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AQUATIC MACROPHYTES AND PERTURBATION DUE TO THE SAUK RIVER IN THE HORSESHOE CHAIN OF LAKES, RICHMOND, MINNESOTA

by

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B.A., St. Cloud State University, 1984

A Thesis

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of

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in Partial Fulfillment of the Requirements

for the Degree

Master of Arts

St. Cloud, Minnesota

November, 1985

This thesis submitted by Timothy C. Chmielewski in partial fulfillment of the requirements for the Degree of Master of Arts at St. Cloud State University is hereby approved by the final evaluation committee.

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AQUATIC MACROPHYTES AND PERTURBATION DUE TO THE SAUK RIVER IN THE HORSESHOE CHAIN OF LAKES, RICHMOND, MINNESOTA

Timothy C. Chmielewski

The Horseshoe Chain of Lakes consists of a glacial lake basin divided into fourteen bay-like lakes impounded by the Cold Spring Dam. The Sauk River flows through a majority of the basin; this results in increased turbidity and nutrient loading as well as fluctuating water levels and water velocity within the basin. Asthetic deteoriation of the lake chain, due to increased aquatic macrophytes, resulted in a need for baseline data on the aquatic macrophytes and the influence of the Sauk River on the system. Investigation of the aquatic macrophytes and perturbation of the Sauk River took place June through August 1984. This study included Browns Lake which is in close proximity to the Horseshoe Chain of Lakes. Macrophytes were identified to species and zonation within the lakes was mapped. Biomass and tissue analysis for nitrogen and phosphorus were determined from macrophyte samples.

Fifty-nine species of macrophytes were identified. Ceratophyllum demersum L. was the dominant submersed macrophyte, and it was found in all lakes including Browns. Frequency of macrophytes throughout the system was 30%. Frequency of macrophyte coverage in individual lakes varied from 88.8% in Becker Lake to 4.2% in Knaus Lake. Ninty-eight percent of all macrophytes were found at a depth of two meters or less. Submerged macrophyte coverage was 26.2% (2.6 x 10 6 m2) of the littoral zone. Average summer dry weight biomass varied from 0.81 g/m2 to 156.5 g/m2 in Knaus and Becker Lakes, respectively. Results on a system-wide basis for analysis of plant tissue, which was primarily Ceratophyllum demersum, was found to vary from 0.37% total phosphorus (TP) in Bolfing Lake to 1.86% TP in macrophytes from Koetter Lake. Percent total Kjeldahl nitrogen (TKN) ranged from 1.82% to 2.95% in macrophytes from East and Zumwalles Lakes, respectively.

Disturbances brought by the Sauk River included: fluctuating water levels and water velocity, turbidity from sediments and alga, and pollution including excessive nutrient loading. Horseshoe and Cedar Island Lakes displayed poor water transparency due to phytoplankton from the increased nutrients. All other lakes (except for Schneider, Mud, Long and Becker Lakes which are isolated and Browns Lake which is not connected to the system) are affected by turbidity and water flow.

October 2 1985
Month Year Approved by Research Committee:

Keith M. Knutson
Keith M. Knutson Chairperson

ACKNOWLEDGEMENTS

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A very special thanks to Marilyn, my wife, for her patients, support and sacrifices.

Many thanks to Carolyn Dindorf, her help and friendship made this thesis a reality; and to Kristi Hanson for her interest and critiquing of this paper. The assistance of Bob Begich, Roger Clark, Mark Gernes, and Pat Kuefler in various aspects of the work reported is greatfully acknowledged. Thanks to Steve Thrune for issuing supplies and equipment. Thanks also to my fellow graduate students, faculty, staff and friends for their knowledge and interest.

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INTRODUCTION

Eutrophication of a body of water may lead to asthetic deterioration in the growth of aquatic weeds (macrophytes). This is one indication to a layman that a body of water has a problem. Eutrophication is a natural process of succession (i.e., changing a body of water to dry land); however, because it tends to restrict recreational·use of the water, it is a major concern of resort and lakeshore home owners and the general public. Such a concern by a local lake association resulted in a grant to Dr. Keith Knutson of St. Cloud State University in 1983 for the investigation of the aquatic macrophytes and perturbation of the Sauk River (Knutson 1985). The macrophyte portion of the study took place during June through August, 1984.

A riverine system is a dynamic and complex system. The rate of eutrophication often is quickened by nutrient pollution, but this process may be altered by perturbation of the riverine system due to changing water velocity, fluctuating water levels, and high levels of turbidity. For example, additional nutrients will not cause any dramatic plant growth without a proper substrate to enable plants to root and hold under increasing water flow or without the ability to obtain sufficient light for photosynthesis during fluctuating water levels.

STUDY SITE

The Sauk River Chain of Lakes, located in Stearns County, Minnesota (Fig. 1), consists of a 9.94 km2 glacial lake basin divided into fourteen bay-like lakes impounded by the Cold Spring Dam (330.7, MSL). The lake chain is fed by the Sauk River and 18 small perennial, intermittent and ephemeral streams from a 2,136 km2 watershed (Knutson 1985). A thick glacial mantle of drift composed of deposited clays, silts, sands, and gravel is the main reservior for water in the county. This chain-of-lakes basin primarily is situated on red drift. Red drift transmits water more efficiently because it has less clay content than grey (or yellow) drift but, it is more susceptible to pollution (Associated Engineers 1972). Soils with more clay content are less permeable. This allows pollutants to remain on the surface of soil available for potential run-off rather than be filtered by soil particals. The chain of lakes system represents a large recreational body of freshwater of approximately 1178 hectares, in central Minnesota.

The Sauk River flows through a majority of the basin; this results in increased nutrient and sediment loading as well as fluctuating water levels, within the basin.


SAUK R.
BECKER LAKE
EAST LAKE
HORSESHOE LAKE
KOETTER
ZUMWALLES
SCHNEIDERS
GREAT NORTHERN
KRAYS
KNAUS
PARKS
BOLFING
Tcc
CEDAR ISLAND LAKE
MUD
LONG LAKE
BROWNS LAKE

Figure 1. Map of study area, Horseshoe Chain of Lakes, Richmond, Minnesota . The Sauk River enters the system (upper left) and flows through Horseshoe, East, Koetter, Zumwalles, Great Northern, Krays, and Knaus Lakes before exiting over the Cold Spring Dam (upper right).

METHODS

Due to the enormous size of the study area and the lack of published data, sample locations were determined on the basis of shoreline distance. Each lake's shoreline was planimetered for kilometers (km) of shoreline, and the minimum number of transects was set at four for the smallest lake; this allowed for one sample each near the inlet, outlet and on opposing sides. The ratio of the smallest lake to the largest provided a rational for assigning transects. This resulted in 131 transects of approximately one km apart throughout the system. Four samples each were taken at 3, 30, and 60 meters along the transect. A 30 meter range finder and marker bouys were used to locate the sample stations along the transect. Because several of the lakes being sampled were very shallow, additional random samples were taken at greater distances from shore.

Secchi Disk transparency depth and water depth were determined at each of the three sample stations along the transects.

Macrophyte samples were taken remotely by using a sampler designed by T. C. Chmielewski and Dr. Keith Knutson. It was modeled after an Eckman dredge design, but it was capable of collecting root biomass (Fig. 2). Up to 6 meters of steel pipe was coupled to the sampler. A nylon mesh bag was fitted to the sampler to contain any trapped

Figure 2. Photograph of macrophyte sampler (0.02323 m2) with nylon mesh bag attached.

macrophytes. The sampler size was 0.02323 m2 in area and capable of removing 30 cm of substrate. This allowed removal of most root biomass. An Eckman dredge was used at sample sites where lake water was deeper than 6 m.

Samples were hand sorted, rinsed, identified when possible, and placed in a cooler for transportation to the laboratory. Wet (drained) and oven dried (8 hr @ 103° C) weights were determined for the entire sample (ANON 1976). Samples then were ground into a powder for use in determining total Kjeldahl nitrogen (TKN) and total phosphorus (TP).

Total Kjeldahl nitrogen was determined by adding 50 mg of plant sample to 50 ml of deionized water. This was followed by a strong acid digestion on a micro-Kjeldahl apparatus, steam distillation and titration with sulfuric acid (E.P.A. 1979; Appendix 2).

Total phosphorus was determined by procedures taken from Standard Methods (ANON 1976). Ten mg of plant material was added to 50 milliliters of deionized water, followed by persulfate digestion and the Stannous Chloride Method (Appendix 3).

A species list for each lake was compiled from the specimens collected (verified by taxonomist Dr. Lester Lindstrom). Herbarium specimens are maintained in the Herbarium of the Department of Biological Sciences, St. Cloud State University.

Percent macrophyte cover of the littoral zone was estimated based on location of recovered plants and lake inspection between transects.

Zonation mapping was based on aerial photographs, using a 35mm camera with Ektachrome 200 slide film, and field verification.

RESULTS

BECKER LAKE

Becker Lake is 89.9 ha in area, is 2.2 x 10 6 m3 in volume, and has a mean depth of 2.4 m (Table 1). Maximum depth is 7.3 m. Submersed macrophytes covered 100% of the littoral zone (Fig. 3), this is 94% of the water/substrate interface. This prolific zone had a diverse aquatic plant composition consisting of 17 taxa of submersed and floating macrophytes (Table. 2). Frequency of plants found in 109 samples was 88.9% (Table 3). Of these, 91% were found at a depth of 2 m or less (Table 4). The dominant species in Becker Lake was *Ceratophyllum demersum* L. (Coontail), with a relative frequency of 67.2%, also present were *Nymphacea tuberosa* Georgi. (white waterlily) at 9.5%, *Chara vulgaris*, (algae) at 9.5%, and *Potamogeton crispus* L. (curly leaf pondweed) with 3.4%. In addition, monospecific stands of *Myriophyllum*, *Utricularia*, and several species of *Potomogeton* were found. Secchi Disk transparency averaged 2.6 m during the summer months and contributed to the largest macrophyte biomass production of the lakes studied. The summer dry weight mean biomass was 156.5 g/m2. Total phosphorus and TKN in macrophytes had an average dry weight percentage of 1.24 (range 0.35 -3.19) and 2.19 (range 1.69 - 2.67), respectively (Table 5).

Table 1. Basin characteristics of the Horseshoe Chain of Lakes, Richmond, Minnnesota.

Lake	Area ha.	Volume x 10 6 m3	Mean Depth m	Max. Depth m	Shore-line km	Littoral Zone %
Becker	89.9	2.20	2.4	7.3	9.7	94
Horseshoe	222.6	12.04	5.4	17.4	25.2	53
East	102.8	1.54	1.5	4.3	8.3	100
Cedar Island	223.0	11.80	5.3	22.9	16.7	75
Mud	28.7	1.32	4.6	10.7	3.5	66
Koetter	49.4	1.14	2.3	10.1	8.5	91
Zumwalles	44.9	1.10	2.4	2.4	8.1	100
Schneiders	21.5	0.97	4.5	16.8	1.9	80
Great Northern	45.6	1.12	2.4	2.4	10.8	100
Krays	36.4	0.89	2.4	2.4	4.5	100
Park	41.7	1.02	2.4	2.4	3.0	100
Bolfing	41.7	1.78	4.3	9.1	4.3	73
Knaus	43.3	1.06	2.4	2.4	3.9	100
Long	186.7	6.90	3.7	10.4	13.8	76
Browns	103.1	2.26	1.7	11.9	4.7	57

