Edward H. Barnard: *River Weeders*, 1893

Plant Harvesting and Water Quality Dynamics in Muskrat Lake for 2000

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Summary

Aquatic Plant Harvesting
An estimated 48 tons (wet weight) of aquatic plant biomass was removed in mid-summer from Muskrat Lake in 2000 for the purpose of opening up fish cruising lanes in the vegetation. This represents a removal of an estimated 29 pounds of phosphorus, a small percentage of the phosphorus loading to Muskrat Lake.

For the first time in the history of harvesting program, curlyleaf pondweed was harvested in June on the Pelican River and in Muskrat Lake. An estimated 123 tons (wet weight) were removed representing 74 pounds of phosphorus removed. The purpose of the early season curlyleaf pondweed harvesting was to slow its spread, and reduce a mid-summer phosphorus load that comes from curlyleaf dieback.

Zooplankton Densities and Biomass in Muskrat Lake
Zooplankton were collected in the middle of the lake on one date in August in 2000. The overall density of zooplankton and the biomass in August were greater compared to 1998 and 1999 August results.

Water Quality in Muskrat Lake
Secchi disc transparency and phosphorus concentrations indicate fair water quality in Muskrat Lake in 2000. However, lake modeling results indicate Muskrat Lake should have even better water quality than it presently has. Internal processes may be a significant factor.

Conclusions of Muskrat Lake Harvesting Program
- Muskrat Lake has acted as a phosphorus sink for the last two years.
- Zooplankton biomass is high and may be increasing.
- Harvesting may contribute to Muskrat acting as a phosphorus sink and to the increase in zooplankton, but it is not known to what extent.
- Although we cannot directly attribute harvesting to water quality improvements, the physical removal of exotic aquatic plants is a benefit.
- Harvesting removes phosphorus at $53/pound. A slightly high cost but not unreasonable.
- Harvesting has a chance at controlling nuisance spread of curlyleaf pondweed.

If harvesting is discontinued some of the following actions could occur:

- Increase in the spread of nuisance curlyleaf pondweed into Muskrat and into Sallie Lake. Dense curlyleaf growth in Pelican River could slow flow and raise water levels in the river.
- More algae growth in Muskrat and possible partial winterkill in Muskrat. This would set back the fish population.
- Muskrat Lake would act more like a phosphorus source than a phosphorus sink.
- As the positive effects of the alum treatment in St. Clair start to decline, harvesting would not be removing phosphorus.

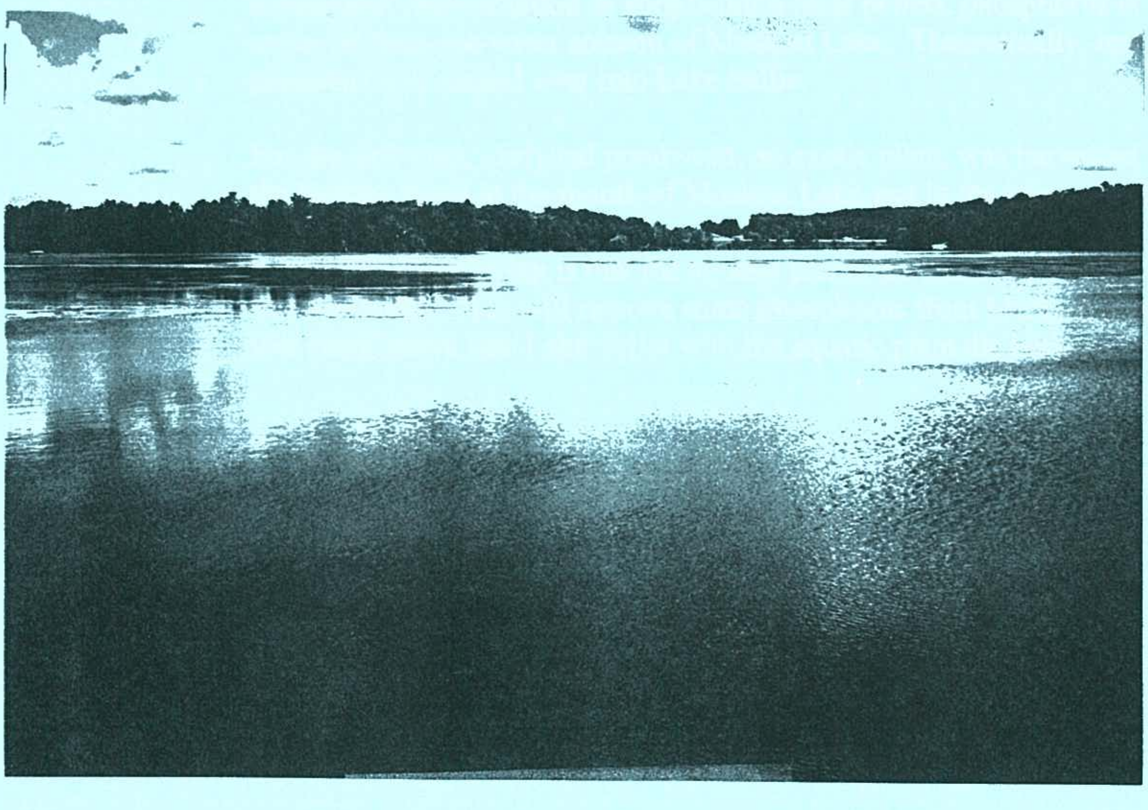
However, if harvesting is continued and the above adverse actions occur anyway, then harvesting would not appear to be influencing those actions and could be discontinued in the future.

