PRODUCTIVITY RESPONSES TO NUTRIENT MANIPULATIONS IN EASTERN SOUTH DAKOTA HILL PONDS

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ABSTRACT

Nitrogen is commonly the limiting nutrient in eastern South Dakota impoundments. Therefore, we measured the effect of nitrogen (urea) fertilizer application on primary production, prey availability, and yellow perch growth in experimental and control ponds. Fertilization increased nitrogen levels and stimulated primary production in experimental ponds. However, effects of fertilizer application on zooplankton and benthic invertebrate abundances were minimal. Yellow perch growth was highest in ponds with increased abundance of *Daphnia* spp. and *CerioDaphnia* spp. and least in ponds with low zooplankton abundance and smaller zooplankton. Increased primary production should have resulted in increased invertebrate prey biomass and improved yellow perch growth. Further research is necessary to fully understand the effects of inorganic nutrient manipulations on yellow perch growth in eastern South Dakota hill ponds.

INTRODUCTION

In the first year of life, prey availability and size are often the most important biotic factors affecting survival and growth rates of yellow perch (Ney and Smith 1975; Mills et al. 1989b). Growth of age-0 yellow perch has been related to the abundance of *Daphnia* spp. (Noble 1975; Mills et al. 1989a) and *Daphnia* spp. size structure (Lott et al. 1998). Growth of adult yellow perch has also been related to the proportion of benthic invertebrates in the diet (Lott et al. 1996). Zooplankton and benthic invertebrate abundances in wetlands are often mediated by nutrient concentrations and primary production (Wetzel 2001).

Fish culture ponds are commonly treated with inorganic or organic fertilizers to maintain adequate nutrient concentrations and a high N:P ratio (Culver et al. 1993). Controlled fertilization stimulates primary production to support an abundant zooplankton population, while reducing densities of blue-green and filamentous green algae (Culver et al. 1993). High N:P ratios (>10:1) and low concentrations of phosphorus (< 30 µg/L) and nitrogen (< 750 µg/L) favor macrophyte growth over phytoplankton communities (Wetzel 2001). Lower N:P ratios (< 7:1) and/or high phosphorus concentrations favor blue-green algae and filamentous green algae, which are largely inedible to zooplankton (Culver et al. 1993). In phosphorus-limited systems, phosphate fertilizers are commonly used and in nitrogen-limited systems ammonium fertilizers or urea are commonly used. Generally, inorganic fertilizer is applied in small amounts to reduce eutrophication potential (Culver et al. 1993).

Natural production of yellow perch *Perca flavescens* within small semi-permanent wetlands in eastern South Dakota is highly variable. Many factors have been attributed to variable natural production, including lack of food availability. Thus, the objective of this study was to measure the effect of fertilizer application on primary and secondary (invertebrate prey abundance) production, and yellow perch growth.

METHODS

This study was conducted in four small impoundments located 9.5 miles northeast of Brookings, South Dakota, in the Deer Creek watershed. The surface area of each pond was measured by mapping the shoreline using a handheld Global Positioning Satellite (GPS) unit (Trimble GeoExplorer 3). Coordinates and depths at points along three parallel transects were also recorded on the GPS unit to calculate pond volume. The area and volume were then calculated using the XTools extension in Arcview 3.2. The surface areas of the ponds were approximately 0.16 (pond B), 0.32 (pond C in 2002; B in 2003), 0.34 (pond D), and 0.47 (pond A) ha. The volumes of the ponds were approximately 5,800 (B), 13,950 (C,B), 15,950 (D), and 27,350 (A) m^3 and the maximum depths were 1.8 (B), 2.4 (C,B), 2.1 (D), and 2.7 (A) m, respectively. In 2003 a new pond (C) with a surface area of 0.25 ha was used instead of the smallest pond (B) from 2002. All four ponds were drained in the fall of 2001 and 2002 to remove all fishes and allowed to naturally refill the following spring.

