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Douglas D. Harris
Nebraska Public Power District

Michael P. Gutzmer
Nebraska Public Power District, mgutzmer@newcenturyenvironmental.com

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MACROPHYTE PRODUCTION, FISH HERBIVORY, AND WATER QUALITY IN A TAILWATER RESERVOIR—LAKE OGALLALA, NEBRASKA

Douglas D. Harris and **Michael P. Gutzmer**

Gerald Gentleman Station
Nebraska Public Power District
P.O. Box 68, Sutherland, Nebraska 69165

Nebraska Public Power District
1414 15th St.
Columbus, Nebraska 68601

ABSTRACT

Nebraska Public Power District (NPPD) began monitoring aquatic-macrophyte production in Lake Ogallala, Nebraska, in 1989 because the lake provides cooling water for a coal-fired electricity generating facility—Gerald Gentleman Station (GGS). Large mats of macrophytes in the cooling water caused several trips of the generating units at GGS, at considerable cost to NPPD. The plants also support macroinvertebrates that supply food for the trout fishery in and downstream of the lake. *Ceratophyllum demersum*, *Potamogeton* spp., *Myriophyllum sibiricum*, and *Zannichellia palustris* were the most commonly observed plants. In the early 1990s, macrophyte production declined to very low levels. Fresh-weight biomass averaged 6887 g/m^2 in 1989 and declined to 20 g/m^2 in 1995. June-July water temperatures also varied, increasing slightly through 1992, then decreasing 3°C through 1995. Fish activity in areas noted for previous high macrophyte production was suggested as a cause of decreased macrophyte production. A fish-exclosure study in 1994 and 1995 showed that herbivory and sediment-disturbance (probably by carp and white suckers) is partly responsible for the macrophyte decline, but productivity in the protected areas did not return to the high levels observed in the late 1980s.

† † †

Lake Ogallala is a small reservoir immediately downstream from Kingsley Dam on the North Platte River (Fig. 1). The lake currently has a maximum surface area of 263 ha (650 ac) at an elevation of 953 m; the main arm has an average depth of 7.8 m and the diversion pond averages 2.2 m. The dam, built in the 1930s, created a much larger reservoir behind it, Lake McConaughy. In the early 1980s, the 50-megawatt Kingsley Hydropower Plant (Kingsley Hydro) was constructed at the base of the dam, altering the water-release regime from Lake McConaughy into Lake Ogallala. The releases now are usually of hypolimnetic water and, as a result, are cooler than surface waters, low in turbidity and dissolved oxygen, and high in nutrients during periods of stratification each summer. As a result, Lake Ogallala provides a unique cold-water environment for salmonid fish, aquatic plants, and other aquatic life, and a put-grow-take rainbow trout fishery has been established. The anoxic water from Lake McConaughy provides cool, nutrient-rich water essential for primary production. Water from the diversion pond flows into the North Platte River and the Sutherland Supply Canal.

Aquatic macrophytes and algae originally grew extensively in Lake Ogallala and the upper reaches of the Supply Canal, to a point where the Korty Supply Canal enters. NPPD's major concern is that free-floating mats of vegetation, at certain times of the year, create operational problems by clogging the screens at the GGS cooling-water intake and can cause "trips" of the generating units, the power plant then being automatically out of service because of high differential water levels caused by vegetation accumulated on the trash bars and traveling screens. These trips are very costly and create major operational problems.

Lake Ogallala and the Supply Canal contain various submersed, floating, and emergent aquatic plants (Table 1). It is generally known that several factors limit the diversity and abundance of aquatic macrophytes: light quality and quantity, temperature, hydrostatic pressure, water currents and turbulence, sediments, and nutrient and inorganic carbon availability (Symoens, 1989). Standing crops or production of various species of aquatic macrophytes differ greatly. Submersed, floating-leaved, and floating plants are usually less productive than emergent plants when the same body of water is considered or if data are averaged for several species in a group (Wood, 1975). Generalizations about the production of individual species are difficult because standing crops of a species may differ