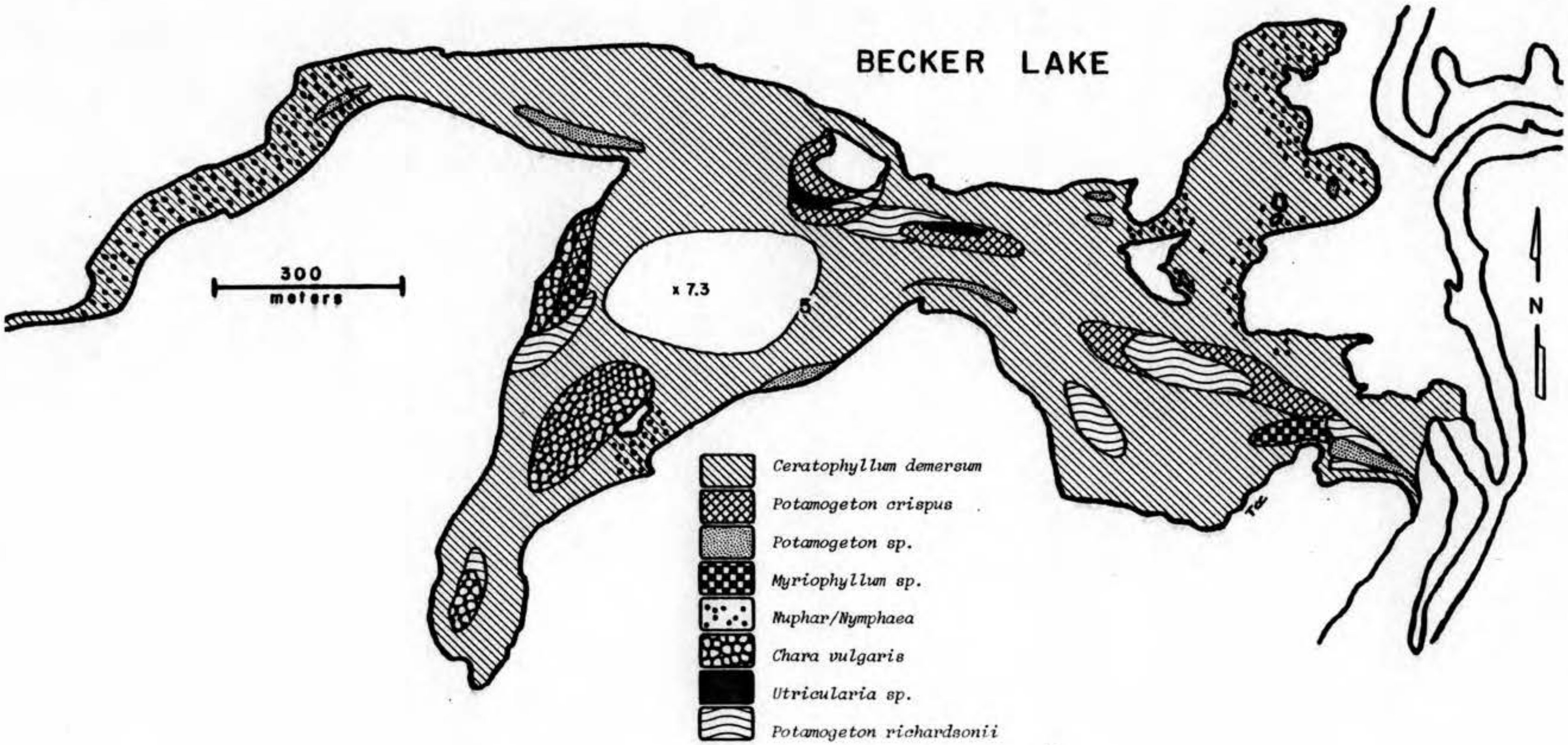

BECKER LAKE
300
meters
x 7.3
5
N
Ceratophyllum demersum
Potamogeton crispus
Potamogeton sp.
Myriophyllum sp.
Nuphar/Nymphaea
Chara vulgaris
Utricularia sp.
Potamogeton richardsonii

Figure 3. Map of Becker Lake showing macrophyte coverage of littoral zone and zonation of major stands of monospecific taxa.

Table 2. List of macrophyte species present in the Horseshoe Chain of Lakes, Richmond, Minnesota. * indicates species presence in lake. x indicates supplemental evidence of presence from herbaria records.

Species	Becker	Horseshoe	East	Cedar Island	Mud	Koetter	Zumwalles	Great Northern	Schneiders	Krays	Park	Bolfing	Knaus	Long	Browns
Agrostis stolonifera L.	x								x						
Alisma subcardatum Raf.	x								x						
Alisma triviale Pursh.	x								x						
Asclepias incarnata L.	*			*	*			*							
Aster junciformis Rydb.	*			*				*							
Campanula aparinoides Pursh.	*			*	*			*							
Carex hystericina Muhl.	*			*	*			*						*	
Carex sp.	*														
Ceratophyllum demersum L.	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Chara vulgaris (Algae)	*							*							
Cyperus diandrus Torr.	*			*											
Cyperus engelmanni Steud.	*			*	*										
Eleocharis calva Torr.	*			*											
Eleocharis palustris (L.) R. & S.	*			*											
Elodea canadensis Michx.	*														
Galium trifidum L.	*			*											
Hypericum virginicum L.				*											
Impatients biflora Walt.				*											
Iris versicolor L.	*							*							
Isoetes echinospora Dur. Var. *braunii*									x						
Lemna minor L.	*	*	*	*	*	*	*	*	*	*		*		*	
Lemna trisulca L.	*							*						*	
Lycopus uniflorus Michx.				*											
Myriophyllum exalbenscens Fern.	*														
Myriophyllum farwelli Morong.	*														
Najas flexilis (Willd.) R. & S.	*	*													
Nuphar variegatum Engelm.	*	*	*	*					*						
Nymphaea tetragona Paine.				*											
Nymphaea tuberosa Georgi.	*	*	*	*	*	*	*	*	*	*	*	*	*	*	

Species	Becker	Horseshoe	East	Cedar Island	Mud	Koetter	Zumwalles	Great Northern	Schneiders	Krays	Park	Bolfing	Knaus	Long	Brown
Phragmites communis Trin.	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Polygonium amphibium L.				*											
Polygonium coccineum Muhl.				*			*							*	
Polygonium lapathifolium L.				*				*							
Polygonium punctatum Ell.				*				*							
Potamogeton amplifolius Tuckerm.									x						
Potamogeton crispus L.	*	*												*	*
Potamogeton natans L.		*													
Potamogeton nodosus Poir.	*	*													
Potamogeton pectinatus L.	*														
Potamogeton richardsonii (Benn.) Rydb.	*														
Potamogeton zosteriformis Fern.	*	*	*	*	*				*	*	*	*	*	*	*
Potentilla palustris (L.) Scop.				*				*							
Ranuculus sceleratus L.	x														
Ranuculus trichophyllus Chaix.	*														
Rorippa islandica (Oeder.) Borbas.				*				*							
Rumex maritimus L.	x	x		x	x			x	x						
Rumex orbiculatus Gray.	*	*		*	*			*						*	*
Sagittaria breviostra Mack. & Bush.				*				*							
Sagittaria latifolia Willd.				*				*							
Scripus acutus Muhl.	*						*								
Scutellaria epilobiifolia Hamilton				*				*							
Sparangium androcladum (Engelm.) Morong.	*			*	*										
Sparangium eurycarpum Engelm.	*			*	*										
Thelypteris sp.				*				*							
Typha angustifolia L.	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Typha latifolia L.	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Utricularia gibba L.	*														
Utricularia vulgaris L.	*														
Wolffia columbiana Karst.	*	*	*	*	*	*	*	*	*	*	*	*		*	

Table 3. Vertical distribution of submerged macrophytes in the Horseshoe Chain of Lakes.

	% by depth (meters)				
Lake	1 or less	1-2	2-3	3-4	4-5
Becker	55	36	8	0	1
Horseshoe	71	18	11	0	0
East	100	0	0	0	0
Cedar Island	58	35	7	0	0
Mud	79	21	0	0	0
Koetters	62	38	0	0	0
Zumwalles	82	18	0	0	0
Schneiders	100	0	0	0	0
Great Northern	100	0	0	0	0
Krays	100	0	0	0	0
Parks	93	7	0	0	0
Knaus	100	0	0	0	0
Bolfing	80	20	0	0	0
Long	78	22	0	0	0
Browns	100	0	0	0	0

Table 4. Summary of the numbers of quadrats sampled, relative frequency of macrophytes, and percent macrophyte coverage for the Horseshoe Chain of Lakes, Richmond, Minnesota

Lake	Quadrats sampled Nbrs.	Frequency of macrophytes %	Macrophyte coverage %
Becker	109	88.9	100
Horseshoe	271	27.3	20
East	102	33.3	17
Cedar Island	201	32.8	20
Mud	48	39.6	20
Koetter	110	20.9	8
Zumwalles	84	13.1	2
Schneiders	48	56.3	14
Great Northern	92	22.8	15
Krays	48	14.6	10
Park	48	29.2	5
Bolfing	60	8.3	23
Knaus	44	6.8	<1
Long	171	37.4	20
Browns	72	29.2	22

Table 5. Total Kjeldahl nitrogen and total phosphorus content of macrophytes from the Horseshoe chain of lakes, Richmond, Minnesota.

Lake	N (%)	P (%)
Becker	2.19	1.24
Horseshoe	2.14	0.69
East	1.82	0.89
Cedar Island	2.32	0.80
Mud	2.65	1.10
Koetter	2.39	1.86
Zumwalles	2.95	1.63
Schneiders	2.24	0.85
Great Northern	2.07	1.42
Krays	2.29	1.32
Park	1.97	1.22
Bolfing	2.08	0.37
Knaus	2.44	0.89
Long	1.84	1.07
Browns	2.21	1.77

HORSESHOE LAKE

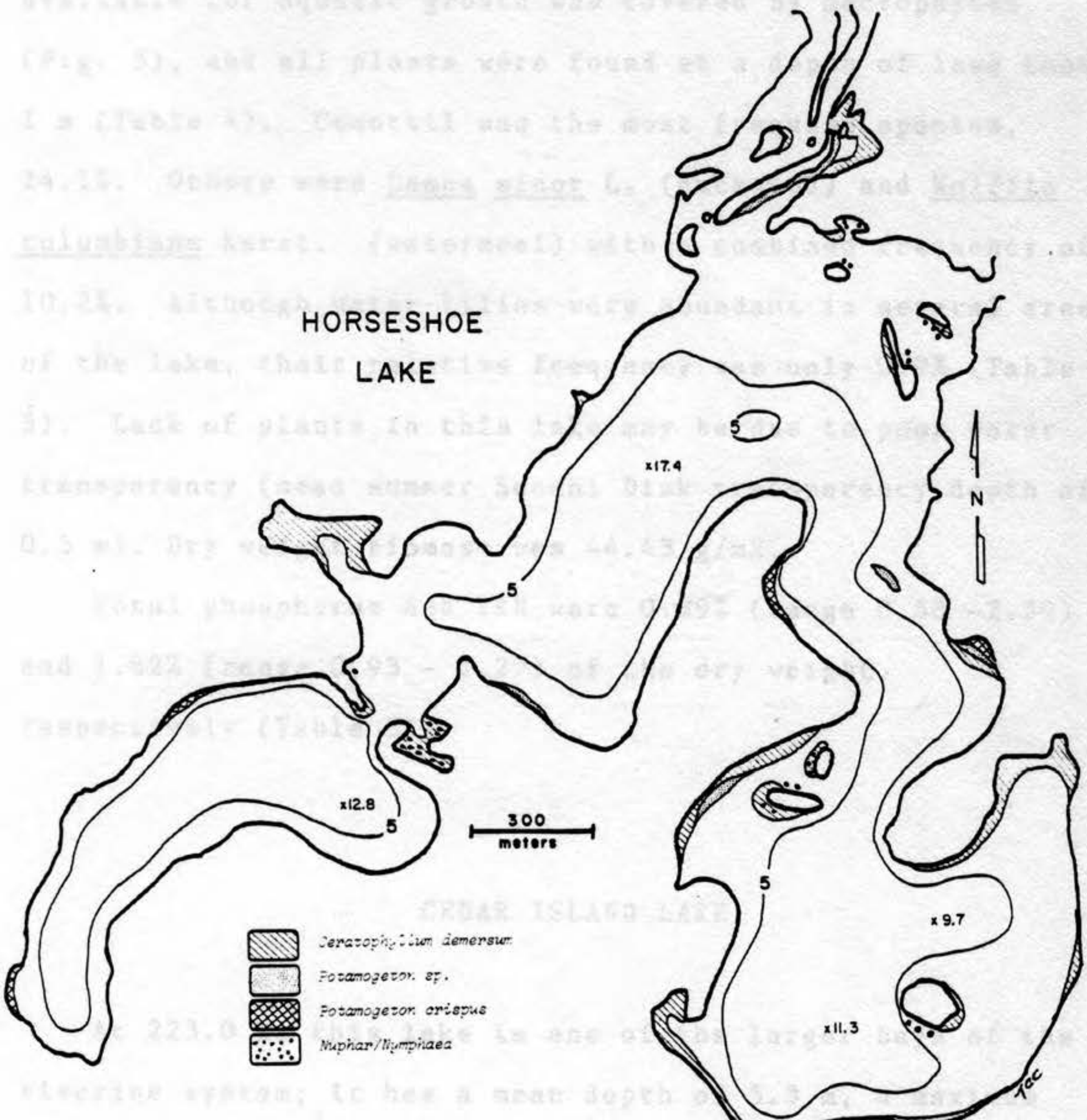
This lake had the smallest littoral area within the chain of lakes: only 52.5% of its 222.6 hectares (Table 1). Its mean depth is 5.4 m, with a volume of 12.04 x 10 6 m3. Horseshoe Lake has several deep areas; the maximum depth is 17.4 meters. Plant cover was about 20% of the littoral zone (Fig. 4). Frequency of plants from 271 samples was 27.3% (Table 3); the most frequent species was coontail (16.5%), followed by water lilies at 3.1%. Most macrophytes (71%), were found at depths of 1 m or less (Table 4). Average Secchi Disk transparency was 1.2 m during the sampling period. Dry weight summer macrophyte biomass of Horseshoe Lake was 20.58 g /m2.

