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Some Aspects of the Ecology of Naturally
Occurring Populations of Submerged
Vascular Hydrophytes in Municipal
Wastewater Lagoons

presented by

Dennis P. Tierney

has been accepted towards fulfillment
of the requirements for

Ph.D. degree in Fisheries & Wildlife

C. D. McNabb, Jr.
Major professor

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ABSTRACT

SOME ASPECTS OF THE ECOLOGY OF NATURALLY OCCURRING POPULATIONS OF SUBMERGED VASCULAR HYDROPHYTES IN MUNICIPAL WASTEWATER LAGOONS I. PRIMARY PRODUCTION AND PHOSPHORUS--NITROGEN ACCUMULATION II. TRACE ELEMENT ACCUMULATION III. POTENTIAL USE AS A FEEDSTUFF AND A SOIL CONDITIONER

By

Dennis P. Tierney

Primary production of _Elodea canadensis_ and _Ceratophyllum demersum_ was determined for naturally occurring populations collected from Fowlerville and Belding sewage ponds and an urban catchment pond in Lansing, Michigan. Plants were studied from late May to early November, 1970. The relative intensity of environmental resistance to plant growth was assessed for the habitats. Simultaneously, the tissue accrual of phosphorus, nitrogen and eight inorganic elements were quantitatively determined (Co, Cd, Ni, Pb, Cu, Zn, Fe, Mn).

The relative intensity of environmental resistance of the ponds was attributed to the different chemical regimes. Plant growth was observed over analogous periods

of the growth curve for *E. canadensis* in the Fowlerville wastewater pond and the catchment pond and the comparative growth rates were assessed. The measure used was doubling time (DT) on a dry weight/square meter basis. The DT of *E. canadensis* growing in the wastewater pond was ~4-fold faster than populations existing in the catchment site. Primary production and productivity measurements produced the opposite conclusions. Where both species coexisted, *E. canadensis* exhibited biomass dominance. The largest maximum standing crop of 410 gm dry weight/m^2 and primary productivity of 6.9 gm dry weight/m^2/day was observed in *E. canadensis* growing in the catchment site. The difference has been attributed to a disparity in the sizes of the initial biomass of the populations prior to the onset of growth and a significantly greater shift in light and water temperature in the Fowlerville wastewater habitat prior to the achievement of maximum standing crop. This increased the intensity of environmental resistance to plant growth in that site relative to the catchment pond.

The size of the maximum standing crop was not related to the ambient soluble-P or nitrate-N concentrations. However, the phosphorus tissue accrual of *C. demersum* and *E. canadensis* among the habitats appeared to reflect the soluble-P concentrations. In all sites the tissue concentration of phosphorus and nitrogen in the submerged hydrophytes indicated the environmental level of both elements was not limiting to plant growth. Seasonal mean phosphorus tissue levels of the plants collected from the wastewater sites were about 1.0% of dry weight. Values for aquatic macrophytes grown in natural lakes and streams are 2 to 10-fold lower than those reported here. The tissue nitrogen content noted here was similar to reported literature values of 3 to 4% of dry weight.

Interspecific genetic differences in phosphorus accrual were absent while the existence of such differences were suggested for nitrogen accrual. Populations of each species growing in more than one habitat exhibited significant differences in phosphorus content, but not in nitrogen accrual. Seasonal patterns of tissue-P in the plants was fairly uniform while no trend was observed for tissue-N. Generally, the rate of phosphorus uptake was approximately equal to dry matter synthesis.

Mean tissue content of each trace element in *E. canadensis* and *C. demersum* was determined over the periods of growth up to and including maximum standing crop. Quantities of trace elements were greater in *E. canadensis* and *C. demersum* occurring in the Fowlerville wastewater pond compared to the catchment pond. However, amounts of some trace elements (Co, Cd, Pb, Fe) were higher in *C. demersum* collected in the latter site than in the Belding population. Pb concentrations were highest in the catchment pond's *C. demersum* population than in either of the wastewater sites. The latter observation is attributed to the Pb inputs from vehicle-industrial combustion associated with an urban-industrial environment. The trace element quantities ranked from least to most abundant were similar regardless of the species or study site (Cd < Co < Ni < Pb < Cu < Zn < Fe < Mn). A similar ranking has usually been observed in other aquatic plants and terrestrial plants.

Interspecific differences in trace element accumulation was demonstrated between species coexisting within a site. Differences in trace metal content in populations of a particular species growing in more than one study site was attributed to environmental variation in the habitats. Seasonal mineral accumulation capabilities of the plants was a dynamic process. The uptake and release of elements varies as a plant ages. For example, the pattern of accrual and release to the environment during autumnal decomposition varied considerably from the one observed during vigorous growth of the species earlier in the season. The relationship between rate of net dry matter production and net trace element uptake was complex. In some cases, uptake of the element was approximately proportional to primary production. The elements most often accumulated in proportion to dry matter synthesis were copper, nickel, lead and cadmium.

E. canadensis and *C. demersum* at the wastewater and the catchment pond had trace element levels several-fold higher than in land plants. For example, cobalt was 15-30 times higher while zinc was 2-4 times greater. Other elements were intermediate to these values. Compared to other studies of *E. canadensis* as well as other aquatic plant species, the levels observed here were in the same range.

Aquatic vascular plants remove large amounts of phosphorus, nitrogen and trace mineral elements from a pond or shallow lake basin. For instance, harvesting of *E. canadensis* at maximum standing crop from the catchment pond removed 3 mg of Co and 1.3 gm of Fe per kilogram of plant (DW) biomass per hectare. The quantity removed by harvesting depends on the size of the standing crop and the tissue level of the elements. The former factor is usually the predominate one. Planting and harvesting of managed crops of aquatic vascular plants in wastewater effluents would remove inorganic elements prior to discharge into natural waterways. However, extensive land area would be required to significantly remove the annual inorganic discharge of even a small rural community.

Use of the harvested plant material as a feedstuff and as a humus-organic fertilizer has been studied. While a favorable Ca:P ratio occurred in tissue of the wastewater grown plants, the high accumulations of trace elements appears to render the former use tenuous. Levels of copper, cadmium and manganese were above toxic levels noted for common herbage fed livestock. Addition of harvested aquatic plants to soil appears to have more feasibility, especially on sandy soils or in other regions where trace element content is deficient or depleted. Lead levels were also high and require attention due to its historical toxic effects on animal and human life.

SOME ASPECTS OF THE ECOLOGY OF NATURALLY OCCURRING POPULATIONS OF SUBMERGED VASCULAR HYDROPHYTES IN MUNICIPAL WASTEWATER LAGOONS I. PRIMARY PRODUCTION AND PHOSPHORUS--NITROGEN ACCUMULATION II. TRACE ELEMENT ACCUMULATION III. POTENTIAL USE AS A FEEDSTUFF AND A SOIL CONDITIONER

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PART I

PRIMARY PRODUCTION AND PHOSPHORUS--
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INTRODUCTION

The man-made increase of inorganic nutrients to lakes and streams has often set the conditions for temporal and/or spatial imbalances in the production-respiration steady-state cycle. Nuisance growths of algae and higher aquatic plants often reflect this instability in the form of excessive organic production and subsequent oxygen demand upon decomposition. The biologic problems tied to inorganic nutrient release, though similar, differ from organic waste disposal where the oxygen demand to and assimilatory capacity of the receiving water mass are the major parameters of interest. These types of measurements tell little about the effect of the effluent's inorganic load to the receiving water (Rohlich, 1969). Sawyer (1944) noted this difference and the need to further treat sewage effluents to remove the fertilizing elements. Odum (1971), in a broader scope, has indicated the need to establish compartmental land-use procedures, whereby portions of a watershed are designated as areas for development of renewable fund and flow resource reclamation facilities. Ideally, the concept would encompass the application of ecologic principles and modern engineering technology to achieve realistic water-mineral recycling programs. The recycling of fund resources (inorganic elements) as well as flow resources (water) for application to biological resources (crops and soil) exemplifies Barry Commoner's Second Law of Ecology: "Everything must go somewhere" and the corollary that "we must learn how to restore to nature the wealth that we borrow from it" (Commoner, 1971).

Some wastewater recycling projects have been demonstrated in recent years (Pennypacker *et al.*, 1967, Merrell *et al.*, 1967). Usually conventionally treated wastewater was sprayed or distributed to adjacent land areas rather than directly discharged into a natural stream or lake. Reduction of the nutrient-laden waters occurred by filtration and adsorption processes within the soil as well as biological uptake by the indigenous vegetation. Aquifers, streams and lakes within the watershed were recharged and the renovated water was made available for further use.

A wastewater reclamation experimental facility is planned for Michigan State University, East Lansing, Michigan. As envisioned, conventionally treated wastewater will flow through a series of shallow man-made lakes prior to being discharged onto forest and agricultural crops. In contrast to the use of man-made lakes in the Santee project (Merrell *et al.*, 1967) as a purely recreational resource, the lakes and biota therein will hopefully be important components in reducing the nutrient-load of the recycled water, as well as provide recreational uses. Aquatic vascular macrophytes are depicted as biological management tools in reducing the inorganic mineral concentration of the wastewater. Managed harvests of this vegetation would be prepared and used as a livestock fodder. Although several biological investigations of aquatic plants are available on the growth and tissue composition of mineral nutrients (Westlake, 1963; Boyd, 1967, 1969; Harper and Daniel, 1934; Riemer and Toth, 1969; Forsberg, 1960), few are available on hydrophyte growth and mineral accural in wastewater derived lakes or lagoons. Studies to date on the phosphorus and nitrogen accumulation in aquatic vegetation have been conducted in relatively oligotrophic or mildly eutrophic nutrient regimes where soluble-P usually varied from 0.01 to 0.35 mg/l (Boyd and Hess, 1970; Boyd, 1970; Boyd, 1969; Forsberg, 1960). This study was carried out in wastewater ponds where the soluble-P generally ranged between 2.20 to 2.85 mg/l. These environments were, then, extremely enriched in regard to phosphorus. It was initially assumed that the chemical milieu of the wastewater represented an enrichment of other inorganic elements as well. To insure a range of eutrophy, a non-sewage catchment pond was included as a comparative baseline or "control" environment.

This paper considers the effect of a wastewater pond's chemical regime on the growth, P-N accural, inter-specific and habitat variation in P-N uptake and temporal fluctuations in naturally occurring populations of submerged hydrophytes. The use of the harvested hydrophytes as a management tool for removal of phosphorus and nitrogen is discussed.

MATERIALS AND METHODS

Three study sites were utilized. One was a catchment pond located on the property of the municipal airport serving Lansing, Michigan. It lacks an inlet and outlet, receiving water through precipitation, groundwater seepage and surface runoff. Individual ponds in established sewage-lagoon treatment facilities provided the other two sites. These facilities consisted of sequentially ordered five and three pond series serving Belding (5,000 people) and Fowlerville (2,000 people), Michigan, respectively. Neither, at the time of the study, received industrial waste. It was primarily of domestic origin.

Naturally occurring populations of submerged hydrophytes were collected from the third pond at each of these facilities and at the catchment site. Plant species sampled were Ceratophyluum demersum and Elodea canadensis. The former was present at all sites while the latter was absent from the Belding location. Collections were obtained on a weekly to biweekly basis from late May to mid-November during 1970. The sampling method consisted of using the entire pond or a known areal section as the "universe." Sampling points were generated within the "universe" from a random numbers table and individual samples obtained at the intersection of the coordinates.

Sample numbers ranged from three to ten. A floating square-meter grid was used to quantitatively estimate the standing crop on an areal basis. Material was clipped, collected by hand, rinsed in the ambient water, placed in plastic bags and stored on ice for the trip to the laboratory. In the laboratory, samples were rinsed of debris in tap-water and allowed to air-dry for 15 minutes. Specimens were then placed in a forced-air drying oven for 48 hours at 80°C. Wet and dry weights were recorded after each procedure. The plants were subsequently ground in a micro-Wiley mill using a 40 mesh screen. Homogeneous subsamples were obtained and stored under dessication in glass bottles.

Chemical analyses were performed on the ground subsamples of whole plants. The amount of phosphorus (as P) in the tissue was determined spectrophotometrically by a modification of the vannadomolybdate method of Rickey and Avens (1955) subsequent to wet digestion. A mixture of nitric and perchloric acid (3:1) to which 2.0 gm/1 sodium bromide had been added to remove arsenic, germanium and silicon interference was used (Lueck and Boltz, 1956). Nitrogen concentration (as N) was determined with a Perkin-Elmer 240 Elemental Analyzer. Ash weight values were obtained by dry digestion in a muffle furnace at 550°C for one hour. Statistical analysis of interspecific and site variation in phosphorus and nitrogen accural was performed according to Siegel (1956) and Sokol and Rohlf (1969).

Water samples were obtained concomitantly with the hydrophyte collections. Samples were gathered from the water column at approximately one foot intervals using a plexiglass tube and composited for each depth. All samples were stored in plastic bottles, preserved with HgCl (Howe and Holly, 1969) and refrigerated prior to analysis. The amount of phosphorus (as P) in the water was expressed in mg/1 of total and soluble phosphorus. Determination consisted of acid hydrolysis, chloroform extraction (Wadelin and Mellon, 1953) and spectrophotometric quantification of the molydophosphorus complex (Anon., 1969). Nitrogen determinations were performed for nitrate-N, nitrite-N, ammonia-N and organic-N and expressed as mg/1. The latter three were analyzed according to procedures in

Standard Methods For the Examination of Wastewater and Sewage (Anon., 1969). Nitrate-N was obtained by the brucine sulfanilic acid method (Jenkins and Medsker, 1964). Hardness (Ca and Mg), total solids and pH were also recorded (Anon., 1969). Temperature was obtained by thermistor.

RESULTS AND DISCUSSION

Hydrophyte Production and Environmental Resistance

Changes in the standing crops of the submerged hydrophytes during the growing season are shown in Figures 1-3. The maximum standing crop of 410 gm/m^2 occurred with *Elodea canadensis* growing in the airport catchment pond. It was about 4-fold larger than *E. canadensis* growing in the Fowlerville wastewater pond. Where both species co-existed, maximum standing crops of *C. demersum* were 3 to 4-fold lower than *E. canadensis*. Relative to reported values for emergent and submerged hydrophytes in the literature, those observed here were several-fold lower (McNabb *et al.*, 1971). Similarly, the net mean primary productivity of the submerged plants up to the maximum standing crop was generally less than the growth rates of aquatic macrophytes observed elsewhere (McNabb *et al.*, 1971). *E. canadensis* existing in the catchment pond had the highest rate of 6.9 gms dry weight/m^2/day. This is

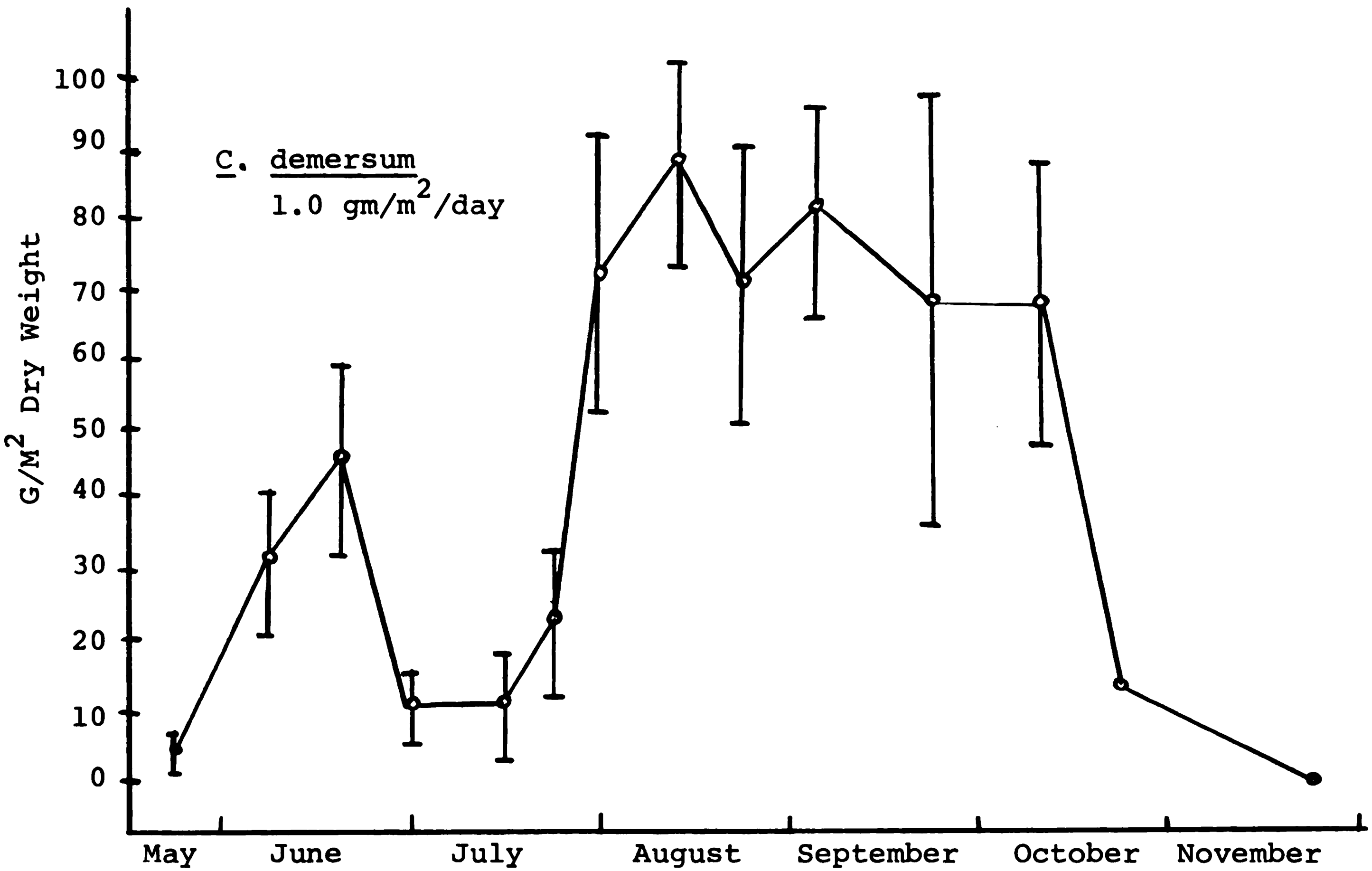

Figure 1. Standing crops of <u>Ceratophyllum</u> <u>demersum</u> at Belding wastewater site. Vertical lines represent $\pm$ 2 SE. The mean net primary productivity calculated from mid-July up to maximum standing crop is indicated.