A third situation also exists. The water quality benefits in the form of reduced phosphorus loading to Lake Sallie may be coming primarily from the St. Clair alum treatment and Ditch 14 aeration, and harvesting is not a significant factor. At this time we cannot separate the impacts of harvesting on water quality dynamics in Muskrat Lake.

However, Muskrat Lake as a stand alone resource supplies benefits to the lake users and there is a beneficial water quality influence on Lake Sallie. At a minimum, harvesting contributes to this with the physical removal of aquatic plants.

Recommendations

- Because of the likelihood that harvesting in Muskrat Lake removes phosphorus, and may control the nuisance spread of curlyleaf, there is likely some water quality benefits for both Muskrat and Lake Sallie, I recommend continuing the harvesting program - both in spring and summer.
- I also recommend curlyleaf distribution should be characterized on an annual basis for the next 5 years in Big and Little Detroit, Muskrat, and Lake Sallie to see if its coverage is expanding and to document the extent of nuisance conditions.



Muskrat Lake in 2000.

Introduction

Muskrat Lake is an important link in the protection and improvement of Lake Sallie. Nearly all surface runoff going into Lake Sallie passes through Muskrat Lake. A long term goal of the Watershed District is to manipulate Muskrat Lake to be a phosphorus sink rather than a phosphorus source. In turn, lower phosphorus loads would then be passed on to Lake Sallie.

In 1997, 1998, 1999, and 2000 aquatic plant harvesting was conducted in Muskrat Lake to indirectly enhance zooplankton biomass, which in turn would increase grazing on algae, possibly reducing water column phosphorus. We are using what Dr. Joe Shapiro has referred to as biomanipulation or what Dr. Steve Carpenter has called the top down trophic cascade.

In 2000, for the fourth year in a row, a mechanical harvester cut cruising lanes through the aquatic plant beds in Muskrat Lake. Cruising lanes are intended to allow gamefish (piscivores) access to forage fish (planktivores), to better control planktivore numbers. In turn, the reduced predation pressure by forage fish on their zooplankton prey should allow zooplankton numbers to increase. Higher zooplankton numbers mean more grazing pressure on algae. By removing algae through grazing and subsequent sedimentation as zooplankton fecal pellets, phosphorus is removed from the water column of Muskrat Lake. Theoretically, less phosphorus is carried over into Lake Sallie.

For the first time, curlyleaf pondweed, an exotic plant, was harvested in the Pelican River at the mouth of Muskrat Lake and in the lake as well.

A benefit of harvesting is that the aquatic plants are removed from Muskrat Lake. This will remove some phosphorus from Muskrat Lake that could move into Lake Sallie with the aquatic plant die back.

Aquatic Plant Harvesting Methods

Pelican River Watershed District Harvester #1 was used to harvest aquatic plants in Muskrat Lake in May, July and August of 2000. The harvester can cut down to a depth of 5 feet below the water surface.

Zooplankton Sampling Methods

We employed methods similar to what the MnDNR - Ecological Services (St. Paul) has used for zooplankton analysis in Long Lake.

Field Procedures: Zooplankton were collected with an 80 μm mesh Wisconsin-style Plankton Net. Near-shore tows were taken from the fishing pier, a shallow shoreline site in 1997. Vertical tows were taken from a boat through the water column in the middle of Muskrat Lake in 1998, 1999, and 2000. The net was lowered to 0.5 meter from the bottom and raised at 0.5 to 1 meter per second to the surface. All tow samples were rinsed from the bucket of the net into a plastic bottle and preserved with 100% Ethanol. The bottle was labeled with the lake name, site number, date, and tow length (in feet). Tows were taken once in June, July, and August in 1998 and 1999 and once in August 2000.

Lab Procedures: The MnDNR Ecological Services - Biology Lab uses the following protocol to analyze lake zooplankton samples and the same protocol was used by Blue water Science. Sample volumes are adjusted to a known volume by filtering through 80 μm mesh netting and rinsing specimens into a graduated beaker. Water is added to the beaker to a volume that provides at least 150-200 organisms per 5 ml aliquot. The beaker is swirled in a figure-eight motion to ensure thorough mixing. A 5 ml aliquot is withdrawn from each sample using a bulb pipet and transferred to a counting wheel and zooplankton samples are counted and measured at 30X magnification under a dissecting microscope. Identification to species (or the lowest taxonomic group possible) is done with the use of a compound microscope. In addition to density estimates, estimates of biomass were calculated using length/weight regression coefficients calculated by the MnDNR-Ecological Services, on a Muskrat Lake sample from August 28, 1997. We assigned unit weights for the various zooplankton taxa for other sample dates.

