# ELODEA NUTTALLII AS A COMPONENT OF A MANAGED WASTEWATER TREATMENT SYSTEM

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ABSTRACT

*ELODEA NUTTALLII* AS A COMPONENT OF
A MANAGED WASTEWATER TREATMENT SYSTEM

By

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*Elodea nuttallii* was studied as a possible component of a managed wastewater treatment system. Shoots were transplanted to the third in a series of three wastewater ponds serving a southern Michigan community. These were planted at a depth of 130 cm. Shoots were also planted in a nutrient poor experimental pond at two depths (90 cm and 150 cm) to observe resulting differences in tissue concentration of harvestable minerals, and the effects of varying light on growth in order to recommend optimum planting depth. Final dry weights of the shoots in the nutrient poor shallow and deep plots and in wastewater were 54.37, 26.00 and 126.87 g $m^{-2}$, respectively, over respective periods of 74, 56, and 70 days. The difference between the areal values of the shallow and deep sites in the experimental pond was attributed to difference in light intensity. Optimum planting depth is recommended to be between 1 to 2 meters.

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Tracings of sampled plants indicated that harvesting at a level equal to one-half the height of the plant would result in the removal of most of the accumulated mineral nutrients while leaving plant shoots in a pond to allow for regrowth of the harvested material. This would be true for any aquatic with the gross morphology of *E. nuttallii*. Shoots in the wastewater site had 1.015 g $m^{-2}$ of phosphorus, and 4.567 g $m^{-2}$ of nitrogen in the tissue at the end of the study (70 days). Although these values are high, concurrent studies with other aquatics indicate that this species has reduced potential as a nutrient remover.

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# INTRODUCTION

Sewage plant effluents containing large quantities of plant mineral nutrients have long been known to promote eutrophication (Hasler, 1947). Rolich (1969) has indicated that while conventional secondary treatment facilities do remove a substantial percentage of these nutrients, the remaining fraction amounts to large absolute quantities in the high flow rate effluent. The rate of eutrophication can thus be greatly reduced with the development of adequate tertiary treatment systems to at least partially eliminate the remaining fraction.

The use of aquatic macrophytes as one component of a waste-water treatment system has been advocated. Harper and Daniel (1934) commented on the possibility of luxury consumption of phosphorus by aquatic angiosperms, and on the feasibility of using macrophytes high in mineral nutrients as a food supply. Recently, Gerloff and Krombholz (1966) have substantiated the theory of luxury consumption, while Boyd (1968a, 1968b, 1969a, 1970a) has done extensive work on the possibility of using aquatic macrophytes as food or cattle forage. Mechanical harvesters of aquatic plants are available (Livermore and Wunderlich, 1969), and considerable progress has been made regarding processing and marketing of harvested hydrophytes (Bailey, 1965; Lange, 1965). As a result, studies on the efficiency of specific macrophyte species as a nutrient accumulator are necessary. Most of the values for concentration of mineral elements in tissues of aquatic vascular plants have been reported from natural stands sampled once, or from natural stands sampled seasonally and reported as means (Schuette and Alder, 1927, 1929; Nelson and Palmer, 1938; Bernatowicz, 1969). Efficiency estimates are difficult to make from these data. Some studies, however, have been done on the effect of nutrient levels in the ambient water on mineral uptake and growth of aquatic macrophytes (Gerloff and Krombholz, 1966; Mulligan and Baranowski, 1969).

The purpose of this study, then, is to determine the growth, morphological, and mineral uptake response of _Elodea nuttallii_ (Planch.) St. John in differing nutrient environments. Studies on the light requirements of _E. nuttallii_ were also conducted to determine optimum planting depth in a managed treatment system.

## MATERIALS AND METHODS

Two sites were chosen for this investigation. One was an experimental pond at the Water Research Laboratory on the campus of Michigan State University. The pond was sloped, providing for relatively deep and shallow areas for experimental purposes. The average depths of the shallow and deep areas were about 90 cm and 150 cm, respectively. The other experimental site was the third in a series of three wastewater lagoons servicing Fowlerville, Michigan (pop. 1800). Water levels at both the Michigan State University site and the Fowlerville site were subject to fluctuations of up to 50 cm.

The experimental plants were taken from a well established clone of stamenate _Elodea nuttallii_ growing in an adjacent pond at the Michigan State University facility. Apical shoots approximately 3 cm long were cut from selected plants and placed in water in a plastic bucket to prevent drying of the tissue. Care was taken to insure that the cut shoots were relatively green, and actively growing. One half of these shoots were set aside for later analyses. The remaining shoots were individually planted into plywood boxes 22.5 cm square and 20.5 cm deep which had been previously filled with ca. 6 cm of sediment. In order to equalize the effect of the substratum on rooted hydrophyte growth (Boyd, 1968c), the sediments were taken from an experimental pond at the Water Research Laboratory . During planting the boxes were partially filled with water to prevent the dehydration of the shoots. Twenty shoots were planted in each box which had been fitted with wooden handles to facilitate placement and retrieval. The planting density was 394 shoots per $m^2$, approximately the density of a natural stand of _E. nuttallii_ in nearby Lake Lansing. After each box was fully planted, it was lowered onto a metal rack previously leveled and in place at the experimental site.

Shoots set aside at planting were analyzed according to methods given below and the information thus obtained was used as day zero estimates in the following tables and figures. At subsequent sampling dates, plants were randomly selected and placed into one of ten polyethylene bags filled with water. Each bag represented one observation, with the number of plants per observation dependent on the size of the plants and the necessity of having enough tissue in each observation for the later analyses. An estimate of the standing crop of the parent clone was done at one point in the study utilizing a square wooden frame 30 cm on a side, and cropping areas visually observed as areas of highest density.

Each sampled plant was washed free of detritus and aquatic fauna, and was measured by placing the fresh plant on a piece of white paper and then covering the paper with a transparent acetate sheet. The outline of the plant was then traced with a marking pencil and the tracings were later measured using a map measurer.

After tracing, the plants were placed in a forced air oven at 80°C for at least 24 hours. The plants were then removed and weighed separately and the weight divided by the number of plants per observation to get estimates of the dry weight per plant. Dried samples were then ground in a micro-Wiley mill to pass through a 40-mesh screen and stored in glass vials until needed.

Organic weight was determined by ashing the samples in a muffle furnace at 550°C for an hour. Phosphorus in the plants was determined by wet ashing the samples in a 3:1 nitric-perchloric acid mixture to which 2.0 g $L^{-1}$ of sodium bromide had been added to remove interferences by arsenic, germanium, and silicon (Lueck and Boltz, 1956). The solution was then analyzed for phosphorus according to the method of Barton (1948), as modified (Rickey and Avens, 1955; Jackson, 1958). Nitrogen and carbon in the tissues were determined with a Perkin-Elmer carbon-nitrogen-hydrogen analyzer.

Water samples from the Water Research Laboratory pond were taken periodically. Hardness, total solids, total nitrogen, total and soluble phosphate were determined using standard methods at the Water Quality Laboratory of the Institute of Water Research. Other field parameters were measured with conventional field equipment. Data of the water chemistry of the wastewater lagoon were taken from Tierney (in preparation).