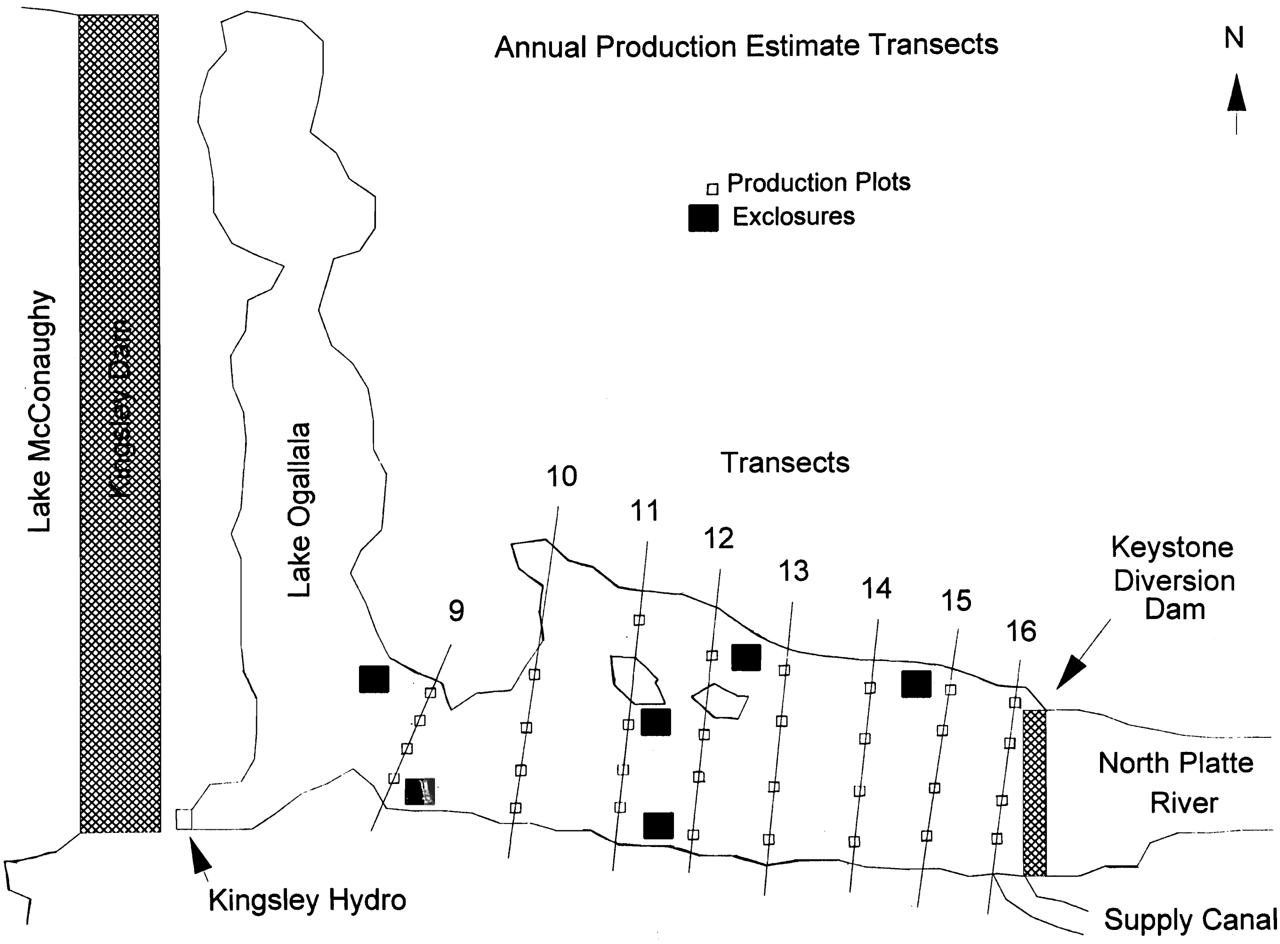

Figure 1. Lake Ogallala with the locations of routine monitoring transects, plots and fish exclosures indicated.

greatly between sites (Hutchinson, 1975). Data for net production are usually reported in terms of dry matter, ash-free dry matter, carbon, or energy equivalents. For purposes of simplicity and to expand a limited database, our study focussed on fresh-weight analysis. In the literature, standing crops are reported to vary from 5 to 2,000 g/m^2 but the figures expressed for wet- or fresh-weight would be much higher. Littoral sediments of running waters are sorted by water movements into particle-size gradients. The geomorphology of the drainage basin influences particle placement and size. In most habitats conducive to aquatic vegetation, the sediments contain appreciable organic matter.