Two of the four ponds (A, B) were fertilized in the summer of 2002 and 2003. Fertilizer was applied to attain high N:P ratios (>10:1), but not to exceed concentrations of 600 µg N/L and 30 µg P/L (Culver et al. 1993) (Table 1). Urea (46-0-0) was used to increase nitrogen concentrations and maintain a high ratio of nitrogen to phosphorus. Phosphorus was not limited and therefore no applications of phosphorus were made. Two ponds (C, D) were not fertilized to serve as controls for comparison with the fertilized ponds. Nutrient concentrations were measured and N:P ratio calculated prior to the first fertilization and weekly thereafter.

In April 2002, each pond was stocked with approximately 20,240 yellow perch eggs per surface ha. Initially, three subsamples were taken from yellow perch skeins for egg enumeration. Each subsample was weighed and the number of eggs counted to calculate an average number of eggs per mL. The number of eggs stocked was determined volumetrically using a 250-ml graduated cylinder. The eggs were collected from a lake adjacent to the four ponds and transported in a 19-L pail to each pond. The eggs were placed in wooden boxes (0.37 m^2) suspended above the sediments with a large-mesh screen bottom and a fine-mesh screen top. In 2003, small yellow perch fingerlings were stocked instead of egg skeins. Fingerlings were collected from Little Brush wetland and

Table 1. Urea applications (kg/ha) by date in fertilized ponds, 2002 and 2003.

DATES									
2002	**5/14**	**5/23**	**5/31**	**6/6**	**6/24**	**8/8**			
Pond A	96	39	51	43	9	21			
Pond B	25	146	0	0	19	31			
2003	**6/16**	**7/8**	**7/18**	**7/28**	**8/6**	**8/13**	**8/21**	**8/27**	**9/5**
Pond A	40	10	0	10	10	10	10	10	5
Pond B	34	11	7	14	7	14	14	7	7

stocked at a rate of 1,000 per surface acre in each pond at the end of June. Initial length and weight were determined from 50 individuals. Fingerlings were approximately 46 mm (SE = 0.3, range 41-51 mm) long and weighed 0.95 g (SE = 0.02, range 0.64-1.36 g) at the time of stocking. At the end of the experiment (October) yellow perch were removed using lighted cloverleaf traps and at least 30 individuals from each pond were weighed and measured.

Zooplankton and benthic invertebrates were sampled weekly to measure changes in size structure, taxa abundance, and diversity. Zooplankton were collected using a 2-m integrated column sampler (75-mm diameter, DeVries and Stein 1991) and filtered through a 63-µm plankton net. Samples were collected at three random locations within each pond and preserved with 5% Lugol's solution (Lind 1985) and stored in whirlpacks. Preserved zooplankton samples were diluted to 30 mL. Three 1-mL subsamples were drawn and zooplankton were enumerated and identified to family or genus. Up to 20 individuals from each taxon were measured to the nearest 0.01 mm. Zooplankton densities were expressed as number/m^3 of water.

Benthic invertebrates were sampled using an Ekman dredge (0.023 m^2). Four samples (two inshore, two offshore) were collected within each pond weekly. Each sample was sieved through a U.S. No. 30 mesh screen and preserved in a solution of 90% ethanol and rose bengal. Samples were sorted in the lab and all benthic invertebrates were enumerated and identified to order or family. Benthic invertebrate densities were expressed as individuals/m^2.

Water quality parameters were measured weekly to monitor changes within each pond. Water temperature, dissolved oxygen (DO), oxidation reduction potential (ORP), turbidity, nitrate-nitrogen, and ammonia-nitrogen were measured at 0.5 m intervals (surface to bottom) using a handheld YSI Model 650 multi-parameter display system. Transparency was measured using a secchi disk. Water samples were collected using the column sampler at the deepest point in each pond. The samples were stored in dark bottles on ice for transport back to the lab. Soluble reactive phosphorus (SRP) was determined immediately using a Hach DR 2000 spectrophotometer. A 500-mL portion of each water sample was frozen and sent to the SDSU Water Resources Institute to determine concentrations of total Kjeldahl nitrogen (TKN) and total phosphorus (TP). Chlorophyll *a* was collected by filtering a known volume of water through a 0.7-µm glass micro-fiber filter (47-mm diameter). The filters were placed in aluminum foil and frozen, pending analysis. Filters were placed in vials with 10 mL of magnesium carbonate ($MgCO_3$) supernatant (10-g $MgCO_3$ diluted to 100 mL with distilled water) and acetone solution (10-mL supernatant with 90-mL acetone). Samples were stored for 24 h in a refrigerator to allow sufficient time for chloroplast lysis. Chlorophyll *a* concentration was determined using a Turner Design 700 Fluorometer.

