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John Christopher Young

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IMPACTS OF STOCKING HERBIVOROUS FISHES FOR AQUATIC MACROPHYTE REMOVAL UPON SOUTH DAKOTA PONDS

BY

JOHN CHRISTOPHER YOUNG

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in partial fulfillment of the requirements
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IMPACTS OF STOCKING HERBIVOROUS FISHES FOR AQUATIC MACROPHYTE REMOVAL UPON SOUTH DAKOTA PONDS

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Major Advisor

Head, Wildlife and
Fisheries Sciences
Department

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Abstract

Aquatic macrophyte removal by herbivorous fishes was investigated to determine changes in the predator-prey relationship of largemouth bass, *Micropterus salmoides,* and bluegills, *Lepomis macrochirus,* stocked into 15 prairie ponds. Monosex grass carp, *Ctenopharyngodon idella,* and hybrid grass carp, *Ctenopharyngodon idella* x *Hypophthalmicthys nobilis,* were each stocked at a rate of 247 fish/hectare into five study ponds. Largemouth bass and bluegills were each stocked into 12 study ponds at 247 fish/hectare in July, and 1235 fish/hectare in September, 1984, respectively. Additional largemouth bass were stocked at a rate of 247 fish/hectare into nine study ponds in July, 1985. Conductivity was the only water quality variable which differed significantly ($P \leq 0.05$) due to treatments. Substantial, but not significant ($P > 0.05$), differences in vegetation removal were observed among ponds. The failure to detect statistical differences likely resulted because of greater variability among ponds within treatments than between treatments. Vegetation removal appeared to be greatest in the monosex grass carp treatment with slight differences between the control and hybrid grass carp treatment ponds. Water transparency declines, as measured by secchi disc visibility and turbidity, were greatest in the monosex grass carp treatment. The evaluation of vegetation removal on largemouth bass-bluegill interactions was not possible because of the failure of bluegills to reproduce. Survival of stocked bluegills was low as a result of small stocking length. Mean survival rate for age-I largemouth bass was 38% for eight ponds. Mean growth and mean W_r for age-I largemouth bass was 160 mm and 119 g, respectively. Abundance of age-0 largemouth bass appeared to be influenced greater by the survival rate of age-I largemouth bass than by vegetation abundance.

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INTRODUCTION

Submergent vegetation frequently reaches nuisance levels in prairie ponds because of shallow water depths and high nutrient loads. Excessive macrophyte densities hamper recreational activities and disrupt predator-prey relationships by reducing predator efficiency (Crowder and Cooper 1979). Investigations of different macrophyte densities demonstrate that increased cover reduces predator efficiency (Glass 1971) by decreasing prey vulnerability and subsequent prey capture rates (Crowder and Cooper 1979). Savino and Stein (1982) reported reduced predation movements of largemouth bass, *Micropterus salmoides,* upon bluegills, *Lepomis macrochirus,* with increasing vegetation stem density. Thus bluegills avoid predation by largemouth bass by seeking refuge in aquatic vegetation (Mittlebach 1981).

The traditional largemouth bass-bluegill stocking combination developed in Alabama by Swingle and Smith (1941) must be modified in order to be successful in northern ponds (Modde and Scalet 1986). Excessive bluegill recruitment may occur in northern ponds because bluegills spawn one year before largemouth bass (Dillard and Novinger 1975). Differential growth rates between bluegills and largemouth bass at northern latitudes also decreases the ability of largemouth bass to control bluegill recruitment (Modde and Scalet 1985). Strategies to correct bluegill imbalances in ponds includes stocking more vulnerable prey species such as the fathead minnow, *Pimephales promelas,* as forage for largemouth bass. Also, split-stocking bluegills in the fall and largemouth bass the subsequent summer should insure adequate bluegill recruitment as forage for largemouth bass fingerlings (Hill 1980).

Aquatic macrophyte removal should decrease searching time for largemouth bass and presumably increase bluegill vulnerability.

Methods to control nuisance aquatic macrophytes includes surface drawdowns, herbicides, pond fertilization, and mechanical harvesting. These options are expensive and often impractical in small northern ponds. However, biological control of aquatic macrophytes utilizing grass carp, Ctenopharyngodon idella, represents an economical and longer lasting alternative (Shireman 1982). These fish feed on a broad range of aquatic plant species (Cross 1969) and are capable of consuming large quantities of vegetation. Hickling (1966) stated that mechanical rupturing of aquatic plant cells is necessary for digestion because these fish lack cellulase. Furthermore, to compensate for poor assimilation and rapid food passage in the gut, grass carp are required to consume voluminous quantities of aquatic vegetation (Hickling 1966). Cross (1969) noted that under optimum conditions grass carp consumed their body weight daily.

Grass carp stockings by state agencies and private hatcheries in the 1960's enabled these fish to gain access to several major river drainages in the central United States (Guillory and Gasaway 1978). Concerns for negative impacts on aquatic systems by feral grass carp populations were heightened with the discovery of grass carp reproduction in the lower Mississippi River (Conner et al. 1980). Several states banned grass carp from their waters (Young et al. 1983) fearing waterfowl habitat destruction (Gasaway and Drda 1977) or negative impacts on native fish faunas such as those reported by Vinogradov and Zolotova (1974) in Russia. In response to this concern sex reversal, gynogenesis, triploidization, and hybridization have been attempted to produce sterile fish (Jensen et al. 1983).

Hybrid grass carp, an intergeneric cross between female grass carp and male bighead carp, Hypophthalmithchys nobilis (Lazareva et al. 1977), were first produced in Hungary in 1968 and were presumed to be sterile and triploid (Marian and Krasznai 1978). More recently it was determined that both diploid and triploid fish resulted from this cross (Magee and Philipp 1982). Hybrid grass carp were anticipated to provide aquatic macrophyte control while eliminating the chance for natural reproduction. Subsequent research has shown that the hybrids are inferior to grass carp for aquatic vegetation removal (Young et al. 1983; Harberg and Modde 1985; Osborne 1985). Monosex grass carp, an exclusively female population, represent an alternative for aquatic macrophyte control (Boney et al. 1984). Their use should obviously be limited to watersheds where male grass carp are absent.

Documentation of the effects of grass carp introductions on predator-prey interactions are limited in the literature. Previous studies of grass carp introductions have been confined either to lakes (e.g. Ware and Gasaway 1976; Mitzner 1978; Bailey 1978) or hatchery ponds (e.g. Ball 1977; Lembi et al. 1978; Rottman and Anderson 1977; Baur et al. 1979). Savino and Stein (1982) noted that prior to their experimental observations, the relationship between vegetation density and bluegill vulnerability had never been explicitly demonstrated. Therefore, aquatic plant control in ponds using herbivorous fishes requires evaluation to ascertain whether aquatic macrophyte removal will increase prey vulnerability to predation.

The objectives of this study were to:

1. Measure the influence of herbivorous fishes upon aquatic macrophytes,
2. determine changes in water quality attributable to the presence or absence of herbivorous fishes , and
3. determine the impact of herbivorous fishes on predator-prey relationships.

METHODS

Study Area

Study ponds were located in eastern and central South Dakota (Figure 1). This area has a continental-type climate with warm summers and cold winters. Average annual precipitation is 64 cm in the southeast to 33 cm in the northwest of the state (Spuhler et al. 1971). South Dakota is characterized by rolling grasslands intermixed with agricultural crops and pasture.

Design

Criteria used to select study ponds were:

1. maximum pond depth of at least 3.6 m,
2. absence of fish life,
3. surface area of 0.4 - 2.0 hectares, and
4. abundance of aquatic macrophytes

Study ponds were surveyed initially by telephone inquiries utilizing South Dakota Game, Fish and Parks pond stocking requests. Subsequent pond visits evaluated the suitability of each pond site to study criteria.

The study evaluated 15 ponds divided evenly among one control and two treatment groups (monosex grass carp and hybrid grass carp ponds). Control and treatment ponds were distinguished by the absence or presence of herbivorous fishes, respectively. Limited availability of study ponds prevented pond randomization. Herbivorous fishes were stocked into 10 treatment ponds in fall, 1983. Five control ponds were chosen in spring, 1984.

