PRODUCTIVITY OF AQUATIC MACROPHYTES AT ERIE MARSH

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSTIY

Peter H. Rich

1966

PRODUCTIVITY OF AQUATIC MACROPHYTES AT ERIE MARSH

By

Peter H. Rich

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Zoology

1966

ACKNOWLEDGEMENTS

My first acknowledgement goes to Dr. Peter I. Tack who always had time and attention for this project. Dr. John E. Cantlon and Dr. Miles D. Pirnie generously contributed guidance and ideas in the course of many very rewarding discussions. I am also grateful to Dr. T. Wayne Porter who read the manuscript with an editor's eye and who contributed to my Master's program in many ways.

Dr. Stephen Stephenson substituted for Dr. Cantlon during the preparation of the manuscript. Dr. William E. Cooper criticized the statistical techniques, and I attribute what should be a lucid statistical presentation to his efforts.

I acknowledge special thanks to the Soil Science Department for making equipment and facilities available to me. I also take this opportunity to thank Mr. Don Christenson of the Soil Testing Laboratory for helping me interpret the results of the soil tests.

Financial assistance was provided by the Erie Research Committee and the Wildlife Management Institute.

I wish to thank the manager, Mr. Kenneth Reau, and the members of the Erie Shooting Club for the use of their facilities.

I am much indebted to Mr. Dennis R. King who made his daily records from the marsh available to me. Mr. King also granted me permission to reproduce Table 2 of his thesis.

My thanks to all the others who helped, including William Gulish, Herbert Lennon, Robert Lippson, and Ronald White.

Finally, I must express my appreciation to my wife, Nancy, who spent many, many hours sorting samples.

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I. DESCRIPTION OF THE STUDY AREA

The Erie Shooting Club Marsh is located in the extreme southeastern corner of Michigan. It is in Monroe County, near the town of Erie. According to the United States Public Lands System the marsh is placed at T8S; R8E; Sections 14, 15, 21-23, and 26-28. Except for man-made features such as dikes, roadbeds, and overpasses, the area has no relief and very little elevation above modern Lake Erie. The soils in the area represent sediments of lakes ancestral to Lake Erie, and most of the land in the neighborhood is cultivated.

The marsh is essentially a diked-in portion of littoral Lake Erie. The sample areas are in North Bay (Sections 22 and 23) which was isolated from Lake Erie with the completion of the East Dike in the Spring of 1953. Previously North Bay had been part of Maumee Bay, protected from the lake by Woodtick Penninsula. The bays enclosed by the outer dikes brought the total area of the marsh up to its present figure, approximately 1000 acres.

Since 1957 the Erie Research Committee and the

Wildlife Management Foundation have sponsored research in the marsh. The first four years were supervised by Dr. George S. Hunt of the University of Michigan; the next four years by Dr. Miles D. Pirnie of Michigan State University. In 1964 and 1965 Mr. Dennis R. King from U of M and I worked in the marsh under our respective programs. The information gathered in the period since 1957 is available in a series of annual reports submitted to the Erie Research Committee, including a summary prepared in 1964 by Dr. Pirnie and Mr. John Foster.

Location of the sample areas: North Bay is bounded on north and east by the East Dike, on the south by Sand Island and East Bay, and on the west by Secor's Unit and the mainland. Except for a deep area at the extreme north end, North Bay is uniformly shallow. King (1965: 10) approximated the depths as between 10 and 17 inches at summer water levels, i.e. 2.0 inches at the Boathouse Dock gauge. The two sample areas are located in the southern end of the bay, near Sand Island. The locations were chosen on the advice of Dr. Pirnie and Dr. Cantlon who detected differences in the species composition between the two sides of the bay. In fact, it was possible during the summers of 1964 and 1965 to recognize a definite boundary between the two provinces. In 1964, prior to installing the exclosures, the boundary shown in Figure 1 was determined by rowing back and forth over the area and dropping a stake each time the dominant plant changed. The two sample areas were lined up on an east-west axis and then placed approximately equidistant between the province boundary and the shore. The western site, characterized by a predominance of curly-leaved, crispus pondweed (*Potamogeton crispus* L.), was offset toward the center of the bay somewhat to assure that it remained in the same soil province (see Figure 2). The eastern sample area is characterized by the presence of sago pondweed (*P. pectinatus* L.). The "Crispus" area is approximately 1 1/2 inches shallower than the "Sago" area.

Bottom material in the sample areas: The soil map (Figure 2) was drawn by Carl F. Eby in 1958, and he turned in a detailed soil report to the Erie Committee in 1959 (Eby, 1959). The map shows North Bay to contain several soils. However, both sample areas are in the 7771 province, described as marl over organic matter.

Approximate depth of sample areas

Sago = 18'
Crispus = 16 1/2"

Water Level 2.28" (Boathouse gauge)

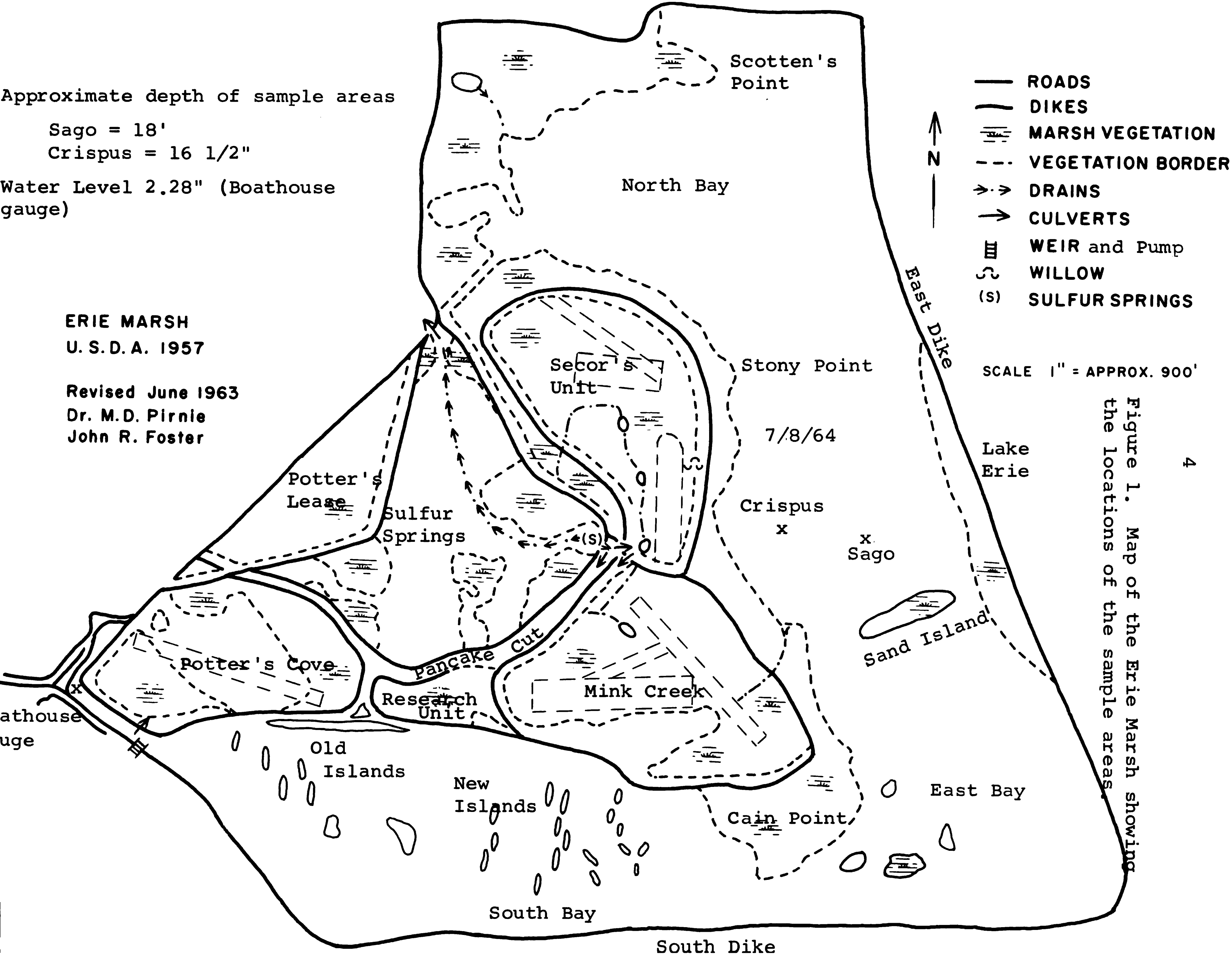

Figure 1. Map of the Erie Marsh showing the locations of the sample areas.

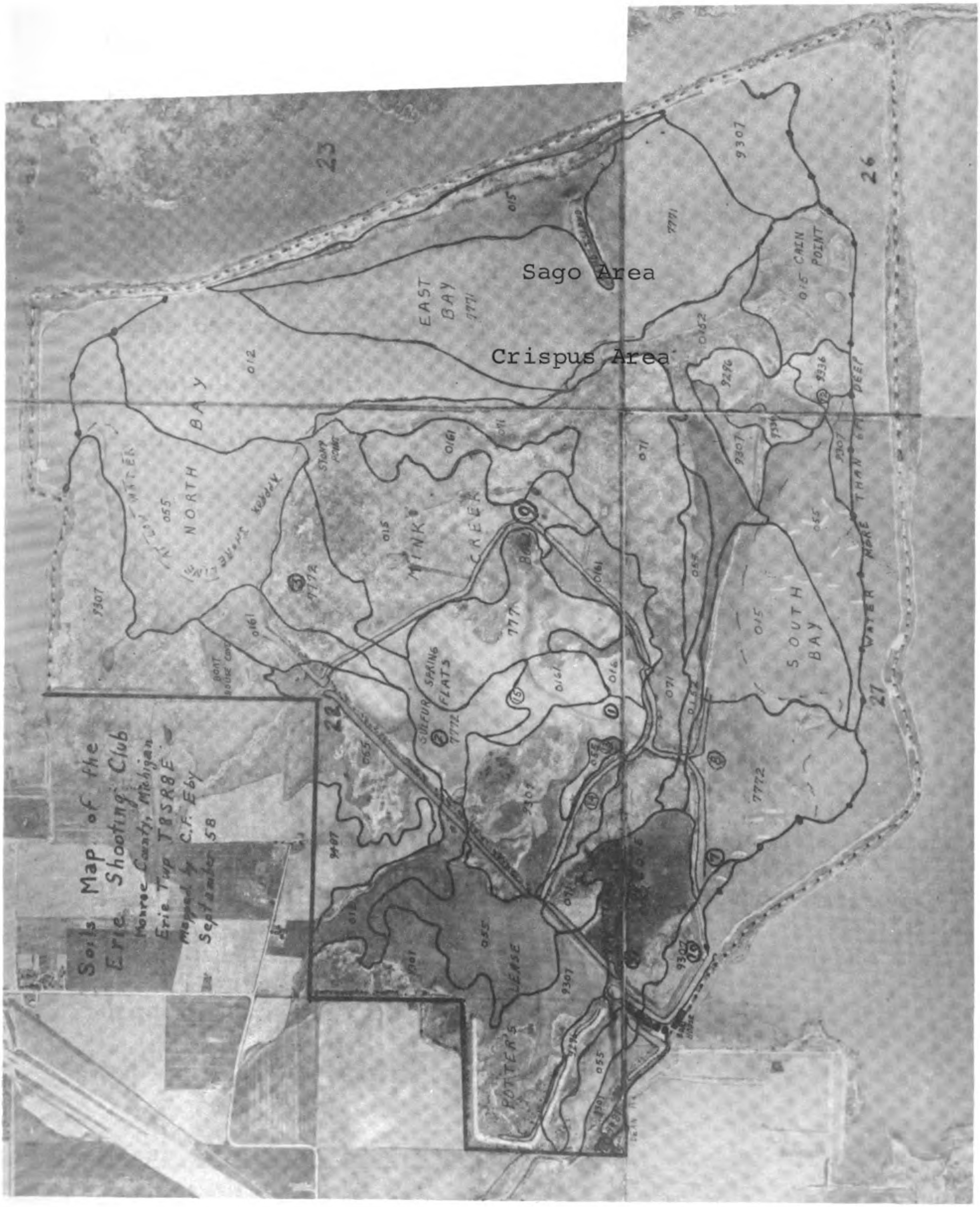
Sago Area
Crispus Area
Soils Map of the
Erie Shooting Club
Monroe County, Michigan
Erie Twp T8SR8E
Mapped by C.F. Eby
September 58
NORTH BAY
EAST BAY
SOUTH BAY
MINK CREEK
CAIN POINT
SULFUR SPRING FLATS
POTTER'S LEASE
23
26
27
22

Figure 2

Marl is defined in the survey as material with a calcium carbonate equivalent of more than 50% and an organic content of less than 30%. Eby characterized the 7771 area as having a marl surface 12 to 30 inches thick, with a lower story of organic matter extending below 66 inches.

While installing the exclosures, certain differences between the soils of the two areas became apparent to me, although they still conform to Eby's generalized description. The Sago area is overlain with a material which is black to grey when wet, and which has a greasy texture. The marl, which is light colored, starts at 4-8 inches with a layer of shell fragment and extends at least 30 inches as Eby described. The Crispus area is overlain with a material which tends toward a brown color, and which is more fibrous and granular in texture. It has the same marl layer, but a firm stratum is encountered at about two feet which releases bubbles smelling of H_2S when disturbed. H_2S was never noticed in the Sago area. The results of soil tests made on samples from both areas appear in Appendix I.

<u>Water levels in 1964 and 1965</u>: Water levels in the marsh have been managed since about 1951. Of course this did

not affect what is now North Bay until the East Dike was finished in 1953. A 20,000 gallon per minute pump is maintained at the weir, and it is capable of regulating the level of the bays at a rate of about one inch in 24 hours (Hunt, 1958:2).

In general, the practice has been to lower the water in the Summer to expose large areas for the cultivation of duck-food plants and to raise the levels to flood the food patches in the Fall. During the Winter, levels are held high. Variations in the degree and time of flooding or draw-down are used to thin vegetation or to select one type over another. In the bays, for instance, high water in 1960 resulted in a retreat of bulrush and cattail in 1961, although it is not clear exactly how the plants were destroyed (Matulis, 1960 and Drum, 1961).

In the latter part of the growing season of 1964, Mr. Reau, the manager of the marsh, had considerable difficulty maintaining desired levels within the marsh. It was a particularly dry Summer, and Mr. Reau had to take advantage of every east wind to force water into the marsh through the weir. As the hunting season approached, he finally resorted to several days of pumping (Figure 3).

Table 1 represents pertinent readings from the Boathouse Dock water level gauge during 1964 and 1965. A large amount of these data were collected by Mr. Dennis King (personal communication) to whom I am grateful. The present gauge on the Boathouse Dock was installed in 1961 (Bennett, Matulis and Drum, 1961), and must not be confused with the gauge previously used by Dr. Hunt (Hunt, 1957, 1958 and 1959). Zero on Dr. Hunt's gauge is equal to 3.30 on the present gauge (King, 1965:10). King (Op. cit. p. 11, Table 1) presents a more synoptic table of water levels which includes records through August 27, 1965.