RESULTS

Nutrient-mediated responses, 2002: In both fertilized ponds (A,B) N:P (TKN:TP) ratios remained high (> 8:1) throughout the summer (Figure 1). In both control ponds (C,D) N:P ratios remained high (> 7:1) until late June when they began to decline (Figure 1). In both fertilized ponds, nitrogen (TKN) concentrations increased with urea application and reached higher levels than in the control ponds; however, concentrations in the fertilized ponds (e.g., pond B) quickly decreased during periods when urea was not applied (Figure 2). Phosphorus (TP) concentrations varied between fertilized and control ponds (Figure 2). All four ponds would be classified as mesotrophic to eutrophic based on nitrogen (750 to 1875 µg/L) and phosphorus (30 to 85 µg/L) concentrations (Wetzel 2001).

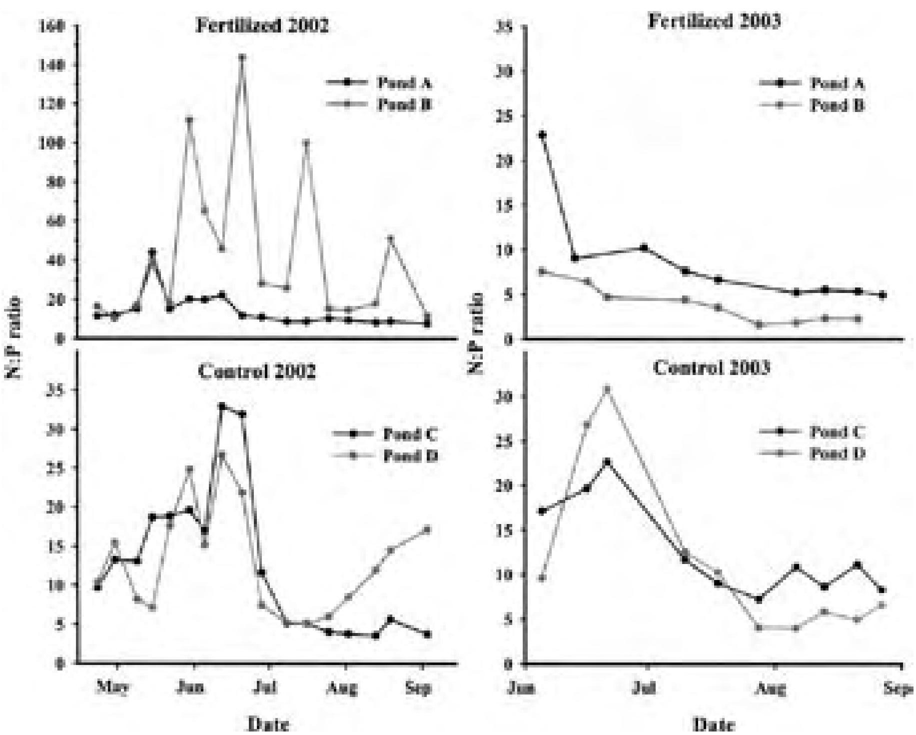

Figure 1. Total nitrogen to total phosphorus ratios (N:P) for fertilized and control ponds, 2002 (left panel) and 2003 (right panel).

