems are the most widely used. Water movement through the soil is essential to successful use of septic tank systems, and much of the research effort has been directed to studies on soil clogging (physical blocking of the soil pores). It is apparent that formation of the surface mat is the combined effect of physical, chemical, and biochemical interactions in the soil.

D. W. Toetz, "Uptake and Translocation of Ammonia by Freshwater Hydrophytes," *Ecology, 55*, 1974, pp. 199-201.

Aquatic macrophytes were cultured in two-compartmented containers which provided separation of the aquatic environments surrounding roots and stems. The water in the root compartment was enriched with ammonia and $^{15}N$. Results indicated that several aquatic species can absorb and translocate N from roots to stems. Some species showed apical enrichment levels equal to those absorbed following direct contact with ammonia solutions. Transport rates for root absorbed ions were slower than for direct (stem) absorption.

# WATER QUALITY

P. Benes and E. Steinnes, "Migration Forms of Trace Elements in Natural Fresh Waters and the Effect of the Water Storage," *Water Research, 9*, 1975, pp. 741-749.

The concentration and physico-chemical state of 18 trace and major elements in river and lake waters were studied as a function of time (2 hr to 35 days) for which the samples of water were stored in polyethylene bottles. It was shown that considerable amounts of Mn, Co, Al, Sc, La, Ce, Fe, Cr, and Th may be lost via adsorption to the walls of polyethylene containers and that the ratio of forms of existence of Co, Mn, La, Ce, Sm, Fe, and Cr in the solution may be substantially changed during the storage for one week or more. Probable interpretations of these changes are given. Conclusions are drawn about the state of individual trace and major elements in the waters studied. (Author's abstract.) **(10)**

J. B. Denton, *Certain Relationships Between the Chemical Composition of Aquatic Plants and Water Quality*, Fisheries Section, Game and Fish Division, Alabama Department of Conservation.

Samples of alligatorweed (*Alternanthera philoxeroides*), parrotfeather (*Myriophyllum brasiliense*), and water hyacinth (*Eichhornia crassipes*) growing in polluted and nonpolluted waters were analyzed for ash, C, N, P, Ca, Mg, K, and Na. Water and sediment samples were collected simultaneously and analyzed for the same components. Plant ash values varied with water hardness while C content differed little with environment. Plant N, Mg, P, and Na varied considerably with the concentration of these elements in water and bottom soil. (Author's abstract.) **(10)**

C. W. Fetter, W. E. Sloey, F. L. Spangler, "Use of a Natural Marsh for Wastewater Polishing," *Journal of the Water Pollution Control Federation, 50*, 1978, pp. 290-307.

The water quality of a stream flowing through a *Typha* marsh was studied for a 15-month period. During low flow periods, as much as 50% of the wastewater monthly streamflow was discharge from a wastewater treatment plant. During passage through the marsh there were significant reductions in concentrations of biochemical oxygen demand (BOD) (80.1%), coliform bacteria (86.2%), nitrate (51.3%), chemical oxygen demand (43.7%), turbidity (43.5%), suspended solids (SS) (29.1%), total P (13.4%), and orthophosphate (6.4%). An estimated mass balance of P indicated the marsh might retain one-third of the entering P over an annual cycle. One source of P removal appears to be precipitation into the sediments. Because passage through a marsh will reduce the BOD, P, N, and SS, discharged effluents may not necessarily need to meet strict water quality standards before entering the system. **(10)**

N. O. Isirimah and D. R. Keeny, *Contribution of Developed and Natural Marshland Soils to Surface and Subsurface Water Quality*, University of Wisconsin, Water Resource Center, 1973.

