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THE DISTRIBUTION AND ABUNDANCE OF SUBMERGED AQUATIC MACROPHYTES IN A REACTOR COOLING RESERVOIR

by

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Paper presented to the Graduate School of Clemson University
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Botany
Clemson, South Carolina
August 1977

MASTER

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July 29, 1977

To the Graduate School:

Herewith is submitted a thesis written by James B. Grace entitled "The Distribution and Abundance of Submerged Aquatic Macrophytes in a Reactor-Cooling Reservoir." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Botany.

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THE DISTRIBUTION AND ABUNDANCE OF SUBMERGED AQUATIC MACROPHYTES IN A REACTOR-COOLING RESERVOIR

A Thesis
Presented to
the Graduate School of
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In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Botany

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ABSTRACT

Measurements of ash-free dry weight were used to characterize the effects of a heated effluent on submerged macrophytes in a reactor cooling reservoir. The species which were most abundant during the summers of 1974 and 1975 were *Myriophyllum spicatum* L. and *Eleocharis acicularis* (L.) R.&S. *Myriophyllum spicatum* comprised more than 50 percent of the total biomass in the areas sampled; the species occurred at depths less than 5m in unheated locations, but not at depths deeper than 3m in heated locations. At depths less than 3m, *M. spicatum* was most abundant in heated locations 600m-1600m from the point where the heated effluent enters the reservoir. However, the amount of biomass of *M. spicatum* was greatly reduced in locations less than 400m from the discharge. Examination of the vertical distribution of the shoot biomass of *Myriophyllum* revealed that plants in heated areas grew closer to the water surface than plants in unheated areas. The biomass of the second most abundant species, *Eleocharis acicularis*, was less at 0.5m depths in heated areas (more than 5C° warmer than unheated areas) than at equal depths in unheated areas. Species diversity was greater at heated locations because of a greater equitability (i.e. evenness of distribution of biomass) among species.

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I. INTRODUCTION

The Effects of Heated Effluents on Aquatic Macrophytes

Research and development in the area of power production has become a topic of considerable interest in recent years. Concern with the environmental impact of processes associated with power production also has gained prominence. One associated process is the alteration of aquatic systems by hyperthermal effluents generated by cooling nuclear reactors. Yet, while the addition of waste-heat to aquatic systems is a potential environmental problem, the resulting alterations of these systems may permit a refined understanding of how temperature-related processes operate in natural systems.

Numerous studies of the effects of heated discharges on aquatic systems have been conducted (5, 10, 11). Within these systems, one ecological group of organisms which is often affected by the heated additions is the aquatic macrophytes. A common effect of heated effluents on macrophytes is elimination of species and replacement by other species.

Sharitz, et al., (31) reported the elimination of many species in areas of a swamp which received large amounts of heated water. They also found evidence that species of hardwoods were replaced by hydrophytic species (*Taxodium*). However, they attributed much of the elimination to direct and indirect affects of flow rather than to temperature. Similarly, Kolehmainen, et al., (16) found that the scouring action of flow associated with a thermal effluent was instrumental in occasional deaths of mangroves. Parker, et al., (24) compared heated and unheated bodies of water which all occurred within the same drainage system and found considerably fewer species in the heated than the unheated waters. They found no species in the heated area which did not occur in the unheated area. Both Anderson (4) and Allen (2) described the replacement of one species by another in heated environments, while Thorhaug (38) found that *Thallasia testudinum* was eliminated but not replaced in greatly heated areas (+ 5C°). These studies indicate that in thermally-elevated areas where conditions are severe enough to cause the elimination of species, remaining species may expand their distributions but new species of macrophytes are unlikely to appear.

Another aspect of aquatic macrophyte communities affected by waste heat is the rate of organic matter production. The most common responses observed in natural populations are the enhancement of production by slight temperature elevations and the drastic reduction in growth rate and eventual elimination of species by large increases in temperature. Thorhaug (38) found production to be, (1) enhanced by a 2C° elevation; (2) reduced as compared to unheated areas by a 3C° elevation; and (3) eliminated at temperature elevations of 5C°. D. Young (50) found twice the net production of *Spartina alterniflora* in a saltmarsh heated 2-6C° above normal compared with an adjacent unheated marsh.

Furthermore, he found that even though respiration rates were more than twice as great in the warmer marsh, the overall response of *S. alterniflora* to elevated temperatures was an increased rate of biomass turnover rather than a change in the ratio of gross production to respiration. C. Young (50) reported a positive correlation between temperature and the biomass accumulation of *Myriophyllum spicatum* in an artificially-heated reservoir. In contrast with these results are those of Anderson (4) which showed respiratory acclimation to increased temperatures (i.e. readjustment to normal respiratory rates) in mature leaves of *Potamogeton perfoliatus*.

Several lines of evidence support the idea that temperature is an important regulator of phenological development in plants. C. Young (49) found that *Myriophyllum spicatum* flowered earlier and more extensively in areas of elevated temperature. Experimental studies by Copeland, et al., (7) on estuarine communities indicated that a 5C° elevation in temperature reversed the growing season; maximum production occurred in winter and plants died or became inactive in summer. Furthermore, D. Young (50) found a 4.5C° elevation of water temperature induced *M. spicatum* to commence growth earlier.

Par Pond, the Study Site

Par Pond is located on the Energy Research and Development Administration's Savannah River Project near Aiken, South Carolina. In 1958 the reservoir was constructed by the impoundment of Lower-Three-Runs Creek for the purpose of cooling waste heat from nuclear reactors. The reservoir is part of a closed-loop cooling system (Figure 1) and is generally described in Table 1.

Numerous ecological studies have been conducted in Par Pond (5, 11). Most studies have dealt with various aspects of the heated effluent. Lewis (18) demonstrated that waste heat is horizontally distributed with little mixing near the discharge and is principally restricted to the upper two meters. This distribution pattern causes a secondary, artificial thermocline during periods of natural stratification and, thereby, greater vertical heterogeneity of water temperatures. Although he presents data and arguments to show that hypolimnetic temperatures are slightly increased by the waste heat, unpublished studies by Tilly (personal communication) indicate that hypolimnetic temperatures are the same at both heated and unheated areas.

According to Tilly (personal communications), reactor operations include several processes which may affect water quality:

1. Savannah River water is added to Par Pond water in the approximate ratio of 1:18 before it passes through the reactor. This is significant because the total input of water from the Savannah River is equal to the annual rainfall run-off to Par Pond and is higher in nutrients than local drainage because of its Piedmont and industrial-urban area origin.

2. Water pumped from Par Pond for cooling is taken from 6m beneath the surface and is likely to be higher in nutrient levels than the surface waters with which it is eventually mixed.

3. The death of organisms which are entrained in the cooling water, as well as the physical and chemical action of the temperatures in the heat-exchange system (> 80°C) are likely to cause changes in both nutrient quality and quantity as well as increases in amounts of suspended material.

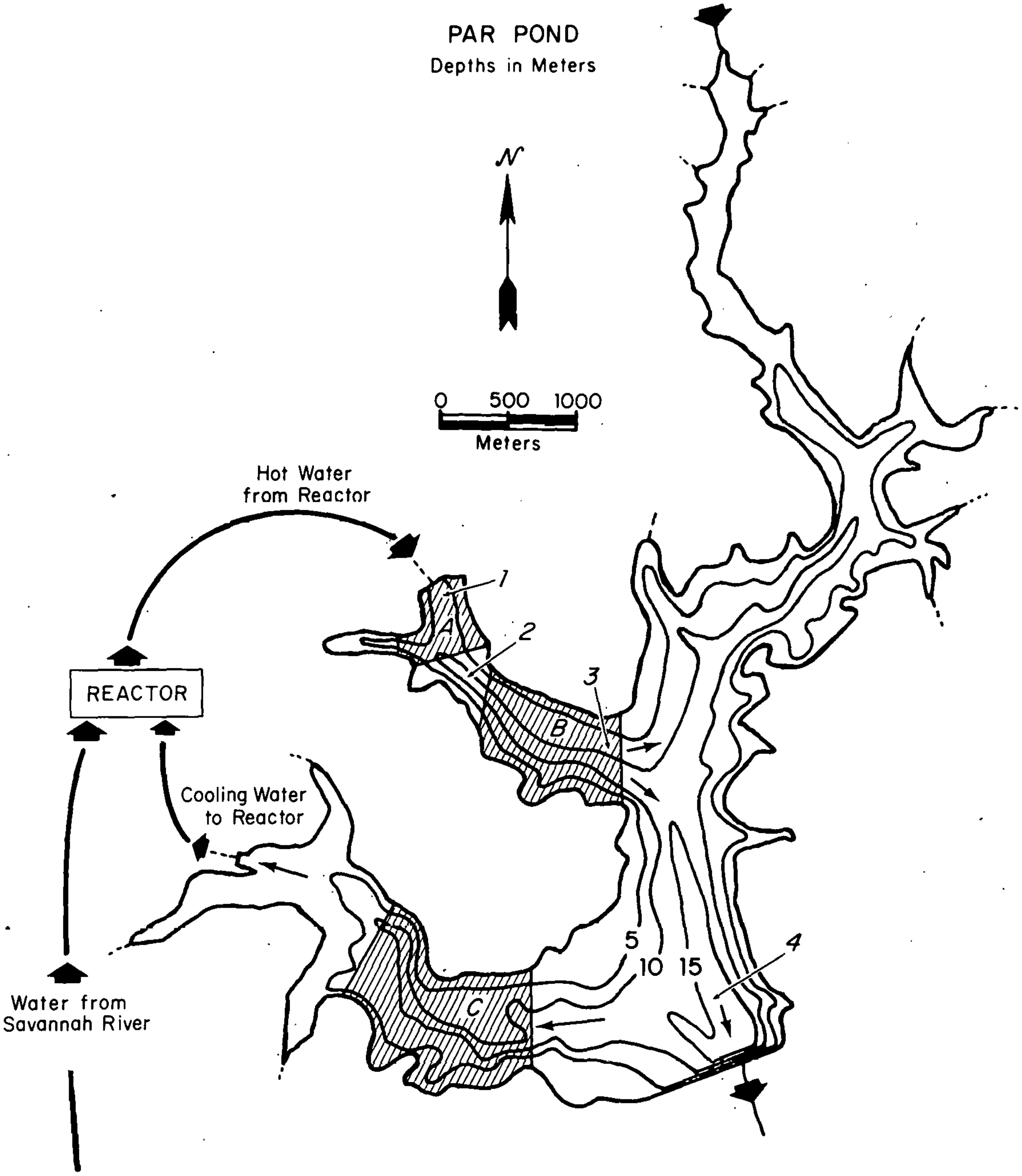
TABLE 1. General features of Par Pond.[a]

Area	$1.0 \times 10^7 m^2$
Mean Depth	6.2m
Euphotic Zone	6m
Secchi Transparency	2.5m
Turbidity	1.2 JTU
Total Alkalinity	15.0 ppm $CaCO_3$
Total Dissolved Solids	40 ppm
pH	7.7
Dissolved Oxygen	7.1 ppm

---

[a] Means are from Tilly (39) and based on samples taken from the unheated portion of Par Pond during June-August, 1967. Water quality data are from the euphotic zone.

Figure 1. The Par Pond system: sampling stations for macrophytes in 1975, water flow, and topography. Arrows indicate the movement of water. Areas A, B and C are stations at which the macrophyte community was sampled. Locations indicated by numbers 1-4 are those stations at which the nutrients and other limnological parameters described in Tables 7 and 8 were obtained. The numbers corresponding to depth isopleths are in meters.


PAR POND
Depths in Meters
N
0 500 1000
Meters
Hot Water
from Reactor
REACTOR
Cooling Water
to Reactor
Water from
Savannah River
1
A
2
3
B
C
5
10
15
4

4. Water passes through miles of precooling streams and ponds which contain resident populations of algae and bacteria which are capable of influencing the nature of the effluent.

Many ecological studies of thermal effects in Par Pond have been summarized by Beyers (5) and more recently by Gibbons and Sharitz (11). Their discussions of the effects of the heated discharge center around species elimination, thermal tolerances of species populations and life-history phenomena. Generalizations from these studies include: (1) the tendency for species to be eliminated at extreme temperatures; (2) a great deal of variability among different species with regard to physiological and behavioral adaptations to altered temperatures; and (3) the tendency for sublethal elevated temperatures to enhance growth rates and alter seasonal cycles.

Marshall and Tilly (19) and Tilly (39, 40) have examined the primary productivity of phytoplankton and periphyton in Par Pond. In shallow waters (< 2m), phytoplankton productivity is greater in heated than in unheated locations. However, the lower limit of the euphotic zone is deeper in unheated areas. Perhaps of most interest is the discovery (41) that Par Pond water quality parallels that of the Savannah River. Over a 9-year period between 1965 and 1973, levels of phytoplankton production were more influenced by industrially-polluted water from the Savannah River than by the addition of heated water. Periphyton production is also shown to be enhanced by the heated effluent (Tilly, personal communication). However, this enhancement is caused by both differences in water quality and higher temperatures.

Objectives

The overall objective of this study was to obtain a precise, and at least partly quantitative, description of the submerged vegetation in Par Pond. The approach which has been taken is basically that espoused by Whittaker (45) and is referred to as "gradient analysis"; which is ". . . A research approach for study of spatial patterns of vegetation . . . (which) seeks to understand the structure and variation of the vegetation of a landscape in terms of gradients in space of variables on three levels -- environmental factors, species populations and characteristics of communities." This research approach is based on the establishment of correlations between environmental conditions and patterns of vegetation by the examination of vegetation along an environmental gradient. Such correlations may then lead to the formulation of hypotheses which must be tested experimentally if cause and effect relationships are to be established. More specifically, the examination of macrophytes along a definable gradient, such as the one produced by the thermal effluent in Par Pond, may give some insight into the effects produced by a heated discharge on aquatic vegetation, both at the community and species-population levels of organization.

II. METHODS

A preliminary survey of submerged vegetation in Par Pond was conducted to facilitate design of a quantitative sampling program (Appendix A). As a result of this survey quantitative samples were collected at various distances from the discharge point.

Biomass Sampling in 1974

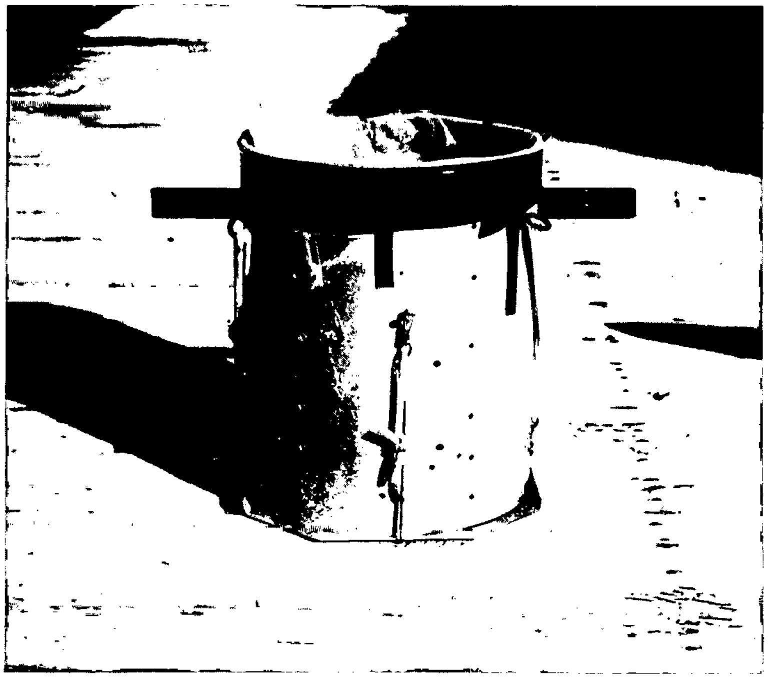
In July of 1974, three stations were chosen to represent hot, warm and unheated areas of the reservoir, and were designated stations A, B and C respectively (Figure 3). Stations had similarly oriented shores and thus were not subject to the confounding effects of differential solar insolation (28). The total lengths of shoreline at each station were: A, 800m; B, 2900m; C, 2500m.

Sampling was restricted to plants which were rooted at depths ≥ 0.5m to avoid emergent macrophytes. Areas in which floating-leaf species such as *Nelumbo lutea, Nuphar advena, Nymphaea odorata* and *Brasenia schreberi* were abundant comprised less than 5 percent of the non-cove areas and were excluded from sampling. *Hydrocotyle umbellata,* a small floating-leaved species, was included in sampling because of its widespread occurrence but was excluded from data analysis because it was not considered to be a submerged species.

Along the shore of each station, sampling locations were chosen randomly within each of four depth-strata: 0.5-1m, 1-2m, 2-3m, and 3-4m. Within a depth stratum, samples were collected at the intersections of randomly chosen transects perpendicular to the shore and depth contours parallel to the shore. Five samples were collected from each depth-stratum at each shore of the three stations for a total of 120 samples.

The sampling apparatus was a modification of the "cylinder" described by Nygaard (22) and is illustrated in Figure 2. The amount of plant material collected in the cylinder was standardized by comparisons with material collected from quadrats by hand (Appendix B). Operation of the cylinder required skin diving from a small boat. Upon location of a sample location, the cylinder was carefully lowered through the water and forced 10 to 20cm into the sediment. The bottom of the cylinder was then capped with the stainless-steel pan and brought to the surface. Living plant material was recovered from samples in the boat with the use of a 1cm mesh screen which was suspended over the side of the boat. Plant material from each sample was placed in a labeled, plastic bag and stored in an air-tight can to reduce desiccation. In the laboratory, samples were separated into species and processed to obtain ash-free dry weights. Drying took place at 105°C until a constant weight was obtained (> 24 hrs.). Subsamples were ashed in a muffle furnace at 550°C for three hours. Duplicate determinations were made of percent ash weight whenever more than 0.1g dry weight of a species was obtained in a sample. This occurred

Figure 2. The sampling apparatus. The sampler was made of an aluminum alloy, had an inside diameter of 0.33m and was .41m tall. The stainless steel pan was attached to the cylinder with latex tubing (inside diameter 0.48cm, wall thickness 0.16cm). The top of the cylinder was covered with #10 mesh plankton netting to prevent the loss of plant fragments.



in more than two-thirds of the samples. The data were expressed as ash-free dry weight because it is the most accurate and least variable method of expressing biomass (43).

Biomass Sampling in 1975

In 1975, samples were collected as described for 1974 with the following exceptions:

1. The proximal boundary of Station A was extended to include the discharge point (Figure 1).
2. Samples were collected at depths of 0.5, 1.5, 2.5, 3.5 and 4.5m along 4 randomly chosen transects at each shore of the 3 stations for a total of 120 samples.

Vertical Distribution of the Biomass of *Myriophyllum* in 1975

At the same time that biomass samples were collected by use of the sampling cylinder, individual plants of *Myriophyllum spicatum* were randomly collected by hand. One plant was collected at each of the locations where sampling with the cylinder was carried out (described above). In the laboratory, each plant was separated into roots and shoots, and shoot material was divided into 50cm sections throughout its length from base to apex. All plant material was dried at 105°C until a constant weight was obtained and then weighed. All values were expressed as percent of total dry weight (e.g., roots = 15 percent of plant dry weight).

Characterization of the Environment

Temperature

In 1974, temperature information which corresponded to the stations used for sampling macrophytes was obtained from the

Savannah River Ecology Laboratory. Temperatures were measured with Taylor maximum-minimum recording thermometers deployed at approximately 1m deep locations in Par Pond. Temperature readings were made at varying time intervals.

In 1975, temperatures were collected by the author with Taylor maximum-minimum recording, mercury thermometers. Thermometers were standardized to known temperatures in a constant temperature bath at 40°C and 15°C. The thermometers were suspended at 0.1m and 2.0m depths from poles located at points 2m deep. A pole was placed at each of the four corners of each sampling station. Temperatures were recorded weekly from 6/9/75 to 11/13/75.

Water Chemistry and Limnological Features

Basic limnological information for 1974 and 1975 periods, including major cation and anion concentrations, was obtained from the Savannah River Laboratory. Below is a list of the types of information. Methods are described in *Standard Methods* (3).

1. #10 net seston by filtration and centrifugation
2. conductivity by a conductivity meter
3. light penetration at midday by Secchi Disc
4. dissolved oxygen at midday by the Winkler method
5. pH by a Beckman pH meter
6. water color by the Hellige comparator
7. turbidity with a Hack Turbidimeter
8. Ca, Mg, K, Na and Si ions by Atomic Absorption Spectrometry
9. Cl ions by the Mercuric Thiocyanate method
10. sulfates by the Turbidimetric method
11. orthophosphates by the stannous chloride method
12. nitrates by the phenoldisulphonic acid method

Analyses of Data

Statistical analyses follow the notations of Sokal and Rohlf (33) and Siegel (32). The following symbols are used in the text:

Symbol	Definition
$\overline{Y}$	arithmetic mean
N	number of elements in a statistical population
S	standard deviation
$S\overline{y}$	standard error of the mean
P	probability
r	product-moment correlation coefficient
*	$P < .05$
**	$P < .01$
NS	$P > .05$
$A > B << C$	C is greater than both A and B, and A is greater than B.

Data analyses were performed with the aid of an IBM 360 computer and a Model 500 Wang Programable Calculator. Computer programs of the Statistical Analysis System (30) were used for parametric treatments of the data.

III. RESULTS

Environmental Conditions in Par Pond

Water Temperature

Water temperatures were measured by two methods to represent the littoral zone in Par Pond. First, maximum-minimum recording thermometers were suspended at 0.1m and 2.0m depths from poles located in areas 2.0m deep. Second, water temperatures at depths of 0, 1, 2, 3, 4 and 5m were measured biweekly at deep locations by personnel at the Savannah River Laboratory.

Deep Locations

Data obtained from the Savannah River Laboratory are shown in Figure 4. During 1974, water temperatures at heated and unheated stations, Station 1 and Station 4 respectively, differed by 3.5C° at the surface but less than 1C° at 3m depths. In 1975, water temperatures were 3.75C° higher at Station 1 at the surface but less than 0.5C° different at 3.0m (Figure 4). However, temperatures at Station 1 (Figure 3) are considerably lower (ca. 5.0C°) than temperatures in the littoral zone at an equal distance from the discharge (unpublished data of Tilly). This difference between temperatures in the deep area and the littoral occurs because the heated water moves along the shores as it flows away from the discharge point.

Figure 3. Sampling stations for macrophytes in 1974. Hatched areas indicated by A, B and C are stations at which the macrophyte community was sampled.

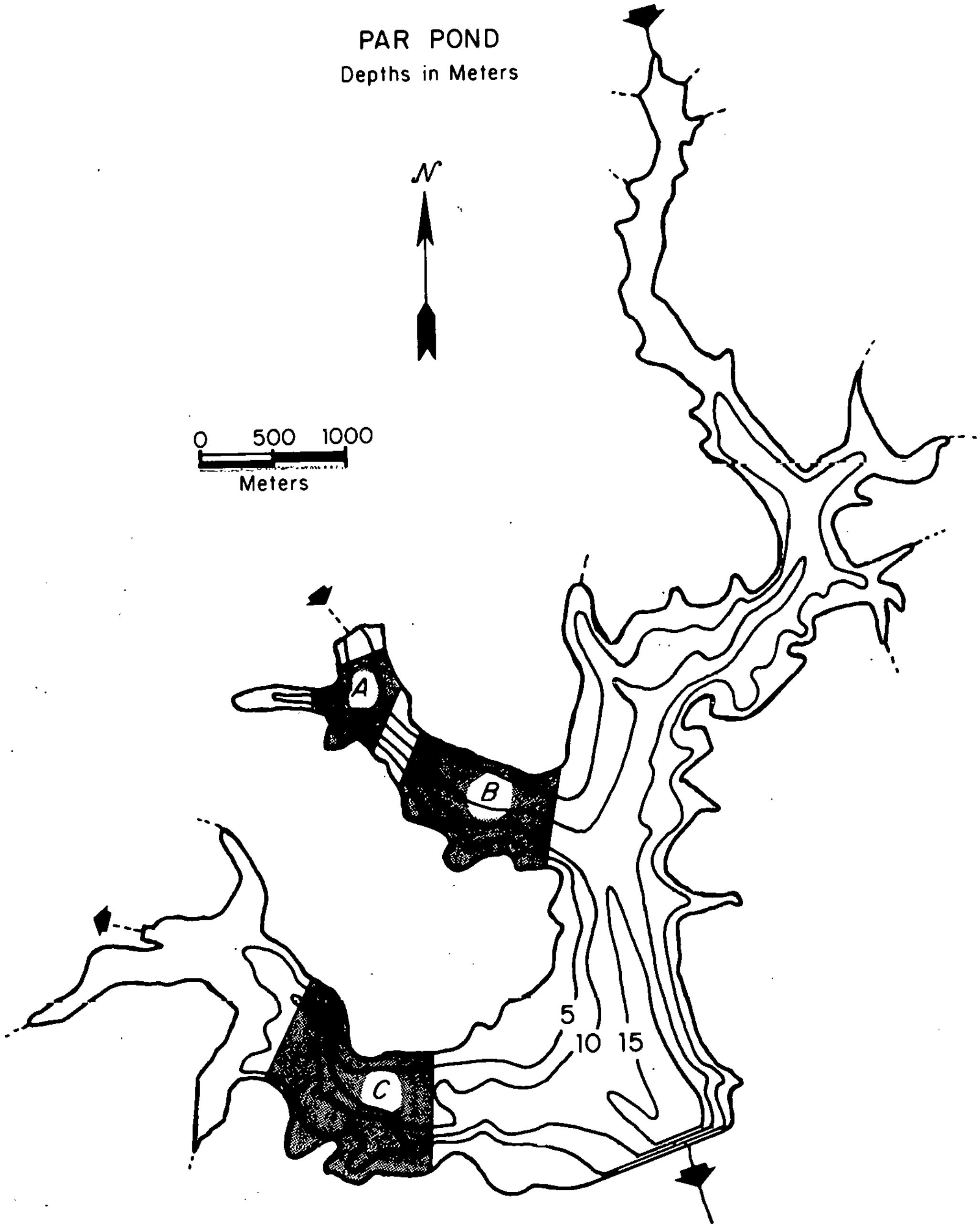

PAR POND
Depths in Meters
N
0
500
1000
Meters
A
B
C
5
10
15

Figure 4. Vertical profiles of water temperatures. Data were obtained from the Savannah River Laboratory. Stations are shown in Figure 1. Plotted points represent means of 15 measurements taken at biweekly intervals during the 1974 and 1975 growing seasons (March through September).