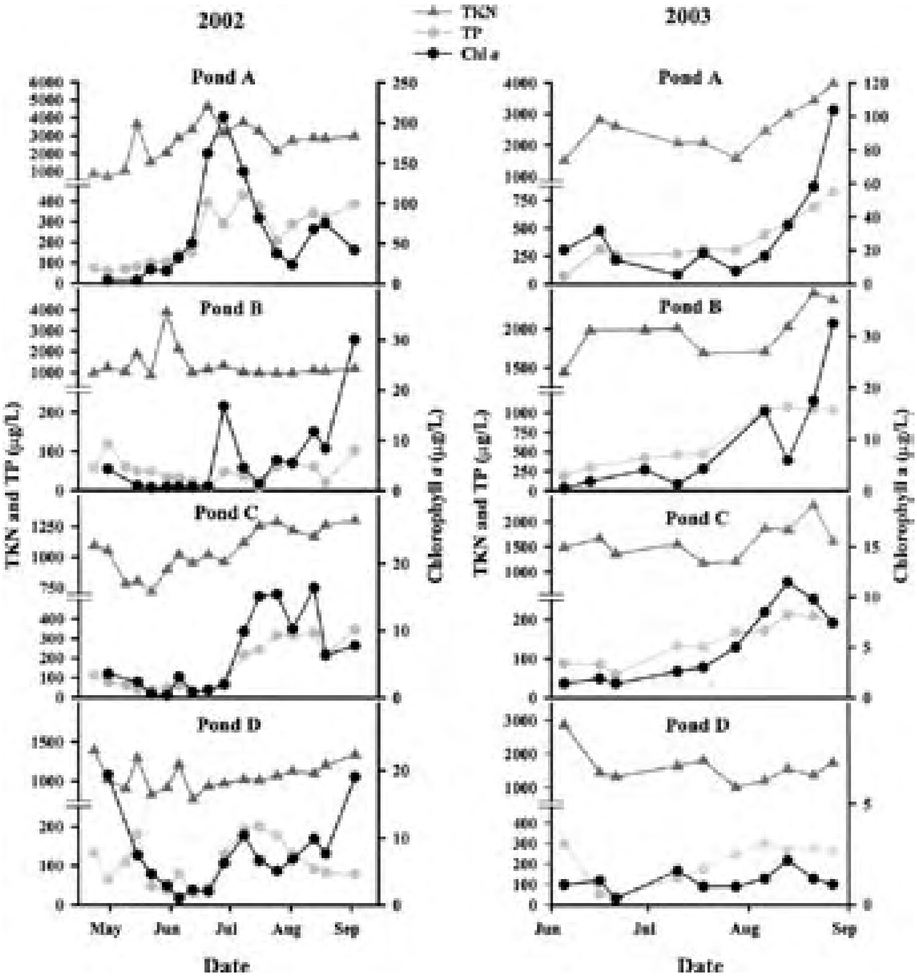

Figure 2. Concentrations of total Kjeldahl nitrogen (TKN), total phosphorus (TP), and chlorophyll a in fertilized (A, B) and control (C, D) ponds, 2002 (left panel) and 2003 (right panel).

Chlorophyll *a* concentrations reached higher levels in both fertilized ponds and reached hyper-eutrophic (>100 µg/L) levels in pond A during July (Figure 2). Ponds B, C, and D had lower chlorophyll concentrations (<25 µg/L) than pond A and would be classified as mesotrophic (4.7 µg/L) to eutrophic (14.3 µg/L)(Wetzel 2001). Increases in chlorophyll a concentrations coincided with increases in nitrogen and phosphorus concentrations in all four ponds (Figure 2). Turbidity (NTU) levels were highest in pond A (Table 2). Ponds B, C, and D had similar turbidity readings. Dissolved oxygen readings near the bottom were reduced in ponds A and C (Table 2). Other water chemistry variables are shown in Table 2.