Composition of plant material when compared to dry weight, was 2.14% mean TKN (range 1.35 - 3.14) and 0.69% mean TP (range 0.49 - 1.11), (Table 5).

EAST LAKE

East Lake, a shallow lake with a mean depth of 1.5 m and a volume of 1.54 x 10 6 m3; it has 100% of its 102.8 hectares as littoral zone (Table 1). Only 17% of the area

Figure 4. Map of Horseshoe Lake showing macrophyte coverage of littoral zone and zonation of major stands of monospecific taxa.


HORSESHOE LAKE
x17.4
5
N
x12.8
5
300 meters
5
x 9.7
x11.3
Ceratophyllum demersum
Potamogeton sp.
Potamogeton crispus
Nuphar/Nymphaea
JCC

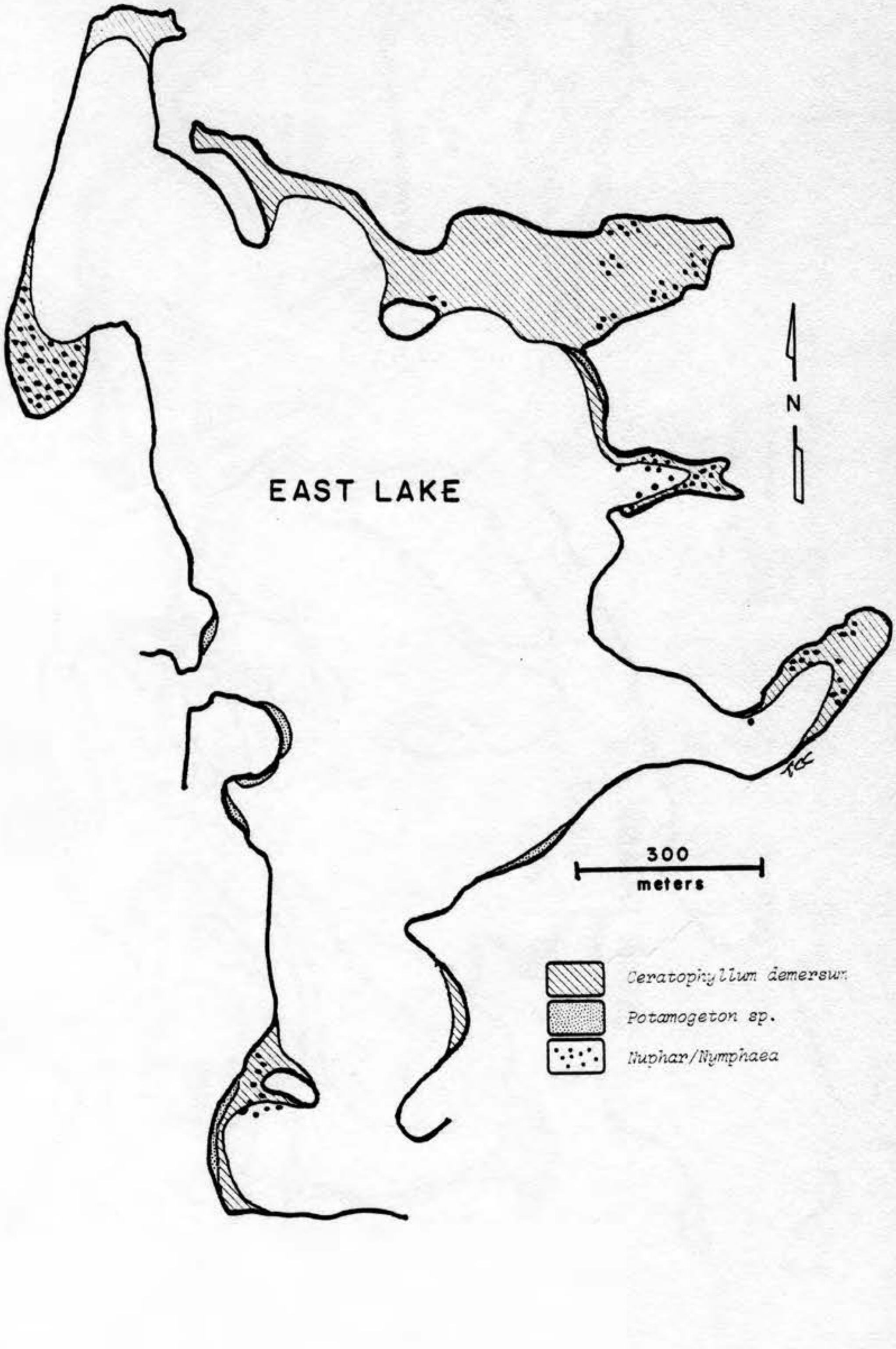
available for aquatic growth was covered by macrophytes (Fig. 5), and all plants were found at a depth of less than 1 m (Table 4). Coontail was the most frequent species, 24.1%. Others were Lemna minor L. (duckweed) and Wolffia columbiana Karst. (watermeal) with a combined frequency of 10.2%. Although water lilies were abundant in several areas of the lake, their relative frequency was only 0.9% (Table 3). Lack of plants in this lake may be due to poor water transparency (mean summer Secchi Disk transparency depth of 0.5 m). Dry weight biomass was 44.43 g/m2.

Total phosphorus and TKN were 0.89% (range 0.58 -2.59) and 1.82% (range 0.93 - 2.27) of the dry weight, respectively (Table 5).

CEDAR ISLAND LAKE

At 223.0 ha this lake is one of the larger bays of the riverine system; it has a mean depth of 5.3 m, a maximum depth 22.9 m, and a volume of 11.8 x 10 6 m3 (Table 1). The littoral zone covered approximately 75.2% of lake surface area. Only about 20% of the available area for submersed macrophytes was being utilized (Fig. 6). Of 201 samples taken in Cedar Island, 32.8% yielded macrophytes (Table 3). Ninty-two percent were found at 2 m or less; and 8% were as deep as 3 m (Table 4). The composition of macrophytes in

Figure 5. Map of East Lake showing macrophyte coverage of littoral zone and zonation of major stands of monospecific taxa.


EAST LAKE
N
300
meters
Ceratophyllum demersum
Potamogeton sp.
Nuphar/Nymphaea

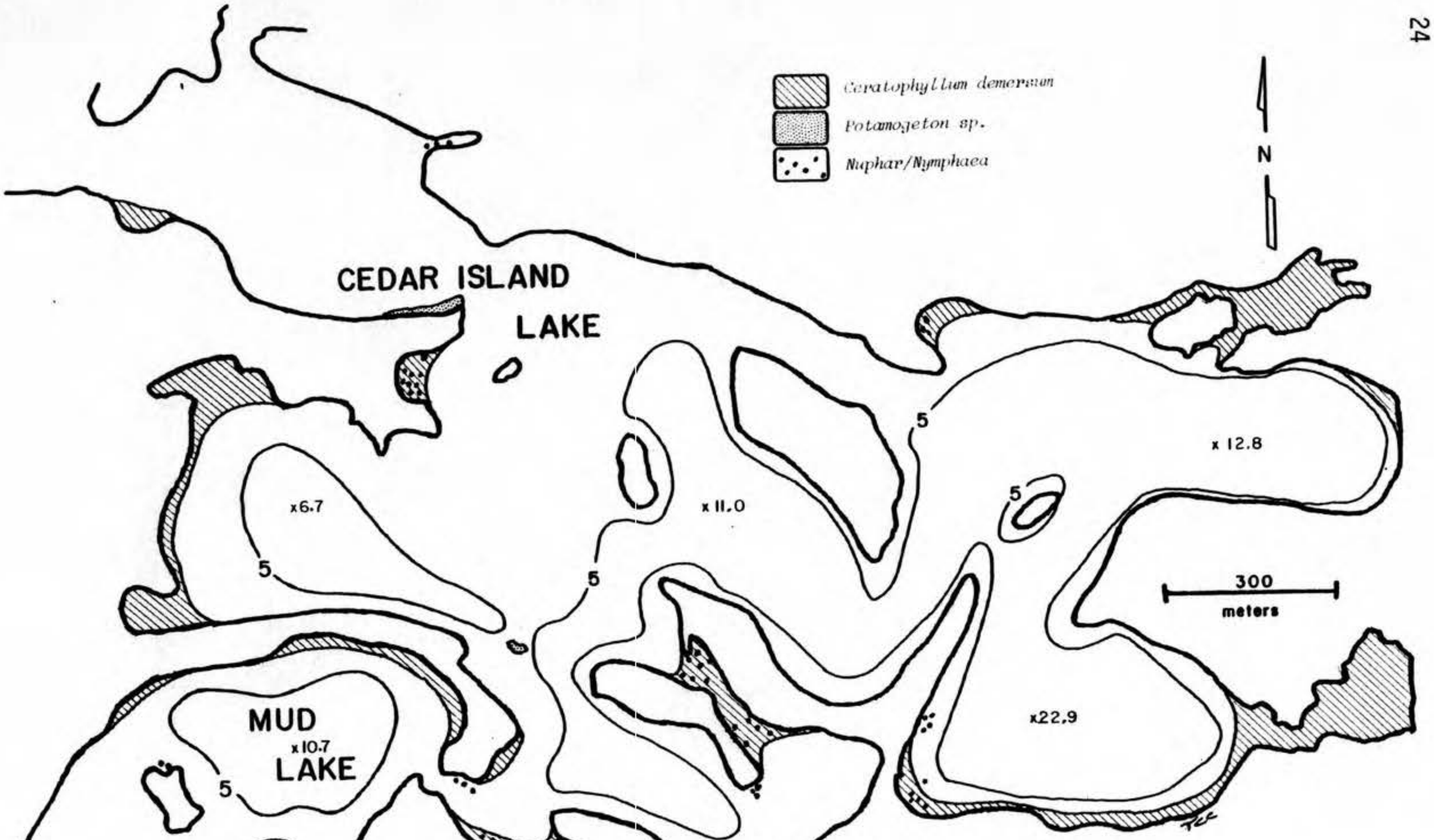

Ceratophyllum demersum
Potamogeton sp.
Nuphar/Nymphaea
N
CEDAR ISLAND
LAKE
x6.7
5
x 11.0
5
5
x 12.8
5
300
meters
x22.9
MUD
x10.7
LAKE
5

Figure 6. Map of Cedar Island and Mud Lakes showing macrophyte coverage of littoral zone and zonation of major stands of monospecific taxa.

the samples was 24.8% coontail and 8.1% curly leaf pondweed. Floating bogs of Typha angustifolia L. (common cattail), T. latifolia L. (narrowleaf cattail) and many other emergents and terresterials were numerous in this lake (Table 2). The average summer Secchi Disk transparency depth was 1.4 m, and the mean summer dry weight biomass was 37.32 g/m2.

Total phosphorus was 0.8% (range 0.69 - 0.98), and total Kjeldahl nitrogen was 2.32% (range 1.80 - 2.63) of dry weight (Table 5).