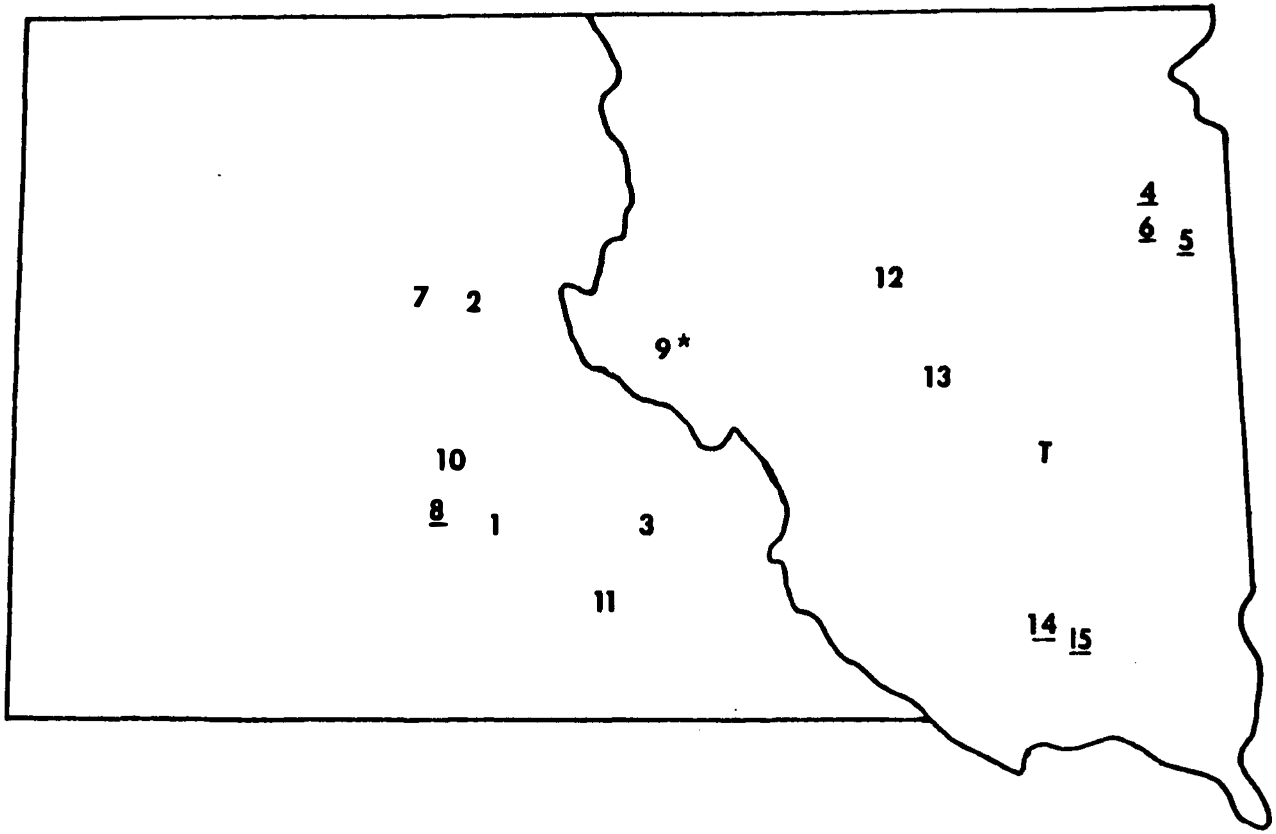

Figure 1. Map of South Dakota illustrating locations of control ponds (1-5), hybrid grass carp ponds (6-10), and monosex grass carp ponds (11-15). Pond code numbers underscored identify ponds eliminated from fish data analysis due to fish contamination. *Indicates one hybrid grass carp pond which winterkilled during 1984.

Study ponds were stocked with fish in the following sequence.

1. Monosex grass carp (mean TL 63.2 mm) were stocked into five treatment ponds at 247 fish/hectare on 18 August, 1983.
2. Hybrid grass carp (mean TL 170.6 mm) were stocked into five treatment ponds at 247 fish/hectare on 7 - 8 September, 1983.
3. Largemouth bass (mean TL 31.7 mm) were stocked into 12 ponds at 247 fish/hectare on 12 - 13 July, 1984.
4. Bluegill (mean TL 31.7 mm) were stocked into 12 ponds at 1235 fish/hectare on 11 - 12 September, 1984.
5. Largemouth bass (mean TL 48.5 mm) were stocked into nine ponds at 247 fish/hectare on 10 July, 1985.

Largemouth bass were stocked in only 12 ponds in 1984 due to contamination of piscivorous fishes in three ponds (Table 1). In 1985 two additional ponds were contaminated and one pond was subject to winterkill.

Field and Laboratory Methods

Physical and chemical water quality variables were sampled during three periods in both 1984 and 1985. Sampling periods for water quality will be referred to as sessions in this study. Conductivity, salinity, and surface temperature were determined with a Yellow Springs Instrument S-C-T meter. Secchi disc visibility in the water column was measured with a standard secchi disc. A 1 liter water sample was collected 30 cm beneath the pond surface near the pond center for chemical analysis. An additional water sample from 1 m depth was returned to the South Dakota

Table 1. Pond name, group, date detected, and fish species contaminating nine South Dakota study ponds between May, 1984, and May, 1985.

Pond Name	Group	Date	Contaminating Fish Species
Kippes	monosex	May, 1984	Pimephales promelas
Fox	monosex	May, 1984	Pimephales promelas
Ortman	monosex	May, 1984	Lepomis cyanellus
Willis	hybrid	May, 1984	Ictalurus nebulosus
Heathon	control	Jul, 1984	Lepomis macrochirus
Ridings	hybrid	Aug, 1984	Pimephales promelas
Thompson	hybrid	Aug, 1984	Pimephales promelas
Dailey	control	May, 1985	Perca flavescens
Dailey	hybrid	May, 1985	Perca flavescens

State Water Quality Lab for free potassium determination. Lembi et al. (1978) recommended sampling potassium as a possible means to measure macrophyte removal by grass carp. Maximum pond depth was determined with a Lowrance X-15 chart recorder.

Nitrate-nitrogen, phosphate, sulfate, and turbidity were measured with a Hach DR-EL spectrophotometer. Phenol and total alkalinity and total hardness were determined by titration. A Hellige Lilliput portable meter was used to measure pH. Surface areas for all ponds were estimated initially utilizing a field chart[1] integrating pond perimeter length with pond shape and later re-estimated by standard survey methods in July, 1984 (Table 2). Wooden stakes calibrated in 10 cm increments were placed into ponds to document water level fluctuations.

Height of aquatic vegetation in the water column was traced with a Lowrance X-15 chart recorder along three transects at two different depths for two sessions in 1984 and three sessions in 1985. The X-15 transducer was mounted at pond surface level on the stern of an outboard motor driven boat. A 30 m rope with floats at 3 m intervals delineated transects in 1.5 - 2.1 m and 2.4 - 3.0 m water depths. Transects were obtained by running the boat parallel to the transect rope at a given depth and scoring a vertical line on the X-15 graph at each float thereby establishing a station for aquatic vegetation height and pond depth determinations. Field notes assisted interpretation of graph results in the lab. Macrophyte reductions were measured by changes in the vegetation height:pond depth ratio at each station. Common species

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[1] Mimeo, Missouri Department of Conservation

Table 2. Pond name, group, code number from Figure 1, and comparison of surface areas (hectares) estimated with Missouri field chart and standard survey methods for 15 South Dakota study ponds between August, 1983, and August, 1984.

Pond Name	Group	code number	Surface Area Estimated	Surface Area Surveyed
Moore	control	1	0.73	0.56
Madsen	control	2	0.61	0.54
Frantz	control	3	0.81	0.63
Dailey	control	4	1.01	0.64
Heathon	control	5	1.42	0.84
Dailey	hybrid	6	1.21	1.70
Ridings	hybrid	7	1.42	1.80
Thompson	hybrid	8	1.42	1.32
Krull	hybrid	9	0.40	0.23
Willis	hybrid	10	1.01	no map
Pajl	monosex	11	1.21	1.36
Fox	monosex	12	1.26	1.03
Demray	monosex	13	0.73	0.60
Ortman	monosex	14	0.61	no map
Kippes	monosex	15	0.81	0.45

of aquatic macrophytes encountered in this study include *Chara* spp., *Ceratophyllum demersum, Potamogeton* spp., *Ranunculus* spp., and *Utricularia vulgaris.*

Fish populations were sampled in the spring, 1985, using a 39 m x 2.4 m seine with a mesh of 191 mm and a 240-volt electrofishing unit. Captured fish were anesthetized with MS-222 at a rate of 79 mg/liter in a small basin. Age-I largemouth bass were marked for population estimates by clipping the left pelvic fin. These fish were measured for total length (TL) to the nearest millimeter and total weight to the nearest gram. Largemouth bass scales were taken below the lateral line and just above the pectoral fin apex to determine growth to first annulus formation. Fish were dipped into a saturated salt solution and placed in a recovery tub prior to release into the pond.

Scale impressions were made on cellulose acetate strips with a roller press as outlined by Smith (1954). Impressions were viewed on a Bell and Howell microfiche projector. First annulus and scale radius were measured to the nearest millimeter from the scale focus.

Analysis

Population estimates were determined with the modified Peterson equation:

$$\hat{N} = \frac{(M + 1)(C + 1)}{(R + 1)} \quad \text{(Ricker 1975)}$$

where,

$\hat{N}$ = estimated population number at time of marking

M = number of fish marked

C = catch or sample taken for census

R = number of recaptured marks in sample

The 95% confidence interval around the population estimate (Table 3) was calculated by the equation:

$$\hat{N} \pm 1.96 \sqrt{\hat{V}(\hat{N})} \quad \text{(Everhart and Young 1981)}$$

where,

$\hat{V}(\hat{N})$ = sampling variance for N, calculated by the equation:

$$\hat{V}(\hat{N}) = \frac{N^2 \; (C - R)}{(C + 1)(R + 2)} \quad \text{(Everhart and Young 1981)}$$

Survival rates were determined by dividing the population estimates by the number of fish stocked to study ponds in 1984 (Table 4).

Condition for age-I largemouth bass was determined using the index of relative weight (W_r):

$$W_r = \frac{W}{W_s} \times 100 \quad \text{(Wege and Anderson 1978)}$$

where,

W_r = relative weight

W = actual weight of the fish

W_s = standard weight for a fish of a given length calculated by:

Table 3. Pond name, group, population estimate ($\hat{N}$), sampling variance $\hat{V}(\hat{N})$, and 95% confidence interval around $\hat{N}$ for age-I largemouth bass, *Micropterus salmoides*, from eight South Dakota study ponds sampled between April and October, 1985.