Zooplankton abundances and composition fluctuated throughout the summer in all four ponds (Figure 3). Apparent effects of fertilization on zooplankton

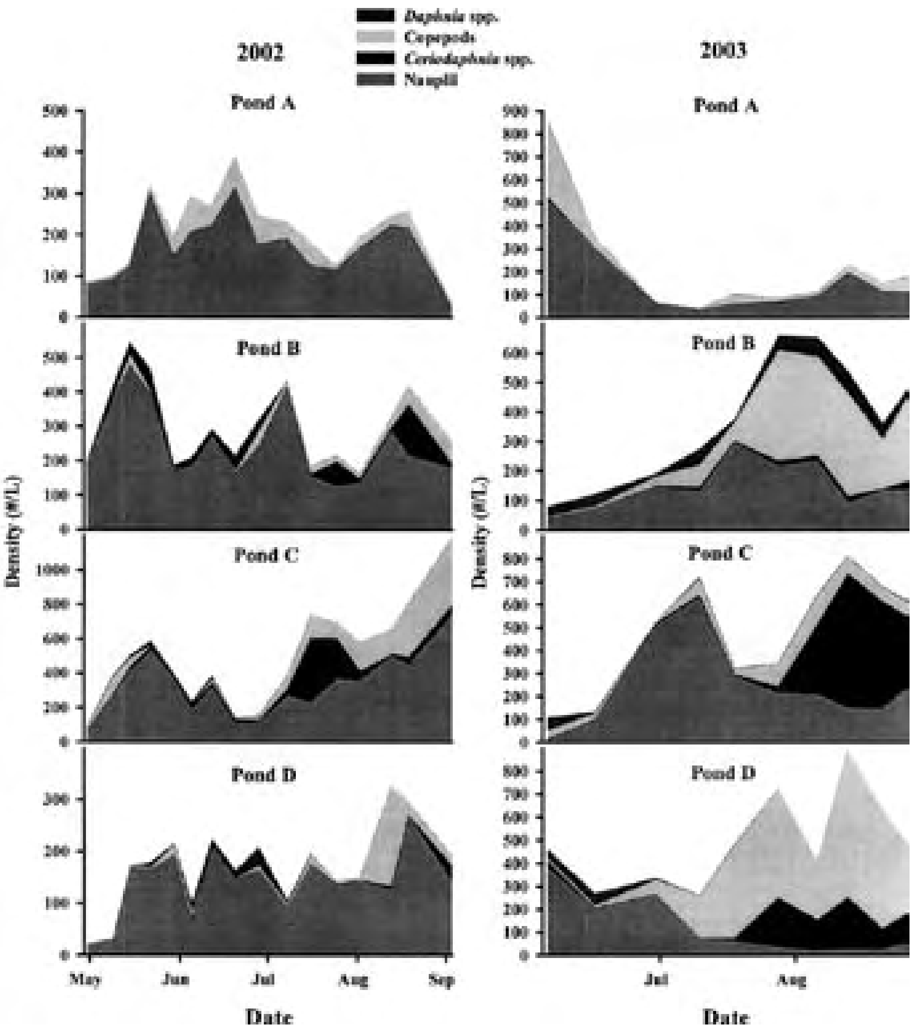

Figure 3. Dominant zooplankton taxa densities in fertilized (A, B) and control (C, D) ponds, 2002 (left panel) and 2003 (right panel).

abundances were minimal. In all four ponds nauplii and copepods were abundant throughout the year. *Daphnia* spp. were present in ponds B, C, and D early in the year but were not found in the samples past mid-July. *Ceriodaphnia* spp. were also present in samples from pond B, C, and D, and abundances increased in late summer. Rotifers were most abundant in pond A.

Benthic invertebrate abundances also varied throughout the summer in all four ponds and fertilization effects apparently were minimal (Figure 4). Chironomids and amphipods were most abundant benthic invertebrates in all four ponds. Amphipod abundances increased in all four ponds in June and early July. Ephemeropterans, odonates, and trichopterans were also found in all four ponds, but in lower abundances.

