Benthic invertebrate management in plastic-lined fish culture ponds

Sarah Elizabeth Kaatz
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Benthic invertebrate management in plastic-lined fish culture ponds

by

Sarah Elizabeth Kaatz

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

MASTER OF SCIENCE

Major: Fisheries Biology

Program of Study Committee:
Joseph E. Morris (Major Professor)
Clay Pierce
Gregory Courtney

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2003
Graduate College
Iowa State University

This is to certify that the master’s thesis of

Sarah Elizabeth Kaatz

has met the thesis requirements of Iowa State University

Signatures have been redacted for privacy
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CHAPTER 1. GENERAL INTRODUCTION

Many agencies are building plastic-lined ponds in place of earthen ponds for fish culture; however, limited information is available on their management (Barkoh, 1996; Barkoh et al. 1996; Buurma et al. 1996; Sparrow 1996). When compared to earthen ponds, plastic-lined ponds have both advantages and disadvantages. Advantages include: a more controlled environment; ability to be drained and flushed following each growing season, thereby reducing influences of past events; and decreased growth of aquatic macrophytes, in so doing making fish harvesting easier. Besides the high initial costs of construction, plastic-lined ponds are dependent on external sources of nutrients, e.g., leaf litter, or organic material, for the promotion of primary production. The limited amount of organic substrate also limits the number of potential benthic macroinvertebrates, which are important prey for larval fish (Crowder and Cooper 1982; Fox 1989; Culver and Geddes 1993; Summerfelt et al. 1993; Flowers 1996; Mischke 1999).

In addition to the limited number of studies on the use of plastic-lined ponds for fish culture, there are few studies that have investigated the use of benthic organisms by larval fish in this type of pond. Benthic organisms, especially chironomids (Order Diptera), are an important food item for walleye (Sander vitreus); walleye fingerlings switch from zooplankton to benthic organisms within 3-4 weeks after being stocked in culture ponds (Summerfelt et al. 1993; Flowers 1996). However, no studies have been done to determine Dipteran, specifically, chironomid, colonization rates, abundance, or distribution in plastic-lined ponds.

Pond fertilization regimes have been widely studied; however, most of the research has focused on plankton management in earthen ponds (Geiger 1983a; Geiger 1983b; Geiger et al. 1985; Fox 1989; Geiger and Turner 1990; Summerfelt et al. 1993; Flowers 1996). Given the importance of benthic organisms to larval walleye as well as the limited amount of
information about the management of plastic-lined ponds, research is necessary to characterize types and colonization rates of benthic organisms in plastic-lined culture ponds.

**Fertilization**

Fertilization of culture ponds can increase fish production by introducing and releasing important nutrients, e.g., carbon, nitrogen, and phosphorus into the water column (Seymour 1980; Geiger 1983a). These nutrients promote development of a simple food web by promoting bacterial, algal, zooplankton, and benthic invertebrate growth. Due to lack of nutrients coming in from sediments, plastic-lined ponds need to be fertilized to enhance primary production, which can be described as an example of trophic cascading. The trophic-cascade hypothesis states there are “bottom up” (nutrient mediated) and “top down” (predator mediated) effects (Carpenter et al. 1985). Fertilization is a “bottom up” type of trophic cascade. Phytoplankton communities are regulated by available nutrients (Moriarty 1997); zooplankton production, in turn, is regulated by the phytoplankton community and other micro-invertebrates (Geiger et al. 1985; Armitage et al. 1995).

Inorganic fertilizers are used to stimulate the autotrophic food web. They supply nitrogen and phosphorus to phytoplankton. This causes an increase in phytoplankton abundance, which in turn promotes growth of zooplankton communities. Inorganic fertilizers can increase energy at the bottom of the food web, which allows more energy to be transported up the food web (bottom-up effects). Olsson et al. (1992) was able to increase both phytoplankton and zooplankton biomass by fertilizing with small amounts of inorganic fertilizer.

Inorganic fertilizers can be applied as a liquid or in granules. Soderberg and Marcinko (1999) compared both and found that the type of fertilizer did not affect fish production or growth. They did, however, recommend that granular fertilizer be dissolved before application. Others recommend using a liquid fertilizer because they are easier to
Phosphorus can be a limiting nutrient to phytoplankton in freshwater communities; Boyd (1997) demonstrated that addition of only phosphorus can increase fish production in nutrient-poor waters. Phosphate, however, quickly adsorbs to sediments or precipitates out when added to ponds (Boyd 1990).

It is important to maintain nitrogen to phosphorus (N:P) ratios in production ponds using inorganic fertilizers. The optimum ratio according to Rhee and Gotham (1980) is “the ratio at which a transition from one nutrient limitation to another takes place.” Seymour (1980) found that keeping a high N:P ratio could be selective for algae more favorable to zooplankters.

Organic fertilizers stimulate the heterotrophic food web. In addition to nutrients being slowly released into the water column as organic material is broken down, bacterial and fungal populations are promoted. Organic fertilizers can have a positive effect on zooplankton abundance, but may take up to 2 weeks to see results (Johnson and Schlosser 1991). Also, accumulation of organic material can provide food for benthic invertebrates (Geiger 1983b).

Decomposition of organic material may occur at a slow rate, e.g., a slow release of nutrients, and thus may not be useful for short-term culture seasons. Furthermore, decomposition of organic material may cause oxygen depletions (Johnson and Schlosser 1991).

Zooplankton populations

Rotifers are usually the first zooplankters to populate ponds. They have short life spans and typically are asexual reproducers. Cladocerans and copepods replace rotifers as the dominant zooplankters as they out-compete them for resources. Cladocerans are similar to rotifers in that they are asexual reproducers. Both groups are also able to reproduce
sexually. Copepods are unique, in that they typically are sexually reproducing. Cladocerans reach their peak populations in about 14 days, whereas copepods typically need 10 more days to reach their peak (Allan 1976).