<u>Climate</u>: The nearest U. S. Weather Station to the Erie Marsh is at the Toledo Express Airport in Swanton, Ohio, a distance of about 22 miles.[1] The average temperature at this station is 49.8°F (through 1965), the average precipitation is 31.38 inches, and the mean hourly wind from the west-southwest at 9.5 MPH. The growing season

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[1]U. S. Weather Bureau, 1964-1965.

Figure 3: Pump in Operation at the Weir, September 9, 1964.

Table 1. Water levels and temperatures recorded at the Boathouse Dock.

Date	Gauge Reading in Feet	Temp. °F	Time	Remarks
2/16/64	2.20	-	-	-
4/11	1.80	55	7:30 PM	water let out
4/18	1.80	60	8:30 PM	-
4/25	2.10	59	1:30 PM	-
5/2	2.28	65	2:00 PM	-
5/3	2.26	60	10:00 AM	-
5/21	1.90	65	9:30 AM	water let out
5/27	1.87	70	10:00 AM	-
5/30	1.78	68	10:00 AM	water let in
6/4	1.89	64	8:15 AM	water let in
6/9	2.00	-	-	water let in
6/11	1.96	73	noon	-
6/15	1.97	-	9:00 AM	water let in
6/16	2.01	66	9:00 AM	water let in
6/22	2.05	-	-	water let in
7/2	1.93	76	10:30 AM	-
7/9	1.98	-	-	water let in
7/13	2.00	-	-	water let in
7/27	-	-	-	water let in
7/28	screens removed from wier			water let in
7/30	1.84	83	noon	-
8/4	2.11	86	noon	-
8/12	2.29	-	-	-
8/19	2.14	-	-	-
8/20	2.26	-	-	-
8/24	2.44	70	noon	-
8/25	2.44	73	noon	-
8/26	2.40	72	noon	-
8/29	2.42	-	-	water let in
9/8	2.28	-	-	-
9/12	2.25	-	-	-
9/14	2.20	-	-	-
9/16	2.30	50	noon	water pumped in
10/30	2.56	-	-	water pumped in
12/19	2.95 ice	32	-	-
1/30/65	3.50 ice	32	-	water let out
*4/3	2.86	-	-	-
*4/24	2.34	-	-	water let out
5/1	2.36	59	2:00 PM	-
*6/1	2.18	-	-	-
*6/9	2.32	-	-	-
7/4	2.06	83	noon	-

*King, 1965:11, Table 1.

averages 160 days. The last freezing temperature occurs on April 27th on the average, and the first on October 15th. Winter is characterized by frequent thaws and light snowfall. The average snowfall per Winter is 34.7 inches and the average number of days with a tenth of an inch or more of snowfall is 27. In 1964 the average temperature was 49.2^{o}F; precipitation was 24.28 inches. In 1965 the average temperature was 48.3^{o}F; precipitation was 40.85 inches.

The meteorologist in charge at the weather station, D. E. Coleman, has assured me by personal communication that temperatures in the agricultural areas around Erie are close to those at the station. He pointed out, however, that rainfall is very variable in the Summer due to thundershowers.

Pertinent Information During the Sample Periods

	1965		1964		
	May	June	July	August	September
Monthly temperatures	63.5	66.9	73.8	67.8	62.5^{o}F
Monthly precipitation	3.80	2.57	1.58	3.80	1.61 inches
Clear days	2	8	7	6	11 days
Partly cloudy	17	15	15	14	7 days
Cloudy days	12	7	9	11	12 days
Mean monthly temperatures	58.3	68.3	72.7	70.9	63.4^{o}F
Mean monthly precipitation	3.04	3.79	2.59	3.33	2.13 inches
Mean clear days	7	7	7	8	10 days
Mean partly cloudy	10	13	15	12	9 days
Mean cloudy days	14	10	9	11	11 days

II. MATERIALS AND METHODS

Two major objectives were sought in this study. First, the effect of carp on the standing crop of aquatic macrophytes in the open water areas of the marsh was estimated, and, second, a macrophyte productivity estimate was made so that any measurable effect of carp could be put on an absolute basis. The estimate of carp effect was based on an exclosure and control area study. Macrophyte productivity was estimated by measuring standing crop at the beginning and the peak of the growing season.

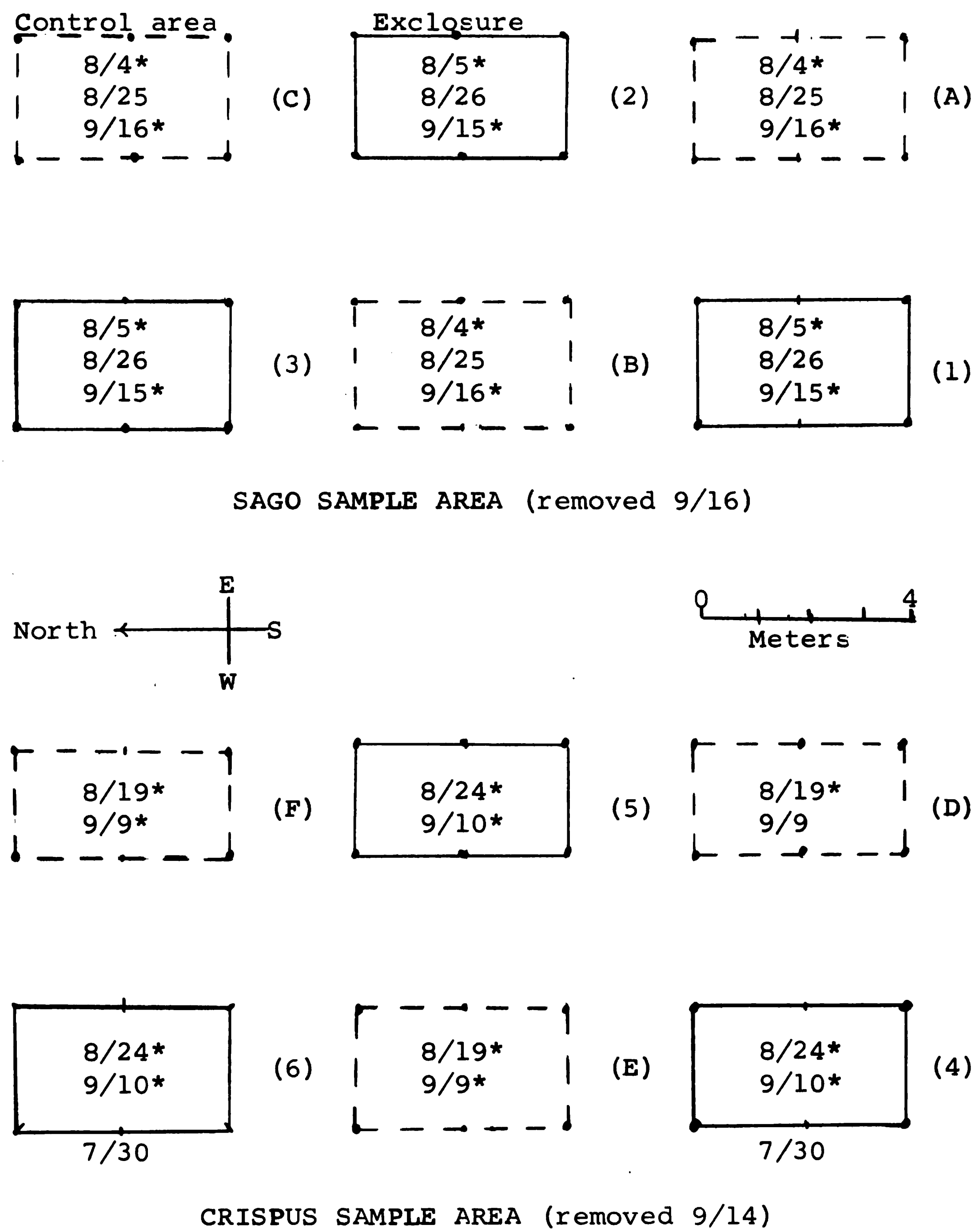
<u>The exclosures</u>: The exclosures were constructed of 1 1/2 inch poultry netting, 5 feet in width. The dimensions of the exclosures were 2 by 4 meters, with a stake supporting the wire at 2 meter intervals, i.e. 3 stakes on each long side. The stakes were 8 foot 1 by 4's. The exclosures and controls were oriented on a north-south axis and arranged as shown on the sampling diagram of the two areas (Figure 4). A total of 6 exclosures were constructed, 3 in each sample area.

The installation of the exclosures was the biggest problem encountered during the whole project and delayed sampling by about 3 weeks. The first attempt at installation, using a prefabricated exclosure, was a failure. The substrate in the sample area is so soft that it is difficult to get any leverage on the wire and stakes to place them in position. Although this method is not impossible, I decided that it inflicted too much damage upon the substrate.

A second attempt, using prefabricated sides only, was a great improvement, but still unsatisfactory. I did not feel that secure seams could be made underwater with a hammer and fence staples. Two exclosures were installed in this manner, however.

Finally a method was discovered that was both quick and effective. A 1/2 inch staple gun was purchased for the purpose of fastening the wire underwater. This worked so well that these staples were used for all fastenings, both in and out of water. The only operations necessary ashore were the cutting of the wire to the correct dimensions and folding up the bottom one foot, so that later, after the wire had been installed,

Figure 4. Diagram of sample areas 1964, with dates of installation of exclosures (below figures) and sampling dates (enclosed).



*Bottom samples also taken.

Figure 5: The Sago Exclosures, looking north, September 9, 1964.

Figure 6: The Crispus Exclosures, looking north, September 9, 1964.

it could be pressed into the mud to form a burrow-proof apron. At a sample area it was necessary only to drive the stakes, which could be done from the boat with no danger of disturbing the bottom, and then hang the wire which can be done from the outside, again with no danger of disturbing the area actually sampled.

Because the staple gun was heavily chromed, the only parts liable to corrosion were the spring feed for the staples, the large driving spring, and the staples themselves. The only maintenance necessary on the gun consisted of removing and discarding any unused staples at the end of a day, shaking out all the water possible, and rinsing the gun off with outboard gas. Anyone interested in this device might investigate larger models using larger and heavier staples, particularly where the staples would be exposed to harsher conditions for a longer duration.

It was apparent during the demolition of the exclosures that those fastened with the staple gun were tougher than the two fastened with hammer driven fence staples. The actual fastening can only be as strong as the strand of wire it fastens, and the gun staples were quite sufficient in this respect. Because the staple gun is quick and easy, it is possible to triple the number of fastenings on a seam and still save time.

<u>The controls</u>: The controls were staked out in the same manner as the exclosures, but they were not enclosed with netting. Because I had to walk around the exclosure to install the wire, I also made a path around each of the controls. This was done to reduce the probability of spurious treatment effects resulting from the disturbance inherent in the installation of the exclosures.

<u>Plant sampling technique</u>: The samples were taken from a 1/4 square meter wooden frame. The frame was 1/2 meter on a side, with legs projecting down from the corners to hold the frame in place. Although the frame was buoyant, the mud held the legs firmly once the frame was pushed into place against the bottom. Four such sub-samples were taken from each exclosure and control on a sampling date.

Thanks to the properties of both the mud and the plants, rather accurate sampling was probably achieved in spite of the extreme turbidity which necessitated doing everything by touch. When a plant leaned out of the sample area, causing the main part to be excluded by the frame, I discovered that the plant would slide back under the frame when the roots inside were pulled up. When, on the other hand, the plant leaned into the sample area and was pulled from the top rather than from the bottom, the stem simply broke off at the edge of the frame.

Washing and transportation of the plant samples: The samples were washed in a wooden box with a window screening (16 mesh to the inch) bottom at the time they were taken. The samples were subsequently stored in 11-quart plastic pails until sorted. For convenience, the screened box was made 1/2 meter on a side so that it could be used as a measuring device to help position the sampling frame in an exclosure or control area.

In order to completely remove the rather tenacious bottom material from those plants with roots, the plants were washed vigorously. This led to sorting difficulties as the washing fragmented and tangled the plants and plastered sago pondweed debris over everything. The washing also removed most of the silt and/or periphyton which covered the plants in the extremely turbid water.

The first samples from both the Sago and Crispus areas were sorted almost immediately, and no samples remained unsorted for more than 24 hours. In this case, the pails were kept full of water. At the time of the second Sago sample, the weather made it necessary to take the samples as rapidly as possible, with sorting delayed for up to 48 hours. After 24 hours the plants developed a bad odor and became blackened. These samples were drained at that time, and thereafter samples were kept moist but drained at all times. Hopefully, this kept the plants alive and prevented decomposition.

The last samples in 1964 from the Sago area were taken at the last possible moment before the exclosures had to be removed. This meant that the exclosures were removed before sorting started. The samples, themselves, were extremely tedious to sort. All this resulted in very long wet storage times, as follow:

Sample #1 - 48 hours
2 - 72 hours
A and B - 72 hours
C - 96 hours
3 - 144 hours

After sorting, the plants were dried on newspaper and placed in paper bags. The drying process never took more than 12 hours, although an additional 12 hours were allowed. The bags were stored in a dry, unheated building until oven dried for dry weight and organic weight determinations.

Oven drying of plant samples: The plants were dried at 170°F in a forced air, electrically heated, drying oven provided by the Soil Science Department. The 1964 samples were dried for 48 hours, and the 1965 samples for 72 hours. The drying times in both years were far in excess of the times used for the same amount of much tougher terrestrial plants for which the oven is regularly used. Samples weighing less than one-tenth of a gram were called "trace," and were calculated at a value of 0.05 grams in both dry and organic weight figures. Some samples were re-weighed at the end of the weighing procedure to determine the effects of atmospheric moisture upon the exposed samples. The results were slight (0-3%), and, although some error was undoubtably introduced, the effect was ignored.

Organic weight: The dried samples were sorted for seeds and Winter leaf buds, then ground in a manually operated corn grinder. Sub-samples of the ground material, never less than 75% of the total material, were redried at 105°C, weighed, and burned in a muffle furnace at 550°C. The ash weight was subtracted from the 105°C dry weight to determine organic weight. The organic weight was then divided by the 105°C dry weight to produce a quotient. The quotient was multiplied by the 170°F dry weight (minus the weight of seeds and Winter leaf buds) to give total organic weight for the foliage. Seeds and Winter buds received the same treatment except these smaller samples did not have to be ground and sub-sampled. The total organic weights appearing in the statistical analyses represent the sum of seeds, Winter leaf buds, and foliage.

Bottom samples: Samples were taken with a 6 inch Ekman dredge inside the plant sampling frame after the plants had been removed. Each sample consists of two sub-samples, one from the north and one from the south end of each exclosure and control area. The samples were washed in the same screen lined box that the plant samples were washed in. My ignorance of statistical techniques at the time led me to lump together all the samples from each sample area. Thus, no error term can be computed for these data. The samples were stored in approximately 10% formaldehyde until sorted, a period ranging between 3 and 18 months.

