

**Fingerling walleye production in plastic-lined ponds**

by

**Matthew Lee Rogge**

A thesis submitted to the graduate faculty  
in partial fulfillment of the requirements for the degree of

**MASTER OF SCIENCE**

Major: Fisheries Biology (Aquaculture)

Program of Study Committee:  
Joseph E. Morris (Major Professor)  
John Downing  
Charles Drewes

Iowa State University

Ames, Iowa

2002

Graduate College  
Iowa State University

This is to certify that the master's thesis of

Matthew Lee Rogge

has met the thesis requirements of Iowa State University

Signatures have been redacted for privacy

## TABLE OF CONTENTS

<b>CHAPTER 1. GENERAL INTRODUCTION</b>	<b>1</b>
Introduction	1
Thesis Organization	9
Literature cited	9
<b>CHAPTER 2. EFFICACY OF ORGANIC AND INORGANIC FERTILIZATION ON PRODUCTION OF FINGERLING WALLEYE IN PLASTIC-LINED PONDS</b>	<b>17</b>
Abstract	17
Introduction	18
Materials and Methods	19
Results and Discussion	23
Acknowledgements	40
Literature Cited	40
<b>CHAPTER 3. FERTILIZATION REGIMENS FOR PLASTIC-LINED PONDS USED FOR FINGERLING WALLEYE CULTURE</b>	<b>45</b>
Abstract	45
Introduction	46
Materials and Methods	48
Results and Discussion	51
Acknowledgements	74
Literature Cited	74
<b>CHAPTER 4. GENERAL CONCLUSIONS</b>	<b>78</b>
General Discussion	78
Literature Cited	85
<b>ACKNOWLEDGEMENTS</b>	<b>88</b>

## CHAPTER 1. GENERAL INTRODUCTION

For centuries, fish culturists have used fertilizers to increase fish production (Avault 1996); to date, most published literature on pond fertilization regimens has dealt with earthen ponds. Given there are few sediments and therefore less available nutrients, it is anticipated fertilization regimens will be much more important in plastic-lined ponds.

The analogy of using a bathtub to culture fish describes using plastic-lined ponds for fish culture, i.e., no sediment, but a hard, smooth bottom surface. Perceived benefits are better water retention and limited rooted macrophyte growth, but a possible limitation is a reduced benthic macroinvertebrate prey base. Thus, fertilization may be necessary to sustain food sources, zooplankton and benthos, needed for fingerling production.

Using allochthonous materials creates a trophic cascade to increase succeeding levels of production from the bottom of the food web to the top. The trophic cascade hypothesis states there are “top-down” (predator mediated) and “bottom-up” (nutrient mediated) effects that take place in an ecosystem (Carpenter et al. 1985). Diana et al. (1991) described aquaculture ponds as good systems for studying the trophic cascade hypothesis; high density stocking of small fish causes food resources to deplete faster, causing “top-down” effects. Processes at the bottom of the food web can control interactions in higher levels (Hunter and Price 1992). McQueen et al. (1986) determined bottom-up interactions are heavy in lower trophic levels, but weaken towards the top. Lammens (1988) found bottom-up effects were more significant than top-down effects.

Phytoplankton populations are controlled by available nutrients (Hambright 1994; Moriarty 1997), which is a bottom-up effect. Schroeder et al. (1990) found increased

primary production alone could promote high fish production. Geiger et al. (1985) determined zooplankton production to be related to phytoplankton production, in agreement with Lammens (1988). Strauss et al. (1994) fertilized ponds with ammonium and phosphate; chlorophyll a concentrations increased by a factor of seven within 4 days and large cladocerans increased by a factor of eight after the chlorophyll a increase. The inference from this study was phytoplankton is a food source for zooplankton.

However, simply increasing phytoplankton abundance without regard to species composition does not automatically increase zooplankton numbers. O'Brien and DeNoyelles (1974) determined phytoplankton greater than 30- $\mu\text{m}$  in size may be too large for zooplankton to ingest. Geiger (1983a) and Geiger et al. (1985) found changes in zooplankton food sources, increased fish predation, and decreases in chlorophyll a shifted the zooplankton population from cladocerans and copepods to rotifers. Larval fish typically feed on copepods and cladocerans, with cladocerans being highly preferred because of a high caloric value and high susceptibility to predation (Parmley and Geiger 1985). This, however, results in rapid decline in cladoceran population (Geiger 1983a; Geiger et al. 1985). Copepods are less susceptible to predation because of their ability to escape; copepods can move up to 50 times faster than cladocerans (Allan 1976). Fox et al. (1989), Fox and Flowers (1990), Fox et al. (1992), Culver and Geddes (1993), Summerfelt et al. (1993), and Flowers (1996) found when zooplankton numbers declined, larval fish preyed on benthic chironomid larvae. However, in plastic-lined ponds, sediment is limited, so benthic populations may also be limited.

### Zooplankton populations

Rotifers are typically the first zooplankters to reach high densities in ponds (Allan 1976), because they mature quickly and can reproduce parthenogenetically, thus reaching high numbers quickly. However, they are soon out-competed for food and space by cladocerans and copepods. Copepods and cladocerans have similar life spans, but copepods require about 10 more days to reach peak reproduction rates and do not exhibit parthenogenesis, thereby taking longer to increase in population. Cladocerans reach their population peak after about 14 days and are parthenogenetic, allowing them to increase their density quickly. This, along with their high filter-feeding rates, gives them an ecological advantage over rotifers and copepods. However, this advantage is countered by increased predation by fish (Allan 1976).

### Fertilization

Fertilization increases fish production by releasing carbon, nitrogen, and phosphorus (Seymour 1980; Geiger 1983a; Geiger 1983b), promoting growth of bacteria, protozoa, algae, zooplankton, and aquatic insects. Hence, fertilization can create a productive ecosystem that utilizes a simple food chain (Odum 1971). A simple ecosystem generates better energy transfer between the lowest and highest trophic level. Within the chain, primary producers (phytoplankton) are at the bottom, then primary consumers (zooplankton and macroinvertebrates), and finally secondary consumers (larval fish). By having a lot of energy at the base of the web, much more can be transferred to each successive level, based on the trophic cascade hypothesis (Carpenter et al 1985). Added nutrients stimulate algal and

bacterial growth, providing food bases for zooplankton. Zooplankton, in turn, provide a food base for larval fish.

### Inorganic Fertilizers

The basis for using inorganic fertilizers is to provide essential nutrients, e.g., nitrogen and phosphorus, for phytoplankton. Olsson et al. (1992) fertilized a lake with small amounts of inorganic fertilizer, attempting to enhance phytoplankton biomass without changing the composition of the phytoplankton community. Both phytoplankton and zooplankton biomass increased without changes in dominant phytoplankton species.

Soderberg and Marcinko (1999) compared use of liquid and granular inorganic fertilizers. Fish growth and production were not affected by fertilizer type; however, they recommended dissolving granular fertilizers before application as a substitute for liquid fertilizers. Geiger and Turner (1990) recommend using liquid inorganic fertilizers over granular fertilizers because they are easier to use and handle, can be custom formulated, are more soluble, and phytoplankton can quickly utilize nutrients.

Phosphorus is usually the limiting nutrient needed by freshwater phytoplankton, and studies have shown that adding only phosphorus will increase fish yields (Boyd 1997). However, phosphate, when added to ponds, may adsorb to sediments, making it unavailable to phytoplankton; waters with high hardness levels (increased divalent cations) may also result in precipitated phosphorus (Boyd 1990). Once phosphorus is bound, it is essentially unavailable for uptake by phytoplankton. Because plastic-lined ponds have little sediment, phosphorus may not be as limiting as noted for earthen ponds.

Inorganic fertilizers can also be used to maintain nitrogen to phosphorus (N:P) ratios. Rhee (1978) concluded that optimum N:P ratios may be species-specific, and either nitrogen or phosphorus can limit growth, but not both at the same time. Rhee and Gotham (1980) define the optimum ratio as "...the ratio at which a transition from one nutrient limitation to another takes place," and found a range of ratios among species, with an average ratio of 17:1. Downing and McCauley (1992) found blue-green algae (Cyanobacteria) to be present when N:P ratios were low, in agreement with McQueen and Lean (1987) and Mischke (1999). This may occur because of the ability of Cyanobacteria to convert atmospheric nitrogen ( $N_2$ ) to nitrate ( $NO_3^-$ ), a usable form of nitrogen for algae (Bold and Wynne 1985). Barica et al. (1980) determined additions of nitrogen to a system impeded the development of  $N_2$ -fixing cyanobacteria. Seymour (1980), Culver and Geddes (1993), and Geiger and Turner (1990) concluded that maintaining a high N:P ratio could be selective for species of algae a more favorable food source for zooplankton. Reasons for selectivity against Cyanobacteria is their ability to produce toxins harmful to fish (Bold and Wynne 1985), and Cyanobacteria are not considered desirable prey to zooplankton (Olsson et al. 1992).

There are management concerns related to inorganic fertilizers. There has been some anecdotal evidence these fertilizers often give rise to increased levels of filamentous algal populations, which cause numerous problems to fish culturists. In addition, increased phytoplankton populations often result in increased variability of dissolved oxygen and pH levels associated with higher levels of primary production. The higher levels of pH could become a problem if unionized ammonia (UIA) levels are high, which is possible with

increased amounts of nitrogen added to the system. Increasing spring temperatures also will increase levels of toxic UIA.

Many scientific studies have evaluated inorganic fertilizers for fingerling walleye Stizostedion vitreum production. Qin and Culver (1992) grew walleye to about 0.4 g with 77% survival with inorganic fertilizer. Qin et al. (1995), using two stock densities, achieved 0.467 g fish with 63% survival with a low stocking density (250,000 fish/ha) and 0.239 g walleye with 70% survival at a high density (500,000 fish/ha). Using a stocking density of 10 fish/m<sup>3</sup>, Qin and Culver (1995) produced 0.7 g walleye, but at a higher density of 50 fish/m<sup>3</sup>, fish grew to only 0.4 g. Tice et al. (1996) produced 0.31 g walleye with 56% survival and 0.10 g fingerlings with 26% survival stocked at 16 fish/m<sup>3</sup> and 50 fish/m<sup>3</sup>, respectively. Soderberg et al. (1997) achieved 61% survival of 0.42 g fingerlings. Soderberg and Marcinko (1999) grew 0.33 g fish with 53% survival and 0.37 g with 27% survival for liquid and granular inorganic fertilizers, respectively. Soderberg et al. (2000) produced 0.27 - 0.32 g fish with 26 - 47% survival.

#### Organic Fertilizers

Organic fertilizers are used to stimulate heterotrophic food webs. Organic fertilizers also slowly release nutrients used by phytoplankton. Additionally, organic material serves as a substrate for bacterial and protozoan growth, creating food bases for zooplankton (Geiger 1983a; Parmley and Geiger 1985; Boyd 1990; Geiger and Turner 1990). Johnson and Schlosser (1991) found organic fertilization had a strong positive effect on zooplankton abundance; however, the effect was not apparent until 2 weeks into the study. Over half of organic carbon in aquatic systems is processed by bacteria; zooplankton predation on these

bacteria can convey energy from carbon to higher trophic levels (Markosova 1993; Moriarty 1997). Accumulation of organic material also provides forage for benthic invertebrates (Geiger 1983a).

There are problems associated with organic fertilizer use: decomposition of organic material will deplete dissolved oxygen, and slow releases of nutrients may not be useful when culturing larval species having a short-term culture period, e.g., walleye (Johnson and Schlosser 1991). Qin and Culver (1992) also found increased ammonia levels in ponds fertilized with organic material.

Many studies have been done evaluating organic fertilizer for fingerling walleye production. Fox et al. (1989) fertilized with various amounts of organic fertilizer and produced fish from 0.45 - 0.99 g with 39 - 52% survival during a 55-59 day culture season. Fox and Flowers (1990) cultured walleye fingerlings for about 42 day at three stocking densities: 20 fish/m<sup>3</sup>, 40 fish/m<sup>3</sup>, and 60 fish/m<sup>3</sup>. Final mean weights and survival were 0.788 g with 72% survival in the low-density treatment; 0.565 g fish with 79 % survival in medium density; and 0.470 g fish with 69% survival in high stocking density. Johnson and Schlosser (1991) produced 0.235 g walleye with 27.6% survival. Fox et al. (1992) produced 0.486 g fish with 49% survival. Qin et al. (1995) achieved a mean fish size of 0.407 g with 69% survival in ponds stocked at 250,000 fish/ha, but only 0.323 g fingerlings at 58% survival at 500,000 fish/ha. Tice et al. (1996) obtained 0.41 g walleye with 43% survival. Call (1996) reported 3,744 fish/kg (ca. 0.27g) with 76% survival at Garrison Dam National Fish Hatchery. Wawronowicz and Allen (1996) reported 917-990 fish/kg and 30-75%

survival during a 40 day culture period at Lac du Flambeau Indian Reservation. Soderberg et al. (1997) produced only 0.33 g fish with 50% survival.

#### Mixed fertilizer regimens

Since inorganic fertilizers enhance autotrophic food webs and organic fertilizers stimulate heterotrophic webs, it may be safe to assume both organic and inorganic fertilizers should be used. Parmley and Geiger (1985) used of organic and inorganic fertilizers in culture ponds without fish. They found both zooplankton and phytoplankton populations were established after 16 days. Fox et al. (1992) grew 0.933 g walleye fingerlings with 36% survival during a 41-42 day culture period. Qin and Culver (1992) produced large fingerlings (0.9 g), but had only 2.5% survival using a mix of fertilizers. Myers et al. (1996) produced 0.51g, 0.64 g, and 0.60 g walleye with 52%, 11%, and 13% survival, respectively in three stocking densities: 20 fish/m<sup>3</sup>, 30 fish/m<sup>3</sup>, and 40 fish/m<sup>3</sup>.

The fertilization studies described above have all been done in earthen ponds. Relative to fish culture, publications dealing with plastic-lined ponds are very limited. Barkoh et al. (1996) and Buurma et al. (1996) examined differences between alfalfa meal and cottonseed meal as organic fertilizers in culture of largemouth bass Micropterus salmoides and palmetto bass Morone saxatilis x M. chrysops fingerlings, respectively, in plastic-lined ponds. Barkoh (1996) compared effects of organic fertilizer and combinations of organic and inorganic fertilizers for striped bass (Morone saxitilis) culture. Since little has been done with plastic-lined ponds, no one quite knows how fertilization will affect them.

## Thesis Organization

This thesis contains four chapters; two of which chapter being manuscripts to be submitted to a professional journal. Chapter 2 has been submitted to Journal of the World Aquaculture Society with the following authorship: Matthew L. Rogge, Alan A. Moore, and Joseph E. Morris. Chapter 3 will be submitted to North American Journal of Aquaculture with the following authorship: Matthew L. Rogge, Alan A. Moore, and Joseph E. Morris. Each chapter is formatted according to journal instructions of Journal of World Aquaculture Society, except where thesis requirements conflicted.

In addition to these chapters, there are General Introduction and General Conclusions sections. Both sections were formatted according to instructions for the journal, Journal of the World Aquaculture Society. References cited follow each section.

### General Introduction Literature Cited

- Allan, J. D. 1976. Life history patterns in zooplankton. *The American Naturalist* 110: 165-180.
- Avault, J. W. 1996. Fundamentals of Aquaculture: A Step-by-Step Guide to Commercial Aquaculture. AVA Publishing Company, Baton Rouge, Louisiana, USA.
- Barica, J., H. Kling, and J. Gibson. 1980. Experimental manipulation of algal bloom composition by nitrogen addition. *Canadian Journal of Fisheries and Aquatic Sciences* 37:1175-1183.
- Barkoh, A. 1996. Effects of three fertilization treatments on water quality, zooplankton, and striped bass fingerling production in plastic-lined ponds. *The Progressive Fish-Culturist* 58:237-247.

- Barkoh, A., M. Stacell, and D. Smith. 1996. Efficacy of two organic fertilizers for production of Florida largemouth bass fingerlings in plastic-lined ponds. Management Data Series No. 129, Texas Parks & Wildlife, Austin, Texas.
- Bold, C. H. and M. J. Wynne. 1985. Introduction to the algae, 2<sup>nd</sup> ed. Prentice Hall, Inc., Englewood Cliffs, New Jersey, USA.
- Boyd, C. E. 1990. Water quality in ponds for aquaculture. Birmingham Publishing Co., Birmingham, Alabama, USA.
- Boyd, C. E. 1997. Practical aspects of chemistry in pond aquaculture. The Progressive Fish-Culturist 59:85-93.
- Buurma, B. J., A. Barkoh, and G. A. Alexander. 1996. Effects of cottonseed and alfalfa meals as fertilizers on production of palmetto bass (Morone saxatilis x M. chrysops) fingerlings in plastic-lined ponds. Journal of Applied Aquaculture 6(3):59-70.
- Call, J. E. 1996. Pond production of fingerling walleye at Garrison Dam National Fish Hatchery. Pages 109-110 in R. C. Summerfelt, editor. Walleye culture manual. NCRAC Culture Series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames, Iowa, USA.
- Carpenter, S. R., J. F. Kitchell, and J. R. Hodgson. 1985. Cascading trophic interactions and lake productivity. Bioscience 35(10):634-639.
- Culver, D. A., and M. C. Geddes. 1993. Limnology of rearing ponds for Australian fish larvae: relationships among water quality, phytoplankton, zooplankton, and the growth of larval fishes. Australian Journal of Marine and Freshwater Research 44:537-551.

- Diana, J. S., D. J. Dettweiler, and C. K. Lin. 1991. Effect of Nile tilapia (Oreochromis niloticus) on the ecosystem of aquaculture ponds, and its significance to the trophic cascade hypothesis. Canadian Journal of Fisheries and Aquatic Sciences 48:183-190.
- Downing, J. A., and E. McCauley. 1992. The nitrogen: phosphorus relationship in lakes. Limnology and Oceanography 37(5):936-945.
- Fox, M. G., and D. D. Flowers. 1990. The effect of fish density on growth, survival and production of juvenile walleye in rearing ponds. Transactions of the American Fisheries Society 119:112-121.
- Fox, M. G., D. D. Flowers, and C. Watters. 1992. The effect of supplementary inorganic fertilization on juvenile walleye (Stizostedion vitreum) reared in organically fertilized ponds. Aquaculture 106:27-40
- Fox, M. G., J. A. Keast, and R. J. Swainson. 1989. The effect of fertilization regime on juvenile walleye growth and prey utilization in rearing ponds. Environmental Biology of Fishes 26:129-142.
- Flowers, D. D. 1996. Fingerling production in drainable ponds at White Lake Fish Culture Station. Pages 123-128 in R. C. Summerfelt, editor. Walleye culture manual. NCRAC Culture Series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.
- Geiger, J. G. 1983a. Zooplankton production and manipulation in striped bass rearing ponds. Aquaculture 35:331-351.

- Geiger, J. G. 1983b. A review of pond zooplankton production and fertilization for the culture of larval and fingerling striped bass. *Aquaculture* 35:353-369.
- Geiger J. G., and C. J. Turner. 1990. Pond fertilization and zooplankton management techniques for production of fingerling striped bass and hybrid striped bass. Pages 79-98 in R.M. Harrel, J.H. Kerby, and R.V. Minton, editors. *Culture and propagation of striped bass and its hybrids*. Bethesda, Maryland: Striped Bass Committee, Southern Division, American Fisheries Society.
- Geiger, J. G., C. J. Turner, K. Fitzmayer, and W. C. Nichols. 1985. Feeding habits of larval and fingerling striped bass and zooplankton dynamics in fertilized rearing ponds. *The Progressive Fish-Culturist* 47(4):213-223.
- Hambright, K. D. 1994. Morphological constraints in the piscivore-planktivore interaction: implications for the trophic cascade hypothesis. *Limnology and Oceanography* 39(4):897-912.
- Hunter, M. D., and P. W. Price. 1992. Playing chutes and ladders: heterogeneity and the relative roles of bottom-up and top-down forces in natural communities. *Ecology* 73(3):724-732.
- Johnson, S. R., and I. J. Schlosser. 1991. Effects of organic enrichment on zooplankton abundance and walleye fry growth and survival in artificial rearing ponds. *Journal of Freshwater Ecology* 6(3):315-321.
- Lammens, E. H. R. R. 1988. Trophic interactions in the hypertrophic Lake Tjeukemeer: top-down and bottom-up effects in relation to hydrology, predation and bioturbation during the period 1974-1985. *Limnologica* 19(1):81-85.

- Markosova, R., and J. Jezek. 1993. Bacterioplankton interactions with Daphnia and algae in experimental enclosures. *Hydrobiologia* 264:85-99.
- McQueen, D. J., and D. R. S. Lean. 1987. Influence of water temperature, and nitrogen : phosphorus ratios on the dominance of blue-green algae in Lake St. George, Ontario. *Canadian Journal of Fisheries and Aquatic Sciences* 44:598-604.
- McQueen, D. J., J. R. Post, and E. L. Mills. 1986. Trophic relationships in freshwater pelagic ecosystems. *Canadian Journal of Fisheries and Aquatic Sciences* 43:1571-1581.
- Mischke, C. C. 1999. Fertilization of walleye production ponds. Ph.D. Dissertation. Iowa State University, Ames, Iowa.
- Moriarty, D. J. W. 1997. The role of microorganisms in aquaculture ponds. *Aquaculture* 151:333-349.
- Myers, J. J., R. W. Soderberg, J. M. Kirby, and M. T. Marcinko. 1996. Production of walleye, Stizostedion vitreum, in earthen ponds fertilized with organic and inorganic fertilizers and stocked at three rates. *Journal of Applied Aquaculture* 6(2):11-19.
- O'Brien, W. J. and F. DeNoyelles. 1974. Relationship between nutrient concentration, phytoplankton density, and zooplankton density in nutrient enriched experimental ponds. *Hydrobiologia* 44(1):105-125.
- Odum, E. P. 1971. *Fundamentals of Ecology*, 3<sup>rd</sup> ed. W.B. Saunders Company, Philadelphia, Pennsylvania, USA.

- Olsson, H., P. Blomqvist, and H. Olofsson. 1992. Phytoplankton and zooplankton community structure after nutrient additions to the oligotrophic Lake Hecklan, Sweden. *Hydrobiologia* 243/244:147-155.
- Parmley, D. C., and J. G. Geiger. 1985. Research and development communications: succession patterns of zooplankton in fertilized culture ponds without fish. *The Progressive Fish Culturist* 47(3):183-186.
- Qin, J., and D. A. Culver. 1992. The survival and growth of larval walleye, *Stizostedion vitreum*, and the trophic dynamics in fertilized ponds. *Aquaculture* 108:257-276.
- Qin, J. and D. A. Culver. 1995. Effect of young-of-the-year walleye (Percidae: *Stizostedion vitreum*) on plankton dynamics and water quality in ponds. *Hydrobiologia* 297:217-227.
- Qin, J., S. P. Madon, and D. A. Culver. 1995. Effect of larval walleye (*Stizostedion vitreum*) and fertilization on the plankton community: implications for larval fish culture. *Aquaculture* 130:51-65.
- Rhee, G. Y. 1978. Effects of N:P atomic ratios and nitrate limitation on algal growth, cell composition, and nitrate uptake. *Limnology and Oceanography* 23(1):10-25.
- Rhee, G. Y., and I. J. Gotham. 1980. Optimum N:P ratios and coexistence of planktonic algae. *Journal of Phycology* 16:486-489.
- Schroeder, G. L., G. Wohlfarth, A. Aldon, A. Halevy, and H. Krueger. 1990. The dominance of algal-based food webs in fish ponds receiving chemical fertilizers plus organic manures. *Aquaculture* 86:219-229.