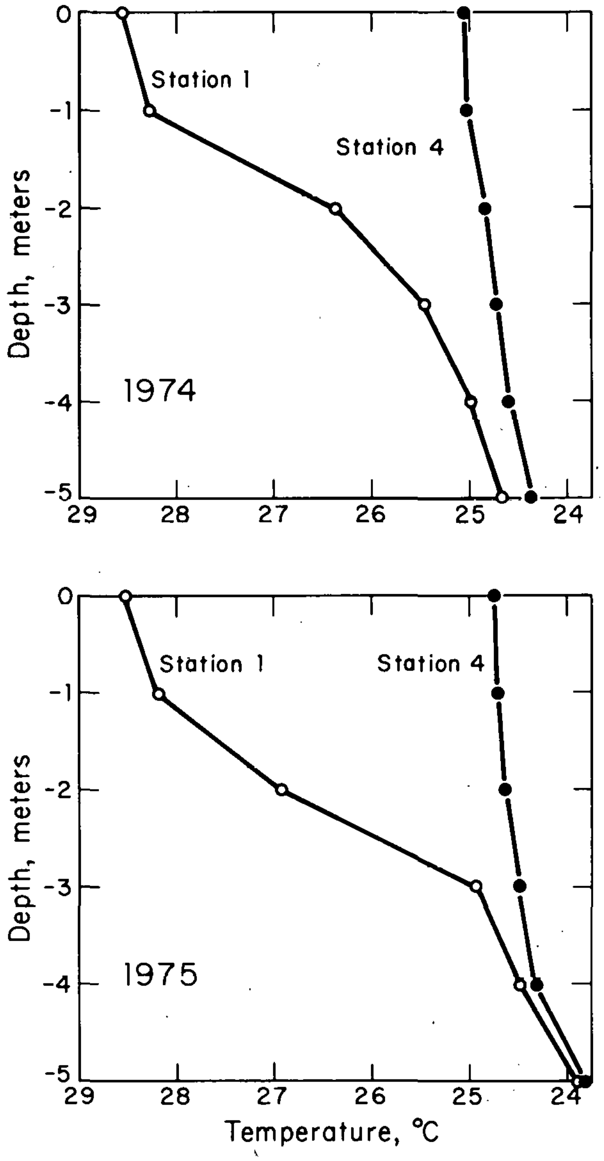

Station 1
Station 4
1974
Depth, meters
0
-1
-2
-3
-4
-5
29
28
27
26
25
24
Station 1
Station 4
1975
Depth, meters
0
-1
-2
-3
-4
-5
29
28
27
26
25
24
Temperature, °C

TABLE 2. Average maxima, minima and ranges of water temperatures from March to August of 1974.[a]

			Stations			
	A		B		C	
Avg. maximum, °C	33.9[b]	**	31.0	NS	30.8	**
Avg. minimum, °C	27.0	**	24.4	**	22.2	**
Avg. range, °C	7.0	*	6.5	**	8.6	**

---

[a] Previously unpublished data of Gibbons and Sharitz, Savannah River Ecology Laboratory, Aiken, South Carolina.

[b] Mean of 23 observations made during March-August, 1974.

* The two station averages on either side of an asterisk differ significantly ($P < .05$) by the nonparametric Sign Test (32). If asterisk is at the right of Station C, it means that Stations A and C differ significantly.

** The same as above except $P < .01$.

NS The same as above except $P > .05$ and the means are judged as being not significantly different.

TABLE 3. Average maxima, minima and ranges of water temperatures from June to November of 1975[a]

	Stations					
	A		B		C	
Avg. maximum, °C	33.6[b]	**	30.2	**	29.3	**
Avg. minimum, °C	28.1	**	26.9	**	25.9	**
Avg. range, °C	5.5	NS	4.9	**	3.4	**

---

[a] Stations are those shown in Figure 1.

[b] Averages are of 20 median values collected at weekly intervals during June-November, 1975. Medians were determined by averaging temperatures collected at both shores of the opposing boundaries of a station.

** The two averages on either side of the asterisk differ significantly ($P < .01$) by the nonparametric Wilcoxon Sign Rank Test (32). If asterisk is at the right of Station C, it means that Stations A and C differ significantly.

NS The same as above except $P > .05$ and the means are judged as being not significantly different.

TABLE 4. Vertical comparison of water temperatures at 0.1m and 2.0m during 1975.[a]

				Stations			
	Depth (m)	A		B		C	
Avg. maximum, °C	0.1	34.2	**[b]	32.4	**	29.4	*
	2.0	32.8		31.3		29.1	
Avg. minimum, °C	0.1	28.9	**	27.2	*	25.9	NS
	2.0	27.4		26.6		26.0	
Avg. range, °C	0.1	5.4	NS	5.2	*	3.7	*
	2.0	5.4		4.6		3.1	

---

[a] Averages are of 20 median values collected at weekly intervals during June-November, 1975. Medians were determined by averaging temperatures collected at both shores of the opposing boundaries of a station.

[b] * Means at 0.1m and 2.0m depths are significantly different at the .05 level using a Wilcoxon Sign Rank Test (32).

** Significantly different at the .01 level.

NS Not significantly different at .05 level.

TABLE 5. Comparisons of vertical differences in water temperature between 0.1m and 2.0m during 1975.[a]

	A		B		C	
Avg. difference between maxima °C	1.4	NS[b]	0.9	*	0.3	*
Avg. difference between minima °C	1.5	**	0.6	**	-0.1	**
Avg. difference between ranges °C	0.0	NS	0.6	NS	0.6	NS

---

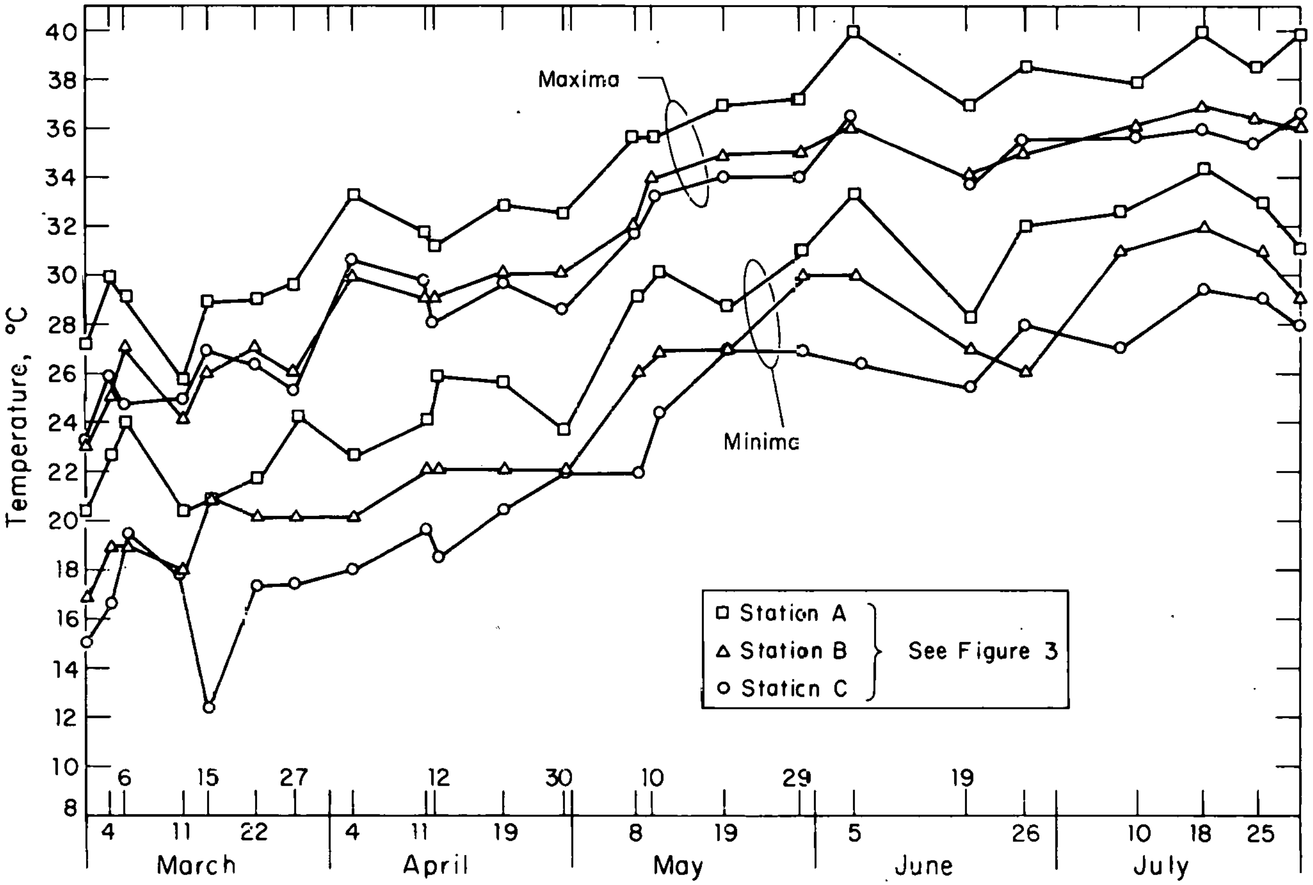
[a] Differences are calculated from Table 3.

[b] * The two averages on either side of the asterisk differ significantly ($P < .05$) by the nonparametric Wilcoxon Sign Rank Test (32). If asterisk is at the right of Station C, it means that Stations A and C differ significantly.

** The same as above except $P < .01$.

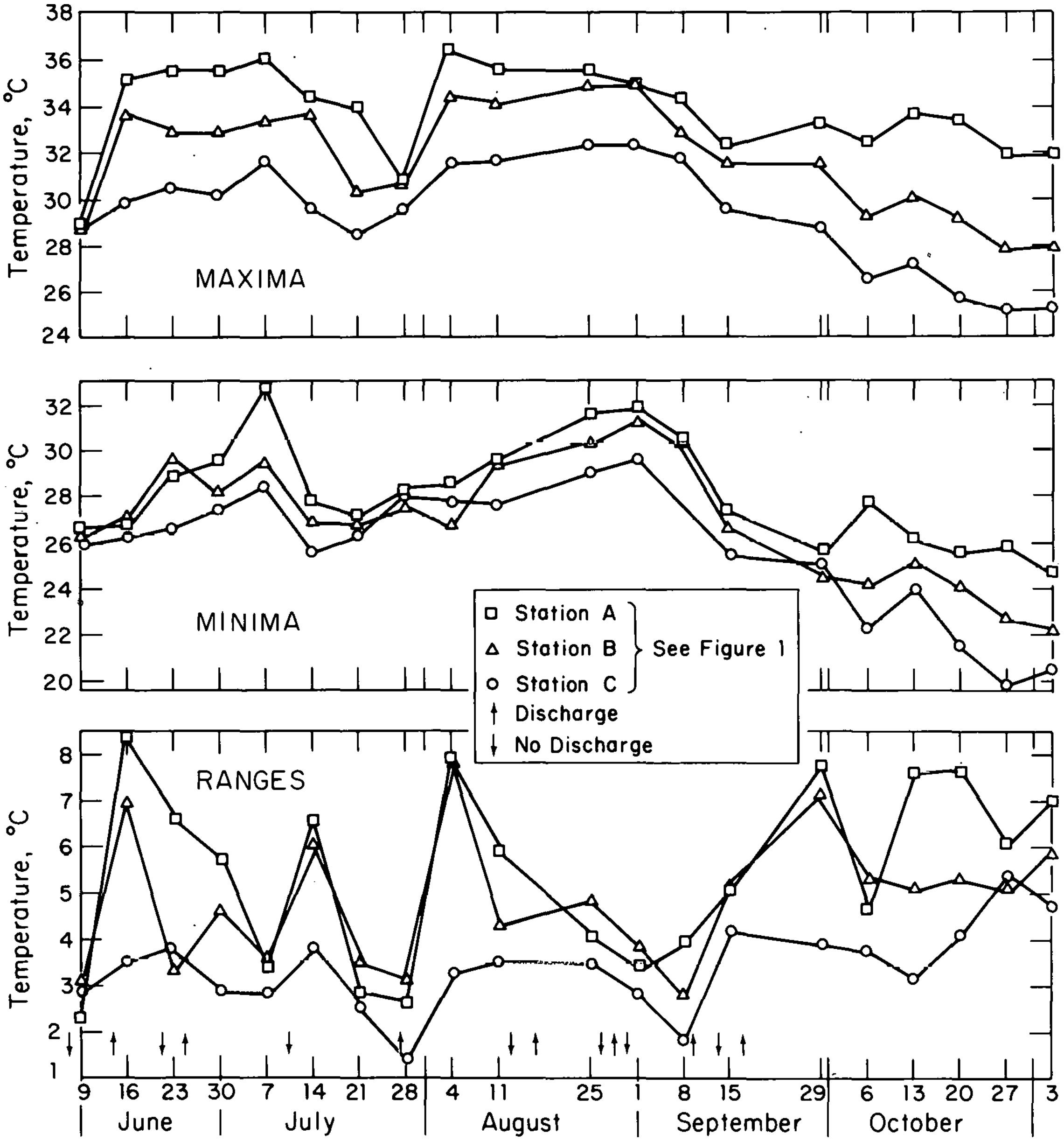
NS The same as above except $P > .05$ and the means are judged as being not significantly different.

Figure 5. Station temperatures: average maxima and minima at 1.0m in 1974. The data were obtained from Drs. J. W. Gibbons and R. R. Sharitz at the Savannah River Laboratory in Aiken, South Carolina. Values plotted are the means of all temperatures collected within each of the author's sampling stations. Means are derived from three locations within Station, one location in Station B, and two locations in Station C.



Temperature, °C
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
Maxima
Minima
□ Station A
△ Station B
○ Station C
See Figure 3
6
15
27
12
30
10
29
19
4
11
22
4
11
19
8
19
5
26
10
18
25
March
April
May
June
July

Figure 6. Station temperatures: average maxima, minima and ranges at 0.1m and 2.0m in 1975. Values plotted are the averages of temperatures collected at 0.1m and 2.0m depths at the four corners of each station.


38
36
34
32
30
28
26
24
Temperature, °C
MAXIMA
32
30
28
26
24
22
20
Temperature, °C
MINIMA
8
7
6
5
4
3
2
1
Temperature, °C
RANGES
□ Station A
△ Station B
○ Station C
See Figure 1
↑ Discharge
↓ No Discharge
9
16
23
30
7
14
21
28
4
11
25
1
8
15
29
6
13
20
27
3
June
July
August
September
October

Two-Meter Locations

During 1974, water temperatures in the upper 2m of the littoral zone increased from 15°-30°C in March to 25°-40°C during June and July (Figure 5). Throughout the entire period of March through July, Station A had consistently higher temperature maxima and temperature minima than did Stations B and C (Figure 3, Table 2). Although temperature minima were usually higher at locations nearer the discharge, temperature maxima were not significantly higher at Station B than at Station C (Figure 3, Table 2). Significant differences were also found among the average temperature ranges (range = maximum-minimum), with Station B having the lowest average range and Station C having the highest average range (Table 2).

In 1975, water temperatures were measured at weekly intervals from June through October. As shown in Figure 6, temperatures were 25-37°C during June and July, but declined to 20-34°C by October. Both weekly maxima and weekly minima temperatures were higher at locations nearer the discharge among all stations (Table 3). Weekly temperature ranges were highly erratic and showed no seasonal trends during the period June-October (Figure 6). However, the average temperature fluctuation (range) was significantly less at Station C than at Stations A and B. The latter stations were not significantly different.

A comparison of the average water temperatures in 1975 between depths of 0.1m and 2.0m is shown in Table 4. The average maximum temperatures at all stations were higher at 0.1m than at

2.0m. The average minimum temperatures were also higher at 0.1m than at 2.0m at Stations A and B, but not at Station C (Table 4). The average ranges of weekly temperatures did not differ between 0.1m and 2.0m at Station A, but Stations B and C showed higher ranges at 0.1m. The quantitative differences between 0.1m and 2.0m depths at each station are shown in Table 5. The average difference between maxima is less at Station C than at Stations A and B. The average difference between minima is greatest at Station A, intermediate at Station B and least at Station C (Table 5). However, the average differences between temperature ranges at 0.1m and 2.0m did not vary significantly among stations (Table 5).

Water and air temperatures are shown in Figure 7 and correlations are provided in Table 6. Correspondence between air and water temperatures was greatest at the unheated area (Station C) and least at the warmest area (Station A).

A plot of temperature versus the distance from the discharge (Figure 8) results in a curved line. However, transformation of the abscissa to the square root of the distance from the discharge straightens the line considerably (Figure 8).

Nutrient Levels of Surface Waters

Data were obtained from the Savannah River Laboratory for nutrient levels in Par Pond surface waters during 1974 and 1975 (Table 7). Reported values were calculated as "growing-season averages" that represent the average nutrient condition of the

TABLE 6. Correlation between air and water temperatures in 1975.[a]

Station		
A	B	C
[b] $r = .5756$	$r = .8580$	$r = .9317$
[c] $P = .0097$	$P < .0001$	$P < .0001$

---

[a] Refer to Figure 7.

[b] "r" is the product-moment correlation coefficient (33).

[c] "P" is the probability that the observed correlation is the result of chance.

TABLE 7. Average concentrations of nutrients in Par Pond surface waters during the growing seasons of 1974 and 1975.[a]

Date	Station[b]	PO_4 µg/l	NO_3 µg/l	Cl mg/l	SO_4 mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Si mg/l
1974	1	[c] 2.23	↑ 9.23	5.57	4.49	4.28	.34	4.90	.94	1.98
	2	1.40	8.42	5.67	3.91	4.61	.94	5.35	.99	2.23
	3	2.00	7.03	5.93	4.24	4.69	.94	5.59	.99	2.34
	4	1.58	2.33	5.67	3.91	↓ 4.71	↓ .91	↓ 5.34	.95	1.94
1975	1	2.80	↑ 6.07	4.79	3.95	3.80	.77	4.85	.94	2.44
	2	2.67	4.57	5.09	3.87	4.14	.84	5.04	.99	2.67
	3	2.00	4.07	5.16	4.05	4.15	.85	5.16	.99	2.67
	4	2.27	1.43	5.21	4.22	↓ 4.16	↓ .84	↓ 5.22	↓ .99	2.62

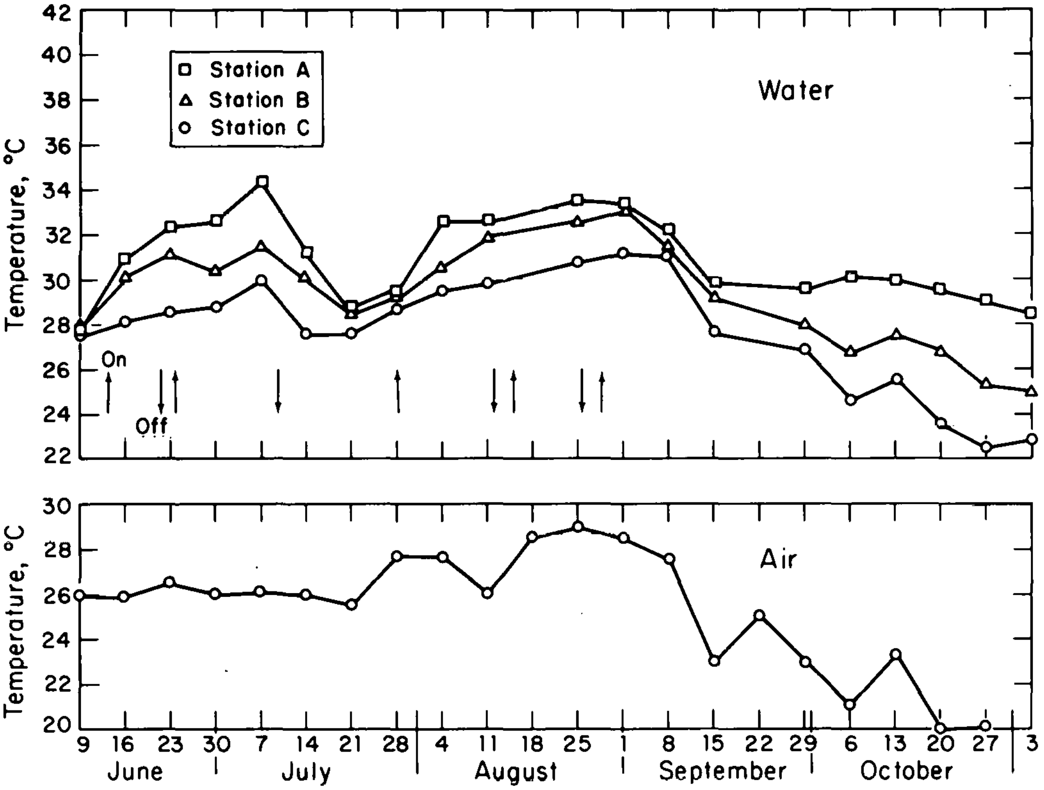
---

[a] Data were obtained from the Savannah River Laboratory. The growing-season for macrophytes in Par Pond was from March through September.

[b] Stations are those shown in Figure 1.

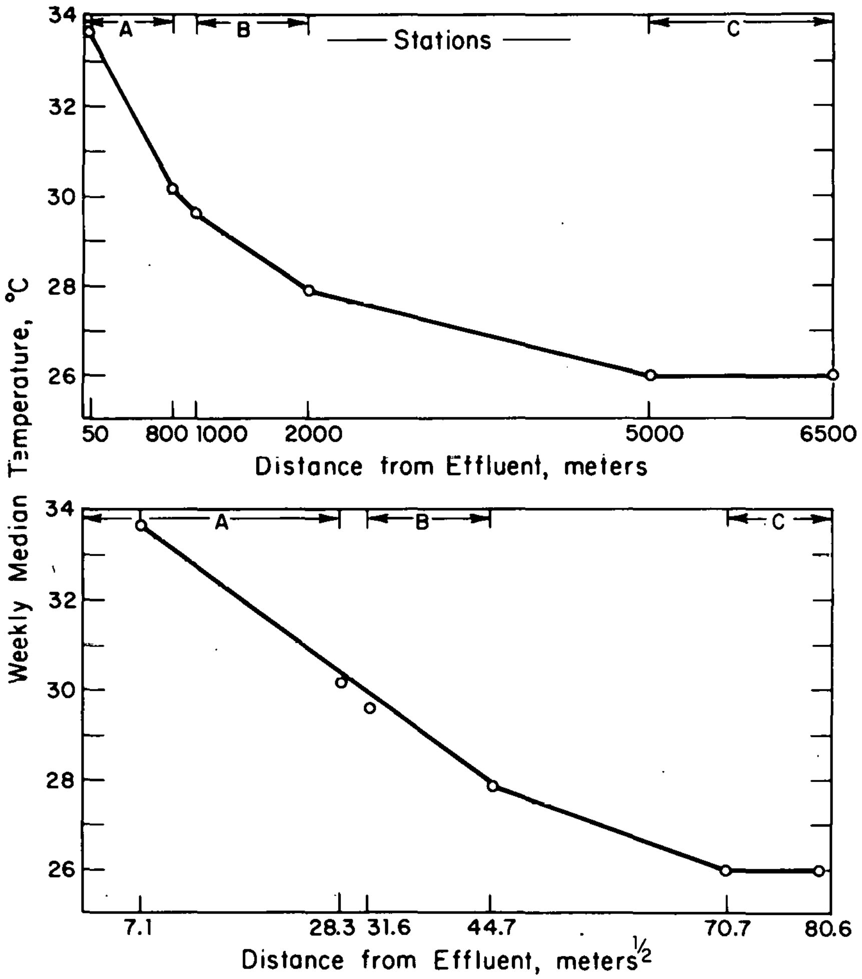
[c] Solid vertical lines indicate no significant trend in the means. Arrows indicate a significant difference by the Wilcoxon Sign Rank Test between stations 1 and 4, and the direction of the arrow indicates the direction of increase for this variable.

Figure 7. Water and air temperatures during 1975. The water temperatures represent the median during a week's time [(maximum + minimum)/2]. Each value is a station average (described in the caption of Figure 6). The arrows indicate whether the reactor was discharging ("on") or not discharging ("off"). Air temperatures were measured within 0.5 mile of Par Pond. Correlation coefficients are shown in Table 6.



Water
Air
□ Station A
△ Station B
○ Station C
Temperature, °C
42
40
38
36
34
32
30
28
26
24
22
20
On
Off
9
16
23
30
7
14
21
28
4
11
18
25
1
8
15
22
29
6
13
20
27
3
June
July
August
September
October

Figure 8. The temperature gradient in Par Pond: temperature versus distance from the discharge. The values plotted are weekly median temperatures taken during the growing-season (March through September) of 1975 while the reactor was continuously discharging heated water. The graphs represent the means of 6 values for the upper 2m of the water column. Stations are those shown in Figure 1.


Weekly Median Temperature, °C
34
32
30
28
26
A
B
Stations
C
50
800
1000
2000
5000
6500
Distance from Effluent, meters
34
32
30
28
26
A
B
C
7.1
28.3
31.6
44.7
70.7
80.6
Distance from Effluent, meters½

water during the period when macrophytes were growing (March-September). No significant differences were found in the concentrations of phosphates, chlorides, sulfates or silicates at the three stations in either year (Table 7). However, significant differences do exist for concentrations of nitrates as well as calcium, magnesium and sodium ions among the stations (Table 7). Potassium ion concentrations were significantly variable among stations during 1975 but not during 1974.

Only nitrate concentrations were higher at Station 1 than at Station 4 (Table 7). During both 1974 and 1975, the Stations which occurred within the heated arm of Par Pond (Stations 1, 2 and 3) all possessed considerably higher nitrate concentrations than the unheated station (Station 4). By contrast differences among stations which occurred in levels of calcium, magnesium, sodium and potassium ions indicated higher values at the unheated station (Station 4) than at the warmest station (Station 1) (Table 7). For these ions, concentrations at Stations 2, 3 and 4 are similar but Station 1 is considerably lower.

A highly significant decrease ($P < .01$) in overall levels of ions between 1974 and 1975 was revealed by the binomial test. This was consistent with the fact that the conductivity of surface waters was significantly lower in 1975 than in 1974 ($P < .05$) by the Students' "T" Test.

Additional Features of the Environment

In addition to data on nutrients, data on several other characteristics of surface water in Par Pond were obtained from the Savannah River Laboratory (Table 8).

Calculations of light penetration were derived from the Secchi Disc values (Table 8) and are shown in Table 9. In 1974, the estimated differences in light penetration between Stations 1 and 4 are such that the light intensity at 4.5m at Station 1 was approximately equal to the intensity at 5.0m at Station 4. For the 1975 growing season, differences in light penetration between Stations 1 and 4 were even greater than for 1974.

