MODIFICATION OF MUNICIPAL WASTEWATERS USING DUCKWEED AND ALLIGATORWEED COMMUNITIES

by

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Pamela C. Ellis. MODIFICATION OF MUNICIPAL WASTEWATERS USING DUCKWEED AND ALLIGATORWEED COMMUNITIES. (Under the direction of Graham J. Davis) Department of Biology, August 1981.

Six experimental lagoons were constructed at the Murfreesboro, N. C. wastewater treatment facilities to explore the possibilities of using floating vascular plants to improve the quality of municipal wastewater effluent. Two lagoons contained alligatorweed communities, two contained duckweed communities, and two lagoons served as controls.

Static systems employing a 12 day detention were not effective at wastewater processing, while both duckweed and alligatorweed communities in a flowthrough system improved the quality of the effluent of the Murfreesboro lagoon. BOD, total suspended solids, water transparency, and pH were significantly improved by the lagoons with plants as compared to the control lagoons. Ammonium and dissolved oxygen levels of the plant community lagoons were adversely affected by the floating vascular plant systems and the concentrations of these components could have a detrimental effect on receiving waters. Algal unit counts were strongly correlated with total suspended solids with 59% of the variance being explained by the presence of algae. Alligatorweed communities were more effective in improving wastewater quality than were the duckweed communities, but the effectiveness of alligatorweed as a wastewater processor decreased following its infestation by what appeared to be the alligatorweed stem borer (*Vogtia malloi* Pastrana). There was a significant reduction in total nitrogen in the water by the alligatorweed communities.

MODIFICATION OF MUNICIPAL WASTEWATERS
USING
DUCKWEED AND ALLIGATORWEED
COMMUNITIES

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INTRODUCTION

Within the past decade interest has grown in the use of vascular aquatic plants as a cost-effective method of improving wastewater effluent. Conventional treatment of raw sewage, as with stabilization lagoons, often results in effluents which exceed statutory limits for biochemical oxygen demand (BOD) and total suspended solids (TSS). Also high levels of nitrogen and phosphorus may be present (Boyd 1970). Floating vascular plant systems can lower the concentrations of some of these wastewater components, thereby improving the quality of the effluent. This, of course, results in less damage to the environment.

Most of the research using floating vascular plants to upgrade wastewater has been with waterhyacinth and has been restricted to the Gulf Coast of the U.S.A. and California. Effluent from lagoons stocked with waterhyacinth has been shown to meet EPA standards for BOD (30 mg/l) and TSS (30 mg/l) with as little as a 3 day retention time (Wolverton and McDonald 1976a; Wolverton and McDonald 1976b). One study (Wolverton et al. 1976) gave a 97% reduction in BOD by waterhyacinth exposed to raw sewage for 7 days, while alligatorweed cut BOD by 92%. BOD reduction in controls was 61% and 68% respectively. In the same study TSS was decreased by 75% by waterhyacinths exposed to secondary effluent for 7 days, whereas alligatorweed decreased TSS by 94%. TSS reduction in controls was 15% and 48% respectively. Although few data are available, shading by floating vascular plants probably results in a decrease in phytoplankton biomass and therefore a reduction in TSS. Habitats for various species of bacteria, protozoa, fungi, and invertebrates are associated with the root zone of floating vascular plants (Dinges 1978). These organisms can be major contributors to the effectiveness of the system by reducing available energy, and hence BOD, in succeeding trophic levels of a food chain.

The use of vascular aquatic plants to remove metals and toxic organic pollutants from wastewaters shows promise. Wolverton and McKown (1976) found that one hectare of waterhyacinth could possibly remove 160 kg of phenol over 72 h. Experiments conducted by Exxon Research and Engineering Company have shown that waterhyacinth exposed to wastewater takes up heavy metals such as nickel, zinc, and chromium (Chambers 1978). In another study (Wolverton et al. 1976) alligatorweed removed metal pollutants such as lead, mercury, silver, and cobalt, but was less efficient than waterhyacinth in removal of these elements.

Ornes and Sutton (1971) found a correlation between nitrogen and phosphorus in wastewaters and plant growth. For example, waterhyacinth maintained on sewage effluent covered 71% of a circular pool (2.8 m) after 11 weeks, while waterhyacinth maintained in a pool of well water covered only 16% of the surface in the same length of time (Scarsbrook and Davis 1971). Waterhyacinth biomass increased by as much as 47% per week when maintained on lagoons receiving raw sewage (Wolverton and McDonald 1979).

For maximum reduction of wastewater pollutants, floating vascular plants should be harvested frequently (Wolverton and McDonald 1976b). Harvested aquatic plants could be used as animal feeds, compost, mulch, and fertilizers (Mitchell 1974; National Academy of Sciences 1976). Methods of harvesting aquatic plants have been developed but they are not generally cost-effective.

Although waterhyacinth has been studied extensively and shown to be very efficient in improving wastewater quality, its potential as an aquatic pest may make it an unfavorable candidate for use in areas devoid of the plant. Many other aquatic plants (floating, emergent, and submersed) have been suggested and studied as alternatives. Duckweed, because of its cold hardiness and rapid growth rate, is a good candidate for use in North Carolina (Wolverton 1979b). When maintained in tanks receiving cattle waste, duckweed biomass doubled in 1.5 to 3 days (Hillman and Culley 1978). It prevents algal growth by shading and thus lowers suspended solids. Because of its small size, it can be skimmed from the water's surface when harvesting is necessary. Winds are a problem with duckweed treatment, since duckweed can be easily blown to shore. This problem could be alleviated by pool design (Serfling and Alsten 1979). Solar Aqua Systems, Inc. of Encinitas, California utilizes duckweed in its packaged systems now being employed in Hercules, California (Golueke 1979).

Alligatorweed is another floating vascular plant with potential for wastewater treatment. It has a growth pattern similar to waterhyacinth in that extensive stem and root systems may develop underwater. Stems of alligatorweed above the water die back during the winter in North Carolina. Renewed growth in the spring is from underwater stems, many of which overwinter. Alligatorweed mats which develop in the spring limit light penetration and therefore algal growth. Alligatorweed grows rapidly in nutrient rich water and can be harvested from the water's surface.

The purpose of this research was to explore the possibilities of using duckweed and alligatorweed systems as methods for upgrading wastewaters in the temperate zone. The emphasis was on nutrient reduction by the floating plant systems rather than nutrient removal by plant harvest. The research was conducted at the site of the municipal wastewater lagoons of Murfreesboro, N. C. from June through November 1980.

METHODS

Six experimental pools were constructed at the municipal wastewater lagoon site at Murfreesboro, N. C. Two 3.2 hectare wastewater lagoons, located next to the Meherrin River, are operated in parallel and have a mean depth of 1.2 m with a input of approximately 800 m^3/day. The ponds do not normally meet effluent limits (maximum of 30 mg/l BOD and 30 mg/l TSS) specified by the North Carolina Division of Environmental Management. Mean influent BOD is 175 mg/l and mean effluent BOD is 60 mg/l. Influent TSS averages 280 mg/l and effluent TSS averages 50 mg/l, while mean influent ammonium is 50 mg N/l and mean effluent ammonium is 20 mg N/l (Mr. Jack Beatty, personal communication).

Preliminary studies were done in December 1979 to determine the effects of temperature (particularly freezing temperatures) on alligatorweed (*Alternanthera philoxeroides* (Mart.) Griseb.) and duckweed (probably *Spirodela oligorhiza* (Kurz) Heglm.). The plants were collected from sites in eastern N. C. and were placed in plastic wash tubs (48 X 48 X 43 cm) in an open area of a fourth story roof top. Data taken included air and water temperature, dissolved oxygen, and water depth. Changes in the status of the plants caused by changing temperatures were noted.

In May 1980 duckweed (*S. oligorhiza*) was collected from a small pond near Columbia, N. C. and alligatorweed was collected from Hares Mill Pond near Winton, N. C. Following collection, the plant material was placed in lagoons 3.1 m wide by 9.1 m long. Galvanized steel sheets used in construction of these lagoons were bolted together in a rectangular fashion and were placed in holes dug to a depth of 1-1.5 m. The lagoons were lined with 6 mil black polyethylene. Two lagoons contained alligatorweed, two contained duckweed, and two (controls) contained no floating vascular plants (Figure 1).

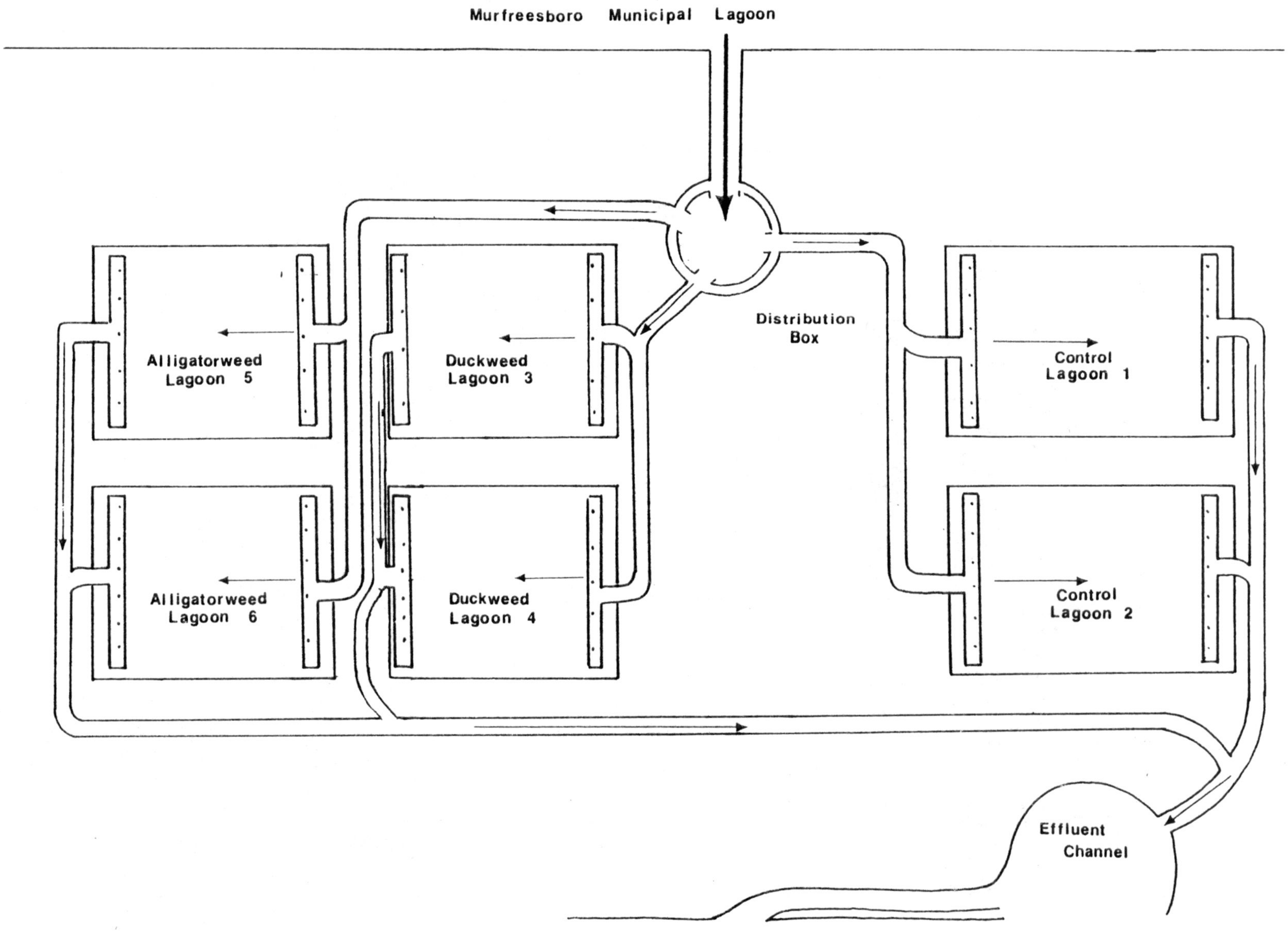
Three consecutive 12-day wastewater treatment experiments were run using the lagoons as static pools before the entire system was converted to flowthrough. At the end of each 12-day period, the pools were pumped as dry as possible and refilled with water from the municipal lagoon.

In the flowthrough phase of the study water was siphoned from the Murfreesboro lagoon through PVC pipe to a distribution box. From the distribution box PVC pipes with flow control devices led to perforated PVC pipes suspended across the influent ends of the lagoons. Flow rate into the lagoons was maintained at approximately 2.6 l/min and the water depth was kept around 0.5 m, resulting in a retention time of 4 days. Screens were used to restrict duckweed and alligatorweed from the discharge ends of the pools. This free surface area at the discharge end (around 25% of the pool surface area) was intended for reaeration of the effluent (Dinges 1979).

From the static systems complete data sets were taken at the beginning and at the end of each 12-day run. Every 3 days during the 12-day period a basic data set was taken which included air and water temperature, water depth, Secchi depth, BOD, TSS, pH, O_2 (surface, middle, and bottom), nitrite, nitrate, ammonium, and total phosphorus. The complete data set included the basic data set plus dissolved phosphorus, ortho-phosphate, total Kjeldahl nitrogen, and dissolved Kjeldahl nitrogen. Water samples were taken 5 cm below the surface and 5 cm above the bottom of the lagoon.

Basic data sets from the flowthrough system were collected approxi-

Figure 1. Diagram of the experimental facilities at the Murfreesboro study site (not to scale).


Murfreesboro Municipal Lagoon
Distribution Box
Alligatorweed Lagoon 5
Duckweed Lagoon 3
Control Lagoon 1
Alligatorweed Lagoon 6
Duckweed Lagoon 4
Control Lagoon 2
Effluent Channel

mately every 3 days and complete data sets were collected approximately every 12 days. Samples were collected at the junction of the lagoon drain and the outfall line while the reaeration zone was examined for dissolved oxygen. Sampling of the flowthrough system began in early August and continued through November with reduced intensity during October and November.

Biochemical oxygen demand and TSS were determined according to Standard Methods (APHA 1975). Dissolved oxygen was measured with a YSI Model 54 A field oxygen meter. A Fisher Accument Model 210 portable field meter was used for pH measurements, water temperature was measured with a thermistor, and air temperature was measured with a maximum/minimum thermometer A Secchi disc was used for transparency determinations.

Inorganic nutrient analysis was under the supervision of M. N. Jones, Manager of the Water Quality Laboratory of the Department of Biology of East Carolina University. Analyses of dissolved nutrients were made on water filtered through Gelman Type A-E filters (nominal pore size, 0.3μm). An Orion ammonia electrode was used to analyse ammonium from 6 June through 5 September. Subsequently, ammonium was measured by the indophenol method (Scheiner 1976). Particulate organic nitrogen was calculated by subtraction of dissolved Kjeldahl nitrogen from total Kjeldahl nitrogen. Nitrite was determined by the azo-spectrophotometric method (EPA 1979), while the UV-spectrophotometric method was used for analysis of of nitrate (APHA 1975).

Phosphorus analysis was by the ascorbic acid method (EPA 1979). Total phosphorus was determined following persulfate digestion, ortho-phosphate was determined following filtration, and dissolved phosphorus was determined following filtration and digestion of the filtrate.

Plant biomass determinations were based upon the random selection of three 0.1 m^2 quadrats from each lagoon. Following collection of the samples, all plants were washed, centrifuged in a washing machine for 5-7 min on spin cycle, and weighed to the nearest 0.1 g. Material not processed on the day collected was placed in a cold room at 5 C, usually for no more than 24 h. Plant material was then dried in an oven at 85 C to a constant dry weight, ground in a Wiley mill, and stored in sealed plastic bags in a dessicator prior to chemical analysis. Processing the dry plant material (ashing, acid digestion, and filtering) to determine inorganic nutrients followed methods outlined by Brinson and Davis (1976). A Perkin-Elmer Model 305B atomic absorption spectrophotometer was used for cation analysis of the plant material (Perkin-Elmer Corporation 1976). Organic dry weight was determined by subtracting the ash of each sample from the dry weight of the sample.

For the phytoplankton studies a 100 ml aliquot of each water sample was placed in a dark plastic bottle, and eight drops of Lugol's solution plus sodium acetate was added for preservation (Hobbie 1971). The sample bottles were then capped and stored at room temperature until analyzed. Sample sets were randomly chosen for analysis from each month's collection. A Palmer counting cell was used for determination of unit counts (Wetzel and Likens 1979). Cellular volumes were calculated and used to determine wet weight biomass. Linear regression was performed on a programable calculator (Texas Instruments Model TI-59) for determination of the correlation coefficient of TSS and unit counts. Effluent from one lagoon of each pair (Control Lagoon 1, Duckweed Lagoon 3, and Alligator-weed Lagoon 5) was analyzed to determine percent reduction of algal biomass and percent reduction of algal unit counts.

Water and plant sample data were analyzed with the SAS package (SAS Institute 1979). Statistical analysis and data organization included means, standard deviations, standard errors, ranges, t-tests, plots, and Duncan's Multiple Range tests.