- Seymour, E. A. 1980. The effects and control of algal blooms in fish ponds. *Aquaculture* 19: 55-74.
- Soderberg, R. W., J. M. Kirby, D. Lunger, and M. T. Marcinko. 1997. Comparison of organic and inorganic fertilizers for the pond production of walleye, *Stizostedion vitreum*. *Journal of Applied Aquaculture* 7(2):23-29.
- Soderberg, R. W., J. M. Kirby, and M. T. Marcinko. 2000. Lack of response of juvenile walleyes to increased levels of fertilization of liming in soft-water ponds. *North American Journal of Aquaculture* 62:26-32.
- Soderberg, R. W., and M. T. Marcinko. 1999. Substitution of granular for liquid fertilizers for the production of juvenile walleye, *Stizostedion vitreum*, in earthen ponds. *Journal of Applied Aquaculture* 9(4):33-40.
- Strauss, E. A., W. K. Dodds, and C. C. Edler. 1994. The impact of nutrient pulses on trophic interactions in a farm pond. *Journal of Freshwater Ecology* 9(3):217-228.
- Summerfelt, R. C., C. P. Clouse, and L. M. Harding. 1993. Pond production of fingerling walleye, *Stizostedion vitreum*, in the northern Great Plains. *Journal of Applied Aquaculture* 2(3/4):33-58.
- Tice, B. J., R. W. Soderberg, and J. M. Kirby. 1996. Growth and survival of walleyes reared in ponds fertilized with organic or inorganic materials. *The Progressive Fish-Culturist* 58:135-139.

Wawronowicz, L. J., and W. G. Allen. 1996. Walleye fingerling production techniques in drainable ponds on the Lac du Flambeau Indian Reservation. Pages 111-113 in R. C. Summerfelt, editor. Walleye culture manual. NCRAC Culture Series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames, Iowa, USA.

CHAPTER 2. EFFICACY OF ORGANIC AND INORGANIC FERTILIZATION ON  
PRODUCTION OF FINGERLING WALLEYE STIZOSTEDION VITREUM IN PLASTIC-  
LINED PONDS

A paper submitted to Journal of the World Aquaculture Society

Matthew L. Rogge, Alan. A. Moore, and Joseph E. Morris

Abstract

Inorganic and organic fertilization regimens were evaluated for production of fingerling walleye Stizostedion vitreum in plastic-lined ponds. Inorganic fertilizer was nitrogen (10-0-0) and phosphorus (12-49-6) solutions applied to maintain a targeted 7:1 nitrate-nitrogen to total phosphorus ratio. Organic fertilizer was an equal mix of alfalfa and cottonseed pellets applied at 42.5 kilograms of each fertilizer/ha/wk. During the 5 wk culture period, dissolved oxygen readings were significantly lower in organically fertilized ponds than control and inorganically treated ponds ( $P < 0.10$ ) on the bottom. Inorganic fertilization produced higher afternoon dissolved oxygen levels than organically treated ponds. pH was also higher ( $P < 0.10$ ) in inorganic ponds, sometimes as high as 10. Although nitrogen or phosphorus was added weekly for the inorganic treatment, there were no significant differences in nitrogen or phosphorus concentrations among treatments. Daphnia species and copepod population trends were also similar among treatments; however, copepod populations increased late in the season in fertilized ponds. Ponds treated with organics had fish with significantly higher ( $P < 0.10$ ) final lengths and weights compared to fish from control and inorganically treated ponds. Results suggest organic fertilizers facilitate better walleye fingerling production compared to inorganic or no fertilizer in plastic-lined ponds.

## Introduction

Walleye Stizostedion vitreum populations are frequently maintained in public waters through state agency stocking programs. Conover (1986) estimated over a billion walleye are stocked in U.S. and Canadian public waters annually; 98% are stocked as fry. However, fingerling walleye usually have much higher survival than fry (Paragamian and Kingery 1992).

Walleye fingerlings have often been cultured in earthen ponds using a variety of fertilization regimens involving organic and inorganic fertilizers (Fox et al. 1989; Fox et al. 1992; Qin and Culver 1992; Harding and Summerfelt 1993; Qin et al. 1995; Myers et al. 1996; Tice et al. 1996; Soderberg et al. 1997; Soderberg and Marcinko 1999; Soderberg et al. 2000). Several of these studies advocate using inorganic fertilizers rather than organic or a mix of organic and inorganic fertilizers because of higher survival (Qin and Culver 1992; Qin et al. 1995) or lower costs of materials and labor (Tice et al. 1996; Soderberg et al. 1997). The question remains whether or not these protocols produce the same results in plastic-lined ponds.

Many public hatcheries are now constructing plastic-lined ponds. Advantages of using a plastic liner are less water seepage, less aquatic macrophytes, and ease of harvest (Kriofske 1990). The lining, however, will eliminate nutrients in the sediments, such as organic carbon, from being accessible to organisms. Lack of sediments may also hinder colonization of benthos by insect larvae, which are an important food source for fingerling walleyes (Fox et al. 1989; Fox and Flowers 1990; Fox et al. 1992; Summerfelt et al. 1993; Flowers 1996). Thus, fertilization will be the major supply of nutrients needed to stimulate

food webs, providing larval walleye with food sources. However, there has been little research on fertilization of plastic-lined culture ponds (Barkoh 1996; Barkoh et al. 1996; Buurma et al. 1996).

Barkoh et al. (1996) compared alfalfa meal to cottonseed meal for culture of largemouth bass *Micropterus salmoides* in plastic-lined ponds. Water quality, phytoplankton abundance, and fish growth were better in ponds treated with cottonseed meal; however, zooplankton populations developed sooner in ponds treated with alfalfa meal. Buurma et al. (1996) found similar results in lined ponds used for palmetto bass *Morone saxatilis X M. chrysops* culture. Barkoh (1996) evaluated organic and inorganic fertilizers for the culture of striped bass *M. saxatilis*, comparing organic fertilizer to two mixes of organic and inorganic fertilizer. Water quality was better in ponds with organic fertilizer; ponds treated with both organic and inorganic fertilizers had pH levels reaching 9.6.

The goal of this study was to develop a fertilization regimen to produce advanced walleye fingerlings ( $\leq 1,760$  fish/kg) with high survival ( $\geq 50\%$ ) in plastic-lined ponds. These numbers are based on Iowa Department of Natural Resources' desired production values. The specific objective was to evaluate the efficacy of organic and inorganic fertilizers in relation to walleye fingerling production in plastic-lined culture ponds.

#### Materials and Methods

##### Study site

This study was conducted at Rathbun Fish Culture Research Facility, Moravia, Iowa. Six previously unused 0.04 ha ponds were used to evaluate the efficacy of two fertilization regimens for walleye fingerling production. Individual ponds served as experimental units.

Treatments were applications of 1) no fertilizer (control), 2) inorganic fertilizer, and 3) organic fertilizer, and were randomly assigned to ponds, resulting in two replicates per treatment. Water from Rathbun Lake was used to fill all ponds. Ponds began filling 21 April 2000 and were full on 25 April 2000; water was periodically added to compensate for evaporation. Larval walleyes (3-4 d post-hatch) were stocked on 1 May 2000 at 250,000 fish/ha. Individual fish were counted to using a fry counter (Jensorter Model FC2, Jensorter Incorporated, Bend, Oregon).

#### Fertilizer applications

Alfalfa and cottonseed pellets were used as organic fertilizer. Each type of organic fertilizer was added weekly at a rate of 1.7 kilograms (kg) per pond (total of 10.2 kg/pond). Six organic applications were used per pond, the first being on 21 April 2000. Phosphorus (12-49-6) and nitrogen (10-0-0) were used as inorganic fertilizer. Granular fertilizer was dissolved in water and sprayed onto pond surfaces. The first application of inorganic fertilizer was on 28 April 2000. Inorganic fertilizer was applied weekly, following water quality analyses. Additions were based on the amount of fertilizer needed to maintain a nitrate-nitrogen to total phosphorus ratio ( $\text{NO}_3\text{-N:TP}$ ) of 7:1 (Mischke 1999) in inorganic ponds; if water chemistry analyses determined a pond in the inorganic treatment had a ratio of 7:1, no fertilizer was added. We did not attempt to maintain minimal nutrient levels. No target ratio was used in organic ponds.

#### Sampling and analytical methods

Beginning 26 April 2000, water samples were taken twice weekly (Monday and Thursday) from each pond using a tube sampler (entire water depth sampled). Samples were

analyzed in the facility laboratory. A Hach DR/2010 spectrophotometer (Hach, Loveland, Colorado) was used to measure ammonia-nitrogen ( $\text{NH}_3\text{-N}$ ), nitrite-nitrogen ( $\text{NO}_2\text{-N}$ ),  $\text{NO}_3^-$ , N, and TP.

Morning (0600 h) and afternoon (1500 h) temperature and dissolved oxygen concentrations were recorded twice weekly using a YSI Model 55 Oxygen Meter (Yellow Springs, Ohio) at three depths: bottom (1.6 m), middle (0.8 m), and surface (0.3 m). Daily pH measurements were recorded using an Orion Ionanalyzer/Model 407A pH meter (Boston, Massachusetts).

For analyses of photo-pigments, 200-250 ml sample volumes were collected on GF/F glass-fiber filters under low vacuum (< 75 mm Hg). Filters were then immediately frozen and stored in darkness until analyzed. Frozen filters were placed in 100% acetone, sonicated and extracted in darkness at -20 C for at least 12 h for chlorophyll and carotenoid analyses. Filtered extracts (75-125 mL) were injected directly into a Hewlett Packard model 1090 HPLC equipped with one monomeric C18 column (Hewlett Packard ODS-Hypersil; 200 x 4.6 mm, 4mm) and two polymeric C18 columns (Vydac 201TP; 250 x 4.6 mm, 5 mm) in series. The mobile phases and solvent flow rates follow that described by Pinckney et al. (1996). Pigments were then identified and quantified using a diode array detector (436 nanometer); a pigment library of standards for chlorophylls (Sigma Chemical Company) and carotenoids (U. S. Environmental Protection Agency) was used to confirm pigment identities.

Zooplankton were sampled twice weekly with oblique tows of an 80  $\mu\text{m}$  Wisconsin plankton net (Wildco Company, Saginaw, Wisconsin) and preserved with a chilled formalin/sucrose solution (APHA et al. 1998). Specimens were counted in lab and identified

using keys by Pennak (1989). Plastic lining prevented us from taking grab samples of benthos; therefore, benthos was sampled using Hester-Dendy multiple-plate samplers (Hester and Dendy 1962). Once ponds were full, three sets of eight plates were placed onto each pond bottom at a depth of 0.3 m. In each pond, one sampler was retrieved 1 wk prior to harvest with the remaining sets retrieved at harvest. Benthos samples were preserved in 10% buffered formalin for later identification.

Fish were harvested 5-7 June 2000. Ponds were drained and fish collected in a basin in the pond. A sample of 100 fish from each pond was obtained and mean lengths and weights were recorded. Number of harvested fish was estimated using total weight divided by mean fish weights.

#### Data analyses

Treatment differences were analyzed using the Mixed Model from Statistical Analysis Systems version 8.2 (SAS Institute, Incorporated, Cary, North Carolina) to determine significant differences in nutrient levels, plankton populations, and relative fish production between treatments. Pairwise comparisons were adjusted using Tukey's Honestly Significant Difference (HSD). Treatment comparisons were evaluated using pond(treatment) as the error term. Daily differences were assessed using an error term of day\*pond(treatment). Significance was set at  $P \leq 0.10$ . Homogeneity of variance was tested using the General Linear Model of Statistical Analysis Systems version 8.2 with the Brown-Forsythe modification of the Levene Test.

## Results and Discussion

### Fertilizer

Nitrogen (10-0-0) was frequently the inorganic nutrient added to inorganically treated ponds. A total of 14.1 kg 10-0-0 was used in both ponds treated with inorganics, compared to a total of 0.5 kg 12-49-6, suggesting nitrogen is limiting in plastic-lined ponds. A possible reason for the low amount of phosphorus needed is lack of bottom sediments. In earthen ponds, large fractions of phosphorus adsorb to sediments and suspended particles, making it unavailable to phytoplankton (Boyd 1990). The lack of sediment allowed phosphorus to stay in solution.

### Water Quality

Dissolved oxygen concentrations exhibited few significant differences among treatments (Table 2.1). Bottom morning and afternoon dissolved oxygen concentrations in organically fertilized ponds were significantly lower than levels in inorganically fertilized. Qin and Culver (1992), Qin et al. (1995), and Barkoh (1996) also found depressed dissolved oxygen levels associated with organic fertilizer. Minimal morning dissolved oxygen levels on the bottom were 1.2 mg/L in organically treated ponds; minimal concentrations for control and inorganically treated ponds were 4.9 and 5.4 mg/L, respectively. However, middle levels in the organic treatment did not fall below 6.2 mg/L.

In agreement with Qin et al. (1995) and Barkoh (1996), inorganic fertilization produced significantly higher pH readings than control and organically treated ponds ( $P < 0.10$ ). pH levels in inorganically treated ponds sometimes rose to 10.0; levels in organically

treated ponds never were higher than 9.0. High pH levels in inorganic ponds could pose problems if ammonia levels and water temperatures also rise.

Higher dissolved oxygen and pH levels imply more photosynthesis in inorganic ponds, but chlorophyll *a* levels were not significantly different among treatments (Fig. 2.1) until the end of the culture season, suggesting inorganic fertilization did not improve the phytoplankton base. Mean chlorophyll *a* levels were  $4.1 \pm 1.28$  and  $4.9 \pm 1.28$  nanograms (ng)/mL in inorganic and organic treatments, respectively. The lower dissolved oxygen and pH levels in organically treated ponds may be due to biological decomposition of organic material consuming dissolved oxygen and producing higher amounts of carbon dioxide, thus lowering pH.

Incoming water during pond filling had 0.3 mg/L NO<sub>3</sub>-N and 0.02 mg/L TP (15:1 NO<sub>3</sub>-N:TP ratio). TP levels (Fig. 2.2) were similar among treatments throughout the season. This can be expected because of the low amount of phosphorus added in the inorganic treatment. Because nutrient ratios were usually low (< 7:1), nitrogen was commonly added to increase the ratio. Nitrate concentrations (Fig. 2.3) in inorganically treated ponds were similar to values in control and organically treated ponds, even though large quantities of 10-0-0 were added. An insufficient application method, not enough fertilizer, or a constant consumption of nitrogen could have caused this. However, adding more nitrogen fertilizer could pose problems; ammonia levels could increase with higher nitrogen levels or increases in primary production can increase pH. More research needs to be done to evaluate different types of inorganic fertilizer and the uptake of nitrogen in plastic-lined ponds.

Table 2.1. Means  $\pm$  SEM (range) of water quality variables in plastic-lined walleye culture ponds receiving no fertilizer (control), alfalfa and cottonseed pellets (organic), and nitrogen and phosphorus (inorganic) during the 2000 walleye fingerling culture season at Rathbun Fish Culture Research Facility, Moravia, Iowa. Values in a row with the same letter are not significantly different ( $P > 0.10$ ).

Variable	Treatment		
	Control	Inorganic	Organic
<b>Dissolved Oxygen (mg/L)</b>			
Morning			
Bottom ( <u>N</u> =22)	8.5 $\pm$ 0.30 a (4.9-10.8)	9.1 $\pm$ 0.30 a (5.4-12.8)	6.5 $\pm$ 0.30 b (1.1-10.6)
Middle ( <u>N</u> =22)	9.2 $\pm$ 0.30 a (7.4-10.9)	9.8 $\pm$ 0.30 a (7.7-11.3)	8.6 $\pm$ 0.30 a (6.5-10.7)
Top ( <u>N</u> =22)	9.2 $\pm$ 0.30 a (7.5-10.9)	9.9 $\pm$ 0.30 a (7.9-11.3)	8.6 $\pm$ 0.30 a (6.5-10.8)
Afternoon			
Bottom ( <u>N</u> =24)	9.7 $\pm$ 0.30 a b (7.8-11.6)	10.5 $\pm$ 0.30 a (8.0-13.2)	9.1 $\pm$ 0.30 b (6.4-12.3)
Middle ( <u>N</u> =24)	9.7 $\pm$ 0.30 a (8.0-12.2)	10.6 $\pm$ 0.30 a (8.0-12.9)	9.6 $\pm$ 0.30 a (6.2-12.5)
Top ( <u>N</u> =24)	9.6 $\pm$ 0.30 a (7.9-11.6)	10.5 $\pm$ 0.30 a (8.2-12.7)	9.6 $\pm$ 0.30 a (7.1-12.1)

Table 2.1 (continued).

Chlorophyll <i>a</i> (ng/mL)	$2.7 \pm 1.28$ a	$4.1 \pm 1.28$ a	$4.9 \pm 1.28$ a
( <u>N</u> =12)	(0.5-14.2)	(0.14-15.5)	(0.1-10.0)
pH ( <u>N</u> =24)	$8.8 \pm 0.07$ a	$9.3 \pm 0.07$ b	$8.7 \pm 0.07$ a
	(8.2-9.1)	(8.1-10.0)	(7.8-9.0)
NH <sub>3</sub> -N (mg/L) ( <u>N</u> =24)	$0.11 \pm 0.02$ a	$0.09 \pm 0.02$ a	$0.14 \pm 0.02$ a
	(0.00-0.32)	(0.00-0.31)	(0.01-.0.25)
NO <sub>2</sub> -N (mg/L) ( <u>N</u> =24)	$0.014 \pm 0.003$ a	$0.011 \pm 0.003$ a	$0.014 \pm 0.003$ a
	(0.002-0.046)	(0.003-0.038)	(0.003-0.52)
NO <sub>3</sub> -N (mg/L) ( <u>N</u> =24)	$0.19 \pm 0.03$ a	$0.23 \pm 0.03$ a	$0.17 \pm 0.03$ a
	(0.0-0.9)	(0.1-0.5)	(0.1-0.5)
TP (mg/L) ( <u>N</u> =24)	$0.06 \pm 0.01$ a	$0.06 \pm 0.01$ a	$0.08 \pm 0.01$ a
	(0.01-0.24)	(0.01-0.24)	(0.01-0.20)
Nutrient Ratio	$5.0:1 \pm 1.20$ a	$5.7:1 \pm 1.20$ a	$4.0:1 \pm 1.20$ a
(NO <sub>3</sub> -N:TP) ( <u>N</u> =24)	(0.0-20.0)	(1.1-20.0)	(0.6-30.0)

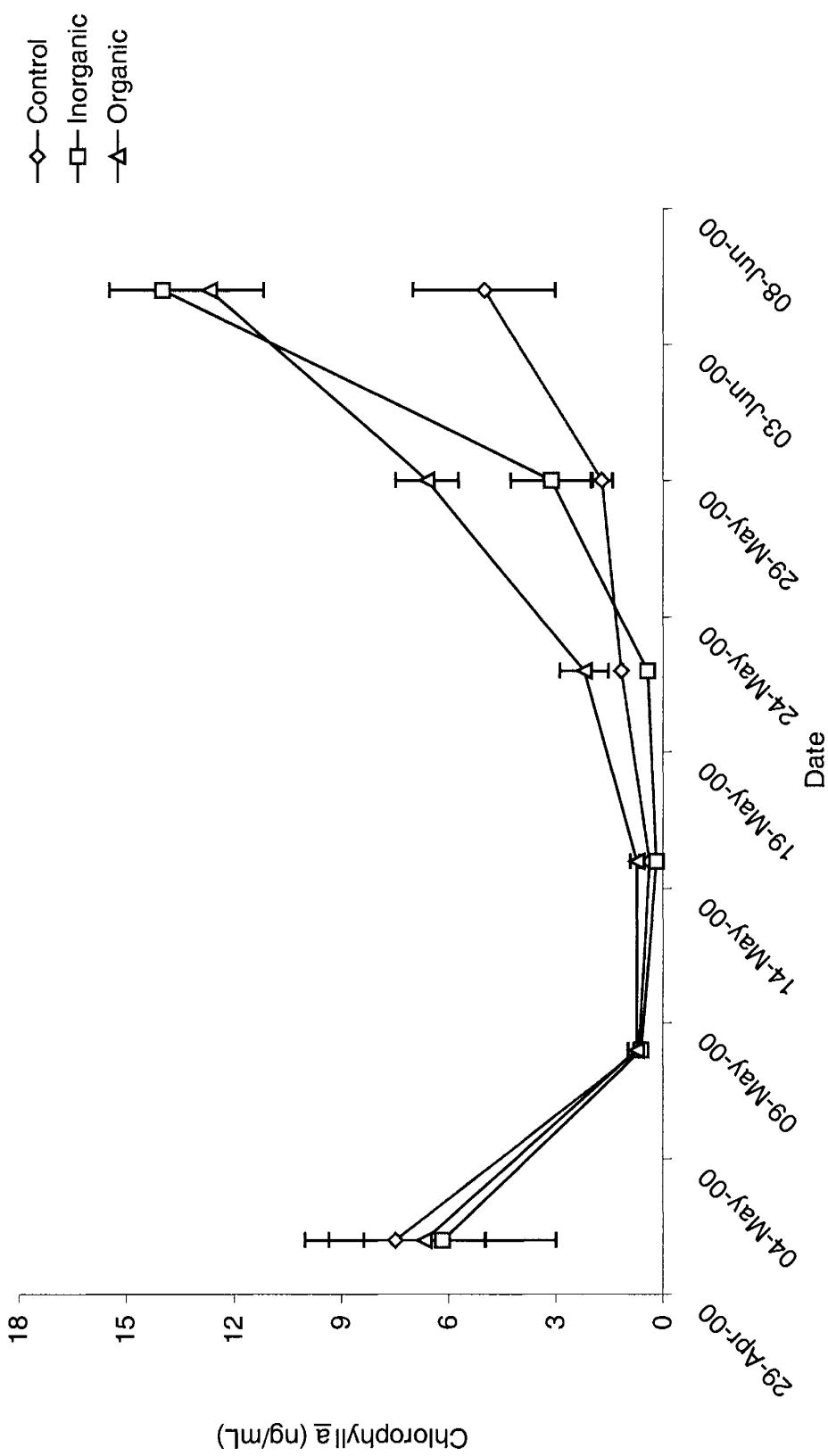


Figure 2.1. Mean chlorophyll *a* concentrations in plastic-lined walleye culture ponds receiving no fertilizer (control), alfalfa and cottonseed pellets (organic), and nitrogen and phosphorus (inorganic) during the 2000 walleye fingerling culture season at Rathbun Fish Culture Research Facility, Moravia, Iowa.