The bottom samples were sorted into seeds, Winter leaf buds, and foliage for each species. They were dried, weighed, burned, and weighed as previously described to get organic weight. These weights were then multiplied by a factor (21.6) to make the 1/2 square foot per replication they actually represent equivalent to the one square meter per replication the plant samples represent (Table 9).

Depth data: The sounding data was taken on September 8, 1964. At that time the water level gauge at the Boathouse Dock registered 2.28 inches. The data were taken under ideal conditions, with glassy calm water and with the exclosure and control stakes in place to provide a rigid and accurate grid. The measurements were made to 1/4 of an inch with a yard stick tipped with a 20 cm. metal disk. The disk made it possible to sense the very soft mud-water interface. Care was also taken to avoid paths made in the bottom during the construction of the exclosures.

Sampling techniques in 1965 (The productivity study): In 1965 plant sampling differed from that mentioned previously because no exclosures were installed and no control areas were staked out. The sub-sampling arrangement was the same, and the same number of control samples were taken at each sampling area. There were no exclosure samples. A sample consisted of four, one-quarter meter sub-samples taken while swinging about an anchor. Following this, the anchor was raised and then released a few oar strokes to the north for the second sample. In this manner the samples remained on a north-south axis in the sample areas as they were in 1964. The plants were treated like those in 1964 in all other respects. Wet storage times were kept to 24 hours.

Soil analysis: The differences in the appearance of the bottom material between the two sample areas prompted me to have a soil test performed to determine physical (mechanical) properties and fertility. One bottom sample from each area was analyzed by the Soil Testing Laboratory at Michigan State University. The samples were taken on September 8, 1964 with an Ekman dredge. The results appear in Appendix I.

III. RESULTS AND DISCUSSION

The exclosure study: The exclosure study was undertaken to detect the direct effects of carp upon the vegetation. Unlike the study by Threinen and Helm (1954) in which a 75 acre bay was fenced off, the exclosures did not protect the vegetation from the indirect effects of carp, i.e. turbidity and silt deposition. These effects are discussed in Chapter VI.

Probably the most important direct effect of carp is the mechanical uprooting of the plants (King, 1965:95). The uprooting is apparently caused by the bottom feeding activity of carp which is known to produce significant changes in the bottom (see: The analysis of the depth data). In 1958 Dr. Hunt (1958:23) stated that the application of toxaphene that year and the resulting destruction of carp eliminated uprooted plants in the bays. In 1961 Bennett, Matulis and Drum (1961:5-6), recorded the presence of windows of sago pondweed and wild celery on the shores of the bays. They observed that the plants were unmarked and that their roots were intact. Examination of the growing plants in the bays revealed that they were firmly rooted, but that large holes with interconnecting channels were present in the vegetation. They concluded that carp were grazing in the area. In 1963 Foster (1963:5) also observed uprooted plants. King (1965:96) has an excellent color photograph of windrowed vegetation in East Bay.

The other direct effect which carp inflict upon the vegetation in the marsh results from their utilization of some species for food. In 1963 Foster (1964:5-6) examined the stomach contents of 12 carp: six taken over *Chara* and six taken over pondweeds, algae and dead cattails. Four of the carp taken over *Chara* contained *Chara*, but only algae was identified from the fish collected over pondweeds.

In the Spring and Summer of 1964, King (1965:34, 43-45) examined 24 carp: 15 taken over *Chara* and 9 taken over pondweeds. Of the contents taken over *Chara*, he discovered 45.7% (by volume) *Chara*. The contents taken over pondweeds were not so conclusive, but they do indicate some utilization of pondweeds by carp. King's data from the 9 carp taken over pondweeds are reproduced in Table 2 with his permission.

Analysis of the exclosure data: The two sample areas were analyzed separately because they represent two distinct plant associations, with different species compositions and dominants. The analysis consists of a three-way analysis of variance of the organic weight data. Treatments (A) consist of exclosures (A_1) and controls (A_2). There are three important species (B) in the Sago area and four in the Crispus area. In addition to the important species is an "others" category in both samples which contains the balance of minor species. The time (C) intervals between samples are approximately 20 days. Three samples were taken in the Sago area and only two in the Crispus area. There are three replications, each representing four subsamples.

An assumption of variance homogeneity could not be verified for the raw data. Means and variances in both areas were found to be directly related. Consequently, a log transformation was made on both sets of data. In both cases the raw data was multiplied by 10 to prevent observations with values of less than one from producing negative logarithms. Barlett's Test for variance homogeneity is not applicable to these data due to the small number of replications. The Box Modification is available, however

Table 2. Summer carp food habits in Erie Marsh in 1964[1].. (Nine carp taken over pondweeds June 29.)

Food Item	Total Vol. ml.	Percent Volume	Percent Occur.
Total Plant	93.60	57.8	100
Sago leaves	3.53	2.2	33
Crispus leaves	0.75	0.5	9
leaf fragments	16.22	10.0	33
stem fragments	7.60	4.7	22
root fragments	3.33	2.1	22
Crispus winter leaf buds	12.05	7.4	67
Scirpus validus seeds	1.38	0.8	33
Polygonum lapathifolium seeds	0.33	0.2	9
filamentous algae	1.30	0.8	33
other	47.11	29.1	91
Total Animal	9.30	5.7	100
Unidentified (mucus)	59.10	36.5	100
Total	160.00		

[1]Reproduced in part from King, 1965:44, Table 2.

the simple, non-parametric Corner Test of the transformed data was so far from significance that the complicated parametric test was considered unnecessary.

The data conform to a mixed model. The treatments (A) represent a fixed component of variance, while species (B) and time (C) are considered random. The estimated mean sums of squares (EMSS) are shown in Appendix II.

The only factor found to be significant is species (B), which only reflects the phenomenon of dominance within the vegetation. All the other factors and interactions are not significant at the 5% level.

In 1964 and 1965, King (1965) analyzed the effects of exclosures upon the wet weights of vegetation at five and four locations in the marsh, respectively. Sampling occurred four times during the growing season. In an analysis of variance of his 1964 data, using each of his 20 samples as blocks, treatments are heterogeneous at the 5% level. The differences within blocks are significant at the 1% level (Op. cit. p. 49, Table 5). In the analysis of his 1965 data, 16 blocks, the treatments are different at the 1% level, and differences within blocks are not significant (Op. cit. p. 51, Table 7).

In spite of replicated samples within a more limited area, which my data represent and which should provide greater testing precision, it is not clear that my results refute King's. In the first place, King was primarily interested in the effects of carp and possibly biased his choice of sample areas. On the other hand, my observations were confined to the south end of North Bay; an area chosen for its apparent homogeneity and lack of concentrated carp activity. Second, only two of the five areas analyzed by King in 1964 were in pondweeds, and both showed very little or even negative differences between exclosures and controls (King, 1965:48, Table 4). The area in dense Chara showed much greater differences, which may reflect the preference for Chara by carp suggested in the two stomach analyses. Third, my data was taken over a more limited time than Kings's, and King reported a reduction of the effect of carp during at least part of that period. King discovered that an analysis of variance of his 1964 data for the 1st, 2nd and 4th samples from each sample area was significant at the 2.5% level (Op. cit., p. 58, Table 9), while his test for all samples was only significant to the 5% level. As he pointed out, the decreased degrees of freedom of his test on the 1st, 2nd, and 4th samples would tend to decrease significance

(Op. cit., p. 59). Thus, there is an indication that carp produce a greater effect early and late in the growing season, with a lesser effect sometime between the middle of June and the middle of August. King (Op. cit., p. 67) attributes the early season effect to intense breeding activity by carp and to the vulnerability of young plants which Robel (1951) also suggests. The question remains, however, as to why my final samples, which were taken later than King's, do not show significance.

I attribute the lack of significance at my sample areas to an absence of carp during most of the sample period. I did not observe any of the effects of carp upon the vegetation described by Bennett, Matulis, and Drum (1961:5-6) until late August and early September. At that time holes began to appear in the vegetation near the samples, and uprooted plants became noticable.

The ultimate purpose of the exclosure study was to determine the rate of turnover at the sample areas. Turnover represents the rate at which biomass is cropped-off or otherwise removed during the growth period, and its significance to a productivity determination is discussed in more detail in the section on productivity. Because significant differences failed to develope between the exclosures and controls in 1964 suggests the conclusion that turnover is absent at the sampling sites in North Bay. However, the data used for the productivity estimate was taken in 1965, and King (1965:57) stated that carp had a greater effect in that year. If this is true, and if the effect was felt at my sample areas, I may not be able to assume negligible turnover in 1965.

King based his conclusion upon his statistical analysis. He achieved greater significance in 1965 than in 1964: 1% in 1965 compared to 5% in 1964. He also stated that he observed more and bigger carp in 1965 (Op. cit., p. 90). He suggested that the greater effect in 1965 resulted from both increased carp population and increased pondweed production that year which caused the carp to be less selective for Chara. However, as King pointed out (Op. cit., p. 57), a bias occurred in his samples in 1965 which was not present in 1964. In 1964 he placed only 2 out of 5 of his exclosures in Chara as opposed to 3 out of 4 in 1965. His sample area #5' (1965) (1965:50, Table 5) showed greater significance than #5 (1964) (Op. cit., p. 48, Table 4), and this leads me to believe that the carp did, indeed, reach the pondweed areas in North Bay earlier in 1965 than in 1964.

A filamentous alga (*Cladophora*) colonized the sides of all three Sago exclosures sometime between the second and third sample period (Figure 9). However, it was only present in the samples in small amounts (2.0 grams/m^2. organic weight).

Table 3. Exclosure data for the Sago sample area. Y = organic weight in grams (550°C).

Treatment (A)	Species (B)*	Dates (C) 8/4-5	8/25-26	9/15-16
Exclosures	P. pectinatus	18.5	11.6	3.5
		32.2	18.4	8.3
		6.9	5.6	1.3
	Elodea canadensis	38.8	29.8	27.5
		57.5	29.9	25.0
		58.5	32.1	31.0
	P. foliosus	4.9	0.3	5.7
		2.5	2.1	1.6
		1.9	0.4	2.9
	others	7.0	5.3	7.7
		13.7	3.9	12.6
		6.9	3.6	13.6
Controls	P. pectinatus	16.4	4.0	3.6
		10.1	2.0	0.9
		7.2	4.3	0.2
	Elodea canadensis	20.6	22.5	24.4
		27.8	14.7	5.8
		67.8	49.2	39.8
	P. foliosus	1.2	1.9	15.1
		2.9	5.7	7.4
		1.2	0.6	0.4
	others	9.7	7.9	5.6
		5.0	0.4	0.3
		2.3	3.9	0.4

*Reference: Gray's Manual of Botany, 8th Ed.

Table 4. Transformed exclosure data for the Sago sample area. $Y' = \log_{10}(10Y)$

Treatment (A)	Species (B)	Dates (C) 8/4-5	8/25-26	9/15-16
Exclosures	*P. pectinatus*	2.267	2.065	1.544
		2.508	2.265	1.919
		1.839	1.748	1.114
	Elodea canadensis	2.589	2.474	2.439
		2.760	2.476	2.398
		2.767	2.507	2.491
		1.690	0.477	1.756
		1.398	1.322	1.204
		1.279	0.602	1.462
	others	1.845	1.724	1.887
		2.137	1.591	2.100
		1.839	1.556	2.134
Controls	*P. pectinatus*	2.215	1.602	1.556
		2.004	1.301	0.954
		1.857	1.634	0.301
	Elodea canadensis	2.314	2.352	2.387
		2.444	2.167	1.763
		2.831	2.692	2.600
	P. foliosus	1.079	1.279	2.179
		1.462	1.756	1.869
		1.079	0.778	0.602
	others	1.987	1.898	1.748
		1.699	0.602	0.477
		1.362	1.591	0.602

A = treatments = 2 (fixed)
B = species = 4 (random)
C = time = 3 (random)
n = replications = 3

Figure 7a. Log_{10} organic weight/time (Confid. Coef. 95%). Sago area Controls, 1964.