# RESULTS

The two experimental sites differed markedly in water quality. Water chemistry of the sites are given in Tables 1 and 2. It should be noted that the wastewater lagoon had hardness values higher than those generally associated with occurrence of _E. nuttallii_ (Moyle, 1945). The pH of the experimental pond was rather high, ranging from 9.3 to 9.5 during the course of this study. The dissolved oxygen ranged from 12 ppm at mid-afternoon to about 6 ppm in the early morning. The wastewater pond had an average pH of 8.2, while the dissolved oxygen never fell below 2 ppm during the course of this study.

Light and temperature data at the experimental sites are given in Table 3. The decline in water temperature was the reason for terminating the experiments, on the strength of the observations by Ikusima (1965, 1966) that in many aquatic macrophytes growth is restricted at about 15$^{\circ}$C. Relative light intensity at a depth of 1 meter are also given to illustrate changes in turbidity. Growths of phytoplankton and filamentous algae have not been known to occur in the Fowlerville sewage lagoon and did not occur during the study. Blooms of plankton were observed in the Michigan State University experimental pond at various times over the study.

Table 1. Water chemistry of experimental pond site during time of study. (Values in mg/l).

| Date | Hardness | Total Solids | $NO_3$-N | $NH_3$-N | Org.-N | Total-N | Soluble $PO_4$-P | Total $PO_4$-P |
|---|---|---|---|---|---|---|---|---|
| 14-7 | 139 | 196 | 0.07 | 0.58 | 0.98 | 1.63 | 0.02 | 0.02 |
| 19-7 | 136 | 200 | 0.07 | 0.47 | 1.10 | 1.64 | 0.02 | 0.04 |
| 25-7 | 120 | 191 | 0.04 | 0.40 | 0.51 | 0.95 | 0.02 | 0.03 |
| 3-8 | 166 | 191 | 0.04 | 0.08 | 0.51 | 0.63 | 0.01 | 0.02 |
| 11-8 | 185 | 329 | 0.07 | 0.03 | 1.42 | 1.52 | 0.02 | 0.03 |
| 17-8 | 187 | 338 | 0.02 | 0.08 | 0.96 | 1.06 | 0.02 | 0.04 |
| 27-8 | 150 | 216 | 0.03 | 0.06 | 0.35 | 0.44 | 0.02 | 0.03 |
| 2-9 | 145 | 203 | 0.08 | 0.15 | 0.44 | 0.67 | 0.03 | 0.04 |
| 22-9 | 138 | 185 | 0.01 | 0.08 | 0.36 | 0.45 | 0.02 | 0.03 |

Table 2. Water chemistry of wastewater lagoon site during time of study. (Tierney, In Preparation). (Values in mg/l).

| Date | Hardness | Total Solids | $NO_3$-N | $NO_2$-N | $NH_3$-N | Org.-N | Total-N | Soluble $PO_4$-P | Total $PO_4$-P |
|---|---|---|---|---|---|---|---|---|---|
| 7-16 | 328 | 678 | 0.09 | 0.17 | 2.61 | 1.58 | 4.45 | 3.23 | 3.75 |
| 7-24 | 336 | 122 | 0.04 | 0.11 | 2.61 | 0.85 | 3.61 | 3.83 | 4.41 |
| 7-30 | 429 | 593 | 0.17 | 0.36 | 1.52 | 1.60 | 3.65 | 3.07 | 4.27 |
| 8-6 | 329 | 724 | 0.15 | 0.38 | 0.71 | 1.30 | 2.54 | 3.89 | 4.28 |
| 8-13 | 333 | 673 | 0.23 | 0.16 | 0.28 | 1.38 | 2.05 | 3.36 | 3.57 |
| 8-20 | 337 | 611 | 0.11 | 0.27 | 0.42 | 1.58 | 2.38 | 2.60 | 2.77 |
| 8-26 | 319 | 661 | 0.13 | 0.22 | 0.19 | 1.24 | 1.78 | 2.50 | 2.87 |
| 9-24 | 318 | 710 | 0.15 | 0.33 | 1.54 | 3.52 | 5.54 | 3.42 | 4.41 |
| 10-9 | 343 | 660 | 0.06 | 0.21 | 0.08 | 1.46 | 1.81 | 3.58 | 4.24 |

Table 3. Some environmental parameters at the two experimental sites during the time of the study (July-October, 1970).

Water Research Laboratory

| | % Incident Light Remaining | | | | |
|---|---|---|---|---|---|
| Date | 1 m | Shallow tips | Deep tips | Date | Temp. (°C) |
| 22-7 | 42 | 72 | | 1-8 | 28 |
| 30-7 | 45 | 68 | | 28-8 | 22 |
| 1-8 | 53 | 77 | | 11-9 | 20 |
| 15-8 | 51 | 71 | 42 | 29-9 | 17 |
| 27-8 | 65 | 82 | 58 | | |
| 17-9 | 46 | | 61 | | |
| 1-10 | 52 | | 59 | | |

Wastewater Lagoon

| | % Incident Light Remaining | | |
|---|---|---|---|
| Date | 1 m | Growing tips | Temp. (°C) |
| 11-8 | 39 | 42 | 28 |
| 25-8 | 51 | 49 | 24 |
| 11-9 | 41 | 48 | 23 |
| 1-10 | 50 | 54 | 16 |

Dry weight estimates are given in Figure 1 on a per plant basis. After an initial lag phase of about 15 days during which the wastewater lagoon plants grew at a rate comparable to the rates in the experimental pond, the lagoon plants grew rapidly, reaching the early stationary growth phase after about 70 days. The length of the lag phase and the time until the stationary growth phase was reached agree well with data for Ceratophyllum demersum grown concurrently in the wastewater lagoon (McNabb, Tierney, and Kosek, in preparation). Increased competition among individuals as the population approached maturity was reflected in the increased standard error with time.

Dry weight, carbon weight, and percent organic weight estimates are given in Table 4 on a g $m^{-2}$ basis, along with both dry weight and carbon productivity estimates. These areal production estimates were made by multiplying the individual estimate by 394, the density at which the shoots were planted. All final tabled parameters of the wastewater plants were higher than plants grown at either plot in the experimental pond. Final dry and carbon weights, and respective productivity values, were higher in the shallow plot than in the deep.