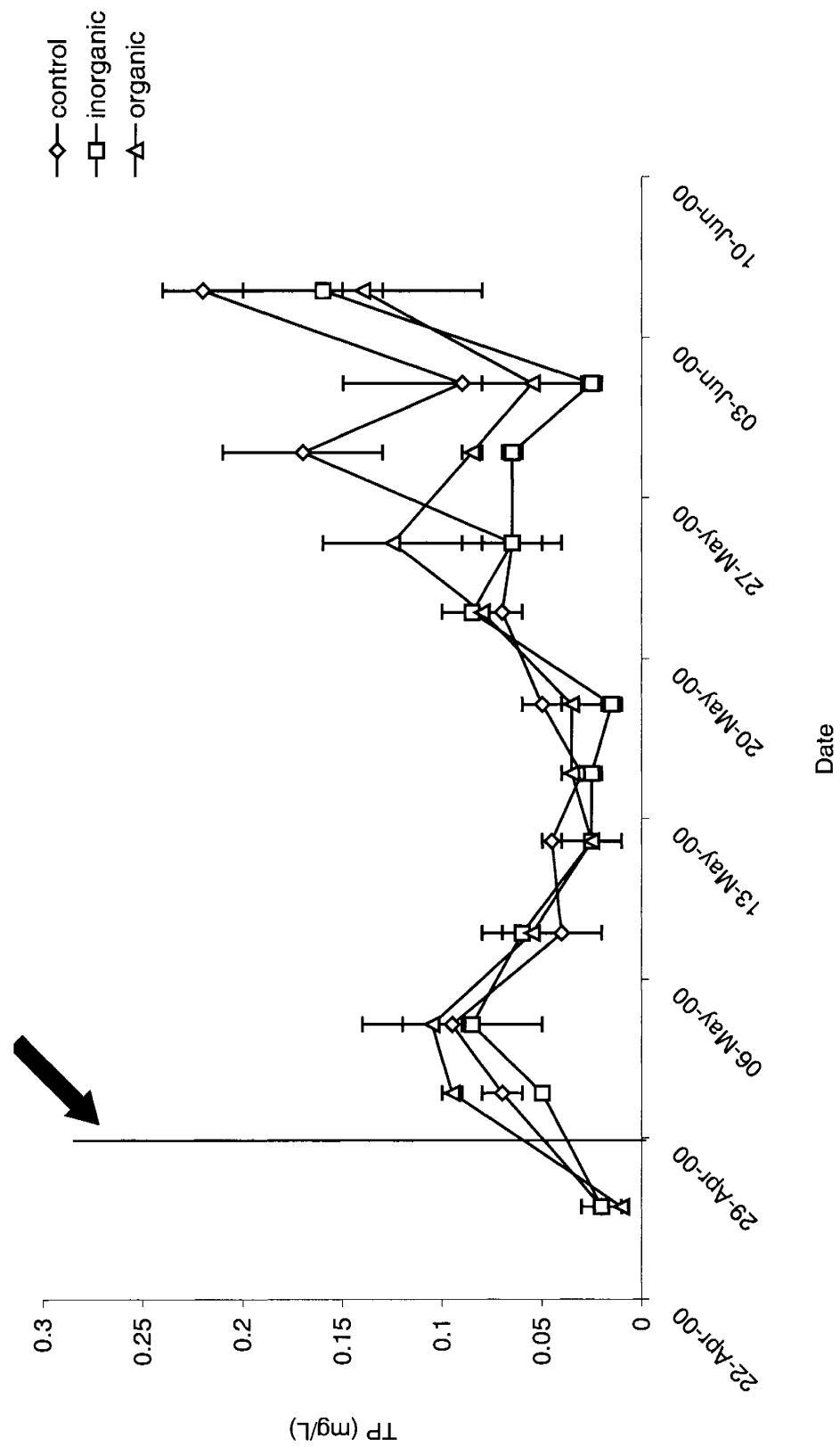


Figure 2.2. Mean total phosphorus concentrations in plastic-lined walleye culture ponds receiving no fertilizer (control), alfalfa and cottonseed pellets (organic), and nitrogen and phosphorus (inorganic) during the 2000 walleye fingerling culture season at Rathbun Fish Culture Research Facility, Moravia, Iowa. Black arrow indicates first inorganic application.

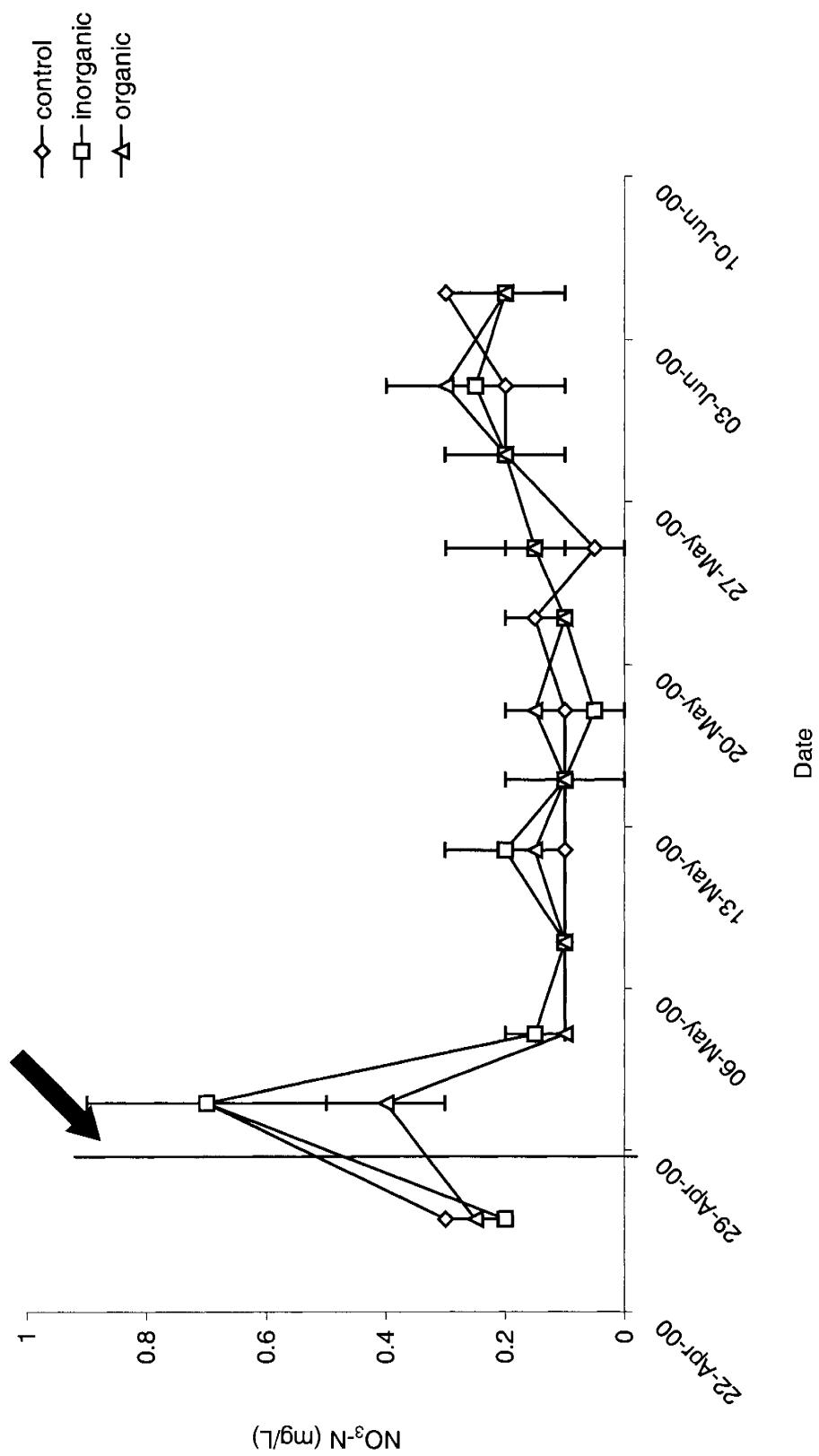


Figure 2.3. Mean  $\text{NO}_3\text{-N}$  concentrations in plastic-lined walleye culture ponds receiving no fertilizer (control), alfalfa and cottonseed pellets (organic), and nitrogen and phosphorus (inorganic) during the 2000 walleye fingerling culture season at Rathbun Fish Culture Research Facility, Moravia, Iowa. Black arrow indicates first inorganic application.

### Zooplankton and Benthos

Zooplankton population trends were similar among treatments throughout the study. Daphnia species (spp.) densities peaked 3 d after walleyes were stocked; however, they quickly declined. A sharp decline in Daphnia spp. following stocking in walleye culture ponds has also been reported by Fox et al. (1989) and Fox et al. (1992). This decline suggests intense predation pressure by larval walleye. Daphnia spp. densities reached maximum levels on 4 May 2000, 13 d after initial organic enrichment and 6 d following initial inorganic enrichment. Parmley and Geiger (1985), Johnson and Schlosser (1991), Barkoh (1996), and Buurma et al. (1996) also found adequate zooplankton populations established 2 wks following organic treatment. Maximum densities in both fertilization treatments were not significantly different from the control, suggesting fertilization had little or no effect on Daphnia spp. populations (Fig. 2.4).

Adult copepod densities (Fig. 2.5) and total copepod (adult and copepodite stages) densities (Fig. 2.6) were similar among treatments initially, but fertilization appeared to positively influence densities as the culture season progressed. In both fertilization treatments, copepod densities increased later in the season, whereas densities in control ponds remained relatively low.

Zooplankton populations in all treatments were low at the end of the season. However, Daphnia spp. in organically treated ponds had a late peak, suggesting predation pressure was reduced at the end of the season. This late peak may have been caused by fingerlings preferring benthic insect larvae. Culver and Geddes (1993) found decreased zooplankton numbers caused larval fish to prey upon benthic invertebrates. Fox et al. (1989),

Fox and Flowers (1990), Fox et al. (1992), Summerfelt et al. (1993), and Flowers (1996) agree chironomid larvae are highly important in fingerling walleye culture. Mean benthic invertebrate populations were highest in organic ponds (Table 2.2) with significant differences between control and organically treated ponds ( $P < 0.10$ ). Higher replication may have teased out significant differences between organic and inorganic fertilization. Benthos was primarily comprised of chironomids. Walleye  $> 22$  mm predominantly prey upon chironomid larvae (Fox et al. 1989). Hence, higher densities of benthic invertebrates in organic ponds may have facilitated higher walleye growth. The addition of organic material in plastic-lined ponds may be important, if only to provide substrate for invertebrate colonization.

Much of the literature on walleye fingerling culture focuses on zooplankton density management. Benthic organisms are rarely discussed; however, Fox et al. (1989), Fox and Flowers (1990), Fox et al. (1992), Summerfelt et al. (1993), and Flowers (1996), discuss the importance of chironomids in fingerling walleye diets. In an environment with little sediment or organic carbon, such as plastic-lined ponds, benthic invertebrate populations may be depressed. Therefore, based on results from this study, it is important to include organic fertilization in the management of plastic-lined culture ponds.

#### Walleye Production

Organic fertilization was the only treatment that produced  $< 1,760$  fish/kg (Table 2.3). Final mean weights in organic ponds were 0.69 g, whereas control and inorganic ponds produced only 0.21 and 0.42 g fish, respectively. There were no treatment differences in percent survival (Table 2.4). Survival was low, similar to reports by Johnson and Schlosser

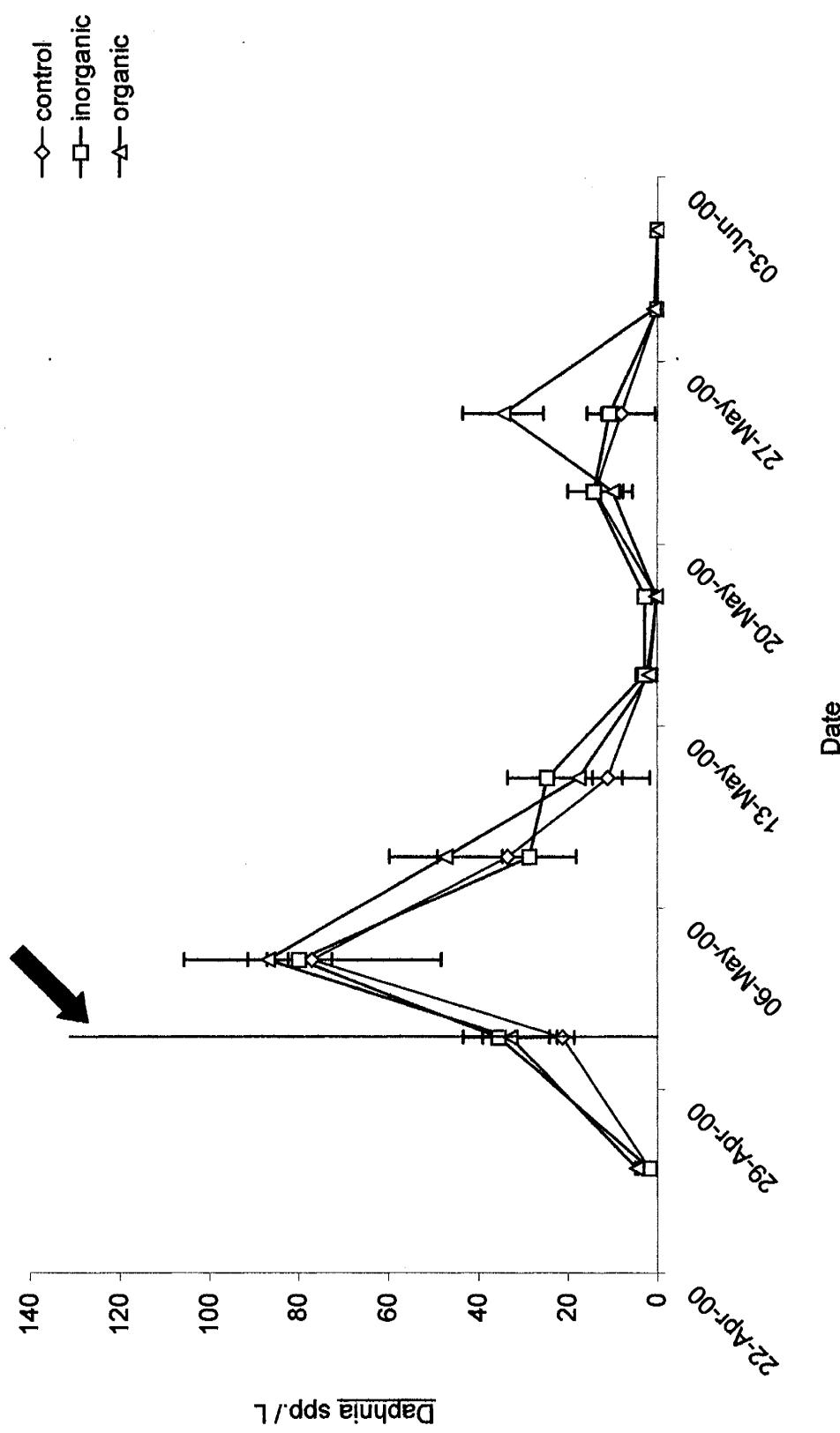


Figure 2.4. *Daphnia* spp. densities in plastic-lined walleye culture ponds receiving no fertilizer (control), alfalfa and cottonseed pellets (organic), and nitrogen and phosphorus (inorganic) during the 2000 walleye fingerling culture season at Rathbun Fish Culture Research Facility, Moravia, Iowa. Black arrow indicates day larval walleye were stocked.

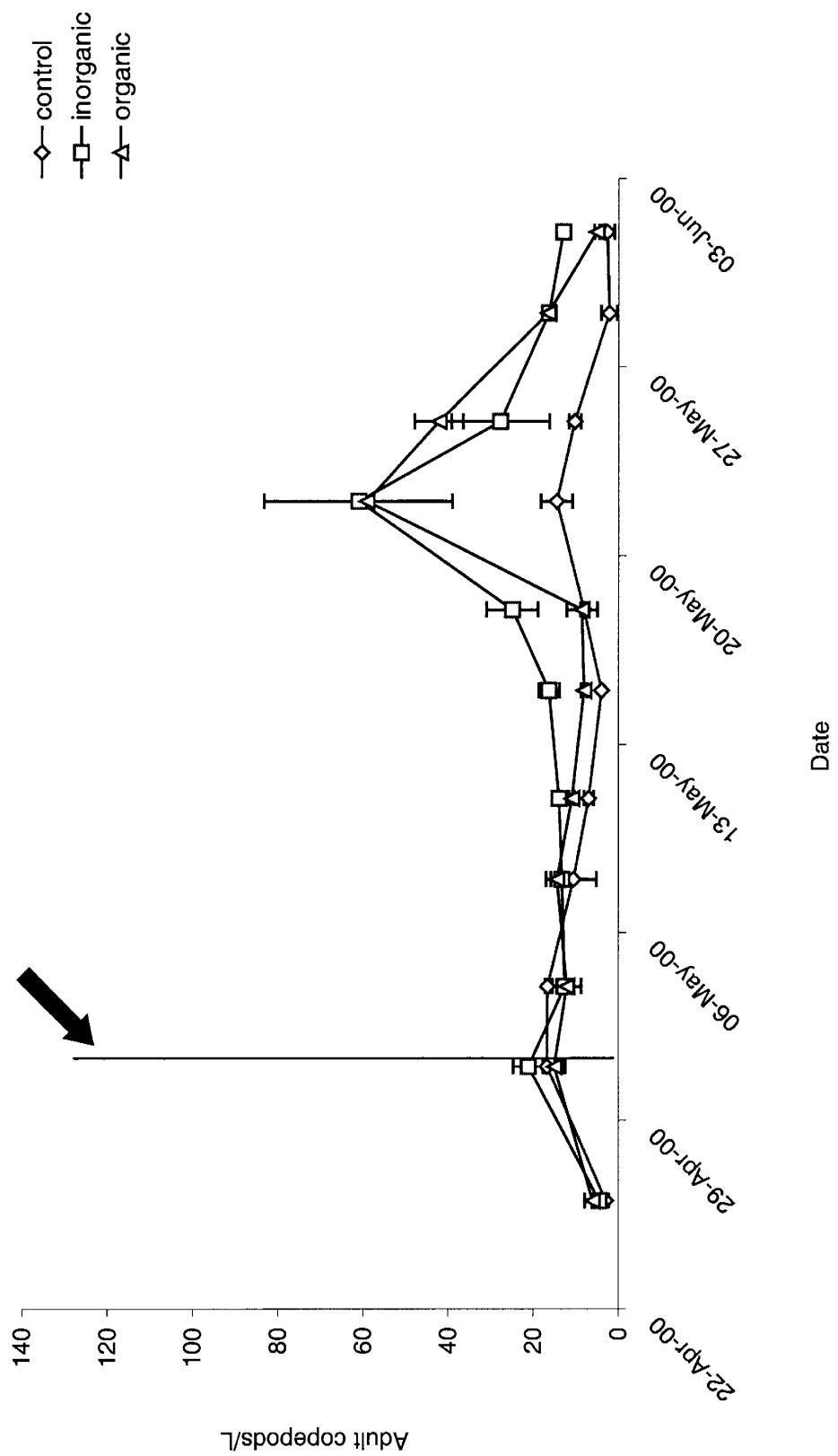


Figure 2.5. Adult copepod densities in plastic-lined walleye culture ponds receiving no fertilizer (control), alfalfa and cottonseed pellets (organic), and nitrogen and phosphorus (inorganic) during the 2000 walleye fingerling culture season at Rathbun Fish Culture Research Facility, Moravia, Iowa. Black arrow indicates day larval walleye were stocked.

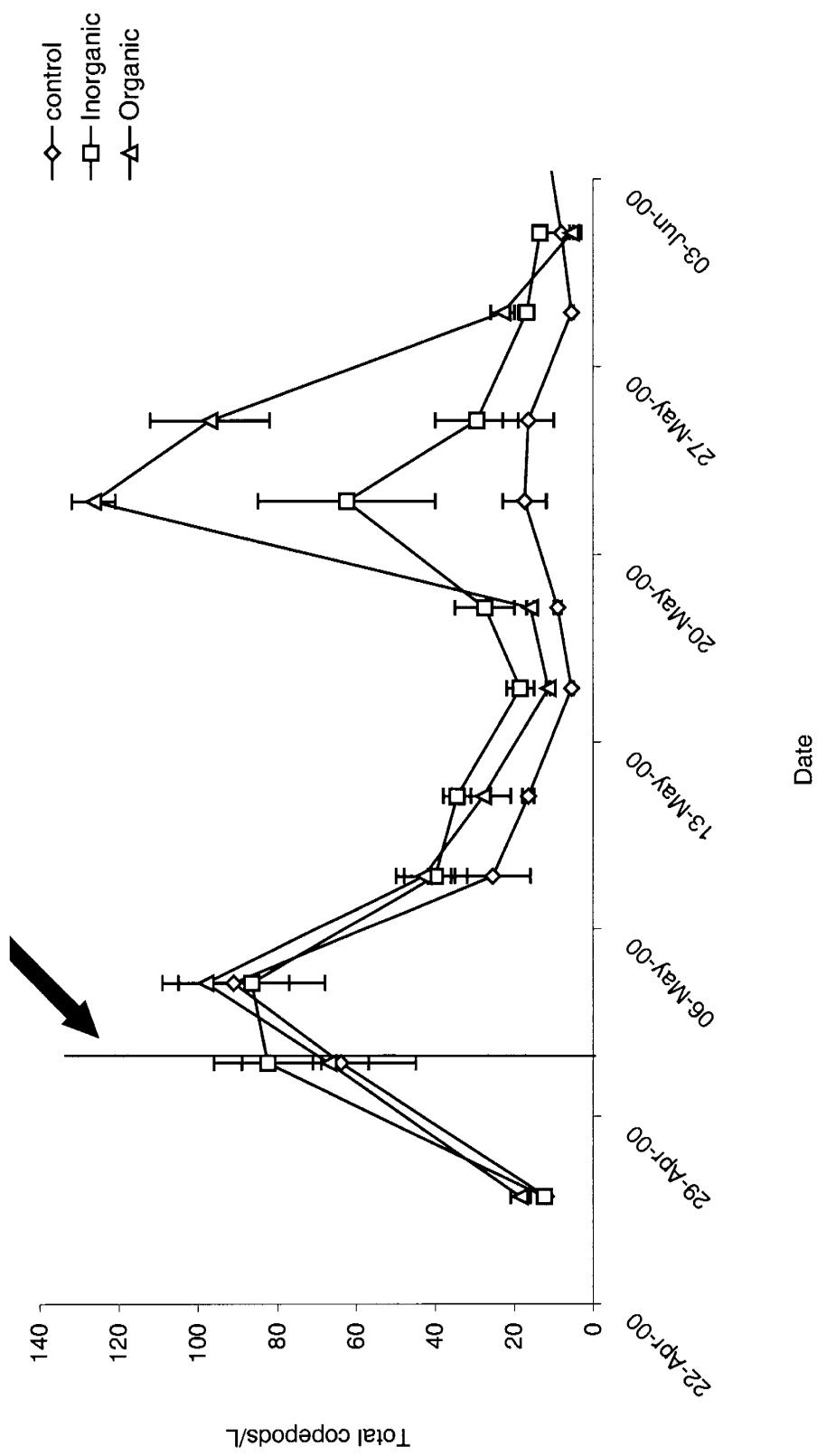


Figure 2.6. Total copepod (adult and copepodite stages) densities in plastic-lined walleye culture ponds receiving no fertilizer (control), alfalfa and cottonseed pellets (organic), and nitrogen and phosphorus (inorganic) during the 2000 walleye fingerling culture season at Rathbun Fish Culture Research Facility, Moravia, Iowa. Black arrow indicates day larval walleye were stocked.