RESULTS AND DISCUSSION

Static Systems

The duckweed and alligatorweed systems were not effective in improving the quality of wastewater maintained in static lagoons during 12-day experimental periods from 8 June to 13 July (APPENDIX A). Duncan's Multiple Range Tests showed no significant differences in BOD, TSS, and other water quality indicators between the control and experimental lagoons. Due to production of organic matter by macrophytes and phytoplankton, BOD often increased beyond that of the original wastewater. Phosphorus and nitrogen were not reduced. Periodic (12-day) replacement of the water in the static lagoons apparently prevented the build-up of complex microbial communities, an essential factor in BOD removal in a floating vascular plant system.

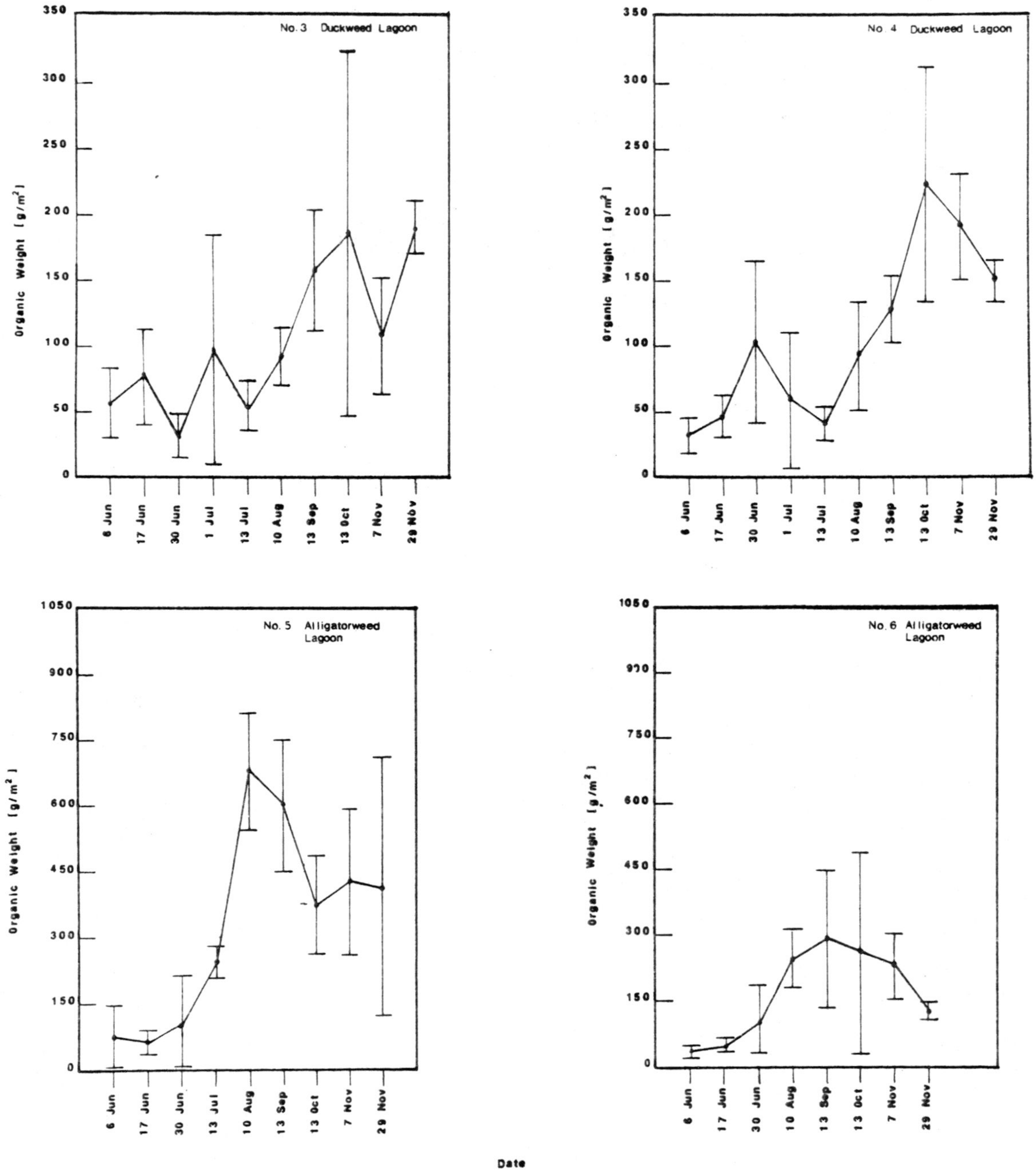
Flowthrough System

Due to lack of success in upgrading the wastewater, the static lagoons were converted to a flowthrough system on 12 August as described in Methods. An attempt was made to maintain a 2.6 l/min flow with around a 4 day detention period, but this was not accomplished due to problems with the flowthrough system (APPENDIX B). Problems included breaking of the siphon to the distribution box and clogging of the influent system by water boatmen (*Arctocorixa interrupta* (Say)) from the municipal lagoon.

Biomass and Nutrient Content of Plants

Organic weight of duckweed fluctuated over time (Figure 2: No. 3, No. 4). Field observations showed that often an accumulation of biomass

Figure 2. Organic weight of duckweed and alligatorweed (6 June to 29 November 1980) at the Murfreesboro study site. Vertical bars indicate $\pm$ 1 S.D. of three random samples taken at each sampling date.


No. 3 Duckweed Lagoon
No. 4 Duckweed Lagoon
No. 5 Alligatorweed Lagoon
No. 6 Alligatorweed Lagoon
Organic Weight (g/m²)
0
50
100
150
200
250
300
350
450
600
750
900
1050
6 Jun
17 Jun
30 Jun
1 Jul
13 Jul
10 Aug
13 Sep
13 Oct
7 Nov
29 Nov

Date

was followed by death and decay of some of the plants. This is attributed to factors such as self-shading within the duckweed population. Greater accumulation of duckweed occurred during late August and into the fall resulting in a peak biomass of 225 g/m^2 during October. Following field studies of some species of duckweed in Baton Rouge, La., Culley et al. (1978) also reported less growth of some duckweeds (particularly Lemna gibba and Wolffia sp.) during the summer months than during the fall and winter months.

Low temperatures did not appear to reduce the standing crop (biomass) of duckweed. The air temperature ranged from 35 C in June to -6 C in November. In late November following some freezing nights the duckweed was healthy and showed no effects of frost damage. Healthy duckweed overwinters in the pond near Columbia, N. C. where the duckweed used in the Murfreesboro studies was collected (Richard Gay, personal communication). For one year, at least, it overwintered in a lake near Charlotte, N. C. (Douglas Caldwell, personal communication). Also, I observed duckweed growing during winter at the Ayden-Grifton Wastewater Treatment Plant. In my preliminary study (December 1979) duckweed survived deep freezing and thawing which occurred during 7 days of the experiment.

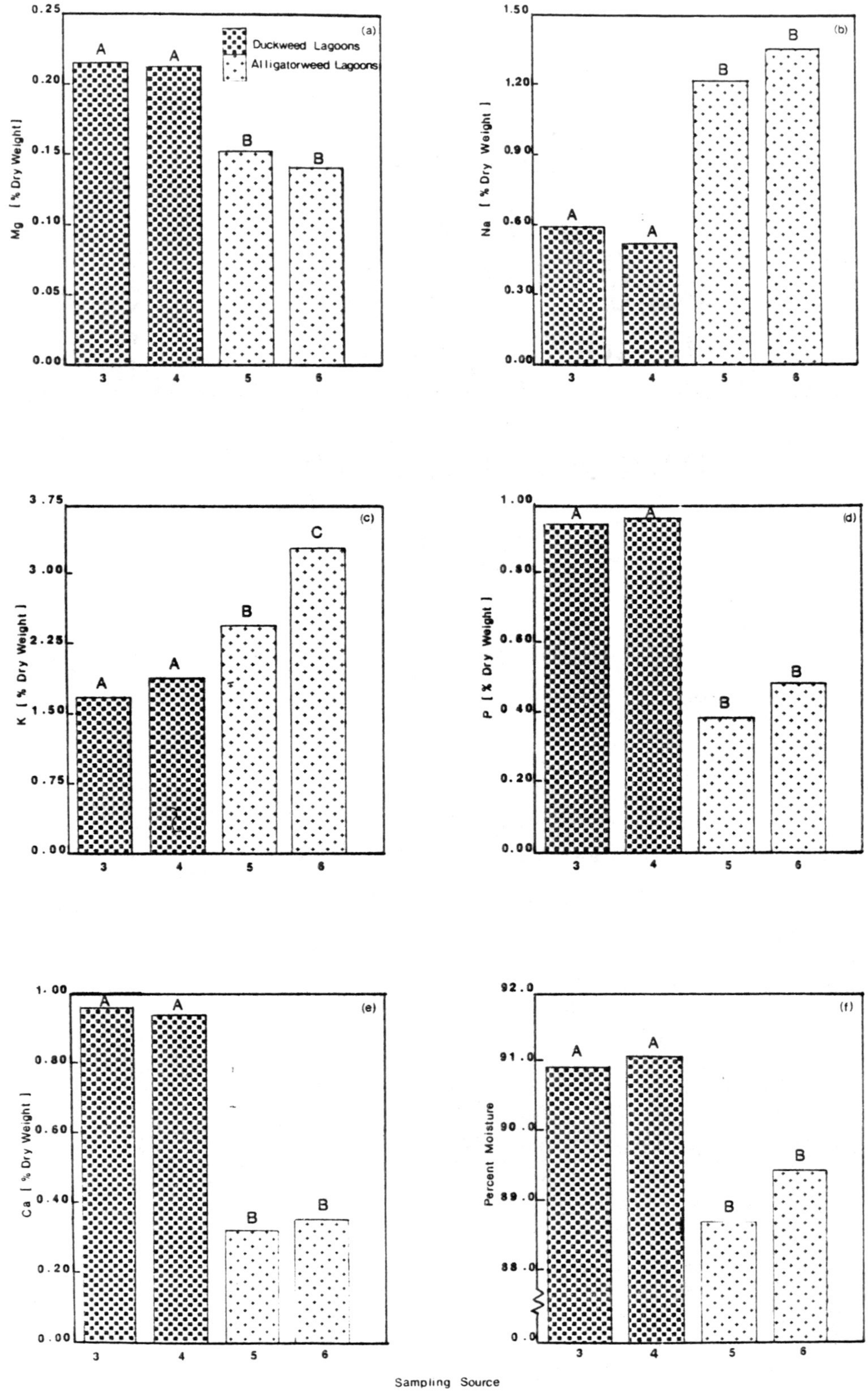
Low temperature appeared to depress growth of alligatorweed (Figure 2: No. 5, No. 6). I have observed that soon after freezing weather begins in eastern North Carolina, above water alligatorweed shoots die back. However, a large proportion of the shoots and underwater stems appear to survive through the winter. In the preliminary study, above water alligatorweed died back after about 3 days of freezing and thawing, but the below-water portions appeared healthy at the end of the experiment. However, the biomass decrease observed in the Murfreesboro experiments can be attributed only in part to temperature.

During August shoots were obviously unhealthy. Leaves were often mottled and chlorotic, and there were "waves" of die-back followed by re-growth of healthy shoots. In early September insect larvae tentatively identified as Vogtia malloi Pastrana, the alligatorweed stem borer, were found in the plants. At this time wilting plants with stem apexes sometimes abscised were found. These conditions are characteristic of Vogtia infestations. Subsequently, plant biomass decreased (Figure 2: No. 5, No. 6) and by November almost all above water vegetation was destroyed. However, many underwater stems appeared healthy as late as December.

Vogtia was first brought into the United States in 1971 from Argentina and was released as a biological control agent at various locations in the Southeast (Spencer and Coulson 1976). Vogtia larvae feeding on alligatorweed girdle the stems, causing a blockage in conducting fibers, and subsequently death of the stem above the girdle. Because of a rather short life cycle (about 39 days) Vogtia can rapidly destroy large stands of alligatorweed. For example, following the release of Vogtia on Lake Alice in Gainesville, Florida, alligatorweed was reduced from 565 to 43 stems/m^2 after only four generations of the insect (Brown and Spencer 1973). During 1971-72 Vogtia was released in the vicinity of Wilmington, N. C. (Coulson 1977), but no control was obtained (Rebecca Galloway, N. C. Department of Agriculture, personal communication).

Inorganic nutrient levels were determined for duckweed and alligatorweed following their introduction to wastewater (Figure 3). Duckweed had significantly higher levels of magnesium, phosphorus, and calcium than did

Figure 3. Summary of inorganic nutrients and percent moisture in duckweed and alligatorweed at the Murfreesboro study site. Values indicated by the same letter are not significantly different at the 0.05 level as determined by Duncan's Multiple Range Test. Each value is the mean of 23 to 27 measurements made during the sampling period from 6 June to 29 November 1980.


(a)
Duckweed Lagoons
Alligatorweed Lagoons
Mg [% Dry Weight]
0.25
0.20
0.15
0.10
0.05
0.00
A
A
B
B
3
4
5
6
(b)
Na [% Dry Weight]
1.50
1.20
0.90
0.60
0.30
0.00
A
A
B
B
3
4
5
6
(c)
K [% Dry Weight]
3.75
3.00
2.25
1.50
0.75
0.00
A
A
B
C
3
4
5
6
(d)
P [% Dry Weight]
1.00
0.80
0.60
0.40
0.20
0.00
A
A
B
B
3
4
5
6
(e)
Ca [% Dry Weight]
1.00
0.80
0.60
0.40
0.20
0.00
A
A
B
B
3
4
5
6
(f)
Percent Moisture
92.0
91.0
90.0
89.0
88.0
0.0
A
A
B
B
3
4
5
6
Sampling Source

alligatorweed (Figure 3a, d, e), while duckweed levels of sodium and potassium were significantly lower than for alligatorweed (Figure 3b, c). Moisture content of duckweed was 91% while that of alligatorweed was slightly but significantly lower at 89%. Total nitrogen was not determined for the plant material.

Fluctuations of phosphorus content in the plants suggests that duckweed accumulated phosphorus over time (see APPENDIX C). Initially (6 June 1980), phosphorus levels in duckweed were 0.57% of dry weight (DW) while 6 months later phosphorus levels were 1.1%. Ortho-phosphate in the water ranged from 4.34 to 9.56 mg/l (see APPENDIX A, B). Calculations of the rates of accumulation and loss of phosphorus by duckweed indicated that highest accumulation occurred in June (0.186 mg $P \cdot g\ DW^{-1} \cdot day^{-1}$) and the highest rate for loss occurred from September to October (-0.075 mg $P \cdot g\ DW^{-1} \cdot day^{-1}$). Culley et al. (1975) found that by increasing lagoonal nutrients the nutrient content of duckweeds would also increase. Culley and Epps (1973) observed fluctuations of phosphorus (percent DW) in S. oligorhiza from 1.1% when grown on a municipal waste lagoon to 1.8% when grown on an anaerobic swine waste lagoon.

Alligatorweed accumulated higher levels of phosphorus than did duckweed. Initial levels were 0.15% of DW and by September the concentration had increased to 1.2% of DW. The highest rate of accumulation of phosphorus by alligatorweed occurred from October to November and was 0.248 mg $P \cdot g\ DW^{-1} \cdot day^{-1}$ while the highest rate for loss occurred from September to October and was -0.302 mg $P \cdot g\ DW^{-1} \cdot day^{-1}$. The mean water concentration of orthophosphate during this time was about 8.0 mg/l. Davis and Stanley (1981) found that in a South Carolina stream (Black Creek) increases in alligatorweed phosphorus levels tended to be positively correlated with increases in water phosphorus levels. Ortho-phosphate levels were lower (0.07 mg P/l) above the outfalls of a paper pulp mill treatment facility and wastewater treatment plant than below (0.19 mg P/l). Similarly, phosphorus of the alligatorweed increased from 0.2% of DW above the outfalls to 0.5% of DW below the outfalls. Thus, while ortho-phosphate in the Murfreesboro lagoons was 44 times higher than in Black Creek, there was only about a two fold increase in alligatorweed phosphorus content above that of alligatorweed in Black Creek. This suggests that the levels of phosphorus in the Murfreesboro plants may have approached the maximum for this species.