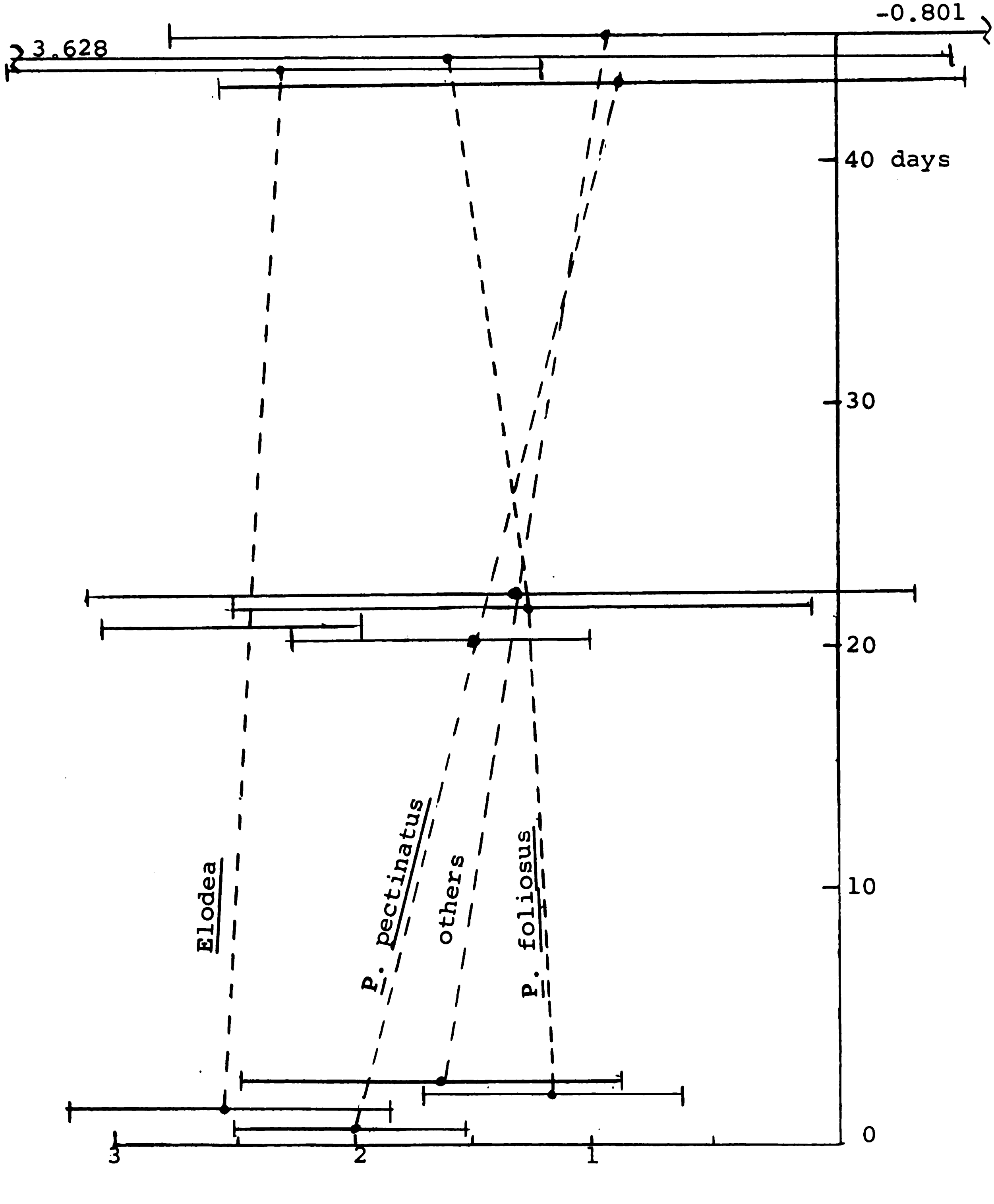
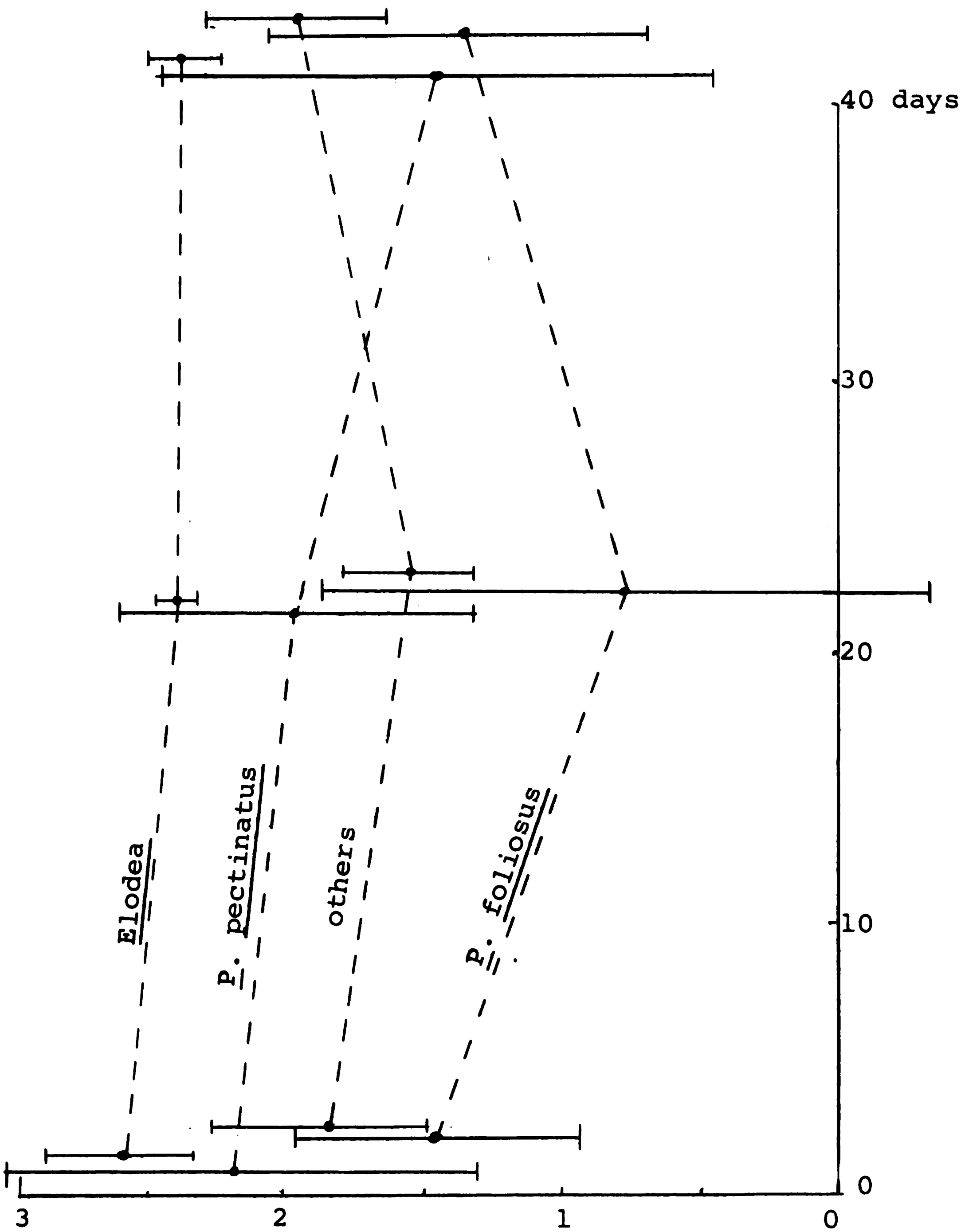


Figure 7b. LOG_{10} organic weight/time (confid. coef. 95%). Sago area exclosures, 1964



Log_{10} (Organic weight 10)

Table 5. Analysis of variance of the transformed exclosure data from the Sago sample area.[1]

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F
A (fixed)	1	1.1628	1.1628	1.9739^{o}
B (random)	3	13.5060	4.5020	12.1939^{xx}
C (random)	2	1.4913	0.7457	2.0198^{o}
AB	3	1.1095	0.3698	3.6578^{o}
AC	2	0.6407	0.3204	3.1691^{o}
BC	6	2.2152	0.3692	2.4845^{o}
ABC	6	0.6063	0.1011	0.6803^{o}
Error	48	7.1329	0.1486	
Total	71	27.8647	0.3925	

[1] Table of Estimated Mean Sums of Squares, Appendix II.

Table 6. Exclosure data for the Crispus sample area. Y = organic weight in grams (550°C).

Treatment (A)	Species (B)	Dates (C) 8/19,24	9/9-10
	P. crispus	18.9	10.2
		4.5	3.9
		5.7	42.8
	P. foliosus	14.4	16.7
		1.4	6.9
		6.7	22.0
Exclosures	*Ceratophyllum*	0.4	0.3
	demersum	0.3	0.9
		0	0.7
	Heteranthera	0	T
	dubia	0	0
		T	5.8
	others	2.7	1.8
		1.4	1.4
		0.9	3.5
	P. crispus	9.2	10.8
		7.8	5.2
		4.6	1.1
	P. foliosus	1.9	3.5
		3.1	5.8
		0.8	2.6
Controls	*Ceratophyllum*	1.1	0.9
	demersum	0.1	0.5
		2.0	8.4
	Heteranthera	0.3	0
	dubia	0	0
		0	0
	others	3.1	2.4
		1.3	1.8
		3.3	0.9

T = trace (less than 0.1 grams)

Table 7. Transformed exclosure data for the Crispus sample area. $Y' = \log_{10}(10Y)$

Treatments (A)	Species (B)	Dates (C) 8/19,24	9/9-10
	P. crispus	2.277	2.009
		1.653	1.591
		1.756	2.631
	P. foliosus	2.158	2.223
		1.146	1.839
		1.826	2.342
Exclosures	*Ceratophyllum*	0.602	0.477
	demersum	0.477	0.954
		0	0.845
	Heteranthera	0	T
	dubia	0	0
		T	1.763
	others	1.431	1.255
		1.146	1.146
		0.954	1.544
	P. crispus	1.964	2.033
		1.892	1.716
		1.663	1.041
	P. foliosus	1.279	1.544
		1.491	1.763
		0.903	1.415
Controls	*Ceratophyllum*	1.041	0.954
	demersum	0.000	0.699
		1.301	1.924
	Heteranthera	0.477	0
	dubia	0	0
		0	0
	others	1.491	1.380
		1.114	1.255
		1.519	0.954

T calculated as 0.
A = treatments = 2 (fixed)
B = species = 5 (random)
C = time = 2 (random)
n = replications = 3

Figure 8a. Log_{10} organic weight/time (Confid. Coef. 95%). Crispus area controls, 1964.

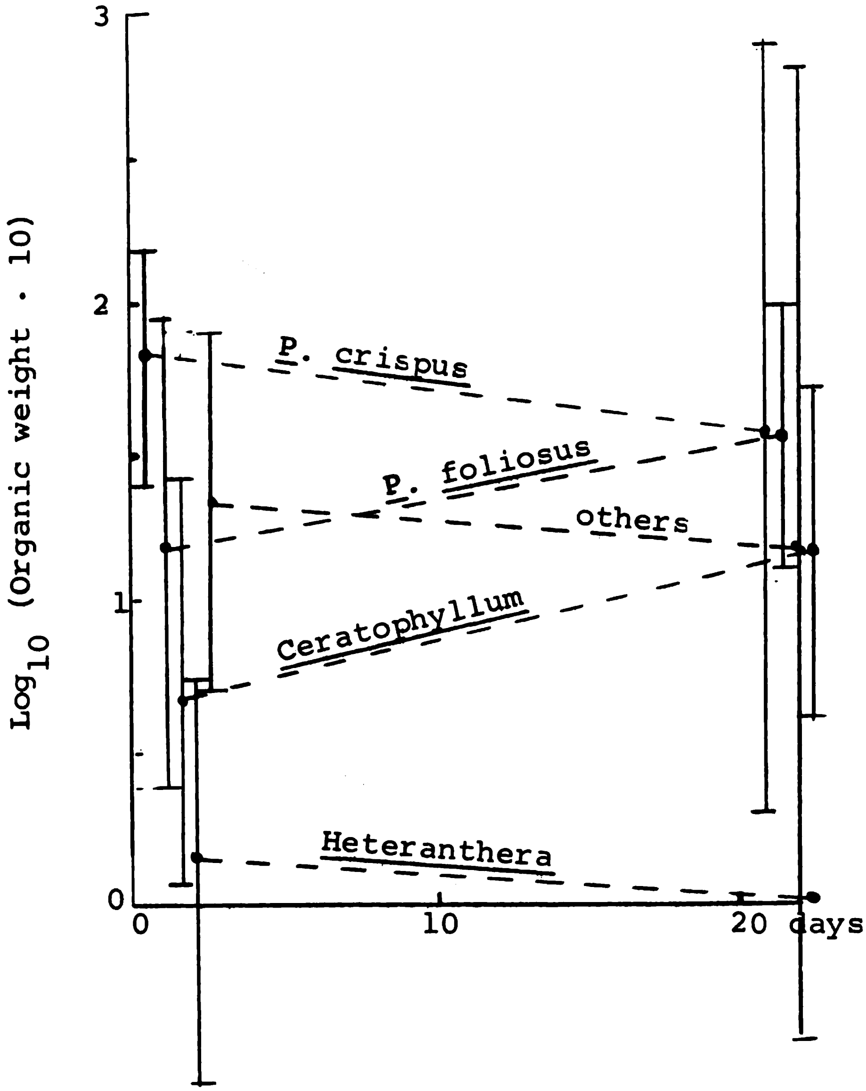


Figure 8b. Log_{10} organic weight/time (Confid. Coef. 95%). Crispus area exclosures, 1964.

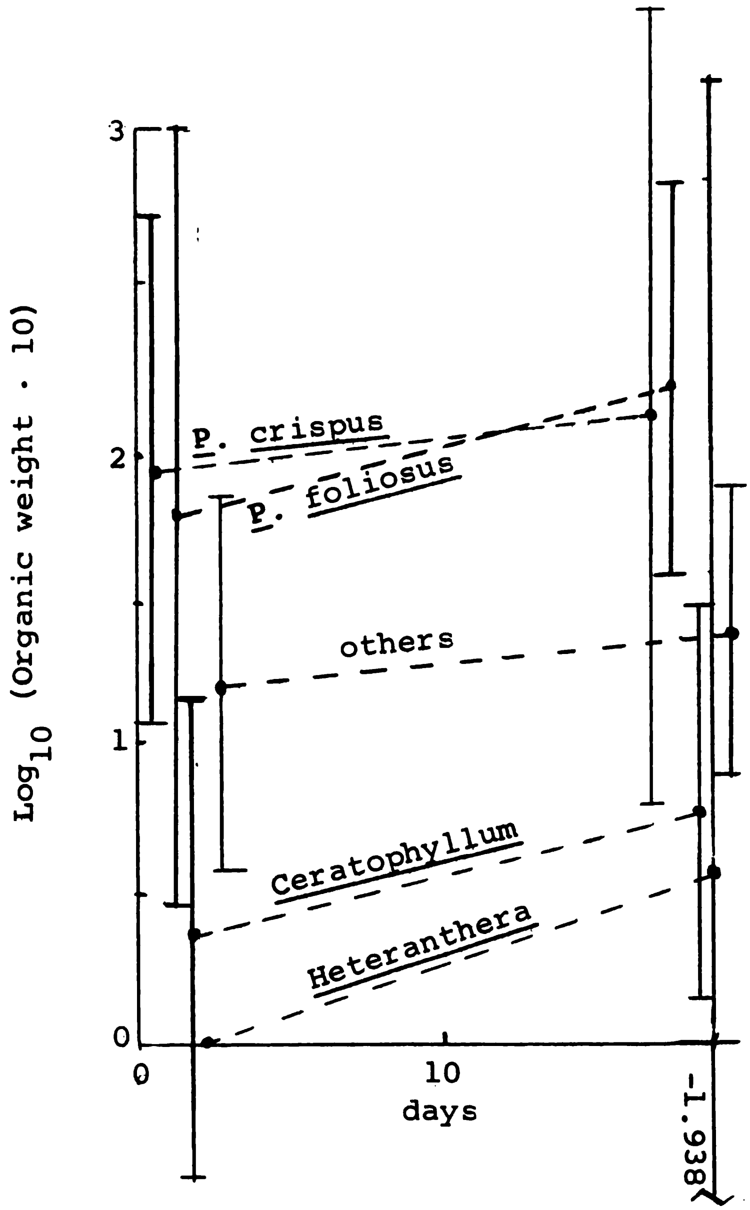


Table 8. Analysis of variance of the transformed exclosure data from the Crispus sample area.[1]

Source	Degrees of Freedom	Sums of Squares*	Mean Squares*	F
A (fixed)	1	0.174	0.174	0.2555^{o}
B (random)	4	22.050	5.513	41.1418^{xx}
C (random)	1	0.548	0.548	4.0896^{o}
AB	4	1.553	0.388	5.7059^{o}
AC	1	0.361	0.361	5.3088^{o}
BC	4	0.537	0.134	0.7701^{o}
ABC	4	0.271	0.068	0.3908^{o}
Error	40	6.977	0.174	
Total	59	32.471		

*This test was checked for only three decimal places.

[1]Table of Estimated Mean Sums of Squares, Appendix II.