(1991), Tice et al. (1996), and Soderberg et al. (1997). Harding and Summerfelt (1993) had higher survival (61-69%) in control and organically treated ponds; however, mean weights did not exceed 0.47 g (2,127 fish/kg). Qin and Culver (1992) reported increased walleye fingerling mortality in relation to low dissolved oxygen levels; however, lower dissolved oxygen in organically treated ponds did not foster a significantly lower survival percentage.

Table 2.2. Means ( $\pm$  SEM) and mean differences of benthic invertebrate densities in plastic-lined walleye culture ponds receiving no fertilizer (control), alfalfa and cottonseed pellets (organic), and nitrogen and phosphorus (inorganic) during the 2000 walleye fingerling culture season at Rathbun Fish Culture Research Facility, Moravia, Iowa.

Treatment	Treatment means (organisms/m <sup>2</sup> ) (N=3)	Mean difference from
		organic treatment
Control	756 (459.5)	2395 (P = 0.0688)
Inorganic	1199 (419.5)	1952 (P = 0.1016)
Organic	3151 (459.5)	—

Table 2.3. Mean ( $\pm$  SEM) length, weight, survival, and fish/kg of walleyes cultured in plastic-lined walleye culture ponds receiving no fertilizer (control), alfalfa and cottonseed pellets (organic), and nitrogen and phosphorus (inorganic) during the 2000 walleye fingerling culture season at Rathbun Fish Culture Research Facility, Moravia, Iowa.

Treatment	Final length, mm	Final weight, g	Survival %	Fish/kg
Control	32.3	0.21	29	4991
<u>N</u> =200	(1.4)	(0.050)	(2.3)	(466.1)
Inorganic	40.7	0.42	30	2410
<u>N</u> =200	(1.4)	(0.050)	(2.3)	(466.1)
Organic	48.5	0.69	24	1468
<u>N</u> =200	(1.4)	(0.050)	(2.3)	(466.1)

Table 2.4. Treatment mean differences for length, weight, survival, and fish/kg for walleyes cultured in plastic-lined walleye culture ponds receiving no fertilizer (control), alfalfa and cottonseed pellets (organic), and nitrogen and phosphorus (inorganic) during the 2000 walleye fingerling culture season at Rathbun Fish Culture Research Facility, Moravia, Iowa.

Treatment	Length mean	Weight mean	Survival mean	Fish/kg mean
Comparison	difference (mm)	difference (g)	difference (%)	difference
Control/ Inorganic	8.5 ( $P = 0.0438$ )	0.21 ( $P = 0.1138$ )	1 ( $P = 0.9161$ )	2581 ( $P = 0.0591$ )
Control/ Organic	16.2 ( $P = 0.0071$ )	0.49 ( $P = 0.0126$ )	4 ( $P = 0.4541$ )	3523 ( $P = 0.0259$ )
Inorganic/ Organic	7.8 ( $P = 0.0543$ )	0.28 ( $P = 0.0586$ )	6 ( $P = 0.3153$ )	942 ( $P = 0.4328$ )

Final mean weights were different among all treatments with organic fertilization producing the largest animals similar to results by Johnson and Schlosser (1991), Harding and Summerfelt (1993), and Tice et al. (1996). This suggests organic fertilization provided more desirable food items for larval walleye, meaning organic fertilizer is better than inorganic or no fertilizer in plastic-lined ponds. The mean weight of fish from inorganically treated ponds in our study was 0.42 g, similar to Qin and Culver (1992), Qin and Culver (1995), and Qin et al. (1995). The goal in this study calls for a mean weight of about 0.57 g

or 1,760 fish/kg, which was only achieved in the organically treated ponds. The goal of 50% survival was not achieved in any treatment.

Qin and Culver (1992) recommended inorganic fertilizer over a mix of inorganic and organic because of higher survival rates; however, the mixed treatment produced larger fish. Qin et al. (1995) recommended a stocking rate of 250,000 fish/ha and inorganic fertilizer when fish size was important, but the largest fish from these ponds did not yield 1,760 fish/kg. Final mean weights of walleyes in their studies were 0.4-0.5 g, which equals 2,500 – 2,000 fish/kg, a size too small for our production goals. Qin and Culver (1995) produced large walleye fingerlings (about 0.7 g) using only inorganic fertilizer, but the larvae were stocked at 10 fish/m<sup>3</sup>, which is equal to approximately 91,000 fish/ha, less than half our stocking rate. Fish stocked at a higher density of 50 fish/m<sup>3</sup> (about 450,000 fish/ha) only grew to about 0.35-0.40 g.

Soderberg et al. (1997) found no significant differences in final length, final weight, or survival of walleye between organic and inorganic fertilizer treatments. Tice et al. (1996) found similar results, except final mean weights were higher in organically treated ponds. However, inorganic fertilizer was recommended in both studies because of lower costs in labor and materials. Once again, fish from these studies did not yield ≤ 1760 fish/kg. Inorganic fertilizer may be cheaper on a per application basis, but materials and time needed to determine and monitor nutrient levels may quickly close the gap on cost.

Fox et al. (1989) stocked ponds at 437,500 fish/ha and produced fish between 0.45 and 0.99 g with survival ranging from 19-53% using organic fertilizer during a 55-59 d culture period. Fox et al. (1992) stocked larval walleye at 30/m<sup>3</sup> (about 255,000 fish/ha) and

produced 0.486 g fish in ponds treated with organic fertilizer and 0.933 g fish in ponds treated with both organic and inorganic fertilizers during a culture period of 41-42 d. Survival was 49.3% and 35.9% for control and mixed fertilizer ponds, respectively.

Further work with plastic-lined ponds is important to determine if a mix of organic and inorganic fertilizers can or should be used for walleye fingerling culture in plastic-lined ponds. Fox et al. (1992) produced 0.99 g fish in earthen ponds during a 41-42 d study using a mix of organic and inorganic fertilizers. Qin and Culver (1992) found a mix of fertilizers produced lower walleye survival rates than inorganics in earthen ponds, possibly because of increased ammonia levels or lower dissolved oxygen concentrations in mixed fertilizer ponds. Fertilizer mixes have worked well with striped bass culture. Barkoh (1996) found an organic and inorganic mix produced striped bass with higher mean weights in plastic-lined ponds when compared to organic fertilizer; however, survival was lower in the mixed fertilizer ponds. Geiger (1983) reported increased striped bass production in earthen ponds using an organic and inorganic mix rather than organics alone.

An important question is how different are lined ponds from earthen ponds in terms of nutrient needs? Earthen ponds may lose a great deal of dissolved nutrients in the water through precipitation or macrophyte uptake, thereby needing more inorganic fertilizer; plastic lining will prevent leaching and rooted macrophytes, requiring less inorganic fertilizer. Earthen ponds do not need as much supplemental organic carbon added; relative to lined ponds, there is an abundant supply of organic material in the sediment, so there needs to be more control over inorganic nutrients. In plastic-lined ponds, the lack of sediment multiplies the need for supplemental organic material. It is important to maintain a sediment base in

ponds for colonization by benthic invertebrates to provide a food source for walleye fingerlings once zooplankton populations crash or fish seek a larger prey item.

#### Acknowledgments

We would like to thank Iowa Department of Natural Resources (grant number 1434-HQ-97-RU-01560) for financial and technical support during this study. We sincerely thank Ryan Lane, Greg Bond, and Andy Fowler for their technical support, as well as staff of the Rathbun Fish Culture Research Facility.

#### Literature Cited

- APHA (American Public Health Association), American Water Works Association, and Water Pollution Control Federation. 1998. Standard methods for the examination of water and wastewater, 17<sup>th</sup> edition. American Public Health Association, Washington, DC, USA.
- Barkoh, A. 1996. Effects of three fertilization treatments on water quality, zooplankton, and striped bass fingerling production in plastic-lined ponds. The Progressive Fish-Culturist 58:237-247.
- Barkoh, A., M. Stacell, and D. Smith. 1996. Efficacy of two organic fertilizers for production of Florida largemouth bass fingerlings in plastic-lined ponds. Management Data Series No. 129, Texas Parks & Wildlife, Austin, Texas, USA.
- Boyd, C. E. 1990. Water quality in ponds for aquaculture. Birmingham Publishing Company, Birmingham, Alabama, USA.

- Buurma, B. J., A. Barkoh, and G. A. Alexander. 1996. Effects of cottonseed and alfalfa meals as fertilizers on production of palmetto bass (Morone saxatilis x M. chrysops) fingerlings in plastic-lined ponds. *Journal of Applied Aquaculture* 6(3):59-70.
- Conover, M. C. 1986. Stocking cool-water species to meet management needs. Pages 31-39 in. R. H. Stroud, editor. *Fish culture in fisheries management*. American Fisheries Society, Fish Culture Section and Fisheries Management Section, Bethesda, Maryland, USA.
- Culver, D. A, and M. C. Geddes. 1993. Limnology of rearing ponds for Australian fish larvae: relationships among water quality, phytoplankton, zooplankton, and the growth of larval fish. *Australian Journal of Marine and Freshwater Research* 44:537-551.
- Flowers, D. D. 1996. Fingerling production in drainable ponds at White Lake Fish Culture Station. Pages 123-128 in R. C. Summerfelt, editor. *Walleye culture manual*. NCRAC Culture Series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames, Iowa, USA.
- Fox, M. G., and D. D. Flowers. 1990. The effect of fish density on growth, survival and production of juvenile walleye in rearing ponds. *Transactions of the American Fisheries Society* 119:112-121.
- Fox, M. G., D. D. Flowers, and C. Watters. 1992. The effect of supplementary inorganic fertilization on juvenile walleye (Stizostedion vitreum) reared in organically fertilized ponds. *Aquaculture* 106:27-40

- Fox, M. G., J. A. Keast, and R. J. Swainson. 1989. The effect of fertilization regime on juvenile walleye growth and prey utilization in rearing ponds. *Environmental Biology of Fishes* 26:129-142.
- Geiger, J. G. 1983. Zooplankton production and manipulation in striped bass rearing ponds. *Aquaculture* 35:331-351.
- Harding, L. M., and R. C. Summerfelt. 1993. Effects of fertilization and of fry stocking density on pond production of fingerling walleye, *Stizostedion vitreum*. *Journal of Applied Aquaculture* 2(3/4):59-79.
- Hester, F. E., and J. S. Dendy. 1962. A multi-plate sampler for aquatic macro-invertebrates. *Transactions of the American Fisheries Society* 91:420-421.
- Johnson, S. R., and I. J. Schlosser. 1991. Effects of organic enrichment on zooplankton abundance and walleye fry growth and survival in artificial rearing ponds. *Journal of Freshwater Ecology* 6(3):315-321.
- Kriofske, K. P. 1990. Evaluation of pond liners. Mid-continent warmwater fish culture workshop, Council Bluffs, Iowa, USA.
- Mischke, C. C. 1999. Fertilization of walleye production ponds. Ph.D. Dissertation. Iowa State University, Ames, Iowa, USA.
- Myers, J. J., R. W. Soderberg, J. M. Kirby, and M. T. Marcinko. 1996. Production of walleye, *Stizostedion vitreum*, in earthen ponds fertilized with organic and inorganic fertilizers and stocked at three rates. *Journal of Applied Aquaculture* 6(2):11-19.

- Paragamian, V. L., and R. Kingery. 1992. A comparison of walleye fry and fingerling stockings in three rivers in Iowa. North American Journal of Fisheries Management 12:313-320.
- Parmley, D. C., and J. G. Geiger. 1985. Research and development communications: succession patterns of zooplankton in fertilized culture ponds without fish. The Progressive Fish Culturist 47(3):183-186.
- Pennak, R. W. 1989. Freshwater invertebrates of the united states, 3<sup>rd</sup> edition. John Wiley & Sons Incorporated, New York, New York, USA.
- Pinckney, J. L., D. F. Millie, K. E. Howe, H. W. Paerl, and J. P. Hurley. 1996. Flow scintillation counting of <sup>14</sup>C-labeled microalgal photosynthetic pigments. Journal of Plankton Research 18:1867-1880.
- Qin, J., and D. A. Culver. 1992. The survival and growth of larval walleye, Stizostedion vitreum, and the trophic dynamics in fertilized ponds. Aquaculture 108:257-276.
- Qin, J., and D. A. Culver. 1995. Effect of young-of-the-year walleye (Percidae: Stizostedion vitreum) on plankton dynamics and water quality in ponds. Hydrobiologia 297:217-227.
- Qin, J., S. P. Madon, and D. A. Culver. 1995. Effect of larval walleye (Stizostedion vitreum) and fertilization on the plankton community: implications for larval fish culture. Aquaculture 130:51-65.

- Soderberg, R. W., J. M. Kirby, D. Lunger, and M. T. Marcinko. 1997. Comparison of organic and inorganic fertilizers for the pond production of walleye, *Stizostedion vitreum*. Journal of Applied Aquaculture 7(2):23-29.
- Soderberg, R. W., J. M. Kirby, and M. T. Marcinko. 2000. Lack of response of juvenile walleyes to increased levels of fertilization of liming in soft-water ponds. North American Journal of Aquaculture 62:26-32.
- Soderberg, R. W., and M. T. Marcinko. 1999. Substitution of granular for liquid fertilizers for the production of juvenile walleye, *Stizostedion vitreum*, in earthen ponds. Journal of Applied Aquaculture 9(4):33-40.
- Summerfelt, R. C., C. P. Clouse, and L. M. Harding. 1993. Pond production of fingerling walleye, *Stizostedion vitreum*, in the northern Great Plains. Journal of Applied Aquaculture 2(3/4):33-58.
- Tice, B. J., R. W. Soderberg, and J. M. Kirby. 1996. Growth and survival of walleyes reared in ponds fertilized with organic or inorganic materials. The Progressive Fish-Culturist 58:135-139.

## CHAPTER 2. FERTILIZATION REGIMENS FOR FINGERLING WALLEYE STIZOSTEDION VITREUM CULTURE IN PLASTIC-LINED PONDS

A paper to be submitted to North American Journal of Aquaculture

Matthew L. Rogge, Alan. A. Moore, and Joseph E. Morris

### Abstract

Organic fertilizer was compared to a mix of organic and inorganic fertilizers for the culture of walleye Stizostedion vitreum fingerlings in plastic-lined ponds. Organic fertilization consisted of weekly additions of alfalfa and cottonseed pellets. Each type of organic fertilizer was applied at 2.3 kg/pond/week. Nitrogen (36-0-0) and phosphorus (12-49-6) were used weekly to adjust nitrate-nitrogen to total phosphorus ratios ( $\text{NO}_3\text{-N}:\text{TP}$ ) to 7:1 in the mixed-fertilizer treatment. Organically treated ponds had similar nutrient values when compared to the organic/inorganic mix; however, water used to fill ponds was initially high in both nitrogen and phosphorus, which may have reduced nutrient differences between treatments. Bottom dissolved oxygen levels were sometimes below 1 mg/L in the morning in both treatments; however, this had no apparent effect on survival in either treatment.

Daphnia species (spp.) and copepod populations sharply declined in both treatments following fish stocking, indicating larval walleye immediately fed on small crustaceans. Benthic invertebrate densities were high throughout the season in both treatments with no differences between them. Stomach content analyses revealed walleye fingerlings consumed Daphnia spp. and copepods throughout the season, with dipteran larvae becoming increasingly important once walleyes were >20 mm. Both fertilization treatments produced large fish (< 1760 fish/kg) with good survival (> 50%). Results from this study suggest

benthos management is important for providing food items for larval walleye, and high nutrient influx from water sources may reduce the requirement for inorganic enrichment in fingerling walleye plastic-lined culture ponds.

### Introduction

Many government agencies are constructing plastic-lined ponds in place of earthen ponds for larval fish culture. Perceived benefits of plastic-lined ponds include elimination of rooted aquatic macrophytes, less water loss by percolation, and ease of harvest (Kriofske 1990). Unfortunately, lining also provides a barrier against essential nutrients useful in food webs. Therefore, fertilization becomes more critical in plastic-lined ponds.

In 1999, Iowa Department of Natural Resources constructed ten 0.4 ha plastic-lined production ponds and six plastic-lined 0.04 ha research ponds at Rathbun Fish Culture Research Facility, Moravia, Iowa. Walleye *Stizostedion vitreum* fingerlings are raised in these ponds for stocking into public waters within the state. While numerous fertilization studies have been conducted on earthen ponds used for fish culture, relatively little research has been done on fertilization regimens of plastic-lined ponds (Barkoh 1996; Barkoh et al. 1996; Buurma et al. 1996; Rogge et al. in review). Of these studies, only Rogge et al. (in review) evaluated fertilization regimens for walleye fingerling culture.

Barkoh et al. (1996) found cottonseed meal provided better water quality, phytoplankton density, and fish growth compared to alfalfa meal in largemouth bass *Micropterus salmoides* fingerling culture. However, alfalfa meal facilitated quicker zooplankton population development. Buurma et al. (1996) cultured palmetto bass *Morone saxatilis* X *M. chrysops* in plastic-lined ponds with alfalfa and cottonseed meals and found

similar results to Barkoh et al. (1996) in terms of water chemistry and zooplankton. Barkoh (1996) compared the use of organic fertilizer with two mixes of organic and inorganic fertilizers in striped bass M. saxatilis culture. Ponds treated with organic fertilizers had higher fish survival, but lower growth, suggesting organic fertilization did not produce adequate food sources. Rogge et al. (in review) compared a control (no fertilizer), inorganic, and organic fertilizers for walleye fingerling culture in plastic-lined ponds. Organic fertilization produced larger walleye fingerlings, with no differences in survival. Organically treated ponds also had significantly more benthos, mainly chironomids, in ponds; chironomids have been shown to be important food items to fingerling walleye (Fox et al. 1989; Fox and Flowers 1990; Fox et al. 1992; Summerfelt et al. 1993; Flowers 1996).

Recommendations for fertilization regimens differ among studies. Studies done in earthen ponds suggest using inorganic fertilizer for fingerling walleye culture because of better survival (Qin and Culver 1992; Qin et al. 1995) and less cost (Tice et al. 1996; Soderberg et al. 1997). Fox et al. (1992) found organic fertilization with supplementary inorganic fertilization increased fingerling walleye production. Once again, however, these recommendations are based on earthen ponds. Plastic-lined ponds may require different nutrients than earthen ponds. Rogge et al. (in review) concluded organic fertilization was important in plastic-lined ponds, because the organic matter provided needed substrate and food for benthos.

#### Goals and Objectives

Our goals for this study were to produce  $\leq 1,760$  fish/kg with  $\geq 50\%$  survival. Specific objectives were to 1) compare organic fertilizers to a mix of organic and inorganic

fertilizers, hereafter called “mix” or “mixed” to determine if one regimen facilitates better water quality, an improved food base, and consequently better walleye fingerling production; and 2) evaluate what food items walleye fingerlings prefer.

### Materials and Methods

#### Study site

Six 0.04 ha plastic-lined ponds at the Rathbun Fish Culture Research Facility, Moravia, Iowa were used to compare organic fertilizers to a mix of organic and inorganic fertilizers for walleye fingerling culture. Ponds were randomly assigned a treatment. Each pond was rinsed out following previous culture seasons; however, ponds were not sterilized. Water from Rathbun Lake was used to fill all ponds beginning 16 April 2001; ponds were full 20 April 2001, 12 days prior to stocking. Walleye larvae (3-4 d post-hatch) were stocked 2 May 2001 at 10,000 fish/pond (250,000/ha). A fry counter (Jensorter Model FC2, Jensorter Incorporated, Bend, Oregon) was used to determine fish number.

#### Fertilization

Organic fertilization consisted of weekly applications of alfalfa and cottonseed pellets. Each organic fertilizer was applied to all ponds at a rate of 2.3 kg/pond/wk. Organic fertilization for both treatments began 20 April 2001. A total of six organic applications were used in each pond. Granular phosphorus (12-49-6) or nitrogen (36-0-0) was dissolved and added weekly to each pond in the mixed treatment to maintain a targeted nitrate-nitrogen to total phosphorus ratio ( $\text{NO}_3\text{-N:TP}$ ) of 7:1 (Mischke 1999). Amounts of inorganic fertilizer added were determined by water chemistry analyses. Inorganic fertilization of the mixed treatment began 27 April 2001.

### Sampling methods

Water sampling began 20 April 2001 using a tube sampler to sample the water column. Water quality analyses were conducted twice weekly. A YSI Model 60 pH meter (Yellow Springs, Ohio) was used to record pH at bottom and top levels of each pond. Water chemistry was conducted using a Hach DR/2010 spectrophotometer (Hach, Loveland, CO). Variables analyzed included ammonia-nitrogen ( $\text{NH}_3\text{-N}$ ), nitrite-nitrogen ( $\text{NO}_2\text{-N}$ ),  $\text{NO}_3\text{-N}$ , and TP. Total nitrogen (TN) was measured weekly using second-derivative analyses (Crumpton et al. 1992). Morning (0600 h) and afternoon (1500 h) temperature and dissolved oxygen levels at bottom (1.6 m), middle (0.8 m), and top (0.3 m) of ponds were taken twice per week with a YSI Model 55 Oxygen Meter (Yellow Springs, Ohio).

Water samples were filtered twice weekly for phytoplankton pigment analysis. Samples were analyzed using procedures described by Standard Methods (APHA et al. 1998). Zooplankton samples were taken the same days as water samples using an 80- $\mu\text{m}$  Wisconsin net (Wildco Company, Saginaw, WI). Samples were preserved with chilled formalin and sucrose solution (APHA et al. 1998). Taxonomic keys by Pennak (1989) were used to identify specimens counted in the lab. Hester-Dendy samplers (Hester and Dendy 1962) were used to sample benthic invertebrates. Five sets of samplers were placed into each pond at initiation of the culture season. Each week, one sampler was retrieved from each pond. Benthic invertebrate samples were preserved using buffered formalin for later identification and enumeration.

Fingerling walleye were harvested 5-7 June 2001, resulting in a 34-36 d culture period. Mean lengths and weights were determined from a sample of 100 fish from each

pond. Number of fish harvested was estimated by dividing the total weight harvested by mean fish size.