Recent fish surveys conducted by the Nebraska Game and Parks Commission show large populations of carp (*Cyprinus carpio*) and white suckers (*Catastomus* sp.) in Lake Ogallala (Madsen, 1995). Visual evidence of fish herbivory on submerged macrophytes suggest the fish to be a potential cause of declines in macrophyte production.

The initial objective of this study was to monitor macrophyte production to predict operational problems at GGS. A second objective was to determine the role the large populations of carp and white suckers had in macrophyte decline. Evidence of fish activity (visual sighting and presence of "craters") in areas previously noted for high macrophyte production led to formulation of the hypothesis that sediment disturbance and herbivory by carp and/or white suckers were the causes of decreased macrophyte production. Renovation of the lake is scheduled for October, 1996, in an attempt to reduce the large populations of these rough fish.

METHODS

Several transects were established across the diversion pond of Lake Ogallala in 1989 to begin annual monitoring of macrophyte production (Fig. 1). Along these transects, several 0.25-m^2 plots were sampled with a modified Osborne Sampler to estimate biomass production. A specially constructed vegetation cutter (serrated blade on a 3-m conduit pipe) was used to cut

Table 1. Submergent macrophytes sampled 1989–1995 from Lake Ogallala.

	1989	1990	1991	1992	1993	1994	1995
Macrophytes							
Ceratophyllum demersum	x	x	x				
Myriophyllum sibiricum	x	x	x				
Potamogeton crispus	x	x					
Potamogeton filiformis		x	x		x	x	
Potamogeton foliosus			x	x			
Potamogeton pusillus	x	x	x	x	x	x	x
Ranunculus longirostris	x						
Zannichellia palustris	x	x	x	x	x		x
Macrophytic algae							
Chara sp.	x	x	x				
Other algae	x	x	x				

the plants at their base. This sampler (Fig. 2) was unique in that it was manually lowered from the side of a boat into 1–2 m of water. Because the pond was mostly that depth, the sampler was very effective in vegetation extractions. Estimates were made at least once annually through 1995.

The vegetation, once trimmed, was drained and placed in a graduated bucket and weighed as fresh weight to the nearest gram. Total weights were recorded and percent composition by species estimated (Table 2). Visual estimation was used to determine percent species composition of vegetative cover in each sample. The samples were averaged to produce an estimate of macrophyte production in the lower pond of the lake for each sample date. The same observer made all observations in all years.

Determination of the extent to which herbivory by white suckers and carp was limiting macrophyte production was done through a series of fish exclosures. These allowed paired comparisons of vegetation biomass production in grazed and ungrazed areas and provided information about what macrophyte production could be expected following the planned renovation of the lake. The monitoring program identified substantial declines in macrophyte production in the early 1990s.

Five exclosures were installed in 1994 and six in 1995, early in the spring before macrophyte growth. Three of the five 1994 exclosures were placed in shallow water so they became periodically dewatered as the water level fluctuated; these three were excluded from the final analyses to avoid bias caused by dewatering effects. Several exclosures were placed along the south shoreline of the diversion pond because of easy access to that area (Fig. 1). However, some exclosures were placed along the north shoreline and near the islands