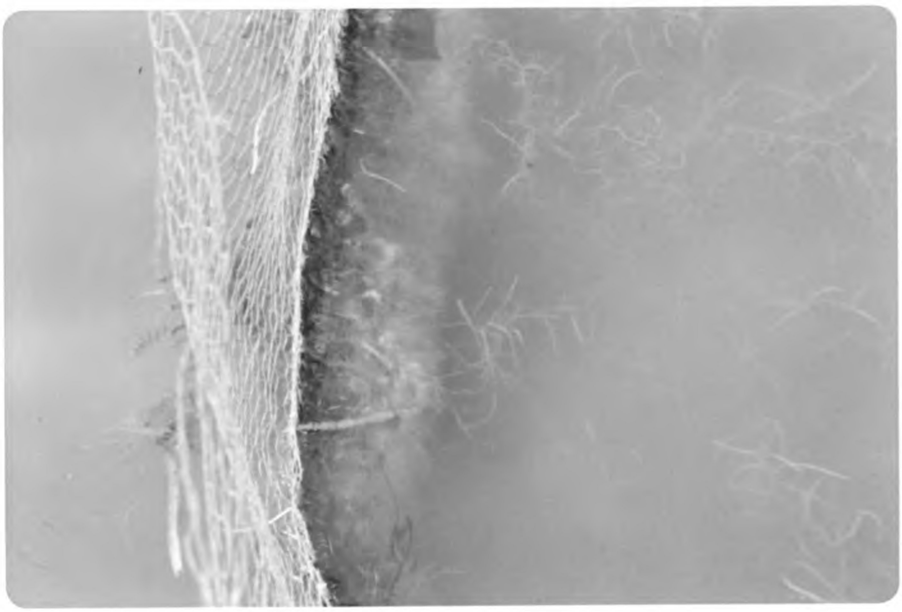


Figure 9: Cladophora on Sago Exclosure #2, September 9, 1964.

Bottom samples: The organic weights of the various plant parts found in the bottom samples are shown in Table 9. Note that these samples represent three replications lumped together, i.e. three square meters. Table 10, shows the relative amount (percentage) of the total plant material sampled which occurred in the bottom samples; in other words, sampling error.

These figures show that the most important errors encountered in the plant samples involved reproductive structures in the form of Winter leaf buds of *P. crispus* and *P. foliosus* and the seeds of *P. pectinatus*. This is not surprising as both the Winter leaf buds and seeds break away from the parent plant rather easily, are small and rather buoyant. This means that not only would they not be seen because of the turbidity but that they would not be encountered when one sifts through the mud for stems and roots. By allowing things to settle for a moment before gently feeling around on the bottom, many buds and seed heads were recovered that might have otherwise been overlooked. However, the sampling frame was only 12 inches high, and I suspect that many buds and seeds were able to float over its rim in the remaining 5 or 6 inches of water. It is worth noting that this material would also be overlooked in the bottom samples.

The relative amount of error (Table 10) is surprising. Physically, the amount of plant material appearing in the bottom samples is very small, but because the structures involved largely represent energy storage mechanisms, they become important in an organic weight determination. The increase in error over the season probably represents continued Winter bud and seed production with accelerating foliage destruction at the end of the growing season.

The only other plant important to the error value is *Elodea canadensis*. This became very brittle and difficult to sample late in the season. Earlier, as it was dying back, *P. pectinatus* was also necrotic and brittle with measurable effect in the exclosures.

Table 9. Plant material in the bottom samples. Y = organic weight in grams/3 m^2.

Sago Sample Area

Material	Exclosures 8/5	Exclosures 9/15	Controls 8/4	Controls 9/16
P. pectinatus				
foliage	10.8	0	1.1	0
seeds and tubers	10.8	6.5	15.1	51.8
P. crispus	1.1	0	1.1	0
Elodea	1.1	58.3	1.1	34.6
P. foliosus	2.2	8.6	2.2	8.6
Heteranthera	0	8.6	0	0
Total	26.0	82.0	20.6	95.0

Crispus Sample Area

Material	Exclosures 8/24	Exclosures 9/10	Controls 8/19	Controls 9/9
P. crispus				
foliage	0	0	0	8.6
seeds and buds	21.6	51.8	30.2	34.6
P. foliosus	2.2	19.4	1.1	21.6
P. pectinatus (seeds)	1.1	0	2.2	4.3
Ceratophyllum	0	8.6	0	1.1
Elodea	0	1.1	0	0
Heteranthera	0	1.1	0	0
Total	24.9	82.0	33.5	50.8

Table 10. Sampling error (grams organic weight/$3m^2$.).

Sago Sample Area	Exclosures		Controls	
	8/5	9/15	8/4	9/16
Total Plant Samples	249.3	140.7	172.2	103.9
Total Bottom Samples	26.0	82.0	20.6	95.0
Total	275.3	222.7	192.8	198.9
% in Bottom Samples	9.5%	36.1%	10.7%	47.7%

Crispus Sample Area	Exclosures		Controls	
	8/24	9/10	8/19	9/9
Total Plant Samples	57.4	117.0	38.6	43.9
Total Bottom Samples	24.9	82.0	33.5	50.8
Total	82.3	199.0	72.1	94.7
% in Bottom Samples	30.1%	41.2%	46.4%	53.7%

<u>Analysis of the depth data</u>: The primary purpose of the depth data was to confirm, in my sample areas, the evidence that carp tend to excavate areas they use and fill-in adjacent areas in which they are not active. King reported up to three inches difference between exclosures and controls in several of his sample areas (1965:46, Table 3). Figure 9 (Op. cit., p. 30) of his thesis is a photograph of both an exclosure and control area completely filled up by carp activity. How this effect may come about is discussed in detail in Chapter VI.

Because the effect of carp on depth seemed to be a good indicator of their presence, the sounding data served a second purpose. By comparing the depth of the controls to the depths of the areas bordering the samples, it is possible to detect any changes in the controls which would indirectly indicate an increased or decreased utilization by carp. The previously mentioned Figure 9 in King's thesis suggests that in clear water, anyway, carp are wary of stakes and avoid control areas. King points out that this wariness disappears in turbid water (Op. cit., p. 29). However, I felt it worthwhile to check the controls in this manner to be sure that the combination of stakes and path around the control areas did not affect activity of carp inside.

Thus, a 3-way analysis of variance was made on the depth data (Figure 10) to test 1) the hypothesis that the exclosures filled up somewhat, and 2) the hypothesis that the controls remained at the same level as the outside areas. In order to test these specific hypotheses, it was necessary to make individual degree of freedom computations following the test for treatment mean heterogeneity.

Although soundings were made in the areas between the exclosures and control areas, these data were thrown out, *a priori*, as the bottom had been disturbed during the installation of the exclosures. Treatments (A) consist of exclosures (A_1), controls (A_2), outside east (A_3), and outside west (A_4). There are three sets of samples (B) in each of the two plant provinces (C). The replications consist of two observations taken two meters apart as shown in Figure 8. Assumptions of variance homogeneity and independence of means and variances were tested and accepted.

The data conforms to a mixed model. The treatment (A) and plant provinces (C) represent fixed components of variance, while the sample component of variance (B) is random. Thus, the estimated mean square for treatment is made up of error effect, treatment effect, and 1st and 2nd order interaction with the random variable (B). Similarly, the other fixed component of variance (C) is made up of error, plant province effect, plus 1st and 2nd order interaction involving (B) and (C). On the other hand, the estimated mean square for samples (B), the random component, consists of error effect and sample effect, only. This is because components (A) and (B) are constant, and any variation within the samples of a given treatment in a given province can only be caused by random effects. This is summarized in the table of estimated mean sums of squares (EMSS), Appendix III.

The null hypothesis of treatment mean homogeneity is rejected at the 5% level but accepted at the 1% level. The specific hypothesis that the mean exclosure depth is the same as the average of the means of the other treatments, tested by an individual degree of freedom computation, is rejected at the 1% level. The second specific hypothesis that the mean depth of the controls is the same as the mean depths outside the sample areas, used to find evidence of deferential use by carp, is accepted at the 5% level and suggests that the treatment mean homogeneity is confined to the exclosure means.

The analysis of variance also suggests that the mean depths of the two plant provinces are different. At most this implies a certain amount of universality for the carp effect.

The 2nd order interaction, which is significant at the 5% level, probably carries over from the very significant difference between plant provinces.

When the data is plotted (Figure 11) it becomes apparent that the outside depths on the west side of the Crispus province are shallower than expected. This appears as treatment-province interaction, but is not significant at 5% level. I interpret this as resulting from the shelving of the bottom toward shore. One would expect this on the west side of the bay as it represents the original shoreline of Lake Erie. The east side of the bay is a recent (1953) dike.

Although the first specific hypothesis, that the exclosures are at the same level as the rest of the area tested is significant, my observations of the vegetation in the sample area lead me to believe that the carp did not reach the Sago area, at least, until very late in August. These observations are supported by the results of the exclosure study which suggested that carp did not affect the vegetation. Consequently, I attribute the filling effect to carp activity between late August and September 8th when the depth data were collected. Due to the relatively sparse vegetation at the Crispus area the effects of carp upon the vegetation were not so easily determined. Possibly carp were present in the Crispus area over a longer period, although their effect upon the bottom there does not appear to be significantly greater than the Sago area (Figure 11).

Observations by King (1965:46, Table 3) tend to support the idea that carp did not penetrate the large areas of pondweed in North Bay until late in the season in 1964. He reported no filling in at his area #5 (organic soil) in the northeastern corner of North Bay in the approximately 10 weeks between May 18th and August 1st. My exclosures (marl) filled in approximately one inch in about six weeks between the end of July and September 9th. King stated that in 1965 sample #5', in the same area, filled in 1 1/2 inches between May 28th and August 1st. This suggests that the carp may have reached my sample areas in the same year and produced significant amounts of turnover.

Figure 10. Depth data from the sample areas. Y = inches.

Sago Sample Area (C_1)

17.50	18.00		19.50	18.25		18.25	17.25
18.00	18.00	18.25*	17.00	16.50	18.25*	18.00	17.25
17.50*	17.50* (B_3)		18.25*	17.50* (B_2)		18.25*	17.50* (B_1)
17.25	17.75	17.75*	18.00	17.50	18.25*	17.25	16.50
18.00	18.00		17.50	18.00		19.00	16.50

E

N ← —+— S

W

Crispus Sample Area (C_2)

16.25	17.00		17.00	16.50		16.25	17.25
17.50	17.25	16.75*	16.00	16.00	16.75*	17.75	17.00
17.00*	16.75* (B_6)		16.25*	17.25* (B_5)		17.00*	16.75* (B_4)
15.25	15.25	16.00*	16.25	16.00	16.50*	16.50	15.50
16.25	16.00		16.25	15.75		16.50	15.00

*Not used in analysis of variance.

Table 11. Depth data used in the analysis of variance. Y = depth in inches.

Plant (C) Province	Sample (B)	A_1 exclosures	A_2 controls	A_3 outside E	$A4$ outside W
	B_1	17.25	18.00	18.25	19.00
		16.50	17.25	17.25	18.50
Sago Area	B_2	17.00	18.00	19.50	17.50
		16.50	17.50	18.25	18.00
	B_3	17.25	18.00	17.50	18.00
		17.75	18.00	18.00	18.50
	B_4	16.50	17.75	16.25	16.50
		15.50	17.00	17.25	15.00
Crispus Area	B_5	16.00	16.25	17.00	16.25
		16.00	16.00	16.50	15.75
	B_6	15.25	17.50	16.50	16.25
		15.25	17.25	17.00	16.00

A = treatments = 4 (fixed)
B = samples = 3 (random)
C = provinces = 2 (fixed)
n = replications = 2

Table 12. Analysis of variance of the depth data[1].

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F
A (fixed)	3	8.2018	2.7339	7.2982^{x}
B (random)	2	0.1484	0.0742	0.3183^{o}
C (fixed)	1	25.1575	25.1575	288.1730^{xx}
AB	6	2.2474	0.3749	1.6070^{o}
AC	3	3.3581	1.1194	1.7275^{o}
BC	2	0.1745	0.0873	0.3745^{o}
ABC	6	3.8881	0.6480	2.7799^{x}
Error	24	5.5937	0.2331	
Total	47	48.7695		

Tests of Specific Hypotheses: (Individual degrees of freedom)

1. $H_o: \mu_{exclosures} = \dfrac{\mu controls + \mu \text{ outside E} + \mu \text{ outside W}}{3}$

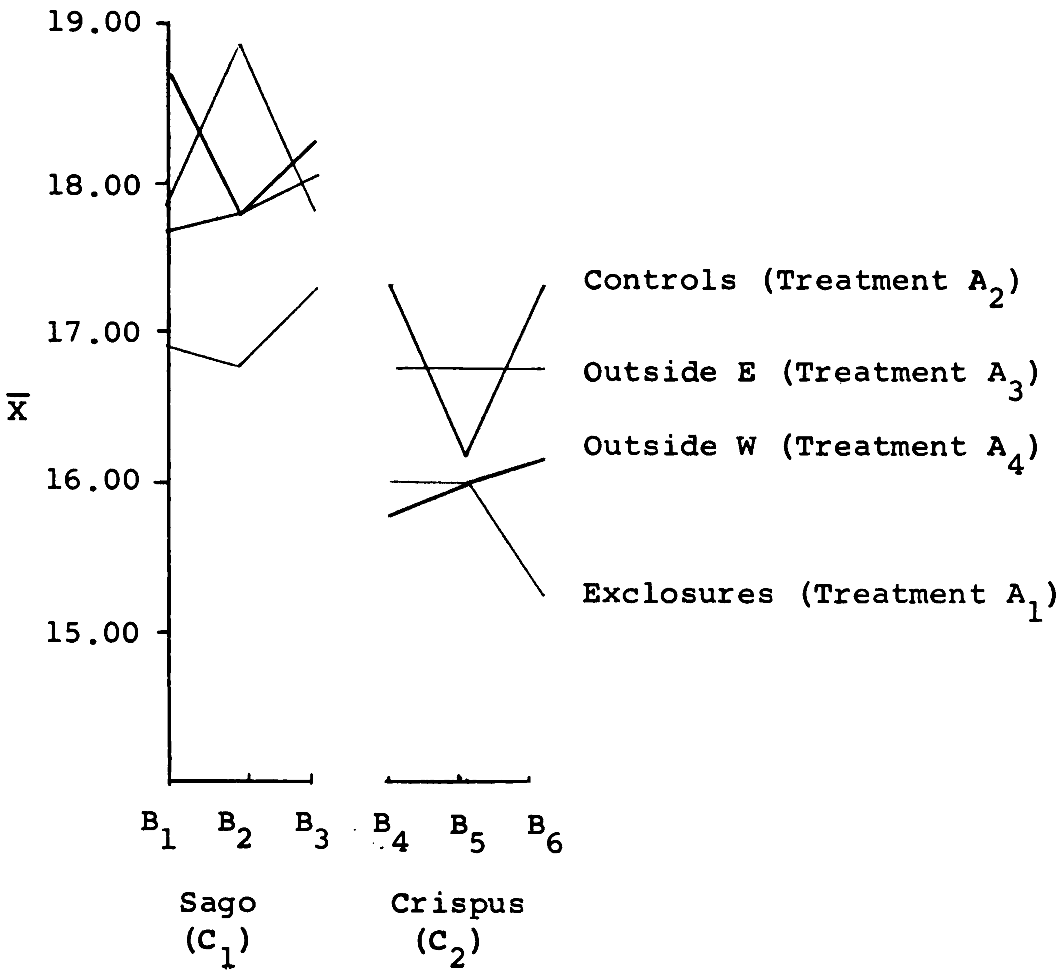
$$F_{(1,\nu)} \quad \frac{0^2}{S^2_{AB}} \quad \frac{7.4529}{0.3746} \quad 19.8956^{xx}$$

2. $H_o: \mu_{controls} = \dfrac{\mu \text{ outside E} + \mu \text{ outside W}}{2}$

$$F_{(1,\nu)} = \frac{0^2}{S^2_{AB}} = \frac{0.0854}{0.3746} = 0.2280^{o}$$

[1]Table of Estimated Mean Sums of Squares, Appendix III.