#### Stomach content analyses

Fish sampling during the first three weeks of the season was done using fry trap samplers described by Summerfelt et al. (1996). Following fry stocking, traps were placed in ponds weekly. The first sample was taken 10 May 2001. Each night, traps were illuminated at 2100 h and retrieved at 2300 h. Fish were sacrificed and preserved in buffered formalin for future stomach content analyses. Traps were ineffective for sampling the third week. During the fourth week, fish were sampled using a seine net. However, due to time and labor constraints, only two ponds were sampled from the organic treatment. During harvest, approximately 30 fish were taken from each pond for gut analyses. Stomach contents were identified to lowest practical taxon and counted. Percent number (%-N) was calculated by dividing number of individuals found in the stomach by total number of food items found each day. Percent occurrence (%-O) was calculated by dividing number of fish with the food item by total number of fish sampled each day. Differences in food selectivity were not compared between treatments. Analyses were done to determine overall feeding strategies.

#### Data analyses

Statistical Analysis Systems version 8.2 (SAS Institute, Inc., Cary, North Carolina) was used for all statistical analyses. The General Linear Model (GLM) was used with the Brown-Forsythe version of the Levene Test to test homogeneity of variance. The Mixed Model was used to determine lsmeans and standard errors and test for significant differences in nutrient concentrations, zooplankton populations, and fish production variables between

treatments. The error term used in treatment comparisons was pond(treatment); the error term for daily comparisons was day\*pond(treatment). Tukey's Honestly Significant Difference (HSD) was used for pairwise comparisons. Significance was set at  $P \leq 0.05$ .

## Results and Discussion

### Fertilizer

In agreement with Rogge et al. (in review), nitrogen was consistently the inorganic nutrient added to ponds in the mixed fertilizer treatment; 6.41 kg 36-0-0 was added, but only 0.18 kg 12-49-6 was used. The amounts of fertilizer needed suggest nitrogen is limiting in plastic-lined ponds, which is probably due to lack of sediment in plastic-lined ponds. Boyd (1990) reported phosphorus quickly binds to clay particles and sediment. By not having phosphorus precipitate out, nitrogen becomes limiting.

### Water Quality

A substantial amount of snowmelt in early spring, and many rainfall events throughout the culture season (Fig. 3.1) may have increased inorganic nutrient loads into all of the culture ponds. This probably lessened observable effects of supplementary inorganic fertilization in the mixed treatment. Initial nutrient levels in ponds were 1.1 mg/L NO<sub>3</sub>-N and 0.13 mg/L TP, an 8.5 NO<sub>3</sub>-N:TP ratio. Compared to values reported by Rogge et al. (in review), these concentrations in incoming water are four and six times greater, respectively, than in 2000. NO<sub>3</sub>-N concentrations started high; however, they quickly decreased and remained relatively stable throughout the season (Fig. 3.2). TN (Fig. 3.3) trends were also similar among treatments until late in the season, when mixed treatment ponds had a higher concentration. TP remained relatively stable throughout the season (Fig. 3.4). Our

supplemental inorganic fertilization regimen did not significantly increase  $\text{NO}_3\text{-N:TP}$  ratio to 7:1, or higher than the organic treatment (Table 3.1). This may be due to an inadequate application technique or too little fertilizer added. However, adding more nitrogen may have increased the amount of toxic unionized ammonia (UIA) or increased pH levels by raising photosynthetic rates. The source of nitrogen in 36-0-0 we used was urea, which quickly reduces to ammonia. Supplemental inorganic fertilization also did not significantly raise chlorophyll *a* concentrations (Fig. 3.5).

There were also no differences in pH or dissolved oxygen concentrations in the current study. Fox et al. (1992) also found no differences in pH or dissolved oxygen when comparing organic fertilizer to a mixed treatment. However, Barkoh (1996) found ponds treated with mixed fertilizers had higher pH than ponds with only organic fertilizer. Qin and Culver (1992) reported low survival correlated with low dissolved oxygen levels in ponds treated with organic fertilizers. However, in the current study, low dissolved oxygen levels (< 3 mg/L) at pond bottom occurred on up to 5 days without significant fingerling losses. Dissolved oxygen concentrations in middle and top levels of the pond did not fall below 4.7 mg/L in any pond, suggesting dissolved oxygen can be low at the bottom without decreasing survival, if upper level dissolved oxygen levels stay at or above appropriate levels.

#### Zooplankton and Benthos

Zooplankton populations were similar between treatments throughout the culture season, in disagreement with Geiger (1983) who found a mix of organic and inorganic fertilizers supported a larger forage base for zooplankton, and subsequently hybrid striped bass when compared to organic fertilization only. Qin and Culver (1992) recommended peak

Table 3.1. Means  $\pm$  SEMs (range), mean differences, and  $P$  values of water quality variables in plastic-lined ponds treated with organic and a mix of organic and inorganic fertilizers during the 2001 walleye fingerling culture period at Rathbun Fish Culture Research Facility, Moravia, Iowa.

Variable	Treatment		Mean Difference	$P$ Value		
	Mix	Organic				
<b>DO (mg/L)</b>						
<b>AM (N=27)</b>						
Bottom	$5.4 \pm 0.51$ (0.4 - 9.7)	$4.5 \pm 0.51$ (0.3 - 9.0)	0.9	1.0000		
Middle	$7.6 \pm 0.51$ (4.8 - 10.9)	$7.1 \pm 0.51$ (4.7 - 10.0)	0.5	1.0000		
Top	$7.7 \pm 0.51$ (5.1 - 10.6)	$7.3 \pm 0.51$ (4.8 - 9.8)	0.4	1.0000		
<b>PM (N=27)</b>						
Bottom	$7.1 \pm 0.42$ (0.2 - 10.7)	$6.7 \pm 0.42$ (0.2 - 10.1)	0.4	0.9862		
Middle	$9.2 \pm 0.52$ (7.6 - 10.6)	$8.9 \pm 0.52$ (6.8 - 10.2)	0.3	0.9984		
Top	$9.4 \pm 0.42$ (7.8 - 11.5)	$9.2 \pm 0.42$ (7.5 - 11.6)	0.2	0.9983		

Table 3.1 (continued).

Chlorophyll a (ng/ml) (N=24)	$18.1 \pm 3.28$ (1.1 - 65.4)	$16.7 \pm 3.21$ (0.3 - 53.1)	1.4	0.7723
pH				
Bottom (N=42)	$8.87 \pm 0.142$ (7.74 - 9.85)	$8.87 \pm 0.142$ (7.68 - 9.92)	0.11	0.9978
Top (N=33)	$9.07 \pm 0.140$ (7.70 - 9.98)	$8.96 \pm 0.140$ (7.65 - 9.92)	0.17	0.6679
Ammonia (mg/L) (N=42)	$0.29 \pm 0.021$ (0.09 - 0.58)	$0.31 \pm 0.021$ (0.08 - 0.67)	0.02	0.6522
Nitrate (mg/L) (N=42)	$0.4 \pm 0.04$ (0 - 1.1)	$0.4 \pm 0.04$ (0 - 1.1)	0.0	0.4501
Total Phosphorus (mg/L) (N=42)	$0.10 \pm 0.008$ (0.03 - 0.31)	$0.10 \pm 0.008$ (0.01 - 0.41)	0.0	0.9553
$\text{NO}_3\text{-N:TP}$ (N=42)	$5.3 \pm 0.62$ (0 - 15.0)	$5.6 \pm 0.62$ (0 - 30.0)	0.3	0.8010
Total Nitrogen (mg/L) (N=21)	$1.90 \pm 0.058$ (1.48 – 2.35)	$1.71 \pm 0.058$ (1.19 – 2.18)	0.19	0.0819
TN:TP (N=21)	$23.7 \pm 1.41$ (12.19 – 41.70)	$21.0 \pm 1.41$ (9.37 – 32.72)	2.7	0.2338

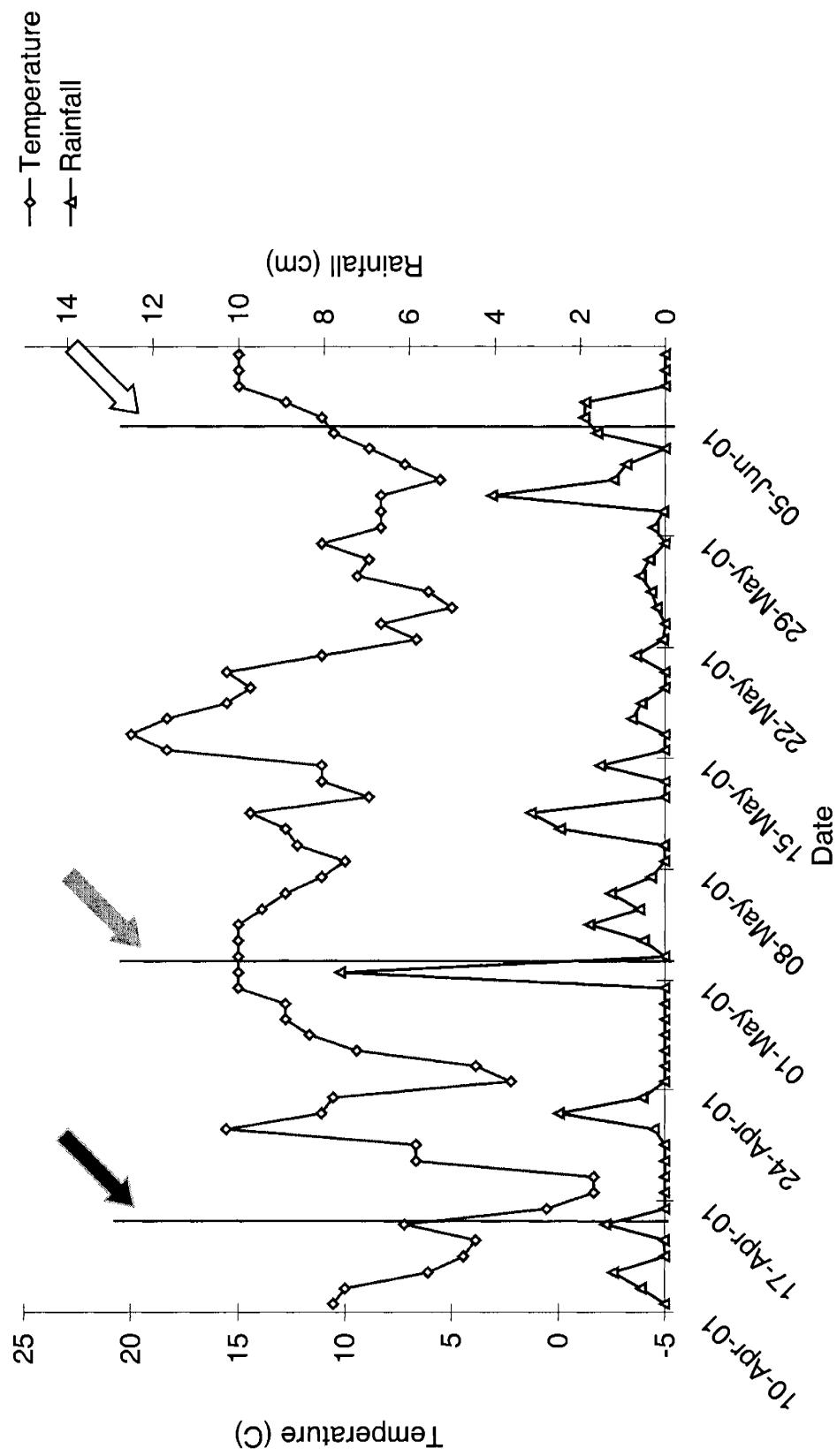


Figure 3.1. Rainfall and temperature during the 2001 walleye culture season at Rathbun Fish Culture Research Facility, Moravia, Iowa. Black arrow indicates pond filling. Gray arrow indicates fish stocking. White arrow indicates approximate harvest dates. Data taken from <http://lwf.ncdc.noaa.gov/servlets/DLY>.

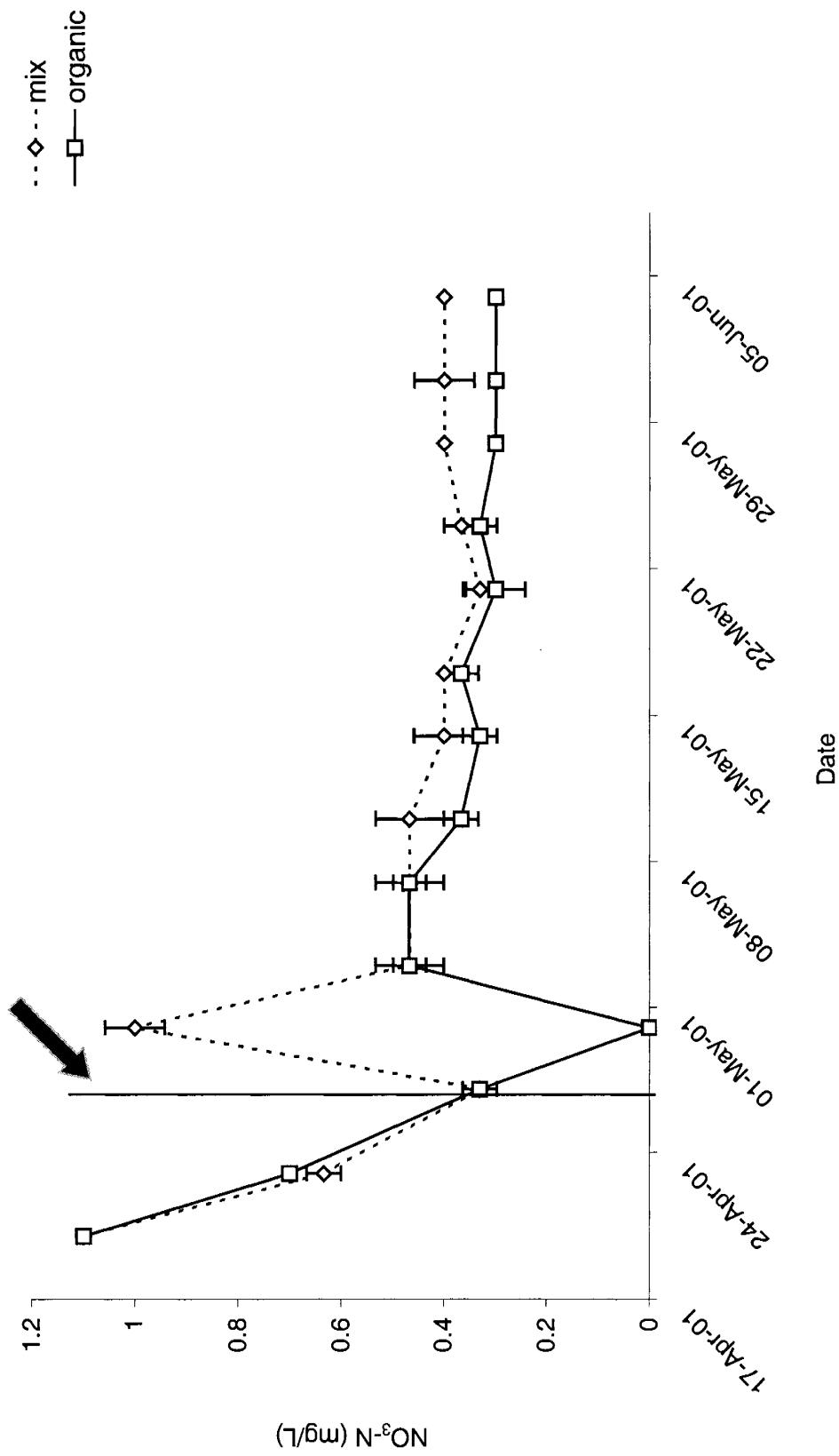


Figure 3.2. Mean nitrate-nitrogen concentrations in plastic-lined walleye culture ponds fertilized with organic and a mix of organic and inorganic fertilizers during the 2001 walleye fingerling culture period at Rathbun Fish Culture Research Facility, Moravia, Iowa. Arrow indicates first inorganic fertilizer application.

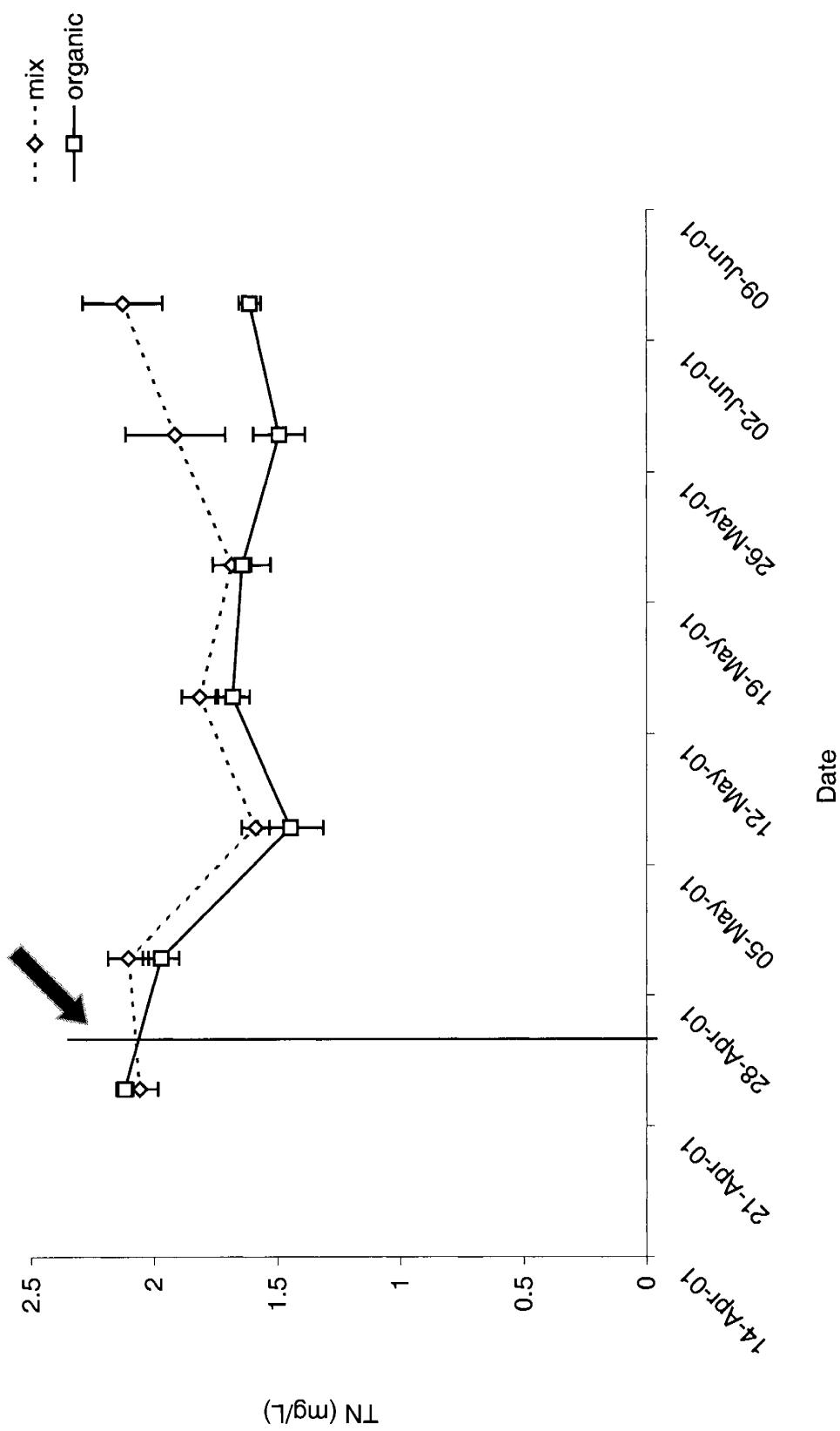


Figure 3.3. Mean total nitrogen concentrations in plastic-lined walleye culture ponds fertilized with organic and a mix of organic and inorganic fertilizers during the 2001 walleye fingerling culture period at Rathbun Fish Culture Research Facility, Moravia, Iowa. Arrow indicates first inorganic fertilizer application.

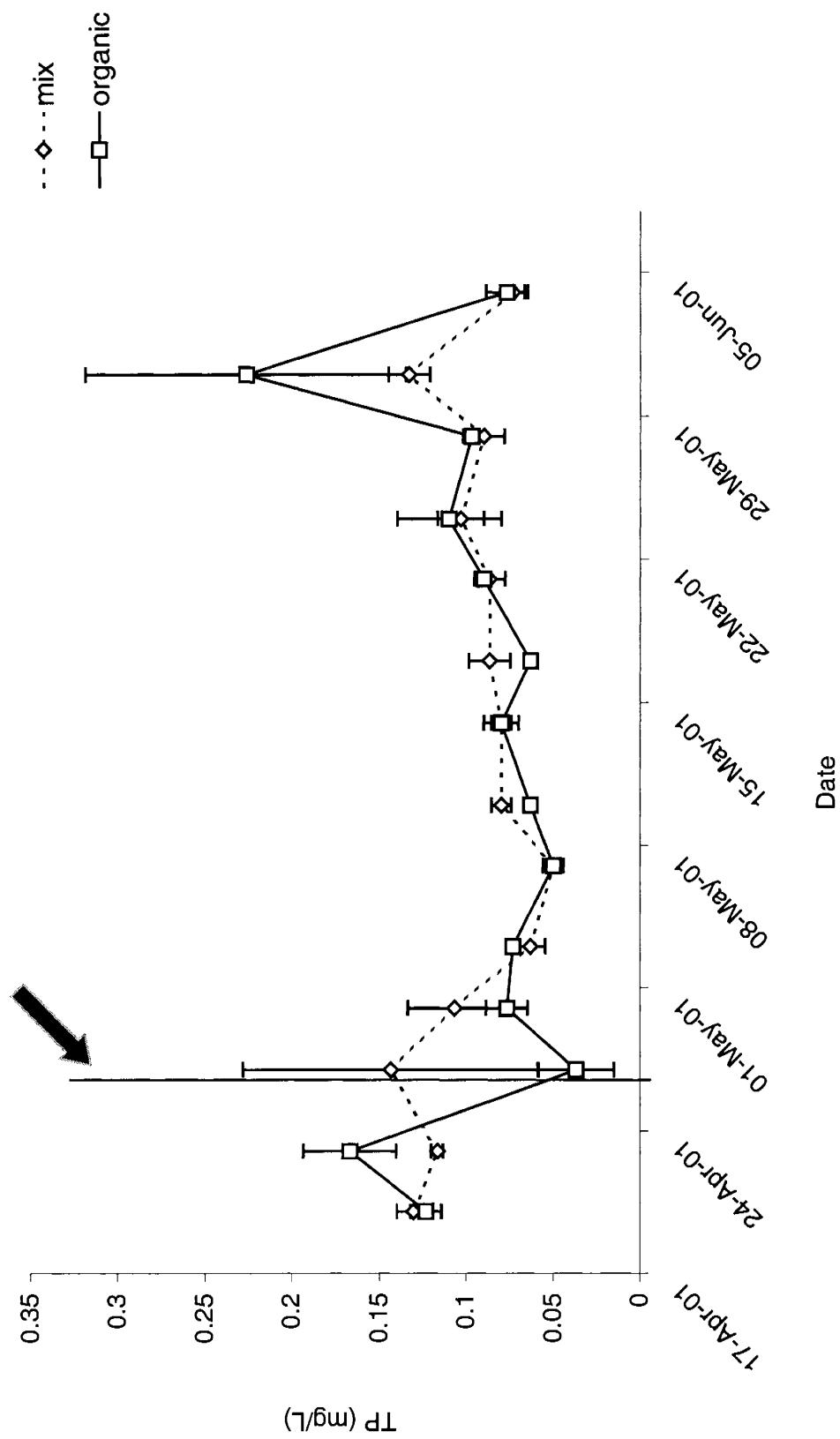


Figure 3.4. Mean total phosphorus concentrations in plastic-lined walleye culture ponds fertilized with organic and a mix of

organic and inorganic fertilizers during the 2001 walleye fingerling culture period at Rathbun Fish Culture Research Facility,

Moravia, Iowa. Arrow indicates first inorganic fertilizer application.