Allan (1976) further states that rotifers and cladocerans are similar in their feeding habits as well. Both are filter feeders and tend to feed on smaller particles. Copepods on the other hand, tend to be raptorial, and actively seek out larger food particles.

**Benthic populations**

Chironomid larvae can be found all types of water systems, including production ponds. There are over 15,000 species of chironomids worldwide (Armitage et al. 1995), and as such, general characteristics for this family vary. Chironomids may be univoltine (one generation per year), bivoltine (two generations per year), or multivoltine (many generations per year) (Armitage et al. 1995). Chironomids have four life stages: egg, larva (with four instars), pupa, and adult. In general, Coffman and Ferrington (1996) found warm water, availability of high quality food, and small species tend to cause shorter life cycles.

Armitage et al. (1995) made several observations regarding the reproduction of chironomids; mating typically occurs in swarms after sunset or before sunrise, and the female either broadcasts her eggs at the water surface, or deposits them in large masses along the water edge. Furthermore, over generations, individuals of a species swarm at the same location in favorable weather conditions. These locations can be above the water, near the shore, in an open wooded area, or a grass prairie.

However, it was noted that the intensity of swarming is correlated with temperature and light; rain and humidity can affect swarming as well. It is further stated that chironomid adults often rest in woods or trees near the water’s edge during the day and come out at night in response to humidity gradients. The chironomid egg varies in size from 170µm long to over 600µm (Nolte 1993). It takes anywhere from 2 to 6 days for the eggs to hatch once deposited.
The larva stage has four instars, each with the goal of dispersal, and can last from 2 weeks to years, depending on species (Armitage et al. 1995). The first instars tend to be planktonic and can go through a 125-µm mesh; the later instars are benthic (Armitage et al. 1995). This paper notes that the larval of many species can go through diapause or aestivation stages that are triggered by harsh environmental conditions (cold temperatures, lack of food, water evaporation).

Chironomid larvae are known to be herbivores, detritivores, and carnivores. Chironomids consume algae/phytoplankton, organic matter and zooplankton (Armitage et al. 1995; Coffman and Ferrington 1996). Most graze on substrate particles, while others are filter feeders. The pupal stage typically is short, after which it swims to the water surface and emerges as an adult. Adults typically do not feed and usually live only 2 weeks (Armitage et al. 1995).

Armitage et al. (1995) found that photoperiod and temperature are major factors affecting the development of the insect, with temperature being the most important. Temperature affects all stages of the chironomid life cycle with particular influence on the rate of egg development as well as hatching time, within a range of 5-30°C; high temperatures (30-35°C) are detrimental to egg development (Armitage et al. 1995). Temperature is also a major controlling factor in larval growth, however, growth rates of larvae increase with higher temperatures; emergence is also temperature related.

The colonization of new lentic habitats by chironomids is done predominantly by the dispersal of fertilized females or drift in lotic systems; however, adult chironomid movement is often influenced by air currents rather than their ability to fly (Armitage et al. 1995). Many colonization studies focus mainly on the larval stage, and the colonization of adults by flight is often overlooked.
Thesis Organization

This thesis is organized into four chapters. This includes general introduction and general conclusion sections, formatted according to the American Fisheries Society. Literature cited follows each chapter.

Literature Cited


CHAPTER 2. EFFECTS OF TWO FERTILIZER REGIMES ON WATER QUALITY, INVERTEBRATE ABUNDANCE, AND WALLEYE PRODUCTION IN PLASTIC-LINED FISH CULTURE PONDS

Sarah E. Kaatz, J. Alan Johnson, Jay Rudacille, and Joseph E. Morris

Abstract

Many natural resource agencies are building plastic-lined ponds in place of earthen ponds for fish culture because of perceived ease of management; however, limited information is available on their use since there are significant differences between these two types of culture ponds. This study was conducted at the Iowa Department of Natural Resources’ Rathbun Fish Culture and Research Facility in Moravia, Iowa. Six 0.04-ha plastic-lined ponds were used to evaluate effects of organic fertilizer on the benthic community and fish production. Walleye (Sander vitreus) 3-4 days post-hatch were stocked 1 May 2002 and harvested 6-7 June 2002. Throughout the growing season, inorganic fertilizers were added to all ponds to sustain primary production. The fertilizer was applied to maintain a target ratio of 7:1 total nitrate-nitrogen (NO₃-N) to total phosphorus (TP). After stocking the fry, organic fertilizer (alfalfa pellets) was applied to three ponds (112kg/ha/week), the other three ponds received only inorganic fertilizers. The goals were to increase energy in lower trophic levels, maximize fingerling size and survival, and produce uniform size walleye in plastic-lined culture ponds. The primary objectives were to evaluate effects of organic fertilization on abundance and distribution of benthic invertebrates in plastic-lined culture ponds, and the effects on walleye fingerling production. We found no significant differences between treatments for any water quality parameters analyzed. Furthermore, there were no significant differences between treatments in numbers of zooplankton or benthic invertebrates. Nevertheless, it was noted that organic fertilizers yielded a greater abundance of both zooplankton and benthic organisms. At harvest, the
walleye in the ponds treated with organic fertilizer were significantly (P<0.10) longer, heavier, and had a greater biomass; however, overall survival and relative weight were not significantly different. These results suggest that organic fertilizer is important for the benthic food base and growth of fingerling walleye.