The Distribution and Abundance of Macrophytes

The Biomass of Macrophytes

July, 1974

Submerged macrophytes were quantitatively sampled and their ash-free dry weights were determined. Values are presented in Table 10 as grams/m^2. Graphical representation and statistical analyses of these data are shown in Figure 9. Three species, *Myriophyllum spicatum, Eleocharis acicularis* and *Najas guadalupensis* are presented individually because of the predominance of their biomasses (Figure 9). *Myriophyllum* occurred primarily at depths greater than 2m at Station C, but was more abundant in the 1.25-2m zone at Station B. By comparison with Station B, the abundance of *Myriophyllum* was significantly less at Station A at

TABLE 8. Limnological features of Par Pond surface waters during the growing seasons of 1974 and 1975.[a]

Date	Station[b]	#10 Net Seston, mg/l	pH, pH units	Dissolved O_2 mg/l-%	Color, Pt-Co units	Turbidity, JTU	Conductivity, μmho	Secchi, meters
1974	1	[c] .047	7.60	6.58-87.0[d]	1.11	3.67	51.8	2.36
	4	.056	7.59	↓ 7.17-87.0	1.12	3.62	53.2	↓ 2.62
1975	1	.073	7.59	7.40-98.0	1.25	↑ 2.77	51.7	2.24
	4	.050	7.63	↓ 7.98-98.0	1.04	1.81	51.0	↓ 2.70

---

[a] Data were obtained from the Savannah River Laboratory. The growing season in Par Pond was from March through September. These limnological features and the methods for their determination are described in *Standard Methods* (3).

[b] Stations are those shown in Figure 1.

[c] Solid vertical lines indicate no significant trend in the means. Arrows indicate a significant difference between stations 1 and 4 by the Wilcoxon Sign Rank Test, and the direction of the arrow indicates the direction of increase for this variable.

[d] Percent of saturation.

TABLE 9. Calculations of light penetration from Secchi Disc values.[a]

	Percent of Surface Light[b]			
	1974		1975	
Depth, m	Station 1	Station 4	Station 1	Station 4
0.5	52.99	56.27	51.17	57.41
1.0	28.08	31.66	26.18	32.96
1.5	14.88	17.82	13.40	18.92
2.0	7.89	10.03	6.86	10.86
2.5	4.18	5.64	3.51	6.23
3.0	2.21	3.17	1.80	3.58
3.5	1.17	1.79	0.92	2.05
4.0	0.62	1.01	0.47	1.18
4.5	0.33	0.57	0.24	0.68
5.0	0.17	0.32	.12	0.39

---

[a] Secchi Disc values are those shown in Table 8.

[b] Percent of surface light was calculated according to Wetzel (44). The equation used was such that $I_z = I_o e^{-nz}$; where I_z = the light intensity at depth z, I_o is the light intensity at the surface, e is the base of natural logarithms, and n is the extinction coefficient. The extinction coefficient is calculated such that $n = (\ell n\ I_o - \ell n\ I_z)/z$; where ℓn is the natural logarithm, and the Secchi depth is assumed to be the depth to which 5% of the light penetrates.

TABLE 10. Distribution and relative abundance of biomass: July, 1974.[a]

Ash-free dry weight, g/m^2

Italics denote % total biomass

	Station A				Station B				Station C			
Sampling depth, m →	0.5-1	1-2	2-3	3-4	0.5-1	1-2	2-3	3-4	0.5-1	1-2	2-3	3-4
Myriophyllum spicatum	0.5	4.6	46.6	1.1	2.8	116.8	139.4	91.8	3.9	2.0	64.6	30.4
	0.7	*4.0*	*70.5*	*97.2*	*7.0*	*80.7*	*100.0*	*98.8*	*6.3*	*6.3*	*96.5*	*99.8*
Eleocharis acicularis	20.4	4.8	0.0	0.0	29.5	10.1	0.0	0.0	49.6	24.1	0.1	0.0
	26.3	*4.2*	*0.0*	*0.0*	*73.8*	*7.0*	*0.0*	*0.0*	*81.0*	*77.2*	*0.2*	*0.0*
Najas guadalupensis	47.8	85.7	4.4	0.0	7.1	15.2	0.0	0.2	0.0	1.5	0.6	0.1
	61.9	*74.7*	*6.6*	*0.0*	*17.8*	*0.5*	*0.0*	*0.2*	*0.0*	*5.0*	*0.8*	*0.2*
TOTAL	77.3	114.7	66.1	1.1	40.0	144.8	139.4	91.9	61.3	31.2	66.9	39.5
Other	11.1	17.1	*22.9*	*2.8*	1.4	*7.3*	*0.0*	*0.4*	12.7	11.5	*2.5*	*0.0*

Myriophyllum spicatum was important fraction of total in 0-2 meter depths only at Station B.
Myriophyllum spicatum was dominant fraction of total in 2-4 meter depths at all stations.
Other species were important fraction of total only in shallows at stations C and A.

---

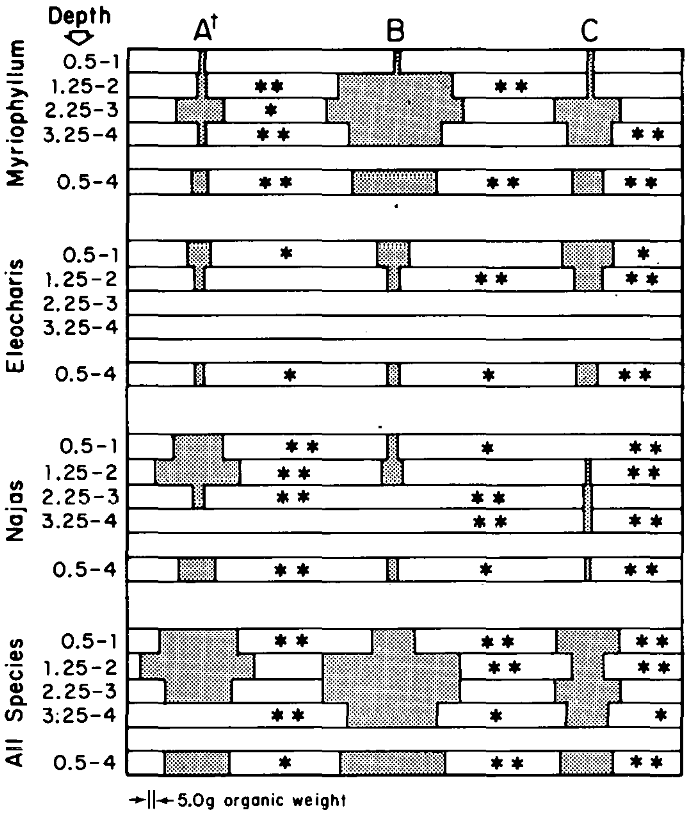
[a] Stations are those shown in Figure 3.

Figure 9. Biomass of macrophytes collected during July, 1974. Depths are in meters.

† Stations A, B and C are those shown in Figure 3.

* Averages on either side of asterisk differ significantly at the 0.05 level of confidence by the Student-Newman-Keuls Test (33). If asterisk is at the right of Station C, it applies to Stations A and C.

** Significant at the 0.01 level of confidence.


Depth
A†
B
C
Myriophyllum
0.5-1
1.25-2
2.25-3
3.25-4
0.5-4
Eleocharis
0.5-1
1.25-2
2.25-3
3.25-4
0.5-4
Najas
0.5-1
1.25-2
2.25-3
3.25-4
0.5-4
All Species
0.5-1
1.25-2
2.25-3
3:25-4
0.5-4
**
*
5.0g organic weight

all depths except 0.5-1.0m (Figure 9). The total biomass of *Myriophyllum* at all depths was greatest at Station B, intermediate at Station C and least at Station A. *Eleocharis* occurred only at depths less than 2m and was progressively reduced at stations nearer the discharge. *Najas* was scarcely present at Station C but was very abundant in the upper two depth zones at Station A.

The combined biomass of all species from all depths was greatest at Station B, intermediate at Station A and least at Station C (Figure 9). Furthermore, biomass was greater at Station B than at Station C for all depths except the shallowest (0.5-1.0m). The biomass at Station A was more abundant at 0.5-1.0m but less abundant at 3.25-4.00m when compared to Station B (Figure 9).

Comparisons among species in Table 10 show that *Myriophyllum* was the dominant component of total biomass at depths greater than 2 meters at all stations. However, *Myriophyllum* was an important component of total biomass at depths less than 2m only at Station B. At Station A and C, other species comprised a significant percentage of the total biomass in shallower areas.

July, 1975

The biomass values for July, 1975 are shown in Table 11 and presented graphically in Figure 10. As in July of 1974, *Myriophyllum spicatum, Eleocharis acicularis* and *Najas guadalupensis* were presented individually because of their relative magnitudes and importance (Figure 10). In addition,

TABLE 11. Distribution and relative abundance of biomass: July, 1975.[a]

Ash-free dry weight, g/m²
Italics denote % total biomass

	Station A					Station B					Station C				
Sampling depth, m →	0.5	1.5	2.5	3.5	4.5	0.5	1.5	2.5	3.5	4.5	0.5	1.5	2.5	3.5	4.5
Myriophyllum spicatum	1.1	27.7	55.7	3.3	0.0	0.5	3.3	13.1	89.8	1.0	0.0	2.4	85.2	71.7	37.1
	1.9	*51.1*	*89.8*	*46.5*	*0.0*	*1.2*	*7.3*	*34.8*	*98.8*	*100.0*	*0.0*	*4.1*	*91.8*	*99.9*	*99.7*
Eleocharis acicularis	3.4	0.0	0.0	0.0	0.0	38.3	5.0	0.0	0.0	0.0	40.9	26.7	4.7	0.0	0.0
	14.4	*0.0*	*0.0*	*0.0*	*0.0*	*88.7*	*11.1*	*0.0*	*0.0*	*0.0*	*93.2*	*45.3*	*5.1*	*0.0*	*0.0*
Najas guadalupensis	13.0	15.4	0.1	0.0	0.0	0.3	12.8	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0
	22.2	*28.4*	*0.2*	*0.0*	*0.0*	*0.7*	*28.4*	*0.3*	*0.0*	*0.0*	*0.0*	*0.0*	*0.1*	*0.0*	*0.0*
Najas gracillima	32.5	0.6	0.2	0.0	0.0	0.7	18.7	21.2	0.0	0.0	0.0	7.8	2.8	0.0	0.0
	55.6	*1.1*	*0.3*	*0.0*	*0.0*	*1.6*	*41.6*	*56.1*	*0.0*	*0.0*	*0.0*	*13.2*	*3.0*	*0.0*	*0.0*
TOTAL	58.5	54.2	62.0	7.1	0.0	43.2	45.0	37.6	90.9	1.0	43.9	59.0	92.8	71.8	37.2
Other	*5.9*	*19.4*	*9.7*	*53.5*	*0.0*	*7.8*	*11.6*	*8.8*	*1.2*	*0.0*	*6.8*	*37.4*	*0.0*	*0.1*	*0.3*

Myriophyllum spicatum was major fraction of total in 2.5-4.5 meter depths at all stations except Station B where *Najas gracillima* was abundant at 2.5 meters depth.
Eleocharis acicularis was predominant fraction of total at 0.5 meters depth at Stations B and C but was replaced by *Najas* spp at Station A.

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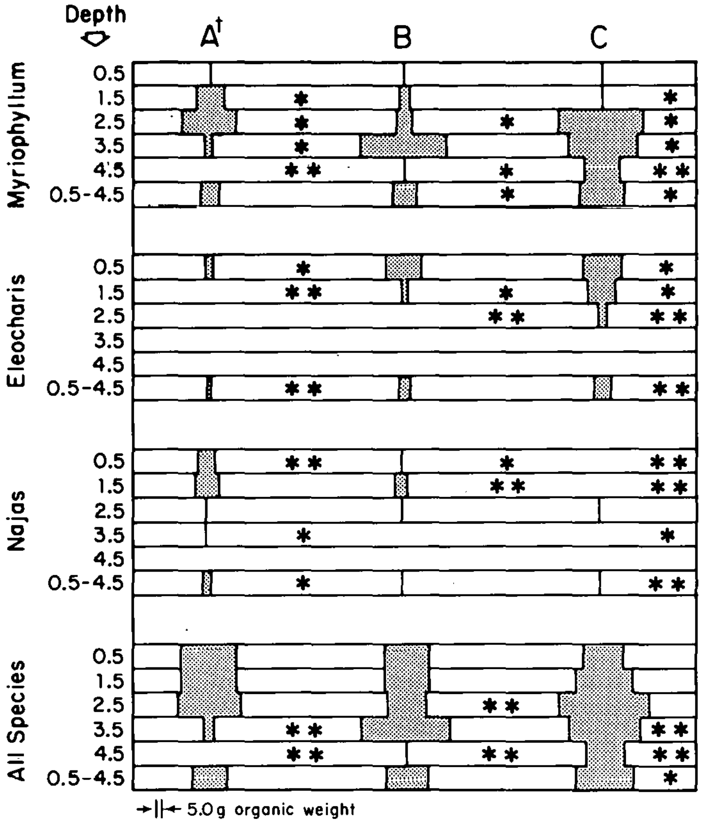
[a] Stations are those shown in Figure 1.

Figure 10. Biomass of macrophytes collected during July, 1975. Depths are in meters. Asterisks are explained in Figure 9.

† Stations A, B and C are those shown in Figure 1.


Depth
A†
B
C
Myriophyllum
0.5
1.5
2.5
3.5
4.5
0.5-4.5
Eleocharis
0.5
1.5
2.5
3.5
4.5
0.5-4.5
Najas
0.5
1.5
2.5
3.5
4.5
0.5-4.5
All Species
0.5
1.5
2.5
3.5
4.5
0.5-4.5
*
**
→||← 5.0g organic weight

Najas gracillima was included in Table 11 because of its abundance at several locations. To allow for comparison, the depth classes (e.g. 1.25-2.00m) of 1974 were considered equivalent to the discrete depths (e.g. 1.5m) of 1975. These comparisons are shown in Table 13. *Myriophyllum* was unchanged at Station C but radically different between times at Station B. Lower levels of biomass were found at Station B at 1.5m and 2.5m in July of 1975. Station A was unchanged at all depths except 1.5m where there was an increase in July of 1975. *Eleocharis* was unchanged at all stations for the average biomass at all depths. However, in July of 1975 there was an increase in *Eleocharis* at 2.5m at Station C and there was a decrease at 1.5m at Station A. Numerous changes occurred in the biomass of *Najas guadalupensis*, but the changes of greatest magnitude were at 0.5m and 1.5m at Station A (Table 13). *N. guadalupensis* was reduced at Station A from a value of 47.8 g/m^2 to 13.0 g/m^2 at 0.5m and from 85.7 g/m^2 to 15.4 g/m^2 at 1.5m (Tables 9 and 10).

No change in total biomass of all species occurred at Station C (Table 13). However, in July of 1975 there were lower levels of biomass at 1.5m and 2.5m at Station B, and 1.5m at Station A.

October, 1975

The biomass values for October, 1975 are shown in Table 12 and summarized in Figure 11. The biomass values obtained for July and October of 1975 were compared in Table 13. *Myriophyllum* did not change at Station C, increased at 1.5m and decreased at

TABLE 12. Distribution and relative abundance of biomass: October, 1975.[a]

Ash-free dry weight, g/m^2

Italics denote % total biomass

	Station A					Station B					Station C				
Sampling depth, m –	0.5	1.5	2.5	3.5	4.5	0.5	1.5	2.5	3.5	4.5	0.5	1.5	2.5	3.5	4.5
Myriophyllum spicatum	0.6	40.6	110.6	13.4	0.0	2.6	14.1	22.6	38.7	6.5	3.6	0.2	84.5	52.4	34.3
	1.8	*89.0*	*98.3*	*99.9*	*0.0*	*3.5*	*39.2*	*99.6*	*100.0*	*95.6*	*9.2*	*0.6*	*100.0*	*00.0*	*100.0*
Eleocharis acicularis	28.8	0.0	0.0	0.0	0.0	64.3	6.1	0.0	0.0	0.0	34.0	30.0	0.0	0.0	0.0
	88.3	*0.0*	*0.0*	*0.0*	*0.0*	*86.8*	*16.9*	*0.0*	*0.0*	*0.0*	*86.7*	*86.7*	*0.0*	*0.0*	*0.0*
Najas guadalupensis	3.2	4.9	1.1	0.1	0.0	3.1	13.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	9.8	*10.7*	*1.0*	*0.1*	*0.0*	*4.2*	*36.7*	*0.4*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
TOTAL	32.6	45.6	112.5	13.4	0.0	74.1	36.0	22.7	38.7	6.8	39.2	34.6	84.5	52.4	34.3
Other	*0.1*	*0.3*	*0.7*	*0.0*	*0.0*	*5.5*	*7.2*	*0.0*	*0.0*	*4.4*	*4.1*	*12.7*	*0.0*	*0.0*	*0.0*

Myriophyllum spicatum was major fraction of total in 2.5-4.5 meter depths at all stations.
Eleocharis acicularis was major fraction of total at 0.5 meters at all stations and extended to 1.5 meters at Station C.

---

[a] Stations are those shown in Figure 1.

TABLE 13. Comparisons of biomass among time periods.^{a,b}

		A		B		C	
	Depth, m	7-74 vs 7-75	7-75 vs 10-75	7-74 vs 7-75	7-75 vs 10-75	7-74 vs 7-75	7-75 vs 10-75
Myriophyllum	0.5	NS	NS	NS	NS	NS	NS
	1.5	*<	NS	**>	*<	NS	NS
	2.5	NS	*<	**>	NS	NS	NS
	3.5	NS	NS	NS	*>	NS	NS
	4.5	--	NS	--	NS	--	NS
	0.5-4.5	NS	NS	**>	NS	NS	NS
Eleocharis	0.5	NS	*<	NS	*<	NS	NS
	1.5	**>	NS	NS	NS	NS	NS
	2.5	NS	NS	NS	NS	**	NS<
	3.5	NS	NS	NS	NS	NS	NS
	4.5	--	NS	--	NS	--	NS
	0.5-4.5	NS	NS	NS	NS	NS	NS
Najas	0.5	**>	**>	NS	NS	NS	NS
	1.5	**>	*>	NS	NS	**>	NS
	2.5	**>	NS	**<	NS	NS	NS
	3.5	**<	NS	**>	NS	**>	NS
	4.5	--	NS	--	NS	--	NS
	0.5-4.5	**>	*>	NS	NS	NS	NS
ALL SPECIES	0.5	NS	NS	NS	*>	NS	NS
	1.5	*>	NS	**>	NS	NS	NS
	2.5	NS	*<	*>	NS	NS	NS
	3.5	NS	NS	NS	*>	NS	NS
	4.5	--	NS	--	NS	--	NS
	0.5-4.5	*>	NS	**>	NS	NS	NS

---

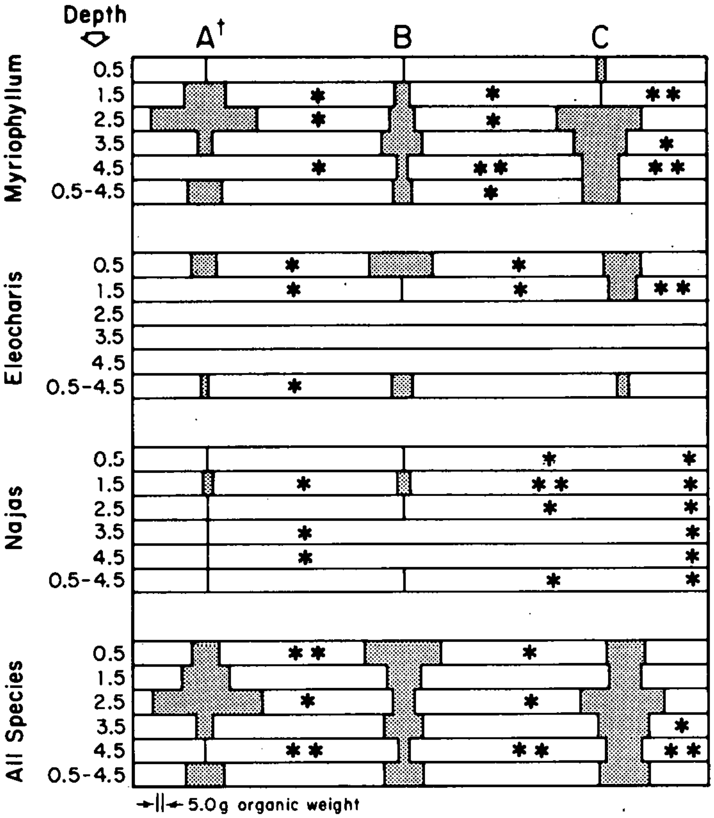
a. Comparisons were made with paired comparisors "t" tests (33).

b. The notation for comparisons is:

* Significant difference at the .05 level.
** " " " " .01 " .
*> 7-74 > 7-75 or 7-75 > 10-75.
*< 7-74 < 7-75 or 7-75 < 10-75.

Figure 11. Biomass of macrophytes collected during October, 1975. Depths are in meters. Asterisks are explained in Figure 9.

† Stations A, B and C are those in Figure 1.


Depth
A†
B
C
Myriophyllum
Eleocharis
Najas
All Species
0.5
1.5
2.5
3.5
4.5
0.5-4.5
*
**
5.0g organic weight

3.5m during October at Station B, and increased at 2.5m at Station A. *Eleocharis* was also unchanged at Station C, but increased at 0.5m at both Stations A and B. *Najas guadalupensis* was changed only at Station A where it decreased in abundance at 0.5m and 1.5m in October.

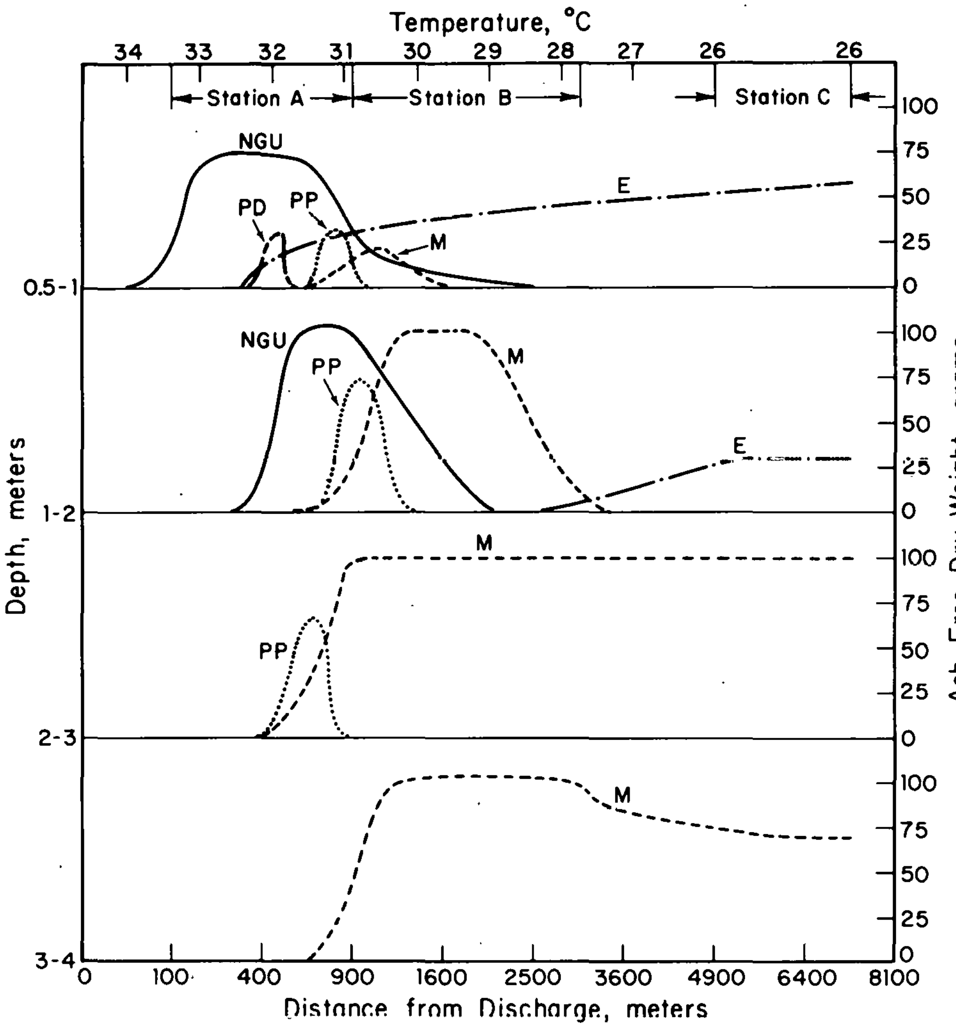
No change in total biomass of all species occurred at Station C (Table 13). However, at Station B, biomass increased at 0.5m and decreased at 3.5m in October. Station A showed no change except at 2.5m where there was a two-fold increase in October.

The Distributions of Species-Populations

Biomass data collected in July of 1974, July of 1975 and October of 1975 were used to construct generalized curves representing the distributions of species-populations in Par Pond (Appendix C, Figures 12-14). Figures 12-14 are plots of biomass against the distance from the discharge on a square root scale. These plots were used because the temperature of the upper 2m of the water column was approximately a function of the square root of the distance from the discharge (Figure 8). Approximate temperatures were plotted on the upper abscissa of Figure 12 to allow for comparisons between temperatures and species-populations which occurred in depths less than 2.0m. Since water below 2.0m was considerably cooler than the water above 2.0m (Figure 4), correlations of temperature with vegetation growing at depths greater than 2.0m required consideration of the vertical distribution of the plants and are presented in Figures 28 and 29.