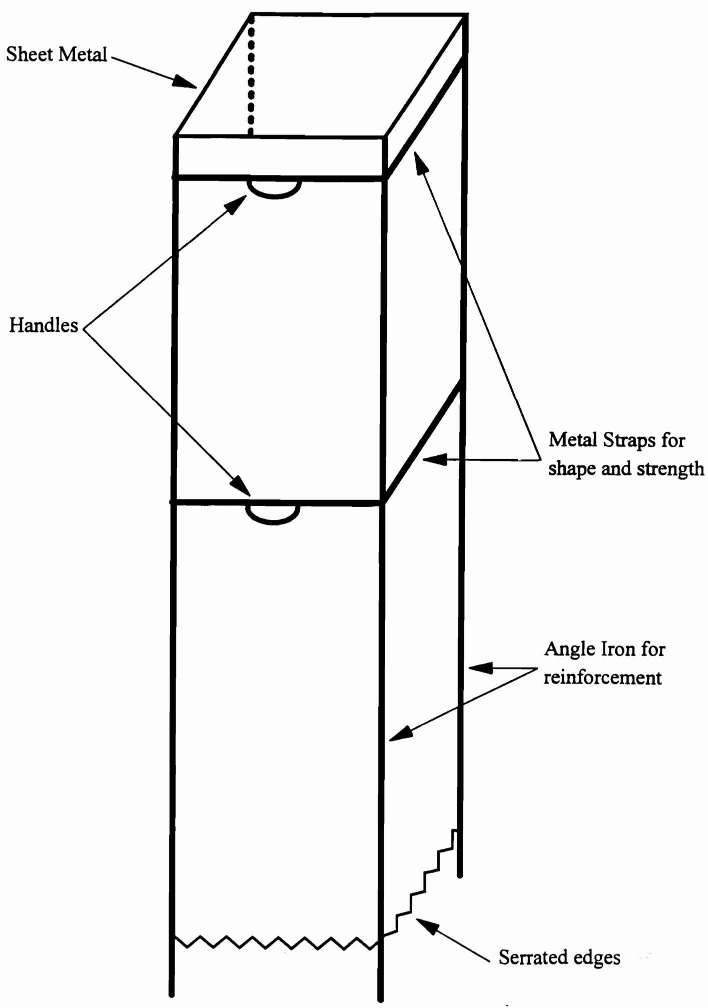

Figure 2. Modified version of the Osborne Sampler used for submergent macrophyte sampling in Lake Ogallala, Nebraska.

Table 2. Fresh weight of submergent macrophytes from Lake Ogallala 1989–1995, expressed as average g/0.25m^2 production plot.

	Species								
Date	*C. d.*	*P. p.*	*P. c.*	*Z. p.*	*M. s.*	Alg.	Misc.	Total	g/m^3
7/19/89	319	670	1	0	33	469	0	1492	5698
8/15/89	1134	259	0	0	153	330	227	2103	8412
8/30/89	1213	399	4	3	133	255	10	2017	8068
9/13/89	1035	349	0	23	126	329	167	2029	8116
9/27/89	349	206	0	7	106	248	52	968	3872
8/15/90	114	104	1	88	27	30	32	396	1584
9/11/90	396	164	0	145	138	510	32	1385	5540
8/14/91	50	60	0	74	25	10	98	317	1268
9/12/91	28	4	0	3	2	160	47	244	976
8/05/92	0	54	0	19	0	0	1	74	296
9/08/92	0	7	0	2	0	1	20	30	120
8/05/93	0	2	0	1	0	0	35	38	152
9/21/93	0	0	0	4	0	0	1	5	20
7/20/94	0	7	0	0	0	0	5	12	48
9/08/95	0	4	0	1	0	0	0	5	20

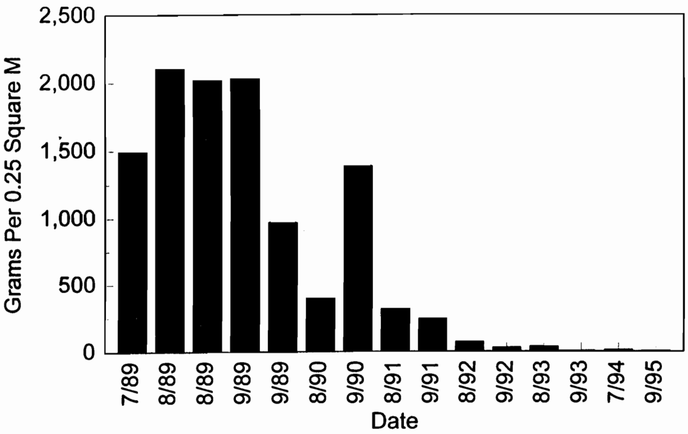

Figure 3. Data from the routine macrophyte production monitoring.