**Introduction**

There are a limited number of peer-review publications on the use of plastic-lined ponds for fish culture (Barkoh 1996; Barkoh et al. 1996; Buurma et al. 1996; Sparrow 1996). While pond fertilization regimes have been widely studied, most research has focused on plankton management and not benthic invertebrate management. Research is necessary to characterize types of benthic organisms found in plastic-lined culture ponds and determine colonization rates, since benthic macroinvertebrates, especially chironomid midges, are a potential food source for larval fish (Crowder and Cooper 1982; Fox 1989; Culver and Geddes 1993; Summerfelt et al. 1993; Flowers 1996; Mischke 1999).

There are a vast number of benthic invertebrates, however, we chose to focus on chironomids (Order Diptera), since they are an important food item for larval fish (Fox 1989). Chironomid larvae are common in benthic samples, and can be found all types of water systems, including production ponds. The life history of chironomids sheds some light on how these invertebrates may enter plastic-lined ponds. Armitage et al. (1995) made several observations regarding the reproduction of chironomids; mating typically occurs in swarms after sunset or before sunrise, and the female either broadcasts her eggs at the water surface, or deposits them in large masses along the water edge. However, the intensity of swarming is correlated with temperature and light; rain and humidity can affect swarming as well. It was further stated that chironomid adults often rest in woods or trees near the water’s edge during the day and come out at night in response to humidity gradients. The chironomid egg varies in size from 170µm long to over 600µm (Nolte 1993), most of which would be able to come in with the water supply for the ponds. The colonization of new
habitats by chironomids is done predominantly by the dispersal of fertilized females; however, adult movement is often determined by the wind rather than their ability to fly (Armitage et al. 1995). Armitage et al. (1995) also stated that many colonization studies focus mainly on the larval stage, and colonization by adults is often overlooked.

This was the third year of the study, with previous work focusing on basic fertilizers (organic vs. inorganic vs. no fertilizers), and a mixed fertilizer regime (organic vs. organic and inorganic) (Rogge 2002). From these past studies, we have determined the importance of chironomids to walleye fry culture but have yet determined the importance of an organic fertilization regime to chironomid populations as well as their actual origins.

The goals of the project were to increase energy in lower trophic levels, maximize fingerling size (<1, 760 fish /kg) and survival (≥50%), and produce uniform size walleye in plastic-lined culture ponds. These goals were set by the Iowa Department of Natural Resources to reach their production numbers. The specific objectives were to evaluate effects of organic fertilization on abundance and distribution of benthic invertebrates in plastic-lined culture ponds and its concomitant effects on walleye fingerling culture.

**Materials and Methods**

**Study site description**

This study was conducted at the Rathbun Fish Culture and Research Facility, Moravia, Iowa. Six 0.04-ha plastic-lined ponds were used to compare the use of inorganic fertilizers to a “mix” of organic and inorganic fertilizers, hereafter referred to as organic/inorganic, for the culture of walleye fingerlings (three ponds/treatment). Individual ponds were experimental units, and were randomly assigned a treatment. Water from Rathbun Lake was used to fill all ponds. Ponds were filled 18-19 April 2002. Walleye 3 to 4-days-old were stocked at a rate of 250,000 fish/ha on 1 May 2002. Fry were counted using an optical fry counter (Jensorter Model FC2, Jensorter Incorporated, Bend, Oregon).
Fertilization

Initial total phosphorus (TP) levels were adjusted to 0.10 mg/L at the initiation of the project; phosphorus (12-46-6) was used (0.04 – 0.08 kg). At initial flooding of the ponds, organic fertilizer was applied to each pond at a rate of 112 kg/ha. Alfalfa pellets were used as organic fertilizer (0.08% nitrogenous compounds, 0.45% phosphorus). Thereafter, organic fertilizer was applied weekly to each organic/inorganic pond at a rate of 112 kg/ha. Inorganic fertilization began 25 April 2002. Nitrogen (36-0-0) was added weekly to each organic/inorganic pond to maintain a nitrate-nitrogen to total phosphorus ratio (NO₃-N:TP) of 7:1 (Mischke 1999). Total organic fertilizer added to the three designated organic/inorganic ponds was 31.8 kg; inorganic ponds received variable amounts of inorganic fertilizers to maintain the nutrient ratio [total application 0.41-1.04 kg in two applications].

Sampling methods

Water sampling began 22 April 2002. Water samples were collected twice a week (Monday and Thursdays), using a tube sampler to sample the entire water column. Pond-side water quality testing included pH, temperature, and Secchi disk readings. A YSI Model 60 pH meter (Yellow Springs, Ohio) was used to record pH and temperature. Standards were used weekly to calibrate pH meter. Water chemistry was conducted using a Hach DR/2010 spectrophotometer (Hach, Loveland, Colorado). Variables analyzed include ammonia-nitrogen (NH₃-N), nitrite-nitrogen (NO₂-N), nitrate-nitrogen (NO₃-N), total phosphorus (TP), and bi-weekly alkalinity, and hardness. Morning (0600h) and afternoon (1500h) temperature and dissolved oxygen levels at the bottom, middle, and top of the ponds were taken twice per week (Tuesdays and Fridays) with a YSI Model 55 Oxygen Meter (Yellow Springs, Ohio).

Water samples for chlorophyll a were collected twice a week (Mondays and Thursdays). Samples of 300-ml were filtered through 47mm glass Microfibre filters using a vacuum pump (Barnant Company, Barrington, Illinois). The filters were frozen and stored in
darkness until analysis. Chlorophyll a and phaeophytin levels were analyzed using the procedures described by APHA et al. (1998).