The changes in percent organic weight may be worth comment. The low values of percent organic weight (especially of plants from the deep plot) tend to support the contention of Wetzel (1960) that the biomass of submerged plants can be more than 50% marl. The initial decline in percent organic weight of the plants grown in the sewage pond, followed by an increase in organic weight, is in agreement with

Table 4. Dry carbon, and percent organic weights and dry and carbon production of transplanted *Elodea nuttallii* (July-October, 1970).

| Location | Time (days) | Dry wt. (g $m^{-2}$) | Carbon wt. (g $m^{-2}$) | % org. | Dry wt. production (g $m^{-2}$ $da^{-1}$) | C wt. production (g $m^{-2}$ $da^{-1}$) |
|---|---|---|---|---|---|---|
| Experimental pond | 0 | 5.90 | 2.14 | 80.0 | | |
| Shallow Plot | 18 | 17.72 | 5.18 | 71.8 | 0.66 | 0.17 |
| | 74 | 54.37 | 14.04 | 52.5 | 0.65 | 0.16 |
| Experimental pond | 0 | 6.30 | 2.17 | 66.5 | | |
| Deep Plot | 23 | 16.94 | 4.02 | 40.9 | 0.46 | 0.08 |
| | 56 | 26.00 | 6.54 | 42.9 | 0.27 | 0.08 |
| Wastewater pond | 0 | 6.70 | 2.00 | 64.1 | | |
| | 14 | 17.72 | 4.84 | 55.3 | 0.79 | 0.20 |
| | 28 | 33.48 | 11.49 | 72.6 | 1.13 | 0.42 |
| | 50 | 73.68 | 24.69 | 71.5 | 1.83 | 0.60 |
| | 70 | 126.87 | 48.36 | 81.2 | 2.66 | 1.18 |

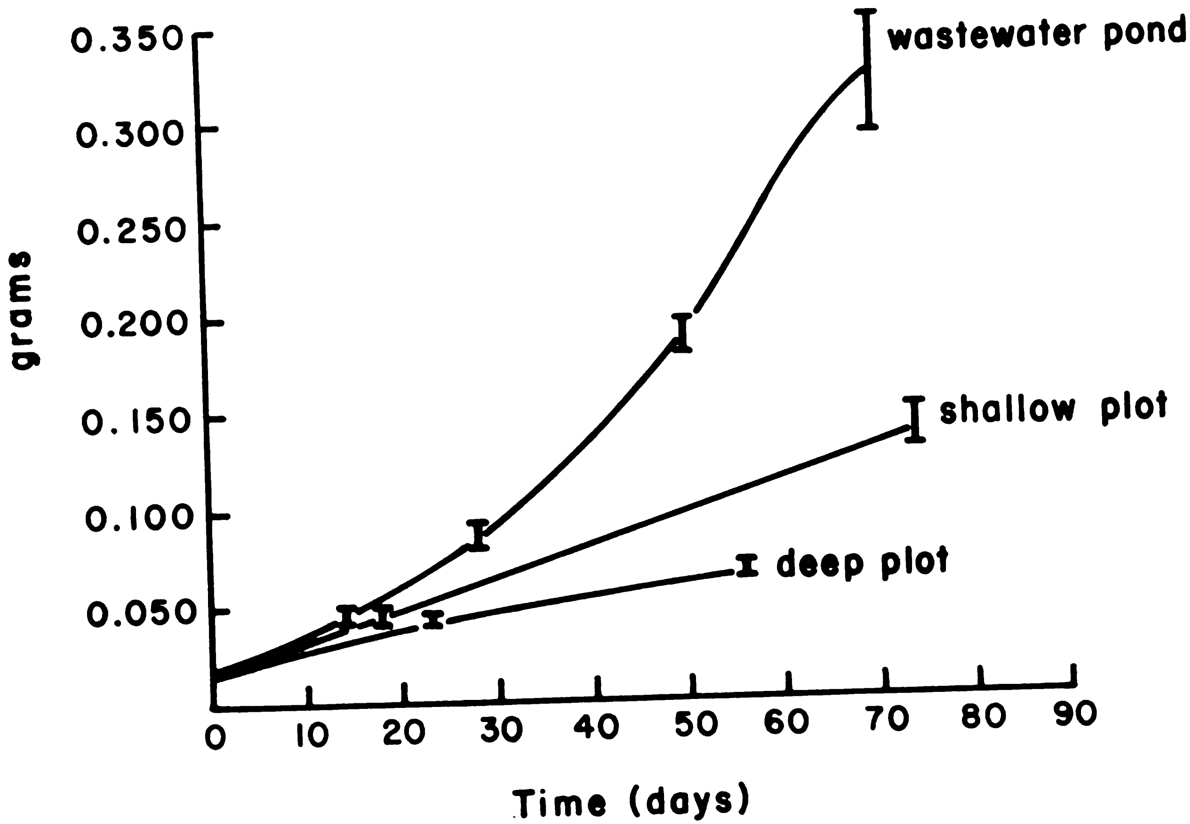


Figure 1. Growth response of individual plants of <u>Elodea nuttallii</u> transplanted to different states of eutrophy. (July-October, 1970).

the trend of percent organic weight of _C. demersum_ transplanted to the wastewater pond (McNabb, Tierney, and Kosek, in preparation). The decline may have been due to an accumulation of mineral nutrients (both macro- and micro-nutrients) during the lag phase of growth. Subsequent increase of organic weight can be explained if one assumes a utilization of the nutrients during the lag phase of growth; a utilization much faster than the rate of mineral uptake by the plant.

Plant measurements are given in Table 5. The plants in the experimental pond did exhibit differences in morphological response, the shoots in the shallow plot after 18 days of growth being taller than the shoots in the deep plot after 56 growing days. The bushiness ratio (total length/main stem length) of the two plots were very similar at the end of the study period (2.7 in the shallow plot, 2.8 in the deep plot). The shoots in the wastewater lagoon grew quickly. The main stem length surpassed the main stem length of the shallow pond shoots in 14 days. The final bushiness ratio (3.4) was higher than in either plot in the experimental pond. The nutrient rich ambient water of the wastewater lagoon apparently was a more conducive environment for the growth of _E. nuttallii_ than the water of the experimental pond.

Table 5 does not include measurement of root production. In studying _E. nuttallii_ as a possible component of a sewage treatment system, it is necessary to study the portions of the plant harvestable from the pond. Current harvesting techniques are likely to leave the roots in the substrate. In a separate study of rooting response, however,

Table 5. Mean morphological response of individual plants of Elodea nuttallii following transplant to differing environments (July-October, 1970).

| Location | Time (days) | Number of Growing Apices | Main Stem Length (cm) | Total Length (cm) |
|---|---|---|---|---|
| Experimental pond | 0 | 1.1 | 6.4 | 7.9 |
| Deep Plot | 23 | 4.6 | 7.4 | 15.5 |
| | 56 | 6.5 | 7.6 | 21.3 |
| Experimental pond | 0 | 1.2 | 6.4 | 7.9 |
| Shallow Plot | 18 | --- | 8.9 | --- |
| | 74 | 7.0 | 9.4 | 25.7 |
| Wastewater pond | 0 | 1.2 | 7.4 | 7.4 |
| | 14 | 5.3 | 10.9 | 24.4 |
| | 28 | 10.1 | 24.4 | 77.2 |
| | 50 | 13.5 | 34.0 | 117.1 |
| | 70[1] | --- | --- | --- |

[1] Plants entangled such that measurements not available.

it was determined that individuals of this species develop a mean of 3.8 roots in 22 days. These roots made up 14.5% of the total dry weight and 39.3% of the dry weight increase following transplant. These data indicate that a good deal of the energy potentially available for shoot growth during the lag phase is used to increase root biomass. Since growth implies concentration of nutrients in the meristimatic tissue, from a managerial point of view it may be worthwhile to develop harvesting techniques which can harvest a substantial portion of the root system.