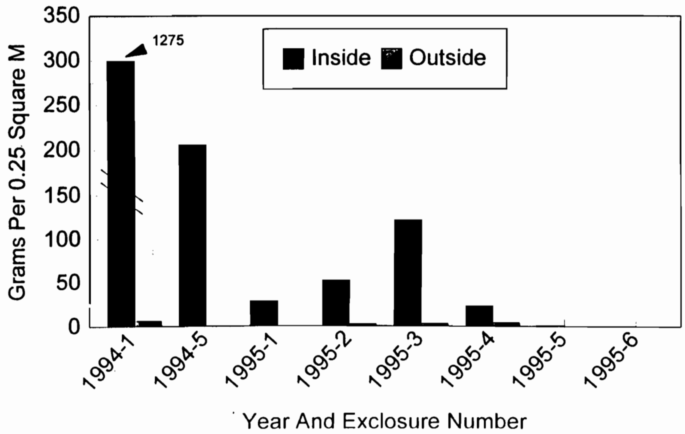

Figure 4. Data from the fish exclosure investigation.

to obtain a representative sample of conditions throughout the lower pond.

Each exclosure was approximately 2 × 3 m. The walls were made of 25-mm wire-mesh 1.5 m high and were supported by 2.25-m posts driven into the bottom. The wire-mesh was buried in the bottom and staked down to prevent fish from entering the exclosure under the walls. During construction of the exclosures, care was taken not to disturb the bottom substrates inside the exclosures, thus leaving the macrophytes undisturbed. The exclosures were checked to be sure that fish were not allowed into them from the top, due to daily water-level fluctuations in the lake.

Sampling of macrophyte production inside and immediately outside the exclosures was conducted using the modified Osborne Sampler. The same procedures used in routine monitoring were followed when sampling macrophytes in the exclosures. Sampling was conducted yearly at the height of macrophyte production (late July to early September). Six samples were collected systematically inside and outside each exclosure. Analysis of variance (ANOVA) tests were used to compare macrophyte biomass production inside and outside the exclosures.

RESULTS AND DISCUSSION

Macrophyte production

Macrophyte biomass-production was highest in the first year of the study (1989), ranging from 968 to 2,103 g/m^2, and production continued at high levels through 1990 but began to decline thereafter (Fig. 3). During

Table 3. Water chemistry in Lake Ogallala, 1989–1995.

	7/21/89	8/31/89	9/28/89	11/1/89	8/21/90	9/12/90	9/9/92	6/2/93	8/5/94	8/5/95
Ammonia (N) (mg/l)	<0.04	0.22	<0.01	<0.04	0.05			0.13		
Nitrate + nitrite (N) (mg/l)	0.9	0.5	0.43	0.5	nd	0.26	0.35	0.35		3.4
Phosphate (as PO_4)		0.1	0.06	0.01				0.18		
Total phosphorous (mg/l)		0.1	0.06	0.1						
Potassium (mg/l)	9	11	9.9	8.5	9.9	4.2				
Chlorophyll a (mg/m^3)	4.3	3.1	5.9	17.7	3	nd				
Total alkalinity (as $CaCO_3$) (mg/l)		177			220	170	140	115	120	135
B. O. D. (5 day) (mg/l)		<10			21	nd				
Calcium (mg/l)		57			46	20				
Chloride (mg/l)		20			18	21	22	20	22	22
C. O. D. (mg/l)		50			nd	nd				
Conductivity (umhos/cm)		716			710	710	550	685	660	690
Total hardness (mg/l) (as $CaCO_3$)		225			180	190	180	195	190	170
Magnesium (mg/l)		20			18	6.8		8		
pH Standard Units		8.2			8.99	8.04	8.45	8.68	8.7	8.32
T. O. C. (mg/l)		6.2			4.8	3.5				
Iron (mg/l)							0.02			
Copper (mg/l)							0.01			
Sulfate (mg/l)							116	133	191	162
Volatile organics (33 analyzed)	nd									

1993–1995, production was extremely low at a mean of < 50 g/m^2.