Results

Aquatic Plant Harvesting

For the fourth consecutive year, the Pelican River Watershed District conducted mid-summer aquatic plant harvesting on Muskrat Lake. The District harvested and removed an estimated 48 tons (wet weight) of plants in mid summer harvesting. In addition, for the first time, curlyleaf pondweed was harvested in the early summer in the Pelican River and in Muskrat Lake. An estimated 123 tons (wet weight) of plants were removed. Harvesting locations are shown in Figure 1. Statistics for aquatic plant removal and phosphorus removal are summarized in Table 1.

Table 1. Amounts of plant material and phosphorus removed by harvesting from Muskrat Lake in 1997, 1998, 1999, and 2000.

Year	Tons of Plants Removed	Pounds of Phosphorus Removed (0.6 lbs-p/ton wet weight)*	Incoming P load from SC 4 and PR 6 and Percent of Incoming P Load Removed by Harvesting**
1997	185	204	4,006 (3%)
1998	146	161	3,777 (2%)
1999	23	25	2,454 (1%)
2000[a]	48	53	1,560 (2%)
2000[b]	123	135	1,560 (5%)

* estimated from various literature values (dry weight is 10% of wet weight and P content as 0.3% of dry weight)
** estimated from PRWD loading estimates
[a] mid summer harvesting in transects /fish lanes
[b] early summer harvesting curlyleaf pondweed in Pelican River and in Muskrat Lake

The primary objective of mid summer harvesting has been to increase zooplankton biomass and grazing pressure on algae, and to indirectly reduce phosphorus loading to Lake Sallie. In 2000, the objectives of early summer harvesting of curlyleaf pondweed were to reduce the spread of curlyleaf pondweed and to reduce a potential mid-summer phosphorus pulse and help both Muskrat Lake and Lake Sallie.