Zooplankton samples were taken twice weekly (Mondays and Thursdays) with oblique tows of an 80-μ Wisconsin net (Wildco Company, Saginaw, WI) and preserved with a chilled formalin/sucrose solution (APHA et al. 1998). Specimens were counted and identified on site using Pennak (1989).

Benthos was sampled using Hester-Dendy slides (Hester and Dendy 1962). Six sets of eight slides were placed into each pond at a depth of 0.3m. One sampler was retrieved each week (Fridays). Samples were preserved in 10% buffered formalin. Samplers were later scraped and organisms identified to family using Merritt and Cummins (1996). Since dry weight of Diptera is linearly related to the width of the head capsule (Smock 1980), we measured chironomids at the middle of the season and at harvest, and used Smock’s regression equation to determine biomass. Benthic samples were also taken using an inverted plastic bucket. One bucket was placed in the shallow end of each pond 1 day before harvest. After the ponds were drained, the contents under the buckets were collected and preserved in 10% buffered formalin. Samples were later analyzed, and organisms identified to family.

Aquatic insect adults were sampled with emergence traps. One trap was placed at water surface in the shallow end of each pond. Traps were emptied once a week (Fridays). Samples were preserved in chilled formalin/sucrose solution (APHA et al. 1998). Samples were later identified to family using Merritt and Cummins (1996).

Fingerlings were harvested 6-7 June 2002. Ponds were drained and fish collected in the catch basin at the end of the pond. Samples of 100 fish from each pond were taken and mean weights and lengths were recorded. Relative weights for young of the year walleye were calculated using the equation formulated by Flammang et al. (1999). Percent survival
was calculated, as well as number of fish harvested, calculated as total weight divided by mean fish weights.

**Data analysis**

Treatment differences were analyzed using JMP 5.0 (SAS Institute, Cary, North Carolina) to determine significant differences in water chemistry parameters, zooplankton, benthic, and adult aquatic insect populations, as well as fish production parameters. The overall differences between treatment effects were analyzed using repeated measures, and weekly differences between treatments were analyzed with a t-test. Significance was set at $P \leq 0.10$.