A substantial decline in species diversity occurred throughout this period (Table 1). In 1989–1991, seven submergent species were identified in the collected samples, but diversity began to decline in 1992 and 1993, and in 1994 and 1995 only two species were observed. The only species present every year was *Potamogeton pusillus*.

Fish herbivory

Eight exclosures were sampled in 1994 and 1995. ANOVA indicated that in five of these, production of macrophytes was significantly greater ($p < 0.05$) inside than immediately outside the exclosure (Fig. 4). Some other exclosures appeared to have more growth inside, but relatively low sample sizes precluded statistical significance. In none of the exclosures was there more growth outside than inside.

Water quality

Various water-quality parameters were monitored at least once a year (except 1991) throughout the study period 1989–1995 (Table 3). They were spot-checked to determine any major or significant changes that may have occurred from year to year. Ammonia, nitrate + nitrate (as N) ranged from less than 0.01 to 0.22 mg/l and not detected to 3.4 mg/l, respectively. Phosphates and total phosphorus remained relatively constant. Chlorophyll a was sampled only in 1989 and 1990 and increased to 17.77 mg/m^3 in November 1989. Total alkalinity generally decreased in 1989–1995. Chlorides, conductivity, and total hardness remained unchanged throughout the study period. Sulfates increased slightly from 116 mg/l in 1992 to 191 and 162 mg/l in 1994 and 1995, respectively. Volatile Organic Analysis was conducted on 33 organics in 1989 and none were detected in the samples.

The majority of monitored water-quality parameters remained unchanged in the 7-year study period. Nitrogen compounds and sulfates increased and could be attributed to non-point-source pollution and the consequent nutrient cycling patterns in Lake McConaughy. This may in turn have led to more periphyton, plankton, and algal growth, which may have affected light penetration and nutrient availability to some extent. Such information was not collected, making determination of trends difficult.

Physical parameters were measured in 1989–1995. Mean observed secchi disc depths taken extensively in 1989 ranged from 1.07 m to 2.4 m. Secchi disc readings taken each year until 1995 fell into that range. The readings indicated that turbidity and light penetration were either not a problem or varied significantly.

Temperature measurements were taken June–September of each year, when Kingsley Hydro was in operation. Instantaneous measurements were taken at the Hydro to determine water temperature of the lake at the point of entry. Figures 5–8 show Lake Ogallala monthly water temperatures with 95% confidence intervals. For all Junes through the period, 1,680 temperature measurements revealed temperatures increas-

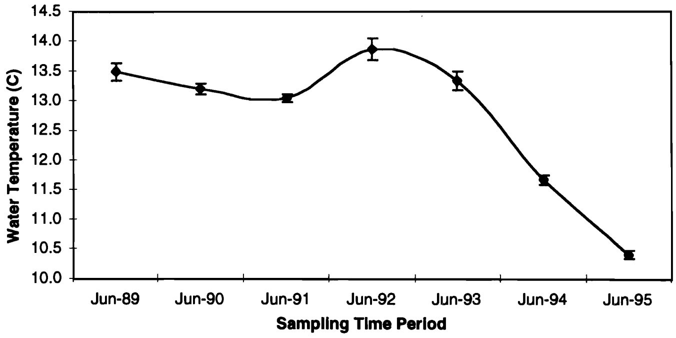

Figure 5. Lake Ogallala June mean water temperatures with 95% confidence intervals.

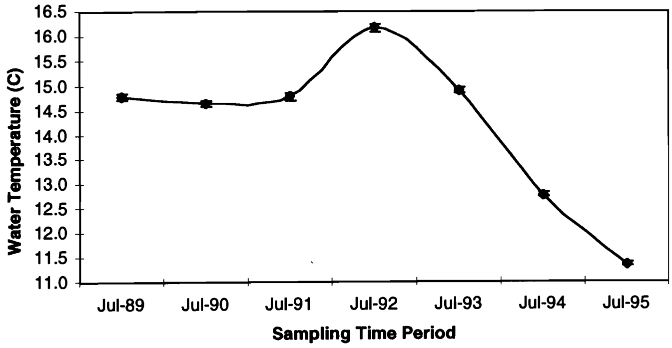

Figure 6. Lake Ogallala July mean water temperatures with 95% confidence intervals.