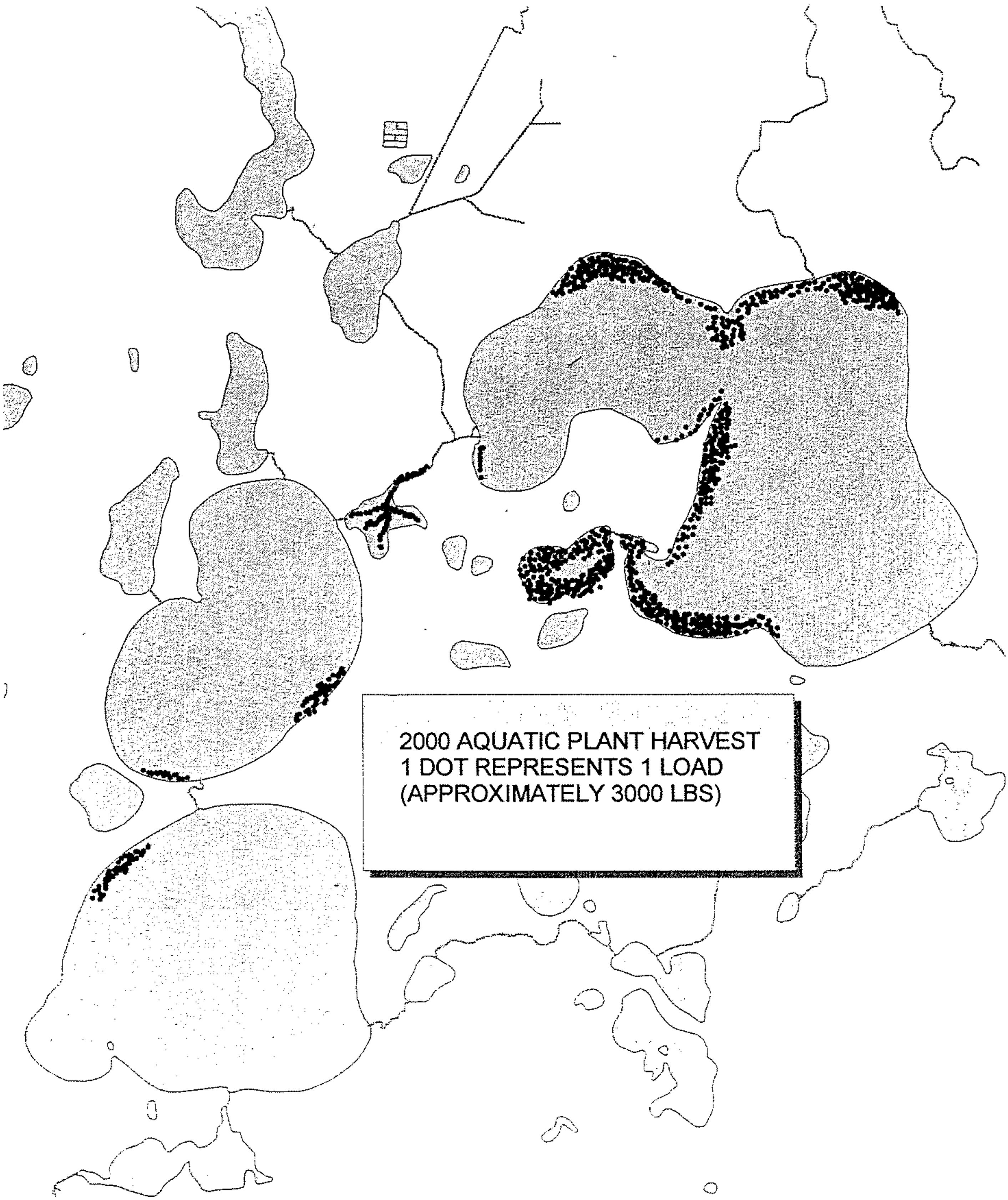


Figure 1. Harvesting areas in 2000.

Zooplankton Densities and Biomass in Muskrat Lake

Zooplankton sampling occurred in the middle of Muskrat Lake on one date in the summer of 2000. Results of zooplankton density and biomass are shown in Table 2. Zooplankton biomass for the last three years is shown in Figure 2. Zooplankton densities for the last three years are shown in Table 3 and Figure 3.

Table 2. Muskrat Lake zooplankton data for August 2000 for zooplankton densities and biomass for middle of the lake.

Date	μg/ organism	8.24.00	
		#/l	wt (μg/l)
Big (>1 mm)	12.00	7	84
Little (< 1 mm)	4.13	29	120
Ceriodaphnia	2.50	0	0
Bosmina	1.18	10	12
Chydorus	1.61	1	2
Cladocerans		**47**	**218**
Calonoids	5.00	4	20
Cyclopoids	1.00	25	25
Nauplii	0.27	80	22
Copepods		**109**	**67**
Rotifers		**0**	**0.00**
Total Zooplankton		**156**	**285**

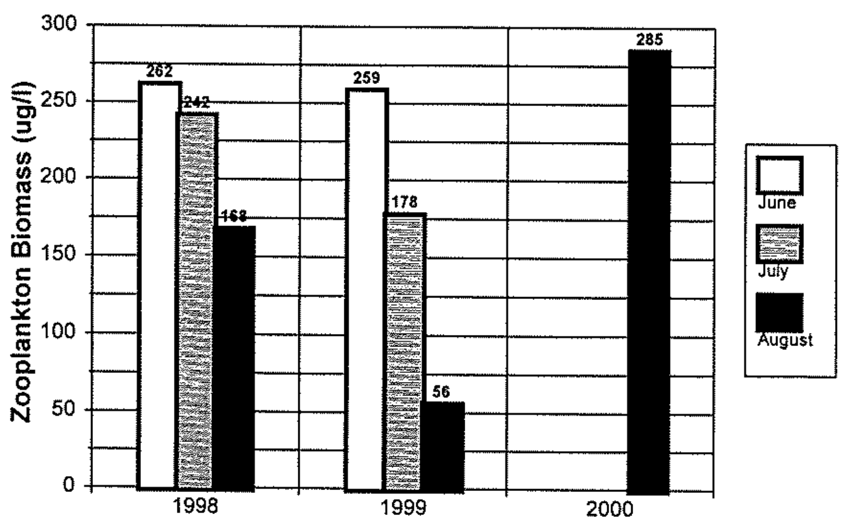


Figure 2. Comparison of zooplankton biomass over the last three years.

Table 3. Comparison of zooplankton densities in number/liter for middle of the lake zooplankton tows in 1998 and 1999.

	Total Cladocerans			Total Copepods			Total Zooplankton		
	1998 (#/l)	1999 (#/l)	2000 (#/l)	1998 (#/l)	1999 (#/l)	2000 (#/l)	1998 (#/l)	1999 (#/l)	2000 (#/l)
June									
week 1*	48	--	--	32	--	--	80	--	--
week 2	37	--	--	61	--	--	98	--	--
week 3	123	20	--	35	35	--	158	55	--
week 4									
July									
week 1	--	--	--	--	--	--	--	--	--
week 2	--	--	--	--	--	--	--	--	--
week 3	40	--	--	21	--	--	61	--	--
week 4	--	32	--	--	90	--	--	122	--
August									
week 1	22	--	--	68	--	--	90	--	--
week 2	--	--	--	--	--	--	--	--	--
week 3	19	6	--	25	41	--	44	46	--
week 4	--	--	47	--	--	109	--	--	156