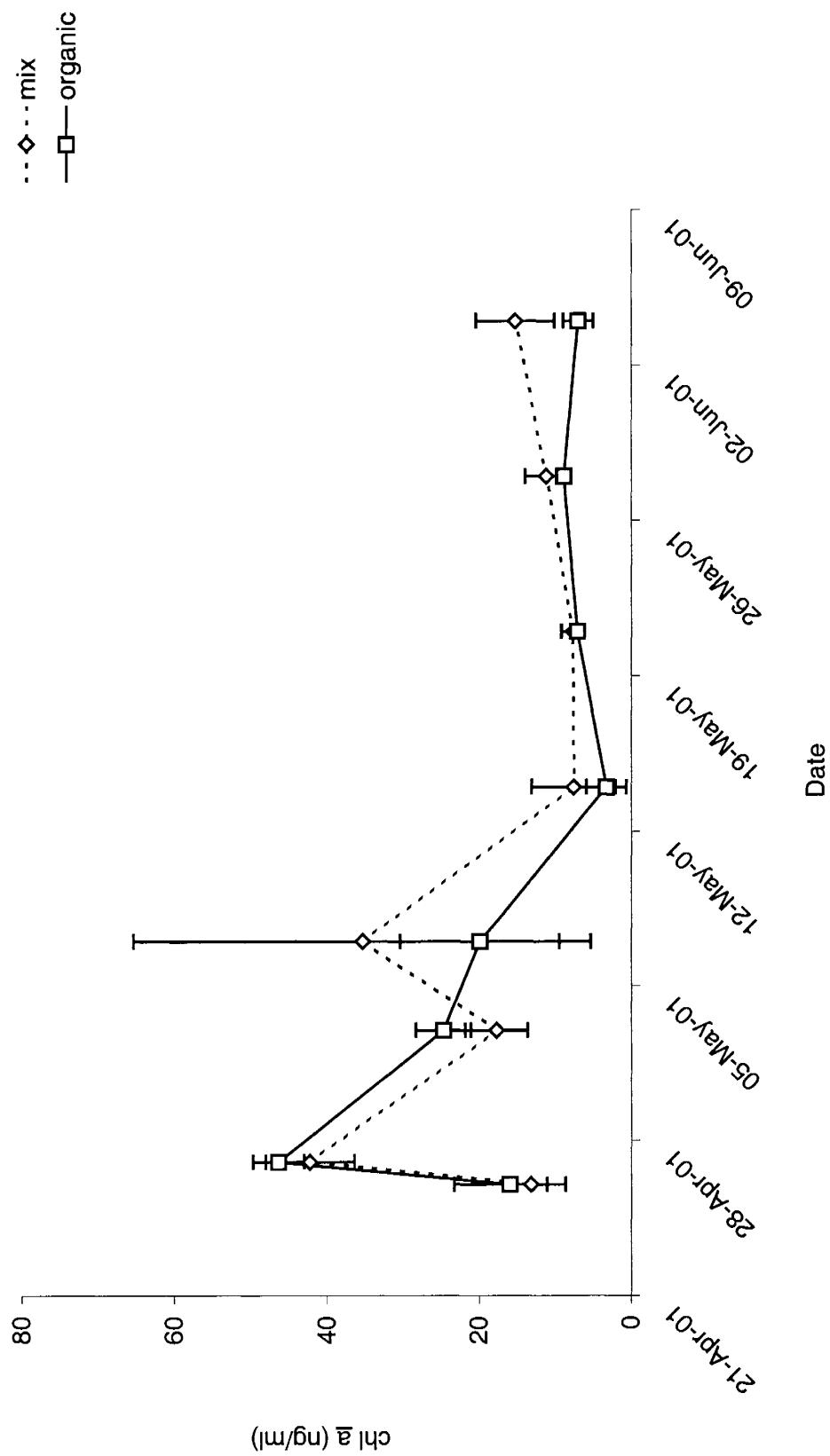


Figure 3.5. Mean chlorophyll  $a$  concentrations in plastic-lined walleye culture ponds fertilized with organic and a mix of organic and inorganic fertilizers during the 2001 walleye fingerling culture period at Rathbun Fish Culture Research Facility, Moravia, Iowa.

zooplankton densities occur after fish stocking, rather than before, to ensure a large forage base for larval walleye. Daphnia spp. populations were highest 3 May 2001, 1 day following fingerling stocking, indicating the fry immediately began feeding on Daphnia spp., a trend also reported by Rogge et al. (in review). Populations steadily declined the rest of the season (Fig. 3.6).

Adult cyclopoid (Fig 3.7) and calanoid (Fig. 3.8) copepods had similar trends in both treatments. Populations peaked shortly after stocking, and then declined. Both calanoids and cyclopoids recovered towards the end of the culture season. The same trend occurred with total copepod (adult and copepodite stages) densities (Fig. 3.9); however, the decline occurred 1 week following stocking, indicating copepods were not heavily fed upon immediately. Declines in zooplankton densities early in the season indicate an early preference for Daphnia spp. and copepods.

Benthic invertebrates were established early in the season in both treatments, with no differences (Fig. 3.10). A majority of the benthic population was comprised of chironomids. High populations of benthic invertebrates are important, because they provide a food source for walleye when zooplankton populations decline (Fox et al. 1989; Fox and Flowers 1990; Summerfelt et al. 1993; Flowers 1996). This was very important for our study, because our goal was to produce a large number of large fish.

Food base densities were dramatically higher in this study than in 2000 (Rogge in review). Daphnia spp. peaked at about 120 organisms/L in 2001 compared to 80 organisms/L in 2000. Total copepods peaked at about 200 organisms/L in 2001, but only to 120 organisms/L in 2000. Benthos densities were also higher in 2001. In 2001, both

treatments began with about 7,000 organisms/m<sup>2</sup>; the highest density in 2000 was only about 3,000 organisms/m<sup>2</sup>. These differences fish prey base could be attributed to increased nutrient loads in 2001. Another explanation is maturation of the system; ponds were rinsed between culture seasons, but not sterilized. In addition, plankton populations in 2001 had more time to mature prior to fry stocking. In 2000, fish were stocked 6 d after ponds were full (Rogge in review). Fish in 2001 were stocked 12 d after ponds were full.

Allan (1976) described typical population dynamics of zooplankton. Rotifers are the first taxon to appear because early maturation and parthenogenetic reproduction allow them to increase numbers quickly. Cladocerans also reproduce parthenogenetically, but do not mature as fast, resulting in longer periods before maximum density. Cladocerans can filter higher volumes of water and out-compete rotifers for food and space; however, cladocerans are preyed upon by many organisms, consequently reducing densities. Copepods only reproduce sexually, taking about 10 d longer to mature than cladocerans. They are the last zooplankton to reach high densities. Geiger (1983) found ponds fertilized 10-14 d before stocking favored development of crustaceans at stocking because of higher numbers of offspring produced and wider range of ingestible food particle size. Parmley and Geiger (1985) found Daphnia spp. reached maximum density 30 d following initial fertilization in fertilized ponds without fish; however, leaving a pond sit for 30 d is not practical for hatchery operations. By having the ponds without fish 5 d longer in 2001, crustacean zooplankton populations had more time to develop, allowing copepods and cladocerans to become the dominant taxa. Having high densities of food early in a fish's life is important so they easily begin exogenous feeding (May 1974).

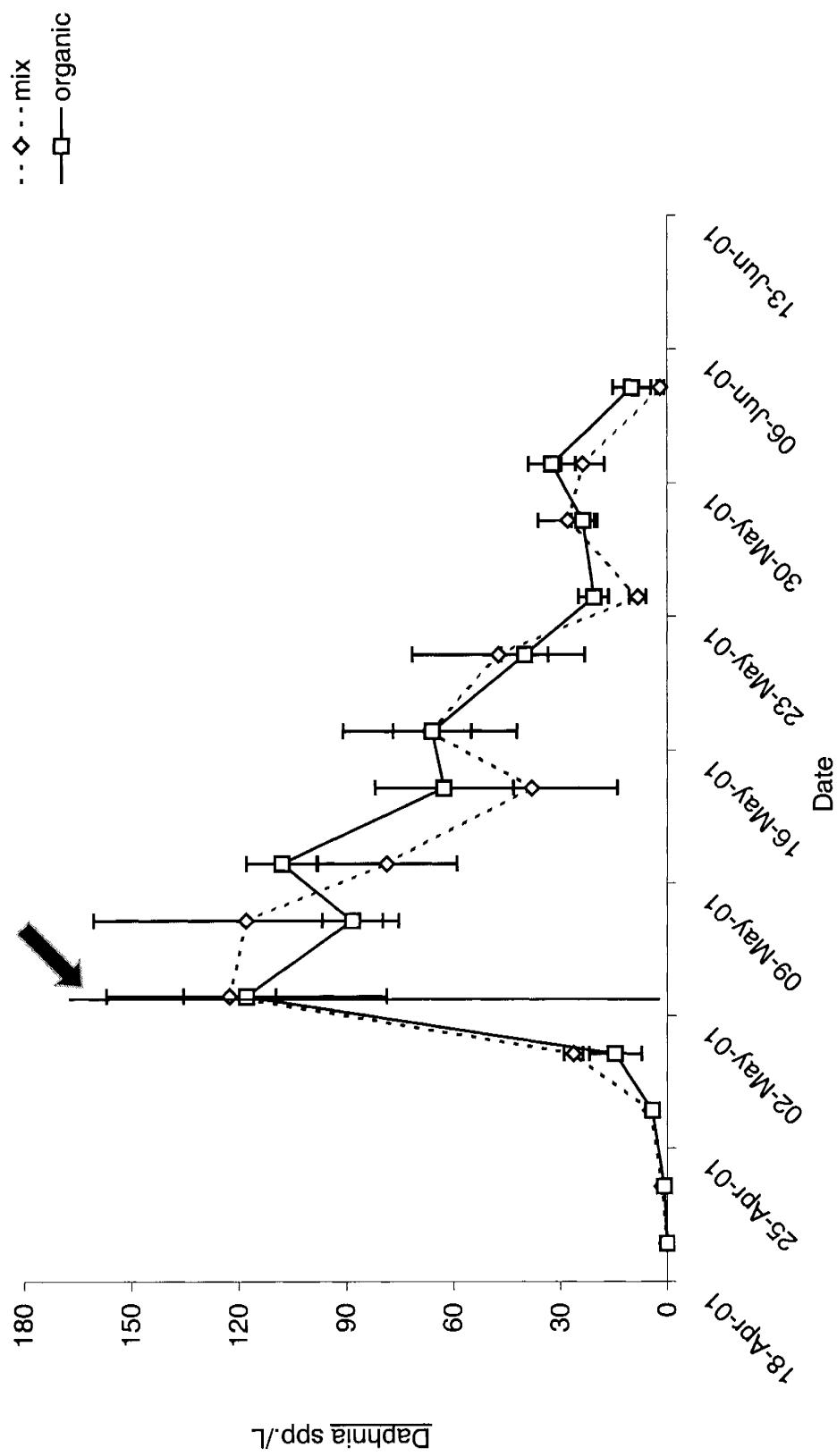


Figure 3.6. *Daphnia* spp. densities in plastic-lined walleye fingerling culture ponds fertilized with organic and a mix of organic and inorganic fertilizers during the 2001 walleye fingerling culture period at Rathbun Fish Culture Research Facility, Moravia, Iowa. Arrow indicates fish stocking.

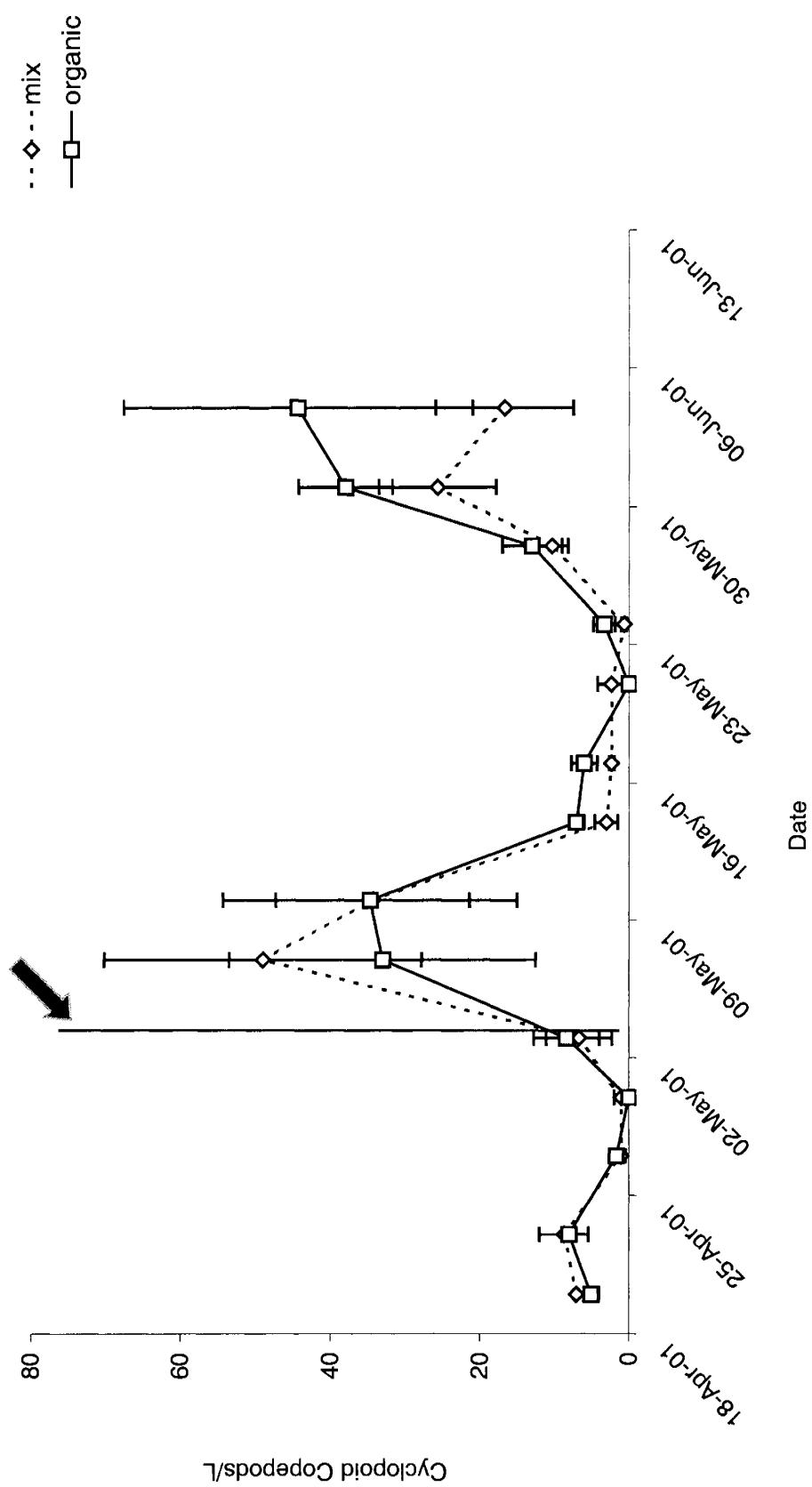


Figure 3.7. Cyclopoid densities in plastic-lined walleye fingerling culture ponds fertilized with organic and a mix of organic and inorganic fertilizers during the 2001 walleye fingerling culture period at Rathbun Fish Culture Research Facility, Moravia, Iowa. Arrow indicates fish stocking.

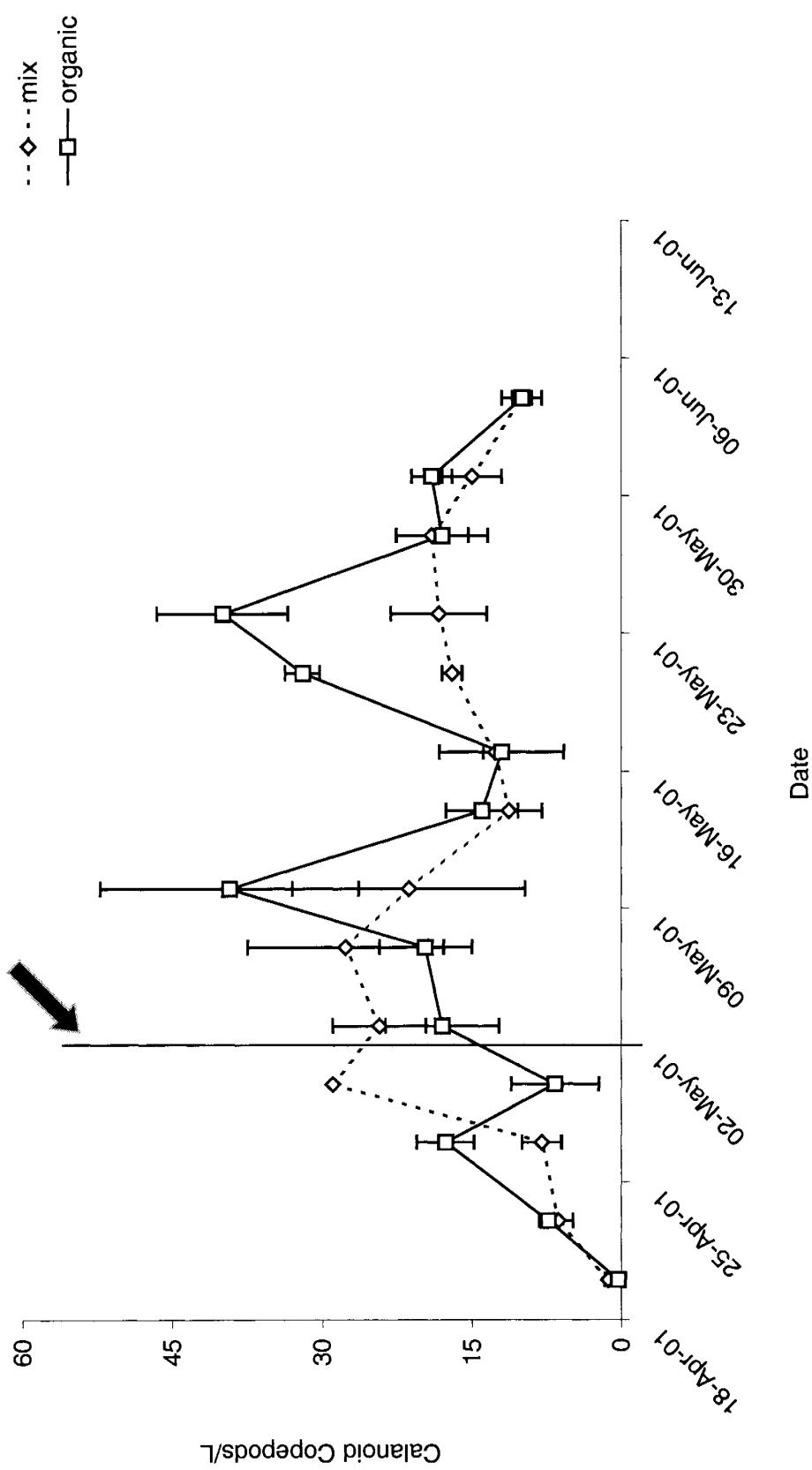


Figure 3.8. Calanoid densities in plastic-lined walleye fingerling culture ponds fertilized with organic and a mix of organic and inorganic fertilizers during the 2001 walleye fingerling culture period at Rathbun Fish Culture Research Facility, Moravia, Iowa. Arrow indicates fish stocking.

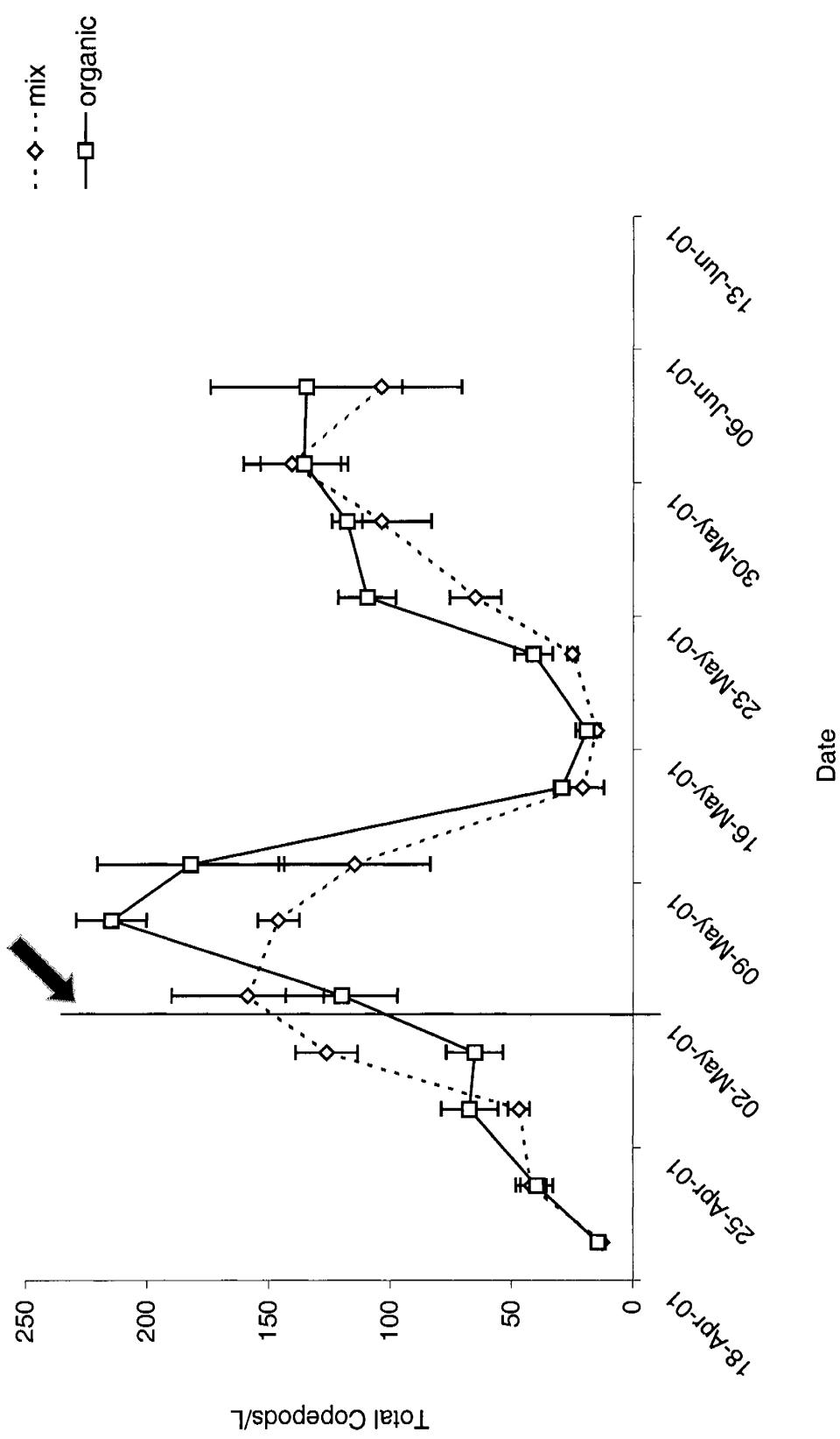


Figure 3.9. Total copepod (adult and copepodite stages) densities in plastic-lined walleye fingerling culture ponds fertilized with organic and a mix of organic and inorganic fertilizers during the 2001 walleye fingerling culture period at Rathbun Fish Culture Research Facility, Moravia, Iowa. Arrow indicates fish stocking.