Figure 12. Generalized distributions of species-populations in July, 1974. The distance from the discharge is on a square-root scale. The stations are shown in Figure 3. Curves were eye-fitted to the data points as demonstrated and described in Appendix C, and are considered approximations. The temperatures were taken from Figure 8. Notations are as follows:

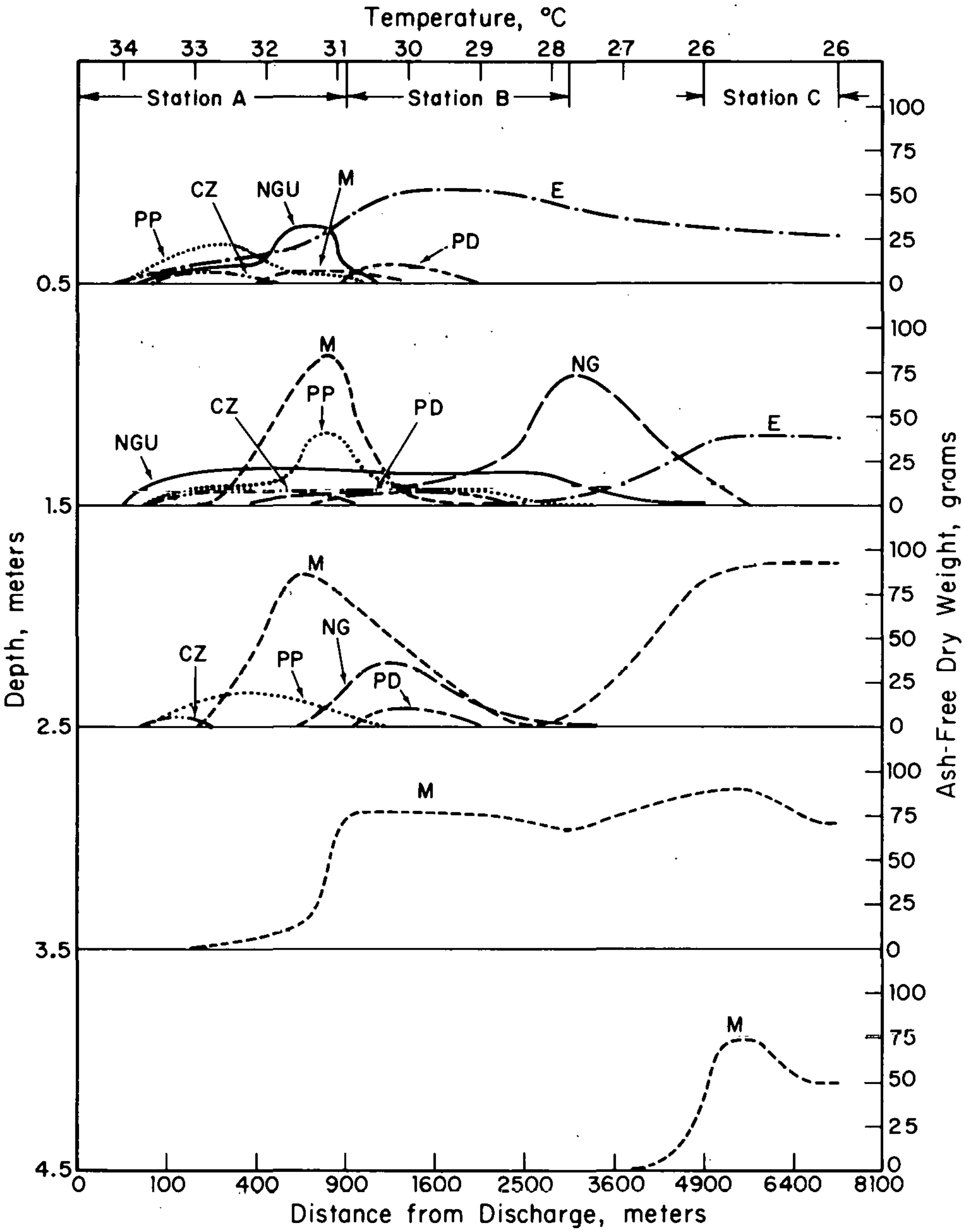
M = *Myriophyllum spicatum*
E = *Eleocharis acicularis*
NGU = *Najas guadalupensis*
PP = *Potamogeton pusillus*
PD = *Potamogeton diversifolius*



Temperature, °C
34
33
32
31
30
29
28
27
26
26
Station A
Station B
Station C
NGU
PD
PP
E
M
0.5-1
1-2
2-3
3-4
Depth, meters
Ash-Free Dry Weight, grams
100
75
50
25
0
0
100
400
900
1600
2500
3600
4900
6400
8100
Distance from Discharge, meters

Figure 13. Generalized distributions of species-populations in July, 1975. Temperatures were taken from Figure 8. The stations are shown in Figure 1. Distance from the discharge is on a square-root scale. Curves have been eye-fitted to the data points as described in Appendix C and are only approximations. Notations are as follows:

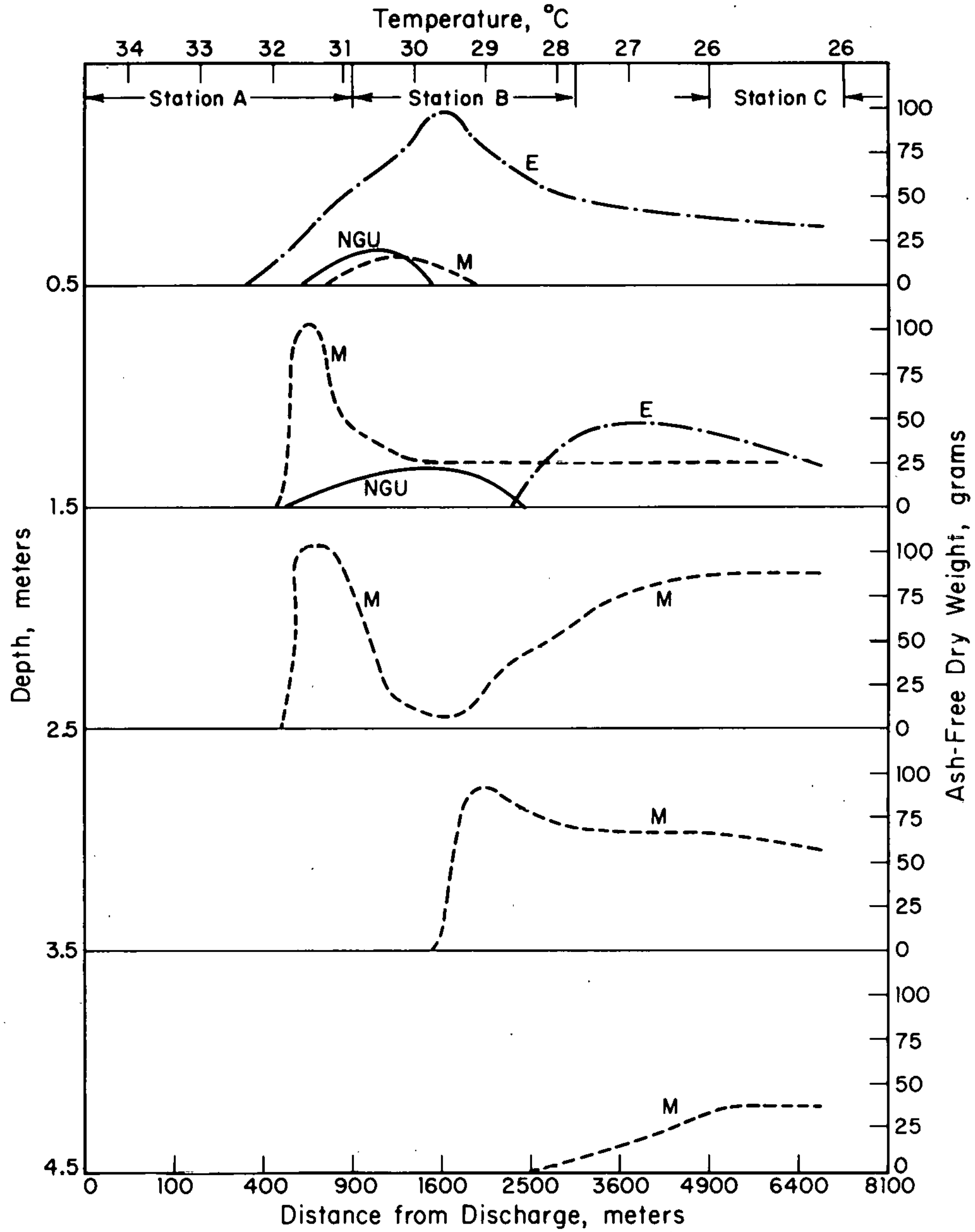
M = *Myriophyllum spicatum*
E = *Eleocharis acicularis*
NGU = *Najas guadalupensis*
NG = *Najas gracillima*
PP = *Potamogeton pusillus*
PD = *Potamogeton diversifolius*
CZ = *Chara zeylanica*



Temperature, °C
34
33
32
31
30
29
28
27
26
26
Station A
Station B
Station C
PP
CZ
NGU
M
E
PD
NG
Depth, meters
0.5
1.5
2.5
3.5
4.5
Ash-Free Dry Weight, grams
100
75
50
25
0
0
100
400
900
1600
2500
3600
4900
6400
8100
Distance from Discharge, meters

Figure 14. Generalized distributions of species-populations in October, 1975. Temperatures were taken from Figure 8. The stations are shown in Figure 1. Distance from the discharge is on a square-root scale. Curves have been eye-fitted to the data points as described in Appendix C and are only approximations. Notations are as follows:

M = *Myriophyllum spicatum*
E = *Eleocharis acicularis*
NGU = *Najas guadalupensis*


Temperature, °C
34
33
32
31
30
29
28
27
26
26
Station A
Station B
Station C
E
NGU
M
M
E
NGU
M
M
M
M
0.5
1.5
2.5
3.5
4.5
Depth, meters
100
75
50
25
0
Ash-Free Dry Weight, grams
0
100
400
900
1600
2500
3600
4900
6400
8100
Distance from Discharge, meters

Generalized distributions of species-populations for July, 1974 are shown in Figure 12. Five species occurred in the 0.5-1.0m depth zone. *Najas guadalupensis* occurred abundantly at the sampling location nearest the discharge. However, qualitative sampling indicated that *N. guadalupensis* did not grow at locations less than 50m from the discharge. *N. guadalupensis* did not grow at locations less than 50m from the discharge. *N. guadalupensis* occurred primarily where water temperatures were between 33° and 31°C, *Potamogeton diversifolius* at ca. 32°C, *Potamogeton pusillus* at 31°-31.5°C, *Myriophyllum* at 29.5°-31.5°C and *Eleocharis* below 32°C (Figure 12). It is perhaps noteworthy that all species except *Eleocharis* were restricted at the 0.5-1.0m depth zone to the heated arm of Par Pond (Figure 12). Four species occurred commonly at the 1-2m depth zone (Figure 12). *Najas guadalupensis* occurred in this zone where temperatures ranged between 30°-32°C, *Potamogeton pusillus* at ca. 31°C, *Myriophyllum* between 28° and 31°C, and *Eleocharis* below 28°C. Again, all species except *Eleocharis* were restricted at this depth to the heated arm of Par Pond. Only two species were found within the 2-3m depth zone. *Potamogeton pusillus* occurred at Station A about 625m from the discharge, while *Myriophyllum* occurred at distances greater than 625m from the discharge. Correlations of the biomass of *Myriophyllum* with temperature require a consideration of the height of the plants because there was a large change in temperature between 2m and 3m. These analyses are considered in Figures 28 and 29. At 3-4m *Myriophyllum* was the only species present and was found no closer to the discharge than 625m.

The generalized distributions of species populations for July, 1975 are shown in Figure 13. Six species occurred at 0.5m. *Potamogeton pusillus*, *Chara zeylanica* and *Najas guadalupensis* were principally found within Station A where temperatures were between 31-33.5°C. *Potamogeton diversifolius* occurred between 29.5°C and 31°C, and *Eleocharis* was found throughout the entire reservoir. At 1.5m, 7 species were found. *Chara zeylanica* occurred principally within Station A between 31-33°C and *Potamogeton diversifolius* occurred within Station B at 2.5-31.0°C. *Najas guadalupensis*, *Myriophyllum spicatum*, *Potamogeton pusillus* and *Najas gracillima* occurred between 26°C and 33.5°C at 1.5m. *Eleocharis* was restricted to Station C at 1.5m depths. At 2.5m rooting depths, 5 species were found. *Myriophyllum* occurred between 225m and 2500m and again at distances greater than 3600m from the discharge. *Chara zeylanica* occurred at distances between 25m and 225m, *Potamogeton pusillus* between 25m and 1225m, *Najas gracillima* between 625m and 3025m, and *Potamogeton diversifolius* between 900m and 2025m from the discharge. Below 2.5m, only *Myriophyllum* was found. At 3.5m *Myriophyllum* occurred at distances greater than 625m from the discharge, and at 4.5m only occurred at Station C, about 3000m from the discharge.

The generalized distributions of species-populations for October, 1975 are shown in Figure 14. At 0.5m, three species were found. *Najas guadalupensis* occurred in waters between 30° and 31.5°C, *Myriophyllum* between 29.5° and 31.5°C, and *Eleocharis* peaked at 30°C but was restricted to locations less than 32°C.

Three species were also present at 1.5m; *N. guadalupensis* between 29 and 32°C, *Eleocharis* at less than 29°C and *Myriophyllum* at less than 32°C with a peak in biomass at 31.5°C. Below 1.5m, *M. spicatum* was the only species present. At 2.5m, *Myriophyllum* occurred at distances greater than 400m from the discharge, with a noticeable decrease in biomass around 1600m. At 3.5m, *Myriophyllum* was only found at distances greater than 1600m and at 4.5m at distances greater than 2500m.

Correlations Between Light Penetration and Distribution of Species-Populations

Eleocharis acicularis

Calculated values of light penetration were compared with the maximum depths at which *Eleocharis* grew at each station (Table 14). The maximum depth at which *Eleocharis* occurred in July of 1974 increased from 0.75m at Station A to 2.00m at Station C. However, the light penetration at the maximum depth of occurrence resulted in three times the intensity at Station A as at Station C. The depths at which equal light intensity occurred were slightly less at Station A than at Station C, but did not correspond to the maximum depths of occurrence.

In 1975, the maximum depth of occurrence was 1.0m at Stations A and 2.0m at Station C. The percent of surface light at the maximum depth of occurrence was 2.5 times greater at Station A than at Station C. Again, differences in light intensity failed to correspond with the maximum depths of occurrence at the two stations.

TABLE 14. Relationship between light penetration and maximum depths of occurrence of *Eleocharis*.

	Station[c]		
1974	A	B	C
[a]maximum depth of occurrence, m	0.75	1.50	2.00
[b]% of surface light at max. depth	38.58	--	10.23
[b]depths of equal light intensity, m	1.80	--	2.00
1975			
[a]maximum depth of occurrence, m	1.00	1.50	2.00
[b]% of surface light at max. depth	26.18	--	10.86
[b]depths of equal light intensities, m	1.65	--	2.00

---

a. Determined *in situ*.

b. Calculated from Table 8 according to Wetzel (44) as described in Table 9.

c. Light penetration values are from Stations 1 and 4 shown in Figure 1, and represent Stations A and C shown in Figure 1.

Myriophyllum spicatum

Calculations of light penetration were compared to the maximum depths at which *Myriophyllum* grew at each station (Table 15). These correlations must be distinguished from those presented for *Eleocharis* in the previous section because, unlike *Eleocharis* which is seldom more than 15cm tall, *Myriophyllum* grows to heights of 4m in some locations. Therefore, the correlations in Table 15 only pertain to the newly-established shoots of *Myriophyllum*. In 1974, the maximum depth of occurrence was 3.0m at Station A and 5.0m at Station C. Differences in light penetration do not correspond well with differences in depths of occurrence since equal light intensities occurred at depths of 4.7m at Station A and 5.0m at Station C. In 1975, the lack of correspondence between light penetration and depth of occurrence was similar to 1974, except that depths of equal light intensities were 4.2m at Station A and 5.0m at Station C.

Species Diversity

Values of species diversity are shown in Table 16. Species richness was greater at all stations in July of 1975 than in July of 1974. A decline in species richness occurred at all stations in October as compared to July of 1975. Equitability was highest at Station A (as compared to Stations B and C) during July of 1974 and July of 1975, but was lowest at Station A in October, 1975. Heterogeneity values were similar to the equitability values at all times and at all stations.

TABLE 15. Relationship between light penetration and maximum depths of occurrence of *Myriophyllum*.

	Station[c]		
1974	A	B	C
[a]maximum depth of rooting, m	3.0	4.0	5.0
[b]% of surface light at max depth	4.42	--	0.73
[b]depths of equal light intensities, m	4.7	--	5.0
1975			
[a]maximum depth of rooting, m	3.0	4.0	5.0
[b]% of surface light at max depth	1.85	--	0.37
[b]depths of equal light intensities, m	4.2	--	5.0

---

[a] Determined *in situ*.

[b] Average light penetration values from March through May were used because the growing tips of *Myriophyllum* shoots would begin growth in March and be 1-2 meters long by June. The Secchi averages for March through May were:
1974-Station 1 = 2.875 and Station 4 = 3.092
1975-Station 1 = 2.260 and Station 4 = 2.667
Light penetration values were calculated according to Wetzel (44) as described in Table 9.

[c] Light penetration values are from Stations 1 and 4 shown in Figure 1, and represent Stations A and C shown in Figure 1.

TABLE 16. Species diversity at sampling stations.

Date	Station	Species Richness[c]	Equitability[d]	Heterogenity[e]	S[f]
7-74	A[a]	6	2.0185	1.8229	8
	B	6	.9038	.8162	8
	C	8	1.5709	1.4187	8
7-75	A[b]	9	1.9835	2.0656	11
	B	10	1.9370	2.0172	11
	C	11	1.4102	1.4686	11
10-75	A[b]	7	1.0047	.9073	8
	B	8	1.7817	1.6090	8
	C	6	1.1314	1.0218	8

---

a. Stations are shown in Figure 3.

b. Stations are shown in Figure 1.

c. Species richness is the total number of species found at a station (26).

d. Equitability is $J' = \frac{H'}{\log S}$, where H is the Shannon-Weaver function and S is the total number of species at all stations (26).

e. Heterogenity is $H' = -\Sigma p_i \log_2 p_i$, the Shannon-Weaver function when p_i = the decimal fraction of total individuals belonging to the i^{th} species (26).

f. S is the total number of species at all stations at a sampling time.

Comparisons of the Distributions of *Myriophyllum* Among Sampling Times

July, 1974 versus July, 1975

Distributions of *Myriophyllum* in July, 1974 and July, 1975 are shown in Figures 15 and 16. The only depths where conspicuous changes in distribution occurred were 0.5m, 1.5m and 2.5m. At 0.5m, *Myriophyllum* occurred mainly around 31°C in 1974 but was found at ca. 29°-32°C in July of 1975. At 1.5m depths, *Myriophyllum* occurred between 28° and 31°C in July of 1974, but was found between 30° and 32°C in July of 1975. At 2.5m depths, the distributions covered the same range, but in July of 1975 the biomass between 900m and 3000m from the discharge was greatly diminished as compared to July of 1974.

July versus October in 1975

Differences between the distributions of *Myriophyllum* in July and October of 1975 occurred at all depths (Figures 16 and 17). At 0.5m, *Myriophyllum* increased in biomass in October, but was further from the discharge. At 1.5m, biomass was greater and more widely distributed in October, and again was further from the discharge. Comparison of distributions at 2.5m shows little overall change in biomass but does reveal a diminution of biomass at 400m from the discharge in October. At the 3.5m depth, *Myriophyllum* occurred to within 800m from the discharge in July; but in October it occurred no closer than 1700m from the discharge. In October *Myriophyllum* increased in biomass at depths of 4.5m that were 225m-2500m from the discharge.

Figure 15. Distribution of *Myriophyllum spicatum* in July, 1974. Data are plotted vs the distance from the discharge on a square root scale. Stations are those shown in Figure 3. Temperatures are from Figure 8.

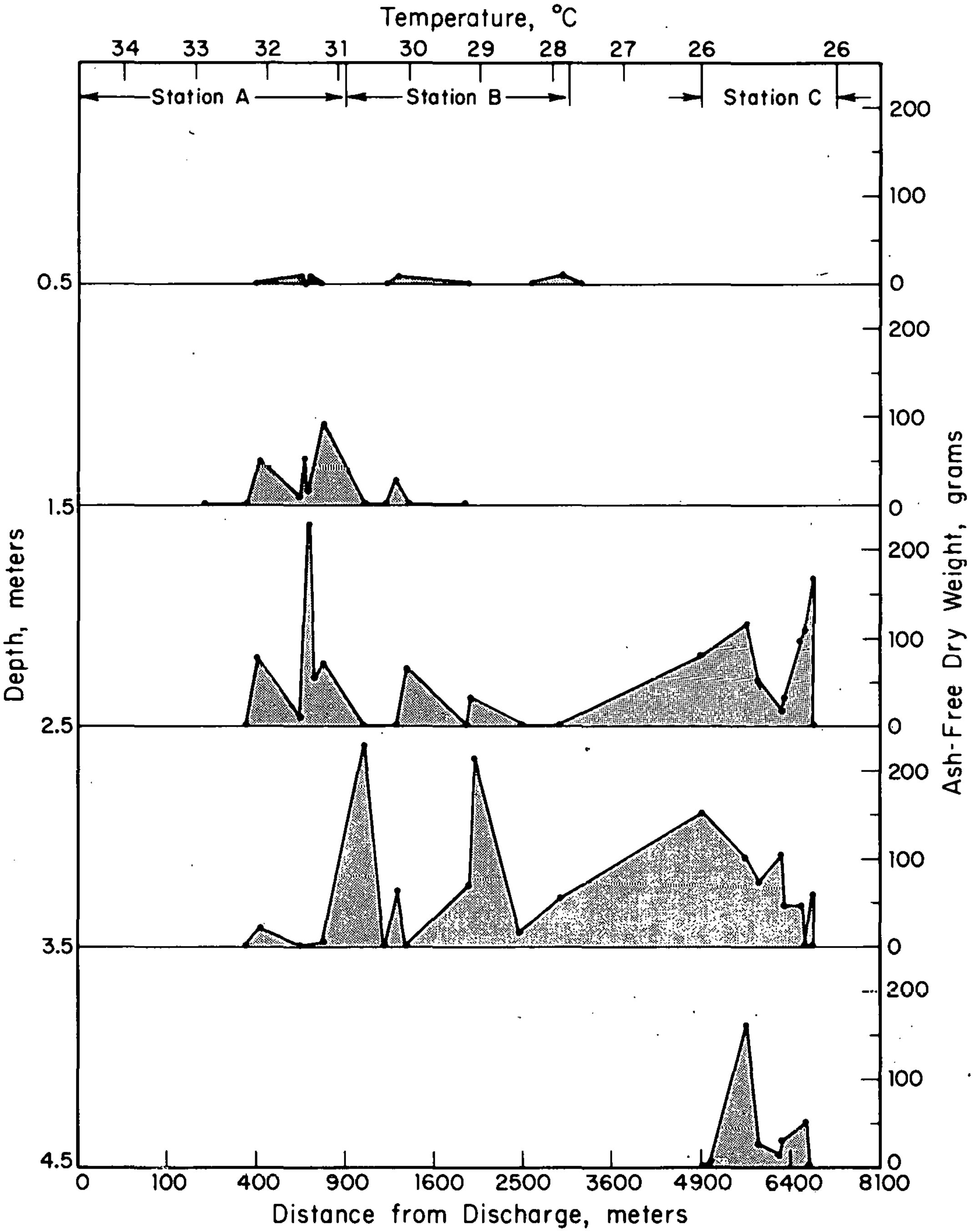

Temperature, °C
34
33
32
31
30
29
28
27
26
26
Station A
Station B
Station C
Depth, meters
0.5
1.5
2.5
3.5
4.5
Ash-Free Dry Weight, grams
200
100
0
Distance from Discharge, meters
0
100
400
900
1600
2500
3600
4900
6400
8100

Figure 16. Distribution of *Myriophyllum spicatum* in July, 1975. Data are plotted vs the distance from the discharge on a square root scale. Stations are those shown in Figure 1. Temperatures are from Figure 8.