MUD LAKE

Mud Lake is a small, isolated lake with an area of 28.7 ha, a volume of 1.32 x 10 6 m3, and a mean depth of 4.6 m, (10.7 m at its deepest point), (Table 1). Its only connection to the chain is a 60 meter wide opening into Cedar Island. Very little of the main body of the lake has a littoral zone, but two shallow backwater areas increase the littoral zone to 66.2% of the lake's area (Fig. 6). Poor light transparency (summer average Secchi Disk depth of 0.8 m) was probably due to decaying organic matter which produced a reddish hue. This resulted in only about 20% submersed macrophyte cover of the littoral zone; of those submersed plants found, 79% were at a depth of less than one meter (Table 4). In 48 quadrats from Mud Lake, no plants were found deeper than 1.4 m. Coontail was the most frequently encountered submersed weed (37.5%). Dense stands of cattail on bogs are characteristic of the south side of Mud Lake. Summer dry weight biomass was 109.9 g/m2; this was the second highest of the system, perhaps due, in part, to the location of some sampling areas in the backwaters. Average total phosphorus was 1.1% (range 0.40 -1.86) of dry weight; TKN was 2.65% (range 2.35 -3.15), (Table 5).

KOETTER AND ZUMWALLES LAKES

Both of these lakes, (areas of 49.4 and 44 .9 ha), respectively, are little more than river channels. Both are similar in spacial characteristics: Koetter has a mean depth of 2.3 m compared to 2.4 m for Zumwalles; Koetter has a volume of 1.14 x 10 6 m3 and Zumwalles 1.10 x 10 6 m3 (Table 1). Koetter has several depressions in its basin, the deepest being 10.1 m. Zumwalles is 2.4 m deep or less. Approximate littoral zone, not including an old river channel cutting through the lenght of both lakes, was 90.9% and 100% for Koetter and Zumwalles, respectively (Fig. 7). Turbidity in the river within the system was high, with a summer average of 10.4 NTU. Koetter Lake averaged 9.9 NTU, had a mean Secchi Disk transparency depth of 0.5 m, and a submersed and floating summer biomass of 6.6 g/m2.

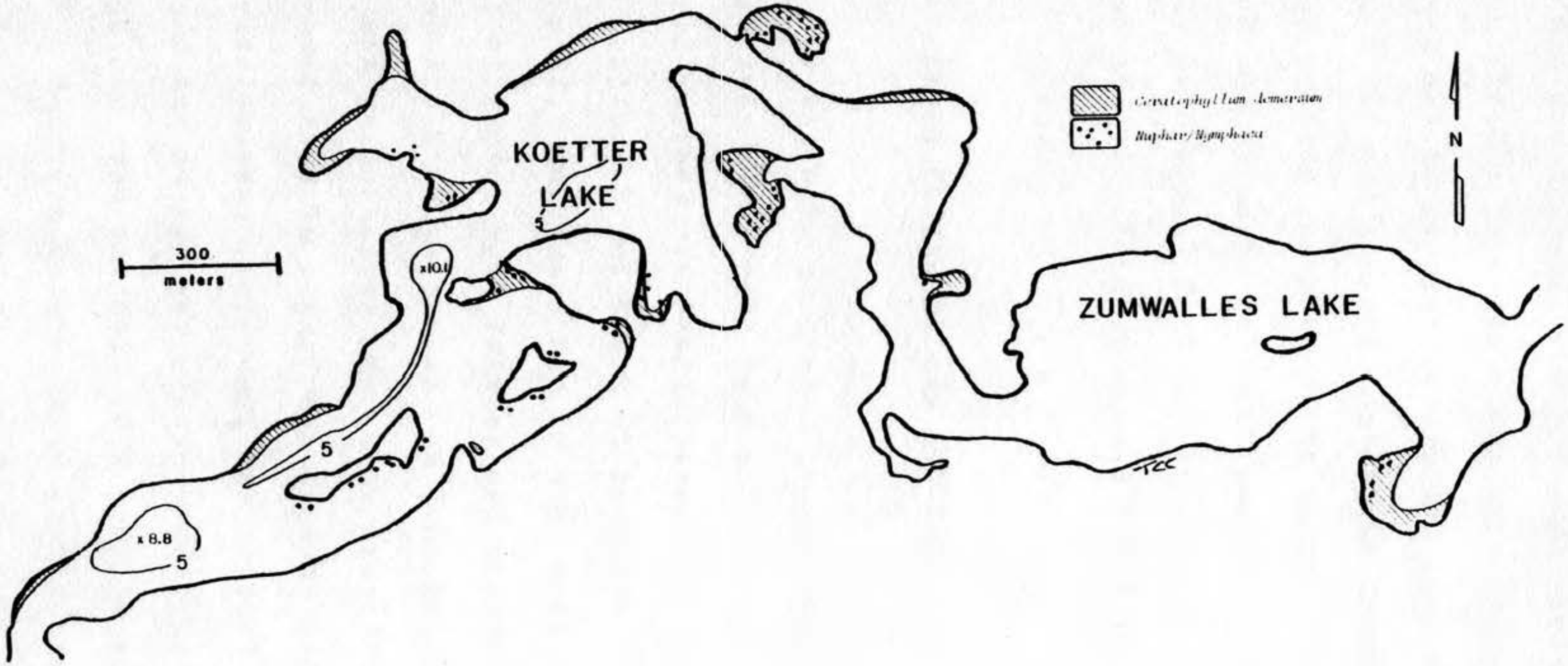

KOETTER LAKE
ZUMWALLES LAKE
300 meters
N
x10.1
5
x 8.8
5
5
Ceratophyllum demersum
Nuphar/Nymphaea
TCC

Figure 7. Map of Koetter and Zumwalles Lakes showing macrophyte coverage of littoral zone and zonation of major stands of monospecific taxa.

Zumwalles Secchi Disk transparency averaged 0.4 m and dry weight biomass averaged 11.94 g/m2. Of 110 samples taken in Koetter, relative frequency of weeds was 20.9% (Table 3). Of these, 61.5% were growing at a depth of less than one meter and 38.5% between 1 and 2 meters (Table 4). Relative frequency of submersed plants in 84 samples from Zumwalles was 13.1%; 82% of the weeds were less than one meter deep. No plants were found deeper than 1.2 m (Table 4). Coontail was found most often in the samples from both lakes and had a relative frequency of 18.9% in Koetter and 10.7% in Zumwalles. White and yellow water lilies were present in both lakes (2.7% frequency in Koetter and 3.6% in Zumwalles). Koetter had the lowest average total phosphorus value, 1.86% (range 0.47 -3.61) and a TKN value of 2.39% (range 1.37 -3.33). TP in Zumwalles was 1.63% (range 1.30 - 1.80); it had the highest average TKN, 2.95% (range 2.66 - 3.25), (Table 5).

GREAT NORTHERN LAKE

Great Northern is a shallow lake. It has a mean and maximum depth of 2.4 meters, an area of 45.6 ha and a volume of 1.12 x 10 6 m3 (Table 1). With the exception of one isolated area, the lake is almost weed free. Frequency of plants in 92 samples was 22.8% (Table 3); 100% were found

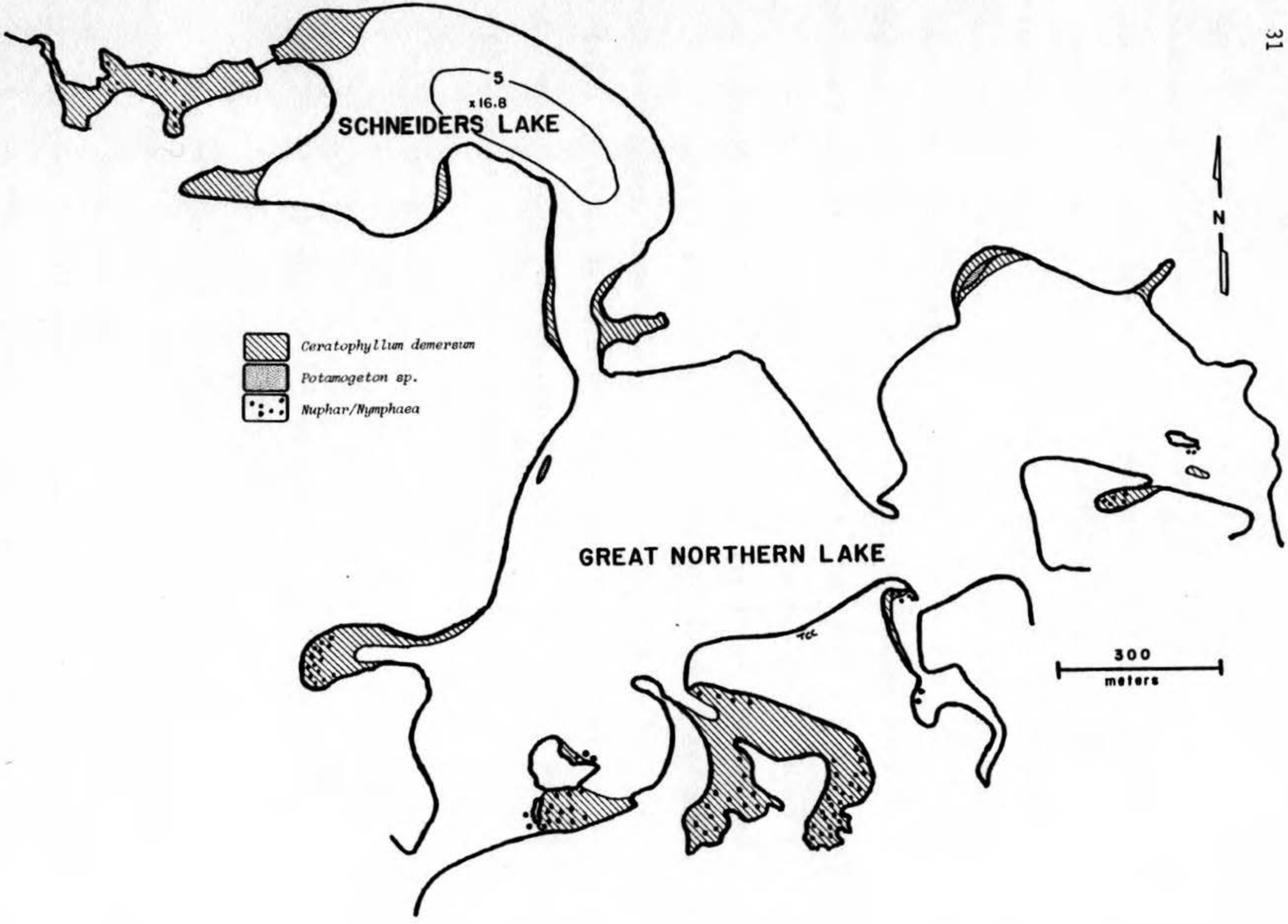

5
x 16.8
SCHNEIDERS LAKE
GREAT NORTHERN LAKE
N
300
meters
Ceratophyllum demersum
Potamogeton sp.
Nuphar/Nymphaea

Figure 8. Map of Schneiders and Great Northern Lakes showing macrophyte coverage of littoral zone and zonation of major stands of monospecific taxa.

less than one meter deep (Table 4). This lake was 100% littoral, but with an average Secchi Disk transparency of 0.8 m, only about 15% of the area had macrophytes (Fig. 8). Coontail was the most frequent plant (20.1%), followed by Lemna trisulca L. (star duckweed) at 12.5%. One isolated cove accounted for almost all the submerged macrophyte biomass, 41.34 g/m2. Luxuriant stands of coontail covered by dense layers of star duckweed were found in the cove. Mean total phosphorus in submersed plants in Great Northern was 1.42% (range 0.47 -2.44), while mean TKN was 2.07% (range 1.41 -2.92), (Table 5).

SCHNEIDERS LAKE

Schneiders has an area of about 21.5 hectares, a volume of 0.97 x 10 6 m3, and a mean depth of 4.5 m (Table 1). Maximum depth in Schneiders is a steep sided 16.8m hole in an otherwise shallow lake. This accounts for the large littoral zone of 80.1% (Fig. 8). Frequency of macrophytes in 48 samples was 56.3% (Table 3), and all plants were found less than one meter deep (Table 4). Of the plants recovered, 46.9% were coontail; 8.9% water lily; 8.9% duckweed and watermeal; and 4.1% curly leaf pondweed. Macrophytes were most abundant on the northwest side of the lake at the inlet of a small stream. Total phosphorus from this stream averaged 210.86 ug/l, TKN 0.68 ug/l. Turbidity from the stream was filtered out by the weeds which improved water clarity (mean summer Secchi Disk transparency of 1.7 m). Schneiders had the third highest biomass production, 75.38 g/m2. Total phosphorus and TKN were found to be 0.85% (range 0.44 -1.19) and 2.24% (range 1.38 - 2.66), respectively (Table 5).