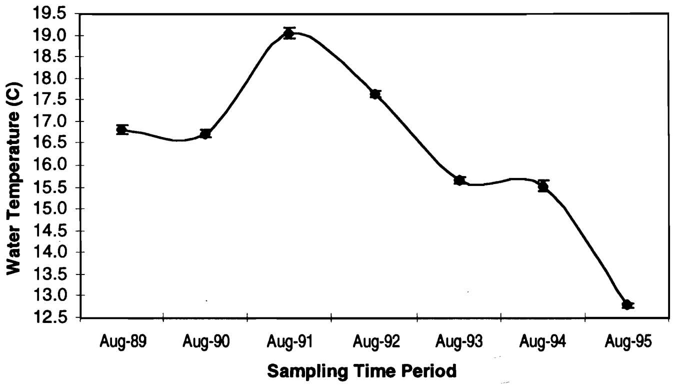

Figure 7. Lake Ogallala August mean water temperatures with 95% confidence intervals.

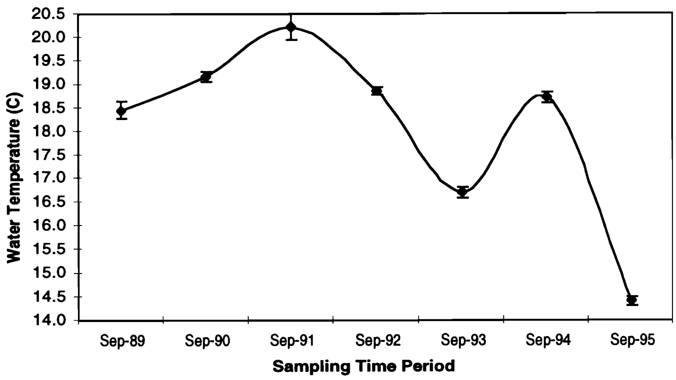

Figure 8. Lake Ogallala September mean water temperatures with 95% confidence intervals.

ing from 13.5° C to 14° and then decreasing to 10.5°. In Julys, 3,390 measurements averaged 14.75°, increased to above 16°, and then decreased to 11.5° in 1995. The 3,215 August measurements from 1989 through 1995 averaged 16.5–17°, increasing to 19° and then decreasing to less than 13°. The 1,250 September measurements started at about 18.5°, increased to more than 20°, and then dropped to 14.5°. The slight increase in temperature in 1991-1992 and significant dropoff through 1995 indicated that temperature fluctuations may have affected plant growth. June-through-September monthly temperatures varied as much as 3–4° during 1989–1995.

Zonation in aquatic plants in the littoral zone is caused by more than one factor, however. Water chemistry is important, as are wave action and chemical and physical properties of the substrate. Globally, macrophytes are found in waters with temperatures ranging from 0° to 50° (Symoens, 1988). There is a correlation between depth distribution and the inherent photosynthetic ability of some species of *Potamogeton* (Cole, 1983).

CONCLUSIONS

During the time period studied, macrophyte production was highest during 1989. In subsequent years production began to decline. The decline continued to the extremely low levels observed during the 1993–95 period. Species diversity also decreased during the study.

Data from the exclosure investigation indicate that herbivory and sediment disturbance by rough fish (probably carp and white sucker) was in part responsible for the observed decline in macrophyte production. However, productivity in the protected areas did not return to the high levels of 1989 and 1990.

Water-quality parameters did not change significantly in the study period, but a more comprehensive and frequent sampling program might have shown changes or trends that could account for such a significant decline in submergent-macrophyte biomass. The initial increase in temperatures and subsequent decrease of 3–4° from 1992 through 1995 may account for some plant decline. This highly dynamic system, with its combination of natural and human perturbations, makes it difficult to determine the factor or factors responsible for the decline in macrophytes. While fish herbivory is one factor, other factors such as the physical-chemical relationships in Lakes Ogallala and McConaughy may be important.

ACKNOWLEDGMENTS

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