*week 1: days 1-7; week 2: days 8-14; week 3: days 15-21; week 4: days 22-31

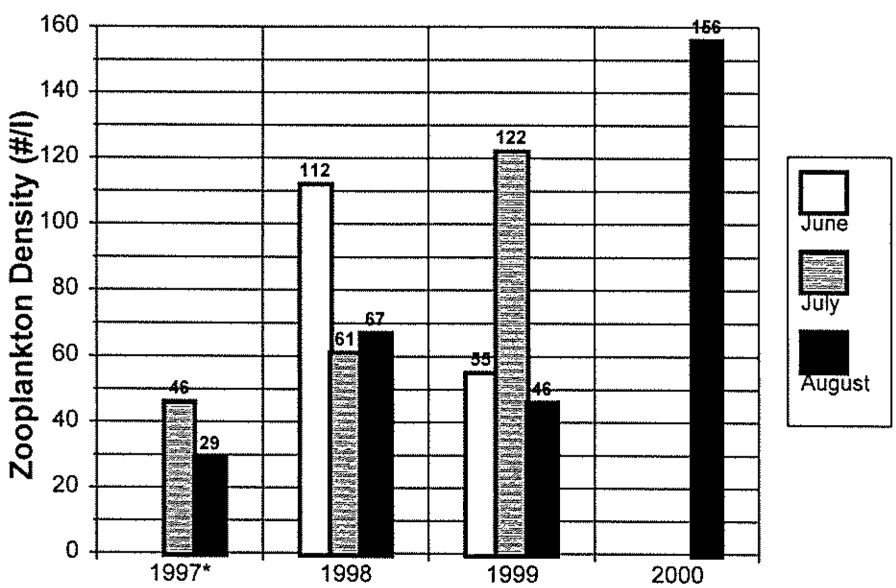


Figure 3. Comparison of zooplankton density over the last few years. Zooplankton tows were made from shore in 1997 and from the middle of the lake in 1998, 1999, and 2000.

Muskrat Lake Water Quality

Water quality sampling parameters in Muskrat Lake in 2000 included: secchi disc transparency, total phosphorus, and chlorophyll a. Secchi disc transparency averaged 11 feet for May, June, July, and August. Phosphorus averaged 31 ppb for the same time period (Table 4).

Table 4. Muskrat Lake 2000 water chemistry data.

	May 31	June 26	July 10	July 26	Sept 1	Summer Average
Secchi disc (ft)	11	14	14	11	7	11
Total phosphorus (ppb)	29	21	44	31	37	31
Orthophosphorus (ppb) - top	0	6	44	--	--	15
Temp (C)	19.5	20.1	--	24.5	19.2	20.8

Water clarity has been good the last 3 years and phosphorus concentrations have been low for the last 2 years (Table 5).

Table 5. Muskrat Lake water quality for the summer growing season.

	1998	1999	2000
Secchi disc (ft)	8.8	8.4	11
Total phosphorus (ppb)	56	34	31
Orthophosphorus (ppb)	23	10	15
Depth (ft) where DO < 2.0 mg/l	9	13	14

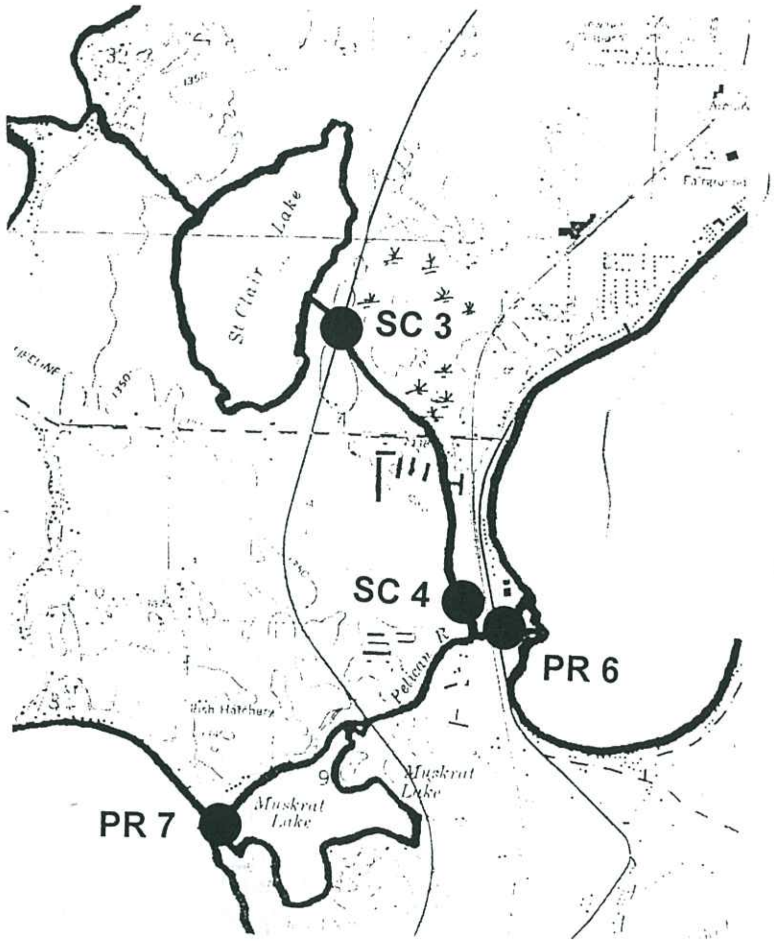
MnDNR-fishery records have some water quality information. Winterkill conditions have been documented for five winters going back to 1976 but not since 1994 (Table 6). A ratio of black to yellow bullheads is used as a water quality indicator. The lower the ratio the better. The ratio of black bullheads to yellow bullheads indicates that water quality in Muskrat Lake is not declining.