Figure 11. Depth Data: Mean of replications/samples. Y = inches.



The productivity study: Primary productivity estimates calculated from standing crop measurements have been made for many areas and have appeared frequently in the literature. Although this method of determining productivity has been justifiably criticized (Wetzel, 1964:24-27, 38-29), the results of such calculations for Erie Marsh would represent a useful index with which comparisons between the marsh and other aquatic systems could be made. For this reason plant samples were taken at both sample areas at the very beginning of the growing season in 1965 (May 1st) and again at peak standing crop (July 4th). The increments in organic weight and dry weight over this period were divided by the number of days in the interval (64) to produce the rate estimates.

Before the results of these calculations can be discussed and accurately interpreted, several assumptions inherent in the method must be understood. Possibly the most sensitive assumption made in this type of productivity estimate involves the presence of turnover. Turnover is the rate at which biomass is cropped off or otherwise removed from the area of production. Significant turnover rates result in depressed biomass measurements and, consequently, under estimates of productivity.

As previously mentioned in the exclosure study, the lack of significance between protected and unprotected vegetation indicates that little or no turnover occurred at the sample areas during the sample period in 1964. In 1965, however, when the productivity samples were taken, King (1965:57) stated that the effect of carp was greater. Also, the productivity study was made during the first half of the growing season, and King (Op. cit., p. 67) suggested that carp have a much greater effect upon young plants.

The analysis of the depth data, taken in 1964, indicates that carp probably did enter the sample areas that year, although apparently not in sufficient numbers to affect the plants. As previously mentioned, King's depth data for his sample #5 (1964), which was in northeastern North Bay, was negative during the early part of the season (through July), but positive for approximately the same period in 1965 (sample #5'). His plant data for both samples #5 and #5' were significant, but #5' (1965) was more so. Consequently, there is evidence that the carp arrived earlier at the pondweed areas in North Bay in 1965 than in 1964. My observations of the vegetation on July 4th in 1965 lead me to believe that carp were in area, however the vegetation was less disturbed by them than it was in September, 1964, when the exclosures still failed to show significance. I think it is safe to say in conclusion, that carp-caused turnover was not very important in the 1965 samples. Other effects of carp are discussed in Chapter VI.

Because of the large interval (64 days) between the two 1965 samples, another assumption is probably invalid for the productivity calculations. Because of limited time, I had to guess when the growing season started and when the vegetation peaked and confine my sampling to these two periods. Although I do think I was able to estimate these points well from having already had a year's experience in the marsh, I cannot be sure, but more important, I have no idea of the <u>shape</u> of the standing crop curve. The calculations assume linearity, so I must limit my conclusions to average productivity over the sample period and carefully avoid any allusion to terms which imply instantaneous rates.

A third assumption concerns sampling error. Material overlooked during sampling systematically lowers the productivity curve. The bottom samples (1964) show that plant sampling error became very important as the growing season progressed and more reproductive, energy storing structures were produced. The 1965 plant samples however, were taken early in the season, before the various reproductive structures matured. Therefore, I feel that sampling error is negligible in the productivity study.

Analysis of the productivity data: Productivity is calculated in Table 15. Note that I ignored *Elodea* in the computation of the Sago sample area figures because this species decreased during the sample period (Figure 12).

Because of the assumptions previously described, these figures are undoubtably underestimates. Turnover probably occurred even if carp were absent. Waterfowl, other fish species (Chapter IV), and invertebrates (Chapter V) are known to be present in the area. Growth probably did not start exactly on May 1st, and photosynthesis certainly did not cease abruptly on July 4th. Figures 7 and 8 show that several species continued to grow late in the 1964 season. Furthermore, the aquatic macrophytes are not the only means of photosynthesis. Periphyton, and photosynthetic bacteria probably add significant amounts to the community. Phytoplankton may also be important in spite of the severe turbidity.

This is probably particularly true when the marsh is frozen over and the turbidity disappears.

Sampling error also affects the productivity estimates, but the direction is not clear. The sampling error derived from the bottom sample data is not the only type of sampling error. The large variance inherent in the sample from both areas in both years suggests a large amount of clumping in the vegetation, both by species and in the absolute amount of vegetation present. The confidence intervals shown in Figures 7 and 8 (1964) and 12 and 13 (1965 (computed together) are still quite large inspite of the log transformation. Confidence intervals for the raw data were invariably twice as large as the means. Thus, as Figures 12 and 13 indicate, very little precision can be expected from these data. As is frequently the case, twice as many samples, twice as large, should have been taken twice as often in this study. Unfortunately, this would have required twice as many workers.

<u>Comparisons of productivity data</u>: Recently, Westlake (1963) reviewed and summarized the productivity figures which have appeared in the literature. Using metric tons of organic production/hectare/year as units, he compared many terrestrial and aquatic communities. Converting the

organic weight data from the July 4th maximum (0.01 times grams/meter^2 = m. t./ha.), produces values of 1.1 and 0.5 m. t./ha. for the Sago and Crispus areas, respectively. This places the sample areas at Erie Marsh at the lower end of the range for submerged angiosperms at infertile sites (1.0 - 2.5 m. t./ha./yr.) according to Westlake. It must be pointed out, however, that my figures represent underestimates (see above), particularly with respect to phytoplankton productivity which Westlake accounted for and I ignored.

For comparison, it is interesting to note that Westlake estimated production of submerged aquatic plants at temperate, fertile sites between 4 and 7 m. t./ha./hr. Temperate, shallow, benthic, marine plant production (25 - 33 m. t./ha./yr.) and fertile reed swamps (30 - 45 m. t./ ha./yr.) are much higher. Figures for temperate, fertile, terrestial sites include: coniferous forests, perennial herbs, and intensive agriculture at 25 - 40 m. t./ha./hr. and deciduous forests, uncultivated herbs, and cultivated annuals at 10 - 25 m. t./ha./hr.

Seed and Winter leaf bud production: Table 16 was drawn up from both the plant data and the bottom sample data, where noted. The plant data represent the mean of 3 one square meter replications. The bottom sample replications were expanded by a factor from 2 thirty-six square inch Eckman dredge samples to be equivalent to a square meter replication.

P. foliosus Winter leaf buds, which were present in most samples in large numbers, are not included. They are so small and so similar to the foliage that no effective method could be devised to isolate them. *P. pectinatus* produced both seeds and tubers, but I saw less than a dozen tubers during all the sampling operations in the marsh. Those which I did find occurred mostly in the Sago area on July 4th, 1965. *P. crispus* produced both seeds and Winter leaf buds in large numbers. The Winter leaf buds are much more important in these figures due to their large size.

Table 13a. Productivity data for the Sago sample area. Y = organic weight in grams (550°C)

Treatment	Species	Dates 5/1/65	7/4/65
	P. pectinatus	T	150.3
		0	54.9
		0	103.7
	Elodea	7.6	2.0
Controls	*canadensis*	6.2	3.9
		20.3	2.0
	P. foliosus	0	0.9
		0	1.8
		0	7.2
	others	T	0.5
		T	0.6
		TT	2.6

Table 13b. Transformed productivity data for the Sago sample area. $Y' = \log_{10}(10Y)$

Treatment	Species	Dates 5/1/65	7/4/65
	P. pectinatus	T	3.177
		0	2.740
		0	3.016
	Elodea	1.881	1.301
Controls	*canadensis*	1.792	1.591
		2.308	1.301
	P. foliosus	0	0.954
		0	1.255
		0	1.857
	others	T	0.699
		T	0.778
		TT	1.415

Figure 12. Log_{10} organic weight/time (Confid. Coe. 95%). Sago area, 1965

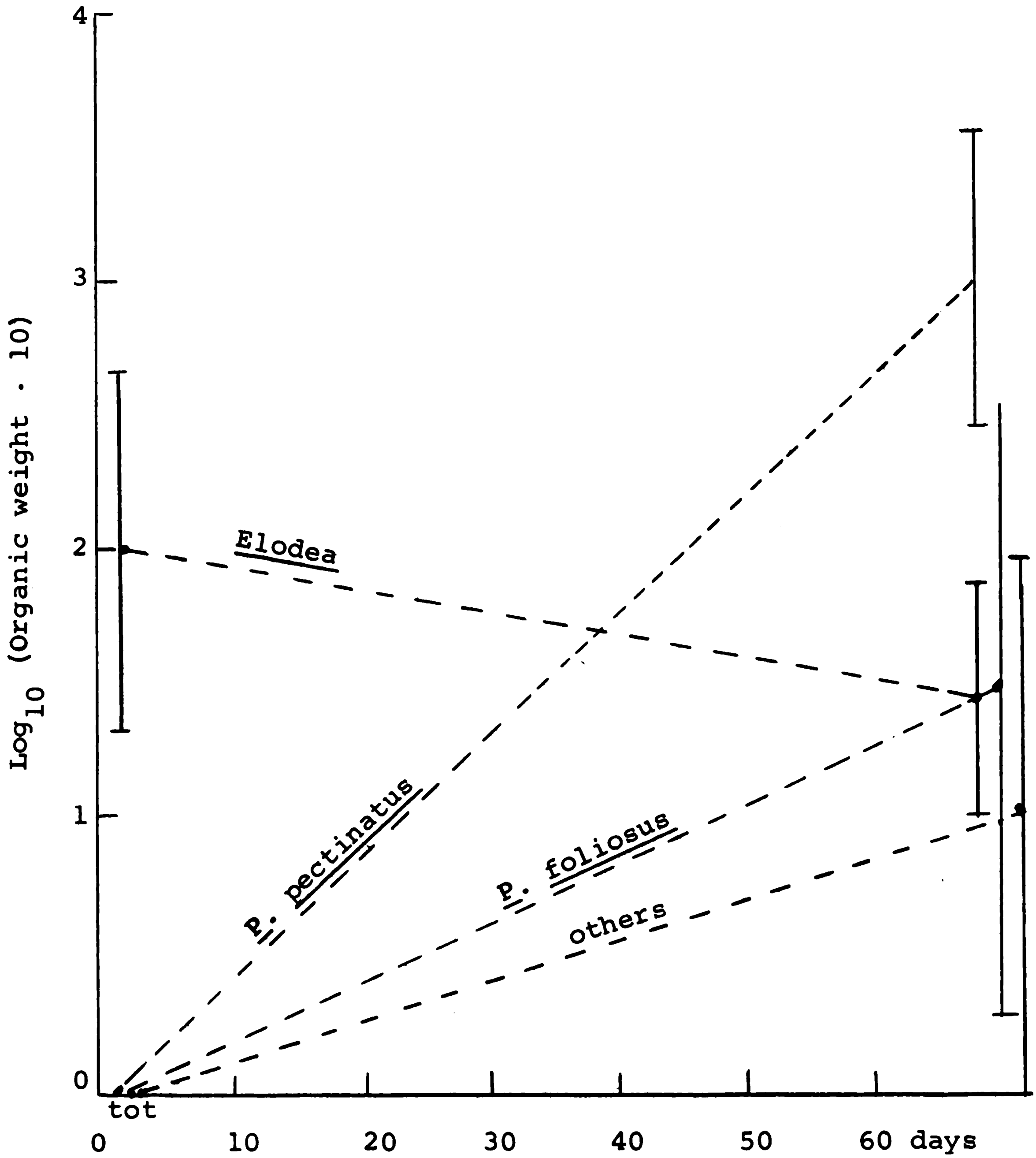


Table 14a. Productivity data for the Crispus sample area. Y = organic weight in grams (550°C)

Treatment	Species	Dates 5/1/65	7/4/65
	P. crispus	0	6.6
		0.4	27.5
		0.2	32.0
	P. foliosus	0	9.8
		0	10.3
		0	15.3
Controls	*P. pectinatus*	0	14.4
		0	13.6
		0	9.6
	others	TT	0.4
		T	0.1
		TTT	0

Table 14b. Transformed productivity data for the Crispus area. $Y' = \log_{10}(10Y)$

Treatment	Species	Dates 5/1/65	7/4/65
	P. crispus	0	1.820
		0.602	2.439
		0.301	2.505
	P. foliosus	0	1.991
		0	2.013
		0	2.185
Controls	*P. pectinatus*	0	2.158
		0	2.134
		0	1.982
	others	T	0.602
		T	0.000
		T	0

Figure 13. Log_{10} organic weight/time (Confid. Coef. 95%). Crispus area, 1965.

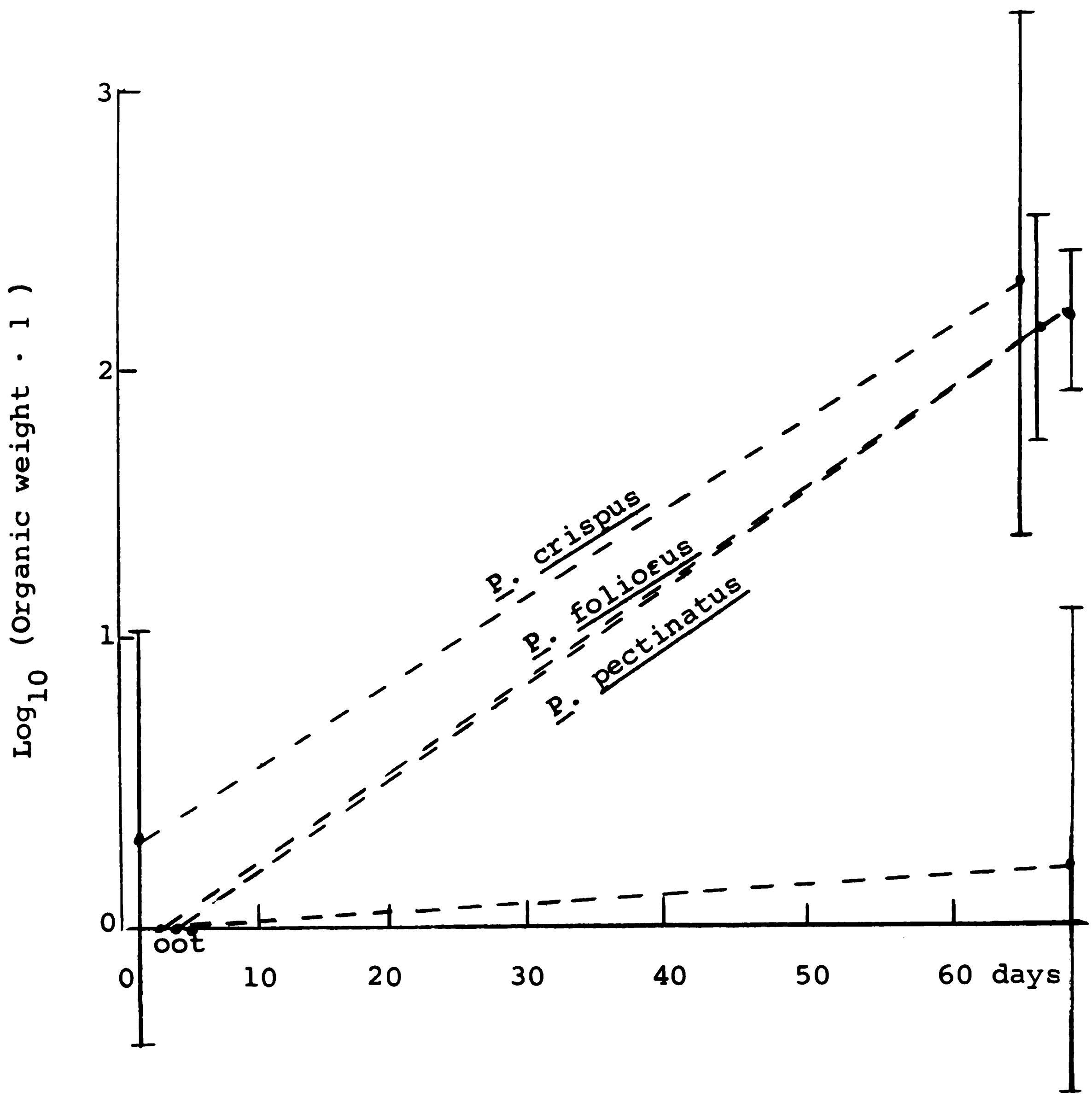


Table 15. Productivity calculations for 1965 samples.