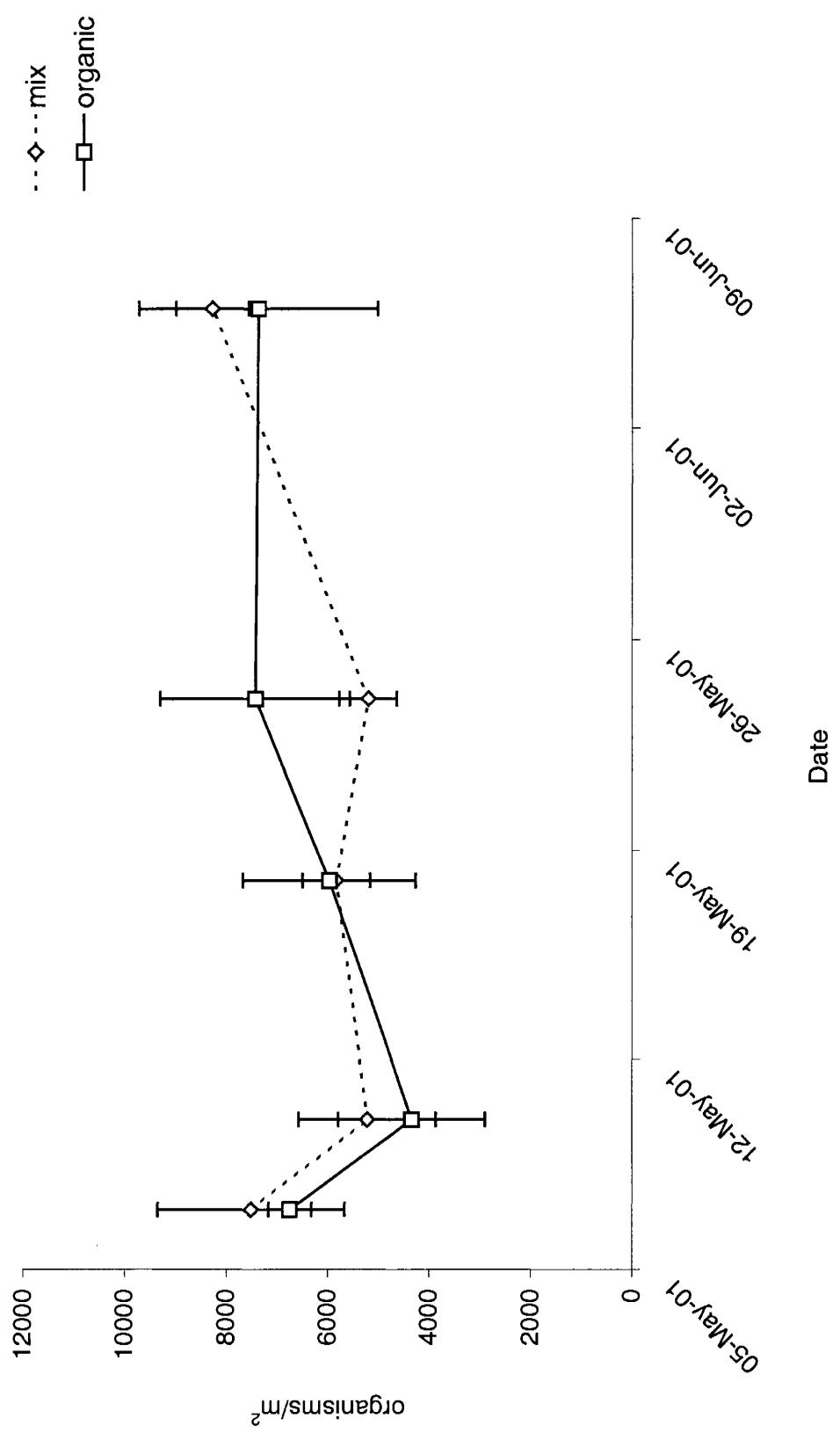


Figure 3.10. Benthic invertebrate densities in plastic-lined walleye fingerling culture ponds fertilized with organic and a mix of organic and inorganic fertilizers during the 2001 walleye fingerling culture period at Rathbun Fish Culture Research Facility, Moravia, Iowa.

### Stomach content analyses

Copepods occurred at high %-O and %-N every week (Figs. 3.11 and 3.12). Daphnia spp. and dipterans also had high %-O and %-N. Rotifers seemed to be relatively unimportant as a food source. Bosmina spp. had low occurrence, but high %-N at the end of the season, probably due to their small size, i.e., more individuals are needed for satiation. Feeding trends of larval walleye can be clearly seen from these data. Daphnia spp. and copepods are preferred early in the season, with insect larvae becoming increasingly important to > 20 mm larval walleye between 2 and 3 weeks post-hatch. Similar selectivity patterns were reported by Fox et al. (1989), Fox and Flowers (1990), Fox et al. (1992), and Summerfelt et al. (1993). Dipterans were found in walleye stomachs as early as 7 May 2001, about 9 d post-hatch.

### Walleye Production

Both organic and mixed treatments resulted in > 50% survival and < 1,760 fish/kg (fish > 0.568 g) (Table 3.2). Barkoh (1996) found plastic-lined ponds treated only with organic fertilizer had higher survival, with no difference in production compared to a mix for the culture of hybrid striped bass fingerlings. Qin and Culver (1992) reported inorganic fertilizer produced better survival, but smaller sizes of walleye fingerlings than an organic and inorganic mix. Low morning dissolved oxygen levels at the bottom of the ponds and significantly higher ammonia levels may have affected survival in that study. During a 41-42 d culture period, Fox et al. (1992) obtained 0.933 g fingerling walleye with 36% survival with a mix of organic and inorganic fertilizers, compared to 0.486 g fish with 49% survival in ponds fertilized with only organic fertilizer.

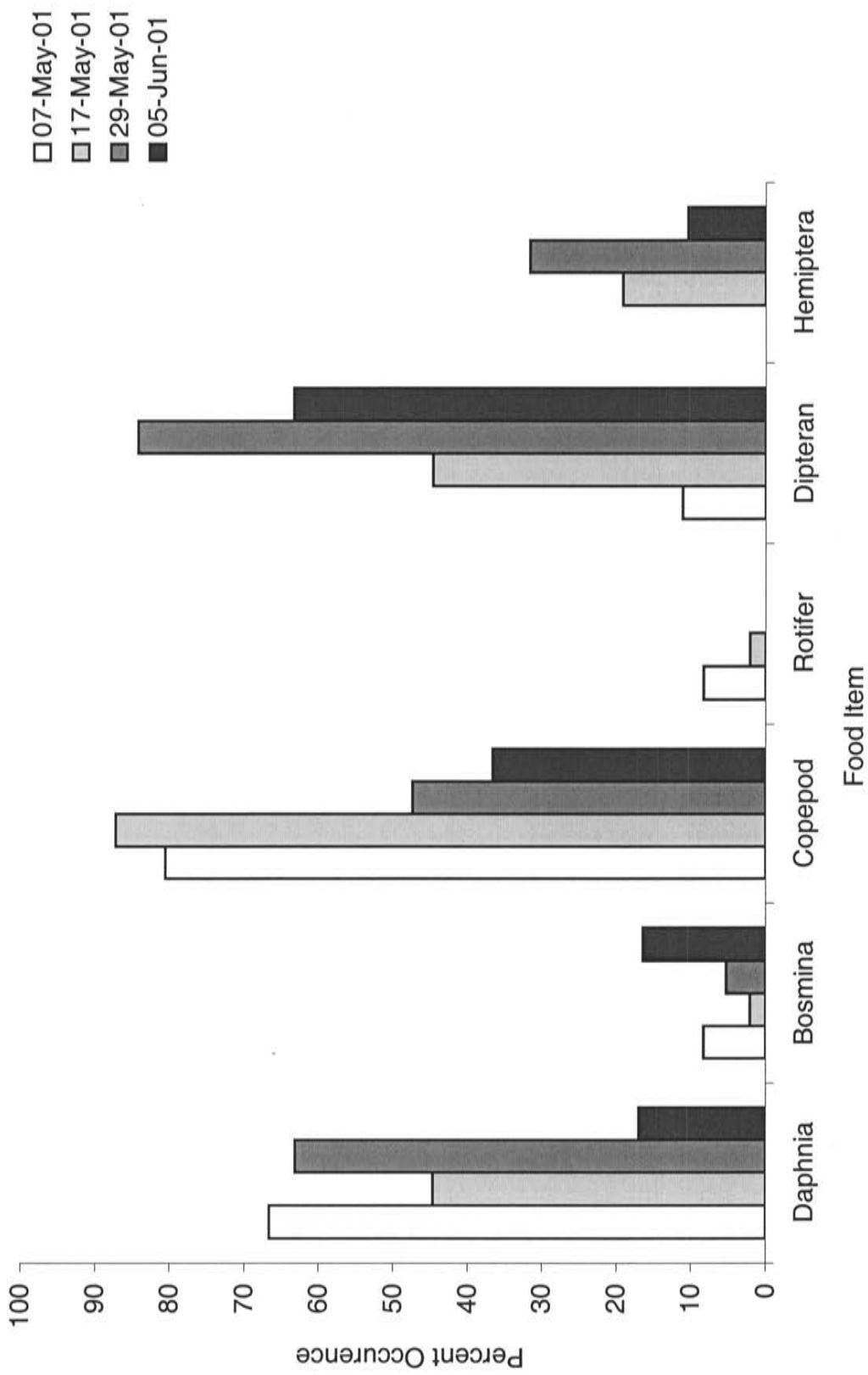


Figure 3.11. Percent occurrence (%-O) of food items taken from fingerling walleye cultured in plastic-lined ponds at Rathbun Fish Culture Research Facility, Moravia, Iowa in 2001.

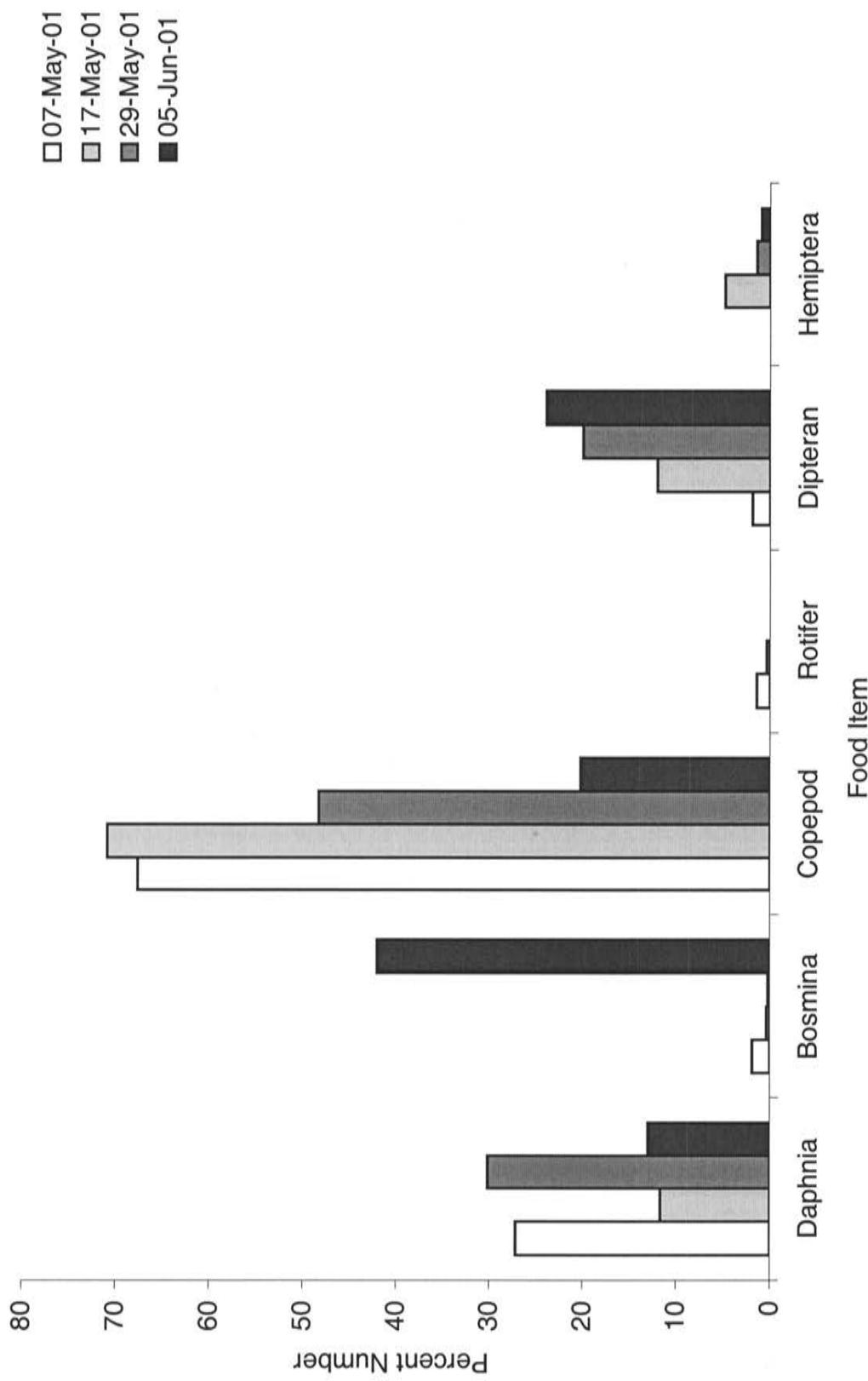


Figure 3.12. Percent number (%-N) of food items taken from fingerling walleye cultured in plastic-lined ponds at Rathbun Fish Culture Research Facility, Moravia, Iowa in 2001.

Table 3.2. Mean  $\pm$  SEM survival, length, weight, and fish/kg of walleyes cultured in plastic-lined ponds fertilized with organic and a mix of organic and inorganic fertilizers during the 2001 walleye fingerling culture season at the Rathbun Fish Culture Research Facility, Moravia, Iowa.

Variable	Treatment mean		<u>P</u> Value
	Mix	Organic	
Survival %	$79 \pm 4.8$	$75 \pm 4.8$	0.5871
Length (mm)	$41.3 \pm 1.01$	$43.9 \pm 1.01$	0.1440
Weight (g)	$0.60 \pm 0.018$	$0.64 \pm 0.018$	0.1418
Fish/kg	$1672 + 46.5$	$1554 \pm 46.5$	0.1469

Few studies evaluating organic fertilization for walleye culture ponds achieved both a fish size and survival percentage to suit our goals. Fox et al. (1989) produced 0.45 to 0.99 g fish with 19-53% survival using organic fertilizer in a 55-59 d culture period. Johnson and Schlosser (1991) achieved 27.6% survival and fish size of 0.235 g. At a stocking rate of 250,000 fish/ha, Qin et al. (1995) achieved 69% survival with a mean fish size of 0.407 g. At a higher stocking rate of 500,000, survival was 58.3%, but fish size was only 0.323 g. Tice et al. (1996) achieved 43% survival and 0.41 g animals. Soderberg et al. (1997) produced 0.33 g fish with survival of 48.8%. Rogge et al. (in review) attained a fish size of 0.69 g; however, survival was only 24%.

A mix of organic and inorganic fertilizers also has not produced desired results. Fox et al. (1992) compared organic fertilization to a mix of organic and inorganic, finding the mix produced fish 0.933 g in weight, but survival was only 35.9%; however, the culture season was 41-42 d. Myers et al. (1996) varied stocking rates and produced 0.51 g, 0.64 g, and 0.60 g fish with 52%, 11%, and 13% survival, respectively. Qin and Culver (1992) produced 0.9 g fish, but only 2.5% survival. Some of these studies produced large fish and others had good survival, but none achieved both.

Studies have shown that, typically, organic fertilization either produces fish of equal or larger size when compared to inorganic fertilizer alone. However, inorganic fertilizers are recommended because of higher survival (Qin and Culver 1992; Qin et al. 1995) or lower perceived cost of inorganic fertilizer (Tice et al. 1996; Soderberg et al. 1997). Rogge et al. (in review) found organic fertilizer produces larger fish with no differences in survival when compared to inorganic fertilizer. Results the current study show no differences between organic and a mix of organic and inorganic, suggesting inorganic fertilization is not needed in plastic-lined ponds. However, the water used to fill the ponds was rich in nutrients, possibly obscuring the need for inorganic nutrients. Rogge et al. (in review) produced large fish with low survival in organically treated ponds; in 2001, nutrient levels were higher, and so was survival. Given these results, it may be beneficial to determine a minimum amount of inorganic nutrients needed in plastic-lined ponds prior to implementation of any subsequent pond fertilization regimen.

Future research on walleye fingerling culture in plastic-lined ponds should include evaluation of weather patterns prior to culture seasons. A major factor in plastic-lined pond

culture of walleye fingerlings may be weather events in early spring that affect incoming water quality. In 2001, there was much snowmelt and rain, increasing runoff into the water supply, Rathbun Lake; Iowa's watersheds are often noted for their high fertility. During pond filling, incoming water in 2001 had 1.1 mg/L NO<sub>3</sub>-N and 0.13 mg/L TP; 2000 incoming water had only 0.3 mg/L NO<sub>3</sub>-N and 0.02 mg/L TP (Rogge et al. in review). High nutrient concentrations may have provided zooplankton with a larger supply of phytoplankton, consequently providing larval fish with more food. In 2000, size of walleye in the organic treatment was similar to sizes in 2001; however, survival was much lower. Both Daphnia spp. and copepod populations were higher following stocking during the 2001 season than during 2000. When the water source is low in nutrients, inorganic fertilizer may be required.

This study and Rogge et al. (in review) show the need for organic fertilizer in plastic-lined ponds. Organic nutrients support zooplankton and benthic invertebrates, providing excellent food sources for young walleye. As fingerling walleye grow, they prey upon larger food items, such as dipteran larvae (Fig. 3.13), there is a need for organic material in the substrate. However, the effects of inorganic fertilization are still unknown.

Colonization of benthos and zooplankton should also be evaluated. Carryover from one season to another could be important in successful larval fish culture in plastic-lined ponds. The effects of cleaning or not cleaning the liner could have a large impact on food sources in subsequent culture seasons; diapause eggs of desirable cladocerans and chironomids may also be rinsed away.

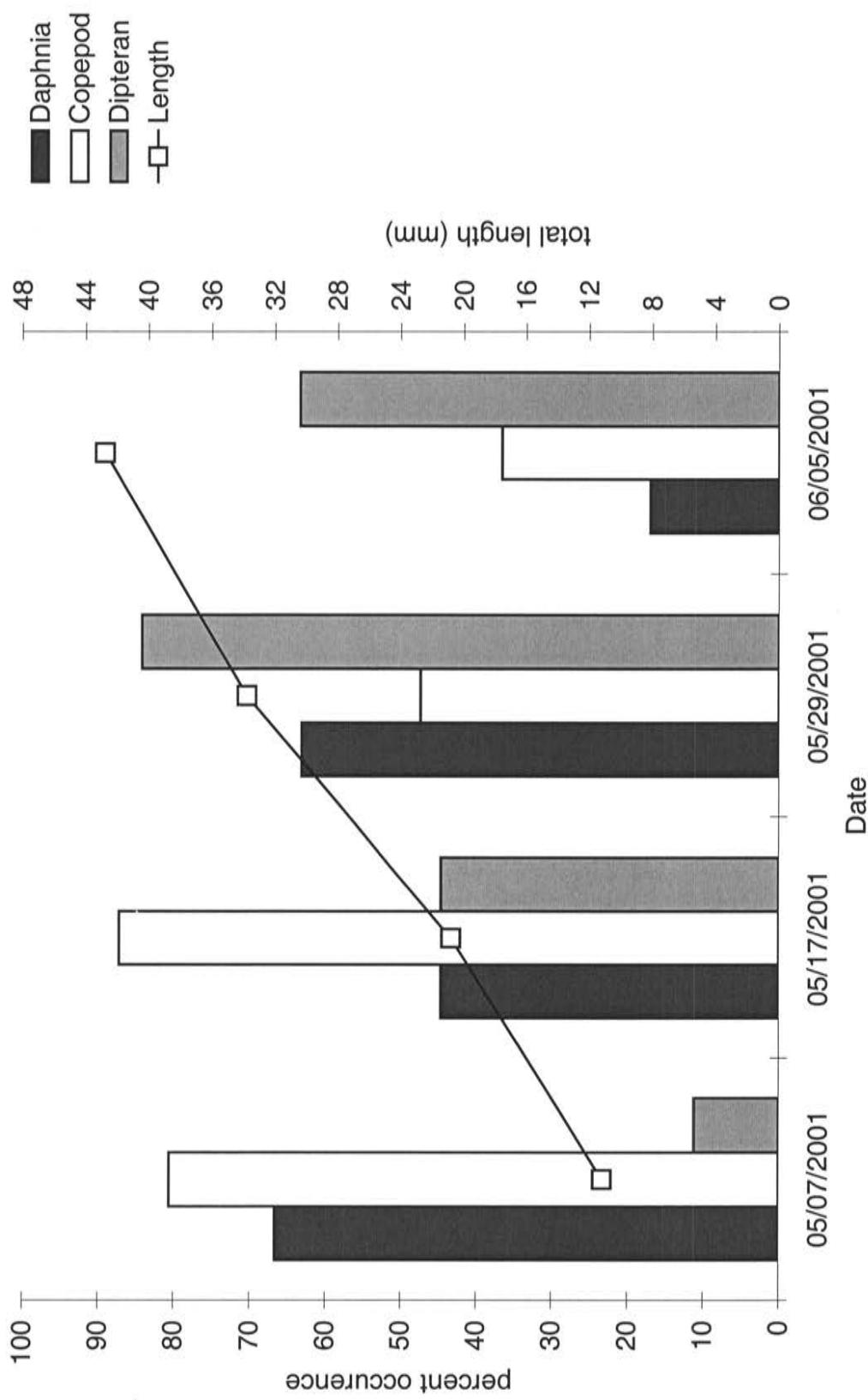


Figure 3.13. Percent occurrence of food items in relation to fish length for fingerling walleye cultured in plastic-lined ponds at Rathbun Fish Culture Research Facility, Moravia, Iowa in 2001.