Table 6. Winterkill and black bullhead/yellow bullhead ratios for Muskrat Lake (source: MnDNR fishery records).

	Winter Fish Kill	Black Bullhead (catch/effort)	Yellow Bullhead (catch/effort)	Ratio Black:Yellow
1976	yes			
1978	no			
1979	no			
1980	no			
1981	no			
1982	no			
1983	--	18.0	2.0	9
1988	--	72.0	1.5	48
1989	yes			
1991	no			
1992	yes			
1993	yes	21.0	0	21+
1994	yes			
1996	no			
1997	no			
1998	--	26.5	3.0	8.8

Phosphorus Export from Muskrat Lake

Phosphorus loading to Muskrat Lake from SC 4 and PR 6, 2000 was estimated at 1,560 pounds (Table 7). Phosphorus export from Muskrat Lake was estimated at 1,543 pounds. In 2000 Muskrat Lake acted as a sink for phosphorus retaining a net of 17 pounds of phosphorus.



Muskrat Lake Phosphorus Dynamics: Source or Sink		
	Source (lbs)	Sink (lbs)
1995	334	
1996		324
1997	886	
1998	66	
1999		449
2000		17

Table 7. Phosphorus loading data. Loadings are in pounds of phosphorus.

	SC 3 St. Clair Outlet to Ditch 14	SC 4 Ditch 14 Outlet	PR 6 PR Outlet from DL	SC 4 + PR 6	PR 7 (Muskrat Lake outlet) = PR inlet to Lake Sallie	Muskrat Lake: source = + sink = -
1995	940	1,058	841	1,899	2,233	+ 334
1996	1,152	1,877	1,232	3,109	2,785	-324
1997	972	1,937	2,069	4,006	4,892	+ 886
1998	762	1,800	1,977	3,777	3,843	+ 66
1999	592	1,135	1,319	2,454	2,005	- 449
2000	353	641	919	1,560	1,343 (1,543)*	- 17

*corrected by a 15% increase to account for a board removed from the dam over the summer

Muskrat Lake Modeling Results

Based on water flows and nutrient loadings to Muskrat Lake, a lake model was run for the years 1998, 1999, and 2000. The predicted in-lake phosphorus concentration was lower than what was observed for the last three years. This indicates that internal processes may be contributing phosphorus to Muskrat Lake. Muskrat Lake probably received above average phosphorus loads in the past and excess phosphorus accumulated in the lake sediments. Some fraction of that phosphorus appears to be released on an annual basis.

Aquatic plant harvesting should help to minimize the impacts of the sediment phosphorus release through biomanipulation and physical removal of the plants.

Table 8. Muskrat Lake phosphorus model results.

	1998	1999	2000
Model Input Data			
Water load (million cubic feet) (SC 4 + PR 6)	1,385	1,075	883
Phosphorus load (pounds) (SC 4 + PR 6)	3,777	2,454	1,560
Water retention time (days)	7.7	9.9	12.2
Lake Data			
Total Phosphorus observed-ppb (growing season average)	56	34	31
Lake Model Results			
Phosphorus lake model prediction--ppb (Canfield-Bachman Natural Lake)	33	28	22

Muskrat Lake area: 67 acres
Muskrat Lake mean depth: 10 feet

Conclusions of Muskrat Lake Harvesting Program

- Muskrat Lake has acted as a phosphorus sink for the last two years.
- Zooplankton biomass is high and may be increasing.
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However, if harvesting is continued and the above adverse actions occur anyway, then harvesting would not appear to be influencing those actions and could be discontinued in the future.