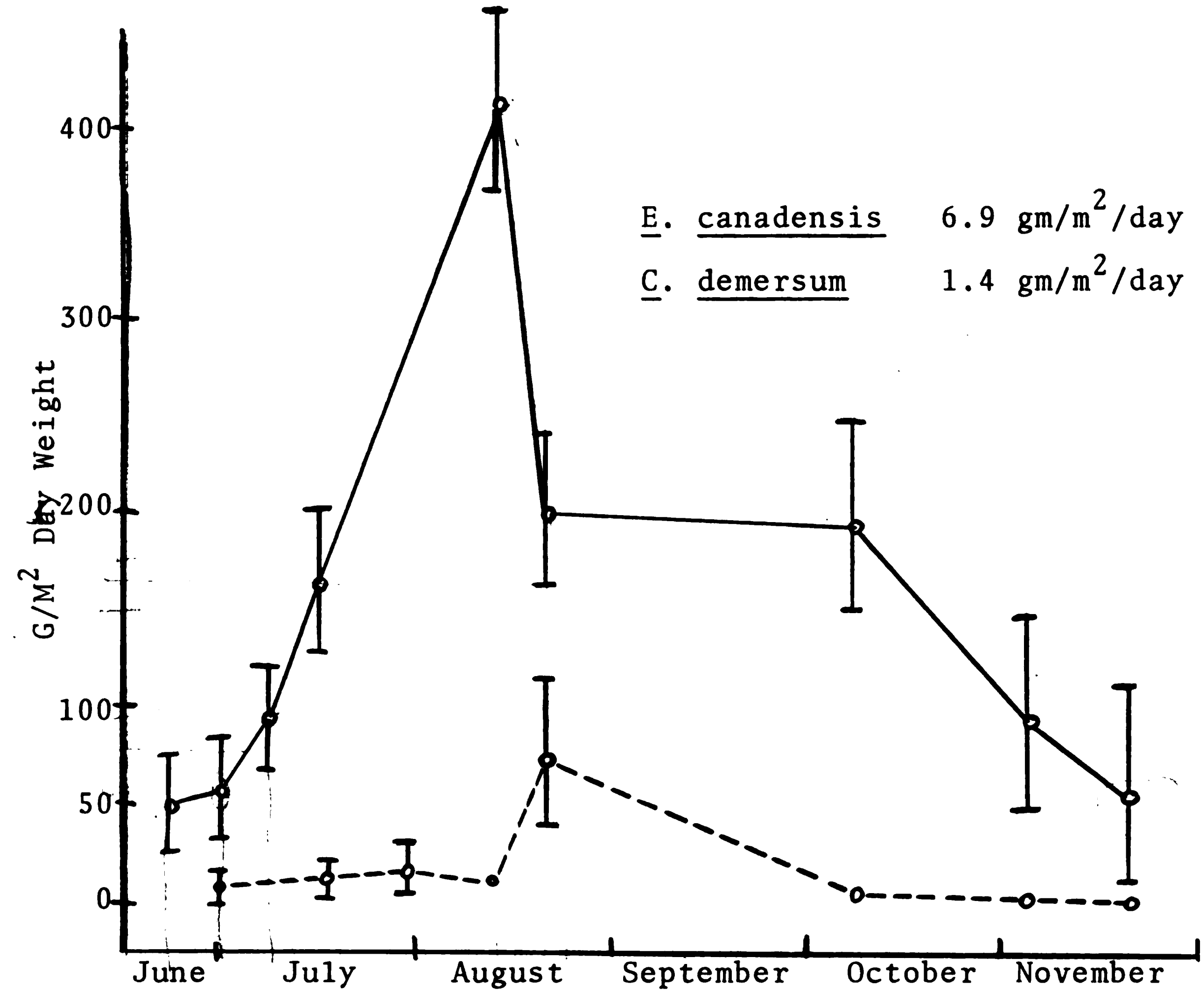

Figure 2. Standing crops of _Elodea canadensis_ (solid line) and _Ceratophyllum demersum_ (dashed line) at airport catchment site. Vertical lines represent ± 2 SE. The mean net primary productivity calculated up to maximum standing crop is indicated.

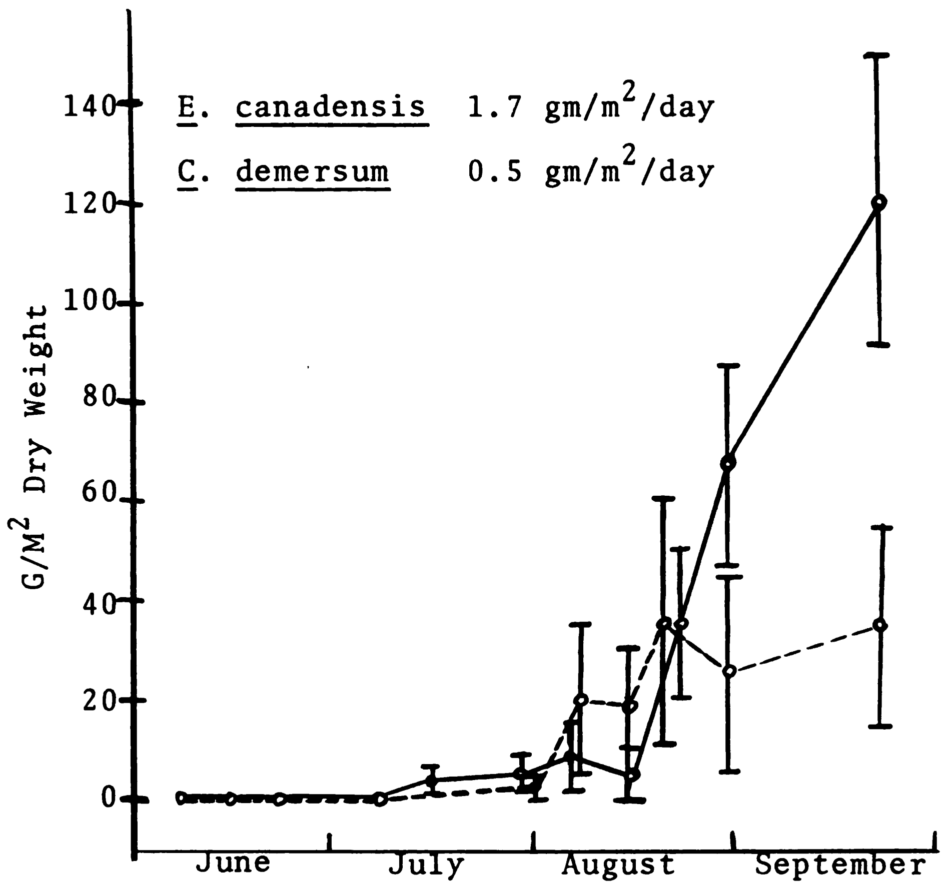

Figure 3. Standing crops of *Elodea canadensis* (solid line) and *Ceratophyllum demersum* (dashed line) at Fowlerville wastewater site. Vertical lines represent ± 2 SE. The mean net primary productivity calculated up to maximum standing crop is indicated.

about 6-fold higher than the other values calculated for *E. canadensis* and *C. demersum* in this study. Where both species were present, productivity rates of *E. canadensis*, the dominant species, were 3 to 6-fold higher. Net productivity rates were lower for populations of the hydrophytes grown in the wastewater ponds than in the catchment pond. It would appear that the latter was the more optimal environment for *E. canadensis* growth.

The question of which habitat presented the least environmental resistance to the growth of the submerged hydrophytes is not adequately resolved when only the net mean productivity rates and size of the maximum standing crops are used as the comparative measures. As indicated by McNabb and Tierney (1972), the standard field method of measuring vascular hydrophyte growth (i.e., unit weight/unit area/unit time) is usually unsuitable for ascertaining the degree of coupling of a hydrophyte's genome to a particular environment. It does not consider differences in the quantity of plant biomass initially present. An alternative method involves comparing the time required for doubling plant biomass (doubling time-DT) as measured from the onset of growth to the inflection point of the seasonal growth curve. The inflection point represents the approximate period in which some resource (as nutrients, lights, temperature) becomes limiting. If the maximum doubling time (*unlimited rate* of growth) is known for a species, the relative suitability of any particular habitat can be determined for that species from several measurements of standing crop in the period up to the inflection point. This period is termed the accelerating phase of growth and when doubling time is at a maximum in this period, the plant theoretically grows in an unlimiting environment with respect to its chemical-physical requirements.

Figure 4 indicates the doubling time (DT) of E. canadensis in the airport catchment pond and the Fowlerville wastewater site. The rates were calculated using analogous portions of the growth curves up to the inflection point. It can be seen that the wastewater site offered less resistance to Elodea canadensis growth as exhibited in a mean DT 4-fold faster than in the catchment pond population. The wastewater pond, though considered limnologically extreme in nutrient levels (Table 1), represents the more favorable habitat for E. canadensis. The genotype of this species is apparently more fitted to the hypereutrophic conditions of the wastewater pond. Genetic similarity of the populations is assumed. Losses of biomass during the interval of measurement to grazers or to decomposition were considered negligible on the basis of field inspections.

Doubling times of 12 and 11 days were reported by McNabb and Tierney (1972) for Elodea nuttallii and

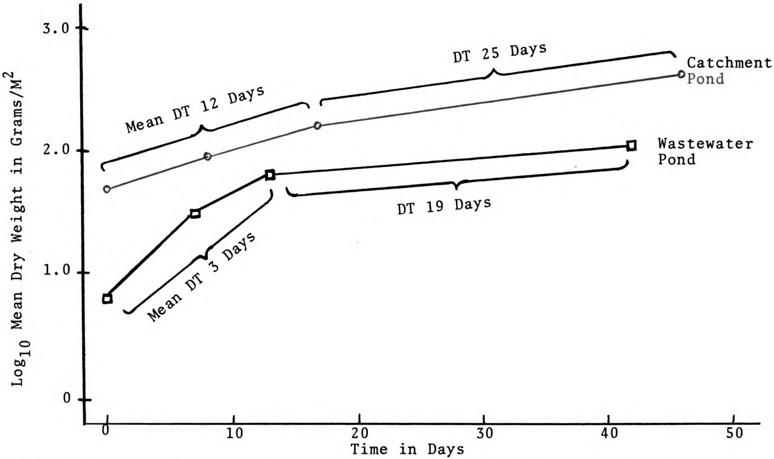

Figure 4. Rates of growth of _E. canadensis_ in the wastewater and catchment ponds. Doubling time (DT) indicated for maximum and minimum slopes of growing species.

Table 1. Mean seasonal chemical composition of water from study areas expressed as mg/l (ppm) where appropriate.[a]

Analysis	Site		
	Airport	Belding	Fowler-ville
Hardness	131.70	276.10	321.42
T.D. solids	267.50	606.12	649.42
Total phosphate-P	0.25	2.94	3.70
Soluble phosphate-P	0.10	2.20	2.85
Nitrate-N	0.16	0.14	0.13
Nitrate-N	0.00	0.15	0.17
Ammonia-N	0.36	2.63	1.19
Inorganic-N	0.52	2.92	1.49
Organic-N	2.89	2.21	1.76
Total-N	3.41	5.13	3.25
pH	8.07	8.02	8.16

[a]Average of 15-18 samples.

Ceratophyllum demersum, respectively. Vegetative growth of both species occurred in wastewater ponds; the former in the Fowlerville pond used in this study and the latter in an Auckland, New Zealand pond. The DT of E. canadensis measured in this study was 4-fold faster. Its adaptability for vegetative growth in hypereutrophic environments seems to be superior to the former species. However, the chemical-physical conditions of wastewater ponds are not always similar and this conclusion can only be considered tentative.

No comparative doubling times were calculated for C. demersum, since it was the subdominant species in two sites (Figures 2 and 3) and was therefore considered to be limited primarily by the biological interaction with E. canadensis, rather than the chemical environment of the respective ponds. However, the trace element accural of the two species was not identical within a site (Tierney, 1972a). The environmentally toxic concentration of an element(s) varies among terrestrial flora (Bowen, 1966). There is no reason to doubt the existence of aquatic species which are relatively tolerant of trace metal concentrations found inhibiting to other hydrophyte species. The possibility of interspecific toxic metabolic suppression of C. demersum cannot presently be ruled out.

Evidence also points to a potential physical control, namely, ambient water temperature, on the photosynthetic rate of _C. demersum_. Laboratory studies of Saitoh _et al_. (1970) indicate that 30°C is the optimum temperature for the highest apparent photosynthetic rate in _C. demersum_. No readings reached this level during this study. The obvious dominance of _E. canadensis_ over _C. demersum_ as seen by the standing crop measurements may be the result of temperature regime relatively more optimal for the former species and it therefore would have a higher rate of photosynthesis. The result of such a condition would find the faster growing _E. canadensis_ eventually producing a shading effect on _C. demersum_ and limiting incident radiation available to it. The biologic effect of shading combined with the suboptimal water temperature could further reduce the rate of photosynthesis in _C. demersum_.

Even though the wastewater pond was the more optimal environment for _E. canadensis_ as determined by the faster doubling time, the maximum standing crop achieved by it was lower than that observed in the catchment pond. Presumably, it would double 4-fold in weight in the time it takes the catchment pond population to double once and thereby eventually surpass it. However, two factors are responsible for the lower maximum standing crop at Fowlerville; the variable intensity of environmental resistance and the initial seed or vegetative shoot density. Doubling time is a measure of the former, but not the latter. As can be seen in Figures 2 and 3, the size of the initial standing crop of _E. canadensis_ at the onset of growth was about 50 and 6 gm/m^2 in the catchment and Fowlerville ponds, respectively. This is an 8-fold difference in dry weight. This initial difference puts limits on the eventual size of the standing crop.

Ideally, the study was organized to follow the growth of _E. canadensis_ in the ponds through similar periods of the year. This was done in an effort to have roughly similar light and temperature regimes at both sites. In that event, the main environmental variable between sites would be the chemical regimes of the ponds. Plant density and occurrence of annual growth were approximately similar at both sites based on observations from the previous year. However, an unfortunate incident occurred in the Fowlerville site in the fall which altered these conditions.

Personnel of the Fowlerville sewage facility mechanically uprooted the submerged hydrophytes. One effect of this effort was to reduce the overwintering plant biomass and thereby reduce the size of the initial plant biomass in the spring. The other effect of macrophyte uprooting was to delay the onset of growth (Figure 3).

This shift obliterated any possibility of measuring the growth of the two populations during the same time of the year. Consequently, the effect of the chemical regimes on the growth rate of E. canadensis is more difficult to assess.