A preliminary attempt was made to determine the ecological pathways of N and P in the marshland ecosystem. The marsh studied was determined not to be a significant nutrient sink, because it did not remove sufficient quantities of N and P to cause the release of nutrient poor waters. **(8)**

G. F. Lee, E. Bentley, R. Amundson, "Effects of Marshes on Water Quality," PhD. Thesis, University of Wisconsin, 1969.

Discharge waters from marshes were shown to have large concentrations of organic matter which contribute to a high oxygen demand. Large amounts of the nitrate entering the marsh were denitrified. In general, a marsh tends to accumulate aquatic plant nutrients (N and P) during the growing season and release them in the high spring flow. Laboratory and field studies on a drained marsh show the release of large amounts of aquatic plant nutrients which would tend to accelerate eutrophication of receiving waters. **(2,10)**

E. T. Linacre et al., "The Evaporation from a Swamp," *Agricultural Meteorology, 7*, 1970, pp. 375-386.

Evaporation from a 3000-ha swamp was compared with evaporation from a lake 16 km away. Evaporation rate was measured over several daylight 1/2-hr periods during three days in summer using an eddy-correlation instrument. The

results suggest that, except immediately after rain, the swamp lost water at a rate significantly lower than the lake. This is attributed to the lower albedo of the clear water surface of the lake, the shelter given by the reeds in the swamp to the water surface, and the internal resistance to water movement of the reeds themselves.

National Academy of Sciences, *Making Aquatic Weeds Useful: Some Perspectives for Developing Countries*, National Academy of Sciences, 1976, pp. 115-126.

The potential of selected aquatic plants for wastewater treatment is discussed.

Water hyacinth has the capacity to increase its surface cover by 15% a day and can produce 18 000 kg to 20 000 kg of wet biomass/ha/day. This quantity of hyacinth can daily assimilate the nitrogenous waste of over 2000 people and the phosphorous waste of over 800 people. Yields of wet duckweed average over 1200 kg ha/day, or over 60 kg of dry matter/ha/day. **(5)**

M. G. McGarry and C. Tongkasame, "Water Reclamation and Algae Harvesting," *Journal of the Water Pollution Control Federation, 43*, 1971, pp. 824-835.

Operation of a pond at 224 kg BOD/ha/day loading, at a 45 cm depth and a 1-day detention time is an efficient system for wastewater treatment and algae production. In Thailand, under these conditions, effluent BOD was lower than 10 mg/l and one ha of pond can produce 112 138 kg of algae (dry weight) per year. Polycations were the most economic aid for coagulating algal cells when added with alum and a controlled pH. Several methods for removal of the algal floc from suspension such as by split flow, through use of supersaturated oxygen, or by the dissolved air principle are discussed. **(1)**

H. Nakahara, M. Yanokura, Y. Murakami, "Environmental Effects of Geothermal Waste Water on the Nearby River System, *Journal of Radioanalytical Chemistry, 45*, 1978, pp. 25-36.

Environmental effects of geothermal waste water discharged into neighboring streams were investigated. Results showed that serious effects of large amounts of discharge in the past were still retained in the sediments of the nearby water system. It was also found that As and Cs were the best chemicals for tracing the long standing effects of past discharge. The problem of chemical pollution of the rivers near geothermal areas have been alleviated since reinjection began. **(2)**

R. T. Oglesby and W. R. Schaffner, "The Response of Lakes to Phosphorus," *Nitrogen and Phosphorus*.

The paper discusses the relationship that exists between summer phytoplankton standing crop and transparency of water. Phosphorus inputs are discussed including estimation sources of P, dynamics of P in lakes, and species of P, and specific P loading. Chlorophyll and transparency are discussed and regression analysis presented. **(2)**

E. D. Parker, M. F. Hirshfield, J. W. Gibbons, "Ecological Comparisons of Thermally Affected Aquatic Environments," *Journal of the Water Pollution Control Federation, 45*, 1973, pp. 726-733.

Three reservoirs on the Savanna River were studied to assess the effects of thermal water on certain floral and faunal characteristics. One effect of thermal water was the elimination of several species of vascular aquatic plants and vertebrates. Hence, species diversity was reduced. Relative abundance of most plant species in the portion of a reservoir receiving chronic thermal loading was reduced. This effect was still noticeable several years after heating had been terminated. Relative abundance of certain plant species was enhanced, possibly a result of reduced competition from other species. **(2,4)**

W. Stewart et al., *Pilot Studies of the Solar Aquacell Controlled Aquaculture Process for Wastewater Reclamation*.

The aquacell system is meant to offer an alternative to typical lagoon wastewater treatment. This article describes a system designed to provide a stable environment that speeds water purification.