**Results**

**Water Chemistry**

Ponds that were treated with the organic/inorganic fertilization regime had increased levels of nitrogenous compounds as well as total phosphorus (Table 2.1, Figures 2.1 and 2.2). There were overall significant differences between treatments; the organic/inorganic treatments had more NH$_3$-N, NO$_2$-N, NO$_3$-N, and TP. There were weekly significant differences between treatments as well; starting in week 4 and continuing through harvest the organic/inorganic treatments had significantly more NH$_3$-N. During week 5, the organic/inorganic treatments also had significantly more NO$_2$-N, NO$_3$-N, and TP. These same ponds also had decreased levels of dissolved oxygen but all levels were adequate for fish culture. Chlorophyll $a$ levels peaked at the start of the culture season (Figure 2.3). From 13 May (week 4) until the end of the culture period, the organic/inorganic treatment ponds had higher levels of chlorophyll $a$, however these differences were not significant. Temperature and precipitation data were also obtained for the culture season (Figure 2.4). The culture season was relatively dry with few rainfall events; it was also temperate, so primary production was not affected by heavy rain or cold weather.
Table 2.1. Means ± SEs (range) of water quality variables in plastic-lined research ponds fertilized with inorganic and a mix of organic and inorganic fertilizers during the 2002 walleye fingerling culture period at Rathbun Fish Culture and Research Facility, Moravia, Iowa.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissolved Oxygen (mg/L)</td>
<td></td>
</tr>
<tr>
<td>Morning</td>
<td></td>
</tr>
<tr>
<td>Bottom</td>
<td>10.10 ± 0.361 (6.4-14.4)</td>
</tr>
<tr>
<td></td>
<td>9.14 ± 0.411 (5.0-14.5)</td>
</tr>
<tr>
<td>Middle</td>
<td>10.15 ± 0.323 (6.2-14.1)</td>
</tr>
<tr>
<td></td>
<td>9.48 ± 0.382 (5.0-14.4)</td>
</tr>
<tr>
<td>Top</td>
<td>9.88 ± 0.301 (6.3-13.3)</td>
</tr>
<tr>
<td></td>
<td>9.38 ± 0.339 (5.1-13.4)</td>
</tr>
<tr>
<td>Afternoon</td>
<td></td>
</tr>
<tr>
<td>Bottom</td>
<td>10.57 ± 0.493 (6.6-14.2)</td>
</tr>
<tr>
<td></td>
<td>9.89 ± 0.451 (5.5-14.1)</td>
</tr>
<tr>
<td>Middle</td>
<td>10.18 ± 0.430 (6.5-12.9)</td>
</tr>
<tr>
<td></td>
<td>9.34 ± 0.415 (5.6-13.5)</td>
</tr>
<tr>
<td>Top</td>
<td>9.99 ± 0.382 (6.4-12.7)</td>
</tr>
<tr>
<td></td>
<td>9.65 ± 0.383 (5.8-13.2)</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td></td>
</tr>
<tr>
<td>Morning</td>
<td></td>
</tr>
<tr>
<td>Bottom</td>
<td>16.92 ± 0.81 (10.5-27.3)</td>
</tr>
<tr>
<td></td>
<td>16.96 ± 0.76 (10.1-27.4)</td>
</tr>
<tr>
<td>Middle</td>
<td>17.22 ± 0.79 (11.3-27.2)</td>
</tr>
<tr>
<td></td>
<td>17.29 ± 0.77 (11.0-27.4)</td>
</tr>
<tr>
<td>Top</td>
<td>17.18 ± 0.77 (11.5-27.0)</td>
</tr>
<tr>
<td></td>
<td>17.31 ± 0.74 (11.3-27.3)</td>
</tr>
<tr>
<td>Afternoon</td>
<td></td>
</tr>
<tr>
<td>Bottom</td>
<td>18.00 ± 0.87 (11.2-26.3)</td>
</tr>
<tr>
<td></td>
<td>18.06 ± 0.86 (11.1-25.0)</td>
</tr>
<tr>
<td>Middle</td>
<td>18.55 ± 0.92 (11.9-27.1)</td>
</tr>
<tr>
<td></td>
<td>18.93 ± 0.93 (11.9-27.3)</td>
</tr>
<tr>
<td>Top</td>
<td>19.28 ± 0.98 (12.1-29.1)</td>
</tr>
<tr>
<td></td>
<td>19.85 ± 1.02 (12.1-29.2)</td>
</tr>
</tbody>
</table>
Table 2.1. (continued)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inorganic</td>
</tr>
<tr>
<td><strong>pH</strong></td>
<td></td>
</tr>
<tr>
<td>Bottom</td>
<td>8.63 ± 0.12</td>
</tr>
<tr>
<td></td>
<td>(7.10-9.35)</td>
</tr>
<tr>
<td>Top</td>
<td>8.89 ± 0.11</td>
</tr>
<tr>
<td></td>
<td>(7.86-9.48)</td>
</tr>
<tr>
<td>Secchi disk (m)</td>
<td>1.5 ± 0.07</td>
</tr>
<tr>
<td></td>
<td>(0.8-1.8)</td>
</tr>
<tr>
<td>Ammonia (NH3-N; mg/L)</td>
<td>0.16 ± 0.008</td>
</tr>
<tr>
<td></td>
<td>(0.08-0.28)</td>
</tr>
<tr>
<td></td>
<td>0.007 ± 0.001</td>
</tr>
<tr>
<td>Nitrite (NO2-N; mg/L)</td>
<td>0.21 ± 0.01</td>
</tr>
<tr>
<td></td>
<td>(0.03-0.15)</td>
</tr>
<tr>
<td>Nitrate (NO3-N; mg/L)</td>
<td>0.09 ± 0.008</td>
</tr>
<tr>
<td></td>
<td>(0.10-0.30)</td>
</tr>
<tr>
<td>Total Phosphorus (mg/L)</td>
<td>3.21 ± 0.359</td>
</tr>
<tr>
<td></td>
<td>(0.5-6.7)</td>
</tr>
<tr>
<td>Ratio (NO3-N:TP)</td>
<td></td>
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<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 2.1. Mean and standard errors of total phosphorus (TP) (mg/L) concentrations in plastic-lined walleye culture ponds fertilized under two regimes, inorganic and a mix of organic and inorganic fertilizers during the 2002 fingerling culture season at Rathbun Fish Culture and Research Facility, Moravia, Iowa.
Figure 2.2. Mean ratios and standard errors of nitrate-nitrogen to total phosphorus (NO$_3$-N:TP) in plastic-lined walleye culture ponds fertilized under two regimes, inorganic and a mix of organic and inorganic fertilizers, during the 2002 fingerling culture season at Rathbun Fish Culture and Research Facility, Moravia, Iowa. Dashed line indicates the target ratio of 7:1 NO$_3$-N:TP.
Figure 2.3. Means and standard errors of chlorophyll a (ng/ml) levels in plastic-lined walleye fingerling culture ponds fertilized with inorganic and a mix of organic and inorganic fertilizers during the 2002 walleye fingerling culture period at Rathbun Fish Culture and Research Facility, Moravia, Iowa.
Figure 2.4. Temperature and precipitation during the 2002 walleye culture season at the Rathbun Fish Culture and Research Facility, Moravia, Iowa. Black arrow indicates fish stocking, and white arrow indicates harvest. Data obtained from http://cdo.ncdc.noaa.gov/dly/DLY, visited 6 November 2003.
Zooplankton

Populations of *Daphnia* spp. peaked 2-3 weeks after fry stocking in both treatments (Figure 2.5). In contrast, cyclopoid and calanoid copepod populations peaked 1 week post-stocking (Figures 2.6 and 2.7). There were no overall treatment effects in any of these plankton populations. During week 3, there was a significant difference in the calanoid population; the organic/inorganic treatment had significantly higher densities. All three plankton populations decreased toward the end of the culture period.

Figure 2.5. Means and standard errors of *Daphnia* spp. densities in plastic-lined walleye fingerling culture ponds fertilized with inorganic and a mix of organic and inorganic fertilizers during the 2002 walleye fingerling culture period at Rathbun Fish Culture and Research Facility, Moravia, Iowa. Black arrow denotes stocking date of walleye.
Figure 2.6. Means and standard errors of cyclopoid copepod densities in plastic-lined walleye fingerling culture ponds fertilized with inorganic and a mix of organic and inorganic fertilizers during the 2002 walleye fingerling culture period at Rathbun Fish Culture and Research Facility, Moravia, Iowa. Black arrow denotes stocking date of walleye.
Figure 2.7. Means and standard errors of calanoid copepod densities in plastic-lined walleye fingerling culture ponds fertilized with inorganic and a mix of organic and inorganic fertilizers during the 2002 walleye fingerling culture period at Rathbun Fish Culture and Research Facility, Moravia, Iowa. Black arrow denotes stocking date of walleye.
Benthos