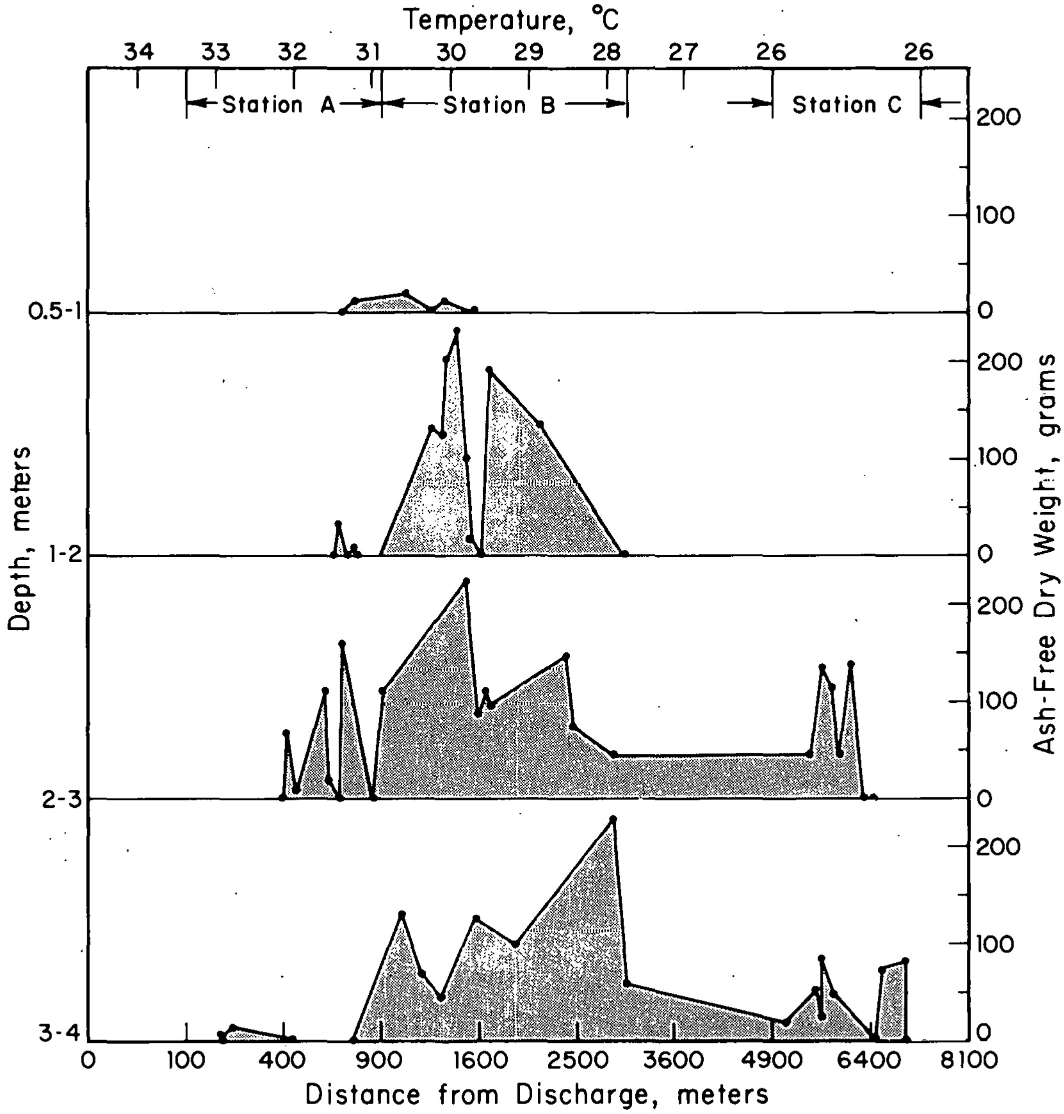
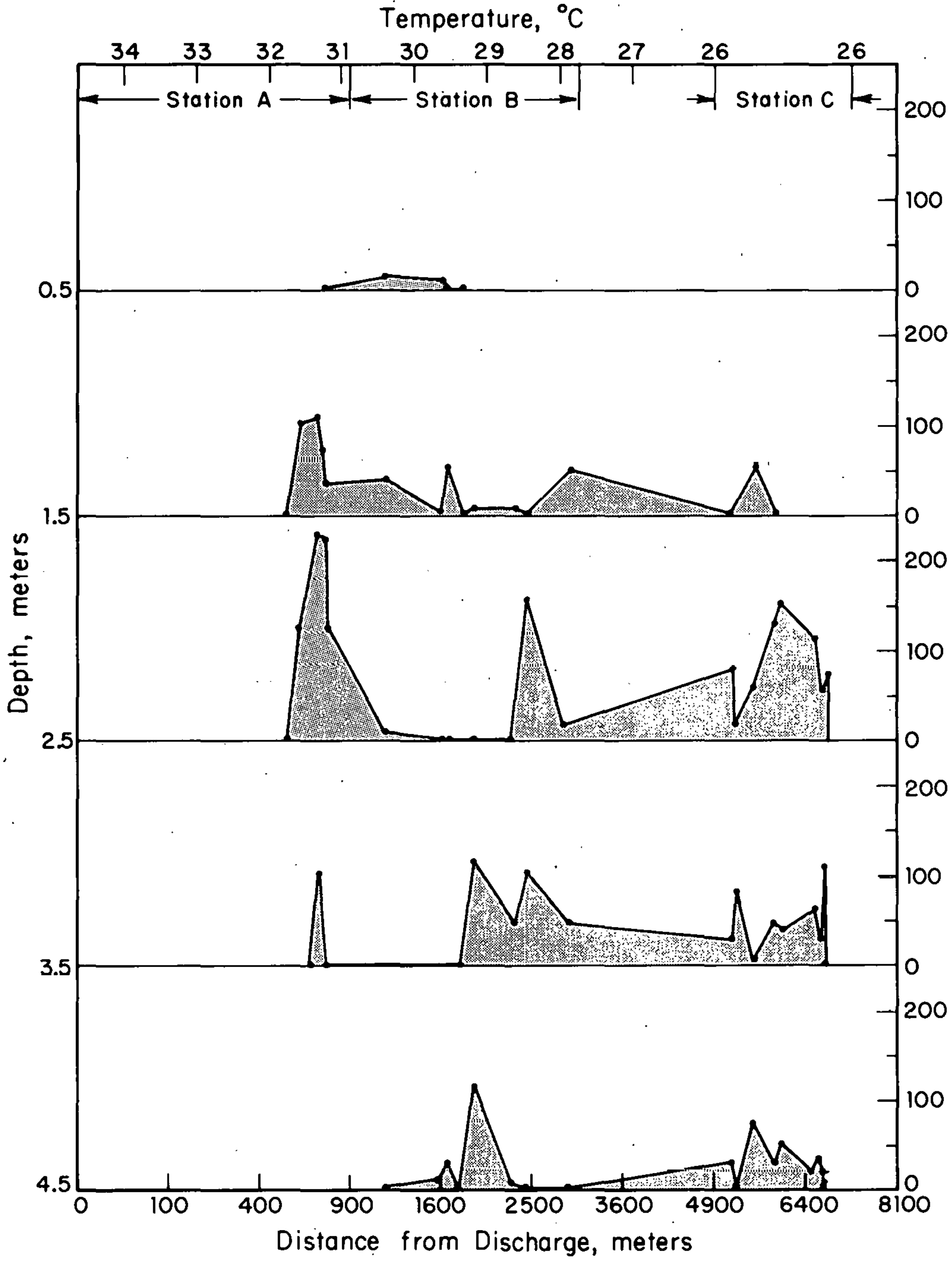

Temperature, °C
34
33
32
31
30
29
28
27
26
26
Station A
Station B
Station C
Depth, meters
0.5-1
1-2
2-3
3-4
Ash-Free Dry Weight, grams
200
100
0
0
100
200
Distance from Discharge, meters
0
100
400
900
1600
2500
3600
4900
6400
8100

Figure 17. Distribution of *Myriophyllum spicatum* in October, 1975. Data are plotted vs the distance from the discharge on a square root scale. Stations are those shown in Figure 1. Temperatures are from Figure 8.


Temperature, °C
34
33
32
31
30
29
28
27
26
26
Station A
Station B
Station C
200
100
0
0.5
1.5
2.5
3.5
4.5
Depth, meters
Ash-Free Dry Weight, grams
0
100
400
900
1600
2500
3600
4900
6400
8100
Distance from Discharge, meters

Comparisons of the Distributions of *Eleocharis* Among Sampling Times

Distributions of *Eleocharis* were similar in July, 1974 and July, 1975 (Figures 18 and 19). However, in July of 1974, biomass progressively increased at increasing distances from the discharge, while in July of 1975, Station B was the area of greatest biomass. In October of 1975, levels of biomass increased considerably at Station B when compared to July of 1975 (Figures 19 and 20). Otherwise, distributions were similar in July and October of 1975.

Combined Biomass of All Species

The combined biomass of all species in July of 1974 is shown in Figure 21. Observations confirmed that no vegetation grew at the discharge point. At 0.5-1.0m, biomass increased from zero at the discharge point to a maximum at 676m from the discharge. The maximum biomass at 1.0-2.0m water depths was at 650m from the discharge, while at 2.0-3.0m water depths the maximum occurred at 1406m from the discharge. In the deepest sampling zone (3.0-4.0m), the biomass maximum was located at 2800m from the discharge. At all depths, biomass increased from zero at the discharge to a maximum and then declined to some lower level at increasing distances from the discharge.

The combined biomass of all species for July of 1975 is shown in Figure 22. Observations again confirmed that no vegetation grew at the discharge point. Maximum biomass samples occurred at the following distances from the discharge: 756m at

Figure 18. Distribution of *Eleocharis acicularis* in July, 1974. Data are plotted vs the distance from the discharge on a square root scale. Stations are those shown in Figure 3. Temperatures are from Figure 8.

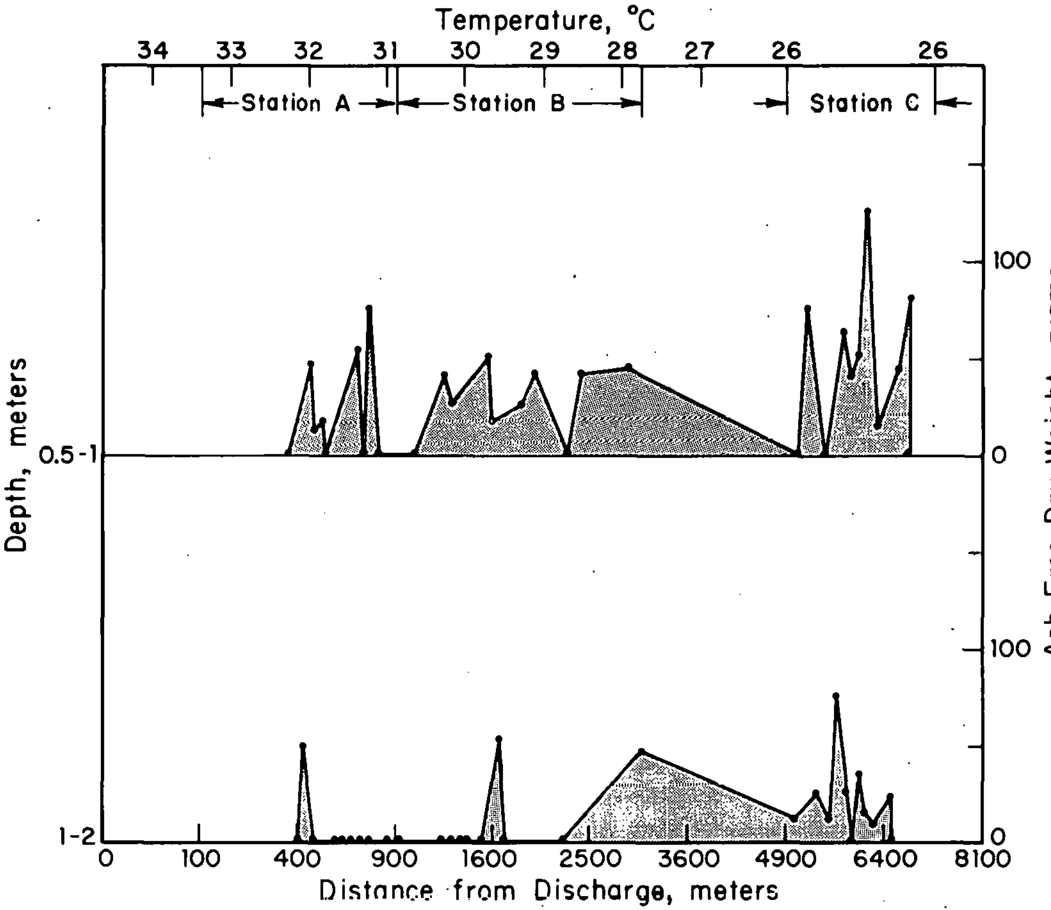

Temperature, °C
34
33
32
31
30
29
28
27
26
26
Station A
Station B
Station C
Depth, meters
0.5-1
1-2
Ash-Free Dry Weight, grams
100
0
100
0
0
100
400
900
1600
2500
3600
4900
6400
8100
Distance from Discharge, meters

Figure 19. Distribution of *Eleocharis acicularis* in July, 1975. Data are plotted vs the distance from the discharge on a square root scale. Stations are those shown in Figure 1. Temperatures are from Figure 8.

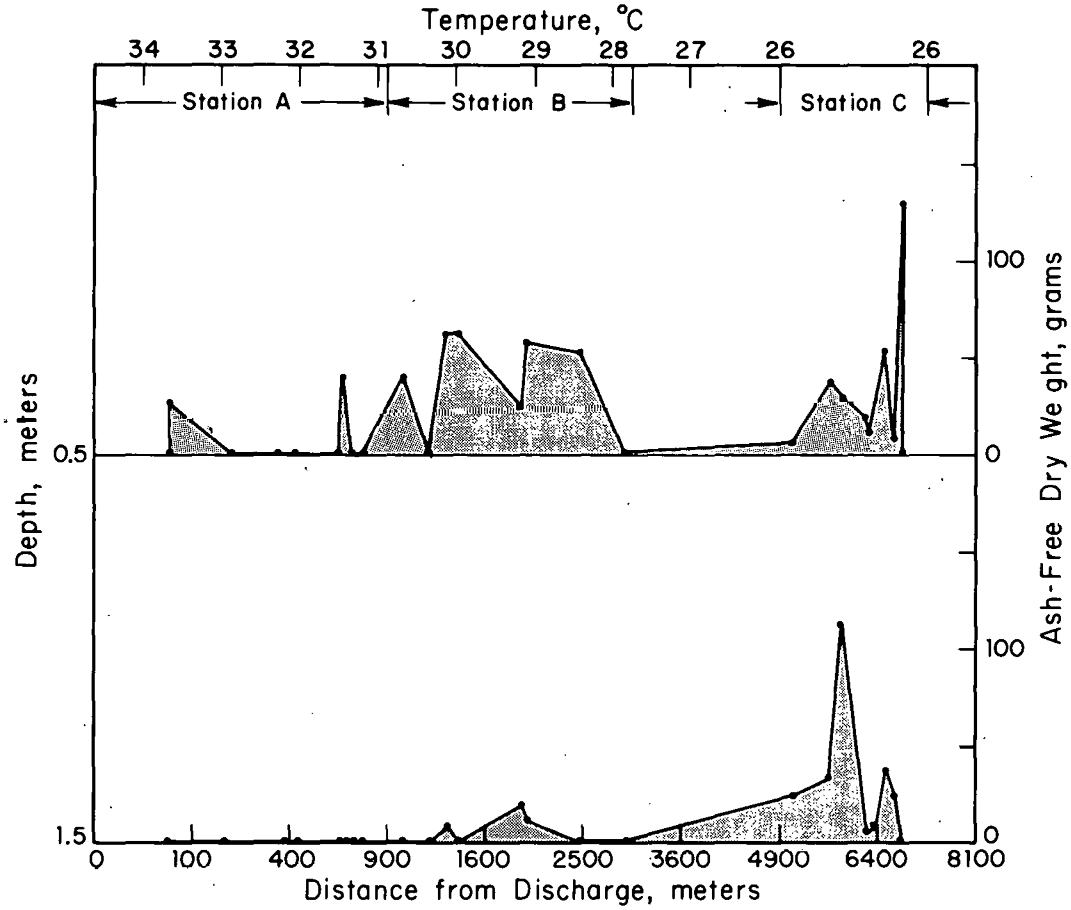

Temperature, °C
34
33
32
31
30
29
28
27
26
26
Station A
Station B
Station C
Depth, meters
0.5
1.5
Ash-Free Dry Weght, grams
100
0
100
0
0
100
400
900
1600
2500
3600
4900
6400
8100
Distance from Discharge, meters

Figure 20. Distribution of *Eleocharis acicularis* in October, 1975. Data are plotted vs the distance from the discharge on a square root scale. Stations are those shown in Figure 1. Temperatures are from Figure 8.

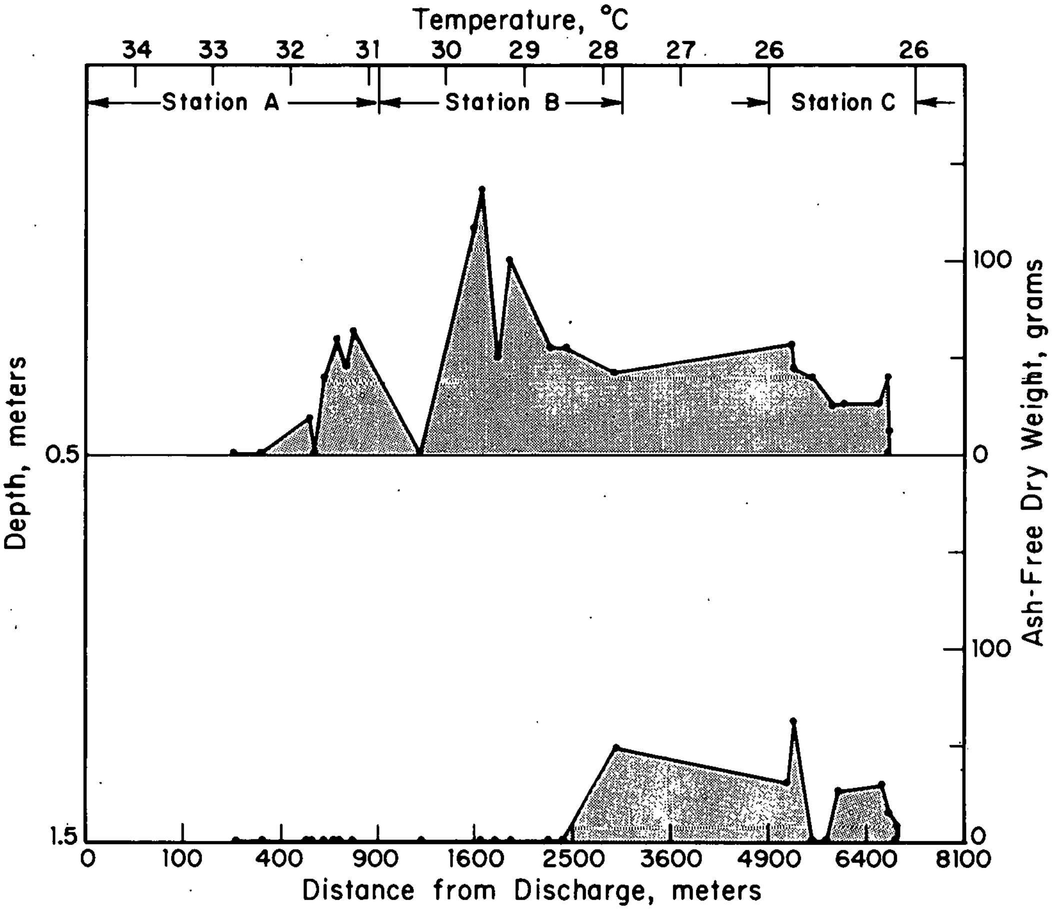

Temperature, °C
34
33
32
31
30
29
28
27
26
26
Station A
Station B
Station C
Depth, meters
0.5
1.5
Ash-Free Dry Weight, grams
100
0
100
0
0
100
400
900
1600
2500
3600
4900
6400
8100
Distance from Discharge, meters

Figure 21. Distribution of total macrophyte biomass in July, 1974. Values represent total biomass of all species collected in a single sample, and are plotted against the distance from the discharge on a square root scale. "Max" represents the position where the maximum biomass at a depth was collected. Stations are those shown in Figure 3. Temperatures are from Figure 8.

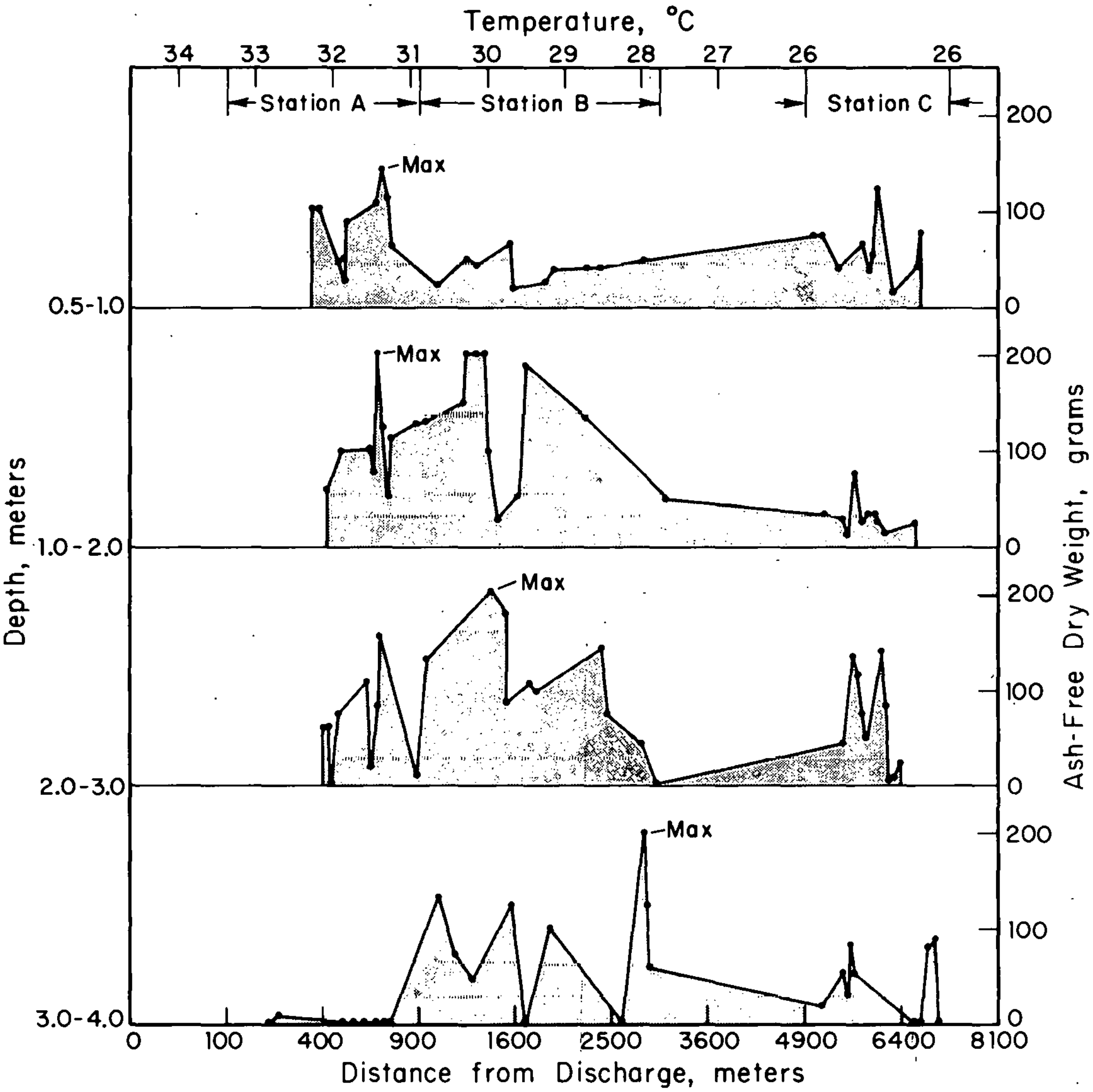
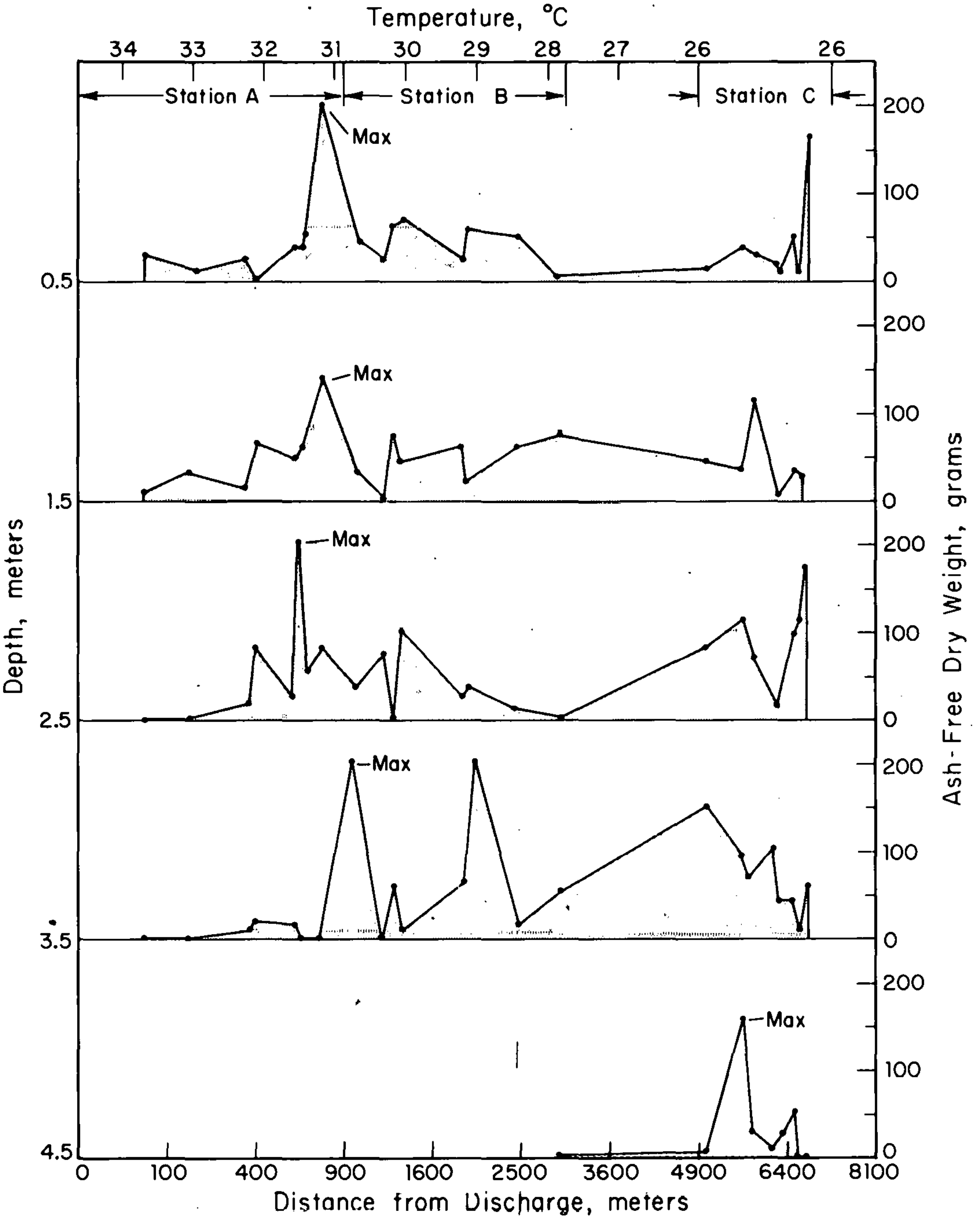

Temperature, °C
34
33
32
31
30
29
28
27
26
26
Station A
Station B
Station C
Max
Max
Max
Max
0.5-1.0
1.0-2.0
2.0-3.0
3.0-4.0
Depth, meters
200
100
0
Ash-Free Dry Weight, grams
0
100
400
900
1600
2500
3600
4900
6400
8100
Distance from Discharge, meters

Figure 22. Distribution of total macrophyte biomass in July, 1975. Values represent total biomass of all species collected in a single sample, and are plotted against the distance from the discharge on a square root scale. "Max" represents the position where the maximum biomass at a depth was collected. Stations are those shown in Figure 1. Temperatures are from Figure 8.


Temperature, °C
34
33
32
31
30
29
28
27
26
26
Station A
Station B
Station C
Max
Max
Max
Max
Max
0.5
1.5
2.5
3.5
4.5
Depth, meters
200
100
0
Ash-Free Dry Weight, grams
0
100
400
900
1600
2500
3600
4900
6400
8100
Distance from Discharge, meters

0.5m depths, 756m at 1.5m depths, 625m at 2.5m depths, 961m at 3.5m depths, and 5625m at 4.5m depths. Distributions in July of 1975 followed the general form described for July of 1974 (Figure 21) except at 2.5m and 3.5m depths where a striking absence of vegetation occurred ca. 2500m from the discharge.

The distributions of total biomass for October of 1975 (Figure 23) were similar in many ways to those of July. However, at 0.5m depths the maximum occurred at 1681m instead of at 756m and at 3.5m depths the maximum was at 1849m instead of at 961m. Therefore, the general distribution of biomass was further from the discharge in October than in July at all depths except 4.5m.