Item	Dry Weight/m^2.		Organic Weight/m^2.	
	Sago*	Crispus	Sago*	Crispus
5/1/65	0.3 g	0.7 g	0.1 g	0.3 g
7/4/65	176.7 g	73.6 g	107.5 g	46.5 g
Biomass (64 days)	176.4 g	72.9	107.4 g	46.2 g
Grams/m^2./day	2.8	1.1	1.7	0.7
Annual gms./m^2./day (365 days)	0.5	0.2	0.3	0.1

*Elodea in the Sago area decreased during the sample period and was ignored in the computations.

Table 16. Seed and Winter leaf bud production[1]. Y = organic weight/m^2. (means of 3 replications)

Sago Sample Area	5/1/65	7/4/65	8/5/64[2]	9/15/64[2]
Exclosures:				
P. pectinatus (seeds)	-	-	5.3	2.6
P. crispus (seeds and Winter buds)	-	-	0.4	0
	5/1/65	7/4/65	8/4/64[2]	9/16/64[2]
Controls:				
P. pectinatus (seeds)	0	0.9	6.2	18.1
P. crispus (seeds and Winter buds)	0	0	0.4	-

Crispus Sample Area	5/1/65	7/4/65	8/24/64[2]	9/10/64[2]
Exclosures:				
P. pectinatus (seeds)	-	-	0.4	0
P. crispus (seeds and Winter buds)	-	-	11.2	22.4
	5/1/65	7/4/65	8/19/64[2]	9/9/64[2]
Controls:				
P. pectinatus (seeds)	0	0.3	0.8	1.4
P. crispus (seeds and Winter buds)	0	0.3	2.0	12.7

[1] *P. foliosus* not included.

[2] Sum of plant and bottom samples.

IV. FISH IN THE SAGO SAMPLE AREA

In order to obtain an estimate of the fish population actually surrounding the sample areas, a small area, approximately 25 yards in diameter, near the sago sample was treated with rotenone on September 9, 1964 (3:00 PM). (See Figure 1.) Mr. Kenneth Reau, the club manager, offered the use of the rotenone for which I am very grateful. The chemical had been exposed to the elements for several years and had obviously deteriorated to some extent. It is not known, therefore, if the minimum toxicity for total kill was achieved. Six 11 quart pails of the dry material were mixed into a slurry, then poured into the wake of the boat. My strategy consisted of making a large ring initially, then blanketing the enclosed area.

The effects were immediate. Gizzard shad came up first, followed by everything else. The bullheads came up last and seemed to be the most resistant to the chemical. Besides the possibility of less than 100% kill, another possible bias entered the sample when I had to compete with a flock of seagulls to pick up the paralyzed fish.

The results of the poisoning are tabulated in Table 17. Young carp are the most frequently encountered fish, with black bullheads a close second. Green sunfish are also common; goldfish and gizzard shad less so. Gizard shad are the largest fish in the sample, and they may approach dominant biomass in the sample area on that basis. If minimum toxicity was not achieved, the apparent susceptability of the shad may have biased the sample in their favor. No adult carp were captured. They were seen in other parts of the bay at the time, but they may have had enough stamina to escape the small lethal area, if any entered it at all.

Sampling was also attempted with a small, commercially produced minnow trap and with a homemade trap of greater proportions supplied by Mr. Reau. In all cases, sunfish were very dominant in these samples, and, if the poisoning results are accurate, represent a tremendous bias in favor of sunfish by the trapping technique.

In addition to these observations made at the sampling site, I caught and saw fish caught at other locations. Several white bass, all about 4 inches long, were caught in South Bay, and club members' children enjoyed great success at the Boathouse Dock catching bullheads and bluegills.

Previous investigators in the marsh have found in addition, yellow perch, black crappie, smallmouth black bass, dogfish, walleye, and gar (Hunt, 1958:37); channel catfish and yellow bullheads (Tack and Singh, 1959:2); "shiners" (Matulis and Pirnie, 1960:7). The poorly screened weir connecting the marsh to Lake Erie makes it possible for any species in western Lake Erie to enter the bays.

As Table 17 indicates, many of the fish in the area could go through the one inch netting of the exclosures. These are probably the only vertebrates that entered the exclosures. The small size and high sides of the exclosures would discourage waterfowl.

Table 17. Fish near the Sago sample area - taken during the Summer of 1964. (Size classes in centimeters standard length.)

Poisoned: September 9, 1964 (rotenone)	0-2	2-4	4-6	6-8	8-10	10-12	Total
Black bullhead Ictalurus melas (Raf.)		35					35
Brown bullhead Ictalurus nebulosus (LeSueur)			1				1
Carp Cyprinus carpio (Linn.)		38	4				42
Goldfish Carassius auretus (Linn.)		7	3				10
Green sunfish Lepomis gibbosus (Linn.)	16	3					19
Pumpkinseed Lepomis gibbosus (Linn.)				1			1
Gizzard shad Dorosoma cepidianum (LeSueur)			4	3	1	2	10
White bass Roccus chrysops (Raf.)				1			1
Total							119

Reference: Eddy, 1957

Table 17. Fish near the Sago sample area- taken during the Summer of 1964. (Size classes in centimeters standard length.) (Con't.)

Trapped	September 8-9		September 10-14			
	2-4	4-6	0-2	2-4	4-6	Total
Minnow trap 17" x 9" dia. opening 1", mesh 1/4"						
Black bullhead *Ictalurus metas* (Raf.)					1	1
Carp *Cyprinus carpio* (Linn.)					2	2
Green sunfish *Lepomis cyanellus* (Raf.)	3		5	25	1	34
Pumpkinseed *Lepomis gibbosus* (Linn.)	2		1	4		7
Big trap 2 1/2' x 3' x 1 1/2' opening 5", mesh 1 x 2"	September 9-14					
Carp *Cyprinus carpio* (Linn.)	1					1
Green sunfish *Lepomis cyanellus* (Raf.)	3	1				4
Total						49

V. INVERTEBRATES IN THE SAMPLE AREAS[1]

Invertebrates were not systematically collected during this study. Many midge larvae (*Tendipides*) were found in the bottom samples, but, because these samples were taken immediately after the plants were removed from the same area with the resulting disturbance of the bottom, the samples are not quantitative. Snails were not common in the vegetation, although there were large numbers of empty shell in the bottom material. Amphipods occurred frequently in the plant samples but not in large numbers. One crayfish [*Orconectes immunis* (Hagen)] was found in a minnow trap, and five more were captured during the removal of the exclosures. One freshwater clam [*Anodonta marginata* (Say)] was found in the Sago area. Leechs [*Placobdells parasitica* (Say)] were frequently seen during the installation of the exclosures. Several damsel fly casts were found on exclosure and control stakes in 1964.

As I will describe later (Chapter VI), piscicides

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[1]Reference: Eddy and Hodson, 1962

have been frequently used in the marsh. Tack and Singh (1959) demonstrated the slow recovery of midges (Tendipides) from the 1958 poisoning. Crayfish were also affected. Backswimmers (Notonectidae) and water boatmen (Corixidae) were wiped out in poisoned areas in 1962 and recovered only slightly in 1963 (Foster, 1962:3 and 1963:6). Dr. Hunt (1958:39-40) experimented with 3 species of snails in 1958 and stated that they have an immunity to toxaphene. In 1962 living snails were observed following the poisoning that year (Pirnie and Foster, 1964:28).

VI. CARP AND TURBIDITY

The effects of carp are a traditional problem in Erie Marsh. Recently, King (1965) dealt with the effects of carp upon the aquatic vegetation specifically. His evidence concerning the direct effects of carp, i.e. those which may be differentiated between exclosed and unprotected areas, have already been discussed with respect to my sample areas. The indirect effects of carp upon the marsh, i.e. turbidity and silting, are much more difficult to measure, and neither Mr. King nor I were able to find good evidence concerning this problem. Mr. King, consequently, confined his discussion almost entirely to the direct effects of carp and made only brief mention of the possible indirect effects.

The dry and organic weight biomass and productivity data discussed in the productivity study are probably the best evidence available concerning the possible detrimental indirect effects of carp upon the vegetation in the marsh. Yet, comparisons drawn between the sample areas at the marsh and other areas described in the literature do not account for the many other environmental factors, unique to an area, which are known to affect plant growth. In addition, I have become aware, both by personal observation and from the literature, of certain phenomena which raise the possibility of significant indirect effects of carp upon aquatic vegetation. Consequently, I would like to supplement Mr. King's topic with a critical review of his discussion of carp and turbidity, as well as other literature, in light of my own observations.

Carp: Carp are always present in the marsh despite four recent attempts to poison them out. Toxaphene was applied on July 17, 1958 (Tack and Singh, 1959:1); June 2 and 5, 1959 (Hunt, 1959:22); July 26, 1962 (Pirnie and Foster, 1964:24), and an application of rotenone was made sometime between 1953 and 1957 (King, 1965:17). Following every poisoning, large numbers of carp were again evident in the marsh within a few months (Hunt, 1958:39, 1959:22-24, and Matulis and Pirnie, 1960:7), and there is some doubt that 100% kill was achieved at any time. Apparently the weir which connects the marsh to Lake Erie is a source of carp reinfestation. Foster (1962:5) reported that two additional poisonings in the immediate vicinity of the weir, following the main poisoning operation by about a month, killed a few large carp and up to 500 small ones. In the early Spring of 1964 and several times in the Winter of 1964-65, I observed hundreds of young and adult carp lining up on the Lake Erie side of the weir. King (1965:30, Figure 8) has an excellent picture of this lining up behavior in the marsh. (In that case the carp were attempting to enter the Sulfur Springs outlet.) A screen, capable of preventing larger carp from passing through the weir (Pirnie and Foster, 1964:26), was removed on July 28, 1964.

Carp are the most commonly observed fish in the marsh, and large numbers of adults could be seen anytime one walked the edge of a canal or dike in 1964 and 1965. In North Bay adults were always evident in one area or another during my sampling trips. Reports to the Erie Committee indicate how dominant and numerous the carp are in the marsh. In 1959, Tack and Singh (1959:2) reported that 95% of the fish (by numbers) poisoned the previous Summer were carp between one and six pounds. They also reported that 4.5% of the kill consisted of goldfish X carp hybrids. In 1962, Wood (1962:1) estimated the kill that year was on the order of 100,000 pounds of fish, of which 99% were carp. King (1965:40) estimated carp density in North Bay on June 22, 1965 at 100 to 200 individuals per acre, or 500-1000 pounds per acre.

Turbidity: Turbidity was a constant feature in North Bay during 1964 and 1965, with the exception of periods with ice cover. In the sample area, I seldom recorded secchi disk readings of more than a foot. King (1965:65) stated that average secchi disk readings for any of his locations were never more than 4 1/2 inches less than the depth. Concurrent with the turbidity was a great deal of silt deposition on the aquatic vegetation. The Erie Reports since 1957 mention turbidity and silting of the vegetation repeatedly.

The evidence concerning the turbidity in Erie Marsh recorded to date poses two perplexing questions whose answers each involve a paradox. First, what causes the observed turbidity? Paradoxically, the water is turbid and the vegetation silted even in the middle of solid, apparently undisturbed vegetation. Second, does the turbidity affect the plants? On the other hand, there are vast areas in the marsh which support extremely dense vegetation in spite of the turbidity and silt deposition which could drastically reduce the energy available for photosynthesis.

<u>The cause of turbidity</u>: The traditional assumption is that the direct cause of turbidity at the marsh is suspended bottom material, and that the roiling produced by feeding carp is the agency which puts the bottom material into suspension. The silt on the vegetation results from the bottom material coming out of suspension. There is good evidence for this mechanism.

First, there are direct observations of the feeding behavior of carp (King, 1965:40, and Black, 1946) which indicate that the carp seek food in the bottom material. These observations are by the strong evidence that carp affect the bottom relief in the marsh. King (Op. cit., p. 40-41) reported that on several occassions he investigated areas where carp had been feeding, and each time he found depressions in the bottom which were devoid of vegetation. In July of 1965, in the northern part of North Bay (an area supporting sago and other pondweeds), he discovered holes in the bottom one to four feet wide and two to six inches deep. He estimated that in an area heavily used by carp that five to ten percent of the bottom area had been directly disturbed by carp activity.

Flats exposed during the record low water of 1964 in Lake Erie, on the other side of the South Dike, gave additional evidence of what the bottom of North Bay may look like. The flats were pitted in a manner which suggested the work of feeding carp. The pits tended to be elongate, with one side abrupt and the other sloping. The pits were generally less than four inches deep. As opposed to the five to ten percent area which King found in North Bay, I estimate that the pitting on the flats approached 50% in some locations. Finally, the large variance in the sounding data from my sample areas suggested the presence of a great deal of irregularity on the bottom which probably reflected a pitted or wrinkled surface.

Second, that carp have the ability to move a significant amount of bottom material in a limited time is suggested by the filling in of exclosures recorded by both King (1965:46, Table 3) and I (See: Analysis of the depth data).