Figure 4 illustrates the reduction in growth rate which occurred in late August and September to E. canadensis in the wastewater pond. A doubling time of 19 days elapsed from the inflection point of the growth curve up to the maximum standing crop (Figure 3). The corresponding duration of growth for E. canadensis in the catchment pond was about 25 days. The wastewater population experienced a 6-fold reduction in growth rate (3 to 19 days) while the catchment pond population had a 2-fold reduction (12 to 25 days). Apparently, the environmental resistance of the wastewater site increased considerably more than the catchment pond. This unequal variation in intensity of environmental resistance combined with the lower vegetative shoot density accounts for the lower maximum standing crop of E. canadensis in the wastewater site.

It is felt that the increase in environmental resistance observed in the wastewater pond is related to changes in two physical parameters, namely, ambient water temperature and solar radiation, rather than any substantial shift in the chemical melieu of the pond. The uprooting of the plants shifted the growth phase of E. canadensis into August and September where rate-limiting effects of falling water temperature and subsiding solar radiation predominately slowed its growth rate. Water temperature declined from a summer high of 28°C to 18°C from mid-July to the end of September in the Fowlerville wastewater pond. It remained near 25°C from mid-June to mid-August in the catchment pond. These temperatures occurred simultaneously with the onset of growth and continued through the determination of maximum standing crop. It is known that temperature effects the metabolism of plants and the relationship is expressed in the form of the Q_{10} approximation, where a 10°C degree rise or fall in ambient temperature produces a corresponding 2-fold change in the plant's metabolic rate (Galston, 1964). Reduction in the metabolic rate of E. canadensis, based on the comparative seasonal temperature reductions, would appear to be significant in the wastewater situated population.

The seasonal reduction in solar radiation was similarly more significant throughout the growth of the wastewater situated E. canadensis. The quantity of direct solar radiation striking a water surface decreases approximately 31% from mid-July to mid-September, and only 12% from mid-June to mid-August at 45°N latitude (Perl, 1935). The maximum quantity of total direct radiation occurs in mid-June. Presumably, the autumnal shift in direct solar radiation followed a similar pattern in the study ponds, though the absolute quantity of radiation delivered would vary due to local climatic conditions and the 42° N latitude position of these ponds.

The effect of differences in temperature and light was a striking increase in environmental resistance to the growth of E. canadensis in the wastewater site after growth had begun as compared to a more gradual shift observed in the catchment pond. The relatively larger shift in intensity of environmental resistance in the wastewater site, particularly in late August and September, contributed to the striking decrease in doubling time seen in Figure 4. The size of the maximum standing crop in the wastewater site was, therefore, less than that observed in the catchment pond.

Hydrophyte Production and Water Nutrient Concentration

The size of the standing crops was not correlated with the concentration of soluble phosphorus in the water. A comparison of Table 1 and Figures 1 through 3 indicate this point clearly. The catchment pond had the largest standing crops and the lowest soluble phosphorus concentration. Boyd and Hess (1970), however, found a positive correlation between dissolved phosphorus in the ambient water and the size of *Typha latifolia* standing crops from various habitats. The absence of a stimulatory effect of high soluble phosphorus concentrations on submerged hydrophyte growth in this study may be explained with the use of the luxury consumption and critical nutrient concentration concepts.

Gerloff and Krombholz (1966) established a tissue phosphorus critical concentration of 0.13% for several aquatic macrophytes in laboratory experiments. Below this value the plant content of phosphorus is closely correlated to plant yield, while phosphorus tissue content above this value represents luxury uptake and has no stimulatory effect on plant yield. The lack of relationship between standing crops (yield) in the catchment pond and the wastewater ponds and their respective ambient soluble phosphorus concentration is apparently due to the fact that the phosphorus tissue content is approximately 4 to 8-fold higher than the critical concentration level established by Gerloff and Krombholz (Table 2). Phosphorus tissue levels of *E. canadensis* and *C. demersum* are, therefore, in the luxury consumption zone. The phosphorus tissue concentration is no longer considered limiting to growth, so differences in the ambient water concentration would not be reflected in the size of the plant yield.

Table 2. Seasonal mean percentage of phosphorus and nitrogen (DW) for *Elodea canadensis* and *Ceratophyllum demersum* at three study sites (±2SE).

Site	*E. canadensis*		*C. demersum*	
	P	N	P	N
Fowlerville[a]	1.05 ± 0.12	3.82 ± 0.22	1.22 ± 0.14	4.42 ± 0.20
Belding[a]	---	---	1.09 ± 0.12	4.53 ± 0.12
Airport[b]	0.52 ± 0.06	3.19 ± 0.18	0.51 ± 0.06	3.93 ± 0.32

[a]Wastewater pond.
[b]Catchment pond.

The phosphorus tissue levels of _Typha_ _latifolia_ in Boyd and Hess's (1970) study are much closer to the critical phosphorus concentration and approximately 20% of the samples are equal to or lower than the 0.13% value, while the mean tissue phosphorus content was only 0.21% dry weight. Given the variability of field conditions and the controlled nature of laboratory studies, the critical phosphorus tissue concentration of 0.13% is to be understood as an estimation and variability about this value is to be expected. Therefore, the correlation between soluble phosphorus and aquatic plant yield would be more likely to occur with the nutrient concentrations observed by Boyd and Hess, where it is feasible that the critical phosphorus tissue concentration had not been obtained.

Seasonal mean tissue nitrogen concentrations (Table 2) of the submerged hydrophytes collected from all sites were 2 to 4-fold higher than the nitrogen critical tissue concentration of 1.3% also established by Gerloff and Krombholz (1966). Again, _E_. _canadensis_ and _C_. _demersum_ were apparently in the luxury consumption zone for this element. The differences in water nitrogen (as nitrate) concentrations among the ponds would seemingly not be reflected in the size of the yields (standing crops) observed in the ponds. Boyd and Hess (1970) found no correlation between ambient water concentrations of nitrogen (as nitrate) and the size of standing crops in _Typha latifolia_ collected from several habitats. Tissue concentrations of nitrogen in approximately 70% of his samples were larger than the critical concentration of Gerloff and Krombholz.

Differences, then, in water concentrations of either elements are apparently not reflected in the size of the standing crops achieved by _E. canadensis_ and _C. demersum_. Both phosphorus and nitrogen water concentrations appear to be unlimiting to growth in the wastewater and catchment ponds. In terms of Gerloff and Krombholz's critical concentration factors, all sites are nutrient rich regarding these elements.

It should be cautioned that the relationship between nutrient water concentration and plant growth is complex. Obviously, environmental conditions are more varied, dynamic and complex in field studies than with the laboratory experiments of Gerloff and Krombholz from which this analysis draws heavily. That other environmental factors (as light and temperature) also influence growth rates should be recognized and was noted in the previous section.

Hydrophyte Mineral Accrual

The mean seasonal tissue accumulation of phosphorus by *E. canadensis* and *C. demersum* was 2-fold higher in the wastewater populations than in the catchment pond populations (Table 2). This difference is statistically significant (Kruskal-Wallis anova, α level 0.001). That this difference was a reflection of the environmental variation in phosphorus concentration is seen in Figure 5. The relationship between *C. demersum* tissue concentration and the external phosphorus water level is noted. The mean tissue-P content is regressed against the mean soluble phosphorus (as P) water concentration for the three sites over the period of June 30 to August 20. This corresponds to the period of growth from the onset up to and including the achievement of maximum standing crop. A significant correlation was obtained between the external phosphorus level and the internal tissue-P accumulations. Specifically, as the water concentration of phosphorus increased from the catchment pond through Belding and Fowlerville wastewater sites, parallel increases were noted in the tissue content of *C. demersum*.

Though *E. canadensis* was absent from the Belding pond, the accrual of phosphorus in this species seems to also increase in response to increased environmental concentrations (Table 2). For example, there is no

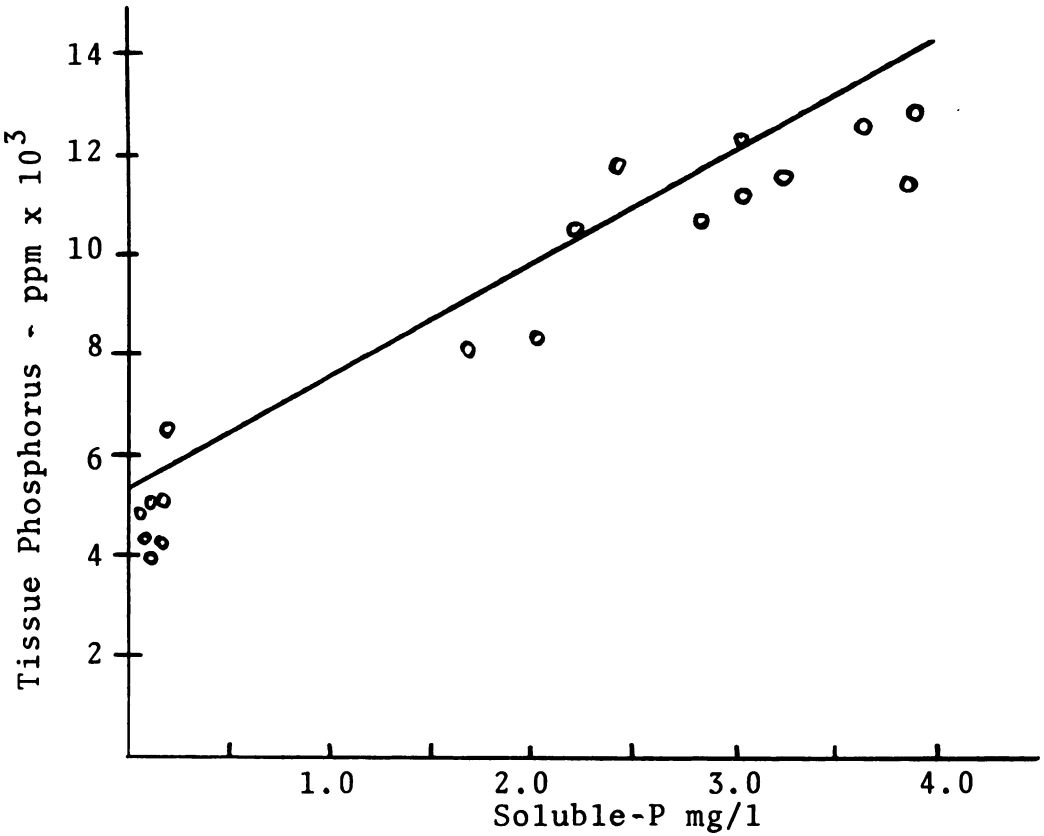

Figure 5. Regression of tissue-P on ambient concentration of soluble-P for *C. demersum* collected from airport catchment pond, Belding and Fowlerville wastewater sites. A regression of $y = 5.196 + 2.31\ x$ was obtained with a correlation coefficient of 0.86 significant at a 0.001 level of probability.

interspecific phosphorus tissue accrual difference between E. canadensis and C. demersum coexisting in either the catchment pond or the Fowlerville site (Kolmogorov-Smirnov, α level 0.01). Apparently this indicates there is a similar response by the submerged plants to the environmental levels of phosphorus encountered in this study. Additionally, Adams et al. (1971) found the tissue-P concentration of E. canadensis increased significantly from clean water conditions to nutrient-enriched water encountered downstream of domestic and industrial discharge pipes.

Nitrogen accrual by coexisting populations of E. canadensis and C. demersum is statistically similar within the catchment and wastewater sites (Kolmogorov-Smirnov, α level 0.05). Though interspecific nitrogen accumulation is not statistically evident, C. demersum uniformly contains greater quantities of nitrogen (Table 2).

While there existed distinct site differences in the tissue-P level of the submerged plants, nitrogen accumulation was not so clearly demarcated. C. demersum and E. canadensis grown in the Fowlerville site contained larger amounts of N than populations collected from the catchment pond (Table 2). However, this difference was only significant at an α level of 0.10. Yet, tissue-N levels of C. demersum were significantly higher in samples collected from Belding than from the airport catchment pond (Kruskal-Wallis, α level 0.001). Presumably, since the nitrate-N and total-N water concentrations were statistically similar in the three ponds (Kruskal-Wallis, α level 0.20) and the soluble and total-P water concentrations were statistically higher in the wastewater sites (Kruskal-Wallis, α level 0.01), the nitrogen gradient among the ponds was smaller than the phosphorus gradient (Table 1). The result is that the wastewater ponds are distinctly different in P concentration from the catchment pond while less distinction exists in nitrate-N and total-N water concentration. For these reasons, the seasonal mean nitrogen content in C. demersum did not exhibit the relationship seen in Figure 5 for tissue-P accumulation.

The wastewater ponds' nitrite-N and ammonia-N levels were significantly greater than values observed in the catchment pond (Table 1). Ammonia-N, as well as nitrate-N, is absorbed by plants (Price, 1970). Though the total-N and nitrate-N values were similar for all sites, the relatively greater availability of the absorbable nitrogen species in the wastewater sites may account for the slightly higher tissue-N levels observed therein (Table 2).

Though interspecific phosphorus accumulation within a site is not evident between E. canadensis and

C. demersum, interspecific variation in phosphorus accrual has been observed by Boyd (1970). Several species of emergent, floating leafed plants and submerged plants exhibited different tissue-P quantities while coexisting in the same pond. Gerloff and Krombholz (1966) also found phosphorus as well as nitrogen variation in submerged macrophytes collected from Lake Mendota, Wisconsin just as Schuette and Alder (1927, 1929) did nearly forty years earlier. Stake (1967, 1968) demonstrated such interspecific mineral accrual as well.

Several instances of tissue phosphorus and nitrogen content varying among populations of an aquatic macrophyte with a cosmopolitan distribution are known (Boyd, 1969, 1970b; Adams et al., 1971; Gerloff and Krombholz, 1966; Caines, 1965). Such differences are usually attributed to the relative fertility of the various habitats. Caines' (1965) investigation experimentally demonstrated a parallel increase in tissue-P of two submerged species after fertilization of a Scotish loch. However, it should be noted that other aquatic plants present actually exhibited a reduction in tissue-P after fertilization. Plant response, then, to increasing environmental nutrient levels is not clear-cut and probably differs with both species and individual elements as Boyd and Hess (1970) noted.

Boyd (1967), in a review of aquatic plant mineral composition, indicated that submerged plants generally contained 3 to 4% nitrogen by dry weight. As seen in Table 2, the nitrogen content here is fairly compatible with that estimate. Phosphorus levels for aquatic angiosperms ranged from 0.1 to 0.6% by dry weight (Boyd, 1967). Other investigators indicated phosphorus tissue levels are generally within this range (Stake, 1968; Gerloff and Krombholz, 1966; Caines, 1965; Boyd, 1970d). Only Adams et al. (1971) observed tissue levels of ~1.0% phosphorus which were approximately similar to values noted in Table 2. The latter study also examined E. canadensis from extremely eutorphic habitats and apparently confirms the tissue-P accrual noted in the wastewater-grown plants. Overall, the levels reported here were 2 to 10-fold greater than those reported for aquatic vegetation collected from less eutrophic lakes and streams.

Temporal variation in tissue-P content of the submerged hydrophytes is indicated in Figures 6 and 7. Phosphorus tissue levels in the aquatic vegetation collected from the catchment pond was fairly constant throughout the summer and fall with rather uniform standard errors about the means. However, variation about the means was more pronounced in the wastewater-grown plants and the tissue-P level varied widely over the seasons in C. demersum while levels were somewhat more uniform in

E. canadensis observed in the Fowlerville wastewater site. Apparently, the higher environmental phosphorus concentration promotes a greater variability in individual plant accrual of phosphorus. Adams *et al.* (1971) also noted increased variability in tissue-P content of *E. canadensis* collected from a habitat of high ambient phosphorus concentration compared to samples obtained from an area of low ambient phosphorus levels. Generally, tissue-P levels were also higher during the summer for both species sampled from the wastewater sites than the catchment habitat, but values approached levels observed in vegetation from the latter site by late fall.

Literature values indicate that the phosphorus and nitrogen content of aquatic emergent and submerged plants declined as the plants aged (Boyd, 1970a; Stake, 1967, 1968; Caines, 1965) or varied indiscriminately (Gerloff and Krumbholz, 1966). Presumably, the percentage decline in macronutrients with growth observed by the former authors is the result of a mineral uptake rate less than that for biomass synthesis. The fairly constant seasonal phosphorus content of *C. demersum* in the catchment pond and *E. canadensis* in the sites where it occurred indicates the rate of phosphorus accrual is fairly close to the rate of biomass synthesis. An inspection of Figures 2-3 with Figures 6-7 indicate this relationship during the period of growth up to and including the achievement of maximum standing crop.