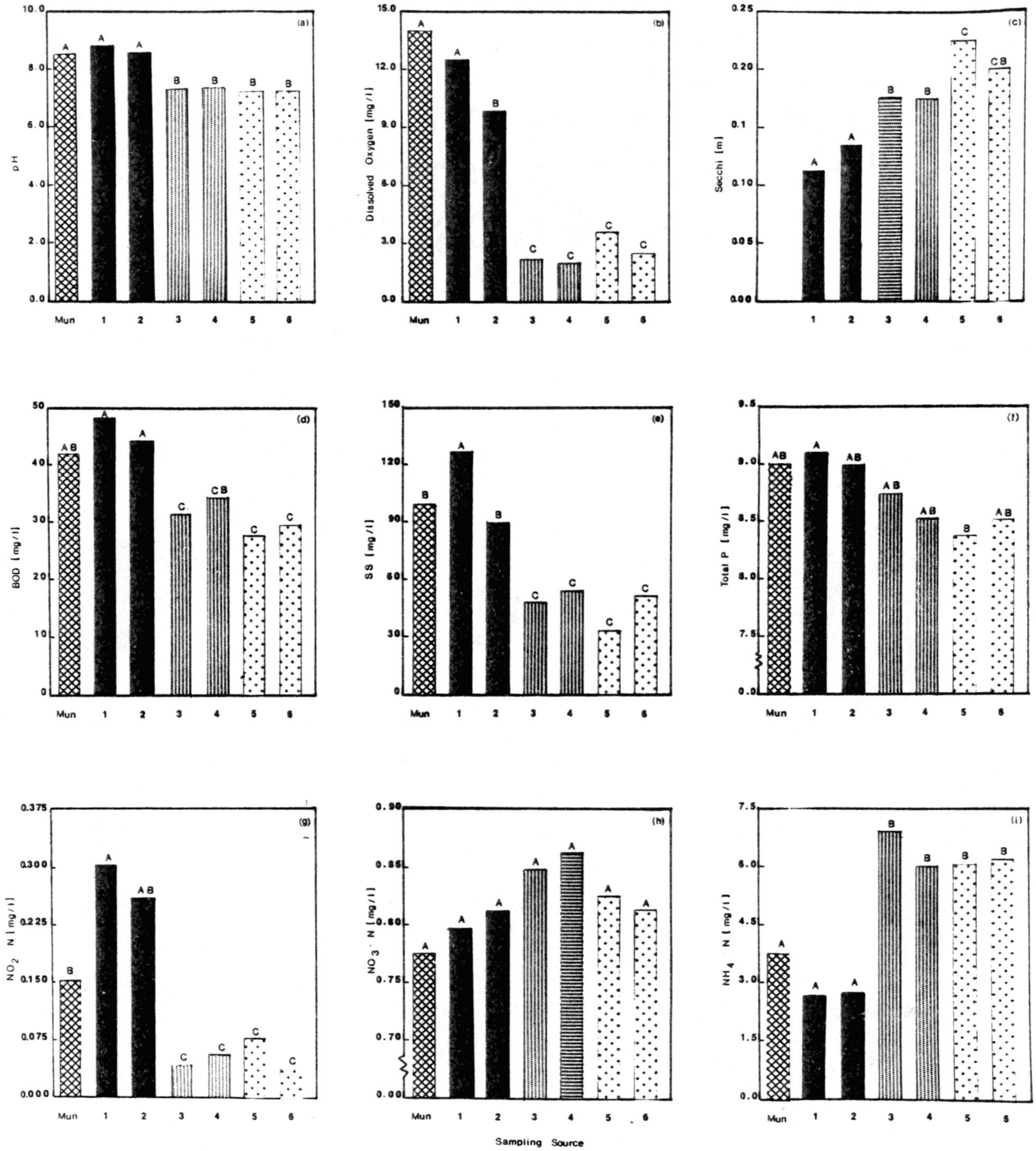
Influence of Plants on Water Quality

pH and O_2

The pH differences between the control and experimental lagoons were significant (Figure 4a). The pH of the experimental lagoons was usually around 7.0, while in the control lagoons it was 8.0 to 9.0 and occasionally higher. This difference is attributed primarily to changes in the inorganic carbon buffer system brought about by photosynthetic utilization of carbon dioxide and bicarbonate by algae in the control lagoons.

Dissolved oxygen levels (surface) at the effluent end were significantly lower in the experimental lagoons than in the control lagoons (Figure 4b; APPENDIX B). High net photosynthesis by phytoplankton in the control lagoons resulted in dissolved oxygen levels up to 15.0 mg/l. However, dissolved oxygen in the control lagoons was low on a few occasions (less than 5.0 mg/l) when there were euglenoid algal mats on the water's surface. Shading by these mats may have depressed oxygen production by

Figure 4. Means of several water quality parameters for the effluents of the Murfreesboro municipal lagoon and the control, duckweed, and alligatorweed lagoons from 12 August through 29 November 1980. Each value is the mean of 25-27 measurements. Values indicated by the same letter are not significantly different at the 0.05 level as determined by Duncan's Multiple Range Test. Secchi depth was not taken for the municipal lagoon. Murfreesboro municipal lagoon; control lagoons; duckweed lagoons; alligatorweed lagoons.


(a)
pH
(b)
Dissolved Oxygen [mg/l]
(c)
Secchi [m]
(d)
BOD [mg/l]
(e)
SS [mg/l]
(f)
Total P [mg/l]
(g)
NO2 N [mg/l]
(h)
NO3 N [mg/l]
(i)
NH4 N [mg/l]
Mun 1 2 3 4 5 6
Sampling Source

photosynthesizing phytoplankton in the water column and reduced surface reaeration. In the experimental lagoons macrophyte cover apparently inhibited surface reaeration and photosynthesis by phytoplankton. Lewis and Bender (1961) reported similar results for a duckweed-covered pond where the underlying water was sometimes anaerobic.

Near the surface of the lagoons dissolved oxygen was generally higher in the influent area than in the effluent area. Vertical stratification was apparent also in the alligatorweed lagoons where dissolved oxygen levels near the surface were around 3.0 mg/l, while the bottom water was nearly anaerobic. The duckweed lagoons were nearly anaerobic throughout except at the surface of the influent area.

TSS, Phytoplankton, and BOD

Suspended solids concentrations were significantly higher in the control lagoons ($\bar{x}$ = 108.0 mg/l) than in the experimental lagoons ($\bar{x}$ = 45.8 mg/l (Figure 4e)). Since TSS in wastewater effluent consists primarily of algae (Koopman et al. 1979; Wolverton 1979a), it was no surprise that algal unit counts were strongly correlated with TSS (59% of the variance explained by the presence of algae). The number of units per liter was generally much higher in the control lagoons than in the experimental lagoons (Table 1). Alligatorweed communities seemed to be more efficient in reducing algal biomass than were duckweed communities (Figure 5; Figure 6). Phytoplankton biomass and TSS were generally lowest in Lagoon 5 (Figure 7; Table 1) and water transparency was greatest in this lagoon (Figure 4c). The high alligatorweed biomass in this lagoon (Figure 2: No. 5) probably accounts for these observations. Blue-greens dominated the algal flora of both the control and plant community la-

Table 1. Algal unit counts (number X 10^6/1), algal biomass (mg/1), and total suspended solids (mg/1) for the effluents of the Murfreesboro municipal lagoon and the control, duckweed and alligatorweed lagoons.

	Sampling Date																				
	Aug. 25			Sep. 8			Sep. 19			Oct. 6			Oct. 27			Nov. 3			Nov. 7		
Sample source	Unit cts.	Biomass	SS	Unit cts.	Biomass	SS	Unit cts.	Biomass	SS	Unit cts.	Biomass	SS	Unit cts.	Biomass	SS	Unit cts.	Biomass	SS	Unit cts.	Biomass	SS
7-Murfreesboro lagoon	195.6	15.3	65.2	146.3	35.3	167.6	159.1	157.4	90.8	21.8	32.2	52.0	432.4	914.0	121.0	255.8	545.6	126.4	215.3	451.2	151.2
1-Control lagoon	151.9	6.3	60.8	548.2	54.2	163.6	332.5	88.6	136.2	11.2	12.4	33.0	544.8	1158.8	109.4	284.5	604.8	118.6	199.7	424.7	140.0
2-Control lagoon	104.9	4.7	17.8	138.4	59.7	104.8	341.2	102.4	120.4	23.7	31.7	28.2	471.1	1022.4	124.6	272.7	468.4	118.0	179.7	382.7	142.4
3-Duckweed lagoon	42.7	535.1	38.0	5.4	4.8	33.0	159.3	9.1	53.0	5.9	7.1	9.2	135.4	281.9	43.0	116.7	247.7	47.4	114.2	380.8	92.4
4-Duckweed lagoon	38.1	516.3	16.6	2.3	10.9	46.4	52.6	32.9	47.0	2.3	3.1	0.0	280.2	593.4	90.0	176.6	374.7	84.8	No sample		
5-Alligatorweed lagoon	77.9	4.6	42.0	0.6	0.8	9.8	6.7	8.9	20.6	0.0	0.0	0.0	147.3	311.7	34.4	128.5	272.9	46.6	48.0	103.0	50.6
6-Alligatorweed lagoon	10.2	10.8	25.2	3.6	54.2	12.6	74.1	26.3	48.2	2.7	3.5	22.0	121.7	255.5	45.2	114.8	245.7	79.4	92.4	1198.1	101.8

Figure 5. Percent reduction of algal units in effluents of Duckweed Lagoon 3 and Alligatorweed Lagoon 5 as compared to Control Lagoon 1.

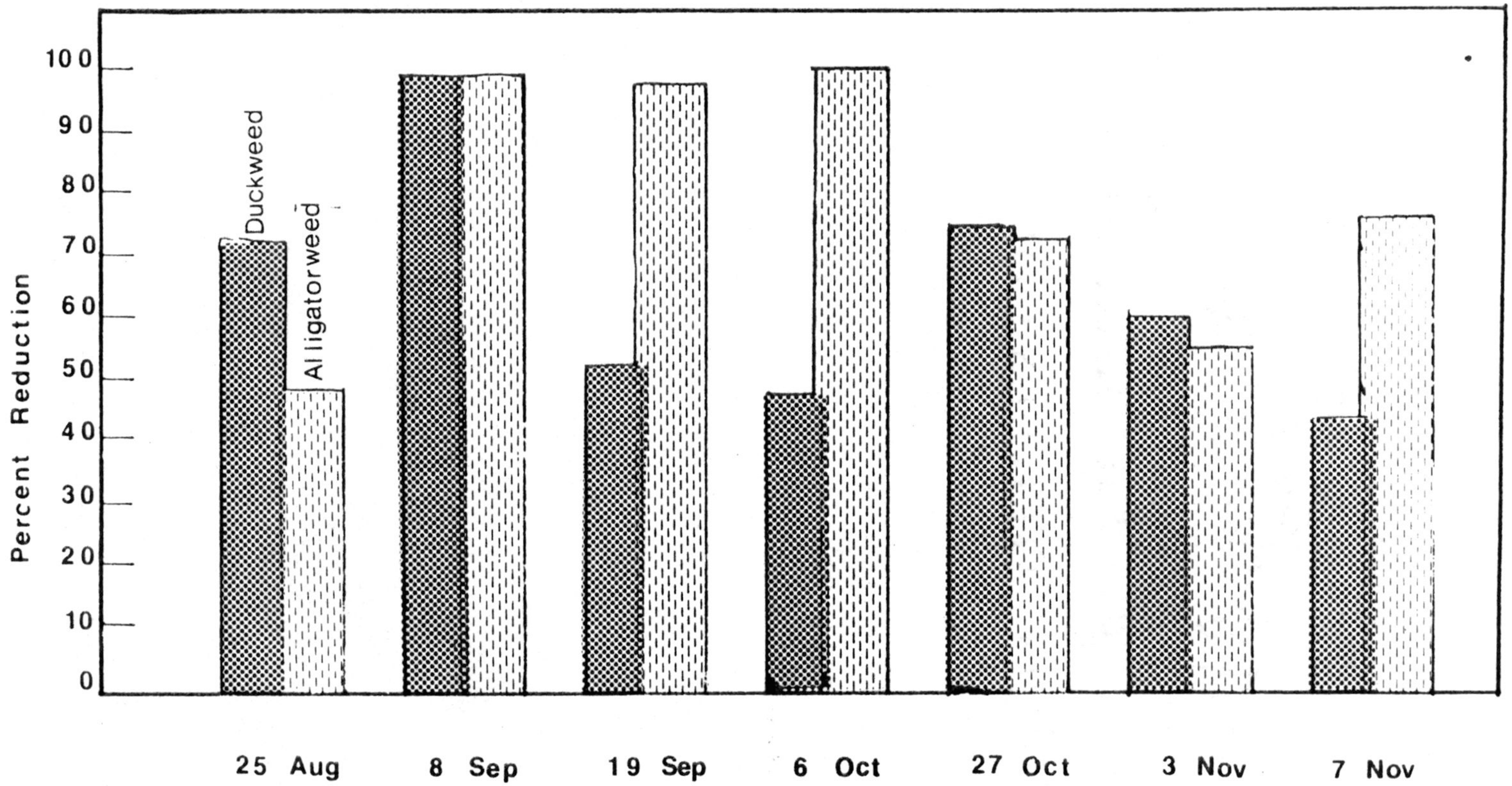

Percent Reduction
0
10
20
30
40
50
60
70
80
90
100
Duckweed
Alligatorweed
25 Aug
8 Sep
19 Sep
6 Oct
27 Oct
3 Nov
7 Nov

Figure 6. Percent reduction of algal biomass in effluents of Duckweed Lagoon 3 and Alligatorweed Lagoon 5 as compared to Control Lagoon 1.

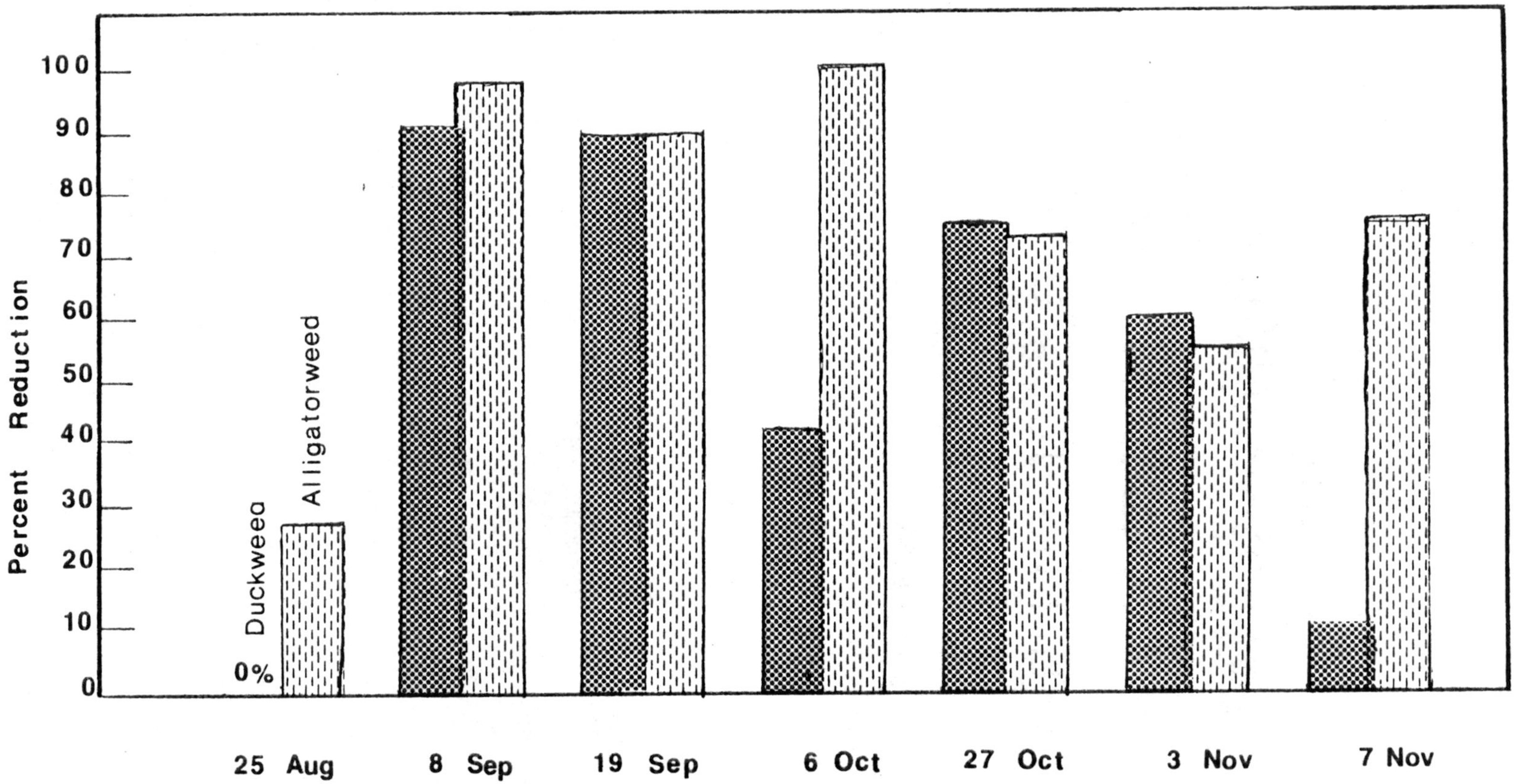
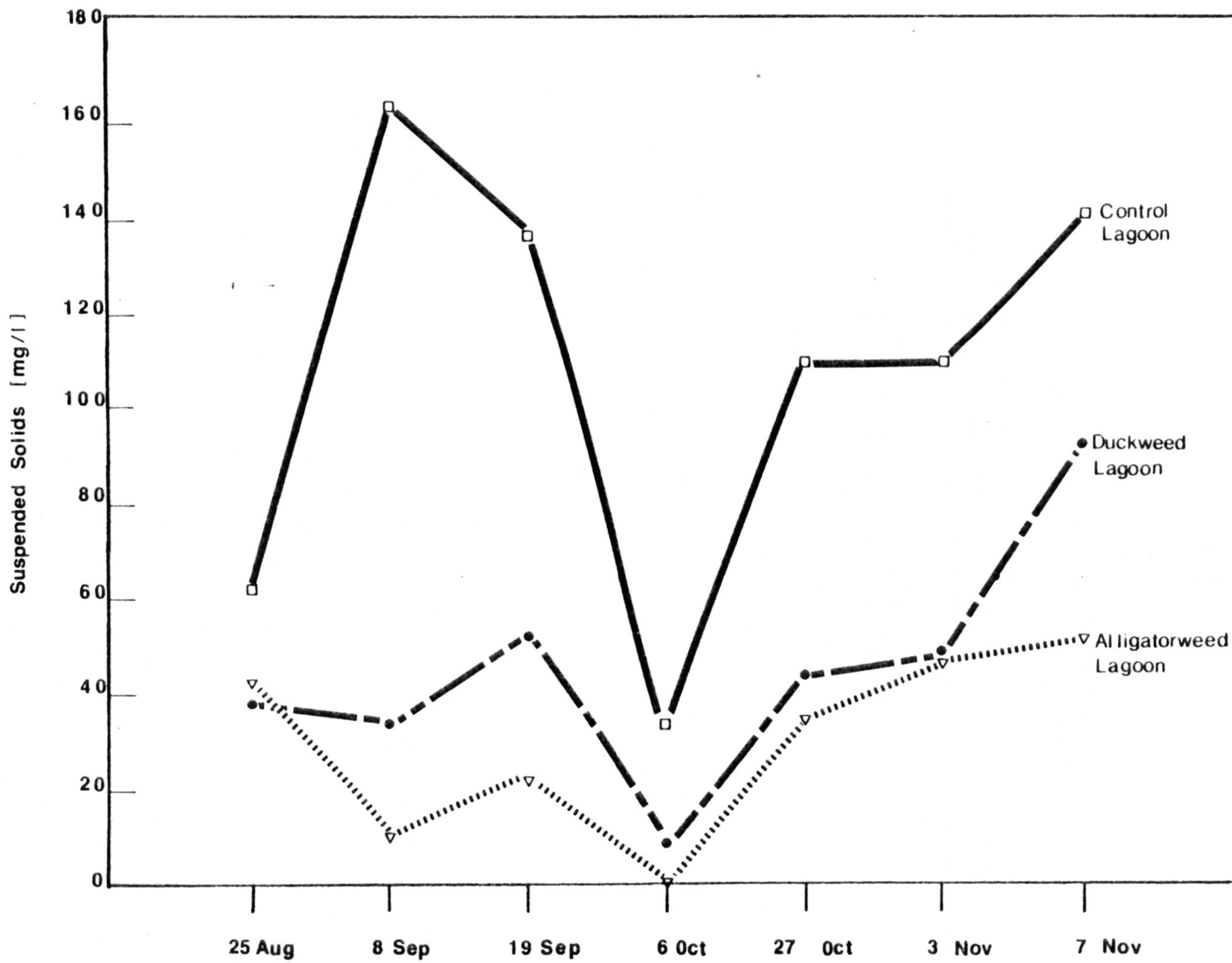