Figure 2 shows percent phosphorus in the shoots. The plants in the deep and shallow plots in the experimental pond decreased in phosphorus concentration from an initial level of about 0.55%. This is the expected response upon transfer to the low nutrient level of the ambient water. Schwoerbel and Tillmans (1964) have shown that the amount of $PO_4$-P in submerged aquatics increases linearly with the amount of $PO_4$-P in the water. The shoots grown in the wastewater lagoon increased in percent phosphorus until about 28 days into the study and then the phosphorus concentration declined steadily. This decline in percent phosphorus coincided with an increase in the dry weight per plant (Figure 1). Competition between the individual plants for phosphorus was reflected in increased standard error with increased percent phosphorus in the tissue.

Figure 3 shows percent nitrogen in the plant tissue. The shoots grown in the two plots in the experimental pond decreased in

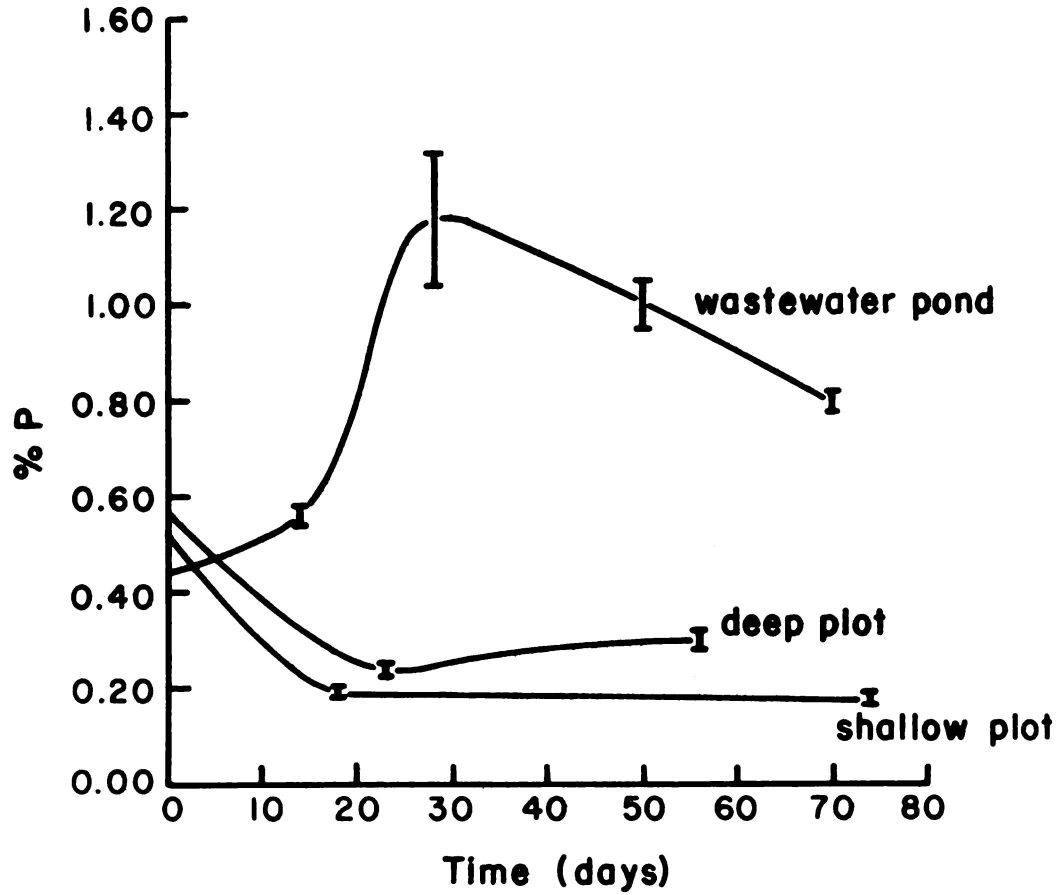


Figure 2. Percent phosphorus in tissue of Elodea nuttallii transplanted to different states of eutrophy. (July-October, 1970).

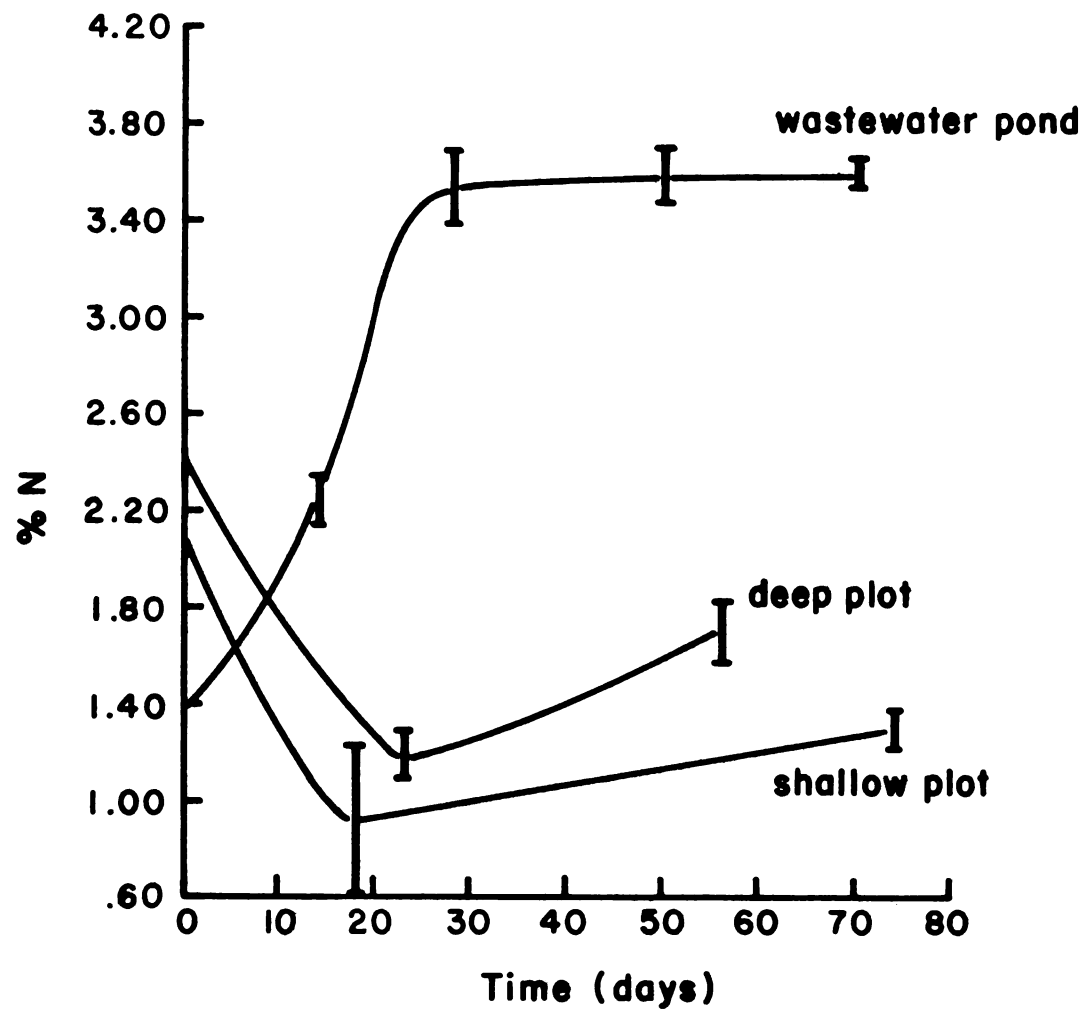


Figure 3. Percent nitrogen in tissue of <u>Elodea</u> <u>nuttallii</u> transplanted to different states of eutrophy. (July-October, 1970).