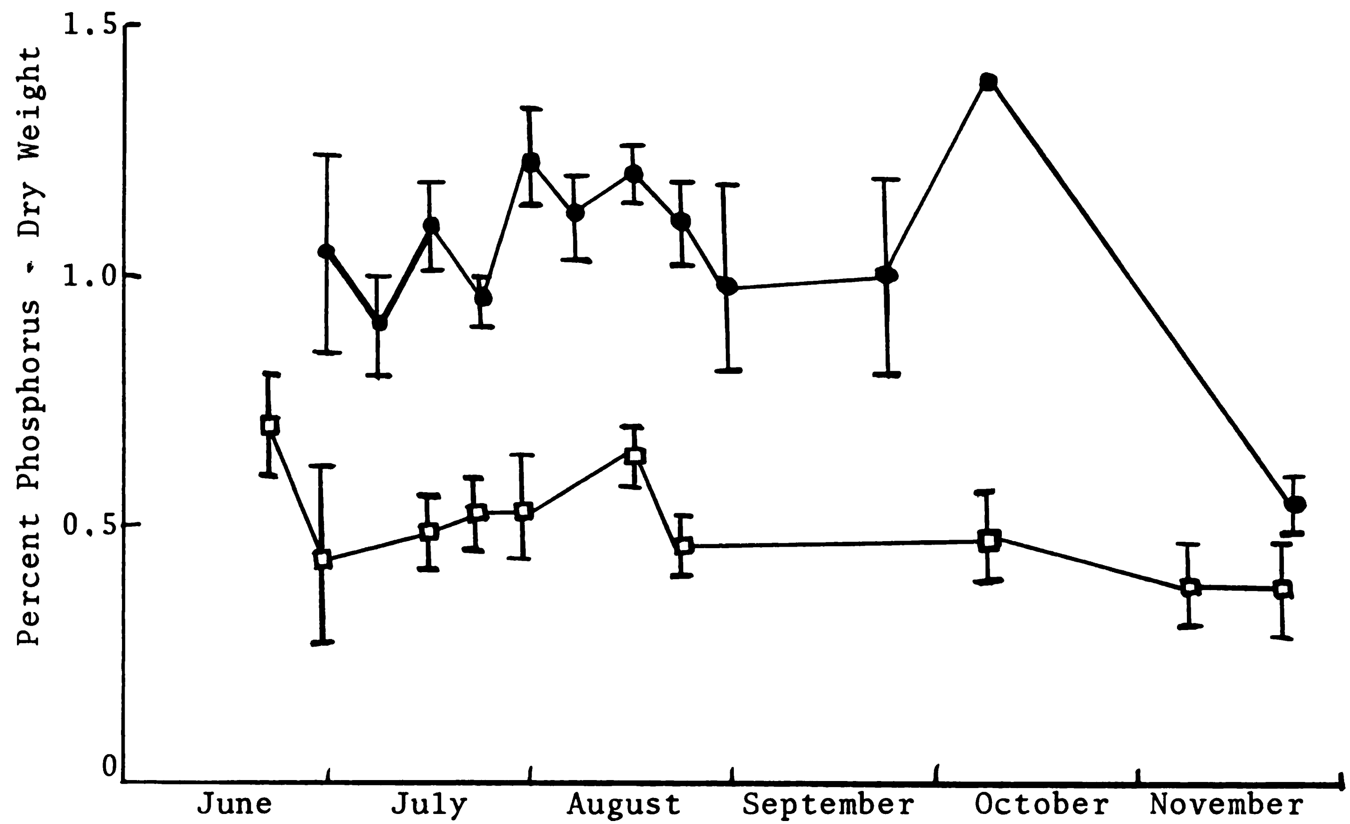

Figure 6. Seasonal tissue content of Elodea canadensis as percent phosphorus in Fowlerville wastewater pond (●) and in the airport catchment pond (□). Vertical lines represent ± 2 SE.

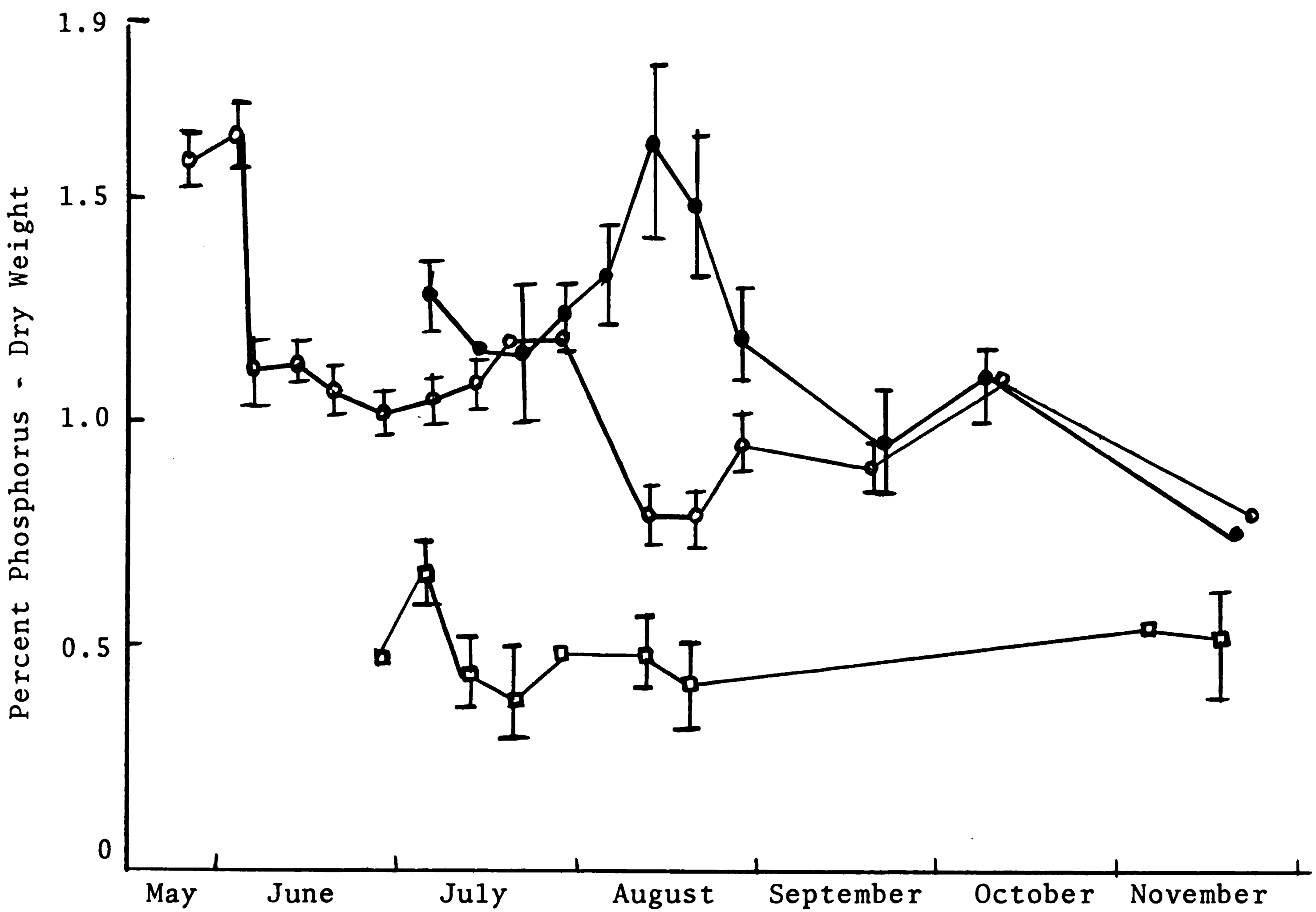

Figure 7. Seasonal tissue content of _Ceratophyllum demersum_ as percent phosphorus in Fowlerville (●), Belding (o) wastewater ponds and airport catchment pond (◘). Vertical lines represent ± 2 SE.

Seasonal patterns of nitrogen accrual are noted in Figures 8 and 9. No clear trends can be noted. Obviously, the general decline noted by the above-mentioned authors is absent. A suggestive decline occurs with the onset of growth as a comparison of Figures 1 to 3 and Figures 8-9 indicates, but tissue values increase at or prior to achievement of maximum standing crop.

No mention of direct inorganic phosphorus toxicity is found in the literature (Bowen, 1966). However, high levels of phosphorus or calcium in forage can indirectly hinder normal growth and development in domestic ruminants (Underwood, 1966). Adequate phosphorus and calcium nutrition depends on a low calcium to phosphorus ratio in the feed or forage. Dietary ratios between 1:1 and 7:1 gave the best results in growing Hereford calves while values between 1:1 to 3:1 are favorable for growing chicks and pigs (Underwood, 1966). The presence of ratios outside of these limits indicates an excess of one element or the other. This excess interfers with absorption of the other element and with several mineral nutrients, such as magneisum, zinc and manganese. Deficiency signs may, therefore, be induced in the livestock for those elements. Indirectly, then, high tissue-P levels may render forage vegetation unsuitable in the presence of normal calcium levels.

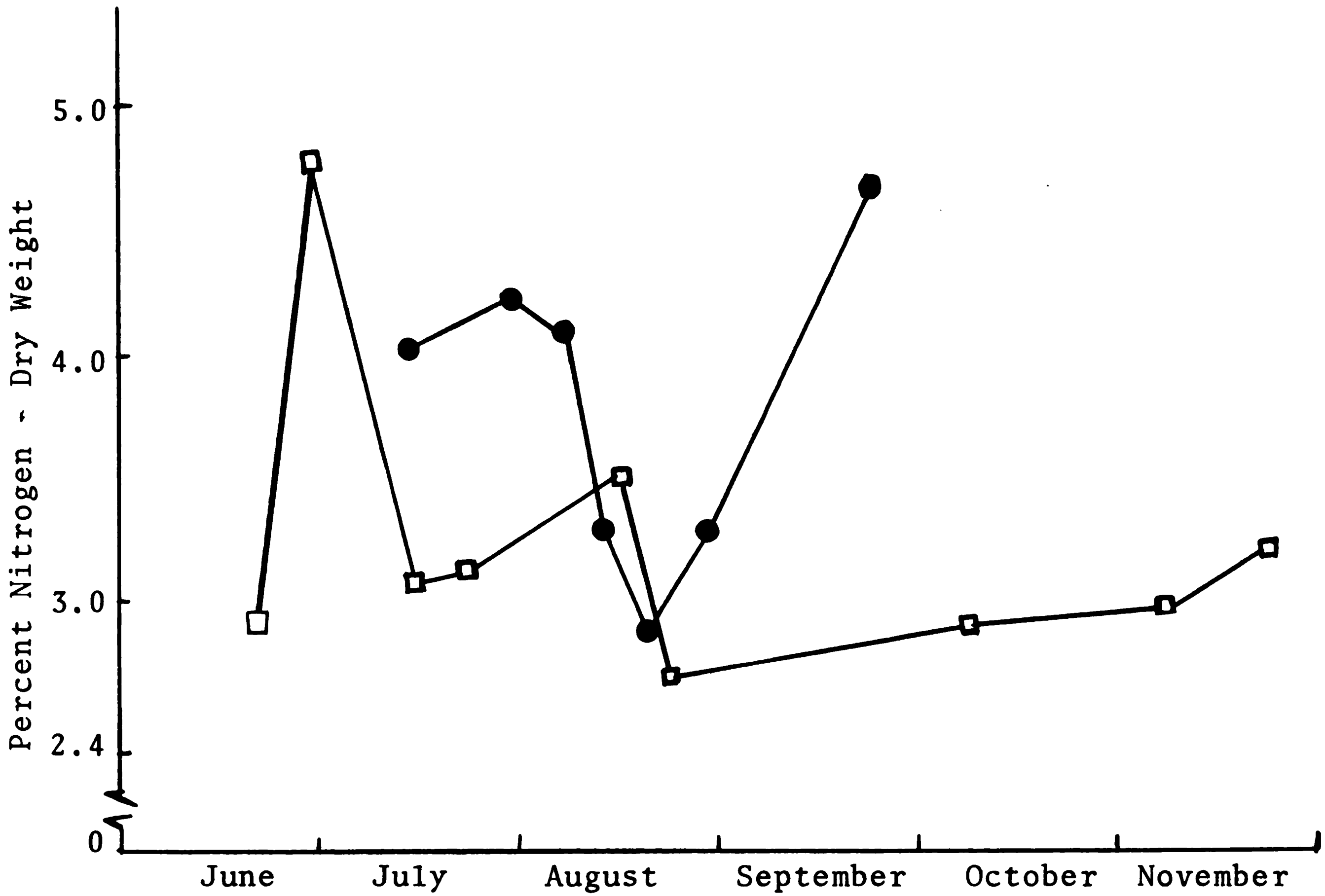

Figure 8. Seasonal tissue content of _E. canadensis_ as percent nitrogen in Fowlerville wastewater pond (●) and in the airport catchment pond (□).

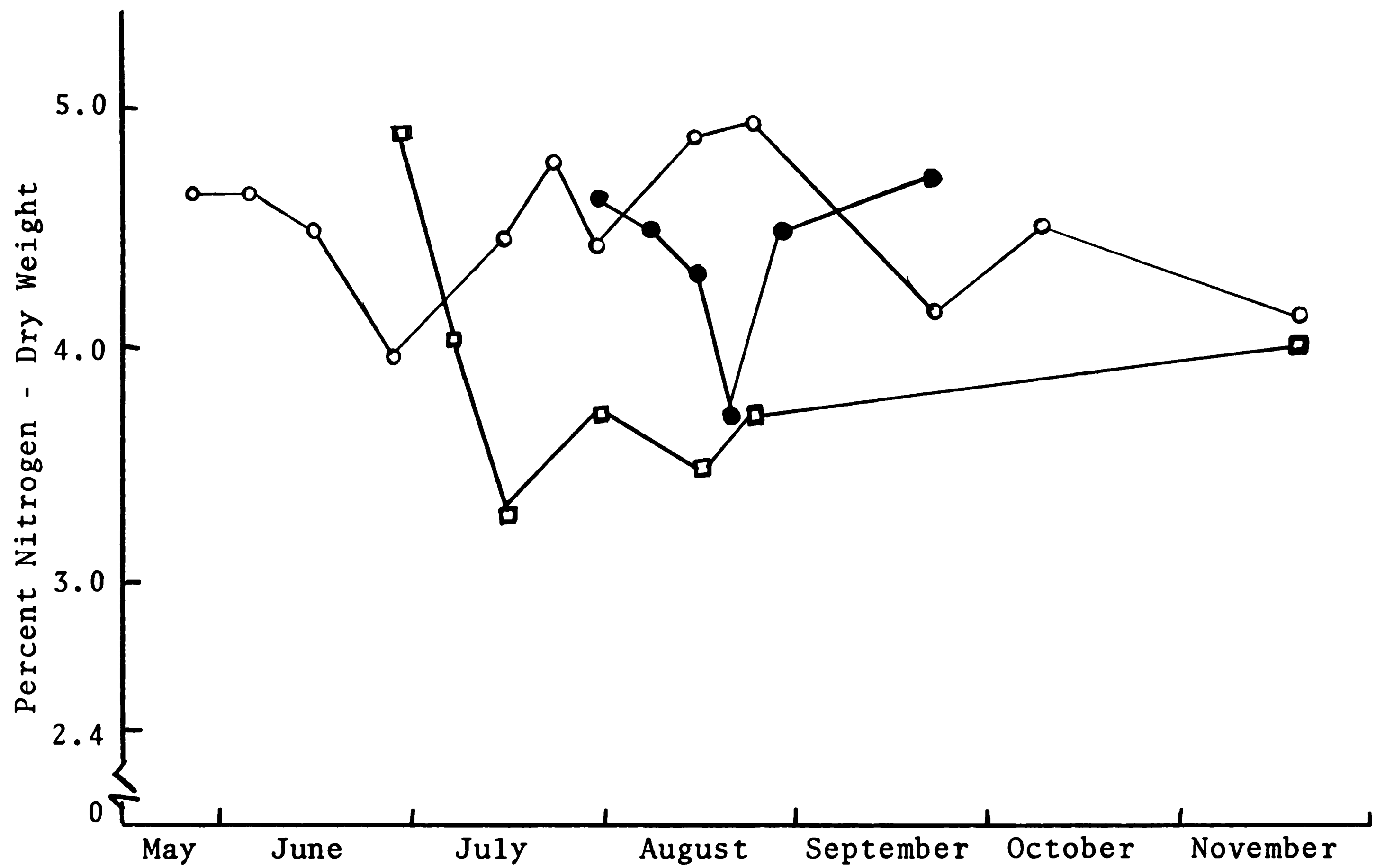

Figure 9. Seasonal tissue content of _Ceratophyllum demersum_ as percent nitrogen in Fowlerville (●), Belding (o) wastewater ponds and airport catchment pond (□).

The ratios calculated for _E_. _canadensis_ and _C_. _demersum_ are indicated in Table 3. The ratio was obtained from the seasonal mean tissue concentrations of phosphorus and calcium. _E_. _canadensis_ sampled from the catchment pond is limited as a forage to ruminants only. As far as the nutritional requirements of livestock is concerned, the most favorable ratios occurred in the wastewater populations. Apparently, the higher tissue-P levels in these populations established a lower Ca:P ratio. From this standpoint, the submerged hydrophytes appear suitable as an animal fodder.