Pond Name	Group	$\hat{N}$	$\hat{V}(\hat{N})$	95% Confidence interval for N
Moore	control	19	14.4	11.6 - 26.4
Madsen	control	18	27.8	7.7 - 28.3
Frantz	control	141	4,418.0	10.7 - 271.3
Ridings	hybrid	85	2,890.0	-20.4 - 190.4
Thompson	hybrid	276	15,870.0	31.0 - 521.0
Pajl	monosex	77	174.0	51.1 - 102.9
Fox	monosex	12	36.0	0.2 - 23.8
Demray	monosex	141	1,729.0	59.0 - 223.0

Table 4. Pond name, group, population estimate, number of fish stocked in study ponds in 1984, and survival rate (percent) for age-I largemouth bass, *Micropterus salmoides*, from eight South Dakota study ponds sampled between 7 and 26 September, 1985.

Pond Name	Group	Population Estimate	Number Stocked	Survival (percent)
Moore	control	19	178	10.5
Madsen	control	18	150	11.7
Frantz	control	141	200	70.5
Ridings	hybrid	85	350	24.3
Thompson	hybrid	276	350	79.0
Pajl	monosex	77	300	26.0
Fox	monosex	12	310	3.9
Demray	monosex	141	180	78.5

$$\text{Log } W_s = -5.316 + 3.191 \text{ Log length}$$

First year growth for age-I largemouth bass was back calculated from scales using the corrected Lee formula:

$$Ln = a + \frac{Sn\ (\ Lc - a\ )}{Sc} \qquad \text{(Carlander 1977)}$$

where,

Ln = length of fish at time of annulus n formation

a = constant value of 22 for largemouth bass (Stone 1981)

Sn = Scale radius at annulus n

Sc = scale radius

Lc = length of fish at capture

Abundances of age-I bluegills, age-0 and age-I largemouth bass were determined by electrofishing shoreline perimeters and calculating the number of fish captured hourly (Table 5). Mouth widths for age-I largemouth bass and body depths for age-0 largemouth bass were determined from equations based on total length (Lawrence 1958) and were graphed to evaluate age-0 largemouth bass vulnerability to age-I largemouth bass predation in ponds with and without fathead minnows (Figure 2).

Nested factorial analysis of variance was used to determine differences in physical and chemical water quality variables sampled during 1984 between treatment and control ponds. Ponds within treatments designated as Pond (Trt) was the error term used to assess whether variability was greater within or between treatments. Nested factorial analysis of variance was also used to determine differences in water quality variables that may have been due to treatments, sessions,

Table 5. Pond name, group, number of fish electrofished per hour for age-I bluegills, *Lepomis macrochirus*, and age-0 and age-I largemouth bass, *Micropterus salmoides*, sampled from nine South Dakota study ponds between August and September, 1985.

Pond Name	Group	Bluegills Age-I	Largemouth Bass Age-0	Largemouth Bass Age-I
Moore	control	36.92	26.54	4.62
Madsen	control	5.81	25.16	11.61
Frantz	control	5.45	0.00	6.82
Thompson	hybrid	5.81	3.87	16.45
Ridings	hybrid	15.29	12.94	4.71
Kippes	monosex	0.00	50.45	0.00
Pajl	monosex	8.94	17.87	20.43
Fox	monosex	0.94	0.94	10.31
Demray	monosex	6.38	7.66	28.09

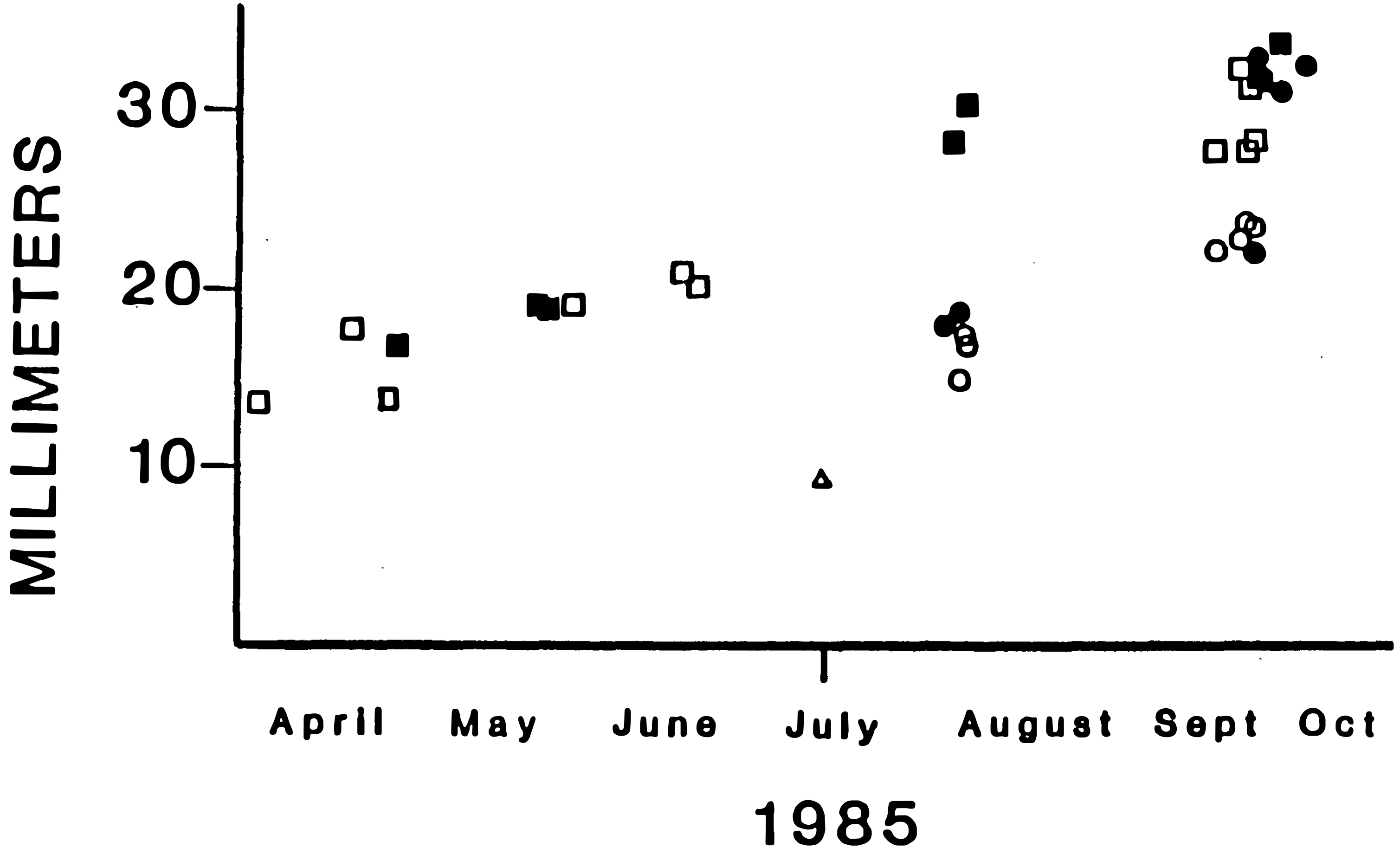

Figure 2. Mouth widths of age-I largemouth bass, <u>Micropterus salmoides,</u> in study ponds with (■) and without (□) fathead minnows, <u>Pimephales promelas,</u> compared to body depths of age-0 largemouth bass with (●) and without (○) fathead minnows, and initial body depth of age-0 largemouth bass (△) at pond stocking 10 July 1985.

and years. Differences in aquatic vegetation heights that may have been due to treatments, sessions, years, and transect water depth were assessed by nested factorial analysis of variance. All effects in the study were fixed. Waller-Duncan k-ratio t-tests were used to detect differences in first year growth and relative weight for largemouth bass in four ponds without fathead minnow contamination.

RESULTS

Pond Selection Evaluation

Water quality variables sampled during 1984 indicated no significant differences ($P > 0.05$) due to treatment effects for secchi disk visibility and maximum pond depth (Appendix Table 1), conductivity and salinity (Appendix Table 2), turbidity and pH (Appendix Table 3), phenol and total alkalinity (Appendix Table 4), total hardness and nitrate-nitrogen (Appendix Table 5), phosphate and sulfate (Appendix Table 6), potassium (Appendix Table 7), and pond surface levels (Appendix Table 8). Since no differences due to treatment effects were determined, study ponds were considered similar for purposes of data analyses.

Water Quality

Conductivity differed significantly ($P \leq 0.05$) due to treatments and to a treatment by year interaction (Table 6). Otherwise water quality variables did not differ significantly ($P > 0.05$) due to treatments likely because variability among ponds within treatments is large

Table 6. Nested factorial analysis of variance for differences in conductivity (micromhos/cm^3) due to treatments, sessions, and years sampled from 14 South Dakota study ponds between June, 1984, and August, 1985. Error terms used for appropriate F-tests indicated by (Trt).