C. H. Wharton, *The Southern River Swamp—A Multiple-Use Environment*, Bureau of Business and Economic Research, Georgia State University, 1970, pp. 23-43.

The river-marsh ecosystem was studied to determine potential water cleansing abilities. Water quality data indicate that the Flint and Alcovy

Rivers and their adjacent swamps apparently have the ability to filter pollutants from water. Swamp streams appeared to eliminate human waste and may have removed toxic pesticides. Swamps induced deposits of silt which may become useful to the biotic community. The swamp and its stream channel seemed intimately associated functionally, and appeared to form a natural hydrogeobiological water treatment system. The value of the cleansing action of 10 km of river and 251 ha of swamp was equivalent to sewage treatment for a city of 50,000. Potentially, the Alcovy River has three times this ability, worth $990,000/year.

B. C. Wolverton and R. C. McDonald, "Upgrading Facultative Wastewater Lagoons with Vascular Aquatic Plants," *Journal of the Water Pollution Control Federation, 51*, 1979, pp. 305-313.

Substantial coverage of water hyacinths was demonstrated to significantly upgrade effluent from a primary wastewater lagoon treating the waste of approximately 2000 people. The addition of water hyacinths to a wastewater lagoon system not only reduces suspended solids and BOD, but also significantly decreases the nutrient and organic carbon content in the lagoon effluent. The use of vascular aquatic plants appears promising as an economical and efficient way of upgrading wastewater lagoon systems in small communities. (Author's abstract.)

# OTHER ASPECTS OF MARSH ECOSYSTEMS

D. R. Anderson and F. Glover, "Effect of Water Manipulation on Waterfowl Production and Habitat," *Thirty-second North American Wildlife Conference on Water Manipulation for Waterfowl Production.*

Nesting and brood observations on the Monte Vista National Wildlife Refuge, correlated with records on water availability, suggest that high waterfowl production occurred when water was plentiful before spring migration. If water was not available until after the spring migration, low production could be anticipated. Objectives of the study included determination of the breeding bird population density, nesting ecology, brood size, total production, and the relationships among these factors. **(2)**

Anonymous, "Energy From Seaweed," *Geotimes, 23,* 1978, p. 22.

Seaweed provides an indirect means of storing solar energy, which is released when the seaweed is converted to gas and the gas is burned. General Electric Co. is operating an experimental seaweed farm in southern California, and according to International Resource Development Inc., Norwalk, Conn., G.E. will begin commercial production of seaweed as fuel when the world price of oil exceeds $40 a barrel. Production of seaweed as fuel could pass several hundred million kg/year by the end of the 1980's, and even $30 a barrel would trigger some production of seaweed as fuel, particularly in states such as California, where conditions favor kelp growing. (Article excerpt.) **(5)**

J. R. Avault, R. Smitherman, E. Shell, "Evaluation of Eight Species of Fish for Aquatic Weed Control," *Proceedings of World Symposium on Warm-Water Fish, 1968*, pp. 109-122.

Eight species of fish were evaluated for their ability to control aquatic weeds. The following criteria for the ideal herbivorous fish for aquatic weed control were used: (a) control a wide variety of weeds, (b) not interfere with other fish species, (c) be hardy and easy to handle, (d) be economical to use, and (e) add to the fishery. This paper discusses the pros and cons of each species as they relate to the above criteria. *Ctenopharyngodon idella* controlled a wide variety of weeds when stocked in ponds at 49 to 99/ha. Common carp, *Cyprinus carpio*, controlled filamentous algae and *Eleocharis acicularis* when stocked at 124/ha. Common carp were not found to be detrimental to other fish populations when stocked at the above rate. *Tilapia melanopleura* controlled filamentous algae and a variety of higher plants when stocked at 2470 to 4940/ha. At this stocking rate *T. melanopleura* did not produce adverse effects on other fishes. *T. nilotioa* and *T. mossambica* showed little promise as weed control agents except for the control of filamentous algae. *T. heudeloti* did not feed appreciably on aquatic plants. *Carassius auratus* and *Ictalurus punctatus* when stocked at rates that would not interfere with other fish populations showed no potential for controlling aquatic roots. (Author's abstract.) **(2,4)**

L. O. Bagnall et al., *Aquatic Forage Processing in Florida, Paper 71-536 Proceedings of the American Society of Agricultural Engineers, 1971*, pp. 1-23.