As noted by Tierney (1972b), trace element accrual may limit such a feasibility. Also, the potential for nitrate poisoning in livestock from submerged hydrophytes is unknown. Normally functioning terrestrial plants usually contain relatively small amounts of nitrate, but under certain environmental conditions fairly high concentrations of nitrate may accumulate (Tucker _et al_., 1961). Since only the total nitrogen content of _E_. _canadensis_ and _C_. _demersum_ was ascertained, no data is available on the tissue nitrate concentration. Wick and Sandstrom (1939) found essentially no nitrate-N in the tissues of _E_. _canadensis_ collected from a small stream. The difference between such a habitat and the chemical regime of the wastewater ponds should be substantial. Examination for nitrate-N and other nitrogen

Table 3. The dry weight ratio of calcium:phosphorus in *Elodea canadensis* and *Ceratophyllum demersum* growing in the wastewater and catchment ponds.

Species	Site		
	Airport	Fowlerville	Belding
E. canadensis	~5:1	~3:1	--
C. demersum	3:1	2:1	~2:1

compounds as well as phosphorus compounds needs to be performed on submerged hydrophytes grown in wastewater. The qualitative composition is as important as the purely quantitative determination.

Hydrophyte Harvestability

The use of aquatic vascular plants as a means of mineral nutrient removal from hypereutrophic waters has been suggested by Boyd (1970) and others. Some basic ecological information has been gathered on primary production, growth rates and mineral composition of vascular hydrophytes. This has, in turn, stimulated discussion of their role as nutrient sinks in aquatic ecosystems as well as the feasibility of harvesting these sinks. Such reasoning led, ultimately, to the question of how to dispose of the harvested aquatic weeds. Several investigators have directed their activities to the use of hydrophytes as novel sources of protein for man and as fodder for domestic livestock. To this end, numerous proximate analysis studies have occurred assessing the nutritive value of various species (Boyd, 1968a, 1968b, 1969; Little, 1968; Lindstrom and Sandstrom, 1939; Nelson and Palmer, 1939; Gortner, 1934). However, few feeding studies exist demonstrating the actual dietary value of vascular hydrophytes to domestic livestock or to man. Furthermore, it has not been demonstrated that removal of vascular hydrophytes stabilizes or reduces the eutrophic state of the treated lake or stream. Bartsch (1972) feels harvesting aquatic macrophytes is not effective as a method of nutrient removal for lakes in general, rather its effect is cosmetic. However, such mechanical cropping is not entirely undesirable and in certain instances is economically and politically favored (Thompson, 1972). Yet, more direct methods such as diversion of nutrient-laden effluent (Edmondson, 1972) and the dilution of nutrient-rich waters (Oglesby, 1969) entering a lake or stream have controlled the rate of eutrophication in certain instances and appear more feasible as direct eutrophication control measures.

Derr (1972), Boyd (1971), and others have stated that a nutrient removal program designed to decrease aquatic productivity by removal of dissolved nutrients would be most effective if applied to effluents prior to discharge into a lake or stream, and if a method(s) was sought to remove all or most nutrients. Generally, eutrophication control procedures center on the use of chemical processes as the vehicle for nutrient removal (Rohlich, 1969; Rohlich and Uttormark, 1972; Derr, 1972). As seen earlier in this paper and in Tierney (1972a) as well as Boyd (1969, 1970a, 1970b), aquatic vascular plants accumulate several essential and nonessential inorganic elements and thereby appear to meet the abovementioned criteria. If intensely managed communities of selected aquatic vascular plants were grown in wastewater stabilization ponds, nutrient removal by harvesting may be more than cosmetic and aid in reducing the dissolved nutrients concentration in the wastewater discharge. Yet, to date, information on the quantities of nutrients actually removable has not been demonstrated <u>in situ</u>, nor are cost estimates available for incorporating aquatic plant harvesting procedures into established wastewater stabilization systems.

Table 4 indicates the quantity of phosphorus and nitrogen harvestable from the wastewater and catchment ponds of this study. For example, under the climatic conditions of this study, one acre with a one-cropping format would remove ~16 pounds of P at the Fowlerville site; the discharge of 5 persons per annum as calculated on the basis of 3.2 lbs (DW) of P per person per year (Van Vuran, 1948). Nitrogen removal consists of 58 lbs/acre, the equivalent discharge of 5 persons as well, calculated on a waste of 11.4 lbs of N per person per annum (Van Vuran, 1948). The original phosphorus (as P) level was adjusted upward to account for increased consumer use of phosphorus detergents.

Based on Rohlich and Uttormark (1972), 5-50% of N and P is removed through primary treatment and conventional activated sludge systems. Presumably, the removal

Table 4. Maximum net accrual of phosphorus and nitrogen (DW basis) potentially harvestable under a one-crop format.

Site	Total[a] lbs/acre	
	P	N
Belding	7.87	38.89
Fowlerville	15.71	57.91
Airport	28.38	191.11

[a]Total of both species where applicable.

efficiency in conventional wastewater stabilization treatment operations would be within this range. Assuming a mean seasonal efficiency of about 25%, the residual quantity of P and N not removed and therefore available to the macrophytes would be equivalent to approximately 2.4 lbs P per person per year and 8.5 lbs of N per person per year. The harvested plants from Fowlerville now represent the discharge of 7 persons per annum for P and N.

The stabilization pond at Fowlerville was about 5 acres, large enough to only accumulate and remove the P and N discharge of ~35 persons per annum. The city of Fowlerville has about 2,000 inhabitants. Approximately 285 acres would be required to remove the P and N load by harvesting the indigenous species of unmanaged submerged hydrophytes. However, the land area required could be reduced if intensive management of the hydrophytes increased the primary production and the number of harvests per year. Data by McNabb <u>et al</u>. (1972) and McNabb and Tierney (1972) indicate higher production is achievable than what was observed here and several cuttings a year is not unrealistic for hydrophytes found favorably "fitted" to the chemical regime of the hypereutrophic wastewater systems. Assuming three cuttings at the maximum standing crop observed in Fowlerville with the naturally occurring unmanaged plants, the acreage requirement is reduced to about 95 acres. Doubling the size of the standing crop at the time of harvest would tend to lower the acreage needed to ~48 with three cuttings. One could, then, increase the retrival of P and N by intensely managing hydrophyte growth, increasing the number of harvests and obtaining the tissue levels of P and N reported here from the wastewater ponds. However, the cost of daily operation and initial cost of land may prove to be prohibitive.

An acre of land in the vicinity of small mid-Michigan towns has an appraised value ranging from 175 to 2,000 dollars depending on a number of socio-economic variables (Larson, 1972). The estimated cost for 48 acres would range between $8,400 and $96,000 for a community the size of Fowlerville. This represents only the initial cost of land acquisition and does not include the costs of construction, maintenance, harvesting and disposal of the hydrophytes. Nor are estimates of the revenue generating capacity of the harvested plants as animal forage available. Comparative nutrient removal cost estimates are available by Rohlich (1969), Rohlich and Uttormark (1972), and Derr (1972) for conventional treatment plants. Land costs should be roughly similar per acre; however, chemical nutrient removal processes require less acreage and are usually incorperated into the existing facility. Total land costs should be lower. Presently, the use of aquatic plants for nutrient removal appears to be faced with limitations due to the land area required, variability in size of standing crops and limited growing season in temperate climates.

In addition to the question of land requirements and associated costs, biologic problems of disposal upon harvesting require further attention. For instance, the possibility exists of heavy metal accrual in the hydrophytes which would pose problems in their use as a feedstuff (Tierney, 1972b). Also, before a complete picture of the hydrophytes potential in a biological nutrient removal system can be formed, the efficiency of nutrient removal needs to be obtained as well. Indirect estimates, such as the pounds of P per person per year, do not fully provide the answer. The measurement of the quantity of P and N entering a system, the amount existing, the quantity residing in the hydrophytes and in the sediments provide the minimum data on which the efficiency of aquatic plants as nutrient sinks can be ascertained. Though the value of harvesting aquatic plants to reduce the ambient dissolved nutrient loads of wastewater discharges is unresolved, one ancillary aspect of harvesting appears beneficial. In existing pond systems loaded with nuisance growths of naturally occurring vascular macrophytes, annual removal by mechanical harvesting would reduce the rate of autumnal organic sedimentation and, thereby, reduce the rate of filling in of the ponds. This would effectively extend the life expectancy of the ponds.

CONCLUSIONS

1. The wastewater chemical melieu was the more favorable environment for the growth of E. canadensis. The doubling time was about 4-fold faster for this species in the Fowlerville wastewater pond than in the catchment pond. The lower primary productivity rates and maximum standing crops achieved by the wastewater-grown E. canadensis is due to reduced spring vegetative density and autumnal shifts in light intensity and ambient water temperature. The effect was to alter the intensity of environmental resistance significantly in the wastewater site compared to seasonal variations in the catchment pond.

2. The size of the standing crop at the study sites was not related to the ambient soluble-P or nitrate-N concentrations. Tissue levels in E. canadensis and C. demersum were above the critical concentration level established by Gerloff and Krombholz (1966). Apparently, tissue levels as high as those observed here indicate that neither the environmental level of phosphorus or nitrogen is limiting to aquatic macrophyte growth.

3. Though the size of the standing crop did not reflect the soluble-P concentration of the study sites, phosphorus tissue accrual by _C. demersum_ and _E. canadensis_ was related to the ambient soluble-P concentrations among the study sites. The tissue phosphorus level increased in the submerged vegetation in a parallel fashion to environmental levels of soluble-P encountered among the three study sites. This site difference in tissue-P content of the plants is attributed to the different environmental conditions and not to genetic uniqueness of the spatially separated populations.

4. Phosphorus levels in the submerged aquatic plants were 2 to 10-fold higher than values reported for aquatic plants grown in natural lakes and streams. Nitrogen levels were similar to the reported range for submerged hydrophytes.

5. _E. canadensis_ and _C. demersum_ did not demonstrate any difference in phosphorus accumulation within the same site. However, nitrogen accrual tended to be higher in _C. demersum_. Presumably, interspecific genetic differences in phosphorus uptake and accumulation are absent while existence of such differences are suggested for nitrogen accrual.

6. On the basis of the Ca:P ratios, the submerged macrophytes appear suitable for use as an animal fodder. However, no information on the content of tissue nitrate-N

is available. The possibility of deleterious accumulations of nitrate-N should be considered.

7. Temporal variation in tissue-P content was fairly constant in the catchment pond plants while more variability was observed in the wastewater populations. Where percentage tissue-P values remained relatively uniform, the rate of phosphorus uptake is considered approximately similar to the rate of biomass synthesis up to and including the achievement of maximum standing crop. Percentage tissue-N varied widely and no seasonal pattern emerged.

8. The quantities of phosphorus and nitrogen harvestable under a one-crop format in the Fowlerville wastewater pond was ~16 and ~58 lbs/acre, respectively. These quantities could be elevated by increasing the number of cuttings and the size of the standing crops at time of harvest. Removal efficiencies were estimated by calculating the annual per person discharge of P and N in domestic sewage. Under the harvesting conditions of this study, macrophyte removal only equalled the P and N annual discharge of 7 people. Extensive land area would be required to serve a community of only 2,000 inhabitants effectively. The problem of disposal of the harvested plants may also be troublesome.

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PART 2

TRACE ELEMENT ACCUMULATION

INTRODUCTION

Interspecific differences in mineral accumulation are a well recognized phenomenon in terrestrial floral investigations (Mitchell 1945, Hill et al. 1953, Beeson et al. 1955, Schütte 1964, Dykeman and Desousa 1965). Equally documented is intraspecific variation in mineral accumulation from different areas (Beeson et al. 1955, Schütte 1964, Dykeman and Desousa 1965). Interspecific mineral accumulation among aquatic macrophytes should be observable since their evolutionary origins are terrestrial (Sculthorpe, 1967). Observable intraspecific differences should also be demonstrable, as inorganic mineral distribution is not quantitively homogenous among aquatic habitats (Hutchinson, 1957). The mineral inputs to watercourses usually reflect the "land-uses" of the region as well as the natural geochemical weathering processes (Kopp and Kroner, 1970).

Boyd (1968, 1970a, 1970b) reports interspecific mineral accumulation in aquatic vascular plants from a single site. Other studies by Boyd (1968, 1969) have described intraspecific variation observable in an aquatic vascular plant's inorganic mineral composition when grown in different environments. Additional studies by Harper and Daniel (1934), Gerloff and Krombholz (1966), Allensby (1966) and Anderson et al. (1966) present evidence of both processes for emergent and submerged vascular plants.

All the above mentioned studies have usually considered nitrogen and phosphorus uptake as well as the other macronutrients. Only a few (for example, Boyd 1969, 1970b) have considered the trace element composition; and then, generally only those elements thought essential to plant nutrition. Additionally, the research occurred in aquatic enviornments relatively devoid of the direct impingement of man's activities. Information also needs to be gathered on the temporal dynamics of trace element accumulation in aquatic macrophytes. As Boyd (1970a) points out, little is known regarding the seasonal periodicity in nutrient uptake or the relationship between dry matter production and nutrient accumulation.

Data on the accumulation of eight trace elements (Cd, Co, Ni, Pb, Cu, Zn, Fe, Mn) was gathered on two naturally occurring submerged macrophytes, Elodea canadensis and Ceratophyllum demersum, growing in municipal sewage-oxidation ponds and a small catchment pond not receiving domestic effluent. The latter site is located in the immediate environs of a moderately large industrial city while the former served two small mid-Michigan towns. Three of the trace elements studies (Pb, Ni, Cd) are thought to be non-essential for plant nutrition, but when accumulated in moderate quantities are relatively toxic to plants and animals (Bowen, 1966). In addition, their distribution in the environment is often largely a by-product of industrial processes (Browning 1969, Kopp and Kroner 1970). In light of the recent discovery of mercury's distribution in the environment and ecologic stress (D'Itri, 1971), collection of information on other heavy metal distributions in the biota is pertinant to developing a better understanding of inorganic mineral flow in the structure and function of ecosystems.

MATERIALS AND METHODS

The study sites consisted of two wastewater ponds, circa 2 and 10 hectares in area, serving the communities of Fowlerville and Belding, Michigan and a 8 hectare catchment pond located in the environs of Lansing, Michigan. Specimens for trace element analyses were collected from naturally occurring populations of _E. canadensis_ and _C. demersum_. Collections were obtained approximately biweekly throughout the summer and fall of 1970. All samples were collected by hand, washed in the pond water to remove debris, placed in plastic bags and stored on ice enroute to the laboratory. Whole plants were washed in deionized water and dried in a forced draft oven at 80°C for 24 hours. Lime incrustations and other adhesions were not removed. Dry weight was recorded and plant material was ground in a Wiley mill adapted for trace element analyses using a 40 mesh screen. Samples were combined for a given date and stored under dessication.

A wet ashing procedure (Gorsuch, 1959) of HNO_3 and $HClO_4$ acid was employed to digest the plant tissue in a Bethge distillation apparatus made of Vycor-ware glass (D'Itri, 1970). Glassware was cleaned according to directions of Thies (1957) and Mizuike (1965) for trace element studies. Subsequent to digestion, samples were stored in polyethylene vessels (Mizuike, 1965). Approximately 0.8 to 1.0 grams of dry plant material was used per digestion. Triplicate determinations were made for each sampling date. Trace elements were determined using a Jarrell-Ash 800 atomic absorption spectrophotometer.

RESULTS AND DISCUSSION

Interspecific and Site Variation in Mineral Accural

Interspecific variation in trace element content of the vascular hydrophytes was observed in this study. While the mean tissue accumulation of Cd, Co, Ni, Cu, Zn and Fe was similar in *E. canadensis* and *C. demersum* growing in the catchment pond, the latter species exhibited significantly higher levels of Pb and Mn. Co-occurring populations of

E. canadensis and C. demersum growing in the chemical regime of the Fowlerville wastewater pond contained similar quantities of Cd, Co, Fe and Mn; but Cu and Zn levels were significantly greater in C. demersum, while E. canadensis had higher levels of Ni and Pb. Thus interspecific variation is striking. It is displayed in Table 1. The degree of similarity or difference in net quantities of trace elements accumulated by the two species is treated statistically in Table 2 (Siegel, 1956). The plants were apparently growing under identical nutrient conditions, so the variation in tissue levels represent species differences in trace element accumulation. This generality is confirmed in the work of Boyd (1970a, 1970b), who found species differences in emergents, submerged and floating leaf plants with respect to macro- and microelement accural. The work of Gerloff and Krombholz (1966) shows differential macronutrient accumulation as well.