The benthic community was found to be lacking in diversity. It is estimated that 95% of the samples consisted of chironomids, and were determined to be *Chironomus* spp. Beginning in mid-May, chironomid populations were greatest in the ponds treated only with organic/inorganic fertilizers; however, just prior to harvest, there were no significant differences overall (Figure 2.8). During week 5 there was a significant difference between treatments; the organic/inorganic treatment had significantly more chironomids. There was also a significant difference in biomass (dry weight, g/m²) at this time; the organic/inorganic treatment had significantly more biomass. There were no significant differences in biomass at time of harvest. There were similar numbers between the bucket samplers, and overall, there were no significant differences between treatments (Figure 2.9).
Figure 2.8. Means and standard errors of chironomid densities in plastic-lined walleye fingerling culture ponds fertilized with inorganic and a mix of organic and inorganic fertilizers, sampled with Hester-Dendy samplers, during the 2002 walleye fingerling culture period at Rathbun Fish Culture and Research Facility, Moravia, Iowa.
Figure 2.9. Means and standard errors of chironomid densities in plastic-lined walleye fingerling culture ponds fertilized with inorganic and a mix of organic and inorganic fertilizers, sampled by bucket sampler, during the 2002 walleye fingerling culture period at Rathbun Fish Culture and Research Facility, Moravia, Iowa.
Emerging Adults

The emerging aquatic adults were identified as chironomids. There were no significant differences, overall or weekly, between treatments for the emerging aquatic insect adults. However, 3 of 4 of the organic/inorganic treatments had more adults per sample (Figure 2.10).

Figure 2.10. Means and standard errors of total emerging chironomid adults from walleye fish culture ponds fertilized with inorganic and a mix of organic and inorganic fertilizers during the 2002 walleye culture season at Rathbun Fish Culture and Research Facility, Moravia, Iowa.
Walleye Production

There were significant differences between the two treatments in fish size and biomass, but not in survival or relative weight (Table 2.2). Fish cultured in ponds with organic fertilizers were longer and heavier than those in ponds treated only with inorganic fertilizers. The relative weight index, used as an index for fish body condition, was first introduced by Wege and Anderson (1978) for largemouth bass (Micropterus salmoides). Since then, it has been developed for many other fish species, including walleye (Piper et al. 1982). The relative weights are based on a scale of 100, in which a value of 100 indicates good fish health; scores below and above this level reflect respectively either fish being robust or thin. In this case, the low relative weights for this culture season indicate that the fish were thin; this is probably reflective of the limited prey base for these fish towards the end of the culture season.

Table 2.2. Mean (±SE) length, weight, survival, biomass, and relative weight of walleyes cultured in plastic-lined research ponds fertilized with inorganic and a mix of organic and inorganic fertilizers during the 2002 walleye fingerling culture season at the Rathbun Fish Culture and Research Facility, Moravia, Iowa. Parameters marked with an asterisk (*) are significantly different, P<0.10.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Final Length (mm)*</th>
<th>Final Weight (g)*</th>
<th>Survival (%)</th>
<th>Fish Biomass (kg/ha)*</th>
<th>Relative Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inorganic</td>
<td>32.7</td>
<td>0.25</td>
<td>78.7</td>
<td>4.2</td>
<td>70.0</td>
</tr>
<tr>
<td></td>
<td>(0.29)</td>
<td>(0.013)</td>
<td>(14.0)</td>
<td>(0.66)</td>
<td>(3.10)</td>
</tr>
<tr>
<td>Organic/Inorganic</td>
<td>36.6</td>
<td>0.36</td>
<td>78.2</td>
<td>6.3</td>
<td>72.3</td>
</tr>
<tr>
<td></td>
<td>(0.63)</td>
<td>(0.020)</td>
<td>(2.9)</td>
<td>(0.12)</td>
<td>(2.30)</td>
</tr>
</tbody>
</table>
Discussion

The ponds treated with organic/inorganic fertilizers had increased nitrogenous compounds and total phosphorus, as well as depressed dissolved oxygen levels. The same treatment also had increased chlorophyll a concentrations. This indicates that with increased levels of nutrients in the pond, there is a potential for more phytoplankton, as in accordance with Rhee and Gotham (1980), Downing and McCauley (1992), and Moriarty (1997). Furthermore, according to Moriarty (1997), the more primary production, the lower the oxygen levels, due to either organic fertilizer decomposition or diurnal differences in respiration rates.

There were no overall significant differences in the zooplankton populations between treatments, but there was evidence of a weekly difference between calanoids during week 3. The difference may be explained by zooplankton appearing to respond to organic/inorganic fertilizers. Since copepods are raptorial in their feeding habits (Allan 1976), they may have been responding to the increased prey base of phytoplankton, as seen in the increased chlorophyll a levels. *Daphnia* spp., cyclopoids, and calanoids all decreased in numbers throughout the culture season. This decline in numbers is due mostly to fish predation, because larval walleye are zooplanktivors (Fox et al. 1989; Fox and Flowers 1990; Culver and Geddes 1993).

It takes anywhere from 2 to 6 days for chironomid eggs to hatch once deposited (Nolte 1993); however, the chironomid larva population took about 2 weeks to colonize these ponds. Once established, the ponds treated with organic/inorganic fertilizers had more benthic invertebrates, particularly chironomids. However, there was not an overall significant difference between treatments in the benthic samples taken with Hester-Dendy samplers. There was a significant difference between treatments during week 4; the organic/inorganic treatment had significantly more chironomids. The invertebrates responding to an increased organic matter or food base could explain this difference. There
was greater biomass of chironomids in the organic/inorganic treatment during week 4 as well. This can be explained by the greater numbers of chironomids found in this treatment, rather than increased weight, since both treatments had similar average weights. Fox (1989) and Fox et al. (1989) both found dry chironomid biomass in their studies of earthen ponds to average approximately 7g/m² and be as high as 20g/m². We found the chironomid biomass of the plastic-lined ponds to range from 0.34 to 1.58 g/m². This difference can be attributed to the lack of sediments (habitat) for chironomids in plastic-lined ponds. There was no difference between treatments in benthic samples taken with the bucket sampler. There was a difference in magnitude of benthic numbers between the Hester-Dendy samplers and the bucket samples; the Hester-Dendy samples had more chironomids.