Water hyacinth and Florida elodea were dehydrated and processed to determine the effectiveness and efficiency of current processing systems. Three weed processing systems were tested. A citrus pulp pilot plant and a mobile weed processor were found to be ineffective and inefficient means of eliminating weeds or producing cattle feed. The mobile press-stationary dehydrator was the best method tested with the production rate approaching the capacity of the system. However, this method was inefficient at removing water from the plant material, thus the total energy cost required to produce dry matter made the system uneconomic. Harvested aquatic plants could be pressed into very dense pellets, however, initial pelletizing studies showed a low production rate and a high power requirement.

J. E. Bardach, "Aquaculture," *Science, 30*, 1968, pp. 1098-1106.

The possibility of using aquaculture to produce high grade animal proteins and the potential of

NOTE: Numbers in parentheses at the end of the annotations refer to the category of the particular type of reference. The categories are identified in the introduction of this report.

upgrading culture methods to increase yields and reduce production costs per unit of weight were evaluated. Yields varied with the organisms under culture and the intensity of husbandry care. High density stocking of aquatic animals required flushing with flowing water or tidal exchange. Aquaculture practices in different parts of the world were reviewed.

F. C. Bellrose, *Ducks, Geese, and Swans of North America*, Harrisburg: Stackpole Books, 1976, p. 544.

An authoritative text on North American waterfowl which describes the habitat requirements and life hisotry of each species of duck, swan, and goose found in the U.S. In addition, waterfowl disease, migration, and management techniques are described. **(2)**

J. R. Beltz et al., *An Annotated Bibliography of the Effects of Temperature on Fish with Special Reference to the Freshwater and Anadromous Species of New England*, Agricultural Experiment Station, University of Massachusettes, Research Bulletin No. 605, 1974, p. 97.

Recent literature pertaining to freshwater and anadromous fish of the New England area or to species ecologically or physiologically similar to those found in the Northeast are presented in the form of an annotated bibliography. Also, older papers still in common use and articles dealing with unique species are included.

E. Booth, "Some Properties of Seaweed Manures," *Proceedings of the Fifth International Symposium on Seaweeds*, A. G. Young and J. L. McLachlan (eds.), Oxford: Pergamon Press, 1965, pp. 349-357.

The history of use and the projected possibilities of seaweed manure were assessed. It was shown that seaweed manures enhance seed germination, increase nutrient uptake of plants, and aid in frost and phytopathological fungi and insect resistance.

H. D. Bruhn, D. F. Livermore, F. O. Aboaba, "Processing Characteristics of Macrophytes as Related to Mechanical Harvesting," *Transactions of the American Society of Agricultural Engineers*, 1971, pp. 1004-1008.

Harvest and transport of aquatic vegetation was found to be 4 to 6 times more productive by providing processing equipment on the harvester barge. By dewatering plants with machinary, vegetation to be transported was reduced to 16% of the original volume and 32% of the weight. Ninety percent of the original dry matter was removed from the water. Eight-five percent of the protein, 60% of the potassium, and 80% of the phosphorous present in the growing vegetation was recoverable. **(4)**

R. A. Cole, *Habitat Development Field Investigations, Buttermilk Sound Development Site, Atlantic Intracoasted Waterway, Georgia, U.S. Army Engineer Waterways Experimental Station*, D-78-26, 1978.

Several species of marsh plants were established on dredged material, their response to site conditions and substrate changes were monitored, and microbial development and animal presence at the site were documented. It was found that saltmeadow cordgrass and saltgrass were best for stabilization of the substrate. Fertilization did not appear to facilitate plant survival or performance even though the dredged material had low nutrient concentrations. Apparently the fertilizer was either rapidly transported out of the marsh or it was dispersed uniformly over the entire study area in the interstitial water. Seeding was found to be just as efffective as sprigging for all species planted.