The habitat in which a particular species exists effects the uptake of trace elements. Significant site differences in tissue content are observable for all trace elements, except Cu, in E. canadensis removed from Fowlerville compared to plants from the catchment pond. Similarly, levels of Cd, Ni, Cu, Zn, Fe and Mn in C. demersum were significantly higher in plants grown in the Fowlerville wastewater location compared to the airport catchment pond (Tables 1 and 2). Boyd (1969), Harper and Daniel (1934),

Table 1. Quantity of trace elements in _E. canadensis_ and _C. demersum_ (DW) based on mean tissue content up to and including period of maximum standing crop. (μg/gm ± SE). Number of analyses in parenthesis.

Site	Cd	Co	Ni	Pb	Cu	Zn	Fe	Mn
				E. canadensis				
Fowlerville	3.0±0.3 (15)	6.3±0.4 (15)	12.5±0.6 (15)	24.0±1.5 (15)	27.6±5.3 (15)	71.6±7.5 (15)	1878±250 (14)	2688±489 (15)
Airport[a]	2.1±0.3 (15)	4.0±0.3 (15)	9.6±0.6 (15)	21.8±1.7 (15)	30.0±3.6 (15)	51.0±3.9 (15)	1297±128 (15)	691±61 (15)
				C. demersum				
Fowlerville	2.4±0.3 (17)	6.0±0.3 (18)	11.5±0.6 (18)	20.0±0.6 (18)	45.0±6.0 (18)	90.0±5.3 (18)	2045±220 (18)	3229±540 (18)
Airport[a]	1.7±0.1 (10)	5.0±0.5 (10)	9.0±0.7 (10)	25.8±1.9 (9)	23.0±2.9 (10)	69.0±10 (9)	1225±156 (10)	1071±103 (10)
Belding	1.2±0.1 (14)	3.8±0.3 (14)	8.5±0.7 (14)	19.3±1.4 (14)	62.4±4.5 (14)	116 ±15 (15)	642±76 (14)	1386±130 (14)

[a]Catchment pond.

Table 2. Analysis of E. canadensis and C. demersum interspecific trace element accumulation within a site and differential accumulation of each species in different sites. (Mann-Whitney U Test).

Site	Cd	Co	Ni	Pb	Cu	Zn	Fe	Mn
				INTERSPECIFIC ACCUMULATION				
Fowlerville	E[c] = C 0.10[b]	E = C 0.10	E > C 0.10	E > C 0.02	E < C 0.02	E < C 0.05	E = C 0.10	E = C 0.10
Airport[a]	E = C 0.10	E = C 0.10	E = C 0.10	E < C 0.10	E = C 0.10	E = C 0.10	E = C 0.10	E < C 0.02
				SITE ACCUMULATION				
				E. canadensis				
Fowlerville - Airport	F > A 0.02	F > A 0.002	F > A 0.002	F > A 0.10	F = A 0.10	F > A 0.05	F > A 0.05	F > A 0.002
				C. demersum				
Fowlerville - Airport	F > A 0.05	F = A 0.10	F > A 0.02	F < A 0.02	F > A 0.02	F > A 0.02	F > A 0.02	F > A 0.002
Belding - Airport	B < A 0.02	F < A 0.05	F = A 0.10	B < A 0.02	B > A 0.002	B > A 0.002	B < A 0.002	B > A 0.10
Fowlerville - Belding	F > B 0.002	F > B 0.002	F > B 0.002	F = B 0.10	F < B 0.05	F = B 0.10	F > B 0.002	F > B 0.002

[a]Catchment non-sewage pond.

[b]Alpha level of acceptance or rejection of null hypothesis of no difference in trace element content.

[c]E = *E. canadensis*, C = *C. demersum*, F = Fowlerville, Michigan, sewage pond, B = Belding, Michigan, Sewage pond, and A = Lansing, Michigan, airport catchment pond.

Anderson _et al._ (1966) and Adams _et al._ (1971) also report site variation in mineral accumulations in other aquatic plants. Presumably, the genetic composition of the different populations of a species is identical, so the differences in tissue level represent different environmental trace element conditions. However, the possible existence of ecotypes or locally distinct genotypes needs further consideration (Anderson _et al._ 1966).

While comparisons above are for a catchment and wastewater pond, site differences exist between naturally occurring populations of _C_. _demersum_ taken from the two wastewater facilities as well. All trace elements, except Pb and Cu, are significantly higher in samples of _C_. _demersum_ removed from the Fowlerville pond (Table 2). Apparently, this disparity reflects a difference in the quantity of trace elements in the municipalities waste or in the quality of the physical-chemical conditions of each pond. Trace element accumulation in aquatic macrophytes from waters not receiving municipal effluent can also be higher than from wastewater ponds. _C_. _demersum_ sampled from the catchment pond contained significantly higher concentrations of Cd, Co and Fe than populations grown in the Belding wastewater site. Pb tissue content was highest in _C_. _demersum_ from the non-sewage site compared to samples obtained from both wastewater sites (Table 1 and 2).

The location of the catchment pond in close proximity to planes, highways and industrial activity suggests a plausible explanation for the high trace element content of the submerged vascular plants. It was abutting the airport landing area and within a mile of a major highway. Browning (1969) and Kopp and Kroner (1970) have noted that many of the trace elements distribution in nature are mainly the result of man's activity. Atmospheric precipitation contains Pb, Zn, Cu, Fe, Mn and Ni (Lazrus _et al._ 1970). Emission particles from industrial and vehicle combustion processes plus decomposition of metal components through age and wear are distributed over a geographic area by rain and wind currents (Anomous.1966, Carroll 1969). Deposition of Pb and other trace elements on the soil and plant life is greatest near highways (Page and Ganje 1970, Lagerwerff and Specht 1970, Dedolph _et al._ 1970). Based, then, on these sources of trace elements and their patterns of distribution, the accumulation of these elements in the catchment pond appears reasonable. Whether ponds more remotely located from urban-industrial centers contain plants with a significantly lower trace element content needs to be determined. However, such localities may already be lacking since many of the trace elements are considered to be ubiquitous in global distribution (Browning, 1969). Any differences in accumulation may be too small to be significant relative to the other environmental variables that also control plant mineral uptake and accumulation.

The relative abundance of each trace element in the aquatic plants can be seen in Table 1. The elements are ranked from least to most abundant. Cobalt is present in the smallest amounts while iron and manganese are the most abundant. This ranking shows essentially no inter-specific preference or site variation.

Temporal Dynamics of Mineral Uptake

Absolute net accrual of ash and individual trace elements on a square meter basis usually increased up to the maximum standing crop in both species at all sites (Tables 3 - 7). The largest quantities accumulated in populations with the largest plant biomass. *E. canadensis* and *C. demersum* growing in the airport catchment pond had the highest standing crops of 410 and 75 $gm\text{-}m^2$, respectively (Tierney, 1972a). Boyd (1969, 1970b) observed a similar mineral accrual pattern in four emergent aquatic vascular plants.

Percentage values of ash and microelements did not uniformly decrease in *E. canadensis* and *C. demersum* during the periods up to and including maximum standing crop. The individual tissue constituent varied widely over these periods and no general pattern is clearly

Table 5. Percentage composition of ash and ppm-ppt of trace elements and amounts of these constituents per square meter in C. demersum grown in Belding wastewater pond. (Mean ± SE).

Constituent	Date 6-3	6-30	7-30	8-13[a]	9-1	9-24	10-9
				Ceratophyllum demersum			
Ash (%)	16.1[b] ± 0.6	16.0 ± 2.1	17.5 ± 2.5	17.2 ± 0.7	16.3 ± 1.6	16.4 ± 1.8	13.7 ± 2.1
(g/m^2)	5.2	1.8	12.9	15.9	13.6	11.2	9.1
Cd (ppm)	1.4 ± 0.1	1.6 ± 0.1	1.0 ± 0.1	1.2 ± 0.2	1.2 ± 0.2	1.1 ± 0.2	1.0 ± 0.1
($\mu g/m^2$)	44.2	17.9	70.6	103.9	97.4	75.0	67.6
Co (ppm)	4.8 ± 0.8	4.2 ± 0.6	3.3 ± 0.2	3.5 ± 0.6	3.5 ± 0.3	3.4 ± 0.2	4.2 ± 0.2
($\mu g/m^2$)	152.0	46.2	241.1	312.5	290.6	234.5	291.2
Ni (ppm)	9.2 ± 0.8	11.9 ± 3.5	7.5 ± 1.5	6.7 ± 0.7	8.5 ± 1.4	5.4 ± 0.4	7.1 ± 0.4
($\mu g/m^2$)	293.7	131.5	548.3	600.8	708.5	370.2	486.5
Pb (ppm)	21.6 ± 2.1	28.7 ± 1.2	16.9 ± 0.4	17.7 ± 1.9	14.6 ± 1.3	14.0 ± 0.5	15.4 ± 0.7
(mg/m^2)	0.7	0.3	1.3	1.6	1.2	1.0	1.1
Cu (ppm)	85.5 ± 9.8	50.2 ± 2.8	54.2 ± 4.5	63.4 ± 7.1	54.3 ± 7.6	4.4 ± 0.5	7.1 ± 1.1
(mg/m^2)	2.7	0.6	3.9	5.7	4.5	0.30	0.49
Zn (ppm)	119.0 ± 1.4	159.7 ± 0.7	91.1 ± 6.1	57.4 ± 7.4	72.5 ± 1.1	110.6 ± 4.1	130.9 ± 3.3
(mg/m^2)	6.4	1.8	6.7	5.1	6.0	7.5	9.0
Fe (ppm)	774.4 ±92.4	1171.3 ±72.2	436.7 ±27.0	435.0 ±66.4	571.1 ±108.9	567.3 ±39.5	629.6 ±17.7
(mg/m^2)	24.8	13.0	32.1	38.9	47.5	38.7	43.4
Mn (ppt)	1.0 ± 0.1	1.5 ± 0.1	1.3 ± 0.02	1.1 ± 0.1	2.0 ± 0.4	1.83± 0.1	1.9 ± 0.1
(mg/m^2)	32.8	16.7	98.2	98.0	167.3	125.0	130.6

[a]Maximum standing crop. [b]Dry weight.

Table 4. Percentage composition of ash and ppm-ppt of trace elements and amounts of these constituents per square meter in *Ceratophyllum demersum* growing in Fowlerville wastewater pond. (Mean ± SE).

Constituent	Date: 7-30	8-6	8-13	8-20	8-26	9-24[a]
			Ceratophyllum demersum			
Ash (%)	23.9[b] ± 3.4	28.2 ± 1.7	29.7 ± 1.3	24.7 ± 1.0	21.7 ± 0.7	17.7 ± 1.5
(g/m^2)	0.2	6.0	3.7	8.8	5.3	6.1
Cd (ppm)	1.4 ± 0.1	1.9 ± 0.2	2.6 ± 0.1	3.3 ± 0.9	1.7 ± 0.1	4.1 ± 0.3
($\mu g/m^2$)	1.0	39.4	48.2	116.1	40.8	141.8
Co (ppm)	7.8 ± 0.4	7.1 ± 0.3	6.4 ± 0.2	5.4 ± 0.4	5.1 ± 0.3	4.5 ± 0.1
($\mu g/m^2$)	5.5	149.3	118.1	193.3	124.9	154.9
Ni (ppm)	12.1 ± 0.5	14.7 ± 2.7	11.4 ± 0.6	11.3 ± 0.3	9.4 ± 0.5	9.9 ± 0.6
($\mu g/m^2$)	8.6	309.8	210.1	402.7	230.9	340.6
Pb (ppm)	18.9 ± 0.4	22.3 ± 2.0	19.4 ± 1.3	20.1 ± 1.3	19.3 ± 1.7	20.4 ± 1.4
($\mu g/m^2$)	13.4	469.2	359.1	716.4	474.3	702.6
Cu (ppm)	32.1 ± 1.1	51.0 ±17.6	71.3 ± 5.1	58.7 ±15.0	43.5 ±14.5	14.1 ± 1.2
(mg/m^2)	0.3	1.1	1.3	2.1	1.1	0.50
Zn (ppm)	76.4 ± 9.5	88.9 ± 8.9	101.1 ± 7.4	71.2 ± 2.1	84.2 ± 9.3	118.9 ±18.9
(mg/m^2)	0.6	1.9	1.9	2.5	2.1	4.1
Fe (ppt)	2.9 ± 0.5	2.9 ± 0.3	2.1 ± 0.2	2.2 ± 0.1	1.5 ± 0.3	0.7 ± 0.1
(mg/m^2)	2.1	60.3	38.9	78.2	35.6	23.0

[a]Maximum standing crop. [b]Dry weight.

Table 5. Percentage composition of ash and ppm-ppt of trace elements and amounts of these constituents per square meter in *Elodea canadensis* growing in a Fowlerville wastewater pond. (Mean ± SE).

	Date				
Constituent	8-6	8-13	8-20	8-26	9-24[a]
			Elodea canadensis		
Ash (%)	26.0[b] ± 1.1	31.0 ± 1.2	27.2 ± 2.0	25.4 ± 0.9	24.5 ± 0.9
(g/m^2)	2.6	2.2	9.3	16.8	28.4
Cd (ppm)	2.9 ± 0.3	4.5 ± 1.4	2.7 ± 0.2	2.5 ± 0.4	2.6 ± 0.4
($\mu g/m^2$)	28.4	29.3	93.5	168.1	313.8
Co (ppm)	7.5 ± 0.3	6.8 ± 0.7	7.4 ± 0.7	5.4 ± 0.6	4.7 ± 0.3
($\mu g/m^2$)	74.2	44.2	252.6	359.8	554.8
Ni (ppm)	14.1 ± 0.7	13.5 ± 0.8	12.8 ± 1.3	10.4 ± 1.8	11.8 ± 1.0
($\mu g/m^2$)	140.0	88.0	437.0	700.1	1412.8
Pb (ppm)	23.0 ± 2.8	23.2 ± 2.1	25.1 ± 1.8	27.8 ± 7.2	20.9 ± 1.2
($\mu g/m^2$)	228.5	151.2	855.6	1868.9	2489.0
Cu (ppm)	53.3 ±14.7	37.4 ±12.7	20.7 ± 2.8	11.0 ± 0.8	15.7 ± 0.5
($\mu g/m^2$)	529.1	244.1	706.7	733.0	1878.1
Zn (ppm)	69.0 ± 8.7	75.4 ± 7.2	39.6 ± 2.2	52.2 ± 3.9	111.0 ±18.8
(mg/m^2)	0.7	0.5	1.4	3.5	3.2
Fe (ppt)	3.2 ± 0.4	2.8 ± 0.3	1.6 ± 0.1	1.0 ± 0.3	1.3 ± 0.3
(mg/m^2)	31.2	18.1	55.5	66.9	151.3

[a]Maximum standing crop. [b]Dry weight.

Table 6. Percentage composition of ash and ppm-ppt of trace elements and amounts of these constituents per square meter in E. canadensis grown in airport catchment pond. (Mean ± SE of DW).

Constituent	6-23	6-30	7-9	7-17	8-13[a]	8-20	10-9	11-3
				Elodea canadensis				
Ash (%)	21.8[b] ± 1.0	19.7 ± 3.4	18.5 ± 0.6	16.8 ± 0.3	21.8 ± 0.3	20.2 ± 0.3	33.7 ± 1.1	24.2 ± 2.5
(gm/m^2)	10.9	11.7	17.6	27.3	87.5	39.4	43.9	22.5
Cd (ppm)	1.6 ± 0.4	4.2 ± 0.4	2.1 ± 0.4	1.3 ± 0.2	1.5 ± 0.2	1.7 ± 0.2	1.8 ± 0.3	2.3 ± 0.1
(μg/m^2)	78.4	246.3	201.8	216.0	620.3	326.3	363.4	214.0
Co (ppm)	3.9 ± 0.8	4.4 ± 1.1	3.8 ± 0.3	4.1 ± 0.2	4.3 ± 0.3	6.1 ± 2.6	6.1 ± 0.5	6.9 ± 0.7
(μg/m^2)	196.8	262.9	364.5	659.1	1794.2	1195.0	1207.2	637.4
Ni (ppm)	9.3 ± 1.7	11.3 ± 0.4	10.1 ± 1.4	8.2 ± 1.1	8.8 ± 1.2	7.4 ± 0.9	11.7 ± 1.1	11.8 ± 0.6
(mg/m^2)	0.50	0.70	1.0	1.3	3.7	1.5	2.3	1.1
Pb (ppm)	27.1 ± 5.6	18.1 ± 3.0	25.6 ± 4.2	18.2 ± 1.8	19.9 ± 1.2	16.5 ± 1.9	24.0 ± 2.3	29.3 ± 0.4
(mg/m^2)	1.4	1.1	2.4	3.0	8.3	3.2	4.8	2.7
Cu (ppm)	11.0 ± 3.0	42.8 ± 3.7	27.8 ± 8.8	28.3 ± 3.8	40.6 ± 4.7	10.7 ± 1.7	5.9 ± 0.8	5.0 ± 0.6
(mg/m^2)	0.6	2.6	2.6	4.6	17.0	2.1	1.2	0.5
Zn (ppm)	53.2 ± 14.1	56.1 ± 5.6	54.3 ±11.2	47.9 ± 6.6	44.6 ± 8.9	34.7 ± 3.2	42.6 ± 4.3	59.0 ± 6.1
	2.7	3.3	5.2	7.8	18.6	6.8	8.5	5.5
Mn (ppm)	938.0 ±185.0	572.0 ±132.0	655.0 ±50.0	544.0 ±103.0	741.0 ±129.0	427.0 ±39.0	605.0 ±109.0	486.0 ±42.0
(mg/m^2)	46.9	33.9	62.4	88.4	308.9	84.0	120.3	45.3
Fe (ppt)	1.6 ± 0.4	1.0 ± 0.3	1.5 ± 0.1	1.4 ± 0.3	1.0 ± 0.1	0.8 ± 0.1	1.0 ± 0.1	2.1 ± 0.2
(mg/m^2)	80.4	56.5	144.0	223.8	430.4	171.1	196.0	191.7

[a] Maximum standing crop. [b] Dry weight.