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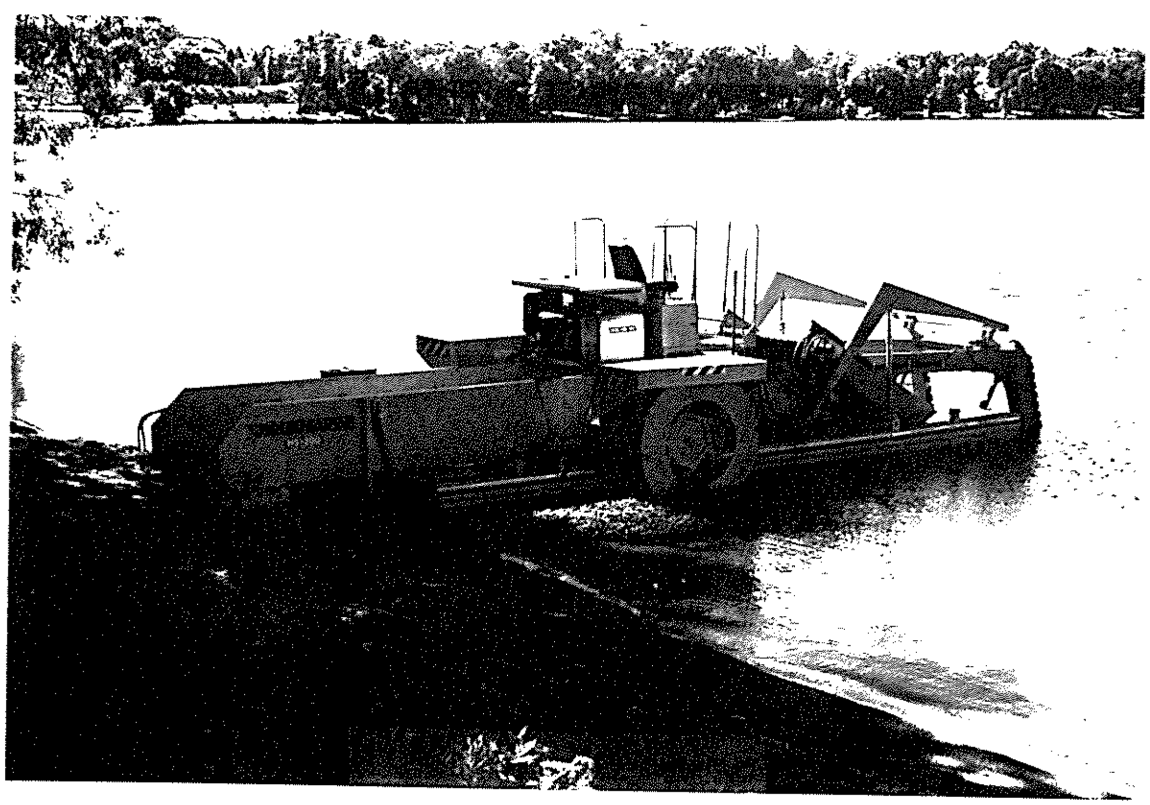
Recommendations

- Because of the likelihood that harvesting in Muskrat Lake removes phosphorus, and may control the nuisance spread of curlyleaf, there is likely some water quality benefits for both Muskrat and Lake Sallie, I recommend continuing the harvesting program - both in spring and summer.
- I also recommend curlyleaf distribution should be characterized on an annual basis for the next 5 years in Big and Little Detroit, Muskrat, and Lake Sallie to see if its coverage is expanding and to document the extent of nuisance conditions.



Appendix

Background Data

Table A-1. Muskrat Lake zooplankton density and biomass in 1999.

Date	µg/ organism	6.15.99		7.26.99		8.17.99	
		#/l	wt	#/l	wt	#/l	wt
Big (>1 mm)	12.00	15	180.00	3	36.00	0	0.00
Little (< 1 mm)	4.13	3	12.39	21	86.73	6	24.78
Ceriodaphnia	2.50	0	0.00	0	0.00	0	0.00
Bosmina	1.18	2	2.36	7	8.26	0	0.00
Chydorus	1.61	0	0.00	1	1.61	0	0.00
Cladocerans		**20**	**194.75**	**32**	**132.60**	**6**	**24.78**
Calonoids	5.00	10	50.00	3	15.00	3	15.00
Cyclopoids	1.00	11	11.00	9	9.00	8	8.00
Nauplii	0.27	14	3.78	78	21.06	30	8.10
Copepods		**35**	**64.78**	**90**	**45.06**	**41**	**31.10**
Rotifers		**4**	**--**	**14**	**--**	**25**	**--**
Total Zooplankton		**59**	**259.53**	**136**	**177.66**	**72**	**55.88**

Table A-2. Muskrat Lake zooplankton data for 1998 for zooplankton densities and biomass for nearshore and middle of the lake tows.

Middle of the Lake Tows

	ug/ organism	6.4.98		7.16.98		8.6.98		8.20.98	
		#/l	wt	#/l	wt	#/l	wt	#/l	wt
Daphnia - big	12.00	6	72	0	0	4	48	3	36
Daphnia - small	4.13	37	153	40	165	10	41	12	50
Diaphanosoma	2.5	0	0	0	0	0	0	1	3
Bosmina	1.18	4	5	0	0	11	13	3	4
Chydorus	1.61	1	2	0	0	1	2	0	0
CLADOCERANS SUBTOTAL		**48**	**232**	**40**	**165**	**22**	**104**	**19**	**93**
Calanoids	5.00	4	20	14	70	10	50	10	50
Cyclopoids	1.00	3	3	7	7	20	20	7	7
Nauplii	0.27	25	7	0	0	38	10	8	2
COPEPODS SUBTOTAL		**32**	**30**	**21**	**77**	**68**	**80**	**25**	**59**
Rotifers	--	3	--	0	--	11	--	3	--
Total Zoop Wt		--	**262**	--	**242**	--	**184**	--	**151**