Source	df	MS	F
Year	1	120,734.20	0.93
Trt*Year	2	561,661.05	4.32+
Year*Pond(Trt)	10	130,064.58	
Trt	2	7,612,223.00	4.04+
Pond(Trt)	11	1,886,441.50	
Session	2	72,052.88	0.97
Trt*Session	4	75,729.23	1.01
Session*Pond(Trt)	21	74,653.97	
Residual	20	99,130.33	

+Denotes significance ($P \leq 0.05$)

compared to variability between treatments. Salinity differed significantly ($P \leq 0.05$) between sessions (Table 7). Differences in total hardness were significant ($P \leq 0.01$) due to a treatment by year interaction (Table 8). Sulfates differed significantly ($P \leq 0.05$) for both years and a treatment by year interaction (Table 9). Potassium levels were significantly different ($P \leq 0.01$) between sessions (Table 10). Pond surface levels declined significantly ($P \leq 0.01$) for sessions with lowest levels recorded in the fall (Table 11). No differences in water transparency were significant ($P > 0.05$), although field observations and examination of graphed raw means of secchi disk visibility (Figure 3) and turbidity (Figure 4) suggested a trend despite the large variability. Remaining water quality variables indicated no significant differences ($P > 0.05$) due to treatments, sessions, and years for secchi disk visibility (Appendix Table 9), turbidity (Appendix Table 10), pH (Appendix Table 11), phenol alkalinity (Appendix Table 12), total alkalinity (Appendix Table 13), nitrate-nitrogen (Appendix Table 14), phosphate (Appendix Table 15), and maximum pond depth (Appendix Table 16).

Vegetation Removal

Aquatic vegetation heights were not significantly different ($P>0.05$) because variability among ponds within groups exceeded differences between groups. Aquatic vegetation heights differed significantly ($P\leq0.01$) between transect water depths (Table 12). Differences in aquatic vegetation heights were not significant ($P>0.05$), although inspection of transect raw means sampled in 1.5-2.1 m (Figure 5) and

Table 7. Nested factorial analysis of variance for differences in salinity (parts per thousand) due to treatments, sessions, and years sampled from 14 South Dakota study ponds between June, 1984, and August, 1985. Error terms for appropriate F-tests indicated by (Trt).

Source	df	MS	F
Year	1	0.0004	0.00
Trt*Year	2	0.2279	1.88
Year*Pond(Trt)	10	0.1241	
Trt	2	3.2729	3.56
Pond(Trt)	11	0.9183	
Session	2	0.2159	4.27+
Trt*Session	4	0.0870	1.72
Session*Pond(Trt)	21	0.0506	
Residual	20	0.0436	

+ Denotes significance ($P \leq 0.05$)

Table 8. Nested factorial analysis of variance for differences in total hardness (mg/l as $CaCO_3$) due to treatments, sessions, and years sampled from 14 South Dakota study ponds between June, 1984, and August, 1985. Error terms used for appropriate F-tests indicated by (Trt).

Source	df	MS	F
Year	1	110,022.45	3.82
Trt*Year	2	226,495.33	7.86++
Year*Pond(Trt)	10	28,826.10	
Trt	2	760,868.10	2.03
Pond(Trt)	11	375,325.31	
Session	2	23,529.71	2.11
Trt*Session	4	8,623.93	0.77
Session*Pond(Trt)	21	11,144.44	
Residual	20	9,820.25	

++Denotes significance ($P \leq 0.01$)

Table 9. Nested factorial analysis of variance for differences in sulfate (mg/l) due to treatments, sessions, and years sampled from 14 South Dakota study ponds between June, 1984 and August, 1985. Error terms used for appropriate F-tests indicated by (Trt).

Source	df	MS	F
Year	1	170,246.39	5.25+
Trt*Year	2	176,041.01	5.43+
Year*Pond(Trt)	10	32,414.51	
Trt	2	1,461,597.50	2.66
Pond(Trt)	11	549,596.28	
Session	2	21,681.36	1.16
Trt*Session	4	29,648.06	1.58
Session*Pond(Trt)	21	18,718.50	
Residual	20	30,379.13	

+Denotes significance ($P \leq 0.05$)

Table 10. Nested factorial analysis of variance for differences in potassium (mg/l) due to treatments, sessions, and years sampled from 14 South Dakota study ponds between June, 1984, and August, 1985. Error terms used for appropriate F-tests indicated by (Trt).

Source	df	MS	F
Year	1	96.15	1.63
Trt*Year	2	45.15	0.77
Year*Pond(Trt)	10	58.99	
Trt	2	16.14	0.03
Pond(Trt)	11	536.19	
Session	2	72.83	6.18++
Trt*Session	4	2.92	0.25
Session*Pond(Trt)	20	11.78	
Residual	19	5.22	

+Denotes significance ($P \leq 0.01$)

Table 11. Nested factorial analysis of variance for differences in pond surface levels (cm) due to treatments, sessions, and years sampled from 14 South Dakota study ponds between June, 1984, and August, 1985. Error terms used for appropriate F-tests indicated by (Trt).

Source	df	MS	F
Year	1	1923.66	2.39
Trt*Year	2	77.19	0.10
Year*Pond(Trt)	7	803.90	
Trt	2	270.75	0.64
Pond(Trt)	11	423.10	
Session	2	1,559.37	10.32++
Trt*Session	4	262.21	1.73
Session*Pond(Trt)	18	151.14	
Residual	3	79.85	

++Denotes significance ($P \leq 0.01$)

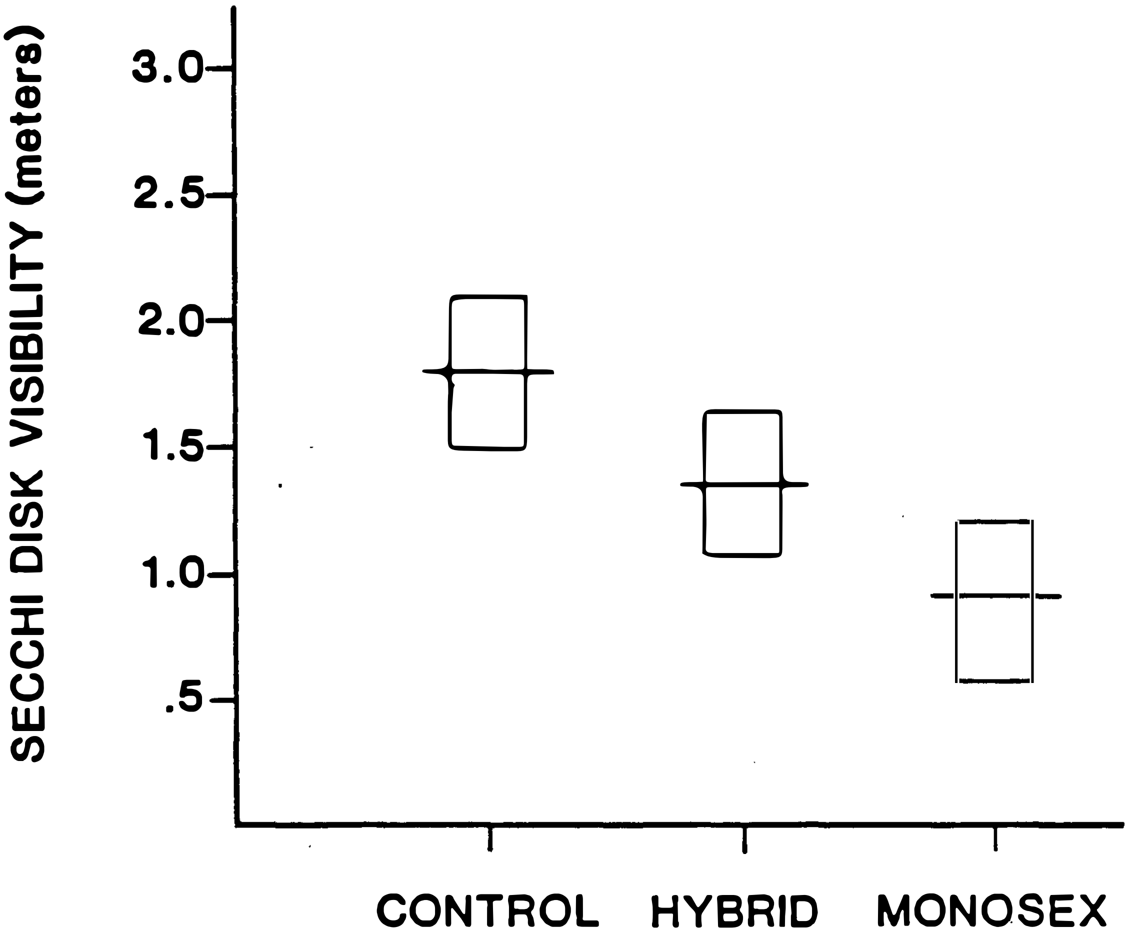

Figure 3. Control and treatment means (horizontal bars) and standard error (rectangles) for secchi disk visibility sampled in 14 South Dakota study ponds between June, 1984, and August, 1985.