nitrogen concentration, similar to the response in the tissue to phosphorus concentration. It appears reasonable to assume that the nitrogen content in these shoots was a reflection of the nutrient level of the water. The nitrogen concentration of the plants grown in the wastewater pond rose to an equilibrium concentration of about 3.6% nitrogen after about 28 days. The increased stabilization of this saturation level is apparent in the decreased standard error with time.

The differing nitrogen and phosphorus concentration response of the shoots grown in the sewage pond are difficult to explain. The uptake of these nutrients is involved in controversy. Boyd (1970b) has said that the concentration of mineral nutrients in aquatic macrophytes is apparently regulated by both physiological and environmental factors, and that active uptake and accumulation of nutrients against a concentration gradient is obvious. Wetzel (1964) has cited Gessner and Kaukal (1952) to the effect that uptake of phosphorus by the vegetative portions of <u>Elodea</u> spp. occurs by diffusion processes without any known active mechanism of assimilation. It may be important to determine whether other aquatic plants absorb nitrogen and phosphorus in a manner similar to <u>E. nuttallii</u> in order to be able to predict the potential nitrogen and phosphorus harvest from hydrophytes grown in a specific managed wastewater system.

## DISCUSSION

The difference in dry weight productivity and final dry weights between the shoots grown in the two plots in the experimental pond on the Michigan State University campus appear due to differences in the light intensity reaching the growing tips. In order to analyze this hypothesis, assume a standing crop of 10 g E. nuttallii $m^{-2}$ growing at a depth such that it receives 80% of the incident light, and another stand of E. nuttallii having the same areal density but receiving only 40% of the incident light energy. According to Ikusima (1967), the gross photosynthetic production (mg $O_2$ per g of dry plant material per day) of E. nuttallii is dependent upon relative light intensity according to the curve shown in Figure 4. From Figure 4, and utilizing a conversion factor of 0.84 g new dry matter/g $O_2$ produced (Ikusima, 1965), the assumed stand of E. nuttallii receiving a relative light intensity of 80% would have a production rate of 0.076 g $m^{-2}$ $da^{-1}$ while the stand receiving 40% of the incident light would have a productivity of 0.067 g $m^{-2}$ $da^{-1}$. These calculated rates are lower than the rates observed in this study (Table 4). The calculations are dependent upon the validity of Ikusima's assumptions

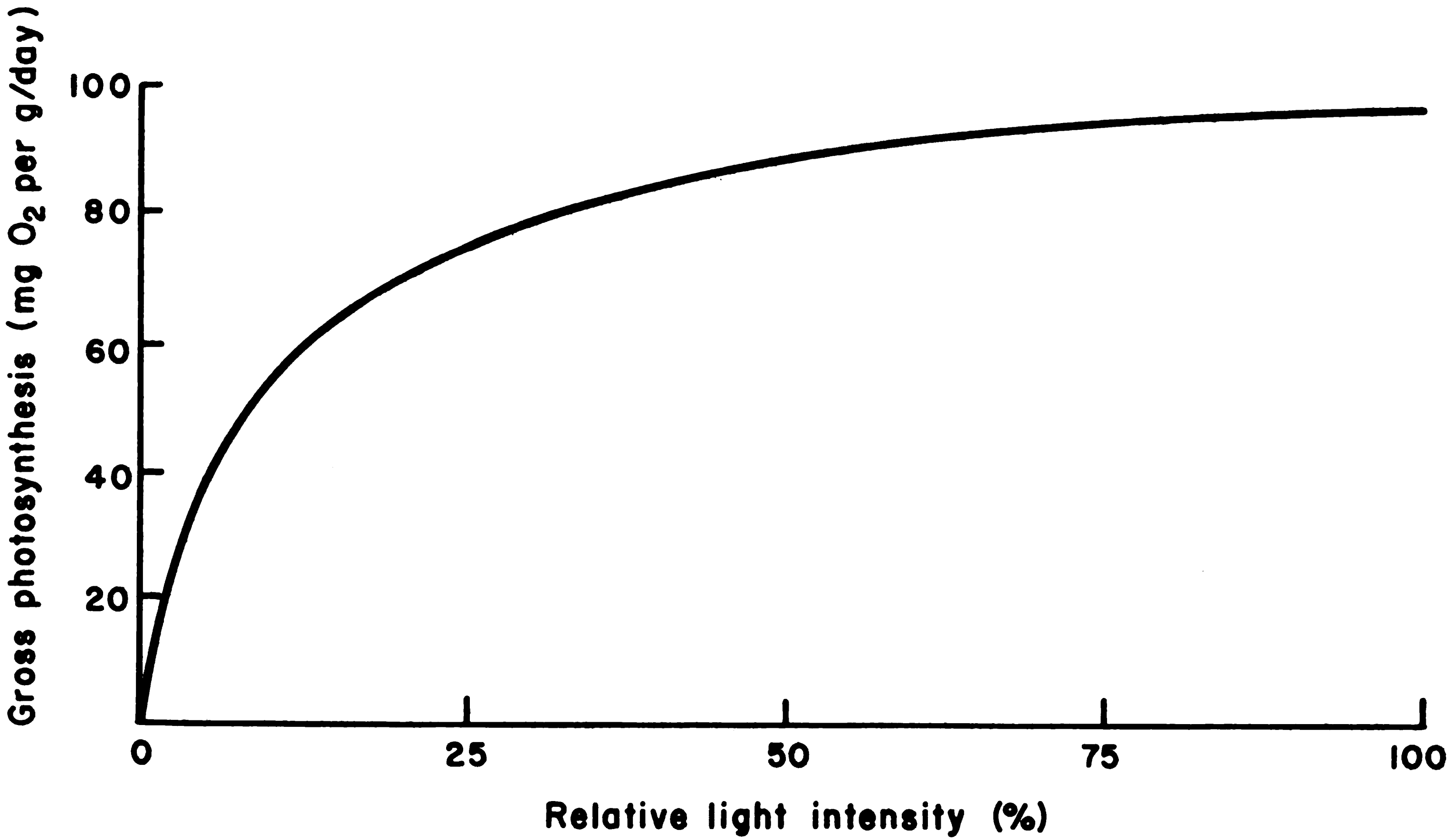


Figure 4. Relative light intensity - daily gross photosynthesis curve for Elodea nuttallii in July-August. (Ikusima, 1967).

and procedures, and also on the size of the standing crop used in determining productivity. Assuming Ikusima's work is farily accurate, comparisons between the calculated and observed production rates can be made by comparing the differences between the shallow and deep plots of the assumed stands, and the shallow and deep plots experimentally observed. The theoretically calculated shallow production rate is 1.13 times faster than the calculated deep rate, while the observed shallow rate is 1.43 times faster than the observed deep productivity. Thus, for shoots grown in the same environment, differences in relative light intensity received by the growing tips can account for the observed productivity differences between the two plots.