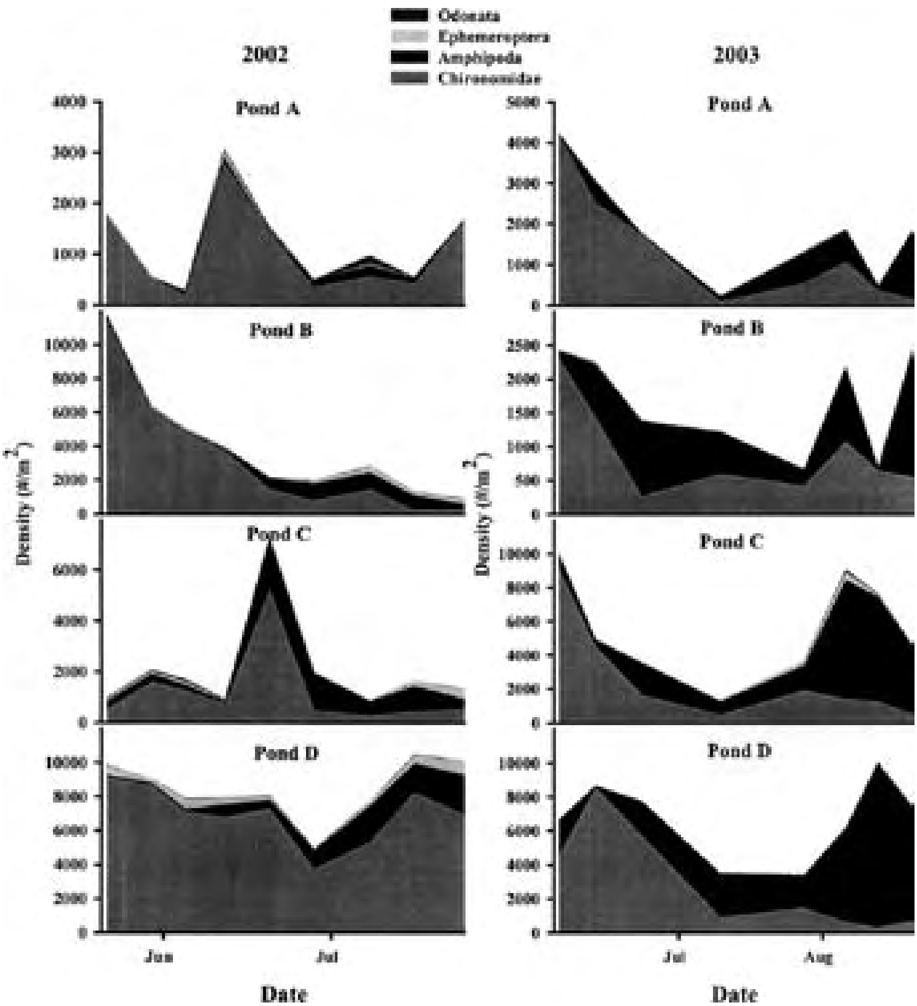

Figure 4. Benthic invertebrate density in fertilized (A, B) and control (C, D) ponds, 2002 (left panel) and 2003 (right panel).

Yellow perch survived through fall in only one of the four ponds (Pond C) in 2002. Decreased survival likely resulted from low spring water temperatures and/or poor hatching success. In mid-October, 518 yellow perch were removed from pond C.

Nutrient–mediated responses, 2003: N:P ratios in the two fertilized ponds (A, B) were below optimal levels (7:1) for most of the experiment (Figure 1). In the control ponds N:P ratios remained above 7:1 in pond C, but decreased below 7:1 in pond D at the end of July. Nitrogen concentrations increased at times in both fertilized ponds, which should have resulted in increased N:P ratios (Figure 2); however, phosphorus concentrations also increased, resulting in the low N:P ratios. Nitrogen concentrations reached higher levels in both fertilized ponds. Phosphorus concentrations in all four ponds were eutrophic (>85 µg/L) during most of the summer (Figure 2).

Table 2. Mean monthly values for water quality parameters (temperature (Temp), dissolved oxygen (DO), oxidation reduction potential (ORP), turbidity (nephelometer turbidity unit, NTU) in fertilized and control ponds, in 2002 and 2003. Measured at 0.5 m below surface (except DO bottom).