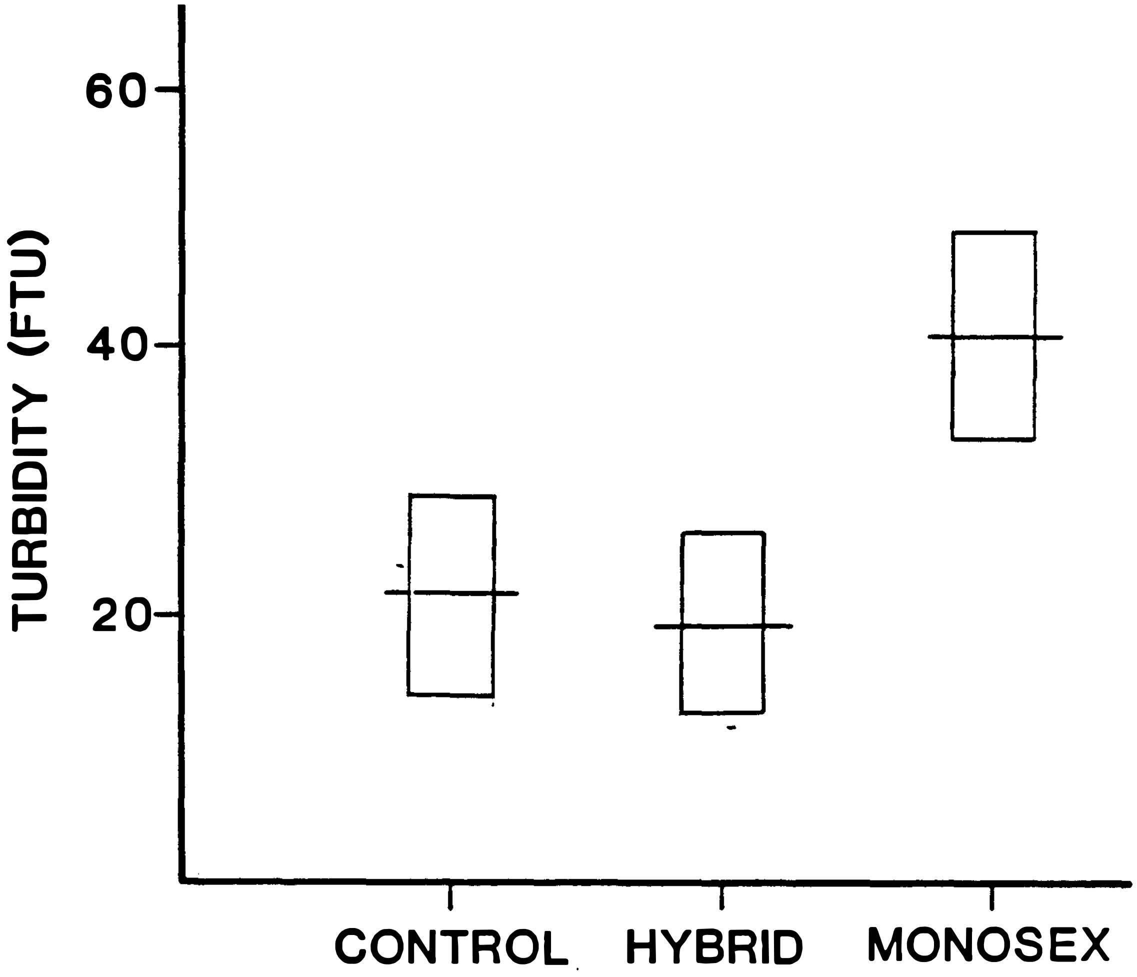

Figure 4. Control and treatment means (horizontal bars) and standard error (rectangles) for turbidity sampled in 14 South Dakota study ponds between June, 1984, and August, 1985.

Table 12. Nested factorial analysis of variance for differences in aquatic vegetation height (cm) due to treatments, sessions, years, and transect water depths sampled from 13 South Dakota study ponds between July, 1984 and August, 1985. Error terms used for appropriate F-tests indicated by (Trt).

Source	df	MS	F
Years	1	7.0925	4.16
Trt*Years	2	0.4263	0.25
Years*Pond(Trt)	10	1.7033	
Trt	2	8.9349	0.56
Pond(Trt)	10	15.8427	
Session	2	0.2168	0.15
Trt*Session	4	0.5613	0.39
Session*Pond(Trt)	20	1.4450	
Years*Session	1	1.3418	5.38+
Trt*Years*Session	2	0.1178	0.47
Yrs*Sess*Pond(Trt)	8	0.2459	
TDepth	1	9.5231	13.98++
Trt*TDepth	2	0.9311	1.37
Pond*TDpth(Trt)	10	0.6812	
Years*TDepth	1	0.5838	1.15
Trt*Sess*TDepth	4	0.6405	0.01
Yrs*Pond*TDpth(Trt)	8	0.5068	
Session*TDepth	2	0.0439	0.12
Trt*Sess*TDepth	4	0.6405	1.74
Sess*Pond*TDpth(Trt)	17	0.3683	
Residual	3193	0.0474	

++Denotes significance ($P \leq 0.01$)
+ Denotes significance ($P \leq 0.05$)

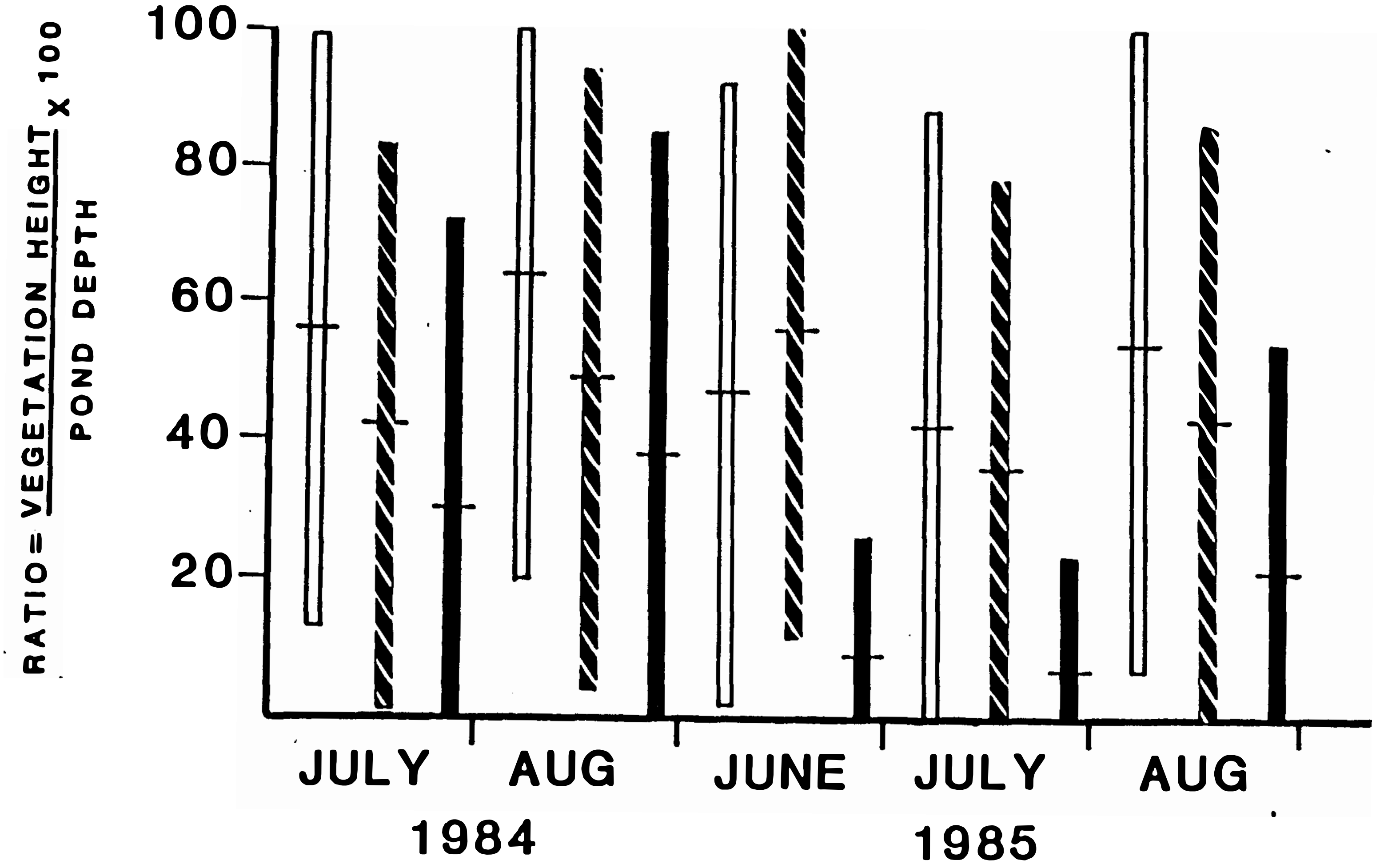

Figure 5. Control and treatment raw means (horizontal bars) and standard deviations (rectangles) of aquatic vegetation heights sampled from 1.5 - 2.1 m transect water depths for control ponds (white), hybrid grass carp ponds (striped), and monosex grass carp ponds (black) for 13 South Dakota study ponds between July, 1984, and August, 1985.

2.4-3.0 m (Figure 6) water depths suggested trends corroborated by field observations that substantial macrophyte reductions occurred in the monosex grass carp treatment.

Fish Populations

The influence of macrophyte removal on bluegill vulnerability was undetected because of the failure of stocked bluegill to reproduce. Bluegill recruitment was never observed in any study pond in 1985. Abundance of age-I bluegills electrofished hourly was observed to be low (Table 5). Five study ponds were eliminated from analyses because of fish contamination. Additionally, one hybrid grass carp pond winterkilled in 1984 and, thus, was ignored in the analyses.