Percent Reduction
100
90
80
70
60
50
40
30
20
10
0
Duckweea
Alligatorweed
0%
25 Aug
8 Sep
19 Sep
6 Oct
27 Oct
3 Nov
7 Nov

Figure 7. Total suspended solids in effluents of Control Lagoon 1, Duckweed Lagoon 3, and Alligatorweed Lagoon 5 from 25 August to 7 November 1980.



180
160
140
120
100
80
60
40
20
0
Suspended Solids [mg/l]
Control Lagoon
Duckweed Lagoon
Alligatorweed Lagoon
25 Aug
8 Sep
19 Sep
6 Oct
27 Oct
3 Nov
7 Nov

goons (Table 2). Genera diversity was higher in the experimental lagoons than in the control lagoons.

Reduction of BOD in the Murfreesboro experimental lagoons was less than in some waterhyacinth systems that have been studied. For example, Dinges (1978) measured a 93% reduction in BOD of municipal secondary effluent passed through four waterhyacinth lagoons in series. The alligatorweed experimental lagoons reduced BOD by only 32.3% while the duckweed lagoons were even less efficient; they reduced the Murfreesboro municipal BOD by only 21.7%. Occasionally, BOD in the control lagoon effluents was higher than in the influents. This could have been due to increased primary production during the 4 day detention time.

Phosphorus and Nitrogen

The experimental lagoons did not remove a measurable amount of phosphorus (Figure 4f). Duncan's Multiple Range Test indicated no significant difference between the control lagoons and the experimental lagoons. Most phosphorus compounds in wastewater treatment are removed either by sedimentation or by biological uptake with harvest. Macrophytes and phytoplankton were not harvested, nor did extensive sedimentation of dead plant and animal material occur. Therefore, one would not expect significant reductions in phosphorus.

The experimental lagoons were significantly higher in ammonium than the control lagoons (Figure 4i). Ammonium in the effluents averaged 6.4 mg N/l for the duckweed lagoons and 6.1 mg N/l for the alligatorweed lagoons; the control lagoons concentrations were 2.6 mg N/l (Lagoon 1) and 2.7 mg N/l (Lagoon 2). The potential nitrogenous dissolved oxygen demand due to these high ammonium concentrations could have a detrimental impact

Table 2. Algal genera in effluent of control, duckweed, alligatorweed, and Murfreesboro municipal lagoon (XX indicates dominant or co-dominant species; X indicates species present).

Sample Source	Oscillatoria	Golenkinia	Phacus	Chlamydomonas	Microcystis/Anacystis	Chlorella	Closteridium	Ankistrodesmus	Scenedesmus	Navicula	Euglena (cysts)	Unidentified crustose green
25 Aug												
7-Municipal Lagoon	XX				XX							
1-Control Lagoon	X				XX							
2-Control Lagoon	X				XX							
3-Duckweed Lagoon	X		X					X	X	X	X	XX
4-Duckweed Lagoon	X											XX
5-Alligatorweed Lagoon	X				XX			X	X		X	
6-Alligatorweed Lagoon	X				XX					X	X	
8 Sep												
7-Municipal Lagoon	XX				XX							
1-Control Lagoon	XX				XX			X	X		X	
2-Control Lagoon	XX		X		XX	X				X	X	
3-Duckweed Lagoon	XX				X							
4-Duckweed Lagoon	XX		X									
5-Alligatorweed Lagoon	XX											
6-Alligatorweed Lagoon	XX		X								X	
19 Sep												
7-Municipal Lagoon	XX		X		XX						X	
1-Control Lagoon	XX				XX							
2-Control Lagoon	XX				XX							
3-Duckweed Lagoon	X				XX							
4-Duckweed Lagoon	XX		X		XX			X				
5-Alligatorweed Lagoon	XX											
6-Alligatorweed Lagoon	XX				XX							
6 Oct												
7-Municipal Lagoon	XX	X										
1-Control Lagoon	XX					X					X	
2-Control Lagoon	XX	X			XX			X			X	
3-Duckweed Lagoon	XX				X			X		X		
4-Duckweed Lagoon	XX											
5-Alligatorweed Lagoon												
6-Alligatorweed Lagoon	XX											
27 Oct												
7-Municipal Lagoon	X	XX				X	X	X	X			
1-Control Lagoon	X	XX						X				
2-Control Lagoon	X	XX	X									
3-Duckweed Lagoon	X	XX		X			X	X				
4-Duckweed Lagoon	X	XX					X	X		X		
5-Alligatorweed Lagoon	X	XX					X	X				
6-Alligatorweed Lagoon	X	XX						X	X	X		
3 Nov												
7-Municipal Lagoon	X	XX				X	X	X	X			
1-Control Lagoon	X	XX						X				
2-Control Lagoon	X	XX	X									
3-Duckweed Lagoon	X	XX		X			X	X				
4-Duckweed Lagoon	X	XX					X	X		X		
5-Alligatorweed Lagoon	X	XX					X	X				
6-Alligatorweed Lagoon	X	XX						X	X	X		
7 Nov												
7-Municipal Lagoon		XX		X				X	X			
1-Control Lagoon	X	XX		X								
2-Control Lagoon	X	XX		X								
3-Duckweed Lagoon		XX		X								
4-Duckweed Lagoon												
5-Alligatorweed Lagoon		XX										
6-Alligatorweed Lagoon		XX										

on receiving waters. High concentrations of ammonium in the experimental lagoons probably resulted from death and decay of vascular plants, phytoplankton, zooplankton, and other invertebrates (waterboatmen) and from excretion by invertebrates. The paucity of sediments on the bottom of the lagoons is evidence of high ammonification and decay rates.

Nitrite concentrations were higher in the control lagoons ($\bar{x}$ = 0.299 mg N/l in Lagoon 1; $\bar{x}$ = 0.259 mg N/l in Lagoon 2) than in the experimental lagoons ($\bar{x}$ = 0.051 mg N/l in the duckweed lagoons; $\bar{x}$ = 0.053 mg N/l in the alligatorweed lagoons (Figure 4g)). However, there were no significant differences among the lagoons in nitrate levels (Figure 4h).

There are two possible explanations for the unusually high nitrite levels in the control lagoons; both involve nitrifying bacteria. First, *Nitrosomonas*, a bacterium which converts ammonium to nitrite, is mesophilic, has a wide temperature range (1 C to 37 C), and is not very active at low pH. *Nitrobacter*, another bacterium which converts nitrite to nitrate, is less tolerant of fluctuating temperatures, and is less active at high pH (Wetzel 1975). Since the influent pH of the control and experimental lagoons was usually above 8.0 and occasionally as high as 10.0, *Nitrobacter* may have been inhibited so that increased levels of nitrite resulted. The second possible explanation is that high BOD could have contributed to inhibition of *Nitrobacter*. There is competition between heterotrophs and autotrophic nitrifying bacteria (Hammer 1975). When food is available, heterotrophs deplete oxygen which then cannot be utilized in food production by the nitrifiers.

Nitrogen in an aquatic system may be lost as a result of sedimentation, denitrification, or outflow. Observations indicated that little sedimentation occurred in the lagoons. In addition, factors affecting nitrification were not favorable, and thus denitrification was not suspected. A nitrogen summary was calculated for the effluents of each of the lagoons to estimate whether any reduction of nitrogen had occurred (Table 3). A t-test indicated a significant difference at the 0.05 level between the alligatorweed lagoon water and the municipal lagoon effluent in total nitrogen. Total nitrogen in the water was 20.8% lower in both alligatorweed lagoons than in the Murfreesboro municipal effluent. Loss of nitrogen in the gaseous form could account for this reduction. Also, rough calculations suggest that the difference in nitrogen measured could be accounted for by a somewhat greater rate of sedimentation in the alligatorweed lagoons. Nitrogen would be removed from the water by growing vascular plants, but during the course of the flowthrough experiments described here (12 August to 29 November) there was a loss of alligatorweed biomass and probably some loss of nitrogen to the water (Figure 2).

The alligatorweed community lagoons were similiar to a facultative lagoon in that they possessed a vertical oxygen gradient from aerobic at the surface to nearly anaerobic on the bottom. I assume that nitrification, an aerobic process, occurred near the surface. The nitrate produced was then converted by denitrification to dinitrogen (N_2 gas) in the anaerobic zone. In the duckweed lagoons there was no vertical oxygen gradient and presumably little or no nitrification.

Table 3. Averages and ranges of nitrogen forms in the effluent from the Murfreesboro municipal lagoon and the control, duckweed, and alligatorweed lagoons from 12 August through 29 November 1980.

Sample Source		mg Nitrogen/l					
		NO_2-N	NO_3-N	NH_4-N	PON	DON	Total nitrogen
7-Murfreesboro lagoon	$\bar{X}$	0.15	0.78	3.8	10.1	1.1	20.9
	range	0.0018-0.993	0.470-1.38	0.160-8.22	3.6-15.76	0.95-17.74	15.99-24.71
1-Control lagoon	$\bar{X}$	0.31	0.79	2.6	8.7	7.6	20.0
	range	0.0023-0.993	0.491-1.12	0.11-7.28	4.2-15.59	4.79-15.52	11.70-29.57
2-Control lagoon	$\bar{X}$	0.26	0.81	2.7	8.5	6.4	18.6
	range	0.0009-0.998	0.454-1.04	0.09-5.97	4.3-13.61	4.14-10.52	16.57-22.82
3-Duckweed lagoon	$\bar{X}$	0.044	0.85	6.8	5.1	5.3	18.1
	range	0.0008-0.229	0.433-1.71	2.31-11.90	2.7-10.48	1.93-8.70	11.29-27.88
4-Duckweed lagoon	$\bar{X}$	0.057	0.86	6.0	4.7	7.3	18.9
	range	0.0016-0.260	0.495-1.54	1.63-11.50	1.6-9.03	3.97-11.70	15.91-25.77
5-Alligatorweed lagoon	$\bar{X}$	0.075	0.83	6.01	2.2	6.4	15.6
	range	0.0007-0.6366	0.46-2.05	2.01-15.10	0.0-7.59	3.24-6.20	12.06-23.53
6-Alligatorweed lagoon	$\bar{X}$	0.03	0.82	6.1	4.9	5.8	17.5
	range	0.0004-0.154	0.485-1.51	1.72-14.70	2.3-10.90	2.88-9.28	13.05-22.74

SUMMARY AND CONCLUSIONS

The processing of municipal wastewater with a floating vascular plant system using duckweed or alligatorweed has potential for success. This study has shown improvement through use of floating vascular plant systems in some water quality parameters, principally TSS and BOD. These floating plants reduced light intensities in the water; hence phytoplankton photosynthesis was inhibited. Since phytoplankton biomass was shown to be directly related to concentration of suspended solids, any reduction in phytoplankton biomass should cause a reduction in TSS. A floating vascular plant ecosystem is a complex assemblage including macrophytes, periphyton, phytoplankton, aquatic invertebrates, and bacteria. Bacteria and other heterotrophs, through respiration, oxidize most of the organic carbon (BOD) lost from the system.

The plant community lagoons were not efficient in reducing inorganic forms of nitrogen and phosphorus. The alligatorweed lagoons did cause a small but significant reduction in total nitrogen, probably through nitrification and denitrification and sedimentation. The reduction might have been enhanced had the surface dissolved oxygen concentrations been greater.

Regular harvesting would have reduced nitrogen and phosphorus levels roughly in proportion to the biomass removed. Since plants were not harvested, the accumulated nutrients were probably recycled. Loss of organic carbon to the aquatic system through decay (and therefore increase in BOD) could also have been minimized if a regular harvesting schedule had been maintained. Even with the loss of alligatorweed biomass due to a *Vogtia* infestation, alligatorweed communities appeared to be more effective as water processors than were duckweed communities. Total suspended solids, BOD, phytoplankton biomass, and Secchi levels were significantly improved over those levels in the duckweed lagoons. Dissolved oxygen levels in water containing alligatorweed were not as low as dissolved oxygen levels of duckweed lagoons. Alligatorweed shows promise as a wastewater processor in eastern North Carolina, despite its susceptibility to Vogtia infestations.

Duckweed, because of its persistence during the winter, could be used in a North Carolina climate. Duckweed coupled with another aquatic macrophyte, such as waterhyacinth, would be a more efficient system. Waterhyacinth grows well in the summer, while duckweed can survive in the winter well enough to maintain a functional treatment system. However, regulatory agencies in North Carolina are concerned that waterhyacinth (presently not a problem in North Carolina waterways) could become a problem weed.

Design criteria for a successful operational system are debatable. From this research it appears that a static system employing a 12 day detention time has little potential in successful treatment of wastewater. A passive zone for reaeration proved to be ineffective. Dissolved oxygen in the reaeration zone was generally as low as that under the plant cover. A mechanical aerator or a series of weirs employing cascades could eliminate this problem.

Studies in the future should seriously consider flowthrough systems which employ either combinations of macrophytes or a single species in lagoons arranged in series. From such research a floating vascular plant system could be developed that would be efficient, reliable, and cost-effective. This would provide an alternative to small communities, rural facilities, and domestic feed lots, etc. for improving wastewater effluents.

From this study it may be concluded that:

a) a static system is not as efficient in improving wastewater quality as is a flowthrough system;

b) both duckweed and alligatorweed communities in a flowthrough system improved most water quality parameters except for ammonium and dissolved oxygen;

c) alligatorweed was more efficient in improving wastewater quality than was duckweed;

d) the effectiveness of alligatorweed as a wastewater processor is inhibited by its susceptibility to Vogtia;

e) duckweed has an advantage of being more cold tolerant, but its effectiveness would be enhanced if it and another floating plant were used jointly.

LITERATURE CITED

American Public Health Association (APHA). 1975. Standard methods for the examination of water and waste-water. 14th ed. American Public Health Association.

Boyd, C. E. 1974. Utilization of aquatic plants, p. 97-105. In D. S. Mitchell (ed.), Aquatic vegetation and its use and control. Unesco.

Boyd, C. E. 1970. Vascular aquatic plants for mineral nutrient removal from polluted waters. Econ. Bot. 24: 95-103.

Brinson, M. M., and G. J. Davis. 1976. Primary productivity and mineral cycling in aquatic macrophyte communities of the Chowan River, North Carolina. Water Resources Res. Inst. of Univ. of N. C., Report No. 120.

Brown, J. L., and N. R. Spencer. 1973. Vogtia malloi, a newly introduced Phyticine moth to control alligatorweed. Environ. Entomol. 2: 519-523.

Chambers, G. V. 1978. Performance of biological alternatives for reducing algae (TSS) in oxidation ponds treating refinery/chemical plant wastewater. Paper presented at the Conference of Water Pollution Control Federation; Available from: Exxon Research and Engineering Company, Baytown, Texas 77520.

Coulson, J. R. 1977. Biological control of alligatorweed, 1959-1972: a review and evaluation. Technical Bulletin No. 1547. Agricultural Research Service, USDA.