KRAYS LAKE

Krays Lake, with inlets from Great Northern and an outlet to Knaus Lake, is traversed by the Sauk river. This 36.4 ha lake has a volume of 0.889 x 10 6 m3, a mean depth of 2.4 m, and a maximum depth of 2.4 m (Table 1). The littoral zone covered 100% of the lake area, but only about 10% had any submersed or floating plants (Fig. 9). Average summer Secchi Disk transparency was 0.4 m. Frequency of plants in 48 samples was 14.6% (Table 3); all were less than one meter deep (Table 4). Areas around the large island in Krays held numerous decaying Potamogeton crispus propagules. These apparently were deposited by the river current because none were growing. Coontail had a relative frequency of 16.7% and water lilies 6.7%. Average dry weight summer macrophytic biomass was 29.87 g/m2. Composition of the plants in Krays was 1.32% (range 0.65 -2.50) TP and 2.29%

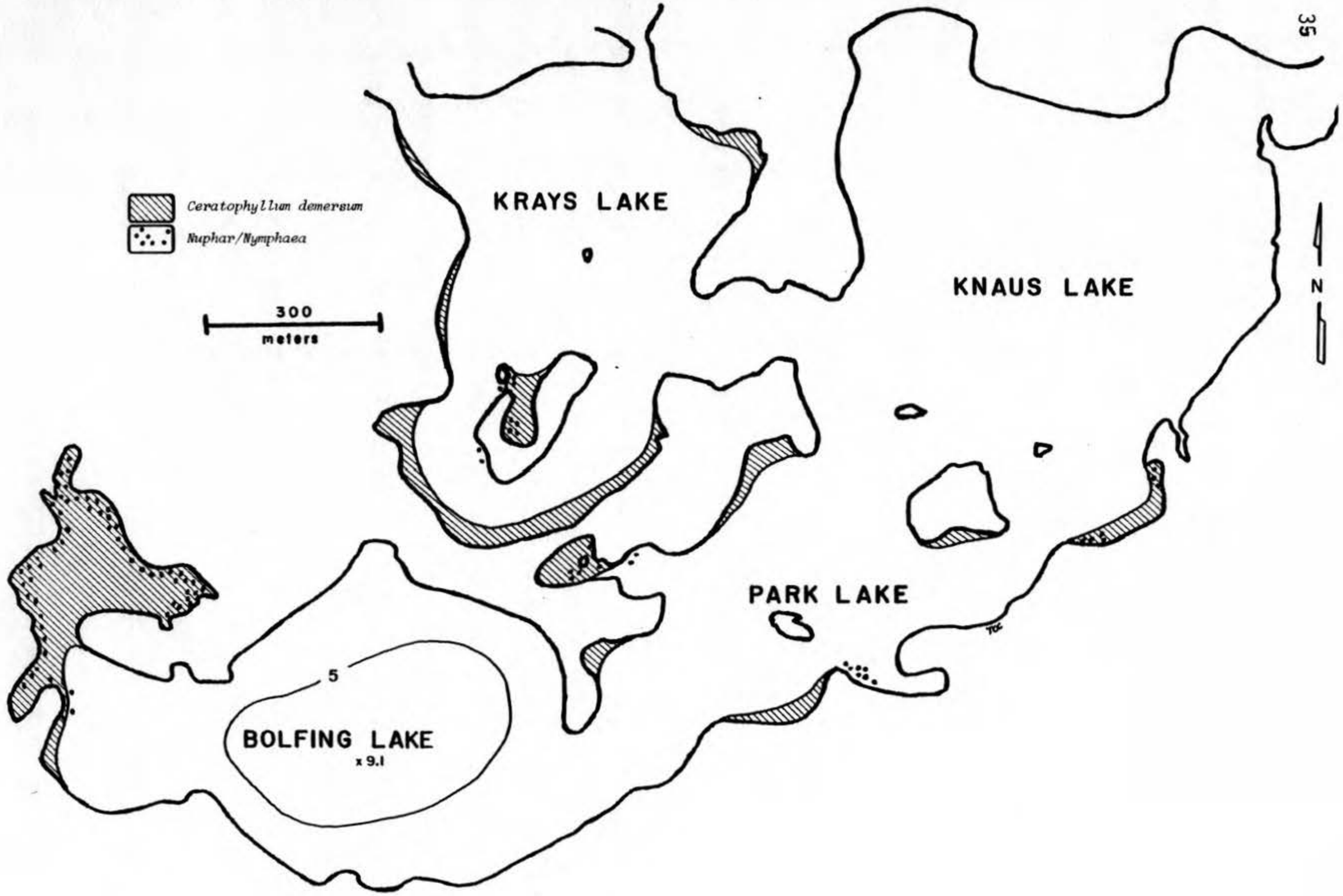

▨ *Ceratophyllum demersum*
⁘ *Nuphar/Nymphaea*
300
meters
KRAYS LAKE
KNAUS LAKE
PARK LAKE
BOLFING LAKE
x 9.1
5
N
TCC

Figure 9. Map of Krays, Knaus, Parks, and Bolfing Lakes showing macrophyte coverage of littoral zone and zonation of major stands of monospecific taxa.

(range 1.50 -2.64) TKN (Table 5).

KNAUS LAKE

This lake is the last to receive water from the Sauk river chain of lakes before it spills over the Cold Spring dam. Turbidity averaged 10.93 NTU, whereas the Secchi Disk transparency averaged 0.6 m. Knaus Lake is 43.3 ha in area, has a volume of 1.06 x 10 6 m3, and a mean depth of 2.4 m (Table 1). The entire lake area was littoral (Fig. 9). Frequency of plants in 44 samples was 8.6% (Table 3); all were found at a depth less than 0.6 m (Table 4). Substrate in this lake was found to be a thick layer of black fine silt, characteristic of river deposition. Maximum depth of Knaus lake was 2.4 m. Frequency of the few plants found were: 2.1%, coontail; 2.1%, white waterlily; and 4.2%, curly leaf pondweed propagules. The curly leaf propagules, although germinating, were found floating and probably had drifted from another lake. Knaus had the lowest summer average biomass for productivity of macrophytes of any in the system, 0.81 g/m2 dry weight. TKN and TP in plants from Knaus was 2.44% (range 1.72 - 2.87) and 0.89% (range 0.44 - 1.89), respectively (Table 5).

PARKS LAKE

No physical boundary separates this lake from Knaus or Bolfing lake. Parks lake has an area of 41.7 ha, a volume of 1.02 x 10 6 m3, and a mean depth of 2.4 m (Table 1). Parks is a shallow lake with a 2.4 m maximum depth and is 100% littoral, but only about 5% had plant cover (Fig. 9). Frequency of plants recovered in 48 samples was 29.2% (Table 3), of which 93% were found at less than one meter (Table 4). Coontail was the only plant found; it had a frequency of 20.1%. Germinating curly leaf pondweed was found floating (frequency of 8.3%). Mean Secchi Disk transparency was 0.5 m, and the mean summer dry weight biomass was 15.77 g/m2. Plant tissue was composed of 1.22% TP (range 0.89 - 1.55) and 1.97% (range 1.68 - 2.40) TKN (Table 5).

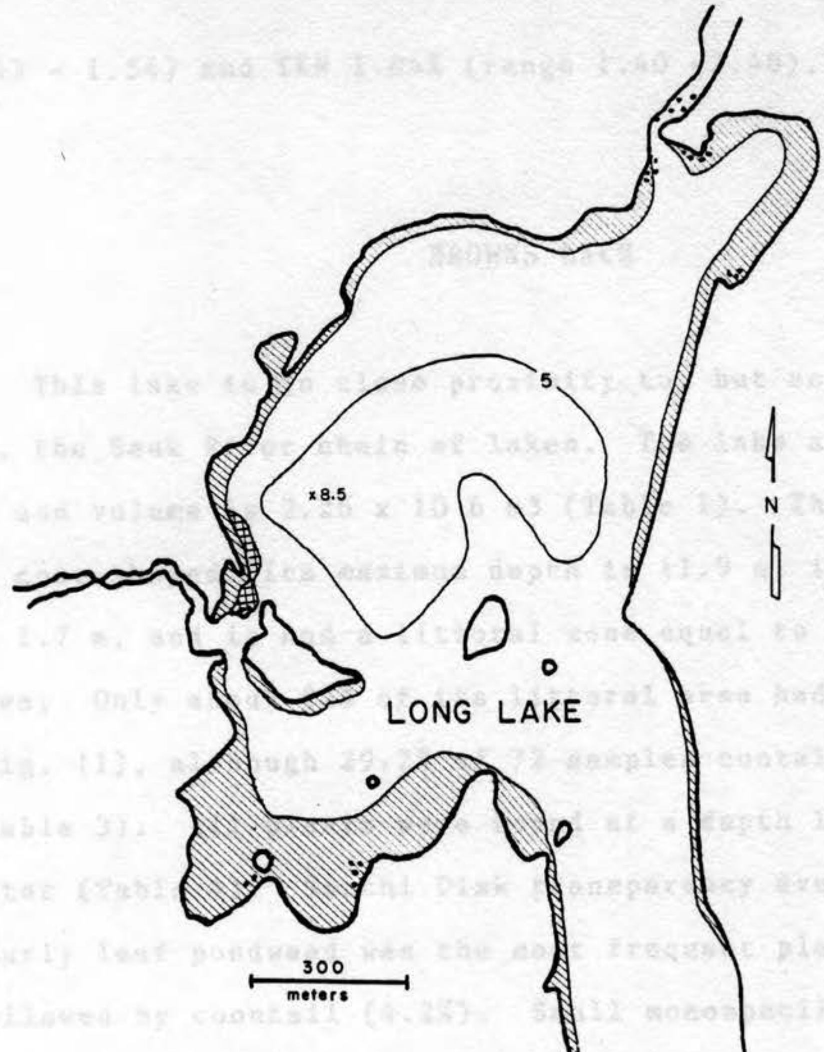
BOLFING LAKE

Bolfing Lake has an area of 41.7 ha, a mean depth of 4.3 m, a volume 1.78 x 10 6 m3 and maximum depth 9.1 m (Table 1). Seventy-three percent of the lake area was littoral. The main body of Bolfing was weed free; only the northwestern side had plants (Fig. 9). Frequency of plants in 60 samples was 8.3% (Table 3), and 80% were found at a depth of less than one meter (Table 4). Only two taxa were found in Bolfing: coontail, 6.7% frequency, and white waterlily, 3.4% frequency. Average summer Secchi Disk transparency was 0.46 m. Dry weight biomass, the second lowest in the system, was 3.87 g/m2. Macrophytes in this lake had the lowest mean total phosphorus value, 0.37% (range 0.34 - 0.43), of the system. TKN averaged 2.08% (range 1.58 -2.57) of dry weight plant material (Table 5).

LONG LAKE

Long Lake is connected to the southern most end of Horseshoe Lake by a narrrow (5 m) inlet. Long Lake has the third largest area (186.2 ha) of the lakes; it also is third largest in volume, 6.9 x 10 6 m3 (Table 1). The mean depth and maximum depth are 3.7 m and 10.4 m, respectively. Approximately 75.5% of the lake area was littoral, and about 20% had plant coverage (Fig. 10). Frequency of macrophytes in 171 samples was 37.4% (Table 3). Coontail and curly leaf pondweed had frequencies of 31.8% and 10.1%, respectively. Waterlilies and duckweeds had frequencies of 0.5% and 3.3%, respectively. No plants were found deeper than two meters; and 78% were at a depth less than one meter (Table 4). Secchi Disk depth in Long lake averaged 1.31 m. Summer dry weight plant biomass was 41.73 g/m2. Total phosphorus content of dried plant material was found to be 1.07% (range

Figure 10. Map of Long Lake showing macrophyte coverage of littoral zone and zonation of major stands of monospecific taxa.