L. M. Cowardian and K. F. Higgins, "Visibility, Movement, and Behavior of Waterfowl on a River Habitat in Minnesota," *Thirty-Second North American Wildlife Conference*, pp. 301-315.

Current census techniques for waterfowl were evaluated and a correction factor was obtained to compensate for variable visability of waterfowl as it differs with species and time of year.

T. Daniel, S. Nichols, J. W. Clark, *Controlling Waterweeds*, Madison: University of Wisconsin, p. 6.

This paper provides a general description of some of the common algae and macrophytes which may occur in excessive stands and describes some simple methods of aquatic weed control. **(1,4)**

F. C. Eady, F. N. Hookham, B. E. Marson, "A Method of Cultivating Aquatic Plants for Experimental Purposes," *New Zealand Journal of Experimental Agriculture, 2*, 1974, pp. 35-37.

The design and operation of an aquarium arrangement consisting of units large enough to handle reasonable numbers of whole aquatic plants were described. The system provides both aeration and water circulation within individual aquaria, and is versital and inexpensive.

T. Fagerstrom and B. Asell, "Caged Fish for Estimating Concentrations of Trace Substances in Natural Waters," *Health Physics, 31*, 1976, pp. 431-439.

This paper attempts to establish a theoretical background for using caged fish as estimators of concentrations of biologically accumulable trace substances in natural waters. The major motive for using this monitoring technique was that, for most trace substances fraction of the total concentration can be expected to be biologically available and, therefore, conventional analytical methods may yield values that are biologically irrelevant.

It was shown that if (i) the metabolic rate of the experimental fish is constant, (ii) the turnover factor of the trace substance in the fish is numerically known and either constant or numerically small, and (iii) the efficiency of oxygen withdrawal is constant and numerically known, caged fish can be used to estimate the mass concentration (relative to oxygen) of accumulable trace substances in the ambient water. (Author's abstract.)

C. W. Gehrs, "Vertical Response of Zooplankton in Response to Heated Water," *Thermal Ecology*, 1974, pp. 285-290.

The vertical locomotory response of individuals of *Diaptomus sanguineus* and *Daphnia parvula* to heated water was tested. All animals moved deeper when the temperature of the water at the level in which they resided was increased 2°C. These results, as well as data in the literature, suggest that the vertical movement of zooplankton can be inhibited either by large temperature gradients over a small vertical range or by a temperature above the preferred temperature of individuals of a particular zooplankton population. Surface waters heated by thermal effluents could restrict the movement of zooplankton, which could result in decreased productivity. **(2)**

S. V. Hallssom, "The Uses of Seaweeds in Iceland," *Proceedings of the Fourth International Symposium on Seaweeds*, A. D., Devirvile and J. Feldman (eds.), London: The Macmillan Co., 1964, pp. 398-405.

This paper reviews the history of seaweed use in Iceland. Major uses for seaweed have been for human consumption, fodder for domestic animals, fuel, and fertilizer. *Rhodymenia palmata* and *Alaria esculenta* had been used as a primary human food item until the last century. These two species are now used extensively as a supplementary feed for cattle and sheep. Promising results of seaweed use as supplementary fertilizer were cited. **(4)**

M. G. Henry and G. J. Atchison, "Behavioral Changes in Bluegill as Indicators of Sublethal Effects of Metals," *Environmental Biology of Fish, 4*, 1979, pp. 37-42.

A technique using changes in the behavior of bluegill (*Lepomis macrochirus*) was utilized to evaluate the impact of five sublethal levels of a Cd and Zn mixture. The technique proved very sensitive, and various changes in behavior occurred at the lowest metal levels used; 21 μg Cd/l and 99 μg Zn/l. Coughs, yawns, partial jerks, and jerk swimming were especially sensitive indicators of elevated metal levels. The frequency, but not the form, of eight of the nine behaviors quantified changed significantly with increasing metal levels. (Author's abstract.)

P. J. Kramer, *Plant and Soil Water Relationships*, New York: McGraw Book Company, 1969.

This book is a technical work on plant physiology and its relationship to water absorption and movement through the plant. A chapter describing the mechanics of salt absorption is included in the text. **(4,8)**

J. M. Lawrence, "Aquatic Weed Control in Fish Ponds," *Proceedings of the World Symposium on Warm Water Pond Fish Culture, 1966*, p. 76-91.