Ikusima (1967) has calculated the effect of depth on macrophyte photosynthetic rate in Lake Biwa, Japan. His calculations for the compensation depth (depth where daily photosynthesis equals daily respiration) of E. nuttallii indicates that for a moderately transparent lake the compensation depth ranges from 5 to 9 m, depending upon the time of the year. Peltier and Welch (1970) have shown that in a reservoir in which the $PO_4$-P concentration in the water was never greater than 0.20 ppm, the amount of light reaching the submerged plants was the limiting factor in plant growth. In this study, E. nuttallii grown in a nutrient rich environment at a depth of 130 cm and an initial light intensity of 40% of the incident light had a much higher production rate than the same species grown in nutrient poor ambient water experiencing a relative light intensity of from 40 to 60%.

Thus, while depth at planting can be a limiting factor in a relatively nutrient poor environment, in a wastewater treatment system of moderate transparency, light is not a critical factor as long as the plants are planted at a depth of less than 5 m. Shoots should be planted shallow enough to promote rapid growth, but deep enough to provide vertical space for growth. Therefore, it is recommended that *E. nuttallii* utilized as part of a managed treatment system be planted at a depth of between 1 and 2 m.

To evaluate the feasibility of *E. nuttallii* as a component of a wastewater treatment system, it seems necessary to compare its productivity with other aquatic macrophytes. Table 6 shows the beginning and final dry weight, dry weight productivity and net phosphorus accumulation of *E. nuttallii* and *Ceratophyllum demersum* grown in experimental plots, and natural stands of *E. canadensis* and *C. demersum* growing in the wastewater pond during the time of the study. Transplanted shoots of *C. demersum* exhibited high productivity rates, comparable to values in the literature for some emergent plants (Boyd, 1969b; McNaughton, 1966), some floating aquatics (Odum, 1957; Penfound, 1956), and some terrestrial plants (Penfound, 1956). *C. demersum* as a nutrient stripper has been discussed elsewhere (McNabb, Tierney and Kosek, in preparation). Although the production rates of the shoots grown in the experimental pond are rather low, shoots grown in the sewage pond have high productivity. While the production rate of *E. nuttallii* grown in the sewage lagoon is lower than some rates reported in the literature for submergents (e.g., Odum, 1957; Ikusima, 1966), it is in general agreement with other productivity values reported (e.g., Forsberg, 1960; Knight, Ball and Hooper, 1962). The tabled values of the naturally occuring stand of E. nuttallii indicate that the shoots may have been planted at a density not approximating highest possible density. These data also indicate that the growth of the shoots at the wastewater pond may have been terminated before maturity was reached. It is clear, though, that this species can accumulate substantial amounts of phosphorus.

Quantity of seed material may be critical in optimizing production from transplanted shoots. In the Fowlerville pond, a seeding of about 7 g $m^{-2}$ of E. nuttallii increased its dry weight about 18 times in 70 days. The transplanted C. demersum, seeded with about 60 g $m^{-2}$, increased its weight about 17 times. Thus, although the productivity estimates of the two species are quite dissimilar, their increases relative to the amount of original tissue planted were approximately the same. If transplanted aquatic plants grow proportionally to the seed material, large amounts of tissue may be planted in a managed sewage system to remove very large amounts of nutrients.

That E. nuttallii can remove relatively large amounts of nutrients is evident from Table 6 and from both Figures 5 and 6, which show the amount of phosphorus and nitrogen in individual plants. Final areal values were 0.098, 0.078 and 1.015 g $m^{-2}$ of phosphorus in

Table 6. A comparison of the dry weight yield and phosphorus accumulation of submerged aquatic angiosperms growing in a wastewater lagoon.

| Author | Conditions of Development | Species | Beginning Dry wt. (g $m^{-2}$) | Duration of growth (days) | Dry wt. net yield (g $m^{-2}$) | Terminal standing crop (g $m^{-2}$) | Dry wt. productivity (g $m^{-2}$ $da^{-1}$) | Dry wt. % P[1] | Net P accumulation (g $m^{-2}$) |
|---|---|---|---|---|---|---|---|---|---|
| This Paper | Transplanted shoots in shallow plot in experimental pond | *Elodea nuttallii* | 5.91 | 74 | 48.46 | 54.37 | 0.65 | 0.18 | 0.09 |
| | Same grown in deep plot | *Elodea nuttallii* | 6.30 | 55 | 19.70 | 26.00 | 0.36 | 0.30 | 0.06 |
| | Transplanted shoots in wastewater lagoon grown until early stationary growth phase | *Elodea nuttallii* | 6.70 | 70 | 120.17 | 126.87 | 1.72 | 0.80 | 0.96 |
| | Natural stand | *Elodea nuttallii* | nil | 100 | 673.30 | 673.30 | 6.73 | 0.46 | 3.10 |

Table 6 (cont'd.)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| McNabb, Tierney, Kosek (In preparation) | Transplanted shoots in wastewater lagoon grown until early stationary growth phase | *Ceratophyllum demersum* | 59.00 | 57 | 986.00 | 1045.00 | 17.30 | 1.30 | 12.80 |
| Tierney (In preparation) | Naturally occurring stand in wastewater lagoon sampled until early stationary growth phase | *Elodea candensis* | 0.29 | 76 | 119.03 | 119.32 | 1.57 | 1.03 | 1.23 |
| | Same until early stationary growth phase | *Ceratophyllum demersum* | nil | 77 | 34.51 | 34.51 | 0.45 | 0.96 | 0.33 |

(1) Percent P at final sampling date.