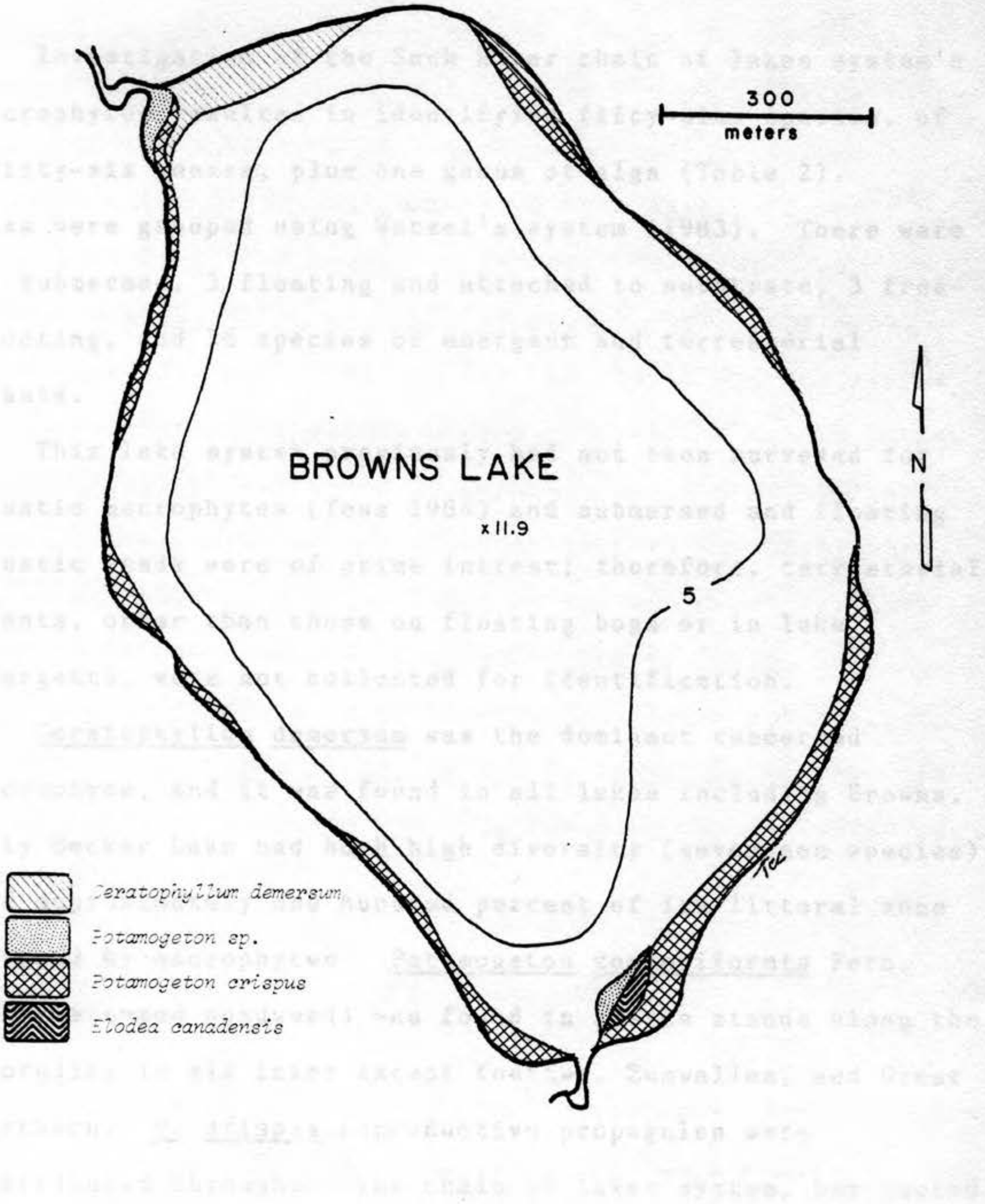

5
x8.5
N
LONG LAKE
300
meters
Ceratophyllum demersum
Potamogeton crispus
Nuphar/Nymphaea
x10.4
5
TCC

0.43 - 1.54) and TKN 1.84% (range 1.40 -2.48), (Table 5).

BROWNS LAKE

This lake is in close proximity to, but not connected to, the Sauk River chain of lakes. The lake area is 103.1 ha and volume is 2.26 x 10 6 m3 (Table 1). The lake basin is cone shaped. Its maximum depth is 11.9 m; its mean depth is 1.7 m, and it had a littoral zone equal to 57% of its' area. Only about 22% of its littoral area had macrophytes (Fig. 11), although 29.2% of 72 samples contained plants (Table 3). All plants were found at a depth less than one meter (Table 4). Secchi Disk transparency averaged 1.5 m. Curly leaf pondweed was the most frequent plant (23.6%), followed by coontail (4.2%). Small monospecific stands of *Elodea canadensis* Michx. (Canada waterweed) were observed at the inlet on the south end; *Potamogeton* sp. could be seen near the lake outlet. Mean summer dry weight plant biomass was determined to be 7.65 g/m2. TP was 1.77% (range 1.13 -2.95) and mean TKN, 2.21% (range 1.99 -2.73), (Table 5).

Figure 11. Map of Browns Lake showing macrophyte coverage of littoral zone and zonation of major stands of monospecific taxa.


300
meters
N
BROWNS LAKE
x 11.9
5
▨ Ceratophyllum demersum
▨ Potamogeton sp.
▨ Potamogeton crispus
▨ Elodea canadensis

DISCUSSION

COMPOSITION OF THE VEGETATION

Investigation of the Sauk River chain of lakes system's macrophytes resulted in identifying fifty-nine species, of thirty-six genera, plus one genus of alga (Table 2). Taxa were grouped using Wetzel's system (1983). There were 17 submersed, 3 floating and attached to substrate, 3 free-floating, and 36 species of emergent and terresterial plants.

This lake system previously had not been surveyed for aquatic macrophytes (Tews 1984) and submersed and floating aquatic weeds were of prime intrest; therefore, terresterial plants, other than those on floating bogs or in lake emergents, were not collected for identification.

Ceratophyllum demersum was the dominant submersed macrophyte, and it was found in all lakes including Browns. Only Becker Lake had both high diversity (seventeen species) and approximately one hundred percent of its littoral zone covered by macrophytes. Potamogeton zosteriformis Fern. (flat-stemmed pondweed) was found in sparce stands along the shoreline in all lakes except Koetter, Zumwalles, and Great Northern. P. crispus reproductive propagules were distributed throughout the chain of lakes system, but rooted vegetative plants only were found in Becker Lake and Browns

Lake.

Water lilies were the dominant floating plants in the system. Nymphaea tuberosa was present in small scattered patches in all lakes except Browns. In protected areas of Becker and East Lakes, N. tuberosa was found covering large areas of the lake surface. Nuphar variegatum Engelm. (yellow water lily) was present in five lakes. Areas sheltered from wind and river currents harbored free-floating Lemna minor and Wolffia columbiana. These areas were generally very shallow, and the plants did not appear to shift during the summer months. Another floating plant, Lemna trisulca, was found in Becker, Long and Great Northern Lakes. Emergents and marsh plants (thirty two taxa) were found on floating bogs in Cedar Island and Great Northern Lakes. On one occasion, a floating bog of Typha, approximately 60 m x 15 m, temporarily closed the entrance to Mud lake. Typha latifolia and T. angustifolia were the most abundant emergents and were found on the perimeter of all lakes.

COMMUNITY DISTRIBUTION

Frequency of macrophytes in 1561 quadrats throughout the system was 30%. Frequency of littoral plants recovered from individual lakes varied greatly. Becker Lake had a frequency of 88.8% submersed and floating macrophytes making it the highest in frequency of coverage. The lowest frequency of coverage was observed in Knaus Lake (4.2%). The dominant plant throughout the system was Ceratophyllum demersum with a frequency of 80.4%, followed by water lilies (8.5%). All other submersed and floating taxa had a combined frequency of 11.1%. On an individual lake-by-lake examination, coontail remained dominant in all lakes except Browns. In Browns, Potomagetom crispus had a frequency of 23.6%; coontail had a frequency of only 4.2%. Monospecific stands of macrophytes were found in all lakes. These were primarily coontail, except for Becker Lake which was more diverse; it also had stands of Potamogetons, Myriophillum, Chara vulgaris, and Utricularia. Browns Lake had monospecific stands of P. crispus, C. demersum, and Elodea canadensis.

MACROPHYTE DISTRIBUTION vs. DEPTH

The shallow nature of this riverine system, 3.34 m mean depth (range 5.41 m - 1.50 m), and poor light penetration in a majority of the lakes, 0.9 m mean Secchi Disk transparency (range 0.4 m - 2.6 m), probably accounted for 83.8% of macrophytes being found at a depth of less than one meter. Additionally, 14.4% of the macrophytes were found between one and two meters; therefore 98.2% of all macrophytes in the chain of lakes system were found at a depth of two meters or less (Table 4). Submerged macrophyte coverage was 26.2% (2.6 x 10 6 m2) of the littoral zone.

MACROPHYTE BIOMASS

Average summer dry weight biomass of the system was based primarily on *C. demersum* because the majority of quadrats had monospecific stands of coontail. Browns Lake summer biomass was based on *P. crispus* because 84.9% of the plants were of that species. Biomass varied greatly between lakes within the system (Fig. 12). Becker, with high water transparency, had an average biomass of 156.5 g/m2. Although alleopathy was not studied it is suggested that the high production of macrophytes in Becker Lake resulted from high transparency. Possibly, continued high summer transparency was enhanced by stands of aquatic macrophytes in Becker which helped to maintain good water clarity by producing and excreting compounds that may have had an alleopathic effect on phytoplankton; these compounds could have interfered with photosynthesis (Hasler and Jones 1949; Pennak 1973; Wium-Andersen *et al*. 1982). This would result in the reduction of algae that normally competed for light with aquatic macrophytes (Hasler and Jones 1949; Wetzel 1983). Two such alleopathic compounds, dithiolane and

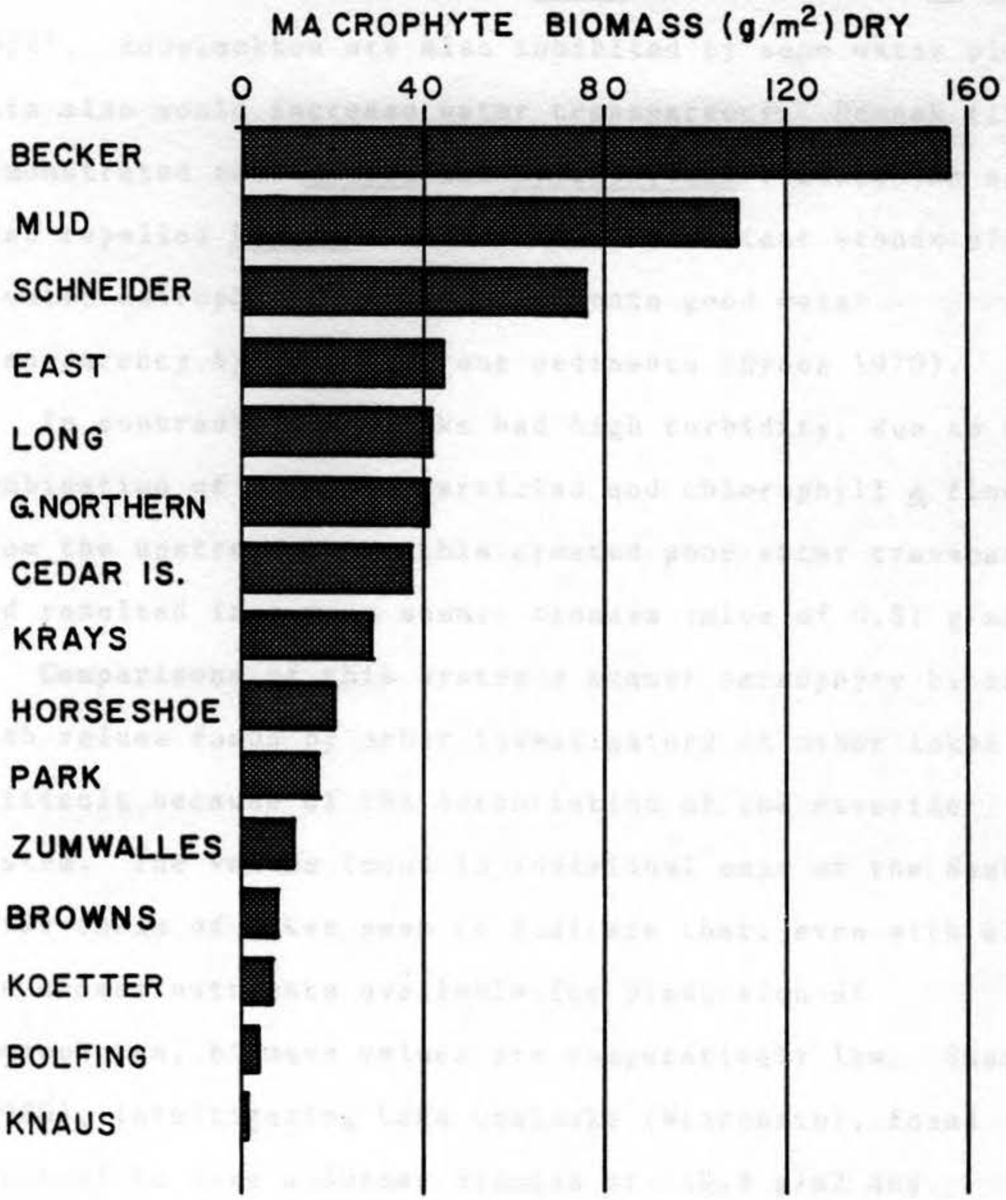


Figure 12. Biomass of summer macrophytes in g/m2 (dry weight) for individual lakes.