Third, the several poisonings of the marsh have produced experimental evidence, as opposed to strictly empirical, of the connection between carp and turbidity. Hunt (1958:23) reported that the turbidity and deposition of silt on the leaves of aquatic plants, all but disappeared following the 1958 poisoning. Secchi disk depths increased from 13 inches before the poisoning to 46 inches only five days after the 1959 poisoning (Hunt, 1959: 24). Foster (1962:3) and Wood (1962:2) again observed a clearing of the water and a disappearance of silt on the vegetation following a poisoning in 1962.

Fourth, if the turbidity in the marsh is due to the presence of phytoplankton or zooplankton, one would expect the turbidity to remain unchanged following a poisoning or even to increase as a result of the nutrients released by the decomposing fish. Following the 1962 poisoning, zooplankton did become noticeable, but not until a dramatic increase in water transparency had already occurred (Wood, 1962:2). Furthermore, it would be difficult to explain the tremendous amount of silt deposited on the vegetation if the turbidity was not caused by suspended bottom material.

Fifth, the possibility that wind may stir up the bottom during mid-season is discredited by the rapid and dramatic clearing following carp removal. Hunt (1958:23) specifically mentions that winds of 20-25 MPH did not produce turbidity following the poisoning of 1958.

If the feeding activities of carp are the only significant cause of turbidity in the marsh, the question remains as to why even large areas of very dense aquatic vegetation are turbid and silted when there is no evidence of physical penetration by carp. This paradox was particularly striking during July and August of 1964 at the Sago sample area. At the time the vegetation of the vast southern part of North Bay was very dense, and obviously had not yet been used by the carp. In spite of this, the vegetation had thick deposits of silt and the water that could be seen was turbid. It was not possible to take meaningful secchi disk readings during the period of very abundant vegetation because when the disk was forced through the vegetation, which grew right to the surface, the silt on the leaves became dislodged and immediately obscured the disk.

Just previous to this period, between June 15 and July 2, King observed that the water was relatively clear (personal communication). This relatively clear period was during the very peak of vegetation that year, and this observation led King to conclude that the turbidity was more closely related to wind and bottom type early and late in the season (1965:95). He felt that the turbidity present during mid-season, while the vegetation was up, was caused by carp, but that this turbidity was not important (1965:65). According to King, then, the turbidity I observed between July and August, i.e. after die back, was caused by wind not carp. I cannot entirely agree with this conclusion. In spite of the dying back of the vegetation from the surface of the water, there was still a dense, resilient layer of Eloden, encountered at a depth of 4-5 inches and continuing to the bottom present in the Sago sample area. Also, this dense but submerged vegetation showed not evidence of carp activity in the Sago area and the exclosures were not statistically significant. Carp were present in the bay but seemed to be limited to the west side. King (1965:41-42) observed heavy carp activity in the northwest corner of the bay, but stated that in 1964, at least, the carp tended to remain localized and in areas of less dense vegetation. By late August, carp did invade the Sago area as evidenced by the depth data taken in September. The results from the exclosure study indicate, however, that at no time was the effect of carp very great in the sample areas.

If the turbidity produced by the carp is so long lasting that it is able to circulate from the limited areas of carp activity in North Bay in 1964 to the middle of my eastern, Sago sample area, then the question remains as to why the marsh clears so quickly following a poisoning. One possible explanation for this is that clay, which can remain in colloidal suspension for long periods of time, is causing the turbidity and that some subtle change in water chemistry precipitates the colloid following a poisoning. Irwin and Stevenson (1951) have shown that any factor which liberates positive ions can produce a rapid flocculation and precipitation of clay turbidity.

Although the marsh contains a good stand of higher aquatics which probably produce an excess of flocculating agents (Irwin, 1945), I had a mechanical soil analysis run on one bottom sample from each sample area to determine the presence of clay in the marsh. The analysis was done by the Soil Testing Laboratory at Michigan State University. Although the results are variable and made it necessary for the Soil Testing Laboratory to make two independent tests on each sample plus an additional one on the Sago sample, the clay determination was always less than ten percent averages approximately 5% in both areas. Of this 5%, possibly only a small fraction is true clay material; the rest simply being very small silt particles. By far the dominant material in the samples was silt which approximated 80% in both samples. The sand component represents small snail shells and other shell fragments as well as true sand. These results, according to Mr. Don Christianson (personal communication) presently in charge of the Soil Testing Laboratory, represent a situation common to marl deposits, and are thus in accord with Eby's description of the area (1959:13).

Investigating the standard soil testing techniques used on these samples, led me to believe that the physical properties of the bottom material, at least in the sample areas, may not be in the marsh. A mechanical analysis of soil by the hydrometer (Bouyoucos) method is based on Stokes' Law which states, in effect, that particles fall through a liquid at a rate directly proportional to the square of their radii. To perform a mechanical analysis, a given amount of soil is shaken up in a given amount of water, 40 seconds allowed for the sand to settle out, and then the density of the solution is measured. Two hours later the density is again measured, and the difference computed to determine the percentage of silt (USDA system), i.e. particles between 0.05 mm. and 0.002 mm. in diameter, which has settled out (Miller, Turk, and Foth, 1965:28-29). Thus the sample areas in North Bay, which are only a few inches deeper than the standard 1000 ml. cylinder used in the soil test, should clear within about two hours in the absence of carp.

As pointed out above, this does not seem to be the case for the Sago sample during July and August, although King recorded relatively clear water in North Bay earlier in the season. If the carp were absent during July and August from the Sago sample area as the vegetation seems to indicate by both visual observation and statistical analysis, then there must have been a very active circulation of suspended sediments from the area of carp activity in the northwestern corner of North Bay to the Sago sample area in the southeastern corner. How this circulation could occur in such dense vegetation is yet another paradox. Possibly the wind, which prevails in roughly the right direction, can cause enough movement of the thin layer of water over the vegetation to transport at least the smaller particle turbidity the required distances. I observed that the turbidity resulting from sampling activities moved down wind rapidly in the sample areas.

In the absence of any real evidence that such circulation exists, at least two areas seem worthy of more investigation. First, an examination of the bottom material under ice cover is in order. Possibly the low percentage of clay present in the Summer when the area is turbid means that most of the clay present is already in suspension in the water. This could also be checked with samples of turbid water and by analyzing the material deposited on the vegetation. Second, the effects of small carp, which were relatively abundant in the Sago sample area (Chapter IV.), may be as significant as the more obvious effects of the adults.

In summary, my observations lead me to believe that the activities of carp, as presently understood, cannot maintain all the turbidity present in Erie Marsh. When very dense vegetation is present, and possibly at other times as well, some sort of synergism may be operating in the marsh which extends the effect of carp or nullifies the apparent two hour time limit imposed upon the suspended bottom material by Stokes' Law. A determination of the importance of this synergism, if it exists at all, is difficult. Possibly in 1965 and in other years when the carp population has not been depleted by recent poisonings, carp have been present in sufficient numbers to maintain turbidity in the usually hypothesized manner. The impact of the carp upon the vegetation during 1965 and the estimate by King of densities between 100 and 200 individuals per acre that year in North Bay is sufficient to make this creditable.

The effects of turbidity: The second question raised by the observations of turbidity in Erie Marsh concerns the effect of the turbidity upon the aquatic vegetation. As described in the previous section, turbidity is virtually unavoidable in the marsh. Following every poisoning, none of which may have been 100% effective, carp were rapidly recruited through the weir, and even low densities of carp in North Bay seem to produce turbidity and deposition of silt on areas remote from carp activity. Also, the poisonings have always occurred near the period of maximum standcrop, and, thus, after the period of maximum productivity (Wetzel, 1964:38-39). Consequently, comparative data on plant biomass in the absence of turbidity has been impossible to obtain. That evidence which is available is inconclusive. The analysis of the exclosure data indicates that the direct effects of carp upon the vegetation, i.e. mechanical uprooting and direct consumption, were not felt at the sample areas in 1964. But the exclosures could not exclude turbidity, and the effect of turbidity must have been the same in both exclosures and controls. The biomass and productivity data give no indication of what productivity might have been if turbidity was absent. Hunt (1958:22) observed regrowth of the aquatic vegetation following the 1958 poisoning, but this could have been due to the cessation of the mechanical effects of carp, alone.

It seems to me that regardless of wind caused turbidity early in the season (King, 1965:95), turbidity caused by carp could be important in terms of absolute primary productivity because the effects of carp caused turbidity are felt most at the time of maximum photosynthetic display, i.e. in the middle of the growing season when the effects of wind are minimized by the plant mat. Further, although turbidity caused by wind action may be significant early in the season, carp must make an important contribution to this at the time by their breeding activities, which start in April continue through May (King, 1965:25-27). As previously mentioned, the turbidity produced by carp may have the ability to circulate through the marsh even if the area used by carp is quite limited.

Concerning the turbidity present during the middle part of the season, i.e. that caused by carp, King stated the opinion that this was not important at depths less than 18 inches and where secchi disk readings are greater than 12 inches (1965:65). I assume this opinion is based upon observations that the vegetation remains very vigorous and dense in spite of the turbidity. If so, I agree with the observations but feel that the effects of turbidity may be expressed in more subtle terms than plant bulk.

Foster (1962:3) observed that leaves of crispus pondweed covered with silt were transparent. My observations confirm this, although in my experience only lower leaves were affected in this way, even when silt had been deposited over the whole plant. Assuming that the transparent leaves are not photosynthetically active and that the plant responds to this by producing more leaves and supporting structures, the possibility arises that plant biomass and photosynthetic activity are not well correlated. In other words, a plant responding to the presence of silt must create more biomass that a plant not bothered by silt to intercept the same amount of light energy. This greater investment of energy and nutrients in photosynthetic machinery might result in decrease in the production of seeds and other energy storing structures. If there is any relationship between the production of these and the attraction of ducks to the marsh, the results of carp caused turbidity may be of practical importance. A study of a nearby and apparently similar area by Anderson (1950) may support this hypothesized relationship between turbidity and seed production. Working at Middle Harbor, Ohio, Anderson found that seed production by sago pondweed was limited to May and June in the presence of carp and turbidity. The following year, after the carp had been poisoned out and a significant increase in water transparency, he discovered that seed production was stimulated to continue through early Fall. Table 16 indicates that seed production continued through August in Erie Marsh in 1964, but the amount of production may still have been affected.

There is a possibility that the effects of carp are not entirely detrimental to vegetation. Dr. Miles D. Pirnie, who is familiar with the Erie Marsh and similar areas in the mid-west, thinks that in some situations carp may provide open, "cultivated" spots on the bottom which may be required for the germination of some species (personal communication). Also, recent work by Dr. Robert G. Wetzel (1965) indicates that organic molecules may chelate certain nutrients, making them available to plants when they might otherwise be limiting. There may be enough organic matter in the bottom material turned over by the carp at Erie Marsh to be significant in this respect.

VII. CONCLUSIONS

1. Excluding the direct effects of carp had no significant effect upon the aquatic macrophytes of the sample areas during the second half of the growing season in 1964.

2. The analysis of the depth data indicates that carp were present in the sample areas in 1964 in sufficient numbers to have a significant effect on the bottom topography.

3. Plant growth between May 1 and July 4, 1965, was estimated at 107.4 grams organic weight/meter^2 in the Sago area and 46.2 grams organic weight/meter^2 in the Crispus area.

4. The average primary productivity by macrophytes during this period (64 days) was estimated at 1.7 grams organic weight/meter^2/day in the Sago area and 0.7 grams organic weight/meter^2/day in the Crispus area.

5. Many factors, including the indirect effects of carp

the presence of several other species of fish may affect the standing crop, productivity, and duck food production by the aquatic macrophytes in the marsh.

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APPENDIX I

Results of Soil Analysis

Laboratory Analysis:

Sample	Lab No.	pH	Pounds per Acre Available P	K	Ca	Mg
Crispus	18848	7.5	14	177	7920	517
Sago	18849	7.5	2	197	7440	404

Mechanical Analysis:

Sample		% Sand*	% Silt*	% Clay*
Crispus		18.40	72.32	9.28
		17.44	79.72	2.78
		12.56	86.62	0.72
	Average:	16.13	79.55	4.26
Sago		8.48	86.17	5.35
		10.08	84.28	5.64
	Average:	9.28	85.23	5.50

*Equivalent Spherical Diameter:

Sand: 0.05 - 2.0 mm.
Silt: 0.002 - 0.05 mm.
Clay: less than 0.002 mm.

APPENDIX II

Estimated Mean Sums of Squares for the 3-Way Analysis of Variance: Plant Samples

Source	EMSS	F
A (fixed)	$\delta^2_e + bcn\,\Sigma\alpha^2 + cn\,\delta^2_{AB} + bn\,\delta^2_{AC} + n\,\delta^2_{ABC}$	*
B (random)	$\delta^2_e + acn\,\delta^2_B + an\,\delta^2_{BC}$	B/BC
C (random)	$\delta^2_e + abn\,\delta^2_C + an\,\delta^2_{BC}$	C/BC
AB	$\delta^2_e + cn\,\delta^2_{AB} + n\,\delta^2_{ABC}$	AB/ABC
AC	$\delta^2_e + bn\,\delta^2_{AC} + n\,\delta^2_{ABC}$	AC/ABC
BC	$\delta^2_e + an\,\delta^2_{BC}$	BC/E
ABC	$\delta^2_e + n\,\delta^2_{ABC}$	ABC/E
Error	δ^2_e	

$*F_A = A/AB+AC-ABC$, i.e.

$$+AB = +\delta^2_e + cn\,\delta^2_{AB} + n\,\delta^2_{ABC}$$

$$+AC = +\delta^2_e + bn\,\delta^2_{AC} + n\,\delta^2_{ABC}$$

$$-ABC = -\delta^2_e - n\,\delta^2_{ABC}$$

$$\overline{\delta^2_e + cn\,\delta^2_{AB} + bn\,\delta^2_{AC} + n\,\delta^2_{ABC}}$$

Degree of freedom:

$$\frac{MS_{AB} + MS_{AC} - MS_{ABC}}{\frac{(MS_{AB})^2}{(a-1)(b-1)} + \frac{(MS_{AC})^2}{(a-1)(b-1)} - \frac{(MS_{ABC})^2}{(a-1)(b-1)(c-1)}}$$

APPENDIX III

Estimated Mean Sums of Squares for the 3-Way Analysis of Variance: Depth Data

Source	EMSS	F
A (fixed)	$\delta^2_e + nbc\ \delta^2_A + nc\ \delta^2_{AB} + n\ \delta^2_{ABC}$	A/AB*
B (random)	$\delta^2_e + nac\ \delta^2_B$	B/E
C (random)	$\delta^2_e + nab\ \delta^2_C + na\ \delta^2_{BC} + n\ \delta^2_{ABC}$	C/BC
AB	$\delta^2_e + nc\ \delta^2_{AB} + n\ \delta^2_{ABC}$	AB/ABC
AC	$\delta^2_e + nb\ \delta^2_{AC} + n\ \delta^2_{ABC}$	AC/ABC
BC	$\delta^2_e + na\ \delta^2_{BC}\ n\ \delta^2_{ABC}$	BC/ABC
ABC	δ^2_e	

*Note: MS_{AB}, the denominator for component A, is also used as the denominator in the individual degree of freedom computations.