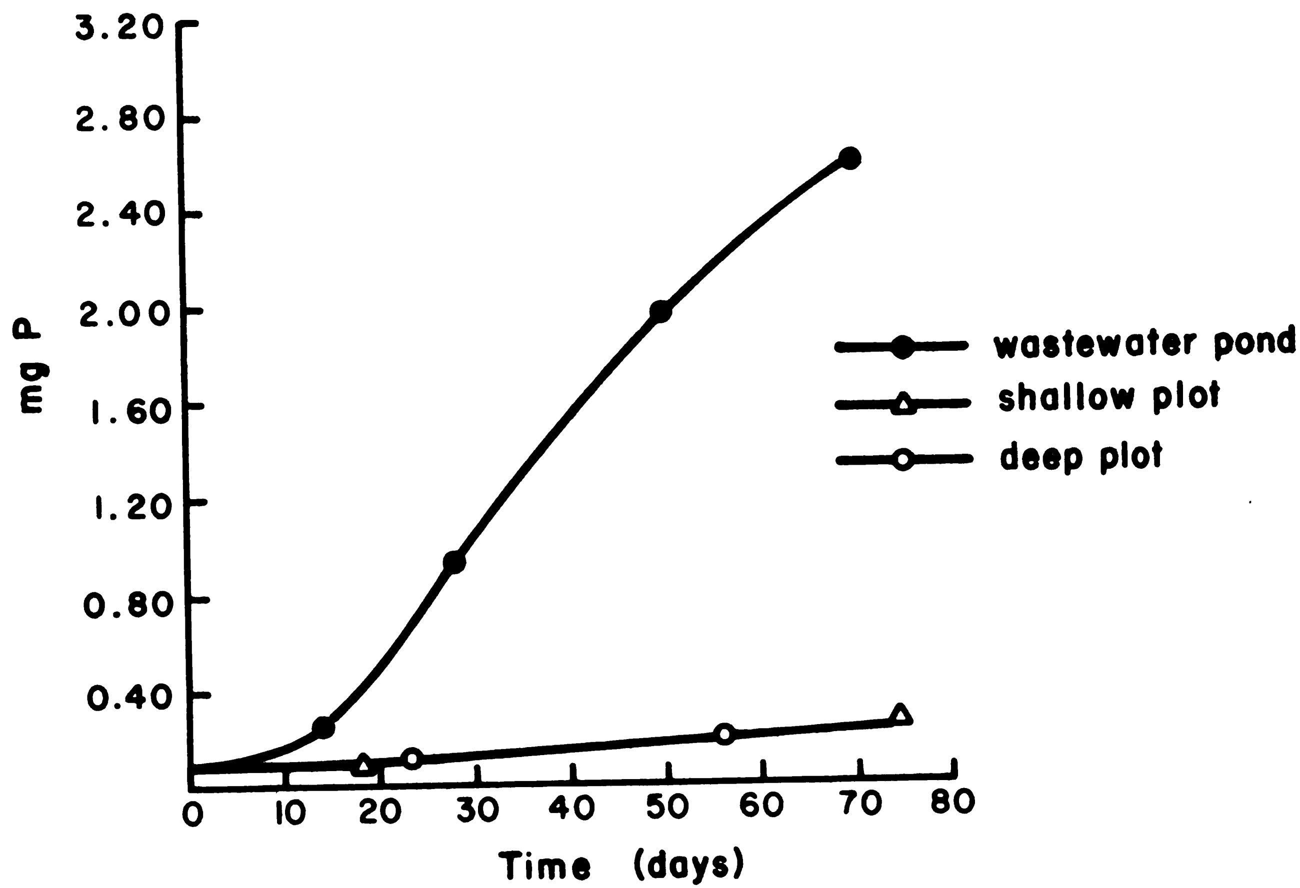


Figure 5. Amount of phosphorus in individual plants of Elodea nuttallii transplanted to different states of eutrophy. (July-October, 1970).

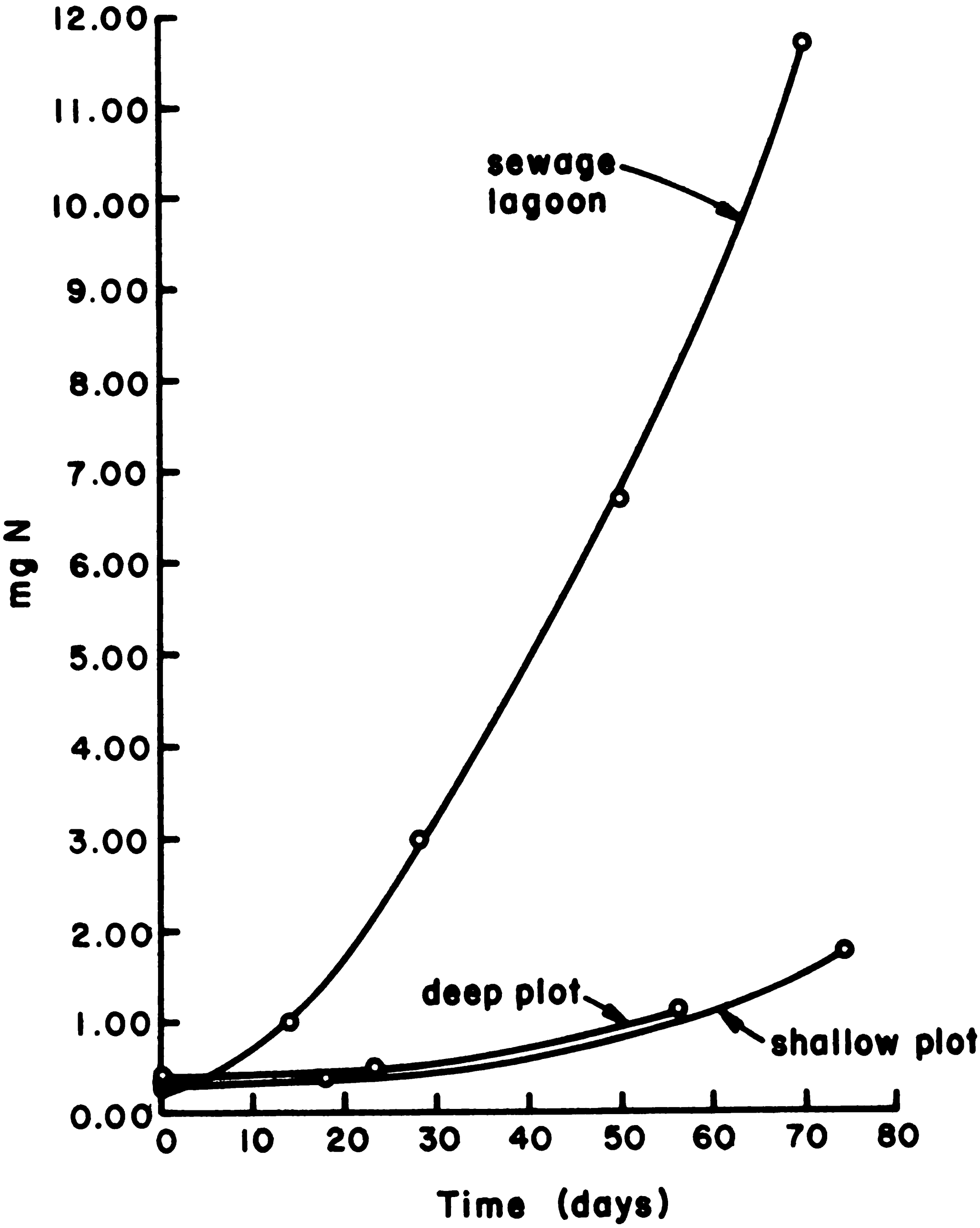


Figure 6. Amount of nitrogen in individual plants of Elodea nuttallii transplanted to different states of eutrophy. (July-October, 1970).

the shallow, deep and sewage lagoon plots respectively, and 0.707, 0.442 and 4.567 g $m^{-2}$ of nitrogen in the respective plots. (These values may be multiplied by 10 to obtain Kg $ha^{-1}$, or by 8.92 to transform the values to lbs $A^{-1}$). Although Mackenthun (1968) concluded that the use of aquatic macrophytes was not practical, these data indicate that hydrophytes grown in a managed wastewater treatment system can absorb substantial amounts of nutrients.