Culley, D. D., Jr., and E. A. Epps. 1973. Use of duckweeds for waste treatment and animal feed. J. Water Poll. Contr. Fed. 45: 337-347.

Culley, D. D., Jr., J. H. Gholson, T. S. Chisholm, L. C. Standifer, and E. A. Epps. 1978. Water quality renovation of animal waste lagoons utilizing aquatic plants. Robert S. Kerr Environmental Research Laboratory. U.S.E.P.A., 600/2-79-047.

Davis, G. J., and D. W. Stanley. 1981. Oxygen demand associated with alligatorweed: a project completion report. Sonoco Products Company. Unpublished ms.

Dinges, R. 1979. Development of hyacinth wastewater treatment systems in Texas, p. 193-226. In R. A. Bastian and S. C. Reed (eds.), Aquaculture systems for wastewater treatment: seminar proceedings and engineering assessment. 11-12, September, University of California, Davis. U.S.E.P.A.

Dinges, R. 1978. Upgrading stabilization pond effluent by water hyacinth culture. J. Water Poll. Contr. Fed. 50: 833-845.

Environmental Protection Agency (EPA). 1976. Methods for chemical analysis of water and wastes. Environmental Monitoring and Support Laboratory.

Golueke, C. C. 1979. Aquaculture in resource recovery. Compost Sci./ Land Utilization 20: 16-23.

Hammer, M. J. 1975. Water and waste-water technology. John Wiley and Sons, Inc.

Hillman, W. S., and D. D. Culley, Jr. 1978. The uses of duckweed. Amer. Sci. 66: 442-451.

Hobbie, J. E. 1971. Phytoplankton species and populations in the Pamlico River Estuary of North Carolina. Water Resources Res. Inst. of Univ. of N. C., Report No. 56.

Koopman, B. L., J. R. Benemann, and W. J. Oswald. 1979. Pond isolation and phase isolation for control of suspended solids concentration in sewage oxidation pond effluents, p. 104-123. In E. J. Middlebrooks, D. H. Falkenborg, and R. R. Lewis (eds.), Performance and upgrading of wastewater stabilization ponds. U.S.E.P.A.

Lewis, W. M., and M. Bender. 1961. Effect of a cover of duckweeds and the alga *Pithophora* upon the dissolved oxygen and free carbon dioxide of small ponds. Ecology 42: 602-603.

National Academy of Sciences. 1976. Making aquatic weeds useful. National Academy of Sciences.

Ornes, W. H., and D. L. Sutton. 1975. Removal of phosphorus from static sewage effluent by waterhyacinth. Hyacinth Contr. J. 8: 26-30.

Perkin-Elmer Corporation. 1976. Analytical methods for atomic absorption spectroscopy. Perkin-Elmer Corp.

SAS Institute. 1979. Statistical analysis system user's guide. SAS Institute.

Scarsbrook, E., and D. E. Davis. 1971. Effect of sewage effluent on growth of five vascular aquatic species. Hyacinth Contr. J. 8: 26-30.

Scheiner, K. 1976. Determination of ammonia and Kjeldahl nitrogen by indophenol method. Water Research 10: 31-36.

Serfling, S. A., and C. Alsten. 1979. An integrated, controlled environment aquaculture lagoon process for secondary or advanced wastewater treatment, p. 124-145. In E. J. Middlebrooks, D. H. Falkenborg, and R. F. Lewis (eds.), Performance and upgrading of wastewater stabilization ponds. U.S.E.P.A.

Spencer, N. R., and J. R. Coulson. 1976. The biological control of alligatorweed, Alternanthera philoxeroides, in the United States of America. Aquatic Bot. 2: 177-190.

Wetzel, R. G. 1975. Limnology. W. B. Saunders Company.

Wetzel, R. G., and G. E. Likens. 1979. Limnological analyses. W. B. Saunders Company.

Wolverton, B. C. 1979a. Engineering design data for samll vascular aquatic plant wastewater treatment systems, p. 179-192. In R. K. Bastian, and S. C. Reed (eds.), Aquaculture systems for wastewater treatment: seminar proceedings and engineering assessment. 11-12, September, University of California, Davis. U.S.E.P.A.

Wolverton, B. C. 1979b. Water hyacinths: wastewater purifier and renewable source of energy, feed, food, and fertilizer. NASA, National Space Technology Laboratories.

Wolverton, B. C., R. M. Barlow, and R. C. McDonald. 1976. Application of vascular aquatic plants for pollution removal, energy, and food production in a biological system, p. 141-149. In J. Tourbier, and R. W. Pierson, Jr. (eds.), Biological control of water pollution. University of Penn. Press.

Wolverton, B. C., and R. C. McDonald. 1976a. Don't waste waterweeds. New Scientist 72: 318-320.

Wolverton, B. C., and R. C. McDonald. 1976b. Water hyacinths for upgrading sewage lagoons to meet advanced wastewater treatment standards: part II. NASA, National Space Technology Laboratories, TM-X-72730.

Wolverton, B. C., and M. M. McKown. 1976. Water hyacinths for removal of phenols from polluted waters. Aquatic Bot. 2: 191-201.

Wolverton, B. C., and R. C. McDonald. 1979. Upgrading facultative wastewater lagoons with vascular aquatic plants. J. Water Poll. Contr. Fed. 51: 305-313.

APPENDICES

APPENDIX ABBREVIATIONS

Airtemp	Air temperature (°C)
Ammonia	Ammonium nitrogen (mg/liter)
BOD	Biochemical oxygen demand (mg/liter)
Ca	Calcium (% dry weight)
Disskjel	Dissolved Kjeldahl nitrogen (mg/liter)
DissP	Dissolved phosphorus (mg/liter)
DO	Dissolved oxygen (mg/liter)
Drywgt	Plant dry weight (g/m^2)
K	Potassium (% dry weight)
Mg	Magnesium (% dry weight)
Na	Sodium (% dry weight)
Nitrate	Nitrate nitrogen (mg/liter)
Nitrite	Nitrite nitrogen (mg/liter)
Organicw	Plant organic weight (g/m^2)
OrthoP	Ortho-phosphate (mg/liter)
P	Phosphorus (% dry weight)
Pash	Plant ash (% dry weight)
Pinsol	Insoluble plant ash (% ash weight)
pH	pH
Pmoistur	Plant moisture (% dry weight)
Psol	Soluble plant ash (% ash weight)
Retenday	Retention time (days)
Secchi	Water transparency (meter)
SS	Total suspended solids (mg/liter)

APPENDIX ABBREVIATIONS (continued)

TotalP	Total phosphorus (mg/liter)
Totkjel	Total Kjeldahl nitrogen (mg/liter)
Trial	One of a set of three plant biomass samples
Wetwgt	Plant wet weight for 0.1 m^2 (g/m^2)
Wtemp	Water temperature (°C)

Appendix A. Water Analyses Data for the Static Systems.

Appendix A Table 1. Water analyses data for the static systems: 5 cm from the top of Lagoon 1 (June 1980 - July 1980).

Month	Day	Wtemp	Secchi	pH	DO	BOD	SS	TotalP	Nitrite	Nitrate	Ammonia	Totkjel	Disskjel	OrthoP	DissP	Airtemp
6	8	28	0.09	9.2	2.2	35.8	102.0	6.13	0.0560	0.771	1.04	8.80	5.35	4.80	5.07	31
6	11	29	0.12	10.3	14.2	43.0	50.0	5.92	0.0110	0.467	0.11	.	.	.	.	32
6	14	25	0.16	8.6	14.2	34.0	59.0	5.74	0.0084	0.203	0.07	.	.	.	.	22
6	17	25	0.13	8.5	15.0	40.0	71.0	6.03	0.0081	0.596	0.17	11.40	4.25	5.04	5.65	22
6	18	22	0.08	9.8	10.5	40.0	115.0	6.44	0.0120	0.622	0.07	11.50	3.09	5.28	6.01	.
6	21	21	0.08	9.4	2.8	51.0	96.4	6.48	0.0022	0.582	1.00	.	.	.	.	26
6	24	20	0.13	10.3	13.4	39.0	124.0	6.56	0.0047	0.644	0.04	.	.	.	.	32
6	27	22	0.08	10.4	9.9	58.0	141.2	6.75	0.0022	0.617	0.09	.	.	.	.	26
6	30	25	0.19	9.7	8.1	38.0	48.6	5.99	0.0040	0.728	0.90	6.89	5.17	5.03	5.42	28
7	1	25	0.05	8.4	5.5	32.0	143.0	6.77	0.0190	0.756	0.58	19.10	4.60	5.09	5.87	.
7	4	24	0.15	10.2	15.0	41.0	72.0	6.25	0.0042	0.639	0.08	.	.	.	.	32
7	7	26	0.18	9.4	3.2	43.0	44.0	6.22	0.0088	0.865	0.11	.	.	.	.	27
7	10	28	0.12	9.4	8.8	38.0	65.0	6.12	0.0023	0.851	0.26	.	.	.	.	29
7	13	26	0.15	9.4	15.0	22.0	56.0	6.25	0.0064	0.712	0.13	8.22	4.52	5.12	5.64	27

Appendix A Table 2. Water analyses data for the static systems: 5 cm from the top of Lagoon 2 (June 1980 - July 1980).

Month	Day	Wtemp	Secchi	pH	DO	BOD	SS	TotalP	Nitrite	Nitrate	Ammonia	Totkjel	Disskjel	OrthoP	DissP	Airtemp
6	8	31	0.07	9.6	4.1	44.0	212.0	5.82	0.0220	0.346	0.07	20.00	4.60	4.49	4.89	31
6	11	29	0.09	.	6.6	50.0	86.0	6.92	0.0140	0.169	0.21	.	.	.	.	31
6	14	26	0.15	9.3	11.0	76.3	90.0	6.15	0.0085	0.416	0.06	.	.	.	.	22
6	17	25	0.32	8.5	15.0	15.5	17.0	5.83	0.0026	0.438	0.22	4.49	4.04	5.06	5.43	22
6	18	22	0.06	9.5	7.4	40.0	115.0	6.44	0.0120	0.622	0.07	11.50	3.09	5.28	6.01	.
6	21	22	0.08	9.7	2.4	61.0	121.6	6.91	0.0009	0.628	0.09	.	.	.	.	26
6	24	19	0.10	10.1	5.6	50.0	69.0	7.15	0.0024	0.610	0.03	.	.	.	.	32
6	27	23	0.06	10.1	7.9	51.0	161.2	6.92	0.0045	0.595	0.06	.	.	.	.	26
6	30	24	0.14	9.9	12.0	52.0	110.0	6.67	0.0052	0.668	0.11	12.50	5.17	5.01	5.44	28
7	1	25	0.05	8.4	1.9	32.0	143.0	6.77	0.0190	0.756	0.58	19.10	4.60	5.09	5.87	.
7	4	25	0.12	10.0	15.0	51.0	90.2	6.75	0.0025	0.626	0.08	.	.	.	.	32
7	7	25	0.12	9.7	13.0	79.0	95.0	6.95	0.0085	0.385	0.15	.	.	.	.	27
7	10	26	0.06	9.1	3.4	54.0	180.0	7.08	0.0097	2.190	0.26	.	.	.	.	29
7	13	27	0.08	9.2	15.0	67.0	176.0	6.67	0.0051	0.896	0.09	20.00	6.73	5.14	5.82	27

Appendix A Table 3. Water analyses data for the static systems: 5 cm from the top of Lagoon 3 (June 1980 - July 1980).

Month	Day	Wtemp	Secchi	pH	DO	BOD	SS	TotalP	Nitrite	Nitrate	Ammonia	Totkjel	Disskjel	OrthoP	DissP	Airtemp
6	8	29	0.15	.	0.7	43.0	28.0	5.31	0.0020	0.771	0.42	.	.	4.44	4.60	31
6	11	30	0.11	.	0.7	37.0	17.0	5.40	0.0140	0.339	0.90	.	.	.	.	31
6	14	25	0.25	8.5	0.9	42.0	.	5.34	0.0080	0.416	1.10	.	.	.	.	22
6	17	23	0.23	8.5	0.7	32.0	35.0	4.62	0.0094	0.452	0.60	6.81	4.70	4.11	4.62	22
6	18	22	0.08	9.4	12.2	40.0	115.0	6.44	0.0120	0.622	0.07	11.50	3.09	5.28	6.01	.
6	21	24	0.08	9.2	0.8	52.0	107.2	6.36	0.0026	0.670	0.25	.	.	.	.	26
6	24	23	0.16	8.4	0.5	55.0	84.6	6.64	0.0019	0.851	0.51	.	.	.	.	32
6	27	22	0.21	7.4	0.8	45.0	15.4	5.88	0.0050	1.030	2.42	.	.	.	.	26
6	30	24	0.22	7.7	0.6	45.0	25.0	6.07	0.0064	1.080	1.37	7.93	5.69	4.77	5.65	28
7	1	24	0.05	8.4	0.4	32.0	143.0	6.77	0.0190	0.756	0.58	19.10	4.60	5.09	5.87	.
7	4	24	0.16	7.3	0.4	57.0	53.0	6.33	0.0018	0.899	3.55	.	.	.	.	32
7	7	24	0.17	7.1	0.8	61.0	39.0	4.30	0.0074	0.333	5.20	.	.	.	.	27
7	10	24	0.14	6.8	0.7	90.0	29.0	6.51	0.0045	2.010	7.31	.	.	.	.	29
7	13	24	0.19	7.0	0.3	65.0	42.0	6.63	0.0150	1.200	9.39	13.10	.	5.90	6.25	27

Appendix A Table 4. Water analyses data for the static systems: 5 cm from the top of Lagoon 4 (June 1980 - July 1980).

Month	Day	Wtemp	Secchi	pH	DO	BOD	SS	TotalP	Nitrite	Nitrate	Ammonia	Totkjel	Disskjel	OrthoP	DissP	Airtemp
6	8	29	0.10	.	0.5	38.5	109.8	5.70	0.0200	0.307	0.60	16.10	4.40	4.72	4.95	31
6	11	29	0.11	.	1.1	25.0	10.4	4.49	0.0130	0.126	0.92	.	.	.	.	31
6	14	25	0.24	8.5	0.9	27.0	32.4	4.67	0.0088	0.433	0.77	.	.	.	.	22
6	17	24	0.27	8.5	0.8	91.3	157.4	5.24	0.0060	0.430	1.04	10.40	3.62	4.34	4.72	22
6	18	25	0.08	9.5	7.7	40.0	115.0	6.44	0.0120	0.622	0.07	11.50	3.09	5.28	6.01	.
6	21	22	0.15	8.8	0.7	48.0	102.4	6.93	0.0020	0.597	0.26	.	.	.	.	26
6	24	20	0.20	7.8	0.5	68.0	78.4	6.95	0.0004	0.783	0.74	.	.	.	.	32
6	27	22	0.22	7.5	0.7	37.0	20.2	5.88	0.0035	0.942	2.27	.	.	.	.	26
6	30	23	0.23	7.6	0.6	46.0	36.4	5.83	0.0066	0.987	1.11	8.56	4.56	4.99	5.38	28
7	1	24	0.05	8.4	0.6	32.0	143.0	6.77	0.0190	0.756	0.58	19.10	4.60	5.09	5.87	.
7	4	24	0.14	7.5	0.5	41.0	59.0	6.20	0.0015	0.725	0.92	.	.	.	.	32
7	7	24	0.17	7.2	0.6	53.0	61.0	4.39	0.0007	0.286	2.09	.	.	.	.	27
7	10	25	0.15	7.0	0.7	71.0	186.0	8.76	0.0004	0.623	4.05	.	.	.	.	29
7	13	24	0.17	7.0	0.0	35.0	41.0	5.72	0.0061	0.819	2.78	6.39	5.16	5.28	5.62	27

Appendix A Table 5. Water analyses data for the static systems: 5 cm from the top of Lagoon 5 (June 1980 - July 1980).

Month	Day	Wtemp	Secchi	pH	DO	BOD	SS	TotalP	Nitrite	Nitrate	Ammonia	Totkjel	Disskjel	OrthoP	DissP	Airtemp
6	8	30	0.05	9.4	2.0	69.0	355.0	7.20	0.0290	0.829	0.08	36.40	5.55	4.33	4.70	31
6	11	28	0.10	.	7.3	43.0	87.0	6.15	0.0140	0.126	1.00	.	.	.	.	31
6	14	24	0.14	8.7	4.8	49.0	59.0	5.67	0.0134	0.211	0.71	.	.	.	.	22
6	17	24	0.12	8.5	4.3	36.0	62.0	5.65	0.0086	0.504	0.09	6.65	2.91	4.83	5.29	22
6	18	23	0.08	9.4	9.4	40.0	115.0	6.44	0.0120	0.622	0.07	11.50	3.09	5.28	6.01	.
6	21	20	0.08	9.5	2.4	47.0	109.8	6.56	0.0017	0.646	0.07	.	.	.	.	26
6	24	22	0.13	9.7	2.4	39.0	105.0	6.56	0.0013	0.654	0.03	.	.	.	.	32
6	27	23	0.12	9.3	3.4	47.0	79.8	6.53	0.0080	0.669	0.07	.	.	.	.	26
6	30	24	0.22	9.4	5.3	28.0	44.0	6.19	0.0052	0.688	0.07	8.44	3.78	4.97	5.44	28
7	1	23	0.08	8.4	1.8	32.0	143.0	6.77	0.0190	0.756	0.58	19.10	4.60	5.09	5.87	.
7	4	23	0.09	9.0	1.9	41.0	127.0	6.66	0.0022	0.721	0.07	.	.	.	.	32
7	7	25	0.12	7.3	1.4	50.0	78.0	3.95	0.0039	0.542	0.53	.	.	.	.	27
7	10	25	0.21	7.0	0.8	83.0	16.0	5.48	0.0057	1.610	4.15	.	.	.	.	29
7	13	24	0.29	7.0	1.8	37.0	34.0	4.55	0.0064	0.877	0.80	5.01	3.81	4.06	4.33	27

Appendix A Table 6. Water analyses data for the static systems: 5 cm from the top of Lagoon 6 (June 1980 - July 1980).