Table 7. Percentage composition of ash and ppm-ppt of trace elements and amounts of these constituents per square meter in C. demersum grown in airport catchment pond. (Mean ± SE).

Constituent	Date 6-30	7-17	8-13	8-20[a]	10-9
			Ceratophyllum demersum		
Ash (%)	18.6[b]	21.5 ± 0.7	27.9	24.1 ± 0.7	23.8 ± 1.4
(gm/m^2)	0.40	3.5	3.4	18.3	0.60
Cd (ppm)	2.0 ± 0.3	1.5 ± 0.3	1.4 ± 0.1	1.8 ± 0.1	1.3 ± 0.1
($\mu g/m^2$)	5.2	24.7	17.2	139.9	3.1
Co (ppm)	4.9 ± 1.2	5.3 ± 0.2	7.4 ± 1.0	4.4 ± 0.8	5.6 ± 0.3
($\mu g/m^2$)	12.8	87.5	40.5	333.0	13.5
Ni (ppm)	10.5 ± 3.0	9.0 ± 1.8	8.6 ± 1.1	7.5 ± 0.3	9.2 ± 0.6
($\mu g/m^2$)	26.9	151.0	106.0	569.5	22.1
Cu (ppm)	11.4 ± 1.1	26.5 ± 0.1	31.9 ± 2.1	18.1 ± 0.8	30.0 ± 3.5
($\mu g/m^2$)	29.4	440.1	392.0	1377.7	72.3
Pb (ppm)	32.3 ± 4.9	28.4 ± 1.0	20.8 ± 2.4	22.8 ± 2.8	26.8 ± 3.7
($\mu g/m^2$)	83.0	471.9	254.9	1730.4	64.5
Zn (ppm)	57.5 ± 8.4	71.1 ± 8.8	92.8 ±24.2	48.8 ± 4.4	116.7 ±12.7
(mg/m^2)	0.2	1.2	1.1	3.8	0.3
Fe (ppt)	1.1 ± 0.1	2.0 ± 0.2	1.3 ± 0.1	0.8 ± 0.1	1.6 ± 0.1
(mg/m^2)	2.7	33.2	15.5	54.2	3.9
Mn (ppt)	0.6 ± 0.01	1.3 ± 0.10	1.1 ± 0.1	1.0 ± 0.2	2.3 ± 0.4
(mg/m^2)	1.6	21.7	13.8	78.3	5.5

[a]Maximum standing crop. [b]Dry weight.

discernable (Tables 3 - 7). For example, lead and copper levels in _C. demersum_ from the Belding pond decreased while the plant aged. However, lead remained constant and copper increased in _C. demersum_ removed from the catchment pond. Boyd (1969, 1970b) found the percentage values of ash and macronutrients decreased in all emergent species as the plants aged. However, the trace element dynamics (Fe, Mn, Zn, Cu) did not as clearly reflect the mineral decline pattern observed with the macronutrients (Boyd, 1969). In this regard, the emergent and submerged plants trace element patterns are in agreement.

In contrast to the declining macronutrient levels observed in the emergent species (Boyd, 1969, 1970b), macronutrient (P and N) percentage tissue content in _E. canadensis_ and _C. demersum_ remained relatively constant as the plants aged (Tierney, 1972a). Presumably, the percentage decline of macronutrients with growth is a plant response to low environmental levels, such that the uptake of nutrients does not match the rate of growth. That some uptake occurs is observed by the increasing absolute quantities of elements per square meter. If the above assumption is tenable, the similarity between trace element accumulation in emergent and submerged aquatic plants is explainable on the basis of the environmental level of these elements being saturated relative to the plant's growth rate. The decline in macronutrients (P and N) in the emergents and not in the submerged plants seems to indicate the latter are in a comparatively enriched macronutrient regime compared to biomass synthesis.

Though *E. canadensis* and *C. demersum* trace element tissue content did not exhibit the general decline up to maximum standing crop as the emergents, the tissue content of the individual trace elements did vary; such that the trace elements net rate of uptake was not always proportional to the net dry matter production as measured by the change in percentage tissue level over time. For example, the uptake of Cu, Pb, Zn, Fe and Mn by *C. demersum* occurring in the catchment pond was not proportional to net primary production while Cd, Co and Ni uptake was roughly proportional. However, *E. canadensis* co-occurring with *C. demersum* exhibited net mineral uptakes approximately proportional to net dry matter production for all trace elements. As Boyd (1969) noted, the standard errors for microelements are much wider than observed for macroelements. Conclusions on temporal uptake are therefore more difficult to discern precisely.

The trace elements most often accumulated in proportion to net dry matter synthesis irregardless of site or species were Cd, Co, Ni, and Pb. Only Co is considered essential for certain plant groups (Price, 1970). The remainder are considered non-essential and relatively toxic to plants (Sauchelli 1969, Bowen 1966). To date, little is known regarding the mobility of these ions. Sites of accumulation and distribution of these cations throughout the plant by translocation and redistribution were not ascertained. Whole plant analysis as performed in this study did not measure these internal physiologic activities.

The field studies of Boyd (1969, 1970b) and others with naturally occurring populations of vascular aquatic plants usually terminated subsequent to the date of maximum standing crop and therefore do not contain information on mineral dynamics during the "moribund" period of growth. Trace element net uptake and loss during autumnal decomposition in _E_. _canadensis_ and _C_. _demersum_ reflect seemly selective processes depending on the element and species considered. For example, _C_. _demersum_ accumulated Zn and Mn in the catchment pond and the Belding pond. Additionally, Fe was also accumulated in the latter site (Tables 7 and 3). _E_. _canadensis_, however, accumulated Cd, Co, Pb and Fe in the catchment pond (Table 6). Only Fe was accured by both species while Cu was preferentially loss by them. No doubt the flux of trace elements is a complex plant-environment interaction dependent on numerous factors. One of which is the physiologic age of the plant. The mineral physiologic processes in the "moribund" stage of growth differs from earlier periods of growth. Just as caution must be used when estimating average production from autumnal terminal biomass (Westlake, 1965), the use of mineral analysis from the "moribund" phase as a seasonal estimate of plant mineral content requires discretion.

Comparative Mineral Accumulation

Relative to Beeson's (1941) extensive analyses of the trace element content of agriculturally important plants, the aquatic plants _E. canadensis_ and _C. demersum_ contain significantly greater quantities of trace elements when expressed as percentage of dry weight. Levels of cobalt, manganese, nickel, copper, iron, and zinc in the aquatic macrophytes were higher by factors of 30-60, 10-30, 8-20, 5-15, 3-10 and 2-5, respectively. Trace element data in the studies of Miller (1958), Beeson _et al._ (1955), Beeson and MacDonald (1951), Beeson _et al._ (1947), Dykeman and DeSousa (1966), Peck and Walker (1970), Hill _et al._ (1953), Mitchell (1945), Pyatnitskaya (1970) and Babov _et al._ (1970) reveal a similar pattern. However, data of Small (1970), Schauble (1970) and Munson (1970) with agricultural crops reveal a tissue content of zinc and copper very similar to levels in these aquatic plants. Kehoe _et al._ (1933), Pyantnitskaya (1970) and Ter Haar (1970) observed quantities of lead in edible crops. Generally, the amounts were 50 to 500 fold lower than in the aquatic plants. Notable exceptions were the leaf and chaff portions of crops growing near highways. These parts had levels approximately equal to those in the aquatic plants

(Ter Haar 1970, Lagerwerff and Specht 1970, Dedolph _et al._ 1970). Lagerwerff and Specht (1970) found tall fescue, blue grass and orchard grass close to highways to have lead levels equal to or 2 fold higher than the aquatic plants. Cadmium, nickel and zinc concentrations in these grasses were usually 2 to 4 fold, 2 to 6 fold and 4 fold lower than those in the submerged aquatic plants, respectively.

Cannon (1960) reports the average metal content of five types of vegetation growing in unmineralized soil. The data are expressed as percentage of ash rather than percentage of plant dry weight. She includes analyses from all classes of vegetation including the edible herbaceous plants. The tissue level of cobalt and lead in the submerged plants is 2 to 3 fold higher than in these, while copper, nickel, manganese and iron values are similar to or slightly greater than levels in the above ground portions of grasses and herbs. Zinc content of the submerged aquatic plants is a strikingly 2 to 3 fold lower. Presumably, the inclusion of many terrestrial plant species normally not considered and the expression of results on an ash basis account for the close similarity between the submerged vascular plants and terrestrial vegetation. The use of dry weight or ash weight as the basis for calculating the percentage mineral content may produce striking differences. Anomalies in mineral accumulation are often more pronounced when expressed in the latter form (Cannon, 1960).

Comparisons of trace element content on an ash basis needs consideration as a supplemental measurement in future studies. It's feasibility as an ecologic measure requires further elucidation.

Comparison of trace element quantities observed in Elodea canadensis and Ceratophyllum demersum from this study with other aquatic plant investigations is hampered by their numerical paucity. Few trace elements have been considered. In addition to this difficulty, differences in the type of analysis used, the plant part(s) sampled, time of sampling, species studied, and variation in local environmental limiting factors place constraints on the interpretation of the data. Bearing this in mind, Nelson and Palmer (1939) reported iron (4080 ppm) and manganese (3310 ppm) levels in young green sprigs of E. canadensis while Mayer and Gorham (1951) observed leaf levels of 1320 and 2441 ppm iron and manganese, respectively. The former authors also found 8.4 ppm copper in E. canadensis. McIntosh (1972) noted a median copper content of 28 ppm in whole plant analyses of Elodea nuttallii, while Riemer and Toth (1968) analyzing an Elodea sp. found levels of copper, zinc, manganese and iron to be 21.5, 119, 4200 and 17200 ppm, respectively. Compared to Table 1, the iron, manganese and zinc levels of Riemar and Toth (1968) are higher. The iron level of Nelson and Palmer (1939) is also greater while

Mayer and Gorham (1951) express an intermediate value. Copper quantities are less or similar for all studies.

Regarding _C_. _demersum_, the mean copper level of 15.2 ppm (DW) reported by Riemer and Toth (1968) is lower than values observed here while the zinc content (164 ppm) is 1.5 to 2.5 times higher. Manganese and iron levels of 2900 and 3000 ppm, respectively, are elevated, especially the latter (Table 1). Boyd (1970a) observed copper and zinc levels in _C_. _demersum_ comparable to quantities accumulated in this study. However, manganese and iron levels were usually lower, especially manganese. Trace element values for other aquatic plants span the range found here as well (Boyd 1969, 1970a, Riemer and Toth 1968, Nelson and Palmer 1939, Mayer and Gorham 1951).

As far as presently discernable to the author, no comparative aquatic plant data is available on cobalt accumulation and the literature is also seemly depauperate of data on Ni, Cd and Pb. In cultivated rice, the lead, cadmium and zinc content was 22, 125 and 4700 ppm (ash) in the polished rice grain. Rice was obtained from a district where chronic cadmium poisoning occurred in Japan (Kobayashi, 1971). Cadmium and zinc levels in _E_. _canadensis_ and _C_. _demersum_ were approximately 10 fold lower (~11 and 344 ppm-ash) than rice content. However, lead concentration is 4 to 5 fold higher (~115 ppm-ash) than in the rice. Lead accumulation in rice grains and nonedible portions collected near Crowley, La. was 4 to 500 fold (0.04-5.8 ppm-DW) lower than in the submerged aquatic plants. The highest quantities residing in the nonedible hulls and straw (Ter Haar, 1970).

Despite the difficulties in comparing the trace element concentration of vegetation from different regions of the biosphere, this type of data is the skeleton of an evolving body of basic ecologic knowledge on mineral relationships in vascular plants as well as ecosystem mineral interfacing. For example, programs designed to use aquatic vascular vegetation as a mineral removal agent in coupled aquatic-terrestrial wastewater reclamation projects have been suggested. Aquatic submerged plants can accumulate large quantities of lead and cadmium. Cadmium and lead are cumulative poisons in mammals. Schemes designed to use these aquatic plants as a domestic animal fodder as suggested by Boyd (1971) and others require a cautionary appraisal. This problem is considered by Tierney (1972b).

CONCLUSIONS

1. Elodea canadensis and Ceratophyllum demersum demonstrated differences in trace metal accumulation within the same site. This has been ascribed to the genetic distinctness of each species with regard to mineral uptake and accural.

2. Populations of each species growing in more than one habitat exhibited differences in trace element content. The variation observed is attributed to the different environmental conditions at each site.

3. The ranking of trace elements from least to most abundant in the tissue (ppm) is similar in the submerged plants irregardless of species or site. Cobalt was present in the smallest amounts and manganese usually the largest quantities.

4. Accumulation of trace elements by submerged aquatic vascular plants is a dynamic process, not a static one, with regard to temporal patterns. Seasonal estimates of plant trace element content must consider this factor. For example, values based on autumnal observations are not necessarily the same as ones obtained in earlier periods of the growth curve.

5. The relationship between rate of net dry matter production and net trace element uptake is complex. In some cases, uptake of the element was approximately proportional to primary production as measured by change in percentage tissue levels over time. The elements most often accumulated in proportion to dry matter synthesis were cadmium, cobalt, nickel and lead. No one element increased proportionally with net primary production in either species in all study sites.

6. Trace element levels in the submerged aquatic plants are usually several-fold higher than in terrestrial plants of agricultural importance on a dry weight basis. Lead, cobalt, manganese, nickel and copper have the highest concentrations relative to land plants. When the comparison is on an ash basis, the difference between the aquatic and terrestrial flora decreases. This method apparently accounts for the differences in ash content of terrestrial and aquatic submerged plants. The latter having approximately 15-25 percent of the dry weight biomass in the ash component while the former usually has only one-half to one-third that amount.

7. Trace element levels in Elodea and Ceratophyllum fall within a range found in other studies of these species. Other aquatic vascular plants had tissue levels ranging about the values found here. The relationship between tissue level of an element and environmental quantity of it is still not clear. Critical field and laboratory studies are needed to elucidate the important physical and chemical processes which mediate the uptake and accural of trace elements.

8. The accumulation of cadmium, lead and nickel in aquatic plants needs further study. These elements are toxic to plants and animals in relatively small quantities.

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PART 3

POTENTIAL USE AS A FEEDSTUFF AND SOIL CONDITIONER

INTRODUCTION

Harvesting of vascular hydrophytes has been one mechanism proposed for nutrient removal in eutrophic waterways (Livermore and Wunderlich, 1969). Such plant removal is often initially stimulated by nuisance growths which reduce the functional as well as aesthetic role of the water. Sculthorpe (1967), Little (1968) and Holm *et al.* (1969) have reviewed the problems incurred world-wide when luxuriant growths of aquatic plants have occurred. Regarding the potential use of harvested aquatic plants, Gortner (1934), Mršič (1936), Nelson and Palmer (1939), and more recently, Bailey (1965), Boyd (1968a, 1968b, 1969) and several authors in Little (1968) have presented evidence, experimental and observational, that indicate aquatic plants are often nutritionally suitable as a component in animal feed or as a fertilizer. Specifically, the nutritional characteristics of *Elodea canadensis* and *Ceratophyllum demersum* have been reported by Gortner (1934), Nelson and Palmer (1939) and Boyd (1968). Additionally, Boyd (1968b, 1970) has noted that some aquatic plants have large quantities of trace minerals and could be used as mineral supplements.