While the types of mechanical harvesters in use have been reviewed by Livermore and Wunderlich (1969), the problem of the proper harvesting technique for a tertiary treatment system has not been discussed. Are aquatics to be harvested so as to include the roots or is it more economical to harvest only that portion of the plant taller than a specified height above the substratum? If some portion of the plant is to be left in the lagoon, how much of the plant should be harvested in order to maximize both nutrient removal and the probability that the remaining portions of the shoot will regenerate the harvested parts?

In order to answer these questions, it seems necessary to study the gross morphology of macrophytes being considered as nutrient removers. To that end, schematic drawings of shoots of _E. nuttallii_ grown in the different plots are shown in Figure 7. Plants grown in all the plots sent out shoots from their bases soon after planting. In the nutrient rich environment of the sewage pond, most of the stem length was in the upper part of the plant. This same form of

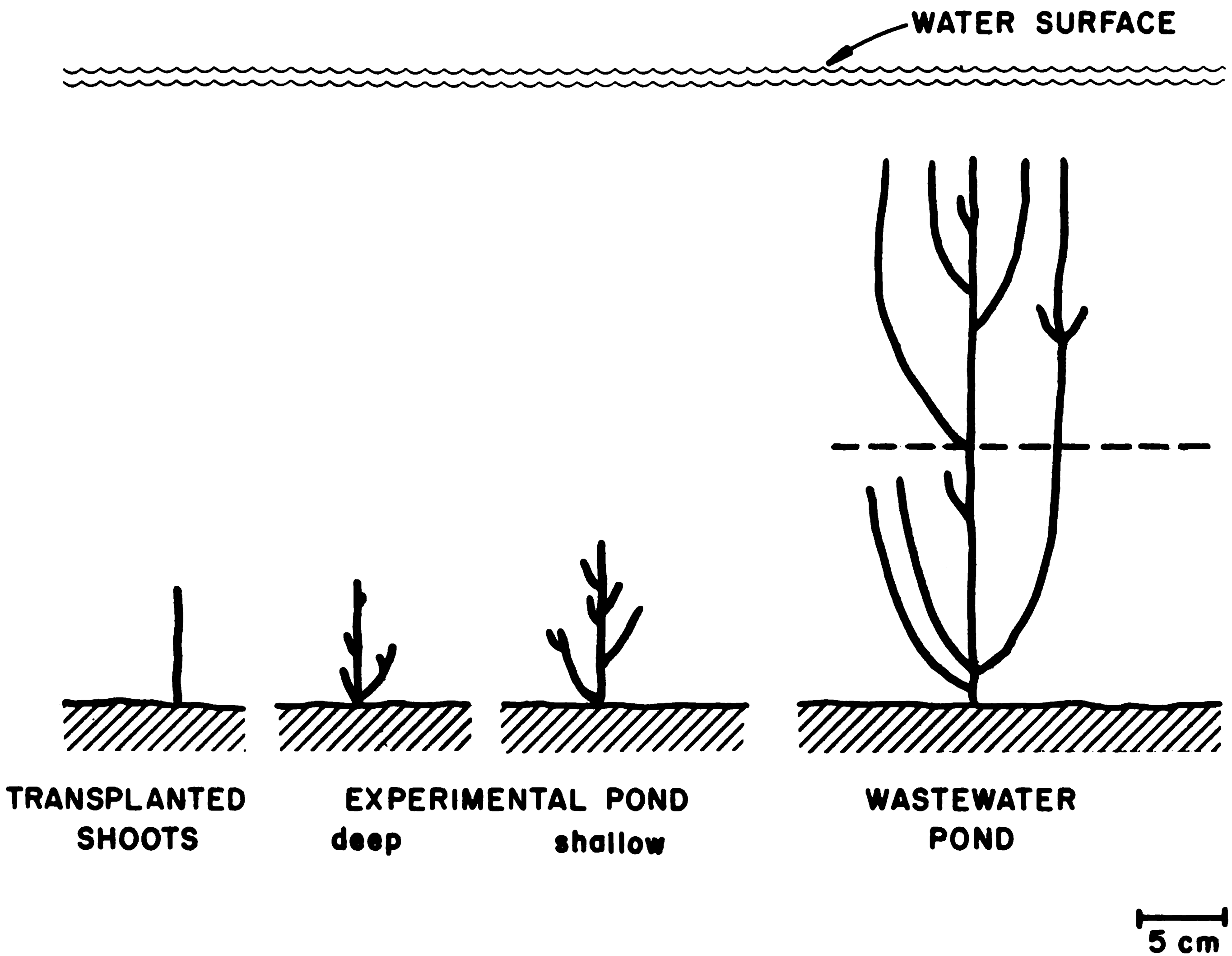


Figure 7. Drawings of the gross morphology of shoots of Elodea nuttallii transplanted to different states of eutrophy. (July-October, 1970).

structural arrangement was noted by Ikusima (1965) in a community of Potomogeton crispus and he postulated that this form may be a characteristic of many rooted aquatic plant communities. Thus, for E. nuttallii in particular, and some rooted aquatics in general, it seems that harvesting at one-half a plants total height would result in removing most of the harvestable biomass and stored nutrients. The dotted line across the figure of the plant grown in the wastewater pond represents a cutting at half the height of the plant. Recalling that these drawings were taken from traces of plants grown in the plots, it is to be noted that there are shoots below the cutting level from which the plant may return to its former height.

The uptake of nutrients by aquatic macrophytes seems·to be a function of the concentration of nitrogen and phosphorus in the ambient water (Gerloff and Krombholz, 1966). Thus, comparisons between E. nuttallii transplanted in this study and values reported in the literature for aquatics growing in natural situations are difficult to make, especially when evaluating the feasibility of a specific hydrophyte as a nutrient remover. Comparing the mineral nutrient content of aquatics grown in enriched situations, E. nuttallii transplanted to the sewage lagoon had higher nutrient concentrations than plants reported by Weatherly and Nicholls (1955), and Caines (1965). Percent phosphorus reported by Fish and Will (1966) for some aquatic plants are generally higher than the values observed in this study, but the high level of arsenic in the ambient water (Fish, 1963) makes these results questionable since arsenic would interfere with their method (Chamberlain and Shapiro, 1969). Concentration of phosphorus by E. nuttallii in the sewage lagoon was lower than the transplanted C. demersum (McNabb, Tierney and Kosek, in preparation), and the naturally occuring stand of E. canadensis (Tierney, in preparation), although this may be due to lower than optimum standing crop of E. nuttallii as indicated by the high areal density of the parent clone. It can be concluded, then, that E. nuttallii can absorb large amounts of mineral nutrients (including nitrogen, phosphorus and carbon), but compared to other plants being considered as part of a managed treatment system (specifically C. demersum), its potential as a nutrient remover is lower.

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