Vertical Distribution of the Biomass of *Myriophyllum*

Comparisons Among Stations

In July and October of 1975, *Myriophyllum* plants were collected, divided into 0.5m sections throughout their lengths and processed for ash-free dry weight. The data thus obtained for July are shown in Figure 24. Comparisons among stations were made at each sampling depth and arranged in a stairstep fashion to reveal the distribution of biomass in the water column. At locations 0.5m deep, *Myriophyllum* only occurred at Station A (Figure 24). At locations 1.5m deep, *Myriophyllum* was distributed closest to the surface at Station A and was completely absent at Station C. Also, the plants at 1.5m depths were 40cm taller at A than at B. Examination of plants found at locations 2.5m deep shows the sequence A > C > B for the distribution of

Figure 23. Distribution of total macrophyte biomass in October, 1975. Values represent total biomass of all species collected in a single sample, and are plotted against the distance from the discharge on a square root scale. "Max" represents the position where the maximum biomass at a depth was collected. Stations are those shown in Figure 1. The temperatures are from Figure 8.

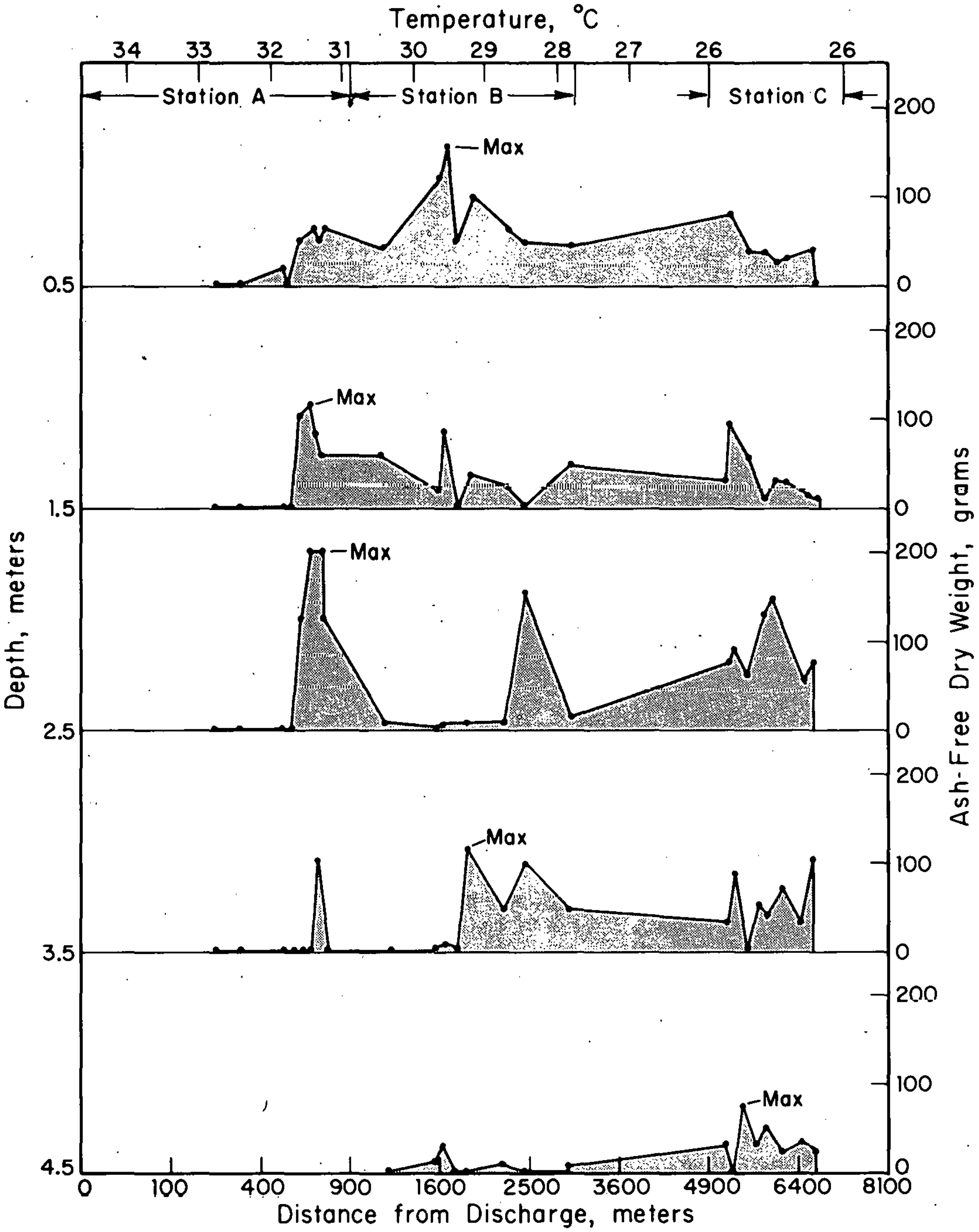
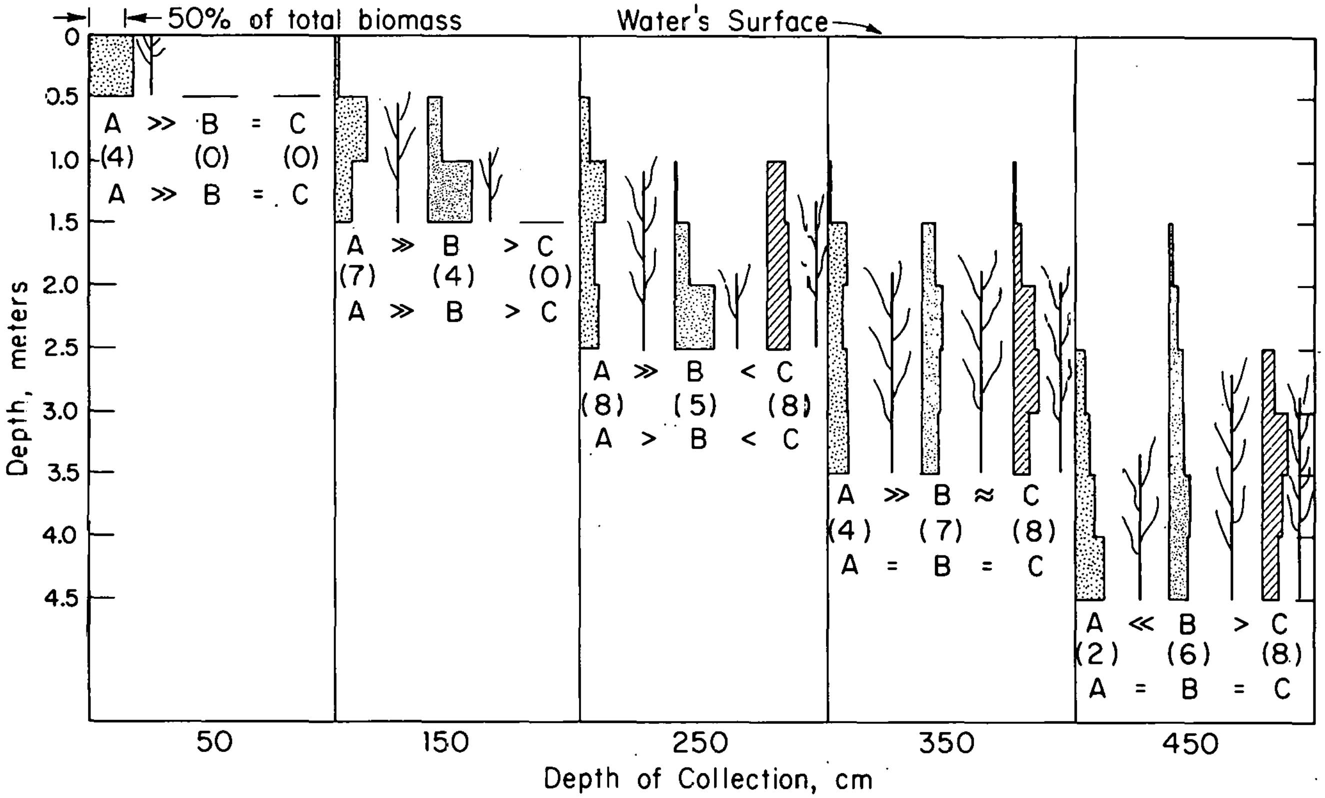

Temperature, °C
34
33
32
31
30
29
28
27
26
26
Station A
Station B
Station C
Max
Max
Max
Max
Max
Depth, meters
0.5
1.5
2.5
3.5
4.5
Ash-Free Dry Weight, grams
200
100
0
0
100
400
900
1600
2500
3600
4900
6400
8100
Distance from Discharge, meters

Figure 24. Vertical distribution of the biomass of *Myriophyllum* in July, 1975. Numbers in parentheses indicate the number of samples. The letters above the numbers in parentheses refer to comparisons among vertical distributions of biomass. The letters beneath the numbers refer to comparisons among heights of plants (A >> B < C means A is greater than both B and C, and C is greater than B). Data were determined by the collection of intact plants, the measurement of their total lengths and the division of shoots into 0.5 meter sections. Samples were processed for dry weight. Comparisons are made among the three sampling stations, A, B and C (Figure 1), at each depth of sampling. At each station there is a bar graph and a figure of a plant. The width of each bar represents the average percentage of the total plant weight (shoot + root material) of that length of the plant. The height of the plant figure represents the average height of plants sampled at that station. Comparisons among vertical distributions of biomass at different stations were made by *a priori* "F" Tests (33) within the upper two 0.5m divisions. To meet the assumptions of parametric tests, the percentages were transformed into arcsine values as described by Sokal and Rohlf (33). The average heights of plants were compared among stations by the Student-Newman-Keuls Test (33).


50% of total biomass
Water's Surface
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Depth, meters
A >> B = C
(4) (0) (0)
A >> B = C
A ≫ B > C
(7) (4) (0)
A ≫ B > C
A ≫ B < C
(8) (5) (8)
A > B < C
A ≫ B ≈ C
(4) (7) (8)
A = B = C
A ≪ B > C
(2) (6) (8)
A = B = C
50
150
250
350
450
Depth of Collection, cm

biomass (Figure 24). However, for the average height of plants at locations 2.5m deep, the sequence A = C > B was observed. At locations 3.5m deep, plants at the three stations did not differ significantly in average height, but the biomass was distributed closest to the water's surface at Station A. Plants collected at locations 4.5m deep did not differ significantly in average height but differed in the distribution of their biomass relative to the water's surface such that B > C > A (Figure 24).

The vertical distribution of biomass for October is shown in Figure 25. *Myriophyllum* occurred at both Station A and Station B at the locations 0.5m deep, but was absent at Station C. An examination of the values at locations 1.5m deep shows the sequence A > B > C for the distribution of biomass but the sequence A = B > C for the height of plants. At locations 2.5m deep, the biomass of *Myriophyllum* was again distributed closest to the water surface at Station A and was also tallest at Station A. A comparison of distributions of biomass at locations 3.5m deep shows A = B > C, but no difference in the average height of the plants. At locations 4.5m deep, *Myriophyllum* was shown to be distributed closest to the water's surface at Station A, but this must be viewed cautiously because only one plant was found.

Data from Figures 24 and 25 were combined across all sampling depths and displayed graphically in Figures 26 and 27. In July, biomass was closest to the water surface at Station A, intermediate at Station B and farthest from the water's surface at Station C. The amount of total biomass which was root material was between 12 and 15% at all stations.

Figure 25. Vertical distribution of the biomass of *Myriophyllum* in October, 1975. The figure is as described in Figure 24 except stations are those in Figure 1.

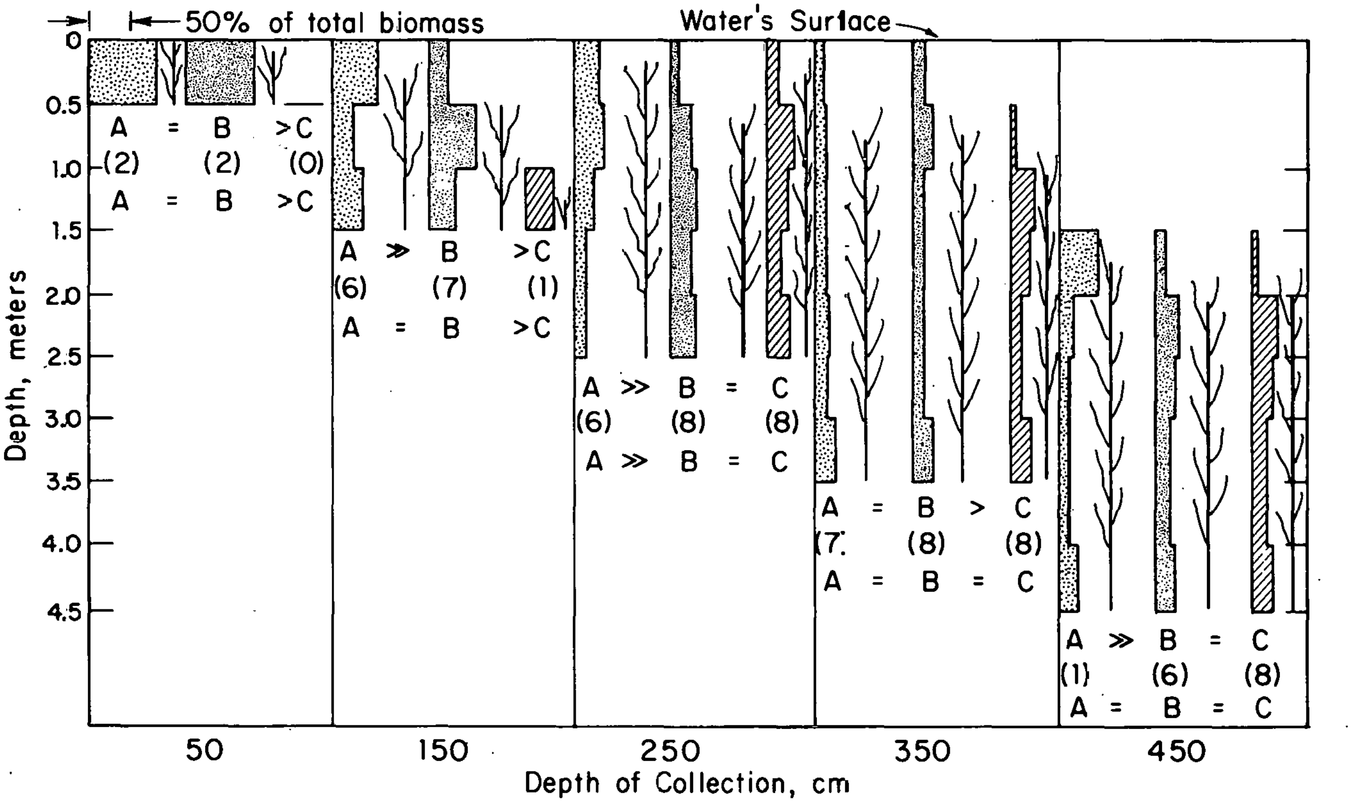
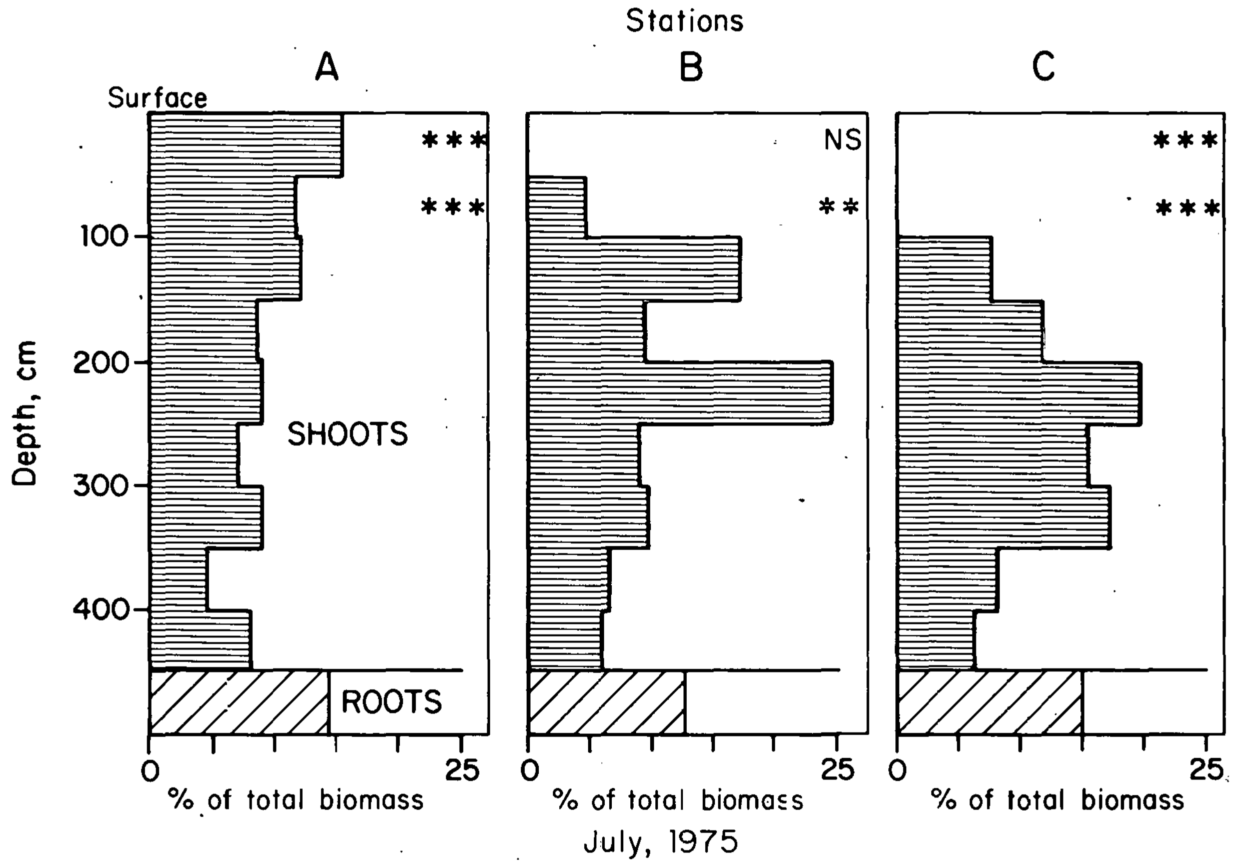
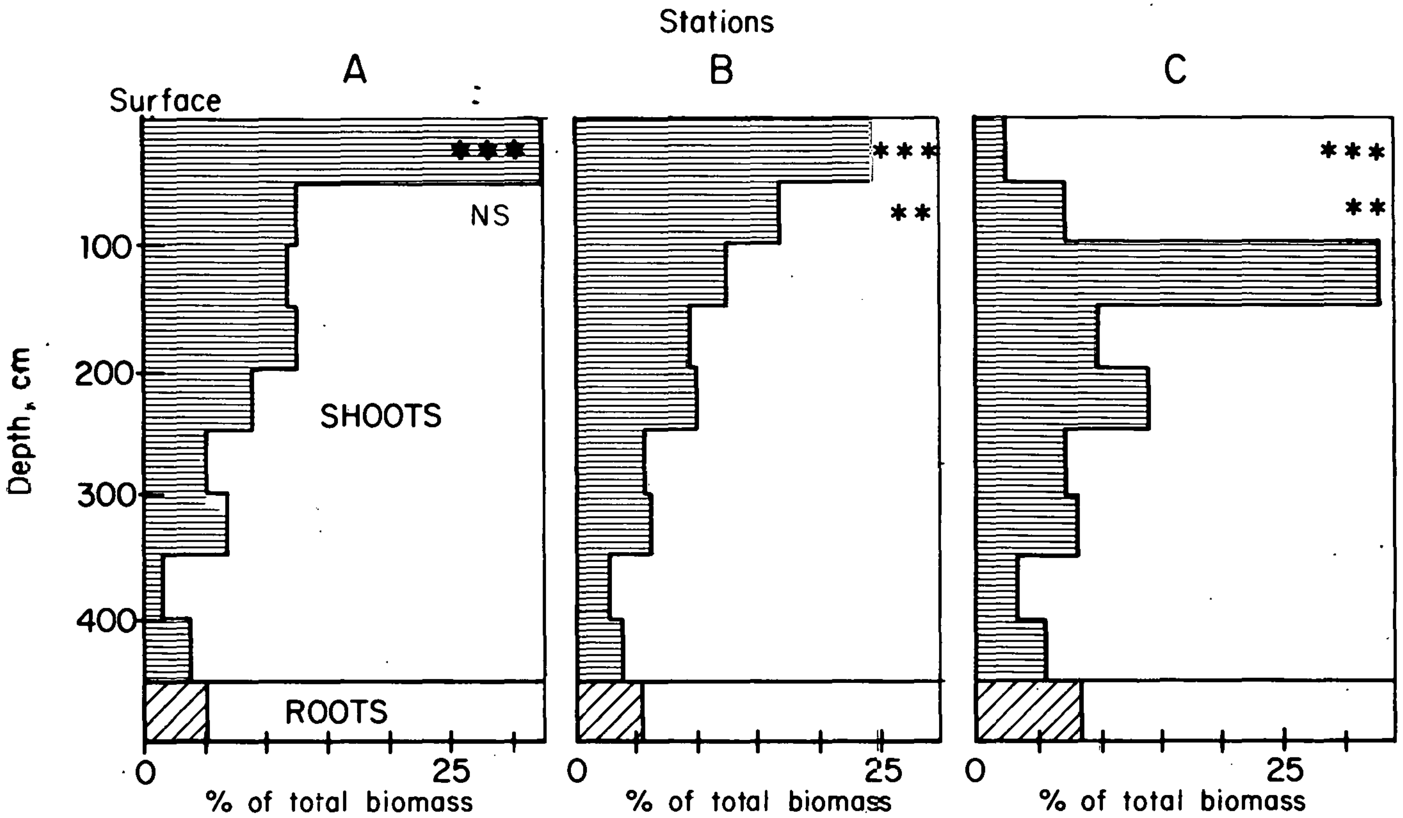

50% of total biomass
Water's Surface
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Depth, meters
A = B >C
(2) (2) (0)
A = B >C
A ≫ B >C
(6) (7) (1)
A = B >C
A ≫ B = C
(6) (8) (8)
A ≫ B = C
A = B > C
(7. (8) (8)
A = B = C
A ≫ B = C
(1) (6) (8)
A = B = C
50
150
250
350
450
Depth of Collection, cm

Figure 26. Vertical distribution of the biomass of *Myriophyllum* combined across all sampling depths in July, 1975. Data were determined by summing the percentages presented in Figure 24 across all sampling depths. Thus, this figure represents the percentages of *Myriophyllum's* biomass which occur beneath the surface of the water for the entire littoral zone at that station. Comparisons among vertical distributions of biomass between different stations were made by *a priori* "F" tests (33) within the upper two 0.5m divisions. To meet the assumptions of parametric tests, the percentages were transformed into arcsine values as described by Sokal and Rohlf (33). The notation used is: * indicates a significant difference between the two station averages on either side of the asterisk at the .05 level, ** indicates a significant difference at the .01 level, *** indicates a significant difference at the .001 level and NS indicates no significant difference at the .05 level. If notation is at the right of Station C, it represents a comparision between Stations A and C.



Stations
A
B
C
Surface
Depth, cm
100
200
300
400
***
***
NS
**
***
***
SHOOTS
ROOTS
0
25
% of total biomass
0
25
% of total biomass
0
25
% of total biomass
July, 1975

Figure 27. Vertical distribution of the biomass of *Myriophyllum* combined from all sampling depths in October, 1975. Data were determined by summing the percentages presented in Figure 25 across all sampling depths. Otherwise, this figure is the same as described for Figure 26.



October, 1975

In October, the biomass was distributed closer (visual impression only) to the water surface at all stations when compared to July (Figure 27). Again, the sequence was A > B > C, but the roots only comprised 5-8% of the biomass in October.

Correlations Between Light Penetration and Plant Heights

Estimates of light penetration were calculated from Secchi Disc measurements to correspond to the average heights of *Myriophyllum* (Table 17). Differences among average heights of *Myriophyllum* are shown in Figures 24 and 25. In July, the light intensities which occurred at the tips of *Myriophyllum* were equivalent at the locations 2.5m deep, although the tips at Station A were 20cm closer to the water's surface. At the locations 3.5m and 4.5m deep the tips at Station C were growing at a higher light intensity. In October, higher light intensities occurred at the tips of *Myriophyllum* at Station A for the locations 1.5m and 2.5m deep, but at lower light intensities for the locations 3.5m and 4.5m deep (Table 17).

Correlations Between Plant Heights and Temperature

The heights of *Myriophyllum* plants collected in July of 1975 were plotted against their distances from the discharge on a square root scale (Figure 28). Included in Figure 28 are estimates of temperature isopleths. At locations 0.5m deep, only three plants were found, all 50cm tall. These three plants occurred in water of approximately 32°-33°C (Figure 28). At locations 1.5m deep, plants were found in water of temperatures

TABLE 17. Light penetration at the average height of *Myriophyllum* shoots during 1975.