trithiane, have been found in Chara (Wium-Andersen et al. 1982). Zooplankton are also inhibited by some water plants; this also would increase water transparency. Pennak (1973) demonstrated that Elodea and Myriophyllum released an agent that repelled Daphnia. Presence of luxuriant stands of aquatic macrophytes may help maintain good water transparency by filtering out sediments (Hynes 1970).

In contrast, Knaus Lake had high turbidity, due to a combination of sediment particles and chlorophyll a flushed from the upstream bays; this created poor water transparency and resulted in a mean summer biomass value of 0.81 g/m2.

Comparisons of this system's summer macrophyte biomass with values found by other investigators on other lakes is difficult because of the perturbation of the riverine system. The values found in individual bays of the Sauk river chain of lakes seem to indicate that, even with all the excess nutrients available for production of macrophytes, biomass values are comparatively low. Smart (1980), investigating Lake Onalaska (Wisconsin), found coontail to have a summer biomass of 150.8 g/m2 and Nymphacea tuberosa, 374.5 g/m2. In Lake Sallie, Mn., Neel (1973) determined the summer biomass of mixed weeds to be 58.8 g/m2. Pure stands of Myriophyllum in a New York lake were found to have a value of 387 g/m2 (Peverly 1979).

In general, macrophyte production was high only in Becker, Mud, Schneiders, and in isolated areas of Great

Northern Lakes. All three lakes had areas of shallow water with high transparency. All the lakes through which the river flows; East, Koetter, Zumwalles, Great Northern, Krays, and Knaus; had low productivity probably due to turbid water. Cedar Island, Horseshoe, and Long Lakes had poor water transparency during the summer months as a result of light attenuation from algae.

CHEMICAL ANALYSIS OF MACROPHYTES

Results on a system-wide basis for plant material, which was primarily coontail, was found to vary from 0.37% TP in Bolfing Lake to 1.86% TP in plants from Koetter Lake (Table 5). Percent TKN ranged form 1.82% to 2.95% in plants from East and Zumwalles Lakes, respectively (Table 5). These figures are similar to percentages found by Smart (1980), 0.59% TP and 2.57% TKN, and those of Allenby (1981), 1.77% TP and 2.80% TKN. Both sets of data were based on percentages of dry weight for C. demersum. Allenby (1981) also found mean percentages of 2.77% TP and 3.10% TKN for P. crispus. Critical concentrations required for minimum growth of C. demersum are 0.10% phosphorus and 1.30% nitrogen (Gerloff, 1975). The mean TP/TKN ratio for macrophytes in the system was 0.49. The mean TP/TKN ratio for Browns Lake, based on Potamogeton crispus, was 0.80.

Phosphorus loading in the chain of lakes was very excessive, 14.1 g/m2/yr (Knutson 1985). In some systems pronounced eutrophication due to excessive nutrients may actually decrease colonization and biomass of submersed macrophytes (Ozimek 1983; Moss 1976). This is due to a reduction in light penetration as a result of marked increases in plankton and periphyton.

FLUCTUATION OF RIVER FLOW AND WATER LEVEL

During 1984, variation of river flow caused by spring runoff and rain storms ranged from 217 cfs to 3018 cfs (944 cfs mean); this is based on combined discretely measured data from the river channel between Horseshoe and East Lakes (Knutson 1985). The water level based on the ordinary high water mark (OHWM), determined by the Minnesota Department of Natural Resources, is 331.2 meters for all lakes in the chain. During 1984, levels ranged from 330.98 to 332.28 meters. The highest measurement was recorded on June 14, 1984; it was 1.1 meters above the OHWM. This was 0.6 meters below the 100 year flood level and 0.5 meters above the 1983 high water level (Holmuth 1984). Aquatic plant growth during these changing water levels results in elongation of stems, senescence from shading due to increased water depth and turbidity, and breaking or uprooting. A flow of 750 cfs is sufficient to remove 80% of a deep rooted macrophyte species (Haslam 1978). Consequently, a large portion of vegetation in the chain of lakes may not have materialized during 1984, and it may be at reduced levels in subsequent growing seasons.

PERTURBATION OF THE SYSTEM

The macrophytes of the Sauk River chain of lakes system are subjected to constant change from the influence of the river. Problems normally encountered in lakes; oxygen depletion, point and non point source pollution, nutrient enrichment, etc. are all compounded in a lotic environment. Constant changes brought by the river flow include: fluctuating water levels, a scouring effect moving sediments and increasing hydrolic tenson on macrophytes, and pollution including nutrient loading. All of these are potential problems affecting the welfare of the chain of lakes system. This is complicated further by the vast watershed, (2136 km2), much of which is agricultural. During this study, two problems that had the most influence on macrophytes were: water flow and turbidity caused by algal chlorophyll and sediment loading from the river. Becker Lake, being relatively isolated from the river, was characterized by clear water and luxuriant weed beds.

Horseshoe and Cedar Island Lakes displayed poor water transparency due to phytoplankton; this resulted in less species diversity in submersed plants and lower biomass. The remainder of the lakes in the system (except for Schneider Lake and Mud Lake which are isolated and Browns Lake which is not connected to the system) are affected by turbidity and water flow. One reason coontail is dominant in this system is that it is very turbidity tolerant (Haslam, 1978).

A graphic correlation (Fig. 13) shows the relationship between Secchi Disk transparency, chlorophyll *a*, and turbidity. When light penetration decreased, there was a reduction in plant taxa and biomass. From the three variables, a multiple regression analysis was performed (Fig. 14). The resulting equation for summer biomass could be of value in the future for predicting values for use in macrophyte management in the chain of lakes.

Biomass =

$$(-34.05 + 71.17\ \text{Secchi} - 0.65\ \text{chl}\ \underline{a} + 1.87\ \text{turbidity})$$

$$r2 = .9758$$

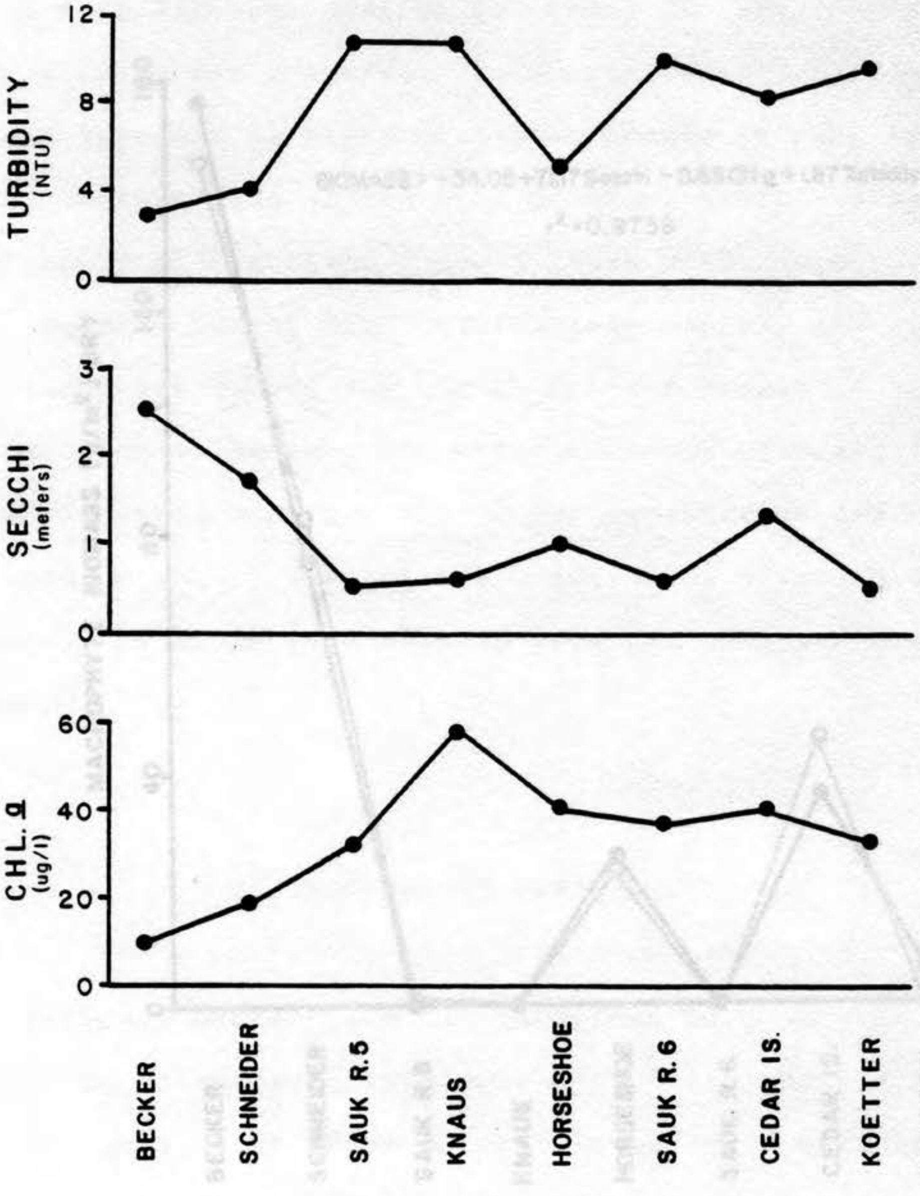


Figure 13. Comparison of summer averages for chlorophyll a, Secchi Disk transparency, and turbidity for several lakes. Sampling station Sauk River 5 is between Horseshoe and East Lakes; Sauk River 6 is between Cedar Island and Koetter Lakes.