A listing of major algae genera and aquatic weed species; information on pond construction features of significance in aquatic weed control, as well as mechanical, biological, and chemical control techniques are also given. Also, data were given on fish toxicity of some herbicides as well as effective rates of herbicide application. **(4)**

G. F. Lee, *Eutrophication, Occasional Paper No. 2*, University of Wisconsin Water Resources Center, 1970.

This paper provides a comprehensive summary of eutrophication, its effect on the ecosystem, and ways to treat it. **(2)**

J. P. Linduska, *Waterfowl Tomorrow*, Washington D.C.: U.S. Department of the Interior, U.S. Government Printing Office, 1964, p. 770.

Somewhat dated but comprehensive book on waterfowl management practices and U.S. waterfowl resources. Topics discussed include waterfowl diseases and parasites, wetland furbearers, waterfowl predators, and waterfowl problems with toxic algae blooms. In addition, conflicts of waterfowl with crop production, waterfowl utilization of various types of water containment areas, and practices used for making wetlands conducive for waterfowl are described. **(1,2)**

A. P. M. Lockwood, *Effects of Pollutants on Aquatic Organisms*, Cambridge: Cambridge University Press, 1976.

Aspects associated with pollution of the aquatic environments are discussed. Major topics covered include: aspects of heavy metal tolerance in aquatic organisms; effects of Cd on fish; hydrocarbon effects on algal physiology, marine zooplankton, and fish; and the effects of organochlorine compounds in aquatic organisms. In addition, physiological responses by freshwater fish to low dissolved oxygen, high carbon dioxide, ammonia, and phenol with particular reference to water balance was discussed. **(1,2)**

K. M. Mackenthun, "A Review of Algae, Lake Weeds, and Nutrients," *Journal of the Water Pollution Control Federation, 34*, 1962, pp. 1077-1085.

Aquatic weed and algal growths often develop into aquatic nuisances interferring with man's desired uses of water. Prolific growths of aquatic weeds or algae usually develop as a result of the fertility of the water in combination with suitable climatological conditions. Application of a chemical to water involves certain hazards including the short- and long-range toxicity to all biological life, the deposition and possible deleterous accumulation of the chemical on the lake bottom, the impact resulting from the destruction of too much biological growth at one time, and the possible disturbances of the general aquatic environment. These inter-relationships are discussed and presented in a brief topical format. **(1,4)**

A. C. Martin, H. S. Zinc, A. L. Nelson, *American Wildlife and Plants—A Guide to Wildlife Food Habits*, New York: Dover Publications, 1961.

This book provides a summary of what wetland fauna eat in proportion to total dietary consumption. Also, plant species are analyzed for value as food for wildlife. **(2,4)**

M. E. McDonald, "Cause and Effects of a Die-Off of Emergent Vegetation," *Journal of Wildlife Management, 19*, 1955, pp. 24-35.

The abrupt die-off of marsh vegetation during the winters of 1945-46 and 1951-52 in marshes connected with Lake Erie is discussed. Coincident rise of water and die-off of emergent marsh plants resulted in succession of submerged species. The marsh was improved for waterfowl during the die-off period. Immediate effects of the die-off were an increase in the amount of submerged waterfowl food plants, the break-up of large blocks of reed marsh, an increase in the amount of edge between reed marsh and water, the formation of expanses of mud banks above the water level, and a reduction in the amount of muskrat habitat. **(2)**

R. F. Milton, "Liquid Seaweed as a Fertilizer," *Proceedings of the Fourth International Symposium on Seaweeds*, A. DeVirvile and J. Feldman (eds.), London: The Macmillan Co., 1964, pp. 428-431.