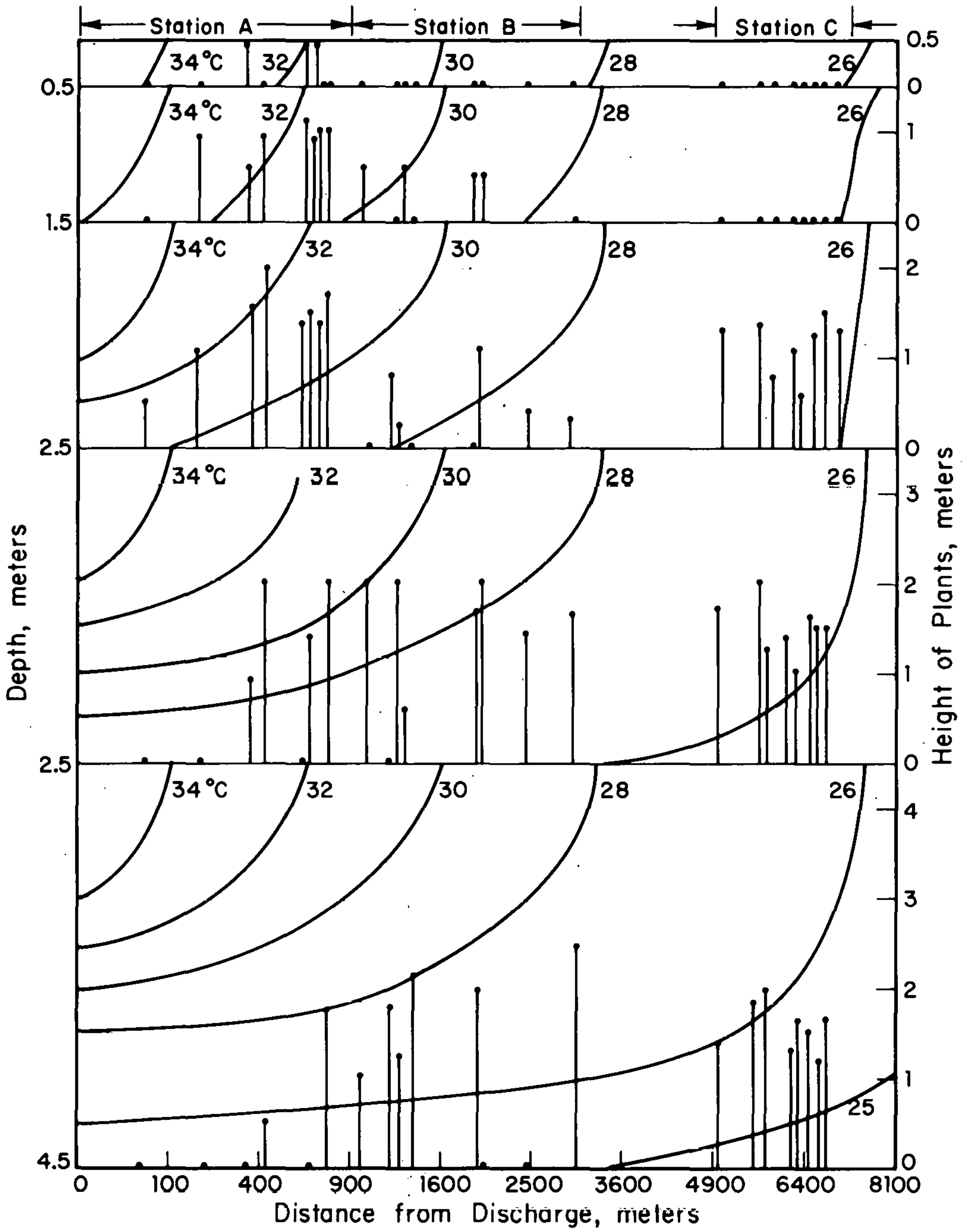
Date	Depth of Rooting, m	[a]Station	Average Height, m	[b]Light Penetration, %
July	0.5	A	0.50	100.00
		C	--	--
	1.5	A	0.95	47.85
		C	--	--
	2.5	A	1.39	22.60
		C	1.15	22.35
	3.5	A	1.61	7.95
		C	1.51	10.98
	4.5	A	1.12	1.08
		C	1.58	3.91
October	0.5	A	0.50	100.00
		C	--	--
	1.5	A	1.21	67.80
		C	0.20	23.62
	2.5	A	2.31	77.52
		C	2.19	60.89
	3.5	A	2.32	20.57
		C	2.45	31.18
	4.5	A	2.76	9.71
		C	2.42	9.94

---

a. Stations are those shown in Figure 1.

b. Light penetration values are from Stations 1 and 4 in Figure 1, and represent Stations A and C in Figure 1. Percent of surface light was calculated according to Wetzel (44) as described in Table 9.

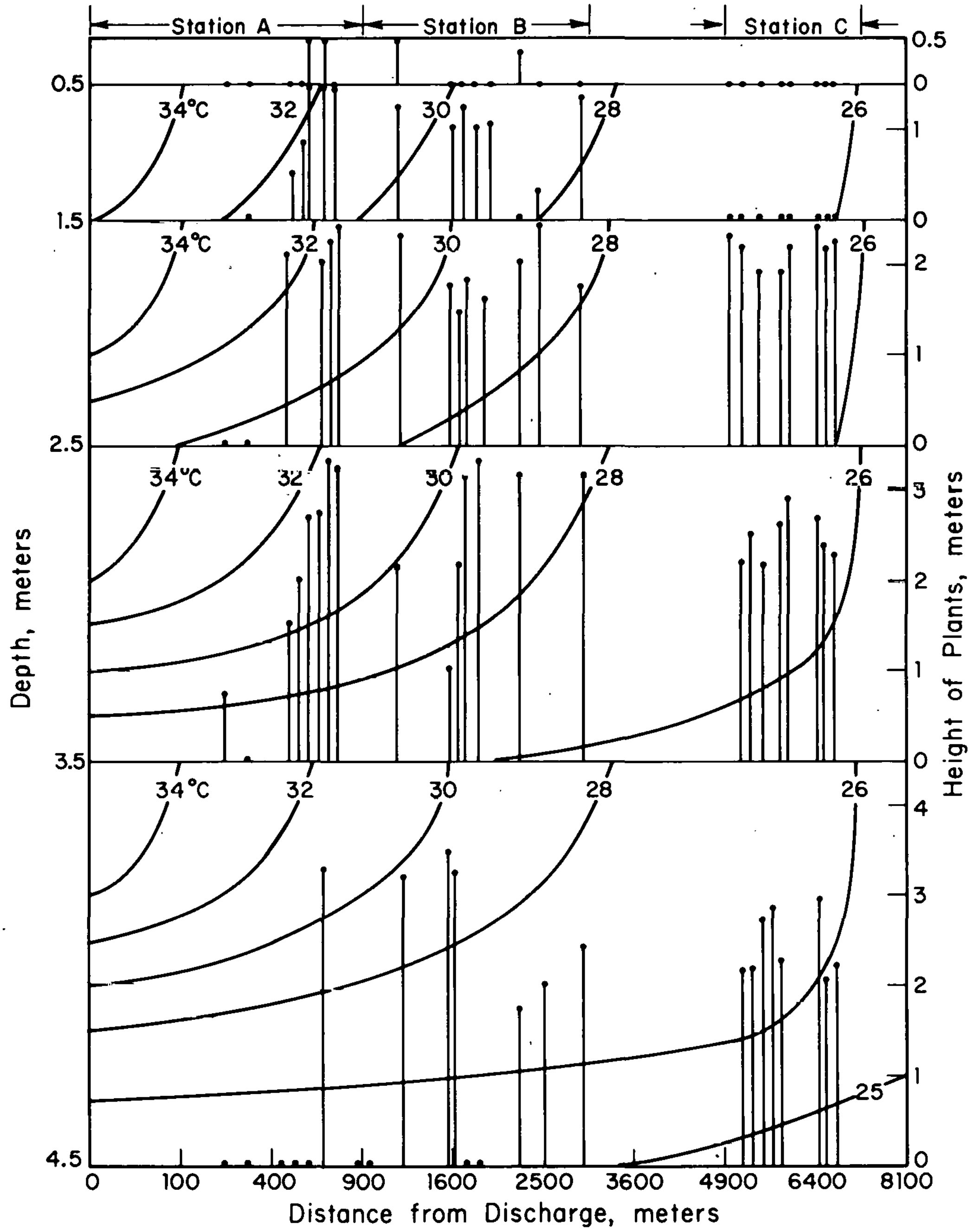
Figure 28. Shoot heights of *Myriophyllum* in July, 1975. Data were plotted against the distance from the discharge on a square root scale. The temperature isopleths were estimated from Figures 4 and 8, and from numerous profiles of temperature measured in the littoral zone (unpublished data of Tilly and Grace).


Station A
Station B
Station C
34°C
32
30
28
26
25
Depth, meters
0.5
1.5
2.5
2.5
4.5
Height of Plants, meters
0.5
0
1
2
3
4
Distance from Discharge, meters
0
100
400
900
1600
2500
3600
4900
6400
8100

between 29°C and 31°C with the tallest plants growing in areas averaging 31°-32°C. Examination of the locations 2.5m deep shows that plants occurred in all sampling locations. However, the tallest plants grew in water between 30°C and 32°C. The plants found between 27 and 30°C were noticeably short. At locations 3.5m deep, plants in the heated arm of Par Pond (Stations A or B) passed through a considerable range of temperatures. The tallest plants were found in water from 26°C to water 31°C, a range of 5C°. At the locations 4.5m deep, most of the plant material grew at ca. 26°C with the tips of plants at 600-1600m from the discharge in water 28-29°C.

The plants collected in October of 1975 are plotted by heights in Figure 29 in the same manner as in Figure 28. The plants collected in October were generally as much as 1.5m taller than those collected in July. Plants at locations 0.5m deep were found growing in water at 29°-32°C in October. At locations 1.5m deep, plants were found in water between 28 and 32°C with the tallest plants again growing at 32°C (as in July). Plants were found almost throughout the range of sampling locations 2.5m deep. The plants 600-1600m from the discharge where they had been short in July showed an increase of as much as 1.5m in length between July and October. At locations 3.5m deep, plants found between 600 and 3000m had grown as much as 1.3m during the three-month interval while plants at Station C had grown no more than 0.9m in the same time period (Figures 28 and 29). The growth at Station C occurred in water 26°C while the

Figure 29. Shoot heights of *Myriophyllum* in October, 1975. Data were plotted against the distance from the discharge on a square root scale. The temperature isopleths were estimated from Figures 4 and 8, and from numerous profiles of temperature measured in the littoral zone (unpublished data to Tilly and Grace).


Station A
Station B
Station C
0.5
1.5
2.5
3.5
4.5
Depth, meters
34°C
32
30
28
26
25
0.5
0
1
0
2
1
0
3
2
1
0
4
3
2
1
0
Height of Plants, meters
0
100
400
900
1600
2500
3600
4900
6400
8100
Distance from Discharge, meters

growth at 600-3000m from the discharge occurred in water 28°-32°C. At locations 4.5m deep, the plants found in water around 28°-29°C grew as much as 1.35m between July and October, while plants at Station C (growing in 26°C water) grew no more than 0.95m.

IV. DISCUSSION

Environmental Conditions in Par Pond

Water Temperatures

Water temperatures in Par Pond decreased with increasing distance from the discharge and with increasing depth beneath the water's surface (Tables 2, 3 and 4; Figures 4, 5 and 6). The increased temperatures which resulted from the heated effluent were primarily restricted to the upper 3m of the water column (Figure 4). In addition, the rate at which temperature declined at increasing depths was faster at heated than at unheated locations (Figure 4). The artificial heating of Par Pond caused water temperatures at heated areas to correlate poorly with air temperatures (Figure 7, Table 6).

The factors which influence the dissipation of heat from a hyperthermal effluent are numerous and complex (42). Therefore, an empirical approach was used to describe a function that relates water temperature to the distance from the discharge. As shown in Figure 8, a plot of the temperature of the upper 2m of the water column against the square root of the distance from the discharge is nearly linear between the discharge point and the distal end of the heated arm. The decrease in temperature in the vicinity of the unheated areas was asymptotic.

Levels of Nutrients and Other Features of the Environment

The nutrient contents of water are characterized by the levels of measurable ions, and by the rates at which these ions are replaced (14). Therefore, the levels of ions must be considered as incomplete information in the absence of an estimate of the replacement rates. In Par Pond, levels of nitrate ions were four times as great at the discharge as they were at unheated areas (Table 7). The decrease in nitrate levels at increasing distances from the discharge was not linear; concentrations were high throughout the heated arm compared to concentrations found in unheated areas (Table 7). Magnesium, sodium, calcium and potassium ions were all found to be higher at unheated areas than at the discharge point (Table 7). These cations were at comparatively high levels at all sampling stations except the area closest to the discharge point. Oxygen levels were also higher at the unheated than at the heated areas. This difference in oxygen levels can be completely explained by the different solubilities at different temperatures (Table 8). Additionally, light penetration (estimated from Secchi measurements) was lower at heated areas as might be expected from the greater turbidity there (Table 8).

The Distribution and Abundance of Macrophytes

Myriophyllum spicatum and *Eleocharis acicularis* consistently had the most biomass in Par Pond. For this reason, they have been singled out for detailed discussion.

Myriophyllum spicatum

The distribution and abundance of *Myriophyllum* is the result of various processes which comprise its life-cycle (25). These processes must be considered individually when evaluating the effects of the heated discharge. According to Patten (25), the processes in the life-cycle of *Myriophyllum* which are most important in determining its distribution and abundance are: dispersal and establishment of plant fragments, and vegetative growth. The importance of seed production in determining the distribution and abundance of *Myriophyllum* within a body of water is assumed to be slight because of a low rate of germination and the large numbers of plant fragments produced (25).

Fragmentation of stems may occur accidentally or by abscission (25). Plant fragments float for several days after abscission and may be dispersed considerable distances before they sink to the bottom. The establishment of plant fragments is dependent upon their survival and their ability to develop roots. Once established, the shoots grow in length up to the water's surface where they may form a dense canopy. Abscission of plant fragments may occur at any time during vegetative growth but seems to be positively correlated with both flowering and senescence (1, 25).

Dispersal and Establishment of Plant Fragments in Par Pond

Knowledge of the dispersal and establishment of plant fragments in Par Pond is largely the result of visual observations and inference from quantitative samples.

Myriophyllum spicatum was not found in Par Pond as recently as 1971 (Boyd, C. E.; personal communication), but occurred throughout the reservoir by 1973; presumably by the processes of fragmentation and dispersal. Also, underwater observations at both heated and unheated areas in March of 1976 revealed far greater densities of established fragments of *Myriophyllum* than could possibly survive to maturity. These evidences indicate that the fragmentation of stems was sufficiently great in Par Pond to account for the maintenance of the population from year to year. Thus, it may be assumed that fragments of *Myriophyllum* have been dispersed to all areas of Par Pond. However, numerous data presented in this thesis demonstrate clearly that *Myriophyllum* did not occur at all locations in Par Pond. Therefore, the establishment and survival of plant fragments was an important process which determined the distribution and occurrence of plants. Since seed production occurred at only a few places in the heated areas of Par Pond and since no seedlings were ever found, reproduction by seeds during 1974 and 1975 was probably not of much importance in maintaining the population.

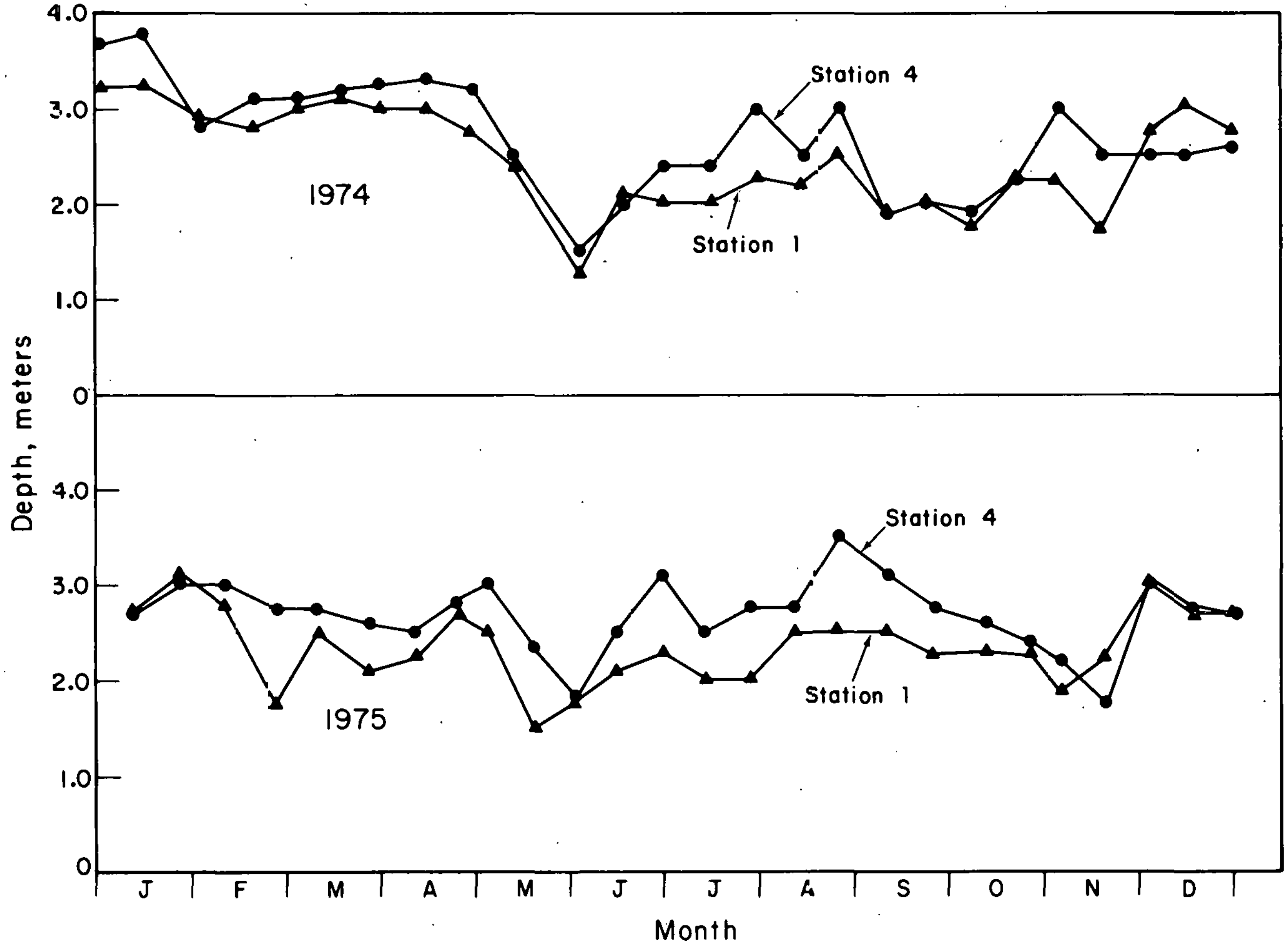
The maximum depths of occurrence

Myriophyllum occurred at depths of 5m at unheated areas of Par Pond (Table 15). However, at Station B the maximum depth of occurrence averaged 4.0m, and at Station A the maximum depth averaged 3.0m (Table 15). If we assume that plant fragments were dispersed at depths of 5m at all stations, then differences in environmental conditions must be responsible for the difference in maximum depths of occurrence. Table 15 shows that differences in light penetration between heated and unheated areas do not entirely explain the differences in depths of occurrence. Although the light penetration values only represent March-May, examination of the seasonal dynamics of Secchi measurements (Figure 30) reveals no time during the year at which light penetration values could account for the differences in depths of occurrence. The differences in light penetration could explain at most a 0.7m decrease in depth at Station A, leaving a difference of 1.3m unexplained (Table 15).

Another factor which could have been involved in the differences in depths of occurrence was temperature (Figures 28 and 29). If decreased light penetration alone caused a 0.7m reduction in the station average of the maximum depth of occurrence at Station A, this would limit the maximum depth to 4.3m. At a depth of 4.3m at Station A, water temperature was approximately 1°C warmer than at Station C at 5.0m (Figure 28). Also, at the observed average maximum depth of 3.0m at Station A, the water temperature was approximately 2°C warmer than at 5.0m at Station C (Figure 22).

Comparison between the amount of biomass and the heights of *Myriophyllum* plants which occurred at 4.5m (Figures 16 and 28) reveals that very few plants were found at Stations A and B, but those which did occur were quite tall (average - 1.6m). This suggests that the cause of the low density of plants was a failure of plant fragments to establish themselves rather than

Figure 30. Light penetration in 1974 and 1975 as calculated from Secchi Disc measurements. The stations are those in Figure 1. The data were obtained from L. J. Tilly, Savannah River Laboratory, Aiken, South Carolina.


Depth, meters
4.0
3.0
2.0
1.0
0
1974
Station 4
Station 1
4.0
3.0
2.0
1.0
0
1975
Station 4
Station 1
J
F
M
A
M
J
J
A
S
O
N
D
Month

an inability of established plants to grow well. If the small amount of biomass was the result of an inability of established plants to grow, numerous short plants would be expected.

These arguments do not negate the possibility that factors other than temperature and light differences might have contributed to the differences in the maximum depth of occurrence. However, they do suggest a possible explanation and thereby a testable hypothesis. This hypothesis is that the inability of plant fragments to establish themselves at depths greater than 3.0m at heated areas was the result of the combined effects of low light intensities and an increase of respiration rates at higher temperatures. This hypothesis is consistent with the studies of Stanley (34) which led him to predict that at higher temperatures the maximum depth of occurrence for *Myriophyllum spicatum* would be decreased because of greater respiratory demands and, therefore, a higher light intensity required for the compensation point.

Minimum depth of occurrence

Examination of Figures 12, 13 and 14 illustrate the differences among stations in the minimum depths at which *Myriophyllum* occurred. In addition, it was observed that the maximum depth of occurrence of *Eleocharis acicularis* was the same as the minimum depth at which *Myriophyllum* occurred. Therefore, Table 14 is also valid as a representation of the correlation between light penetration and the minimum depth at which *Myriophyllum* occurred. However, there is no reason to suspect that either light or temperature limited the establishment of *Myriophyllum* in shallower waters, because in shallow areas (< 2.0m) where *Eleocharis* was not present, *Myriophyllum* was occasionally found (observation of the author). *Eleocharis acicularis* can be a very effective competitor against other species of macrophytes (23), and, therefore, it is reasonable to suspect that the dense mats formed by *Eleocharis* prevented the establishment of *Myriophyllum* in shallow waters.

Restriction of *Myriophyllum* at Station A

Myriophyllum was never found to occur closer than 50m from the discharge point (Figures 28 and 29), and abundant growth was restricted to locations greater than 400m from the discharge and, therefore, temperatures less than 32°C (Figures 15-17, 28). However, a few scattered plants of *Myriophyllum* did occur closer than 400m from the discharge (Figure 28). Comparison between the amount of biomass (Figures 16 and 17) and the height of individual plants (Figures 28 and 29) indicates that, although the density of *Myriophyllum* plants greatly declined at distances closer than 400m, plants which did occur were relatively tall. The density of relatively tall plants was sparce enough to rule out the possibility that higher temperatures at locations closer to the discharge might have caused increased intraspecific competition for light and thereby lower density of plants. However, the presence of a few tall plants suggests a decreased level of fragment establishment.

Of possible significance to understanding the present distribution of *Myriophyllum* in Par Pond are observations of the general distribution of macrophytes before *Myriophyllum* was first seen there. An unpublished 1967 survey of submerged macrophytes showed *Potamogeton perfoliatus* L. to be the dominant macrophyte at most unheated areas now dominated by *Myriophyllum* (Tilly, unpublished data). However, in the hot areas, except for a slight incursion of *Myriophyllum*, the community composition appears largely unchanged; *Najas guadalupensis* dominates now as it did then.

Phenological development of *Myriophyllum*

Comparison between Figures 28 and 29 and examination of Figures 15 and 17 show that *Myriophyllum* occurred closer to the discharge in July than in October of 1975. This is consistent with field observations which indicated that there was a progressive die-off of *Myriophyllum* starting at the heated areas and progressing to the unheated areas during October and November of 1975. The water temperatures during November 1975 were approximately 20°C to 30°C; adequate for rapid growth of *Myriophyllum* (35). Therefore, this difference in the time at which senescence and death of shoot material occurred suggests a shortening of the life cycle of *Myriophyllum* by 2-4 weeks in heated areas.

The advancement of phenological development by elevated temperatures has been commonly observed for aquatic plants (29) as well as for terrestrial plants (17). Allen (2) found phenological advancement of *Elodea canadensis* L., in artificially-warmed areas of Lake Wabamum, Canada, but failed to observe any advancement of *Myriophyllum exalbescens* Fern. He attributed this advancement of *Elodea* entirely to overwintering and the earlier commencement of growth.

Little is known of how temperature influences the development of aquatic angiosperms (29). However, it has been observed for terrestrial plants that although growth rates are higher at elevated temperatures, the duration of the growing season is shorter and it is not necessarily true that the plants growing at the warmer temperatures will be larger (17). *Myriophyllum* plants in Par Pond were observed to have high rates (ca. 2mgC/g plant/hr) of carbon assimilation in early May of 1976 (Tilly and Grace, unpublished results). However, at this time, underwater observations indicated that the plants were of the same height and density at both heated and unheated areas. This indicates that although Myriophyllum may have started growing slightly earlier at heated areas, the difference was not great enough to be detected by height measurements. Therefore, the hypothesis is put forth that *Myriophyllum* had a faster rate of development (i.e. flowered and senesced quicker) at heated areas than at unheated areas.

Vegetative Growth of *Myriophyllum*

Biomass

If it is assumed that the loss of plant material by death and abscission of plant fragments is as great at heated areas as at unheated areas, differences in biomass represent differences in population growth (43). Considerable differences in levels of biomass occurred among stations at all time periods (Figures 10-12). However, some of the trends which were observed in July of 1974 did not recur in 1975. In July of 1974, biomass at all depths roughly approximated a unimodel distribution with the maximum biomass occurring at Station B, an intermediate amount of biomass at Station A, and the least amount of biomass at Station C (Figures 9 and 21). In 1975, the same general trend in biomass occurred as in 1974 except that there was a major reduction in biomass at 2.5 and 3.5m depths at Station B (Figures 10 and 12). Nonetheless, considering all depths less than 4m, the greatest amount of biomass occurred at heated areas at all times. However, the distributions of biomass in 1975 were roughly bimodal curves at locations 2.5m and 3.5m deep, with the largest peaks between 625 and 1600m from the discharge, and the secondary peaks at unheated areas (Figures 22 and 23). These bimodal peaks in 1975 indicate that growth was not directly correlated with distance from the discharge but that factors other than the direct influence of the heated effluent must have been acting on the growth of *Myriophyllum*. Since this reduction in biomass in 1975 occurred at the locations where biomass was greatest in 1974, and since there was no significant difference in parameters monitored during 1974 and 1975, it seems reasonable to hypothesize that some other condition, perhaps of the sediments, had been altered. Despite the bimodality of distributions in 1975, the greatest amount of biomass occurred in heated areas during both years and suggests that conditions in these heated areas favored greater growths of *Myriophyllum*.

Numerous features of the environment are capable of influencing the growth of *Myriophyllum*. However, no attempt has been made to isolate the variables. Rather, correlations have been sought between environmental conditions and the growth of *Myriophyllum* in an attempt to establish plausible hypotheses.

Temperature and light intensity may be important in regulating the growth of *Myriophyllum*. The results of Stanley and Naylor (35), and of Titus (personal communication) indicate that *Myriophyllum spicatum* has a temperature optimum for photosynthesis above 35°C at saturating light intensities. However, observations by Stanley (personal communication) indicate severe inhibition of growth at 35°C and at saturating light intensities which could possibly have been attributed to leakage of photosynthate from cells as a result of the loss of membrane integrity.

C. Young (49) found that *Myriophyllum spicatum* was twice as abundant at locations of 25°C as at locations of 15°C in an artificially-heated reservoir. However, in Par Pond, *Myriophyllum* was almost completely absent from locations less than 400m from the discharge (average temperatures of upper two meters of water > 32°C). Within 100m of the discharge extremely large amounts of periphyton occurred (observations of the author) which would have been capable of shading out higher plants.

However, *Najas guadalupensis* and *Potamogeton pusillus* were abundant between 100m and 400m where *Myriophyllum* was scarce.