	Temp °C	DO (mg/L)	DO bottom	pH	ORP	NO_3 (mg/L)	NH_3 (mg/L)	PO_4 (mg/L)	NTU
Pond A					**2002**				
May	14.6	-	-	8.5	263	1.16	0.012	0.21	-
June	23.1	15.7	0.6	7.7	80	2.62	0.021	0.05	-
July	25.7	8.6	0.3	7.9	170	2.12	0.015	0.45	12.7
August	21.3	9.3	2.9	8.3	203	1.47	0.020	0.55	10.8
Pond B									
May	14.3	-	-	8.0	262	0.66	0.014	0.14	-
June	22.2	10.0	8.7	8.0	201	0.74	0.017	0.05	-
July	25.5	10.1	7.1	8.1	183	0.55	0.006	0.09	6.3
August	21.0	9.2	7.7	8.1	225	1.08	0.005	0.15	5.8
Pond C									
May	13.7	-	-	7.9	220	0.56	0.004	0.27	-
June	21.4	9.6	2.1	7.8	227	0.31	0.007	0.08	-
July	24.5	6.5	1.0	7.8	242	0.68	0.006	0.74	6.6
August	21.3	5.9	3.1	7.8	203	1.48	0.004	0.96	6.1
Pond D									
May	15.2	-	-	8.2	264	0.52	0.008	0.15	-
June	22.9	9.9	5.1	8.2	131	0.41	0.017	0.16	-
July	26.7	8.4	4.0	8.2	105	0.87	0.022	0.51	6.1
August	21.8	9.2	7.9	8.3	203	1.07	0.011	0.34	5.4
Pond A					**2003**				
June	22.0	9.7	0.7	7.9	200	0.67	-	0.02	9.4
July	24.3	6.6	4.1	8.1	240	1.16	-	0.62	4
August	24.7	8.7	1.8	8.6	175	1.55	-	1.12	9.1
Pond B									
June	20.5	6.7	1.7	7.5	219	0.86	-	0.07	3.6
July	22.7	4.5	3.7	7.7	290	1.07	-	1.17	0.7
August	22.8	-	0.3	7.6	276	0.46	-	2.74	3.3
Pond C									
June	21.6	13.5	9.4	8.4	210	0.98	-	0.03	4.0
July	23.4	7.2	7.2	8.5	239	1.15	-	0.22	1.0
August	23.4	7.2	6.8	8.3	131	2.92	-	0.39	1.4
Pond D									
June	22.5	13.7	13.5	8.2	186	0.77	-	0.05	3.2
July	23.9	8.8	8.9	8.5	245	0.84	-	0.39	0.0
August	24.9	9.1	9.3	8.9	161	1.96	-	0.78	0.0

Chlorophyll *a* concentrations increased in both fertilized ponds toward the end of the experiment (Figure 2). The increases in both ponds corresponded with increased nutrient concentrations. In control ponds, chlorophyll *a* concentrations remained low (< 20 µg/L) for the entire experiment (Figure 2). Chlorophyll *a* concentrations in both fertilized ponds reached higher levels than the two control ponds. Turbidity was highest in pond A (Table 2). Dissolved oxygen concentrations were lower in both fertilized ponds near the bottom (Table 2). Other water chemistry variables are described in Table 2.

Zooplankton abundances and composition varied among all four ponds (Figure 3). Nauplii and copepods were abundant in all four ponds, throughout the experiment. *Ceriodaphnia* spp. were found in all four ponds but were in lower abundance in the fertilized ponds. *Daphnia* spp. were present in ponds B, C, and D; however, abundances of *Daphnia* spp. declined in the two control ponds in the beginning of July. Rotifers were most abundant in fertilized pond A throughout the experiment.

Benthic invertebrates were most abundant in the control ponds throughout the experiment (Figure 4). Chironomids and amphipods were the most abundant benthic invertebrates in all four ponds. Chironomid abundances generally declined through the summer, while amphipod abundances increased. Ephemeropterans, odonates, and trichopterans were present but in low abundances in all four ponds.

Growth of fingerling yellow perch was highest in pond B (fertilized), followed by pond C (control) at the end of the experiment (Table 3). Yellow perch in ponds D (control) and pond A (fertilized) had similar, but lower growth. Survival was highest in control ponds (Table 3).

Table 3. Growth in length (mm) and weight (g) and survival (%) of yellow perch in fertilized and control ponds, 2003.