First year survival estimates for largemouth bass in eight ponds ranged from 0-79% with a mean of 38%. Survival did not appear to be associated with macrophyte removal (Table 4). Aquatic macrophytes retarded electrofishing efforts to recapture marked fish particularly in densely vegetated control ponds. Growth (Table 13) and W_r (Table 14) for age-I largemouth bass were compared from four ponds without fathead minnows. Abundance of age-I bluegills from these same four ponds was determined by electrofishing (Table 15). Abundance of age-0 largemouth bass in nine study ponds appeared to be influenced by the survival rate of age-I largemouth bass (Figure 7), however, no significant correlation was determined for this relationship. Growth and survival estimates for monosex grass carp and hybrid grass carp were undetermined because of low numbers of fishes captured in this study. Grass carp seined from two monosex grass carp ponds averaged 569 mm and 2,390 g for 14 fish

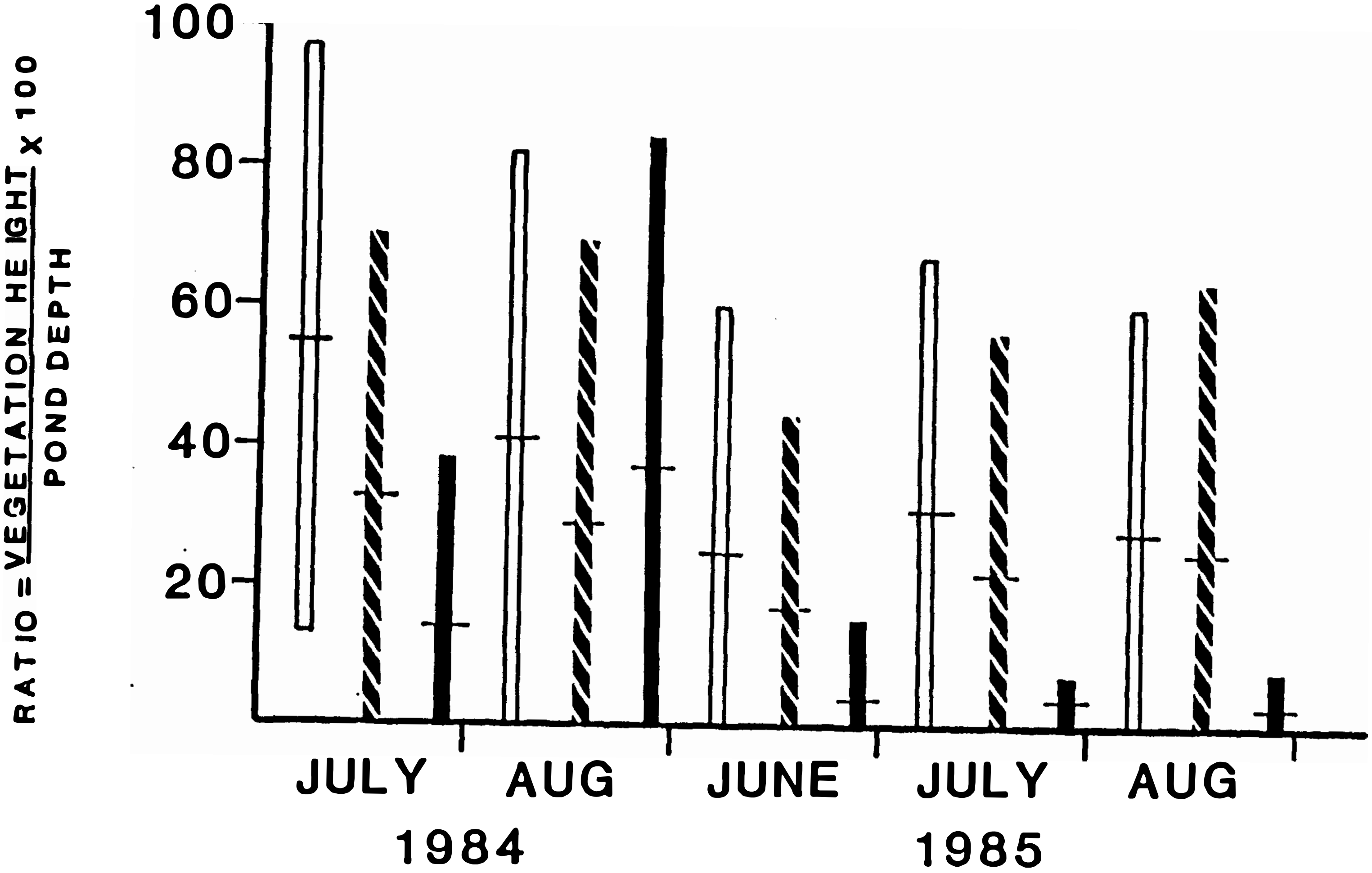

Figure 6. Control and treatment raw means (horizontal bars) and standard deviations (rectangles) of aquatic vegetation heights sampled from 2.4 - 3.0 m transect water depths for control ponds (white), hybrid grass carp ponds (striped), and monosex grass carp ponds (black) for 13 South Dakota study ponds between July, 1984, and August, 1985.

Table 13. Waller-Duncan K-ratio t-test to determine differences in first year growth of largemouth bass, Micropterus salmoides, sampled in four study ponds without fathead minnows between April and June, 1985.

FIRST YEAR GROWTH			
Pajl	Frantz	Moore	Madsen
monosex	control	control	control
148.58	158.29	164.44	68.59
	*		
*			

* Horizontal lines indicate similar growth for largemouth bass.

Table 14. Waller-Duncan K-ratio t-test to determine differences in W_r of age-I largemouth bass, *Micropterus salmoides*, sampled in four study ponds without fathead minnows between April and June, 1985.

<table>
<tr><th colspan="4">RELATIVE WEIGHT</th></tr>
<tr><td>Madsen</td><td>Moore</td><td>Frantz</td><td>Pajl</td></tr>
<tr><td>control</td><td>control</td><td>control</td><td>monosex</td></tr>
<tr><td>101.06</td><td>121.11</td><td>127.21</td><td>127.64</td></tr>
<tr><td></td><td colspan="3">*</td></tr>
</table>

* Horizontal line indicates similar relative weight for largemouth bass.

Table 15. Pond name, sampling date, number of fish electrofished per hour, and (TL) (mm) for age-I bluegills, *Lepomis macrochirus,* from four study ponds without fathead minnows between May and September, 1985.

Pond Name	Date	number of bluegill electrofished per hour	TL (mm)
Madsen	6/15	0.80	
	8/02	0.98	
	9/21	5.81	107.3
Frantz	8/02	14.03	
	9/21	5.45	130.8
Moore	5/26	0.92	61.0
	6/14	4.80	74.0
	6/15	16.92	
	8/03	24.00	107.2
	9/20	36.92	130.7
Pajl	6/16	18.0	
	8/02	32.9	104.0
	9/21	8.94	120.9

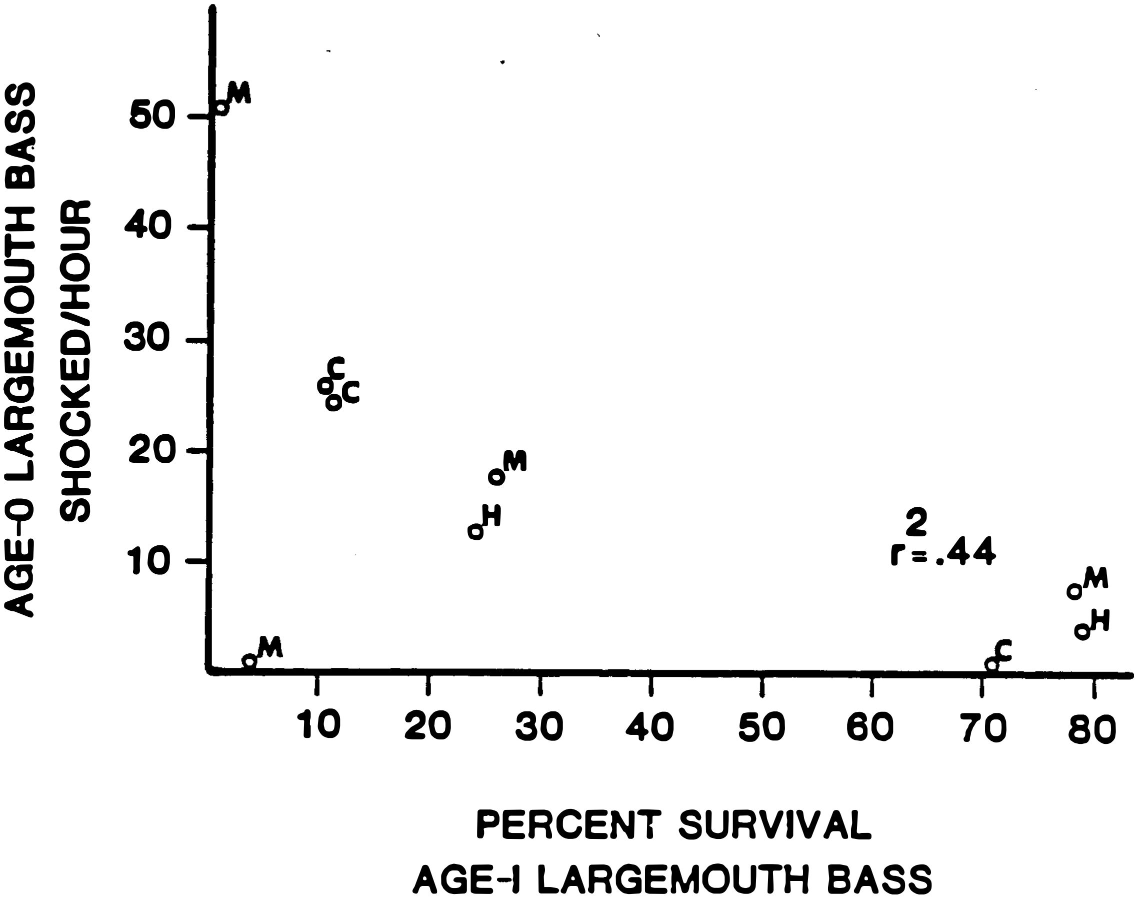

Figure 7. Second order regression of the abundance of age-0 largemouth bass, Micropterus salmoides, and survival rate of age-I largemouth bass from three control ponds (C), two hybrid grass carp ponds (H), and four monosex grass carp ponds (M) sampled between 17 and 30 September 1985.

from one pond, and 520 mm and 1,714 g for six fish in the other pond in the fall, 1985.