Month	Day	Wtemp	Secchi	pH	DO	BOD	SS	TotalP	Nitrite	Nitrate	Ammonia	Totkjel	Disskjel	OrthoP	DissP	Airtemp
6	8	27	0.09	8.8	2.1	23.0	48.0	5.90	0.0260	0.674	0.93	13.20	5.10	4.86	5.11	31
6	11	28	0.10	.	6.3	22.0	47.0	6.59	0.0130	0.169	0.13	.	.	.	.	31
6	14	25	0.18	8.5	2.8	32.0	56.0	6.15	0.0114	0.118	0.05	.	.	.	.	22
6	17	24	0.08	8.5	5.7	41.0	83.0	5.87	0.0095	0.517	0.07	7.53	3.84	4.95	5.33	22
6	18	25	0.08	9.4	10.4	40.0	115.0	6.44	0.0120	0.622	0.07	11.50	3.09	5.28	6.01	.
6	21	21	0.13	9.4	2.4	39.0	77.0	6.36	0.0050	0.644	0.07	.	.	.	.	26
6	24	21	0.09	9.5	3.1	39.0	105.6	6.81	0.0038	0.866	0.03	.	.	.	.	32
6	27	23	0.14	9.1	1.9	59.0	87.4	6.58	0.0022	0.760	0.14	.	.	.	.	26
6	30	24	0.24	9.5	7.9	30.0	52.0	5.65	0.0097	0.688	0.07	7.70	4.58	4.77	5.42	28

Appendix A Table 7. Water analyses data for the static systems: 5 cm from the bottom of Lagoon 1 (June 1980 - July 1980).

Month	Day	Wtemp	Secchi'	pH	DO	BOD	SS	TotalP	Nitrite	Nitrate	Ammonia	Totkjel	Disskjel	OrthoP	DissP	Airtemp
6	8	26	0.09	9.2	1.0	32.0	46.0	6.53	0.0350	0.578	2.17	9.70	5.35	5.06	5.29	31
6	11	28	0.12	10.3	4.8	24.0	2.8	6.26	0.0140	0.092	0.09	.	.	.	.	31
6	14	25	0.16	8.6	7.6	29.0	45.0	5.65	0.0091	0.169	0.05	.	.	.	.	22
6	17	24	0.13	8.5	1.1	94.0	315.0	6.50	0.0150	0.517	0.20	19.90	3.40	5.22	5.49	22
6	18	22	0.08	9.4	10.2	40.0	115.0	6.44	0.0120	0.622	0.07	11.50	3.09	5.28	6.01	.
6	21	21	0.08	9.4	1.3	46.0	91.6	6.89	0.0004	0.649	0.09	.	.	.	.	26
6	24	20	0.13	9.1	1.1	78.0	177.4	7.58	0.0230	0.840	0.18	.	.	.	.	32
6	27	22	0.08	8.8	1.1	66.0	50.6	6.33	0.0025	0.899	0.86	.	.	.	.	26
6	30	25	0.19	7.5	1.0	65.0	136.0	8.86	0.0082	1.500	2.76	27.70	11.50	4.77	7.20	28
7	1	25	0.05	.	5.7	35.0	143.0	6.77	0.0190	0.756	0.58	19.10	4.60	5.09	5.87	.
7	4	24	0.15	.	1.4	62.0	118.0	7.36	0.0020	0.751	2.04	.	.	.	.	32
7	7	26	0.18	.	0.8	45.0	63.0	6.53	0.0072	0.737	0.36	.	.	.	.	27
7	10	28	0.12	.	1.1	41.0	70.0	6.51	0.0097	0.751	0.26	.	.	.	.	29
7	13	26	0.15	.	0.0	18.0	65.0	6.04	0.0110	0.756	0.09	6.38	3.78	5.35	6.00	27

Appendix A Table 8. Water analyses data for the static systems: 5 cm from the bottom of Lagoon 3 (June 1980 - July 1980).

Month	Day	Wtemp	Secchi'	pH	DO	BOD	SS	TotalP	Nitrite	Nitrate	Ammonia	Totkjel	Disskjel	OrthoP	DissP	Airtemp
6	8	31	0.15	.	0.7	34.0	123.0	5.35	0.0260	0.597	0.84	10.90	4.20	4.57	4.74	31
6	11	26	0.11	.	0.9	37.0	27.0	5.36	0.0140	0.399	1.18	.	.	.	.	31
6	14	25	0.25	8.5	0.9	49.0	17.0	5.11	0.0145	0.706	1.17	.	.	.	.	22
6	17	23	0.23	8.5	0.7	41.0	35.0	5.08	0.0078	0.701	1.43	5.48	3.36	4.38	4.80	22
6	18	22	0.08	9.4	10.6	40.0	115.0	6.44	0.0120	0.622	0.07	11.50	3.09	5.28	6.01	.
6	21	24	0.08	9.0	0.9	57.0	147.4	6.91	0.0004	0.726	0.29	.	.	.	.	26
6	24	23	0.16	8.4	0.7	53.0	98.0	6.87	0.0100	0.778	0.44	.	.	.	.	32
6	27	22	0.21	7.7	0.7	67.0	54.0	6.40	0.0025	1.040	2.47	.	.	.	.	26
6	30	24	0.22	7.6	0.8	68.0	37.8	6.37	0.0050	1.740	3.32	9.42	7.10	5.94	7.32	28
7	1	24	0.05	.	0.2	35.0	143.0	6.77	0.0190	0.756	0.58	19.10	4.60	5.09	5.87	.
7	4	24	0.16	.	0.4	69.0	46.0	5.72	0.0028	1.050	5.06	.	.	.	.	32
7	7	24	0.17	.	1.0	45.0	314.0	8.96	0.0038	1.290	11.80	.	.	.	.	27
7	10	24	0.14	.	0.7	97.0	109.0	7.01	0.0160	1.510	12.00	.	.	.	.	29
7	13	24	0.19	.	0.0	111.0	89.0	7.66	0.0076	1.520	14.60	15.70	10.20	6.83	7.05	27

Appendix A Table 9. Water analyses data for the static systems: 5 cm from the bottom of Lagoon 5 (June 1980 - July 1980).

Month	Day	Wtemp	Secchi	pH	DO	BOD	SS	TotalP	Nitrite	Nitrate	Ammonia	Totkjel	Disskjel	OrthoP	DissP	Airtemp
6	8	27	0.05	9.4	0.5	45.0	59.0	5.35	0.0260	0.462	0.74	11.10	3.90	4.61	4.80	31
6	11	24	0.10	.	0.9	31.0	57.0	5.59	0.0110	0.740	0.16	.	.	.	.	31
6	14	24	0.14	8.7	1.0	37.0	65.0	5.53	0.0109	0.425	0.07	.	.	.	.	22
6	17	22	0.12	8.5	1.0	39.0	56.0	5.69	0.0089	0.570	0.15	6.87	2.57	4.13	4.64	.
6	18	23	0.08	9.4	8.7	40.0	115.0	6.44	0.0012	0.622	0.07	11.50	3.09	5.28	6.01	.
6	21	20	0.08	9.2	1.1	37.0	79.4	6.22	0.0010	0.654	0.07	.	.	.	.	26
6	24	22	0.13	9.0	0.6	59.0	109.2	6.58	0.0011	0.685	0.03	.	.	.	.	32
6	27	23	0.12	8.1	0.6	61.0	30.8	6.36	0.0032	0.985	1.85	.	.	.	.	26
6	30	24	0.22	7.8	1.0	65.0	150.0	7.76	0.0086	1.400	3.40	17.80	8.16	6.24	6.81	28

Appendix B. <u>Water Analyses Data for the Flowthrough System</u>.

Appendix B Table 1. Water analyses data for the flowthrough system: Lagoon 1 (August 1980 - November 1980).

Month	Day	Wtemp	Secchi	pH	DO	BOD	SS	TotalP	Nitrite	Nitrate	Ammonia	Totkjel	Disskjel	OrthoP	DissP	Airtemp	Reten
8	12	32	0.12	8.1	5.4	17.5	54.0	9.74	0.0560	1.100	7.28	28.4	22.80	7.89	8.85	32	.
8	19	28	0.18	7.7	2.1	40.0	58.6	9.46	0.0023	0.689	5.37	23.4	14.80	7.53	8.43	29	2
8	22	26	0.16	.	3.4	21.7	56.4	9.03	0.0098	0.790	5.67	.	.	.	.	24	2
8	25	26	0.17	8.7	3.4	20.3	60.8	8.99	0.0310	0.833	4.07	.	.	.	.	28	2
8	29	32	0.11	8.3	15.0	74.5	533.0	13.40	0.0810	0.863	2.52	.	.	.	.	.	2
9	1	34	0.06	10.0	15.0	44.0	164.0	9.82	0.0056	0.688	1.18	.	.	.	.	35	.
9	5	28	0.06	9.8	15.0	68.3	192.0	10.30	0.0340	0.703	1.11	.	.	.	.	.	.
9	15	30	0.09	9.7	15.0	52.5	163.6	9.53	0.5240	0.893	0.18	14.9	5.50	7.49	8.12	34	.
9	19	29	0.07	9.7	15.0	43.0	136.2	12.70	0.0084	0.895	0.15	.	.	.	.	.	2
9	26	27	0.11	9.5	5.0	34.5	74.8	9.38	0.0065	0.588	0.11	11.1	5.01	8.39	8.55	.	3
10	3	22	0.17	8.0	9.3	40.0	65.4	8.76	0.0051	0.701	4.71	.	.	.	.	.	.
10	6	20	0.21	7.8	6.7	27 0	33.0	8.82	0.0095	0.851	6.94	.	.	.	.	21	4
10	10	22	0.13	8.4	15.0	32.5	38.5	9.69	0.0790	0.874	6.29	16.4	12.20	7.99	8.97	28	5
10	13	18	0.10	9.2	15.0	52.0	106.2	9.48	0.0900	0.698	2.83	.	.	.	.	17	8
10	17	23	0.13	9.4	15.0	55.5	90.0	8.60	0.1380	0.826	1.06	.	.	.	.	25	.
10	20	23	0.11	9.4	15.0	35.2	112.6	8.86	0.1370	0.728	1.75	.	.	.	.	18	.
10	24	18	0.10	8.8	15.0	39.0	117.2	8.30	0.5340	0.691	0.94	15.7	9.02	7.24	7.97	15	.
10	27	14	0.11	9.0	.	33.0	109.4	7.77	0.4550	0.695	2.50	.	.	.	.	15	4
10	31	14	0.11	9.1	15.0	47.5	107.0	7.62	0.7470	0.835	0.87	.	.	.	.	17	.
11	3	13	0.11	9.1	15.0	63.0	118.6	8.65	0.7900	0.755	1.57	.	.	.	.	17	3
11	7	12	0.09	9.1	15.0	49.0	140.0	7.62	0.9930	0.819	1.47	.	.	.	.	21	8
11	10	17	0.10	9.1	15.0	81.8	172.4	9.34	0.9920	0.932	1.12	21.5	5.91	6.95	7.45	21	3
11	14	10	0.08	9.0	15.0	51.0	152.8	8.22	0.7810	0.754	1.42	.	.	.	.	.	4
11	17	9	0.10	8.9	13.8	46.0	145.8	7.30	0.6080	0.708	1.30	.	.	.	.	12	3
11	21	7	0.09	8.8	15.0	73.5	141.0	7.95	0.5010	0.893	2.44	.	.	.	.	13	8
11	24	9	0.10	8.2	11.6	82.5	133.2	8.77	0.4250	1.120	1.71	19.7	7.15	7.05	7.12	17	5
11	29	4	0.09	7.4	5.0	70.5	134.0	7.54	0.0360	0.491	3.68	19.2	9.12	7.09	7.71	11	4

Appendix B Table 2. Water analyses data for the flowthrough system: Lagoon 2 (August 1980 - November 1980).

Month	Day	Wtemp	Secchi	pH	DO	BOD	SS	TotalP	Nitrite	Nitrate	Ammonia	Totkjel	Disskjel	OrthoP	DissP	Airtemp	Reten
8	19	28	0.15	7.7	1.8	38.0	50.0	9.14	0.0009	0.844	3.18	19.0	13.70	7.14	8.37	29	2
8	22	27	0.21	.	2.6	31.5	27.0	8.84	0.0021	1.040	4.55	.	.	.	.	24	3
8	25	26	0.21	8.4	2.0	19.7	17.8	8.66	0.0160	0.931	3.39	.	.	.	.	28	2
8	29	34	0.16	7.5	2.0	30.3	34.2	9.69	0.0100	0.838	2.48	.	.	.	.	.	2
9	1	33	0.18	8.1	9.0	23.0	10.0	9.67	0.0130	0.809	1.76	.	.	.	.	35	.
9	5	27	0.18	8.7	7.4	31.0	21.2	9.66	0.0069	1.010	0.26	.	.	.	.	.	.
9	15	28	0.11	9.9	15.0	49.0	104.8	11.20	0.0039	1.020	0.09	16.4	8.14	8.96	9.76	34	.
9	19	30	0.11	9.1	15.0	42.0	120.4	10.10	0.0110	0.947	0.43	.	.	.	.	.	3
9	26	26	0.12	8.1	2.2	51.0	112.8	9.77	0.0066	0.767	2.43	15.8	8.72	8.67	9.32	.	6
10	3	21	0.15	8.1	8.4	31.0	89.0	9.58	0.0057	0.671	4.89	.	.	.	.	.	9
10	6	21	0.18	7.9	10.7	22.5	28.2	6.18	0.0059	0.895	5.97	.	.	.	.	21	4
10	10	21	0.14	7.9	1.9	25.0	42.8	9.35	0.0620	0.958	5,49	16.2	11.90	7.97	8.86	28	5
10	13	18	0.13	8.9	13.6	39.5	48.2	11.20	0.0420	0.857	4.06	.	.	.	.	17	8
10	17	22	0.15	8.6	11.2	47.5	55.2	8.82	0.0380	0.800	3.42	.	.	.	.	25	.
10	20	22	0.14	8.8	15.0	33.8	88.6	8.84	0.1410	0.694	3.88	.	.	.	.	18	.
10	24	18	0.11	8.8	13.1	38.3	114.8	8.24	0.3560	0.638	2.14	17.1	6.57	7.20	7.91	15	.
10	27	14	0.12	9.1	.	29.0	124.6	6.61	0.3690	0.621	3.36	.	.	.	.	15	4
10	31	15	0.11	9.2	15.0	52.0	124.2	8.32	0.8390	0.719	1.53	.	.	.	.	17	.
11	3	13	0.09	9.1	15.0	41.0	118.0	10.70	0.6650	0.692	1.92	.	.	.	.	17	4
11	7	13	0.10	9.2	15.0	56.0	142.4	7.89	0.9980	0.740	1.98	.	.	.	.	21	9
11	10	17	0.08	9.3	15.0	46.0	138.6	7.68	0.9070	0.858	1.30	16.6	7.18	6.93	7.37	21	1
11	14	11	0.08	8.9	15.0	48.5	157.0	9.06	0.5190	0.674	1.88	.	.	.	.	.	3
11	17	9	0.08	8.9	12.1	46.0	146.0	8.74	0.5170	0.658	1.72	.	.	.	.	12	3
11	21	8	0.11	8.9	15.0	87.0	139.6	8.28	0.6500	1.010	2.29	.	.	.	.	13	8
11	24	10	0.09	8.4	10.0	111.8	159.8	8.94	0.5410	0.979	1.30	21.3	7.69	6.86	7.15	17	4
11	29	5	0.08	7.4	5.4	84.8	121.4	8.28	0.0160	0.454	4.39	18.0	8.53	6.62	7.39	11	4

Appendix B Table 3. Water analyses data for the flowthrough system: Lagoon 3 (August 1980 - November 1980).