When fertilizer is applied to the ponds, particularly the alfalfa pellets, it is thrown at the water’s edge around the pond. Alfalfa pellets tend to accumulate approximately 20-25cm below the water surface. This is the same area where the Hester-Dendy samplers are placed, and where chironomids tend to accumulate. Because chironomid larvae are known to be herbivores, detritivores, and carnivores, they consume algae/phytoplankton, organic matter and zooplankton; most graze on substrate particles, while others are filter feeders (Armitage et al. 1995; Coffman and Ferrington 1996). These variable food habits may explain why most of these invertebrates colonized this ring of organic matter. We also noted that when the bucket samplers were placed in the ponds and also at harvest, there was little sediment on the bottom of the pond. This would explain the difference in numbers between the Hester-Dendy samplers and bucket samplers.

Chironomid larvae can build tubes around themselves in sediment (Armitage et al. 1995), and we observed this in the plastic-lined culture ponds as well. We also observed larvae attached to the sides of the ponds with green tubes around themselves, built from the organic matter.
Furthermore, from the best of our knowledge it was determined that the most common Diptera found in these ponds was Chironomidae, specifically, *Chironomus* species. Merritt and Cummins (1996) describe this genus as generalists who can be found in the littoral zone of lakes and ponds; they construct tubes around themselves, and trophically are herbivores, gathering and shredding their food. From this description, they would do well in the culture ponds, and from our results, we are confident that this genus did in fact colonize the ponds.

As previously mentioned, the organic/inorganic-treated ponds having numerically more chironomid larvae, and subsequently, ponds in the organic/inorganic treatment typically had more emerging adults than the inorganic treatment, however, it was not significant due to the limited degrees of freedom.

Lastly, the fish harvested from ponds in the organic/inorganic treatment were significantly longer and heavier; however, survival and relative weight were not significantly different. This difference could be attributed to the greater benthic populations in the organic/inorganic treated ponds. This study fell short in reaching the production goal set by the Iowa Department of Natural Resources, which was less than 1,760 fish/kg (ca. 0.56g/fish). However the goal of greater than 50% survival was met. Nevertheless, the results of this study point to the importance of organic fertilizers when culturing walleye fingerlings in plastic-lined ponds.

**Acknowledgements**

We would like to thank the Iowa Department of Natural Resources for funding this project. We thank Matt Rogge, Andy Fowler, and Anne Marie Zeller of Iowa State University, and the staff at the Rathbun Fish Culture and Research Facility for their technical support.
Literature Cited


Culver, D.A. and M.C. Geddes. 1993. Limnology of rearing ponds for Australian fish larvae: relationships among water quality, phytoplankton, zooplankton, and the


CHAPTER 3. EFFECTS OF FORMULATED FEED ON THE PRODUCTION OF FINGERLING WALLEYE IN PLASTIC-LINED CULTURE PONDS

Sarah E. Kaatz, Jay Rudacille, and Joseph E. Morris

Abstract

Six 0.04-ha plastic-lined ponds were used at the Iowa Department of Natural Resources' Rathbun Fish Culture and Research Facility to evaluate the use of supplemental fish food on walleye (Sander vitreus) fingerling growth and survival, and on the benthic invertebrate community. Walleye were stocked 3-4 days post hatch on 2 May 2003, and harvested 5-6 June 2003. Organic fertilizer (alfalfa pellets, 112kg/ha/week) was used to increase primary production and inorganic fertilizers were added periodically to maintain a target nutrient ratio of 7:1 nitrate-nitrogen to total phosphorus (NO₃-N: TP). Additional nutrients in the form of Lansy CW fish feed were added to three of the ponds. Benthic invertebrates were sampled weekly with Hester-Dendy samplers, and at harvest with bucket and sweep-net samples. In addition to the plastic-lined culture ponds, twelve plastic pools were set up to determine colonization rate and mode of colonization (over land vs. water supply) of invertebrates, without the predation pressure of the walleye. Organic fertilizers were added to the pools at the same rate as the ponds, and benthic invertebrates were sampled twice during the culture season with Hester-Dendy samplers. The goals of the project, set by the Iowa Department of Natural Resources were to maximize fingerling size (<1,760 fish /kg, ca. 0.548g/fish) and survival (≥50%), and produce uniform size walleye in plastic-lined culture ponds. At the end of the culture season, there were significant differences between water chemistry parameters in the ponds; the feed treatments had higher levels of nitrogenous compounds and total phosphorus. There were no significant differences in zooplankton populations or benthic invertebrate populations in the culture.
ponds, nor were there significant differences in the walleye production parameters. Furthermore, there were no significant differences in water quality or in the numbers of benthic invertebrates between pool treatments. There was however, a significant difference in number of organisms between screened and unscreened pools.

**Introduction**

The fertilization of ponds for the enhancement of primary production is not a new practice. There are two categories of fertilizers: organic and inorganic. Both types have their advantages and disadvantages, but have the common goal of adding nutrients (nitrogen and phosphorus) to enhance primary production. Organic fertilizers not only add nutrients to the pond, but as they break down, they also provide substrate and food for benthic invertebrates (Geiger 1983); however, as they break down there can be oxygen depletions (Johnson and Schlosser 1991). Inorganic fertilizers supply needed nutrients directly to the phytoplankton; conversely, the water chemistry of the pond needs to be monitored, as typically a target ratio of nitrogen to phosphorus is desired (Rhee and Gotham 1980).