DISCUSSION

Water Quality

Specific influences of herbivorous fishes on water quality are difficult to summarize because of inconsistent responses reported in the literature (Bailey 1978; Mitzner 1978; Canfield et al. 1983; Mitchell et al. 1984). Hickling (1966) stated that grass carp digestion reduced plant matter into fragments of 3 mm^2 or less. Later Opuszynski (1972) speculated that pulverized grass carp excreta provides nutrients to phytoplankton, often resulting in algal blooms. Gasaway and Drda (1978) noted increases in chlorophyll concentrations and reductions in phytoplankton species diversity following macrophyte removal by grass carp in Florida ponds. Avault et al. (1968) observed the formation of a brown organic scum and a 300% increase in free potassium levels following macrophyte removal by grass carp in research pools. However, Terrell (1982) suggested that nutrients released from grass carp feces are quickly bound in the bottom sediments and are unavailable to phytoplankton in softwater acidic ponds in Georgia. Other studies observed no changes in algal densities (Lembi et al. 1978; Mitzner 1978), whereas some studies noted zooplankton increases following grass carp introductions (Ritenour 1976; Mitchell et al. 1984; Richard et al. 1985).

In the present study, water transparency appeared to decline greatest in the monosex grass carp treatment. Rapid macrophyte removal and subsequent increased pond mixing may explain the reduced secchi disk visibility and the increased turbidity observed in the present study.

Wiley and Gordon (1984) suggested that the influence of herbivorous fishes on aquatic systems depends on stocking density. Perhaps the removal rate of aquatic macrophytes ultimately dictates the impact of grass carp introductions on water quality.

Vegetation Control

Several studies have documented that grass carp are efficient in removing aquatic macrophytes (e.g. Ware and Gasaway 1976; Mitzner 1978; Bailey 1978; Lembi et al. 1978; Mitchell et al. 1984; Fowler 1985). However, no significant ($P>0.05$) reductions in aquatic macrophyte heights between treatment and control ponds were detected in the present study. Most likely, this was because pond variability within groups was large compared to variability between pond groups. Nevertheless, observation suggested that aquatic macrophytes were greatly reduced in the monosex grass carp treatment with slight differences visible between control and hybrid grass carp ponds. Aquatic macrophyte removal by hybrid grass carp was not apparent in the present study. Higher stocking rates for hybrid grass carp are recommended for vegetation control (Shireman 1982; Osborn 1982; Young et al. 1983; Harberg and Modde 1985), although Osborne (1985) concluded that stocking hybrid grass carp to control hydrilla (*Hydrilla verticillata*) in Florida was not economically feasible.

Survival of both herbivorous fishes appeared to be low in the present study. Several factors could account for this. Mitzner (1978) cited hauling stress as a major cause of mortality for grass carp stocked into Red Haw Lake, Iowa. The monosex grass carp and hybrid grass carp used in this study were obtained in Arkansas and endured hauling for 30-50 hours prior to pond stocking. Colle et al. (1978) implicated piscivorous birds as one factor to explain 95% mortality of 5000 grass carp with mean TL of 48 mm stocked to a vegetated Florida pond devoid of piscivorous fishes. This speculation warrants consideration for ponds in the present study since the mean stocking length of monosex grass carp was 63.2 mm, and piscivorous birds were often observed near study ponds. Harberg and Modde (1985) reported survival rates of 59.1% and 32.2% for hybrid grass carp stocked into two western South Dakota ponds after one growing season. Hybrid grass carp were observed to be less numerous in ponds than monosex grass carp in the present study. Hardin and Atterson (1984) observed 98% mortality for grass carp stocked into Lake Wales, Florida, attributing mortality initially to largemouth bass predation and later to other unknown causes. Therefore, stocking length, survival rate, and piscivorous predator abundance are important factors to consider in determining adequate stocking rates of herbivorous fishes for vegetation control.

Fish Populations

The influence of declining cover on the largemouth bass-bluegill relationship was not determined in the present study. Studies by Ball (1977) and Baur et al. (1979) demonstrated that grass carp stocked into shallow hatchery ponds decreased gamefish production only when complete macrophyte removal resulted. Ball (1977) stated that the production estimates for gamefish in ponds exhibited so much variation that it was impossible to isolate the effects of grass carp introductions into

Indiana hatchery ponds. Baur et al. (1979) reported that adverse effects on gamefish in hatchery ponds were less likely when grass carp stocking rates were less than 30 fish/hectare. Wiley and Gordon (1984) reported that declines in centrarchid young-of-the-year production were greatest in ponds overstocked with hybrid grass carp. Bailey (1978) stated that the impact of grass carp introductions on fish populations in 31 Arkansas lakes were negligible but vegetation removal did appear to improve the conditions of largemouth bass, bluegills, and redear sunfish, Lepomis microlophus. Colle and Shireman (1980) observed that the conditions for bluegills, redears, and largemouth bass decreased as hydrilla density increased in the water column in Lake Wales, Florida. Shireman and Maceina (1981) reported low condition factors for largemouth bass > 250 mm TL when hydrilla coverage exceeded 30%, whereas smaller largemouth bass were not affected until coverage surpassed 50% in laboratory studies.

Effects of vegetation removal on survival, growth, and relative weight of age-I largemouth bass were not determined in the present study. Mean survival of 38% for age-I largemouth bass was lower than the 50% value reported by Stone (1981) and the 59% value observed by Beck (1986) for South Dakota ponds stocked with various fish combinations. Mean first year TL of age-I largemouth bass from four ponds without fathead minnows was 160 mm, which is similar to the 153 mm TL recorded by Stone (1981) in 16 eastern South Dakota ponds. Mean W_r for age-I largemouth bass from the same four ponds was 119 g, which exceeded the value of 114 g noted by Stone (1981) in South Dakota ponds. Wege and Anderson (1978) demonstrated that W_r of largemouth bass of less than 203 mm TL and between 203-302 mm TL were significantly correlated ($r=.60$ and $r=.58$, respectively) to the log density of fish prey smaller than 76 mm TL, suggesting the importance of small prey to small largemouth bass. Age-I largemouth bass in Madsen's pond had the highest mean growth of 168.6 mm but the lowest W_r of 101, possibly reflecting a reduced forage base since this pond in particular was noted to have the lowest bluegill abundance among these four ponds.

Bluegill survival was presumably affected by the mean stocking length of 31.7 mm in 1984 compared to the mean length of 50.0 mm stocked by Gilbraith (personal communication) in 1983. Reduced stocking length potentially increased bluegill vulnerability to the age-0 largemouth bass stocked into all study ponds in July, 1984. Werner et al. (1983) reported that bluegill juveniles remain in vegetation to avoid largemouth bass predation at the expense of optimal foraging in the water column and hence their growth is reduced. Small stocking size and constant vulnerability to largemouth bass predation may have accounted for low bluegill survival in the present study.

Reynolds and Babb (1978) found high survival of age-0 largemouth bass in ponds with 50% of the surface vegetated regardless of the adult largemouth density. However, Durocher et al. (1984) determined no relationship between percent cover of submergent vegetation and the abundance of small largemouth bass in 30 Texas reservoirs. The survival rate of age-I largemouth bass appeared to influence age-0 largemouth bass abundance in the present study. Age-I largemouth bass may have preyed upon age-0 largemouth bass in the absence of small bluegills. Comparison of age-0 largemouth bass body depths with age-I largemouth bass mouth widths indicated that age-0 largemouth bass were vulnerable to age-I largemouth bass predation in the present study. Fathead minnow presence appeared to reduce the vulnerability of age-0 largemouth bass to age-I fish toward the end of the study.

Monosex grass carp were observed to remove aquatic macrophytes rapidly in the present study. Decreased water transparency may occur following grass carp introductions. Declines in water transparency in the present study likely resulted from overstocking monosex grass carp. The influence of declining cover on bluegill vulnerability was not evident in the present study. Further research is necessary to ascertain if cover manipulations are a feasible means to enhance bluegill vulnerability to largemouth bass predation.