### Acknowledgements

We thank Iowa Department of Natural Resources for supporting this study. We sincerely thank Dillon Streets, Andy Fowler, and Sarah Kaatz for their technical support, as well as Rathbun Fish Culture Research Facility personnel.

### Literature Cited

- Allan, J. D. 1976. Life history patterns in zooplankton. *The American Naturalist* 110:165-180.
- APHA (American Public Health Association), American Water Works Association, and Water Pollution Control Federation. 1998. Standard methods for the examination of water and wastewater, 17<sup>th</sup> edition. American Public Health Association, Washington, DC, USA.
- Barkoh, A. 1996. Effects of three fertilization treatments on water quality, zooplankton, and striped bass fingerling production in plastic-lined ponds. *The Progressive Fish-Culturist* 58:237-247.
- Barkoh, A., M. Stacell, and D. Smith. 1996. Efficacy of two organic fertilizers for production of Florida largemouth bass fingerlings in plastic-lined ponds. *Management Data Series No. 129*, Texas Parks & Wildlife, Austin, Texas.
- Boyd, C. E. 1990. Water quality in ponds for aquaculture. Birmingham Publishing Co., Birmingham, Alabama, USA.
- Buurma, B. J., A. Barkoh, and G. A. Alexander. 1996. Effects of cottonseed and alfalfa meals as fertilizers on production of palmetto bass (Morone saxatilis x M. chrysops) fingerlings in plastic-lined ponds. *Journal of Applied Aquaculture* 6(3):59-70.

- Crumpton, W. G., T. M. Isenhart, and P. D. Mitchell. 1992. Nitrate and organic N analyses with second-derivative spectroscopy. Limnology and Oceanography 37(4):907-913.
- Flowers, D. D. 1996. Fingerling production in drainable ponds at White Lake Fish Culture Station. Pages 123-128 in R. C. Summerfelt, editor. Walleye culture manual. NCRAC Culture Series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames, Iowa, USA.
- Fox, M. G., and D. D. Flowers. 1990. The effect of fish density on growth, survival and production of juvenile walleye in rearing ponds. Transactions of the American Fisheries Society 119:112-121.
- Fox, M. G., D. D. Flowers, and C. Watters. 1992. The effect of supplementary inorganic fertilization on juvenile walleye (Stizostedion vitreum) reared in organically fertilized ponds. Aquaculture 106:27-40
- Fox, M. G., J. A. Keast, and R. J. Swainson. 1989. The effect of fertilization regime on juvenile walleye growth and prey utilization in rearing ponds. Environmental Biology of Fishes 26:129-142.
- Geiger, J. G. 1983. Zooplankton production and manipulation in striped bass rearing ponds. Aquaculture 35:331-351.
- Hester, F. E. and J. S. Dendy. 1962. A multi-plate sampler for aquatic macro-invertebrates. Transactions of the American Fisheries Society 91:420-421.

- Johnson, S. R. and I. J. Schlosser. 1991. Effects of organic enrichment on zooplankton abundance and walleye fry growth and survival in artificial rearing ponds. *Journal of Freshwater Ecology* 6(3):315-321.
- Kriofske, K. P. 1990. Evaluation of pond liners. Mid-Continent Warmwater Fish Culture Workshop, Council Bluffs, Iowa.
- Mischke, C. C. 1999. Fertilization of walleye production ponds. Ph.D. Dissertation. Iowa State University, Ames, Iowa.
- May, R. C. 1974. Larval mortality in marine fishes and the critical period concept. Pages 1-19 in J. H. S. Blaxter, editor. *The early life history of fish*. Springer-Verlag, New York, New York, USA.
- Myers, J. J., R. W. Soderberg, J. M. Kirby, and M. T. Marcinko. 1996. Production of walleye, *Stizostedion vitreum*, in earthen ponds fertilized with organic and inorganic fertilizers and stocked at three rates. *Journal of Applied Aquaculture* 6(2):11-19.
- Parmley, D. C., and J. G. Geiger. 1985. Research and development communications: succession patterns of zooplankton in fertilized culture ponds without fish. *The Progressive Fish Culturist* 47(3):183-186.
- Pennak, R. W. 1989. *Freshwater Invertebrates of the United States*, 3<sup>rd</sup> ed. John Wiley & Sons Inc, New York, New York, USA.
- Qin, J., and D. A. Culver. 1992. The survival and growth of larval walleye, *Stizostedion vitreum*, and the trophic dynamics in fertilized ponds. *Aquaculture* 108:257-276.

- Qin, J., S. P. Madon, and D. A. Culver. 1995. Effect of larval walleye (Stizostedion vitreum) and fertilization on the plankton community: implications for larval fish culture. Aquaculture 130:51-65.
- Rogge, M. L., A. A. Moore, and J. E. Morris. (in review) Efficacy of organic and inorganic fertilization on production of fingerling walleye in plastic-lined ponds. Journal of the World Aquaculture Society.
- Soderberg, R. W., J. M. Kirby, D. Lunger, and M. T. Marcinko. 1997. Comparison of organic and Inorganic Fertilizers for the pond production of walleye, Stizostedion vitreum. Journal of Applied Aquaculture 7(2):23-29.
- Summerfelt, R. C., C. P. Clouse, and L. M. Harding. 1993. Pond production of fingerling walleye, Stizostedion vitreum, in the northern Great Plains. Journal of Applied Aquaculture 2(3/4):33-58.
- Summerfelt, R. C., C. P. Clouse, L. M. Harding, and J. M. Luzier. 1996. Walleye fingerling culture in drainable ponds. Pages 89-108 in R. C. Summerfelt, editor. Walleye culture manual. NCRAC Culture Series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames, Iowa, USA.
- Tice, B. J., R. W. Soderberg, and J. M. Kirby. 1996. Growth and survival of walleyes reared in ponds fertilized with organic or inorganic materials. The Progressive Fish-Culturist 58:135-139.

## CHAPTER 4. GENERAL CONCLUSIONS

There is much literature available on fertilization of earthen ponds for fish culture. Conclusions as to which type of fertilizer to use are variable, ranging from no fertilizer to combinations of organic and inorganic fertilizer. However, little work has been done for fingerling culture in plastic-lined ponds, and there are no published reports on walleye fingerling culture in plastic-lined ponds. Much is known about ecology of earthen ponds and how fertilizer influences interactions; however, fertilization needs may be different in plastic-lined ponds. These studies are the first to report specific details of water quality, zooplankton and benthos dynamics, and production of walleye in fertilized plastic-lined ponds. Unless specifically indicated otherwise, papers discussed hereafter refer to fish cultured in earthen ponds.

Qin and Culver (1992) reported higher ammonia concentrations with organic fertilizer, compared to inorganic fertilizers; however, ammonia was not significantly different among treatments during either of our studies. High ammonia levels can be deadly to fish, depending on water temperature and pH levels. Midwestern spring weather patterns are unpredictable and sometimes temperatures are high; toxic unionized ammonia increases with increases with temperature and pH. Many times during both years, we added less nitrogen than required to maintain ratios because of high pH levels.

pH was significantly higher in inorganically treated ponds in 2000. Qin et al. (1995) and Barkoh (1996) also found increased pH with inorganic fertilization in earthen ponds. pH was probably higher in inorganically treated ponds in 2000 either because of less decomposition or higher amounts of photosynthesis; however, chlorophyll a levels were not

significantly different among treatments, suggesting decomposition kept pH levels low in organically treated ponds in 2000. On the other hand, pH values in control ponds were not significantly different than organic ponds. There was little decomposition in control ponds because no fertilizer was added suggesting photosynthesis is the reason for the increased pH in inorganically treated ponds. There may have been enough inorganic nutrients released from organic fertilizer to sustain a phytoplankton population equal to that in inorganically treated ponds. Differences in pH may have been because of more decomposition producing more carbon dioxide ( $\text{CO}_2$ ), which lowered pH. Increased  $\text{CO}_2$  levels may have also facilitated better photosynthetic rates.

Qin and Culver (1992), Qin et al. (1995), and Barkoh (1996) found lower dissolved oxygen concentrations with use of organic fertilizers. Dissolved oxygen concentrations in our 2000 study were only different on the bottom of ponds, where most decomposition takes place; morning levels in organically treated ponds were lower than morning levels in inorganically treated ponds. However, concentrations at the top and middle of ponds were not significantly different. This is important because if low oxygen levels on the bottom do not cause high mortality, dangers of organic fertilizer are lessened.

Use of inorganic fertilizer did not raise nutrient ratios to our targeted level of 7:1 ( $\text{NO}_3\text{-N:TP}$ ), possibly because of an ineffective application method or a high demand for nitrogen. Although we added nitrogen to increase the ratios, we still were not successful in significantly raising them. Typically, phosphorus is limiting because it quickly binds to sediments and clay particles, only being able to stay in solution and available to phytoplankton when sediments are saturated (Boyd 1990). However, based on this study

nitrogen seems the limiting factor to phytoplankton in plastic-lined ponds. Because there is little sediment in plastic-lined ponds to saturate, phosphorus is more readily available, increasing the need for nitrogen. However, caution is needed when fertilizing with nitrogen. Increasing nitrogen in ponds can directly cause water quality problems by increasing toxic forms of nitrogen (ammonia and nitrite), and indirectly by increasing photosynthesis, which raises pH.

Zooplankton and benthos densities were elevated in 2001 compared to 2000. Peak levels of Daphnia spp. and copepods in 2001 were approximately 50% higher than levels in 2000. Benthos densities in 2000 had about 3,000 organisms/m<sup>2</sup>; densities in 2001 commonly exceeded 6,000 organisms/m<sup>2</sup>. The cause of these increases may be attributed to one or both of the following: increased nutrient loads in incoming water or carryover of resting eggs from previous culture seasons. In addition, plankton populations in 2001 had more time to mature prior to fry stocking. In 2000, fish were stocked 6 d after ponds were full. Fish in 2001 were stocked 12 d after ponds were full.

Allan (1976) described typical population dynamics of zooplankton. Rotifers are typically the first taxon to appear because of early maturation and parthenogenetic reproduction. Cladocerans also reproduce parthenogenetically, but do not mature as fast. Cladocerans can filter larger volumes of water and soon out-compete rotifers for food and space; however, cladocerans are quickly preyed upon by fish, consequently reducing numbers. Copepods are strictly sexually reproducers and take about 10 d longer to mature than cladocerans. Geiger (1983) found ponds fertilized 10-14 d before stocking favored development of crustaceans because of higher numbers of offspring produced and wider

range of ingestible food particle size. Parmley and Geiger (1985) found Daphnia spp. reached maximum density 30 d following initial fertilization in fertilized ponds without fish; however, leaving a pond sit for 30 d is not practical for hatchery operations. These studies show longer periods between initial fertilization and fish stocking results in more favorable zooplankters to develop. By having ponds without fish 5 d longer in 2001, crustacean zooplankton populations had more time to develop, allowing copepods and cladocerans to become the dominant taxa. Having high densities of food early in a fish's life is important so they easily begin exogenous feeding (May 1974).

Although fertilization regimens varied between culture seasons, zooplankton trends were similar among treatments in both years. In 2000, fertilized ponds, both organic and inorganic, had higher copepod populations than ponds receiving no fertilizer later in the culture season. In both years, zooplankton populations sharply declined shortly following fish stocking, similar to reports by Fox et al. (1989) and Fox et al. (1992), indicating an early preference for zooplankton. Zooplankton populations were low in all treatments at the end of both culture seasons; however, fish in the 2000 organic treatment grew better than fish from control or inorganically fertilized ponds. Therefore, organic fertilizer must have provided better food sources than inorganic fertilization in 2000. Both treatments, organic and mixed, in 2001 had similar zooplankton population trends throughout the culture season with depressed populations at time of fish harvest. Despite depressed zooplankton populations, fish in both treatments grew very well with high survival.

Fox et al. (1989), Fox and Flowers (1990), Fox et al. (1992), Culver and Geddes (1993), Summerfelt et al. (1993), and Flowers (1996) found when zooplankton numbers

declined, larval fish preyed on benthic chironomid larvae. Benthic invertebrate populations were positively influenced by organic fertilization in 2000. Organically treated ponds had 2.6 times more organisms/m<sup>2</sup> than inorganic ponds and 4.2 times more than control ponds. Increased organic loads in organically treated ponds provided a large forage base for chironomids, which feed on organic material and organisms that decompose that material (Coffman and Ferrington 1984; Pinder 1995). Fish from organic treatments grew larger than fish from other treatments in 2000 because of increased benthos densities. In 2001, both treatments received organic fertilizer, and both treatments facilitated good production.

Stomach content analyses of walleye from 2001 revealed an early preference for zooplankton, i.e., Daphnia spp. and copepods. In agreement with Fox et al. (1989), at about 2 weeks of age (20 mm), walleye fingerlings began to heavily feed on chironomids. At this time, about 45% of fish sampled had chironomids in their stomachs. Twelve days later, 84% of fish had fed upon chironomids, indicating a strong preference for chironomids in agreement with Fox et al. (1989), Fox and Flowers (1990), Fox et al. (1992), Summerfelt et al. (1993), and Flowers (1996). At harvest, 79% of fish sampled (not including fish with empty stomachs) were consuming dipteran larvae. This explains the growth of fish in the 2000 organic treatment after zooplankton populations crashed; benthic invertebrate densities were much higher in organic ponds, providing a food source beyond zooplankton for walleye fingerlings. In fact, Daphnia spp. had a second peak late in the 2000 season in organically treated ponds, possibly due to decreased predation on them because of high densities of chironomids. The importance of chironomids in the diet indicates a need for organic

fertilization in plastic-lined ponds. Chironomids feed on algae, detrital microorganisms, and other organic materials; therefore, some sort of organic material needs to be supplied.

Walleye survival in 2000 was low when compared to survival from 2001. Several factors could have contributed to this difference. Increased inorganic nutrient levels in 2001 may have provided higher food source production. Also, 2000 was the first year these ponds were full. Although ponds were rinsed out prior to the 2001 season, there still may have been some carry over, i.e., nutrients and resting eggs of phytoplankton, zooplankton, and insects, from previous culture seasons. The nutrients and resting eggs may have allowed for faster development of food webs. Survival could have also been higher in 2001 because of the higher zooplankton densities. It is important for larval fish to switch from endogenous to exogenous feeding. The more food there is, the easier fry begin exogenous feeding, possibly increasing survival (May 1974).

Growth was significantly better in ponds fertilized with organic fertilizer in 2000. Only the organic treatment in 2000 produced a fish size of < 1760 fish/kg. Mean weight in these ponds was  $0.69 \pm 0.050$  g. Both treatments in 2001 produced fish < 1760 fish/kg. Mean weights for organic and mixed treatments in 2001 were  $0.64 \pm 0.018$  and  $0.60 \pm 0.018$ , respectively. Based on food habits in the 2001 study, the reason for increased fish growth in 2000 organically treated ponds was higher densities of benthic insects, specifically chironomids. Both treatments in 2001 had good growth; both received organic fertilizer, and subsequently, each treatment had high densities of benthos.

Multiple studies with earthen ponds promote using inorganic fertilizers without organic fertilization because of higher survival (Qin and Culver 1992; Qin et al. 1995) or

lower costs of materials and labor (Tice et al. 1996; Soderberg et al. 1997). However, none of these studies produced fish with a combination of < 1760 fish/kg and  $\geq 50\%$  survival. Inorganic fertilizer typically produced higher survival, but final mean weights were low. Organic fertilization has produced high mean weights, but survival has been low. No literature was found describing production of walleye with a size of < 1760 fish/kg with > 50% survival during a culture period of 35-37 d. In addition, inorganic fertilizer may cost less on a per application basis (Tice et al. 1996; Soderberg et al. 1997), but nutrient levels need to be monitored to determine what amounts of nutrients to add. Chemical analyses will require expensive equipment and chemical reagents as well as time. The cost of time and labor can quickly close the gap on costs of fertilizers.

Based on data garnered from these two studies, organic fertilizer is necessary for plastic-lined pond management. The organic carbon from organic fertilizers not only supports growth of zooplankton, i.e., copepods and cladocerans, but also benthic chironomid larvae. Inorganic nutrients released from organic fertilizers also supported a phytoplankton density similar to ponds treated with inorganic fertilizer. In 2000, inorganic fertilization provided similar zooplankton populations compared to organic fertilization, but benthos density was not very well established, probably due to lack of a colonizable sediment. Organic fertilization supplemented with inorganic fertilization did not facilitate better fingerling walleye production than organic fertilization alone in 2001. However, all ponds in 2001 had higher inorganic nutrient concentrations and ratios than ponds treated with organics in 2000. Fish growth was similar between years, but survival was much higher in 2001, suggesting some minimal amount of inorganic nutrients may be beneficial.

Inorganic fertilizer was not deemed important for plastic-lined ponds based on these two studies; however, this should be investigated further. High nutrient levels at the beginning of the 2001 season may have masked needs for supplemental inorganic nutrients. In addition to organic fertilization, a minimum level of inorganic nutrients may be important for walleye fingerling culture in plastic-lined ponds. In 2000, nutrient levels were low, and survival was low. In 2001, water was rich with nutrients and survival was high. Our goal with inorganic fertilizer was to maintain a desired ratio, but a minimal amount of nitrogen and phosphorus may be more important than a specific ratio, especially at the start of each new culture season to boost food bases before walleye fry are stocked.

#### General Conclusions Literature Cited

- Allan, J. D. 1976. Life history patterns in zooplankton. *The American Naturalist* 110:165-180.
- Barkoh, A. 1996. Effects of three fertilization treatments on water quality, zooplankton, and striped bass fingerling production in plastic-lined ponds. *The Progressive Fish-Culturist* 58:237-247.
- Boyd, C. E. 1990. Water quality in ponds for aquaculture. Birmingham Publishing Co., Birmingham, Alabama, USA.
- Coffman, W. P., and L. C. Ferrington. 1984. Chironomidae. Pages 551-652 in R. W. Merritt and K. W. Cummins, editors. *An introduction to the aquatic insects of North America*. Kendall / Hunt Publishing Company, Dubuque, Iowa, USA.

- Culver, D. A., and M. C. Geddes. 1993. Limnology of rearing ponds for Australian fish larvae: relationships among water quality, phytoplankton, zooplankton, and the growth of larval fishes. *Australian Journal of Marine and Freshwater Research* 44:537-551.
- Flowers, D. D. 1996. Fingerling production in drainable ponds at White Lake Fish Culture Station. Pages 123-128 in R. C. Summerfelt, editor. Walleye culture manual. NCRAC Culture Series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames, Iowa, USA.
- Fox, M. G., and D. D. Flowers. 1990. The effect of fish density on growth, survival and production of juvenile walleye in rearing ponds. *Transactions of the American Fisheries Society* 119:112-121.
- Fox, M. G., D. D. Flowers, and C. Watters. 1992. The effect of supplementary inorganic fertilization on juvenile walleye (Stizostedion vitreum) reared in organically fertilized ponds. *Aquaculture* 106:27-40
- Fox, M. G., J. A. Keast, and R. J. Swainson. 1989. The effect of fertilization regime on juvenile walleye growth and prey utilization in rearing ponds. *Environmental Biology of Fishes* 26:129-142.
- Geiger, J. G. 1983. A review of pond zooplankton production and fertilization for the culture of larval and fingerling striped bass. *Aquaculture* 35:353-369.
- May, R. C. 1974. Larval mortality in marine fishes and the critical period concept. Pages 1-19 in J. H. S. Blaxter, editor. *The early life history of fish*. Springer-Verlag, New York, New York, USA.

- Parmley, D. C., and J. G. Geiger. 1985. Research and development communications: succession patterns of zooplankton in fertilized culture ponds without fish. *The Progressive Fish Culturist* 47(3):183-186.
- Pinder, L. V. 1995. Larval food and feeding behavior. Pages 136-168 in P. D. Armitage, P. S. Cranston, and L. V. Pinder, editors. *The Chironomidae*. Chapman and Hall, London, England.
- Qin, J. and D. A. Culver. 1992. The survival and growth of larval walleye, *Stizostedion vitreum*, and the trophic dynamics in fertilized ponds. *Aquaculture* 108:257-276.
- Qin, J., S. P. Madon, and D. A. Culver. 1995. Effect of larval walleye (*Stizostedion vitreum*) and fertilization on the plankton community: implications for larval fish culture. *Aquaculture* 130:51-65.
- Soderberg, R. W., J. M. Kirby, D. Lunger, and M. T. Marcinko. 1997. Comparison of organic and inorganic fertilizers for the pond production of walleye, *Stizostedion vitreum*. *Journal of Applied Aquaculture* 7(2):23-29.
- Summerfelt, R. C., C. P. Clouse, and L. M. Harding. 1993. Pond production of fingerling walleye, *Stizostedion vitreum*, in the northern Great Plains. *Journal of Applied Aquaculture* 2(3/4):33-58.
- Tice, B. J., R. W. Soderberg, and J. M. Kirby. 1996. Growth and survival of walleyes reared in ponds fertilized with organic or inorganic materials. *The Progressive Fish-Culturist* 58:135-139.

#### ACKNOWLEDGEMENTS

I wish to thank the Iowa Department of Natural Resources for support of this study. I would specifically like to thank the people at Rathbun Fish Culture Research Facility for their support and help during those many rainy days. A special thanks goes to Andy Moore for help and guidance during the long field seasons. Appreciation is given to members of my program of study committee, Drs. John Downing and Charles Drewes, for their aid and insight.

Great appreciation goes to fellow graduate students and technicians who have helped me along the way. These include, but are not limited to, Ryan Lane, Sarah Kaatz, Joe Boylan, Dillon Streets, and Andy Fowler. I appreciate the patience and dedication in both laboratory and field. I would also like to express gratitude to Drs. Wendy Sealey and Gibson Gaylord for their support and guidance.

To my major professor, Joseph E. Morris, I would like to extend an immense amount of gratitude for the opportunity to continue my education with this project. I will always be grateful for his assistance in laboratory, field, and life. He has had great patience with me and has shown me how to get the most out of myself.

Last, but not least, I would like to thank my family for financial and emotional support throughout my education. The deepest, heartfelt appreciation goes to my future wife, Rebecca, for her love and patience during two long summers in the field as well as long days and nights spent in the lab. I cannot express how much she has helped me and meant to me throughout my graduate career.