Month	Day	Wtemp	Secchi	pH	DO	BOD	SS	TotalP	Nitrite	Nitrate	Ammonia	Totkjel	Disskjel	OrthoP	DissP	Airtemp	Reten
8	19	28	0.21	7.3	1.6	36.0	49.2	9.30	0.0008	0.776	10.80	27.1	19.50	7.92	8.65	29	2
8	22	26	0.21	.	1.6	35.5	64.0	9.44	0.0018	0.884	11.90	.	.	.	.	24	4
8	25	30	0.21	7.2	1.4	31.0	38.0	8.86	0.0035	0.822	8.74	.	.	.	.	28	6
8	29	28	0.17	7.0	4.2	20.7	20.6	9.16	0.0070	0.742	6.90	.	.	.	.	.	2
9	1	30	0.15	7.3	3.8	23.0	32.8	9.62	0.0100	0.738	6.20	.	.	.	.	35	.
9	5	25	0.15	7.5	1.6	28.3	24.6	9.49	0.0029	1.160	5.78	.	.	.	.	.	.
9	15	26	0.17	7.5	2.5	51.0	33.0	10.10	0.0018	1.240	6.67	15.6	12.90	9.30	9.80	34	.
9	19	27	0.15	7.1	1.6	62.0	53.0	9.63	0.0070	1.710	7.22	.	.	.	.	.	6
9	26	24	0.21	7.0	1.6	48.5	24.6	10.20	0.0065	1.380	10.50	18.6	15.90	9.56	10.10	.	8
10	3	22	0.26	6.9	0.9	32.0	37.0	9.89	0.0034	1.230	10.40	.	.	.	.	.	6
10	6	21	0.23	7.0	0.9	22.7	9.2	9.34	0.0041	0.895	8.53	.	.	.	.	21	3
10	10	21	0.21	7.0	1.1	22.0	15.0	10.20	0.0320	0.923	7.85	16.5	13.60	8.15	9.26	28	6
10	13	18	0.20	7.0	1.6	33.0	6.6	9.24	0.0260	1.000	9.39	.	.	.	.	17	9
10	17	21	0.27	6.9	1.6	19.3	30.0	8.84	0.0061	0.881	8.67	.	.	.	.	25	.
10	20	20	0.24	7.1	3.3	22.6	31.4	8.45	0.0220	0.813	8.19	.	.	.	.	18	.
10	24	17	0.29	7.0	1.2	22.3	37.0	8.38	0.0290	0.748	7.86	16.0	12.30	7.75	8.18	15	.
10	27	12	0.17	6.8	.	24.0	43.0	8.12	0.0140	0.608	6.84	.	.	.	.	15	9
10	31	13	0.14	7.1	0.8	18.3	35.2	8.12	0.0290	0.550	5.68	.	.	.	.	17	.
11	3	11	0.13	7.5	3.4	30.0	47.4	7.21	0.1240	0.550	3.85	.	.	.	.	17	8
11	7	12	0.12	8.0	4.0	26.0	92.4	7.45	0.0390	0.513	4.36	.	.	.	.	21	8
11	10	16	0.08	7.5	1.2	23.7	65.4	8.30	0.0150	0.518	4.89	17.3	6.82	6.75	7.10	21	2
11	14	9	0.07	8.5	6.6	40.0	124.8	8.32	0.2200	0.557	2.74	.	.	.	.	.	3
11	17	9	0.11	8.1	1.5	23.3	103.0	6.77	0.1460	0.611	3.18	.	.	.	.	12	4
11	21	6	0.11	7.9	2.7	47.5	87.8	6.35	0.2290	0.864	2.49	.	.	.	.	13	9
11	24	9	0.11	7.5	2.0	28.7	24.0	7.40	0.1710	0.922	2.31	10.2	7.11	6.53	6.68	17	5
11	29	5	0.08	7.0	2.6	52.0	100.6	8.16	0.0056	0.433	6.35	16.5	8.94	7.11	7.53	11	5

Appendix B Table 4. Water analyses data for the flowthrough system: Lagoon 4 (August 1980 - November 1980).

Month	Day	Wtemp	Secchi	pH	DO	BOD	SS	TotalP	Nitrite	Nitrate	Ammonia	Totkjel	Disskjel	OrthoP	DissP	Airtemp	Reten
8	12	34	0.17	7.0	1.6	18.5	36.6	8.73	0.0042	1.170	10.90	24.6	22.60	7.83	8.51	32	.
8	19	28	0.18	7.3	1.6	29.7	42.2	9.16	0.0029	0.830	9.48	21.5	17.30	7.90	8.65	29	4
8	22	27	0.18	.	1.4	32.0	32.8	9.05	0.0016	0.877	8.89	.	.	.	.	24	2
8	25	34	0.22	7.5	1.4	19.3	16.6	9.11	0.0120	0.868	5.79	.	.	.	.	28	2
8	29	30	0.20	7.4	1.4	20.7	17.2	9.60	0.0058	0.767	4.84	.	.	.	.	.	4
9	1	30	0.16'	7.3	3.5	25.7	44.4	9.69	0.0077	0.660	5.66	.	.	.	.	35	.
9	5	26	0.15	7.9	1.6	40.0	100.2	9.86	0.0026	0.845	5.08	.	.	.	.	.	.
9	15	27	0.16	7.4	1.6	36.0	46.4	10.10	0.0031	0.906	4.93	15.0	11.80	9.04	9.74	34	.
9	19	29	0.14	7.4	1.5	41.0	47.0	9.42	0.0097	1.420	4.87	.	.	.	.	.	3
9	26	24	0.21	7.3	1.4	59.5	37.8	9.92	0.0060	1.410	11.50	18.9	17.30	9.50	9.96	.	5
10	3	22	0.24	6.8	0.9	37.0	41.4	8.04	0.0026	1.540	9.06	.	.	.	.	.	3
10	6	21	0.28	6.9	0.8	20.7	0.0	9.38	0.0039	1.080	8.45	.	.	.	.	21	4
10	10	20	0.24	7.0	1.6	21.0	28.2	9.58	0.0051	1.170	6.84	15.7	13.40	8.19	9.24	28	3
10	13	17	0.23	7.1	1.1	28.3	12.6	8.90	0.0041	0.830	7.91	.	.	.	.	17	8
10	17	21	0.28	7.0	1.0	19.3	20.0	7.59	0.0034	0.847	6.63	.	.	.	.	25	.
10	20	20	0.18	7.4	1.2	30.0	24.8	6.18	0.0095	0.766	6.27	.	.	.	.	18	.
10	24	18	0.20	7.0	1.2	21.7	43.0	7.89	0.0260	0.686	7.00	15.2	11.80	7.56	8.32	15	.
10	27	14	0.15	7.2	.	26.7	90.0	8.16	0.1310	0.590	5.04	.	.	.	.	15	4
10	31	13	0.14	7.5	1.2	21.3	44.2	7.17	0.0330	0.523	3.90	.	.	.	.	17	.
11	3	11	0.13	8.1	10.4	39.5	84.8	8.08	0.2170	0.612	3.01	.	.	.	..	17	9
11	10	16	0.09	7.3	1.4	26.7	67.2	8.53	0.0200	0.535	3.79	15.5	7.76	7.05	7.47	21	5
11	14	9	0.08	8.5	5.6	55.0	124.0	7.63	0.2560	0.586	2.81	.	.	.	.	.	2
11	17	9	0.12	8.4	1.4	38.5	119.0	7.76	0.2150	0.544	2.78	.	.	.	.	12	3
11	21	7	0.09	8.0	5.8	57.0	92.8	5.80	0.2600	0.950	1.63	.	.	.	.	13	6
11	24	9	0.11	7.6	1.8	70.0	100.6	8.22	0.2400	0.922	3.48	16.7	7.88	6.77	7.45	17	4
11	29	5	0.09	7.1	2.0	55.5	99.8	8.53	0.0022	0.495	5.18	18.6	9.57	7.16	7.72	11	3

Appendix B Table 5. Water analyses data for the flowthrough system: Lagoon 5 (August 1980 - November 1980).

Month	Day	Wtemp	Secchi	pH	DO	BOD	SS	TotalP	Nitrite	Nitrate	Ammonia	Totkjel	Disskjel	OrthoP	DissP	Airtemp	Reten
8	12	34	0.25	7.4	2.0	3.5	21.2	5.26	0.0026	0.835	3.36	11.5	14.00	7.32	8.07	32	.
8	19	29	0.22	7.1	2.4	35.0	27.0	8.49	0.0007	0.808	7.11	14.6	13.20	7.81	8.33	29	2
8	22	27	0.29	.	1.8	21.7	24.0	5.56	0.0020	0.768	4.12	.	.	.	.	24	2
8	25	32	0.25	7.1	1.4	28.7	42.0	8.51	0.0026	0.724	3.95	.	.	.	.	28	4
8	29	31	0.24	7.3	15.0	35.3	28.8	8.75	0.0160	0.688	2.71	.	.	.	.	.	1
9	1	29	0.21	7.5	7.5	12.7	8.4	8.77	0.0084	0.606	2.52	.	.	.	.	35	.
9	5	27	0.21	7.2	13.0	23.7	18.4	9.64	0.0066	0.817	3.46	.	.	.	.	.	.
9	15	25	0.24	7.2	1.7	39.0	9.8	10.40	0.0010	1.130	5.83	14.7	11.10	9.80	10.10	34	.
9	19	29	0.21	8.1	1.5	54.0	20.6	10.10	0.0076	2.050	6.40	.	.	.	.	.	4
9	26	25	0.14	7.0	2.8	59.0	22.8	10.70	0.0062	1.420	15.10	22.1	21.20	10.10	10.10	.	6
10	3	22	0.31	6.9	1.1	19.7	28.6	8.86	0.0026	1.080	14.60	.	.	.	.	.	4
10	6	21	0.32	6.8	1.5	18.6	0.0	8.12	0.0034	1.090	10.60	.	.	.	.	21	4
10	10	21	0.33	6.9	2.6	8.7	0.6	9.26	0.0086	1.000	8.80	15.0	15.00	8.55	9.48	28	7
10	13	17	0.28	7.4	3.8	13.0	0.0	9.86	0.0014	0.795	11.80	.	.	.	.	17	7
10	17	23	0.28	6.8	1.6	12.0	22.8	8.06	0.0110	0.932	8.98	.	.	.	.	25	.
10	20	21	0.36	6.9	2.0	8.7	7.4	8.41	0.0043	0.839	9.11	.	.	.	.	18	.
10	24	18	0.36	7.0	2.7	13.0	27.8	7.89	0.0270	0.568	7.20	12.6	12.20	7.85	8.14	15	.
10	27	15	0.16	7.3	.	14.0	34.4	7.69	0.0640	0.498	5.15	.	.	.	.	15	3
10	31	14	0.24	7.0	2.8	9.3	0.4	7.29	0.0730	0.460	4.27	.	.	.	.	17	.
11	3	11	0.16	7.7	2.2	31.0	46.6	7.87	0.3780	0.612	2.86	.	.	.	.	17	2
11	7	11	0.18	7.7	4.1	31.3	50.6	7.97	0.2660	0.618	3.14	.	.	.	.	21	7
11	10	16	0.14	7.1	1.9	29.0	24.8	7.91	0.2940	0.666	3.90	11.1	8.67	8.31	9.26	21	6
11	14	9	0.08	8.1	2.5	52.5	106.6	7.97	0.6360	0.636	2.42	.	.	.	.	.	2
11	17	8	0.16	8.0	3.0	32.7	75.2	7.90	0.0650	0.557	2.86	.	.	.	.	12	2
11	21	6	0.12	7.5	4.0	40.5	95.4	6.24	0.0640	0.691	2.01	.	.	.	.	13	6
11	24	9	0.12	7.3	1.4	38.0	63.6	8.22	0.0690	0.691	3.55	13.2	7.11	7.35	7.73	17	3
11	29	5	0.10	6.7	2.2	62.0	81.4	8.86	0.0034	0.741	6.37	17.2	9.61	7.88	8.30	11	4

Appendix B Table 6. Water analyses data for the flowthrough system: Lagoon 6 (August 1980 - November 1980).

Month	Day	Wtemp	Secchi	pH	DO	BOD	SS	TotalP	Nitrite	Nitrate	Ammonia	Totkjel	Disskjel	OrthoP	DissP	Airtemp	Reten
8	12	34	0.18	7.7	1.8	21.5	113.8	6.96	0.0230	0.817	1.72	21.9	11.00	5.94	6.69	32	.
8	19	30	0.12	7.2	1.5	16.7	26.0	8.15	0.0023	0.735	6.00	15.6	13.10	7.18	7.92	29	2
8	22	28	0.14	.	1.4	20.0	20.0	8.41	0.0042	0.795	6.72	.	.	.	.	24	4
8	25	32	0.40	7.4	1.6	17.0	25.2	8.86	0.0220	0.925	4.61	.	.	.	.	28	2
8	29	30	0.26	7.2	1.8	12.7	5.6	8.71	0.0058	0.738	4.00	.	.	.	.	.	2
9	1	31	0.24	7.4	9.0	17.0	12.8	9.32	0.0099	0.698	3.44	.	.	.	.	35	.
9	5	26	0.20	7.0	2.0	31.0	37.2	9.32	0.0059	0.785	4.04	.	.	.	.	.	.
9	15	28	0.24	7.3	1.5	23.3	12.6	9.20	0.0026	0.846	3.02	12.2	9.83	8.46	9.06	34	.
9	19	29	0.16	8.5	1.6	42.0	48.2	10.10	0.0105	1.510	3.12	.	.	.	.	.	3
9	26	25	0.18	7.0	1.6	40.0	70.6	10.10	0.0058	1.220	11.30	20.6	16.40	9.06	9.75	.	4
10	3	22	0.28	6.7	1.1	44.0	49.8	7.64	0.0270	1.210	14.70	.	.	.	.	.	7
10	6	20	0.27	6.7	1.1	44.0	22.0	8.02	0.0200	1.230	11.50	.	.	.	.	21	5
10	10	20	0.30	7.1	1.1	17.7	23.0	9.69	0.0004	0.910	8.82	17.2	14.90	8.66	9.58	28	9
10	13	18	0.23	7.3	1.4	16.3	0.0	6.36	0.0040	0.914	10.90	.	.	.	.	17	9
10	17	22	0.31	7.0	1.6	24.7	24.8	9.44	0.0350	0.932	9.25	.	.	.	.	25	.
10	20	21	0.27	6.9	1.2	14.3	1.6	8.88	0.0037	0.851	9.57	.	.	.	.	18	.
10	24	18	0.24	7.0	0.9	43.0	43.6	10.10	0.0490	0.861	6.75	17.5	14.30	8.04	8.60	15	.
10	27	14	0.17	.	.	25.3	45.2	8.32	0.0056	0.739	8.22	.	.	.	.	15	6
10	31	13	0.25	6.9	1.0	39.0	19.6	6.01	0.0190	0.773	7.33	.	.	.	.	17	.
11	3	11	0.14	7.8	4.2	33.5	79.4	8.69	0.1520	0.496	3.53	.	.	.	.	17	3
11	7	11	0.14	8.0	7.6	37.5	101.8	8.37	0.0830	0.583	4.25	.	.	.	.	21	9
11	10	16	0.12	7.2	2.8	29.0	71.0	8.16	0.0290	0.592	4.76	14.8	10.40	6.95	7.58	21	5
11	14	9	0.08	8.1	6.0	38.5	125.8	8.60	0.1540	0.510	2.53	.	.	.	.	.	5
11	17	9	0.12	8.0	3.0	23.3	97.6	8.36	0.0390	0.485	3.26	.	.	.	.	12	3
11	21	7	0.12	7.5	3.8	30.7	96.4	8.25	0.0600	0.749	3.50	.	.	.	.	13	9
11	24	9	0.14	7.4	2.0	29.0	50.8	8.08	0.0600	0.662	1.85	12.8	7.61	7.13	7.64	17	5
11	29	5	0.10	6.9	2.4	61.0	94.8	8.11	0.0031	0.500	6.58	17.4	9.46	7.56	8.07	11	4

Appendix B Table 7. Water analyses data for the flowthrough system: Murfreesboro municipal lagoon (August 1980 - November 1980).

Month	Day	Wtemp	Secchi	pH	DO	BOD	SS	TotalP	Nitrite	Nitrate	Ammonia	Totkjel	Disskjel	OrthoP	DissP	Airtemp	Reten
8	12	.	.	8.0	.	13.0	40.8	9.50	0.0087	1.000	2.26	23.7	20.00	7.79	8.47	32	.
8	19	.	.	7.8	.	18.7	36.0	9.18	0.0100	0.671	8.22	18.9	15.30	8.12	8.85	29	.
8	22	.	.	.	.	23.0	55.0	9.11	0.0093	0.842	8.06	.	.	.	.	24	.
8	25	.	.	8.3	.	24.0	65.2	9.58	0.0900	0.886	6.17	.	.	.	.	28	.
8	29	.	.	9.1	.	19.0	54.6	8.75	0.0400	0.777	2.70	.	.	.	.	.	
9	1	.	.	9.6	.	27.0	58.4	11.00	0.0230	0.670	1.45	.	.	.	.	35	.
9	5	.	.	9.4	.	39.5	98.0	10.90	0.0150	0.854	0.89	.	.	.	.	.	.
9	15	.	.	9.9	.	56.0	167.6	10.60	0.0032	0.803	0.16	22.2	6.44	8.70	9.33	34	.
9	19	.	.	8.4	.	31.5	90.8	10.30	0.0085	0.956	2.06	.	.	.	.	.	.
9	26	.	.	9.2	.	52.0	87.4	9.98	0.0220	0.771	0.89	15.2	6.21	8.43	9.03	.	.
10	3	.	.	7.8	.	33.5	50.4	8.02	0.0018	0.887	5.34	.	.	.	.	.	.
10	6	.	.	7.1	.	31.7	52.0	7.17	0.0075	1.380	7.72	.	.	.	.	21	.
10	10	23	.	8.4	15.0	46.0	68.2	9.73	0.1420	0.954	5.77	21.2	11.80	7.99	9.10	28	.
10	13	20	.	8.8	15.0	35.0	71.6	9.07	0.0900	0.716	5.67	.	.	.	.	17	.
10	17	26	.	8.7	15.0	49.5	101.6	9.46	0.0590	0.796	4.67	.	.	.	.	25	.
10	20	24	.	8.8	15.0	22.5	103.6	8.84	0.1270	0.677	4.33	.	.	.	.	18	.
10	24	.	.	8.5	.	28.0	119.6	8.76	0.1500	0.599	4.42	19.3	5.37	6.29	6.88	15	.
10	27	.	.	8.2	.	24.5	121.0	7.69	0.3020	0.573	4.12	.	.	.	.	15	.
10	31	16	.	8.7	15.0	44.0	114.6	8.86	0.1940	0.621	3.30	.	.	.	.	17	.
11	3	13	.	8.4	15.0	39.0	126.4	7.04	0.2360	0.568	2.81	.	.	.	.	17	.
11	7	14	.	8.9	15.0	42.0	151.2	8.72	0.2600	0.736	2.98	.	.	.	.	21	
11	10	19	.	8.5	15.0	60.8	140.0	10.20	0.4800	0.792	2.96	18.1	6.57	7.01	7.66	21	.
11	14	11	.	8.8	15.0	47.5	152.0	5.46	0.2630	0.607	0.88	.	.	.	.	.	.
11	17	10	.	9.0	13.0	48.0	140.0	8.85	0.2870	0.578	2.78	.	.	.	.	12	.
11	21	10	.	8.5	15.0	96.8	153.6	9.05	0.9930	1.120	0.86	.	.	.	.	13	.
11	24	11	.	8.1	6.6	104.3	147.8	8.99	0.2440	0.662	4.48	21.0	7.96	6.77	7.40	17	.
11	29	.	.	7.4	.	79.5	111.0	8.30	0.0300	0.470	5.36	20.1	9.24	6.84	7.55	11	.