Boyd (1968a, 1968b, 1969, 1970) and Holm *et al.* (1969) have considered the question of economic feasibility in harvesting aquatic macrophytes. It is generally held that it is presently not competitive with conventional forage crops in the developed nations. A project developed by the Greater Marshall Industries of Marshall, Texas and funded by the Area Redevelopment Administration of the U.S. Department of Commerce attempted to harvest and process nuisance submerged macrophytes on an economically sound basis (Lange, 1965). The project was abandoned as unsound due to an unusually dry year which reduced the water level and spoiled the plants (Lange, 1971). However, removal of obnoxious plants is beneficial to the economic life of recreation-oriented communities situated on or near enriched shallow lakes (Thompson, 1972).

Stimulation of vascular plant growth in terrestrial species is partially controlled by mineral nutrition as is aquatic plant growth. However, luxuriant growth of the former in an agricultural setting is deemed beneficial and desirable, while such growth in the aquatic-situated species is generally spurned as a nuisance. A vast cadre of scientifically-trained individuals have developed agricultural practices, such as fertilization, conducive to high yields and quality forage and food crops. Traditionally, soil conditioning has consisted of applying various quantities of animal and terrestrial plant residues to the soil as well as inorganic minerals. Ashlander (1958) has reviewed the relative merits of organic and inorganic enrichment of depleted soils to enhance yield. Schütte (1964) and others have noted the naturally occurring trace element imbalances in soils throughout the world, while Thacker and Beeson (1958) described the occurrence of mineral deficiencies and toxicities in domestic herbivores. Sauchelli (1969) has reviewed the importance of trace elements in agriculture as well. The transfer of harvested nuisance aquatic plants to terrestrial agricultural settings as a rich trace element soil conditioner or domestic feedstuff may represent a novel method to better meet the societal approved needs and uses of each sector.

METHODS AND MATERIALS

Naturally occurring populations of *Elodea canadensis* and *Ceratophyllum demersum* were collected from wastewater ponds and from a catchment pond not receiving inputs of domestic waste. The plant material was analyzed for trace element content as well as phosphorus, nitrogen and calcium accumulations. Calcium determinations were performed according to methods reviewed by Elwell and Gidley (1967). Other procedures for plant collection and analysis are reported elsewhere (Tierney, 1972a, 1972b).

RESULTS AND DISCUSSION

Feasibility of Hydrophytes as a Feedstuff

Historically, Gortner (1934) noted that *Elodea* served as an excellent food for cattle and swine in Holland and Germany at the turn of the century. It was equally acceptable as a silage or fresh. Mršič (1936) observed Yugoslavian peasants feeding fresh aquatic plants to cattle. These empirical observations while confirming that domestic livestock will consume aquatic vegetation do not assess the over-all nutritional value. To function as a valuable animal feed, plants must possess adequate amounts of protein, essential amino acids, carbohydrates, fats, crude fiber, vitamins, macroelements and microelements (Miller 1958, Morrison 1961, Cuthbertson 1969). Examples of impaired growth, reproductive failure and death in domestic livestock due to mineral deficiencies or excesses are documented (Underwood 1962, Schütte 1964, Stiles 1961). Excesses of essential microelements can be toxic to domestic herbivores, such as cows, sheep and horses. For example, copper, zinc, cobalt, manganese and molybdenum are some essential trace elements which have been found to be toxic to animals (Underwood 1962, Cuthbertson 1969). Table 1 indicates the average trace element content of the submerged vascular plants. Usually the higher mineral content occurred in plants growing in the wastewater ponds.

Table 1. Average[a] concentration of trace elements in *C. demersum* and *E. canadensis* from wastewater ponds and a catchment pond in Michigan. (mg/kg plant dry weight).

Location	Cd	Co	Ni	Pb	Cu	Zn	Fe	Mn
				C. demersum				
Fowlerville[b]	3	6	11	20	44	91	1,950	3,031
Belding[a]	1	4	8	19	45	119	800	1,564
Airport[c]	2	5	9	26	25	81	1,318	1,348
				E. canadensis				
Fowlerville	3	6	12	25	25	71	1,652	2,590
Airport	2	5	10	25	24	54	1,451	622

[a]Means are based on 15 to 18 measurements up to and including maximum standing crop.

[b]Sewage pond.

[c]Catchment pond.

The essential trace elements are present in greater than adequate quantities for proper growth, but generally below toxic levels with the exception of Cu and Mn in C. demersum. Cadmium content in C. demersum and E. canadensis approached the toxic level as well (Table 2). All cases of trace element accural greater than permissible for normal growth occurred in populations of the aquatic macrophytes from the Fowlerville wastewater pond.

The incompleteness of Table 2 indicates the paucity of knowledge on either the normal or toxic dietary levels of most trace elements. Two of the more comprehensive compilations on mineral composition of forages and cereal grains only contain data on five trace elements; Co, Cu, Fe, Mn, Zn (Miller 1958, Morrison 1961). The International Encyclopedia of Food and Nutrition, Vol. 17, on the nutrition of animals of agricultural importance lists only information on nine trace elements; I, Mo, F, Se and the five mentioned above (Cuthbertson, 1969). Beeson (1941) has information on most of these elements and in addition nickel. The scarcity of data on the amounts of cadmium, lead and nickel in feeds is striking. Apparently, the tissue concentration of Cd in the submerged hydrophytes is only slightly higher than in many land plants (~1 ppm) while the Ni content is up to 35 fold greater than terrestrial plants (~0.35 ppm). The Pb level as well is usually several-fold higher in the aquatic plants (Tierney, 1972b).

Table 2. Approximate concentration of trace elements in diet of livestock and man required for normal growth and toxic disorders.

Organism	Constituent (mg/kg diet dry weight) Cd	Ni	Pb	Co	Cu	Zn	Fe	Mn
					Adequate			
Sheep	--	--	--	1[a]	> 5[a]	> 50[a]	30[a]	40[a]
Cattle	--	--	--	1[e]	> 10[a]	50[e]	30[e]	40[e]
Horses	--	--	--	--	5[b]	--	--	--
Pigs	--	--	--	--	4[c]	> 50[c]	> 60[c]	> 6[c]
Fowl	--	--	--	--	4[d]	35[d]	40[d]	55[d]
Man	1[g]	1[g]	--	--	--	--	--	--
					Toxic			
Sheep	--	--	--	--	> 30[a]	--	--	--
Cattle	--	--	--	--	> 30[a]	--	--	--
Horses	--	--	--	--	--	--	--	--
Pigs	--	--	--	--	50[c]	2,000[c]	5,000[c]	1,000[c]
Fowl	--	--	--	--	325[f]	> 1,000[f]	--	> 4,800[h]
Man	4[g]	--	--	--	--	--	--	--

[a]Cuthbertson, 1969.

[b]Olsson, 1969.

[c]Cuthbertson, 1969.

[d]Hill, 1969.

[e]Greenhalgh, 1969.

[f]Cuthbertson, 1969.

[g]Bowen, 1966.

[h]Underwood, 1962.

Nickel and lead are accumulated in the bones of some mammals while cadmium accumulates in the kidney and liver (Underwood 1962, Browning 1969). Cadmium and lead are considered cumulative poisons in man (Bowen, 1966). Nickel is relatively nontoxic to man compared to cadmium and lead (Underwood 1962, Browning 1969). Presumably, domestic livestock ingesting aquatic plants would respond in a similar fashion as man to these heavy metals. Age, sex, and health of the particular species as well as daily intake modify the absolute amount of each element deemed detrimental to growth and development.

Accumulations of trace elements in aquatic vascular plants from relatively large eutrophic lakes may be smaller than those reported here. The wastewater ponds and the catchment pond were essentially a closed system regarding mineral flow. As the ponds aged, the mineral content would increase since the input of nutrients was continuous in the former and dependent on precipitation and surface run-off in the latter. The catchment pond lacked an outlet while the water in the wastewater ponds was discharged twice a year and from the surface down. Mineral elements would tend to accumulate in such systems and recycle between the water, sediments and plant components. While aquatic vascular plants harvested from eutrophic lakes may be acceptable as animal feedstuff, the use of harvested aquatic plants growing in wastewater as fodder for agriculturally important animals should be approached cautiously. The possibility of toxic effects due to excessive levels of trace elements is very clear.

The Feasibility of Hydrophytes as a Soil Conditioner

The quantity of trace elements removed by harvesting the submerged plants is a function of the standing crop and tissue concentration of the minerals (Tierney 1972a, 1972b). A one harvest format would remove the largest quantity of trace elements at maximum standing crop. As Tierney (1972a) noted, the actual maximum standing crop achieved by the submerged vascular plants in the wastewater ponds during these studies was relatively low. *E. canadensis* harvested from the non-sewage catchment pond removed the largest quantity of trace elements since it represented the highest standing crop (Table 3). However, the plants grown in the wastewater ponds tended to contain higher amounts of each trace element on a per gram basis (Tierney, 1972b). The quantities of trace elements actually removed ranged from a low of 0.2 gm for Cd to 4,639 kg/ha for Fe (Table 3). For comparison Makarov (1971) reported 7.8 gm/ha for Co, 21 for Cu, 32 for Zn and 77 for Mn removed by the harvest of winter rye grain and straw. Potato tuber harvest removed from the soil 11.6 gm/ha of Co, 93 of Cu, 120 of Zn and 264 of Mn. These quantities are fairly similar to those in Table 3 for the

Table 3. Quantity of trace elements removed by a one-harvest format[a] of submerged macrophytes observed growing in wastewater ponds and a catchment pond in Michigan.

Species	Constituent (gm/ha dry weight)[b]							
	Cd	Co	Ni	Cu	Pb	Zn	Fe	Mn
				Fowlerville, Sewage Pond				
E. canadensis	3.1	5.6	14.0	18.7	25.0	132.0	1,547.0	--
C. demersum	1.4	1.6	3.5	4.9	7.1	41.6	245.0	--
				Lansing, Airport Catchment Pond				
E. canadensis	6.2	18.0	36.0	166.5	82.0	183.0	4,639.0	3,038.0
C. demersum	0.2	1.0	1.2	4.5	2.9	13.0	176.0	158.0
				Belding, Sewage Pond				
C. demersum	1.1	3.1	6.0	57.0	15.8	52.0	387.0	980.0

[a]Values calculated on tissue content of the element at time of maximum standing crop (DW). The time of harvesting occurred at maximum standing crop of dominant species (*E. canadensis*) where both co-existed.

[b]Dry weight is circa 6% of wet weight. In this study, wet weight is considered equal to fresh weight.

aquatic plants. The difference is due to variation in the size of the standing crop at time of harvest and the species involved.

Schütte (1964) points out that modern agricultural techniques improve crop yields and simultaneously remove more trace elements from the soil than under less productive practices. For example, Gericke (1957) found that clover hay removed the largest amounts while potatoes accumulated the least; quantities of Mn ranged from 2 to 38 mg, Cu from 2 to 9 mg and Co from 2 to 6 mg/kg (DW) of plant tissue. Table 4 indicates the quantity of each element removed in a kilogram of aquatic plants harvested in this study. Based on this and the above information, the application of the submerged hydrophytes to the soil would more than replace the amounts of trace elements removed by these food and forage crops.

In addition to returning trace elements to the soil, conditions exist where organic manure is essential. For example, as Ashlander (1958) points out, soil initially poor in plant nutrients or depleted in humus content would be more favorably enriched by a combination of organic and inorganic fertilizers. The present system of arable farming tends to decrease the humus content of the soil. The application of organic residues will re-establish the humus and aid in preventing future soil deterioration (Ashlander, 1958).

Table 4. Milligrams of elements removed per kilogram dry weight of submerged vascular plants harvestable per hectare from wastewater ponds and a catchment pond in Michigan.

Species	Constituent (mg/kg plant)									
	Cd	Co	Ni	Pb	Cu	Zn	Fe	Mn	P	Ca
	Lansing, Airport Catchment Pond									
E. canadensis	1.5	4.3	8.8	19.9	40.6	44.6	1,034	741	6,600	30,200
C. demersum	1.4	7.4	8.6	20.8	31.9	92.8	1,259	1,125	5,100	14,971
	Fowlerville, Sewage Pond									
E. canadensis	2.6	4.7	11.8	20.9	15.7	111.0	1,300	--	10,300	27,130
C. demersum	4.1	4.5	9.9	20.4	14.1	118.9	700	--	9,600	17,430
	Belding, Sewage Pond									
C. demersum	1.2	3.5	6.7	17.7	63.4	57.4	435	1,090	8,100	13,800

Usually, organic fertilizer has consisted of animal and plant residues. Plant residues are considered very suitable as humus since the decaying plant would contain the various plant nutrients in approximately the same proportions as needed for crops. The mineral composition of animal manure varys according to the animal involved, since the elements are differentially absorbed and excreted. City compost has also served as a soil fertilizer. Compared to the approximate trace element content of some typical manures, the trace element level of the harvested submerged plants is intermediate (Table 4). Kick (1962) found the Cu levels varying from 2 to 200 mg/kg in stable manure and city compost, while Mn and Zn ranged from 30 to 500 and 1.5 to 2000 mg/kg, respectively. The city compost is higher in Zn and Cu than the submerged vascular plants, while the Mn content of these plants is larger. The aquatic hydrophytes are, however, trace element enriched relative to stable manure.

Good fertilizer usually contains ample quantities of phosphorus, nitrogen and calcium. Farmyard manure is less desirable than plant residues since the phosphorus content of the former is comparatively low (Ashlander, 1958). The harvested hydrophytes accumulated large quantities of phosphorus (Table 4). For example, the phosphorus removed by cropping the maximum standing crop of aquatic plants amounted to 17 to 32 kg/ha for the three sites

(Tierney, 1972a). This represents a phosphorus content 5 to 10 fold higher than farmyard manure originating from livestock (Tierney 1972a, Ashlander 1958). These are strikingly high values. Comparatively, the quantity of inorganic phosphorus added to the soil in Sweden and Belgium during 1953-54 to increase crop production was only 8.95 and 20 kg/ha, respectively (Sylvan, 1955). Furthermore, the nitrogen content is 4 to 5% of the dry weight in the aquatic plants (Tierney, 1972a). This compares favorably with the 5% reported for traditional humus material (Ashlander, 1958). Humus also has the ability to reduce the leaching of nitrates from the soil and tends to promote favorable soil structure (Commoner, 1968). An ample supply of calcium is considered necessary for a fertile soil (Ashlander, 1958). The aquatic plants content of calcium is noted in Table 4. The amount returned to the soil during plant residue decomposition would aid in keeping the acidity of soil from becoming very low.

Aquatic hydrophytes have the potential as an organic fertilizer. However, difficulties do exist. The high moisture content presents problems in harvesting and transporting to the area of use. Some draining seems necessary before application to the soil. The possibility of trace element accumulation in the soil also needs consideration, especially regarding cadmium and lead. Normally cadmium and lead are found in the soil in small quantities

(Browning, 1969). The relative availability in the soil to plants of these and other trace cations is dependent on a number of factors (Millar 1955, Robertson 1958). For example, cations are more readily available in acid soil than in basic soil. Caution must be exercised to prevent excessive accumulation in the soil or in the plant species grown on it.

Other Considerations

The use of aquatic vascular plants as a supplemental protein source needs more consideration. As Boyd (1970) notes, the leaf protein concentrates from two emergent aquatic species are similar to crop plants. However, the presence of heavy metals in foliage used for protein concentrates may be of concern. The possibility of pathogen transfer from adherent water to domestic herbivores or into the food and forage crops and the concentration of slightly biodegradable and potentially toxic exotic organic compounds adhering or accumulating in the submerged hydrophytes requires consideration as well. To accurately ascertain the role of aquatic hydrophytes in wastewater recycling programs which are designed to hopefully minimize the effects of human pertebations on aquatic and terrestrial ecosystems, a highly coordinated interdisciplinary approach will be necessary.

CONCLUSIONS

Submerged vascular hydrophytes remove large amounts of mineral nutrients from ambient water. The harvesting of nuisance aquatic growths, rather than killing and leaving in place, aids in reducing the rate of hypereutrophication in natural waters. The planting and harvesting of managed crops of aquatic vascular hydrophytes in wastewater effluents would remove mineral nutrients prior to their release into natural waterways. The use of the harvested material as a humus and soil conditioner appears more favorable than use as a feedstuff for domestic livestock. The concentration of several trace elements approaches the level found toxic in common herbage fed to livestock. Copper and manganese concentrations were above the toxic level in this study. The economic value of such operations needs further elucidation. Many elements which were formally localized are now distributed throughout the environment (Anon., 1969). Basic data on the mineral composition of present forage and cereal crops as well as other aquatic hydrophytes needs to include a broader spectrum of micronutrients and heavy metals.

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