	Fertilized		Control	
	Pond A	**Pond B**	**Pond C**	**Pond D**
Initial length	46 (0.3)	46 (0.3)	46 (0.3)	46 (0.3)
Final length	112 (1.2)	121 (1.2)	117 (0.8)	110 (1.0)
Difference	*66*	*75*	*71*	*64*
Initial weight	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
Final weight	17.4 (0.6)	24.6 (0.8)	21.0 (0.5)	17.5 (0.5)
Difference	*16.4*	*23.6*	*20.0*	*16.5*
Number stocked	1160	780	610	850
Number removed	716	556	504	635
Survival (%)	*62*	*71*	*83*	*75*

DISCUSSION

Fertilizer application had similar effects on nutrient concentrations and primary production during the two years of the study. Nitrogen concentrations increased with urea application. However, concentrations of nitrogen quickly declined during periods when fertilizer was not applied. This indicates that fertilizer needs to be applied frequently to maintain high nitrogen concentrations. This response has been commonly observed in other studies (Boyd 1979). Phosphorus concentrations also increased with fertilization. In both fertilized ponds, low dissolved oxygen levels near the bottom may have induced a phosphorus release from the sediments and contributed to lower N:P ratios. Although N:P ratios were less than 10:1, phytoplankton abundances increased in fertilized ponds. Increased primary production however, had minimal effects on zooplankton and benthic invertebrate abundances. Only rotifer abundance in pond A during the two years of the study appeared to be influenced by fertilizer application. We also observed a decrease in blue-green algae abundance with fertilization.

All four ponds in the experiment would be considered mesotrophic to eutrophic based on phosphorus (> 26.7 µg/L), nitrogen (> 753 µg/L), and chlorophyll (> 4.7 µg/L) concentrations observed during the growing season (Wetzel 2001). This causes some concern over whether fertilizing these ponds could potentially have a negative impact on the zooplankton populations. High concentrations of phosphorus (> 85 µg/L) and nitrogen (> 1,875 µg/L) favor systems dominated by phytoplankton (Wetzel 2001). This condition may cause increased turbidity, reduced light penetration, reduced macrophyte abundance, and reduced grazing pressure by large zooplankton (Wetzel 2001). In 2002, large additions of fertilizer and increased phosphorus concentrations in pond A resulted in hyper-eutrophic chlorophyll a concentrations. More frequent, small additions of nitrogen fertilizer may better stimulate phytoplankton production, while reducing the risk of eutrophication.

Past studies indicated that yellow perch growth is related to the abundance of *Daphnia* (Mills et al. 1989a) and that slower growth was observed among age-0 yellow perch in years when *Daphnia* spp. abundances decreased in late summer (Noble 1975; Mills and Forney 1981). In 2002, *Daphnia* spp. abundances naturally declined mid-summer in the three ponds (1fertilized, 2 control) in which they were found. Only pond B (fertilized) in 2003 had *Daphnia* spp. present throughout the experiment. Coincidently, yellow perch growth was highest in pond B. *Daphnia* spp. populations declined mid-summer in control ponds (C, D) in 2003 and yellow perch growth was lower than in pond B. Growth rates were second highest in pond C, which had an abundant *Ceriodaphnia* spp. population. Growth rates were lowest in control pond D and fertilized pond A. Pond A, which also had the lowest survival, was dominated by smaller zooplankton (rotifers and nauplii) and the total zooplankton abundance was lower than the other three ponds. Pond A was unique from the other ponds in that turbidity was higher. This may have reduced the abundance of large zooplankton.

In systems with high concentrations of nitrogen and phosphorus, fertilizer application may increase phytoplankton and zooplankton production, decrease production of blue-green algae, and lead to increased yellow perch growth.

However, results from this study were inconclusive and further research is necessary to fully understand the effects of inorganic fertilization on yellow perch growth in eastern South Dakota ponds. If a nitrogen fertilizer is applied to systems with high concentrations of nitrogen and phosphorus, it should be applied frequently and in small amounts to maintain high concentrations of nitrogen while reducing the risk of eutrophication.

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