Net photosynthesis of *Myriophyllum* in Par Pond was typically light saturated in only the upper 1m of the water column (unpublished studies of carbon assimilation by Tilly and Grace). Therefore, at 2.5m and 3.5m depths where few competitors occurred, the failure of *Myriophyllum* to grow at temperatures above 32°C could have been the result of a lower temperature optimum for net production at lower light intensities. However, the restriction of *Myriophyllum* from areas warmer than 32°C which were less than 2m deep may have been partly the result of competition. Field observations in late September of 1974 revealed that much of the *Najas guadalupensis* at Station A had completed its annual cycle and been replaced somewhat by *Myriophyllum*.

Phosphates and nitrates are considered by Hutchinson (15) to be the two factors most likely to limit to the growth and development of aquatic macrophytes. However, it is difficult to evaluate the importance of these substances in the water column because of the ability of macrophytes to take phosphorus, nitrogen and other ions from the sediment as well as from the water (6, 8, 21). Wilson (46) has reported the ability of *Myriophyllum exalbescens* to absorb and store quantities of phosphorus far in excess of its immediate growth needs and concluded that the lowering of phosphate concentrations in natural waters would not control the growth of *M. exalbescens*. Bristow and Whitcombe (6) used radioactive tracers to ascertain that approximately two-thirds of the phosphorus in the shoots of *Myriophyllum spicatum* is derived from the sediments. This finding is supported by Mulligan and Baronowski (20) who found greatly reduced growth in *Myriophyllum spicatum* when natural sediments were replaced by pure sand, thereby indicating a need for roots other than anchorage. Also, Mulligan and Baronowski (20) described optimal nutrient levels of .072 mg/l total-N and .020 mg/l PO_4-P for *Myriophyllum spicatum* in culture experiments. Nichols and Keeney (21) observed that *Myriophyllum spicatum* was able to maintain healthy growth utilizing nitrogen entirely from the sediments.

Levels of nitrates in Par Pond surface waters were very low, averaging .018 mg/l near the discharge and .009 mg/l at remote locations. The only sediment values available for the littoral zone indicate total nitrogen to be 100 mg/l, nitrates and nitrites = 10 mg/l, ammonia = 25 mg/l and extractable phosphorus = .02 mg/l during June of 1975 (12). These values suggest that there may be sufficient nitrogen available for growth of *Myriophyllum* but that phosphorus levels could be limiting because neither sediments nor water column contain more than .02 mg/l. In view of the general lack of data for nutrient turnover times in Par, both nutrient limitation studies and tissue analyses are needed to determine if phosphorus or nitrogen is limiting the growth of *Myriophyllum*.

Sediment features other than nitrogen and phosphorus levels are also capable of influencing the distribution and abundance of macrophytes (15). However, studies by Geisy and Tessier (12) on *Myriophyllum spicatum* in Par Pond, as well as observations by the author, indicate that *Myriophyllum* can root and grow on any sediment type in Par Pond except bare clay.

Levels of calcium, magnesium, sodium and potassium ions were observed to vary with distance from the discharge in Par Pond (Table 7). But, levels of these cations were higher at unheated areas and were therefore negatively correlated with growth rates. Unfortunately, there is insufficient information at present to suggest a generalized response of macrophytes to these cations (15).

Levels of dissolved oxygen were typically high in the water column at depths above the thermocline (6-8m). Measurements of dissolved oxygen at different depths above 4m never revealed levels below 4 mg/l in the water which interfaced the sediments (Tilly and Grace, unpublished data). But, the higher temperatures at Station A caused lower levels of O_2 (Table 8). It is conceivable that lower concentrations of oxygen at the heated areas could have caused reduced levels of photorespiration in the plants at Stations A and B (13) and thereby increased net production. However, studies by Stanley (34) indicated that photorespiration could not be detected in *Myriophyllum* in conditions of high temperature, high light intensity and high oxygen levels.

Heights of plants

Another method of determining the growth of *Myriophyllum* is by measuring the heights of plants. In 1975 plants were found to grow taller at Station A than at Station B although the difference in height was not statistically significant (Figures 24, 25, 28 and 29). At locations 3.5m and 4.5m deep the plants were actually at lower light intensities at Station A than at Station C (Table 17). Comparison between the heights of plants in July and October of 1975 showed that at locations 3.5m and 4.5m deep, the plants in heated areas grew as much as 1.35m in length, while plants in unheated areas grew no more than 0.95m (Figures 28 and 29). This greater growth in length in heated areas occurred in water 4-6C° warmer than that in the unheated areas (Figures 28 and 29). Yet, other environmental factors such as phosphates and nitrates could have influenced these growth rates as described previously.

In addition to the height of plants, the vertical distribution of biomass was determined (Figures 24 and 25). Although the plants were not significantly different in height among stations, the plants at Station A had significantly more of their biomass distributed closer to the water's surface than did the plants at Station C (Figures 24 and 25). Titus (personal communication) has observed that *Myriophyllum spicatum* sloughs its lower leaves as it grows in height and self-shades its lower parts. He suggests that this is an adjustment which reduces the amount of respiratory tissues that are unable to photosynthesize at high enough rates to maintain themselves. This process described by Titus was observed for *Myriophyllum* in Par Pond to a greater extent at Station A than at Station C and is part of the cause of the difference seen in Figures 24 and 25. Within this context, it is reasonable to hypothesize that the greater sloughing of lower leaves at the heated station was the result of both lower light intensities and higher temperatures which caused an increased ratio of respiration to photosynthesis.

Eleocharis acicularis

Eleocharis acicularis is an evergreen perennial which grows to heights of 20cm (9). *E. acicularis* forms dense mats in the shallow areas of the littoral zones and spreads primarily by rhizomes (37). Colonization of new areas is assumed to occur primarily by transported seeds (37), though some colonization may occur when uprooted plants float to areas where they can become established. As *Eleocharis* has been commonly found in Par Pond since 1967 (Tilly, unpublished data), it has had opportunity to colonize all areas. Nevertheless, numerous data presented here demonstrate that *Eleocharis* did not occur at all locations in Par Pond.

Distribution of *Eleocharis*

Although *Eleocharis* occurred at all distances from the discharge in Par Pond (Figures 18-20), differences existed among stations in the maximum depth at which *Eleocharis* occurred (Table 14). Like *Myriophyllum*, the maximum depth of occurrence for *Eleocharis* decreased at decreasing distances from the discharge. At Station A the maximum depth of occurrence averaged 0.75m in 1974 and 1.0m in 1975 (Table 14). At Station C the maximum depth averaged 2.0m for both years. The light intensity at the maximum depth at which *Eleocharis* occurred at Station A was 2-3 times as great as compared to Station C (Table 14). In addition, the temperature was 5°C warmer at 1m at Station A than at 2m at Station C (Figures 18-20). Unfortunately, little information exists concerning factors which influence the distribution of *Eleocharis*. *E. acicularis* has been commonly reported as a shallow-water species (36, 47). Studies by Wilson (47) and Swindale and Curtis (36) have suggested that sediment particle size and organic matter content are factors influencing *E. acicularis'* ability to root and grow. Observations in Par Pond by the author suggest two factors which possibly affect the maximum depth of occurrence for *Eleocharis*. *Eleocharis* seems to be unable to root in soft, silting sediments. Attempts to demonstrate a difference in the organic content of sediments at different depths among different stations have been unsuccessful (Johnson and Tilly, unpublished data). Another factor which could cause *Eleocharis* to be restricted to shallower depths at heated areas is higher levels of epiphytic periphyton. Tilly (unpublished) has documented a positive correlation between temperature and the standing crops of periphyton in Par Pond. The culms of *Eleocharis* have been observed to accumulate larger amounts of periphyton near the discharge than at unheated locations. These higher loads of epiphytes are probably capable of effectively competing for light with *Eleocharis* and could considerably reduce light intensities available to the photosynthetic surfaces of the supporting plants.

Growth of *Eleocharis*

There have been no studies to date which deal with the factors that influence the growth rate of *Eleocharis acicularis*, but if it is assumed that the turnover of biomass is the same at all locations in Par Pond, differences in rates of growth are equivalent to differences in biomass. Figure 18 shows that, in July of 1974, the abundance of *Eleocharis* at 0.5m depths declined steadily at decreasing distances from the discharge. Yet, in 1975 the greatest abundance of biomass was Station A. Comparisons among the distributions of species populations (Figures 10-12) show that several species were primarily restricted to the parts of Station A where *Eleocharis* was at a minimum. *Myriophyllum spicatum*, *Potamogeton pusillus*, *Potamogeton diversifolius*, *Najas guadalupensis* and *Najas gracillima* occurred in heated areas less than 2m deep and probably contributed to the reduction of *Eleocharis* at Station A. However, it was not determined whether the occurrence of these species was due to favorable environmental conditions or to inhibition of *Eleocharis*.

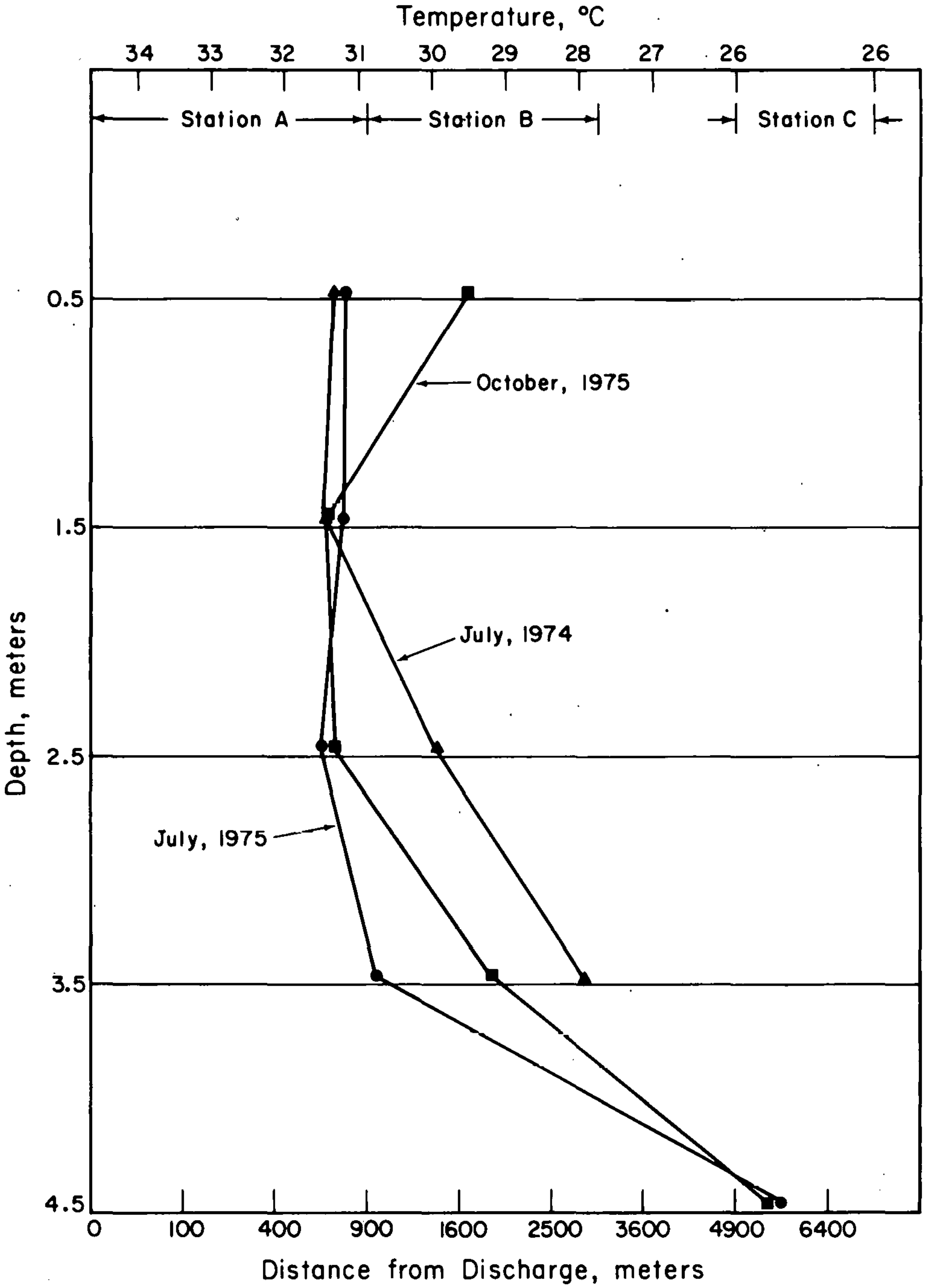
Responses at the Community Level of Organization

The species which make up a community not only respond to their physical environment but also interact and influence each other to a considerable degree. These interactions can either be indirect by alterations in the environment or direct by influence and competition. As a result of these interactions, certain general patterns may emerge (45). Observations made at the community level of organization can rarely, if ever, be dissected into all the causal components which create a response. Rather, these observations can only gain generality by comparison with the community properties of other systems. Therefore, no attempt has been made to explain the community responses observed in this work, but rather, they are simply presented as observations.

Three trends in total biomass accumulation occurred. First: the distribution of biomass with respect to the distance from the discharge tends to describe a unimodal curve (except at 2.5m and 3.5m depths in 1975) (Figures 21-23). Second: the locations where maximum accumulations of biomass occurred were at greater distances from the discharge at greater depths (Figure 31). Third: closer to the discharge a greater percentage of the biomass occurred in shallower water (Tables 10-12, Figures 26 and 27).

Differences in species diversity also occurred among stations (Table 16, Figures 12-14). Species richness was similar among all stations but the equitability of species was higher at heated than at unheated areas. This higher equitability of species (and thereby lower predictability) was also reflected by the differences in abundance of species among sampling times (Table 13). Far more significant difference in the abundances and distributions of species were found at heated than at unheated areas. Therefore, the heated areas were less predictable in a temporal as well as a spatial sense.

Figure 31. Locations of maximum biomass in 1974 and 1975. These points represent the distances from the discharge where the maximum accumulations of biomass occurred within each sampling depth (Figures 21-23).


Temperature, °C
34
33
32
31
30
29
28
27
26
26
Station A
Station B
Station C
October, 1975
July, 1974
July, 1975
Depth, meters
0.5
1.5
2.5
3.5
4.5
0
100
400
900
1600
2500
3600
4900
6400
Distance from Discharge, meters

V. SUMMARY AND CONCLUSIONS

The following statements summarize the salient features of the macrophyte community in Par Pond.

1. The presence of species did not vary greatly among heated and unheated areas; however, the relative composition of the macrophyte community did differ among areas. *Myriophyllum spicatum* and *Eleocharis acicularis* comprised 92% of the total biomass in unheated areas but only 64% of the total biomass at areas elevated 5C° or more. Several species including *Najas guadalupensis* and *Potamogeton pusillus* had greater biomass at heated than unheated areas.
2. The occurrence of *Myriophyllum spicatum*, the species of greatest biomass, differed among stations. At unheated areas, *M. spicatum* was abundant at depths of rooting between 2m and 5m. At heated areas it principally occurred between 0.5m and 3m. However, at areas less than 400m from the discharge (approximately 6°C warmer than unheated areas), *M. spicatum* failed to grow.
3. The locations less than 4m deep where *Myriophyllum spicatum* was most abundant were 1-5C° warmer than unheated areas of equal depth. However, the amount of biomass of *M. spicatum* did not always change linearly with distance from the

discharge and, therefore, factors other than the direct influence of temperature must have been involved.

4. The shoot tissues of *Myriophyllum* were distributed closer to the water's surface at heated than at unheated areas. This was partly the result of *Myriophyllum's* colonization of shallower depths in heated areas, but was also in part the result of a greater sloughing of lower leaves at heated areas.
5. The maximum depth at which *Eleocharis acicularis* occurred averaged 2m at unheated areas but only 1m at heated areas. Also, the biomass of *E. acicularis* was significantly less abundant at 0.5m depths in heated areas (more than 5C° warmer) than at equal depths in unheated areas.
6. The locations less than 4m deep where maximum biomass of all species occurred were 1-6C° warmer than unheated areas. However, scarcely any biomass occurred at locations closer than 50m from the effluent entry point.

The statements presented above suggest numerous hypotheses about how the heated discharge affects the distribution and abundance of macrophytes in Par Pond. However, without experimental testing, temperature effects cannot be separated from other possible influences. Therefore, certain features of the macrophyte community appear to be altered by the addition of the heated effluent, but the role of elevated temperatures *per se* awaits further study.

Appendix A

General Survey of Macrophytes in Par Pond

A survey of the aquatic macrophyte flora was conducted as a first step toward the establishment of criteria which would facilitate the study of effluent effects on submerged macrophytes. Observations, most of which involved skin diving, were made at 88 locations along the shore. At each location, observations were made while snorkeling along a transect perpendicular to the shore. Record was made of species abundance and distribution, as well as lake morphometry. In addition, samples were collected and placed in labeled plastic bottles for more detailed examination in the laboratory. The results of this survey include a partial floristic list (Table A-1) and several generalizations about the distribution of macrophytes in Par Pond.

1. Emergent, floating-leaved and submerged categories of growth form are usually stable throughout all seasons because the water level fluctuates less than one meter per year.
2. Macrophytes are stratified with respect to the depths at which they occur. *Eleocharis acicularis* is very common between the depths of 0.5-2m, whereas *Myriophyllum spicatum* occurs principally between 2-5m.
3. The relative abundance and stratification of plants by the depths at which they occurred were consistent

TABLE A-1. Macrophytes of Par Pond.[a,b]

EMERGENT[c]	OCCURRENCE[d]	SUBMERGED	OCCURRENCE
Eleocharis equisetoides (Ell.) Torrey	2	*Bacopa caroliniana* (Walt.) Robinson	2
Eleocharis quadrangulata (Michx) R.&S.	2	*Chara zeylanica* Kl. ex Willd.	1
Juncus effusus L.	-	*Elatine* L. sp.	1
Ludwigia leptocarpa (Nuttall) Hara.	-	*Eleocharis acicularis* (L.) R.&S.	3
Pontederia cordata L.	1	*Myriophyllum heterophyllum* Michx.	1
Sagittaria latifolia Willd.	-	††*Myriophyllum spicatum* L.	3
Scirpus L. spp.	2	†*Najas gracillima* (A.Br.) Morong.	1
Sparganium americanum Nuttall	2	†*Najas guadalupensis* (Spreng.) Morong.	3
Typha L. spp.	3	*Nitolla acuminata* A.Br. ex Wallm.	2
FLOATING-LEAVED		†*Potamogeton diversifolius* Raf.	2
Brasenia schreberi Gmel.	2	†*Potamogeton nodosus* Poiret	2
Hydrocotyle umbellata L.	2	†*Potamogeton pusillus* L.	3
Nelumbo lutea (Willd.) Pers.	3	†*Sagittaria graminea* Michx.	1
Nuphar advena Aiton	1	†*Sagittaria teres* Wats.	1
Nymphaea odorata Aiton	2	*Vallisneria americana* Michx.	1
Nymphoides aquatica (Walt.) Ktze.	1	FREE-FLOATING: SUBMERGED	
		Ceratophyllum demersum L.	1
		Utricularia inflata Walt.	2

---

[a] Nomenclature follows Fassett (9), Radford, et al. (27), and Wood (48).

[b] Growth form classification modified from Sculthorpe (29).

[c] The list of emergents is incomplete because they fall outside the objectives of this project.

[d] Occurrence values include four subjective categories: - insufficient information; one infrequent; two common; and three frequent, based on the number of locations at which a species was found.

† Identified by Dr. Eugene C. Ogden, State Univ. of New York, Albany, New York.

†† Identified by Dr. T. F. Hall, Plant Studies Section, TVA, Muscle Shoals, Alabama.

throughout the exposed unheated areas for the common species.

4. Protected areas differed considerably from exposed areas by supporting large populations of floating-leaved species.
5. *Myriophyllum spicatum*, which was abundant throughout the unheated portions of the reservoir, was more abundant in heated areas but absent from areas near the discharge point.

Appendix B

Comparison of Quadrat-Removal Sampling and Cylinder Sampling

The sampling cylinder was compared with the more laborious but more accurate process of hand removal from quadrats in a dense stand of *Myriophyllum spicatum*. Comparison was performed in a stand of *Myriophyllum* because, due to its growth habit, this species would be the most likely of all common species present to be biased by the sampling technique. Ten samples were collected at random by both methods and the plant material was processed for dry weight as described in METHODS. Results of this comparison as shown in Table B-1 demonstrate a reduction of *Myriophyllum* shoots collected by the cylinder as compared to the quadrat. This reduction resulted from an "avoidance" effect demonstrated by shoots for the cylinder. As the cylinder was lowered through the stand of *Myriophyllum*, the lower portions of the plant were deflected to the sides causing a loss of approximately 15% of biomass when compared to removal from quadrats by hand. No attempt was made to correct for sample bias since it may have varied between plants of different sizes and different species. However, since bias causes an underestimate of biomass, differences between areas are conservative estimates.

TABLE B-1. Comparison of quadrat-removal sampling and cylinder sampling.

	Dry Weight Per Square Meter					
	Myriophyllum Shoots		*Myriophyllum* Roots		All Species	
	Quadrat	Cylinder	Quadrat	Cylinder	Quadrat	Cylinder
	31.2	22.4	5.5	0.0	71.3	53.0
	41.5	18.3	6.4	9.8	91.7	60.7
	32.0	13.9	10.3	5.8	74.4	67.0
	43.7	33.3	4.8	22.7	80.2	71.4
	44.1	26.5	11.6	3.5	94.3	50.3
	11.6	26.4	2.5	11.0	41.9	84.2
	35.4	19.6	15.2	8.4	58.0	35.8
	18.5	24.9	6.2	16.8	40.3	67.0
	40.2	28.8	8.4	0.0	80.9	47.7
	52.2	40.1	16.2	6.2	87.1	69.2
Mean	35.0 *	25.4	3.7 NS	8.4	72.0 NS	60.6

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* Adjacent means differ at the 0.05 level of significance by the "t" test for paired comparisons (33).

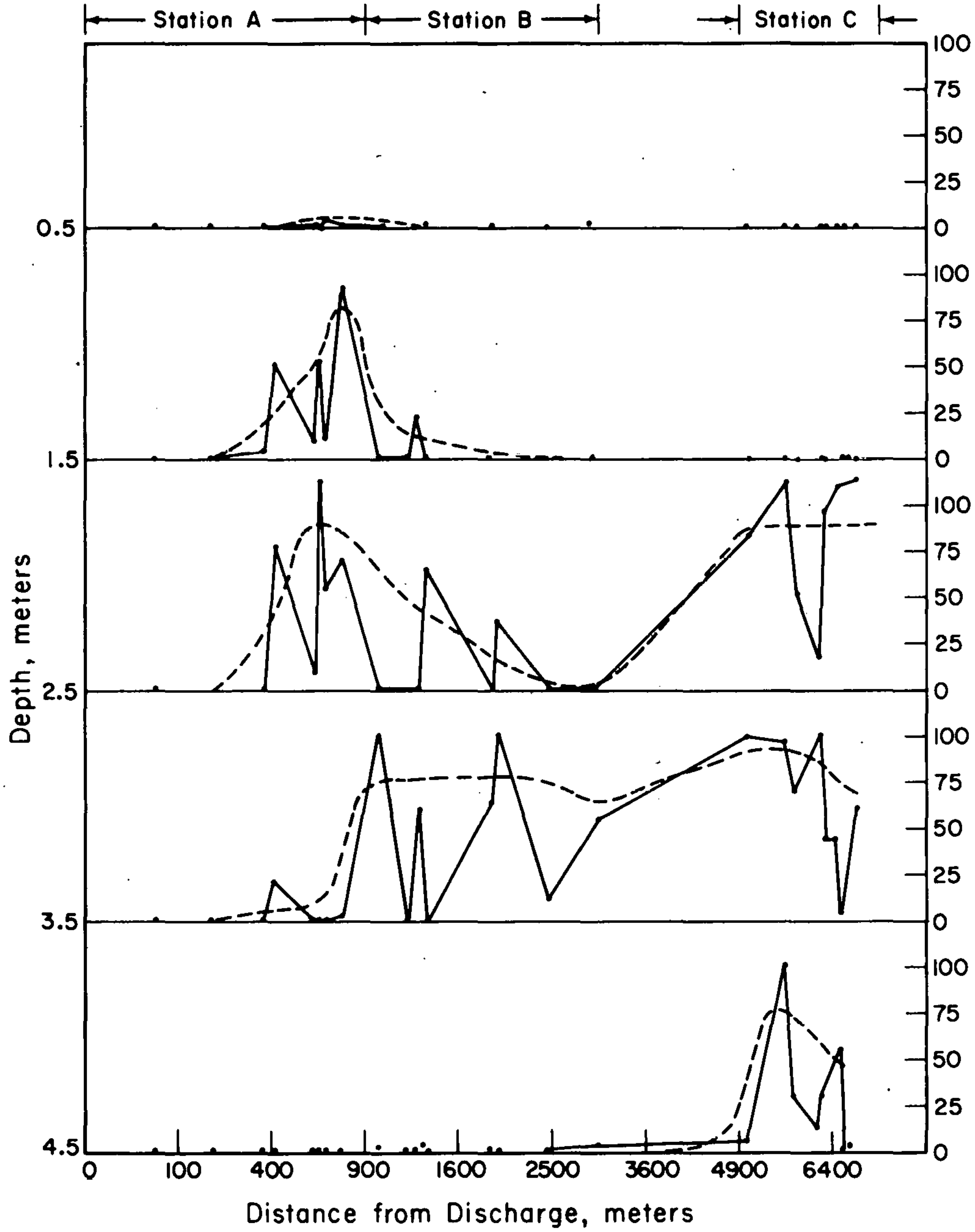
NS No significant difference.

Appendix C

Curve-Fitting Method Used to Generalize the Distributions of Species Populations

It was necessary to construct generalized distributions of species (Figure C-1) for use in Figures 12-14 because a graph of the real distributions of several species would be visually incomprehensible. However, these generalized distributions are only approximations of the data and, therefore, have a limited utility. Curves were determined only for species which occurred at least three times at a location (i.e., occurrence of a species at one point does not represent a curve).

Figure C-1. Example of the curve fitting method used to generalize the distributions of species-populations. The data points for *Myriophyllum spicatum* were plotted against the distance from the discharge on a square root scale, according to the depth at which samples were collected. The generalized curves were eye-fitted and are represented by dashed lines.


Station A
Station B
Station C
Depth, meters
0.5
1.5
2.5
3.5
4.5
100
75
50
25
0
0
100
400
900
1600
2500
3600
4900
6400
Distance from Discharge, meters

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