Application of seaweed to agricultural land as a fertilizer has been practiced for centuries along some seacoasts of Europe. There is a latent period before the fertilizing effect is manifest because seaweed, like other organic matter, needs to be considerably decomposed before its benefits are available for plant growth. Application of seaweed produces an improvement in soil structure with a chain reaction of effects which stimulate soil microorganisms of all types. This results in enhanced nitrogen fixation and releases bound phosphate and potash from the soil. Therefore, the net effect is similar to the controlled application of small amounts of chemical fertilizer over a prolonged period of time. Besides

the effect on soil structure, diluted liquified seaweed appears to bring about mobilization of certain trace elements in soils where these tend to be in unavailable form. **(4,8)**

B. Murphy, G. J. Atchison, A. McIntosh, "Cadmium and Zinc in Muscle of Bluegill and Largemouth Bass From an Industrially Contaminated Lake," *Environmental Pollution, 17*, 1978, pp. 253-257.

Fish in an ecosystem heavily contaminated by trace metals accumulated significantly more metal in edible muscle tissue than did fish in an uncontaminated ecosystem. Bluegills contained higher levels of trace metals than bass.

E. W. Mustard, "From Mess to Marsh," *Soil Conservation*, 1977, pp. 8-9.

The transformation of a surface mine into wildlife marsh habitat was discussed. The major problem encountered was grading the steep perpendicular sides of the excavated areas to render them suitable for revegetation. Community acceptance and use of the newly created wildlife sanctuary is widespread.

S. Mykelestad, "Experiments with Seaweed as Supplemental Fertilizer," *Proceedings of the Fourth International Symposium on Seaweeds*, A. D. DeVirvile and J. Feldman (eds.), London: The Macmillan Co., 1964, pp. 432-438.

Because artificial fertilizer is still economical for most of the world, the use of algae to provide K, N, and P was considered unlikely. However, use as a supplemental fertilizer was considered possible because of its value as an important source of microelements and a soil conditioner. The results of this research showed that the seaweed fertilizer had a positive effect on the content of K, N, and P in soil. On soil in very good condition the effect of seaweed fertilizer was small when given as supplement to a good basic fertilizer. **(1)**

H. Nebb and A. Jensen, "Seaweed Meal as a Source of Minerals and Vitamins in Rations for Dairy Cows and Bacon Pigs," *Proceedings of the Fifth International Symposium on Seaweeds*, A. G. Young and J. L. McLachlan (eds.), Oxford: Pergamon Press, 1965, pp. 387-393.

Fortified seaweed meal and a commercial mineral mixture were compared as sources of minerals for dairy cows. The fortified seaweed meal was found to fully replace the artificial mineral mixture, and in most cases to lead to considerable increase in milk production.

In two experiments with hogs, it was found that fortified seaweed meal could replace the conventional mineral and vitamin supplements in normal rations. Average corrected gain, feed consumption, and carcass percentage were unaffected. **(4)**

S. A. Nichols, *Mechanical and Habitat Manipulation for Aquatic Plant Management, A Review of Techniques*, Department of Natural Resources, Technical Bulletin, No. 77, 1974.

Harvesting and habitat manipulation techniques, along with the requistic biology and planning, were reviewed with regard to managing nuisance aquatic plant growths. Harvesting had beneficial ecological implications as it removed the problem biomass from the water, and its cost and effectiveness had the same magnitude and variability in results as did chemical treatment with herbicides. Habitat manipulation involved a somewhat broader array of management techniques including shading with dyes and black sheeting, dredging, sand or gravel blanketing, overwinter drawdown, and nutrient limitation. Of these techniques, overwinter drawdown, dredging to a depth below the photic zone, and shading with black plastic sheeting appeared to be effective treatments. Sand and gravel blanketing showed initially encouraging but short lived results. The results of dyes and nutrient limitations yielded rather inconclusive results. **(2)**

F. M. Patrick and M. W. Loutit, "Passage of Metals to Freshwater Fish From Their Food." *Water Research, 12*, 1978, pp. 395-398.

Research showed that Cr, Cu, Mn, Fe, Pb, and Zn could be concentrated by tubificid worms after ingesting metal-enriched heterotrophic bacteria. Fish which were fed these worms, showed increased metal levels in their tissues after four days. Only Pb was found in increased concentrations after a shorter period of two days. Both young and older fish were used in the experiments, and the results indicated that increased levels of most metals in the fish reflect the concentrations of the metals in their food if the fish are exposed to the food for longer than two to four days, and

that the age of the fish has an effect on their final metal concentrations. (Author's abstract.) **(2)**

S. Sauter et al., "Effects of Exposure to Heavy Metals on Selected Freshwater Fry," Environmental Research Laboratory EPA, Ecological Resource Series, 1976.