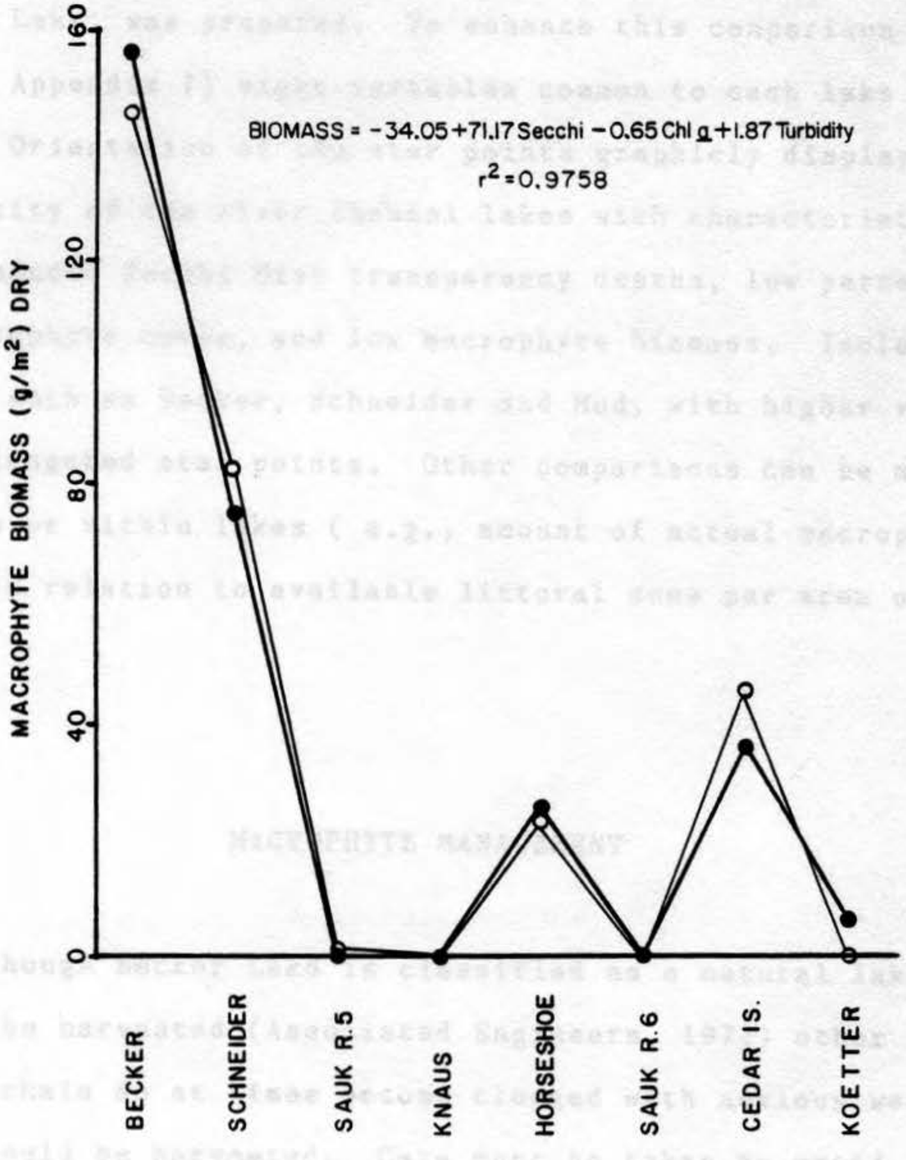


Figure 14. Comparison of actual and predicted macrophyte biomass as a result of a regression equation using variables in Figure 14. Solid circles are actual measurements. Open circles are predicted values.

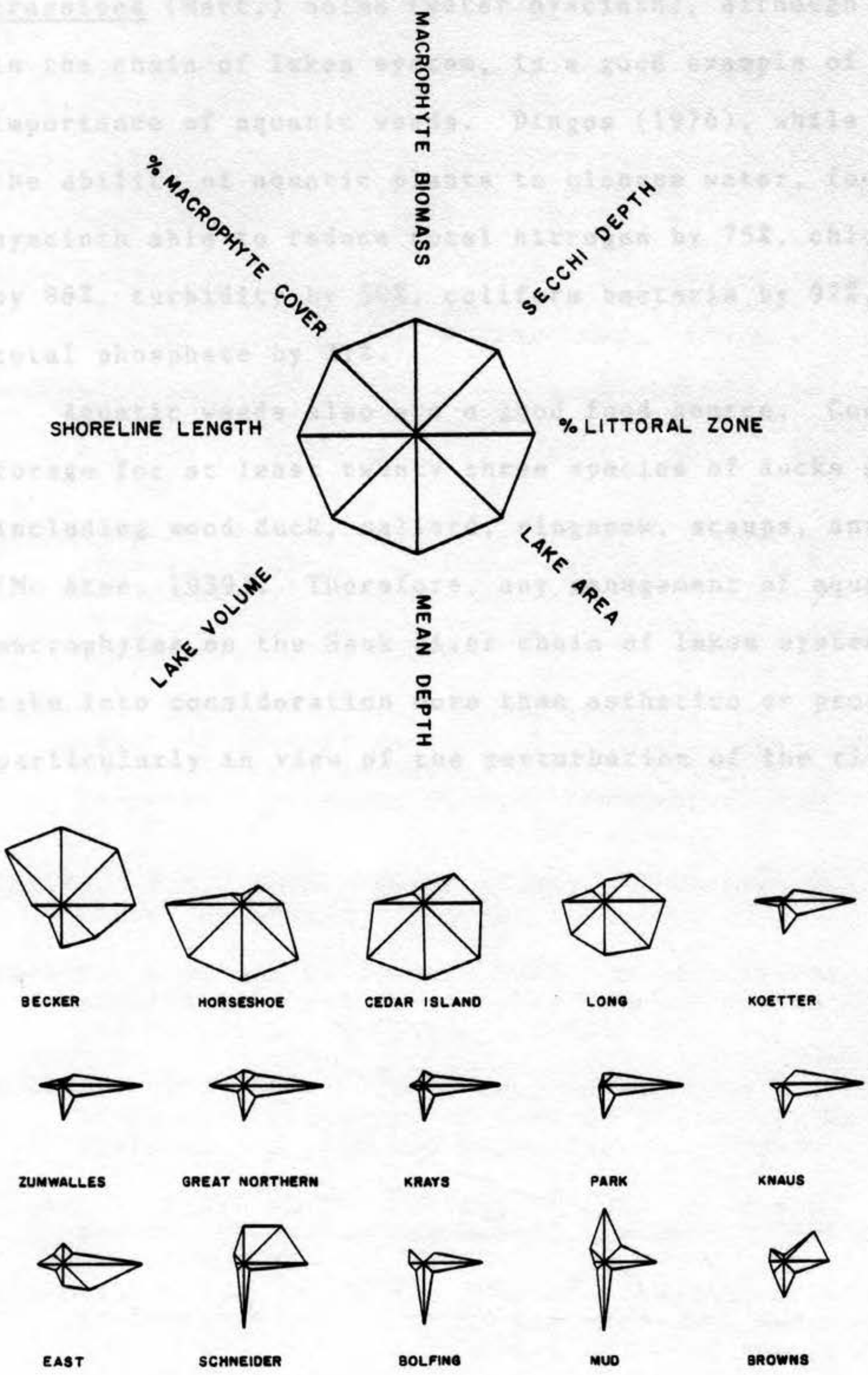
LAKE COMPARISON

A symbolic star plot of the chain of lakes, including Browns Lake, was prepared. To enhance this comparison (Fig. 15 and Appendix 1) eight variables common to each lake were used. Orientation of the star points graphicly displays the similarity of the river channel lakes with characteristics of: reduced Secchi Disk transparency depths, low percentage of macrophyte cover, and low macrophyte biomass. Isolated lakes, such as Becker, Schneider and Mud, with higher values have elongated star points. Other comparisons can be made between or within lakes (e.g., amount of actual macrophyte cover in relation to available littoral zone per area of a lake).

MACROPHYTE MANAGEMENT

Although Becker Lake is classified as a natural lake and cannot be harvested (Associated Engineers, 1972) other lakes in the chain do at times become clogged with noxious weeds which could be harvested. Care must be taken to avoid removal of too many macrophyte beds so as not to destroy nursery areas for fish, to expedite shoreline erosion, and to increase runoff. The latter could lead to additional nutrients and pollutants in the system. Eichhornia

Figure 15. Star plot of eight variables for lake comparison. Each star point is based on a percentage of the maximum value occuring in the lakes studied (Appendix 1.).


MACROPHYTE BIOMASS
SECCHI DEPTH
% LITTORAL ZONE
LAKE AREA
MEAN DEPTH
LAKE VOLUME
SHORELINE LENGTH
% MACROPHYTE COVER
BECKER
HORSESHOE
CEDAR ISLAND
LONG
KOETTER
ZUMWALLES
GREAT NORTHERN
KRAYS
PARK
KNAUS
EAST
SCHNEIDER
BOLFING
MUD
BROWNS

crassipes (Mart.) Solms (water hyacinth), although not found in the chain of lakes system, is a good example of the importance of aquatic weeds. Dinges (1976), while measuring the ability of aquatic plants to cleanse water, found water hyacinth able to reduce total nitrogen by 75%, chlorophyll a by 88%, turbidity by 50%, coliform bacteria by 97%, and total phosphate by 21%.

Aquatic weeds also are a good food source. Coontail is forage for at least twenty three species of ducks and swans, including wood duck, mallard, ringneck, scaups, and gadwalls (Mc Atee, 1939). Therefore, any management of aquatic macrophytes on the Sauk river chain of lakes system must take into consideration more than asthetics or prop fouling, particularly in view of the perturbation of the river.

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APPENDIXES

Appendix 1. Variables for Star Plot of Horseshoe Chain of Lakes.

Lake	Macrophyte Biomass g/m^2	Mean Secchi m	Littoral Zone %	Area $X10^6$ m^2	Mean Depth m	Volume $X10^6$ m^3	Shoreline km	Macrophyte Cover %
Becker	156.5	2.6	94	0.9	2.4	2.2	9.7	100
Horseshoe	20.6	1.2	53	2.3	5.4	12.0	25.2	20
Cedar Island	37.3	1.4	75	2.3	5.3	11.8	16.7	20
Long	41.8	1.3	76	1.9	3.7	6.9	13.8	20
Koetter	6.6	0.5	91	0.5	2.3	1.1	8.5	8
Zumwalles	11.9	0.4	100	0.5	2.4	1.1	8.1	2
Great Northern	41.3	0.5	100	0.5	2.4	1.1	10.8	15
Krays	29.9	0.4	100	0.4	2.4	0.9	4.5	10
Park	16.8	0.5	100	0.4	2.4	1.0	3.0	5
Knaus	0.8	0.6	100	0.4	2.4	1.0	3.9	21
East	44.3	0.5	100	1.0	1.5	1.5	8.3	17
Schneiders	75.4	1.7	80	0.2	4.5	1.0	1.9	14
Bolfing	3.9	0.5	73	0.4	4.3	1.8	4.3	23
Mud	109.9	0.7	66	0.3	4.6	1.3	3.5	20
Browns	7.7	1.5	57	1.3	1.7	2.2	4.7	22

Appendix 2. Procedure for determination of Total Kjeldahl Nitrogen (TKN) in macrophytes using a micro-Kjeldahl apparatus.

I. Digestion

a. Combine approximately 0.05 grams of dry macrophyte with 50 ml of deionized water and place into a Kjeldahl flask.

b. Add 10 ml sulfuric acid-mercuric sulfate-potassium sulfate solution and a boiling stone.

c. Evaporate the mixture in the Kjeldahl apparatus until SO3 fumes are given off and the solution turns colorless or pale yellow. Digest for and additional 30 minutes.

d. Cool the residue 10 minutes and add 30 ml distilled water.

II. Steam Distillation

a. Place 5 ml of 2% boric acid into vial and position under the end of the condensing tube. Make sure condenser tip is below the level of the boric acid.

b. Pour sample into distilling tube. Make digestate alkaline by the careful addition of 10 ml of sodium hydroxide-thiosulfate solution.

c. Steam distill for about 8 minutes after boiling begins.

d. Dilute the distillate to 50 ml.

III. Titration

a. Add 3 drops of mixed indicator and titrate with 0.02N H2SO4, Matching the endpoint against a blank containing the same volume of distilled water and boric acid solution.

b. Record the ml of acid used in the titration.

Procedure taken from EPA Method 351.3, Storet No. 00625.

Appendix 3. Proceedure for determination of total phosphate in macrophytes.

I. Persulfate Digestion

- a. To 50 ml of deionized water, add 0.01 grams of dried macrophyte and 1 drop of phenolphthalein. If red color develops, add H2SO4 solution dropwise to discharge the color.
- b. Add 1 ml H2SO4 solution and 0.4 grams ammonium persulfate.
- c. Boil gently on a preheated hot plate for 30 to 40 min. or until a final volume of 10 ml is reached.
- d. Cool, dilute with deionized water to 30 ml.
- e. Add 1 drop of phenolphthalein and neutralize to a faint pink color with NaOH solution.
- f. Dilute to 100 ml (or 200 ml as needed) with deionized water.
- g. Add strong acid solution dropwise to just discharge the color.

II. Stannous Chloride Method

- a. Add with thorough mixing after each addition, 4.0 ml molybdate reagent I and 10 drops stannous chloride reagent I.
- b. Measure color photometrically at 690 nm after 10 minutes but, before 12 minutes.

Procedure taken from Standard Methods 425 C & E.