Appendix C. Plant Analyses Data

Appendix C Table 1. Plant analyses data: Duckweed Lagoon 3 (June 1980 - November 1980).

Month	Day	Trial	Wetwgt	Drywgt	Organicw	Pmoistur	Pash	Pinsol	Psol	Ca	Mg	Na	K	P
6	6	1	829.0	90.7	75.1	89.1	17.2	22.3	13.4	1.29	0.25	1.63	1.45	0.59
6	6	2	721.0	73.1	65.5	89.9	10.4	8.4	9.5	1.31	0.24	0.33	1.75	0.61
6	6	3	372.0	38.7	34.4	89.6	11.0	6.5	10.3	0.99	0.19	0.33	1.30	0.45
6	17	1	557.0	52.0	45.4	90.7	12.6	5.3	11.9	0.72	0.14	0.27	0.91	0.43
6	17	2	791.0	70.0	62.2	90.5	11.2	8.8	10.2	1.12	0.24	0.55	2.69	0.76
6	17	3	1342.0	118.0	104.3	91.2	11.6	.	.	.	.	.	.	.
6	30	1	600.0	50.4	44.6	91.6	11.5	3.7	11.1	1.15	0.24	0.75	2.03	0.91
6	30	2	340.0	28.2	24.8	91.7	12.0	.	.	.	.	.	.	.
6	30	3	389.0	32.1	28.2	91.8	12.2	5.9	11.5	1.10	0.23	0.58	1.55	0.80
7	1	1	842.0	70.7	63.8	91.6	9.8	13.3	8.5	0.93	0.20	0.43	1.40	0.65
7	1	2	2250.0	187.5	168.8	91.7	10.0	8.3	9.2	1.13	0.23	0.45	1.60	0.91
7	1	3	802.0	65.6	60.4	91.8	8.0	11.2	7.1	1.13	0.23	0.49	1.50	0.76
7	13	1	587.0	48.3	43.2	91.8	10.5	1.0	10.4	0.88	0.24	0.50	1.88	0.90
7	13	2	830.0	70.1	65.9	91.6	6.0	4.8	5.7	0.96	0.21	0.31	1.35	0.78
7	13	3	760.0	67.1	59.7	91.2	11.0	0.1	11.0	0.85	0.22	0.50	1.68	1.02
8	10	1	1295.0	106.0	94.3	91.8	11.0	0.4	11.0	1.04	0.23	0.56	1.79	1.20
8	10	2	1362.0	110.0	99.0	91.9	10.0	3.7	9.6	1.03	0.22	0.49	1.72	1.00
8	10	3	1026.0	87.9	77.4	91.4	12.0	14.3	10.3	0.90	0.20	0.45	1.84	0.96
9	13	1	2402.0	213.0	196.0	91.1	8.0	.	.	0.97	0.22	0.66	2.00	1.29
9	13	2	1743.0	152.0	139.2	91.3	8.4	4.1	8.1	0.95	0.23	0.70	2.15	1.31
9	13	3	1682.0	150.0	134.4	91.1	10.4	2.2	10.2	0.95	0.23	0.64	2.15	1.28
10	13	1	3328.0	300.0	268.5	91.0	10.5	3.4	10.1	0.88	0.22	0.63	1.98	1.07
10	13	2	775.0	78.0	69.8	89.9	10.5	1.3	10.4	0.80	0.22	0.69	2.15	1.05
10	13	3	2812.0	240.0	213.6	91.5	11.0	2.1	10.8	0.90	0.23	0.68	1.85	1.09
11	7	1	816.0	91.0	83.0	88.9	8.8	8.4	8.1	0.80	0.20	0.43	1.81	1.10
11	7	2	859.0	100.0	89.0	88.4	11.0	10.0	9.9	0.75	0.19	0.38	1.93	0.81
11	7	3	1767.0	165.0	145.5	90.7	11.8	8.5	10.8	0.88	0.20	1.13	1.70	1.14
11	29	1	1968.0	196.0	171.7	90.0	12.4	10.5	11.1	0.78	0.19	0.54	1.65	1.18
11	29	2	2185.0	215.0	193.9	90.2	9.8	7.9	9.0	0.84	0.21	0.63	1.75	1.18
11	29	3	2433.0	229.0	204.7	90.6	10.6	4.9	10.1	0.92	0.22	0.71	1.85	1.29

Appendix C Table 2. Plant analyses data: Duckweed Lagoon 4 (June 1980 - November 1980).

Month	Day	Trial	Wetwgt	Drywgt	Organicw	Pmoistur	Pash	Pinsol	Psol	Ca	Mg	Na	K	P
6	6	1	464.0	43.4	39.1	90.7	10.0	4.2	9.6	1.62	0.25	0.27	1.23	0.58
6	6	2	289.0	30.6	27.7	89.4	9.4	12.3	8.2	1.45	0.25	0.30	1.35	0.59
6	6	3	261.0	25.5	22.5	90.2	11.6	.	.	.	.	.	.	.
6	17	1	744.0	62.0	54.6	91.7	12.0	4.5	11.5	0.51	0.11	0.27	1.44	0.51
6	17	2	481.0	44.0	37.8	90.9	14.0	7.8	12.9	0.95	0.23	0.54	3.00	0.70
6	17	3	653.0	57.0	50.2	91.3	12.0	8.3	11.0	1.06	0.23	0.54	2.94	1.00
6	30	1	774.0	62.0	55.9	92.0	9.8	4.8	9.3	0.98	0.21	0.44	1.48	0.76
6	30	2	1441.0	119.5	106.4	91.7	11.0	0.6	10.9	.	.	.	.	.
6	30	3	2130.0	165.0	148.5	92.3	10.0	8.4	9.2	1.13	0.23	0.65	1.95	0.98
7	1	1	210.0	17.7	15.8	91.6	11.0	9.2	10.0	0.93	0.20	0.49	1.83	1.02
7	1	2	1246.0	96.5	86.9	92.3	10.0	1.1	9.9	1.09	0.25	0.50	1.90	1.08
7	1	3	867.0	71.4	64.1	91.8	10.2	1.8	10.0	1.08	0.22	0.53	2.18	1.08
7	13	1	667.0	55.9	50.3	91.6	10.0	2.6	9.7	0.89	0.26	0.51	2.43	0.92
7	13	2	370.0	34.9	30.8	90.6	11.8	7.9	10.9	0.71	0.21	0.53	2.15	0.98
7	13	3	425.0	37.5	33.5	91.2	10.8	7.0	10.0	0.81	0.24	0.45	2.38	1.08
8	10	1	1441.0	107.0	97.4	92.6	9.0	5.6	8.5	1.10	0.21	0.44	1.47	0.91
8	10	2	1717.0	135.0	122.9	92.1	9.0	2.8	8.7	1.06	0.23	0.48	1.60	1.29
8	10	3	973.0	70.3	63.4	92.8	9.8	0.1	9.7	1.13	0.21	0.49	1.42	1.13
9	13	1	1546.0	139.0	122.9	91.0	11.6	5.8	10.9	0.95	0.22	0.49	1.95	1.26
9	13	2	1975.0	165.0	149.5	91.6	9.4	1.0	9.3	0.97	0.22	0.55	1.90	1.26
9	13	3	1487.0	129.0	115.1	91.3	10.8	.	.	.	.	.	.	.
10	13	1	1901.0	172.0	156.5	91.0	9.0	3.0	8.7	0.88	0.21	0.59	1.70	0.82
10	13	2	2850.0	255.0	225.9	91.1	11.4	1.8	11.2	0.89	0.22	0.63	2.00	1.01
10	13	3	3807.0	328.0	290.9	91.4	11.3	1.2	11.2	0.89	0.22	0.65	1.90	1.06
11	7	1	1782.0	197.0	180.5	89.0	8.4	13.7	7.2	0.60	0.15	0.34	1.33	0.58
11	7	2	2691.0	253.0	228.2	90.6	9.8	6.4	9.2	0.75	0.18	0.58	1.74	0.79
11	7	3	1931.0	190.0	171.8	90.2	9.6	9.6	8.7	0.88	0.21	0.68	2.02	1.17
11	29	1	1549.0	173.0	156.7	88.8	9.4	7.6	8.7	0.78	0.19	0.45	1.90	1.11
11	29	2	1616.0	172.0	155.1	89.4	9.8	15.6	8.3	0.74	0.18	0.48	1.70	1.05
11	29	3	1531.0	158.0	141.3	89.7	10.6	7.7	9.8	0.78	0.19	0.51	1.75	1.22

Appendix C Table 3. Plant analyses data: Alligatorweed Lagoon 5 (June 1980 - November 1980).

Month	Day	Trial	Wetwgt	Drywgt	Organicw	Pmoistur	Pash	Pinsol	Psol	Ca	Mg	Na	K	P
6	6	1	731.0	58.0	45,8	92.1	19.2	6.7	17.9	0.52	0.22	1.22	6.90	0.15
6	6	2	2845.0	286.5	245.8	89.9	14.2	2.4	13.9	0.48	0.19	2.23	4.59	0.16
6	6	3	1621.0	157.0	133.5	90.3	15.0	0.4	14.9	.	.	.	.	.
6	17	1	975.0	111.0	92.8	88.6	16.4	6.3	15.4	0.35	0.16	1.38	4.50	0.30
6	17	2	1000.0	122.5	103.6	87.8	15.4	2.2	15.1	0.36	0.14	0.99	4.25	0.21
6	17	3	1858.0	194.0	166.8	89.6	14.0	8.6	12.8	0.38	0.16	1.03	4.25	0.28
6	30	1	1664.0	126.0	111.6	92.4	11.4	10.5	10.2	0.33	0.13	1.17	2.70	0.14
6	30	2	3462.0	412.0	349.4	88.1	15.2	9.8	13.7	0.31	0.15	1.21	2.95	0.17
6	30	3	1485.0	157.0	145.1	89.4	7.6	0.2	7.6	.	.	.	.	.
7	13	1	1783.0	242.0	215.4	86.4	11.0	6.6	10.3	0.25	0.11	1.29	2.53	0.17
7	13	2	2248.0	288.5	245.8	87.2	14.8	2.2	14.5	0.25	0.14	1.08	2.40	0.47
7	13	3	2445.0	300.0	267.0	87.7	11.0	1.7	10.8	0.25	0.11	1.20	2.40	0.25
8	10	1	6883.0	673.3	575.6	90.2	14.5	2.1	14.2	0.33	0.12	2.10	2.81	0.72
8	10	2	6249.0	768.0	683.5	87.7	11.0	2.7	10.7	0.30	0.13	1.23	2.30	0.41
8	10	3	7607.0	876.0	773.5	88.5	11.7	4.1	11.2	0.23	0.10	1.38	1.98	0.56
9	13	1	5502.0	557.0	480.1	89.9	13.8	1.4	13.6	0.33	0.13	0.45	2.50	0.46
9	13	2	6832.0	715.0	620.6	89.5	13.2	0.8	13.1	0.39	0.12	0.43	2.35	0.74
9	13	3	6325.0	784.0	705.6	87.6	10.0	18.4	8.2	0.25	0.11	0.33	1.75	0.62
10	13	1	5020.0	328.0	300.0	93.5	8.7	7.2	8.1	0.26	0.09	1.23	1.15	0.21
10	13	2	4840.0	506.0	462.0	89.6	8.7	.	.	0.33	0.10	1.33	1.05	0.19
10	13	3	3222.0	399.0	364.3	87.6	8.7	8.4	8.0	0.29	0.09	1.18	0.95	0.17
11	7	1	2672.0	323.0	286.2	87.9	11.4	5.6	10.8	0.29	0.08	1.28	1.26	0.53
11	7	2	4255.0	504.0	457.6	88.2	9.2	12.2	8.1	0.35	0.10	1.60	1.23	0.69
11	7	3	3518.0	569.0	521.2	83.8	8.4	10.2	7.5	0.30	0.85	1.33	1.16	0.63
11	29	1	2226.0	226.0	201.1	89.9	11.0	9.8	9.9	0.39	0.12	1.63	1.40	0.81
11	29	2	4453.0	678.0	642.7	84.8	5.2	14.6	4.4	0.23	0.07	0.98	0.95	0.30
11	29	3	3221.0	443.0	401.4	86.3	9.4	11.0	8.4	0.23	0.07	1.10	0.93	0.44

Appendix C Table 4. Plant analyses data: Alligatorweed Lagoon 6 (June 1980 - November 1980).

Month	Day	Trial	Wetwgt	Drywgt	Organicw	Pmoistur	Pash	Pinsol	Psol	Ca	Mg	Na	K	P
6	6	1	1141.0	110.0	86.9	90.4	21.0	10.1	18.9	0.39	0.16	0.92	5.05	0.12
6	6	2	910.0	95.0	73.9	89.6	22.2	5.6	21.0	0.54	0.21	0.92	5.40	0.16
6	6	3	955.0	101.0	83.4	89.4	17.4	4.6	16.6	0.37	0.18	1.04	5.30	0.13
6	17	1	1281.0	132.0	110.1	89.7	16.6	7.8	15.3	0.35	0.16	1.38	4.88	0.42
6	17	2	670.0	73.0	62.1	89.1	15.0	6.5	14.0	0.41	0.15	1.29	5.25	0.28
6	17	3	595.0	76.5	65.9	87.1	13.8	5.8	13.0	0.35	0.15	1.10	4.13	0.26
6	30	1	2747.0	376.0	328.6	86.3	12.6	4.9	12.0	0.25	0.11	0.90	2.55	0.18
6	30	2	1359.0	151.0	133.2	88.9	11.8	.	.	0.38	0.15	1.34	2.65	0.15
6	30	3	1498.0	164.0	144.0	89.1	12.2	2.4	11.9	0.31	0.15	1.32	3.90	0.27
8	10	1	2971.0	327.0	278.0	89.0	15.0	.	.	0.40	0.15	1.05	4.54	0.48
8	10	2	1894.0	217.0	183.1	88.5	15.6	2.3	15.1	0.33	0.14	1.00	3.52	0.26
8	10	3	2647.0	312.0	268.9	88.2	13.8	3.4	13.3	0.38	0.14	1.08	3.52	0.14
9	13	1	3745.0	381.0	334.5	89.8	12.2	1.6	12.0	0.33	0.12	0.30	3.35	1.04
9	13	2	2064.0	193.0	166.0	90.7	14.0	7.1	13.0	0.29	0.11	0.30	2.95	1.18
9	13	3	3484.0	400.5	376.5	88.5	6.0	20.8	4.8	0.29	0.11	0.26	2.70	1.10
10	13	1	4142.0	507.0	456.3	87.8	10.0	11.4	8.9	.	.	.	.	.
10	13	2	2963.0	175.0	155.1	94.1	11.4	2.0	11.2	0.38	0.29	2.69	2.35	0.19
10	13	3	1905.0	191.0	166.7	90.0	12.7	1.3	12.5	0.33	0.17	1.30	2.25	0.18
11	7	1	2479.0	269.0	242.1	89.2	10.0	5.7	9.4	0.26	0.09	1.43	1.81	0.71
11	7	2	1859.0	180.0	162.0	90.3	10.0	6.5	9.4	0.30	0.09	1.58	1.98	0.73
11	7	3	2996.0	304.0	277.9	89.9	8.6	9.3	7.8	0.35	0.12	1.25	1.56	0.63
11	29	1	1407.0	145.0	128.5	89.7	11.4	5.3	10.8	0.44	0.09	1.28	1.88	0.64
11	29	2	1374.0	139.0	124.5	89.9	10.4	5.1	9.9	0.35	0.10	1.34	1.85	0.65
11	29	3	976.0	105.0	93.9	89.2	10.6	4.4	10.1	0.31	0.09	1.25	2.15	0.34