The toxicity levels of Cu, Cd, Cr, and Pb to eggs and fry of seven fish species were assessed. The results of exposures were used to estimate the range of metal concentrations which bracket the maximum acceptable toxicant concentrations for a given metal and fish species. The hardness of the water did not appear to have a significant effect on the observed toxicity in most cases.

S. Serfing and D. Mendola, "Aquaculture Using Controlled Environment Ecosystems," *The Commercial Fish Farmer*, 1977, pp. 15-18.

The qualities of aquadomes were discussed for use in controlled environment experiments. The basic thrust of the article was that higher yields can be obtained in the controlled stable environment that an aquadome can offer.

E. W. Shell, "Herbivorous Fish to Control *Pithopliora sp.* and Other Aquatic Weeds in Ponds," *Weeds, 10*, 1962, pp. 326-327.

Fish used in these tests were the Israeli strain of the common carp (*Cyprinus carpio*), the Nile tilapia (*Tilapia nilotica*), the Java tilapia (*T. mossambica*), and the Congo tilapia (*T. emlanopleura*). Israeli carp and either Nile or Java tilapia in ponds containing only these species virtually eliminated aquatic weeds, but when stocked into established populations of largemouth bass and bluegill, results were less encouraging. The Congo tilapia was probably the most herbivorous of the species of tilapia tested.

Smithsonian Science Information Exchange, Inc., *Utilization and Removal of Nutrients from Fresh Water by Aquatic VAS.*, BA14, 1979.

A review of ongoing research supported by various government agencies concerning aquatic ecosystems and the ability to remove nutrients from fresh water.

W. M. Stephenson, "The Effect of Hydrolysed Seaweed on Certain Plant Pests and Diseases," *Proceedings of the Fifth International Symposium on Seaweeds*, A. G. Young and J. L. McLachlan (eds.), Oxford: Pergamon Press, 1965, pp. 405-409.

Liquified seaweed, marketed in the U.K. as "Maxicrop" and the U.S.A. as "Seaborn", although having no direct insecticidal or fungicidal effect, has been shown to increase the resistance of crop plants to certain pests and diseases. These include aphids, red spider mites, powdery mildew, botrytis, and an unidentified complex of fungi responsible for the damping-off of seedlings. (Author's abstract.) **(1)**

R. Stowell et al., *The Use of Aquatic Plants and Animals for the Treatment of Wastewater*, Department of Civil Engineering, September, 1979.

Potential organisms for use in aquatic systems for the treatment of wastewater are listed. Their probable function and the design considerations for aquatic treatment systems are discussed. **(2)**

R. A. Vollenweider, (ed.), *A Manual on Methods for Measuring Primary Production in Aquatic Environments—IBP Handbook No. 12*, Oxford: Blackwell Scientific Publications, 1974.

Sampling techniques and methods are described for estimating quantity and quality of aquatic biomass, for measuring production rates, for measuring microbial production, and for assessing environmental factors linked with primary production. The techniques discussed, concentrate on sampling phytoplankton, macrophytes, and periphyton. **(1,4,5)**

W. C. Yee, "Thermal Aquaculture: Engineering and Economics," *Environmental Science and Technology, 6*, 1972, pp. 232-235.

This paper discusses aquaculture utilization of thermal effluents from electric power plants, but geothermal water used in this context would also apply. With a continual source of warm water (18°C), an oyster's natural growing period is cut in half from 5 to 2.5 years under culture conditions. Catfish yields in 21 to 23°C water were equivalent of 36 700 kg/ha/year with intensive feeding. The flow rate had to be high enough to maintain temperature control of the water stream and to minimize atmospheric effects on heat loss.

The linear flow rate had to be enough to remove fish wastes, but low enough so there was minimal expenditure of their food intake energy spent on fighting the current. It was desirable to blend ambient temperature water with thermal discharge water, and to aerate channel water to maintain optimum culture conditions the year round.