Nearshore Tows

	ug/ org	5.98		5.22.98		6.8.98		6.16.98		7.1.98		7.16.98		7.30.98		8.12.98	
		#/l	wt	#/l	wt	#/l	wt	#/l	wt	#/l	wt	#/l	wt	#/l	wt	#/l	wt
Daphnia - big	12.0	0	0	1	12	1	12	0	0	0	0	0	0	0	0	0	0
Daphnia - small	4.13	6	25	1	4	5	21	27	112	2	8	9	37	3	12	1	4
Diaphanosoma	2.50	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bosmina	1.18	3	4	1	1	2	2	5	6	0.5	0.6	4	5	4	5	0	0
Chydorus	1.61	2	3	0	0	1	2	3	5	0.5	0.8	1	2	2	3	0	0
CLADOCERANS SUBTOTAL		**12**	**35**	**3**	**17**	**9**	**37**	**35**	**123**	**3**	**9**	**14**	**44**	**9**	**20**	**1**	**4**
Calanoids	5.00	2	10	1	5	9	45	0	0	7	35	6	30	3	15	0	0
Cyclopoids	1.00	15	15	1	1	9	9	24	24	9	9	12	12	19	19	1	1.0
Nauplii	0.27	3	0.9	12	3	25	7	40	11	7	2	47	13	29	8	5	1
COPEPODS SUBTOTAL		**20**	**26**	**14**	**9**	**43**	**61**	**64**	**35**	**23**	**46**	**65**	**55**	**51**	**42**	**6**	**2**
Rotifers	—	1	--	4	--	2	--	27	--	1	--	3	--	10	--	5	--
Total Zoop Wt		--	**61**	--	**26**	--	**98**	--	**158**	--	**55**	--	**99**	--	**62**	--	**6**

Table A-3. Muskrat Lake zooplankton density in 1997. Results are shown in number per liter. Tows are from shore.

Date (1997)	Daphnids						Copepods				Rotifers
	Daphnia		Bosmina	Chydorus	Cladocera	Total Cladocerans	Calonoids	Cycopoids	Nauplii	Total Copepods	
	Big >1mm	Little <1mm									
7.11	1	1	0	23	0	25	1	10	3	14	0
7.16	1	3	0	31	0	35	1	16	5	22	12
7.25	1	2	0	6	0	9	1	5	9	15	6
8.1	0	1	0	3	0	4	1	6	11	18	10
8.8	1	2	0	4	0	7	1	5	7	13	5
8.15	0	5	0	9	1	15	1	2	3	6	1
8.22*	0	1	1	13	1	17	1	2	3	6	1
8.28**	1	0	3	17	2	23	0	9	10	19	0

Table A-4. Muskrat Lake biomass for July and August, 1997 in μg/l-dry weight. Dry weights were based on MnDNR determinations made on the 8.28 sample and the same unit weights were used for the other sample dates.

	μg/l-organism	7.11	7.16	7.25	8.1	8.8	8.15	8.22	8.28
Cladocerans									
Big (>1mm)	12.00	12.0	12.0	12.0	0	12.0	0	0	0.2
Little (<1mm)	4.13	4.13	12.39	8.26	4.13	8.26	20.65	4.13	0
Ceriodaphnia	1.03	0	0	0	0	0	0	1.03	3.09
Bosmina	1.18	27.14	36.58	7.08	3.54	4.72	10.62	15.34	20.06
Chydorus	1.61	0	0	0	0	0	1.61	1.61	3.22
Total Cladocerans		43.27	60.97	27.34	7.67	24.98	32.88	22.11	38.37
Copepods									
Calanaids	5.00	5.0	5.0	5.0	5.0	5.0	5.0	5.0	0
Cyclopoids	1.00	10.0	16.0	5.0	6.0	5.0	2.0	2.0	9.0
Nauplii	0.27	0.81	1.35	2.43	2.97	1.89	0.81	0.81	2.70
Total Copepods		15.81	22.35	12.43	13.97	11.89	7.81	7.81	11.70
Totals		59.08	83.32	39.77	21.54	46.87	40.69	29.99	50.07

Table A-5. Zooplankton biomass (ug/l) for Long Lake 1998.

	5.2	6.5	6.17	7.1	7.13	7.31	8.10	8.24
COPEPODS								
Nauplii	--	0.38	--	0.14	0.21	0.20	0.38	0.28
Copepodites	5.12	1.76	1.64	0.13	2.85	1.16	2.43	0.72
Calanoids	94.29	78.98	37.28	17.88	15.34	52.89	18.25	15.06
Cyclopoids	6.53	51.79	18.18	17.83	38.06	24.68	22.46	16.49
Total Copepods	105.94	132.91	57.10	35.98	56.47	78.92	43.52	32.54
CLADOCERANS								
Big Daphnids	2.90	2.97	19.00	43.44	30.94	24.15	8.08	1.59
Little Daphnids	4.33	6.94	28.70	21.48	8.51	16.35	3.87	6.71
D. pulex	—	--	0.69	1.83	--	--	--	--
Chydorus	0.19	--	--	--	--	--	--	--
Ceriodaphnia	--	—	0.13	--	--	--	--	0.13
Diaphanosoma	—	—	--	1.22	0.97	1.55	0.34	0.31
Bosmina	—	6.56	0.66	--	--	--	1.07	2.82
Total Cladocerans	7.43	16.48	49.17	67.97	40.42	42.04	13.36	11.57
Total Zooplankton Biomass	**113.37**	**149.38**	**106.27**	**103.95**	**96.89**	**120.97**	**56.88**	**44.11**