RECOMMENDATIONS

1. Monosex grass carp appear to be an effective means to reduce aquatic macrophytes in prairie ponds. Subsequent changes in water quality will likely depend on the stocking density.

2. Grass carp stocking rates should be based on the following: vegetated area to be controlled, stocking length, aquatic plant preference of grass carp, and the timetable to achieve a specific level of control. Neither complete macrophyte control nor a rapid removal rate are recommended in order to minimize undesirable changes in water transparency.

3. Grass carp probably should be stocked in the summer months to maximize growth and survival and to be of sufficient size to elude predation by piscivorous birds.

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Appendix
Table 1. Nested factorial analysis of variance for differences in secchi disk visibility (m) and maximum pond depth (cm) due to treatments and sessions sampled from 15 South Dakota study ponds between June and August, 1984. Error terms used for treatment F-tests indicated by (Trt).

Source	df	Secchi MS	MaxDepth MS
Session	2	0.1869	4,013.39
Treatment	2	1.8020	6,031.77
Sess*Trt	4	0.0862	3,296.55
Pond(Trt)	12	2.0547	11,155.16
Residual	21	0.4087	1,734.91

Appendix
Table 3. Nested factorial analysis of variance for differences in turbidity (formazin turbidity units) and pH (standard units) due to treatments and sessions sampled from 15 South Dakota study ponds between June, 1984 and August, 1985. Error terms used for treatment F-tests indicated by (Trt).

Source	df	turbidity MS	pH MS
Session	2	303.20	1.3942
Treatment	2	1,674.94	0.3580
Session*Trt	4	110.49	0.0230
Pond(Trt)	12	1,166.97	1.1158
Residual	23	225.20	0.1512

Appendix Table 4. Nested factorial analysis of variance for differences in phenol and total alkalinity (mg/l as $CaCO_3$) due to treatments and sessions sampled from 15 South Dakota study ponds between June and and August, 1984. Error terms used for treatment F-tests indicated (Trt).

Source	df	Phenol Alka MS	Total Alka MS
Session	2	123.62	1,887.64
Treatment	2	307.09	1,272.51
Sess*Trt	4	190.69	1,255.43
Pond(Trt)	12	1,287.29	14,455.99
Residual	23	139.67	320.35

Appendix
Table 5. Nested factorial analysis of variance for differences in total hardness (mg/l as $CaCO_3$) and nitrate-nitrogen (mg/l) due to treatments and sessions sampled from 15 South Dakota study ponds between June and August, 1984. Error terms used for treatment F-tests indicated by (Trt).

Source	df	Hardness MS	Nitrate MS
Session	2	36,787.16	0.2216
Treatment	2	185,761.77	0.6612
Sess*Trt	4	10,808.34	0.8125
Pond(Trt)	12	167,752.52	0.5552
Residual	23	17,593.03	0.3146

Appendix
Table 6. Nested factorial analysis of variance for differences in phosphate (mg/l) and sulfate (mg/l) due to treatments, and session sampled from 15 South Dakota study ponds between June and August, 1984. Error terms used for treatment F-tests indicated by (Trt).

Source	df	Phosphate MS	Sulfate MS
Session	2	1.5350	397.08
Treatment	2	0.1518	659,189.40
Sess*Trt	4	0.1514	1,416.19
Pond(Trt)	12	0.2823	344,152.44
Residual	23	0.2150	1,123.87

Appendix
Table 7. Nested factorial analysis of variance for differences in potassium (mg/l) due to treatments and sessions sampled from 15 South Dakota study ponds between June and August, 1984. Error terms used for treatment F-tests indicated by (Trt).

Source	df	Potassium MS
Session	2	54.56
Treatment	2	46.58
Sess*Trt	4	1.42
Pond(Trt)	12	406.35
Residual	22	11.06

Appendix
Table 8. Nested factorial analysis of variance for differences in pond surface levels (cm) due to treatments and sessions sampled from 15 South Dakota study ponds between June and August, 1984. Error terms used for treatment F-tests indicated by (Trt).

Source	df	Pond Surface level MS
Session	2	2,465.99
Treatment	2	220.74
Sess*Trt	4	81.91
Pond(Trt)	12	308.08
Residual	17	112.25

Appendix
Table 9. Nested factorial analysis of variance for differences in secchi disk visibility (m) due to treatments, sessions, and years sampled from 14 South Dakota study ponds between June, 1984, and August, 1985. Error terms used for appropriate F-tests indicated by (Trt).

Source	df	MS	F
Year	1	1.1883	1.98
Trt*Year	2	0.0743	0.12
Year*Pond(Trt)	10	0.5994	
Treatment	2	2.7755	1.20
Pond(Trt)	11	2.3137	
Session	2	0.7577	1.59
Trt*Session	4	0.0542	0.11
Session*Pond(Trt)	21	0.4772	
Residual	18	0.2702	

Appendix
Table 10. Nested factorial analysis of variance for differences in turbidity (formazin turbidity units) due to treatments, sessions, and years sampled from 14 South Dakota study ponds between June, 1984, and August, 1985. Error terms used for appropriate F-tests indicated by (Trt).

Source	df	MS	F
Year	1	593.85	3.65
Trt*Year	2	150.74	0.93
Year*Pond (Trt)	10	162.80	
Treatment	2	3,200.72	2.31
Pond (Trt)	11	1,383.69	
Session	2	338.09	1.36
Trt*Session	4	63.71	0.62
Session*Pond (Trt)	21	247.89	
Residual	20	85.58	

Appendix
Table 11. Nested factorial analysis of variance for differences in pH (standard units) due to treatments, sessions, and years sampled from 14 South Dakota study ponds between June, 1984, and August, 1985. Error terms used for appropriate F-tests indicated by (Trt).

Source	df	MS	F
Year	1	0.2856	0.39
Trt*Year	2	0.3192	0.43
Year*Pond (Trt)	10	0.7370	
Treatment	2	1.0689	0.83
Pond (Trt)	11	1.2937	
Session	2	0.2111	0.57
Trt*Session	4	0.2066	0.56
Session*Pond (Trt)	21	0.3708	
Residual	20	0.2581	

Appendix
Table 12. Nested factorial analysis of variance for differences in pheonl alkalinity (mg/l as $CaCO_3$) due to treatments, sessions, and years sampled from 14 South Dakota study ponds between June, 1984, and August, 1985. Error terms used for appropriate F-tests indicated by (Trt).

Source	df	MS	F
Year	1	209.25	0.25
Trt*Year	2	877.50	1.03
Year*Pond (Trt)	10	847.83	
Treatment	2	5.63	0.00
Pond (Trt)	11	1,485.32	
Session	2	108.95	0.61
Trt*Session	4	202.98	1.14
Session*Pond (Trt)	21	177.82	
Residual	20	175.58	

Appendix
Table 13. Nested factorial analysis of variance for differences in total alkalinity (mg/l as $CaCO_3$) due to treatments, sessions, and years sampled from 14 South Dakota study ponds between June, 1984, and August, 1985. Error terms used for appropriate F-tests indicated by (Trt).

Source	df	MS	F
Year	1	3,546.30	3.12
Trt*Year	2	1,036.24	0.91
Year*Pond (Trt)	10	1,135.96	
Treatment	2	3,389.35	0.14
Pond (Trt)	11	23,658.69	
Session	2	502.07	1.04
Trt*Session	4	1,323.82	2.73
Session*Pond (Trt)	21	484.14	
Residual	20	404.40	

Appendix
Table 14. Nested factorial analysis of variance for differences in nitrate-nitrogen (mg/l) due to treatments, sessions, and years sampled from 14 South Dakota study ponds between June, 1984, and August, 1985. Error terms used for appropriate F-tests indicated by (Trt).

Source	df	MS	F
Year	1	0.0326	0.13
Trt*Year	2	0.3334	1.28
Year*Pond (Trt)	10	0.2605	
Treatment	2	1.3023	2.76
Pond (Trt)	11	0.4714	
Session	2	0.1065	0.44
Trt*Session	4	0.4669	1.95
Session*Pond (Trt)	21	0.2395	
Residual	20	0.1966	

Appendix
Table 15. Nested factorial analysis of variance for differences in phosphate (mg/l) due to treatments, sessions, and years sampled from 14 South Dakota study ponds between June, 1984, and August, 1985. Error terms used for appropriate F-tests indicated by (Trt).

Source	df	MS	F
Year	1	0.6451	2.28
Trt*Year	2	0.0932	0.33
Year*Pond (Trt)	10	0.2831	
Treatment	2	0.0722	0.23
Pond (Trt)	11	0.3094	
Session	2	0.2406	1.38
Trt*Session	4	0.0736	0.42
Session*Pond (Trt)	21	0.1739	
Residual	20	0.1327	

Appendix
Table 16. Nested factorial analysis of variance for differences in maximum pond depth (cm) due to treatments, sessions, and years sampled from 14 South Dakota study ponds between June, 1984, and August, 1985. Error terms used for appropriate F-tests indicated by (Trt).

Source	df	MS	F
Year	1	1,980.27	0.58
Trt*Year	2	1,698.27	0.50
Year*Pond (Trt)	10	3,387.43	
Treatment	2	6,021.43	0.28
Pond (Trt)	11	21,810.69	
Session	2	970.58	0.70
Trt*Session	4	2,660.54	1.91
Session*Pond (Trt)	21	1,389.63	
Residual	18	684.01	