Benthic invertebrates, especially chironomids (Order Diptera), are an important food item for many pond-cultured fish (Crowder and Cooper 1982; Fox 1989; Culver and Geddes 1993; Summerfelt et al. 1993; Flowers 1996; Mischke 1999). Colonization rates and modes of colonization are therefore important research foci. However, much of the chironomid literature focuses on colonization of streams or lakes (i.e., Swink and Novotny 1985; Tavcar 1993; Kadono et al. 1999; Ruse 2002). There are a limited number of studies on the colonization of fish culture ponds by chironomids; still there are several studies that look at colonization rates in temporary water bodies or shallow lakes (i.e., McLachlan 1985; Moss and Timms 1989; Matena 1990; Jackson and McLachlan 1991; Bataille and Baldassarre 1993). Currently there are no studies published on the colonization rate of chironomids in plastic-lined fish culture ponds.
Many agencies raise fish for the stocking of lakes and streams. The Iowa Department of Natural Resources has such a stocking program, and their goal is to stock 40 million 203-mm walleye each year. Their stocking program at the Rathbun Fish Culture and Research Facility includes both indoor and outdoor rearing stages. Fertilized eggs are kept inside until hatched, at which point the walleye fry are moved outdoors to plastic-lined ponds. Walleye fingerlings typically eat natural prey in the culture ponds, including zooplankton and benthic invertebrates (Crowder and Cooper 1982; Fox 1989; Culver and Geddes 1993; Summerfelt et al. 1993; Flowers 1996; Mischke 1999). After 5-6 weeks, the walleye fingerlings are brought back inside and reared in cement tanks. It is at this point that they are feed trained and moved back outside until the reach they desired stocking size.

The majority of mortalities occur while the fish are inside being feed trained. The working hypothesis in our study was that by introducing walleye fingerlings to feed before they are brought inside, subsequent mortality would be suppressed. Starting at 3 weeks, walleye in the “feed” treatment were fed Lansy CW feed (58% protein, 14% lipid, and 1.2% phosphorus) from INVE (Salt Lake City, Utah). Ponds in both treatments (feed and no feed) were similarly fertilized with both organic and inorganic fertilizers. Our study is unique in that it not only evaluates the use of supplemental feed for larval walleye, but also the benthic community.

It has been shown that walleye and other fish predators alter the benthic community in both numbers and distribution (Gilinsky 1984, Macchiusi and Baker 1992, Svensson et al. 1999). However, others have found that predators have no effect on the distribution of benthic invertebrates (Thorp and Bergey 1981; Hanson and Legget 1986). Because walleye are known to eat chironomids this could drastically alter our benthic populations and potentially make it difficult to determine the method of colonization as well as the colonization rates. For this reason, microcosms were established to provide a limited picture of the ponds without fish predation.
The goals of the project, set by the Iowa Department of Natural Resources were to maximize fingerling size (<1,760 fish /kg, ca. 0.568g/fish) and survival (≥50%), and produce uniform-size walleye in plastic-lined culture ponds. The objectives of this study were: 1) to determine the effect of a commercial fish diet on benthic populations and fish production, and 2) determine the sources of benthic invertebrates in culture ponds.

Materials and Methods

Study site

This study took place at the Rathbun Fish Culture and Research Facility, Moravia, Iowa. Six 0.04-ha ponds were used to determine the effects of using a formulated feed for the culture of walleye fingerlings. There were three ponds per treatment, which were feed and no feed. Individual ponds were experimental units, and were randomly assigned a treatment. Water from Rathbun Lake was used to fill all ponds. Walleye 3 to 4-days-old were stocked at a rate of 250,000 fish/ha 2 May 2003. Fry were counted using an optical fry counter (Jensorter Model FC2, Jensorter Incorporated, Bend, Oregon). Pools (0.26 m³) were set up in an attempt to determine how chironomids enter the ponds, without walleye predation pressure. Twelve pools were set up in a two-by-two factorial design of filter/no filter, screen/no screen. Water from one culture pond was used as the water supply.

Fertilization

Alfalfa pellets were used as organic fertilizer. At initial flooding of the ponds, organic fertilizer was applied to each pond at a rate of 112 kg/ha. Initial TP was adjusted to 0.10 mg/L at the initiation of the project; phosphorus (12-49-6) was used (0.09 – 0.15 kg). Nitrogen (36-0-0) was added weekly to each pond to maintain a nitrate-nitrogen to total phosphorus ratio (NO₃-N:TP) of 7:1 (Mischke 1999). Inorganic fertilization began 29 April 2003. Total organic fertilizer added to all ponds was 18.1 kg; ponds received variable amounts of inorganic fertilizers to maintain the nutrient ratio (total application 1.02-2.03 kg
in seven applications). Pools received a total of 0.08 kg of organic fertilizer over five applications.

**Feeding**

Feeding started the evening of 14 May 2003. Sweeney feeders, (Model AF3, Boerne, Texas) were mounted on the kettle at the deep end of the pond. When set in the “feed” position, feeders were directly over a submerged light; light was used to concentrate the walleye in an attempt to get them on feed quicker (Howey et al. 1980). The light was powered by a deep cycle 12-volt battery, and regulated by a 12-volt digital timer. Feeders were set to disperse feed every half hour starting at 2100h and ending at 0530h the next morning, for a total of 18 feeding events. The feed was Lancy CW larval diet (58% protein, 14% lipid and 1.2% phosphorus) from INVE (Salt Lake City, Utah). The ratio was 2:1 Lancy CW 4/6 (400-600µm) to Lancy CW 8/12 (600-800µm). The larger size feed was used as a carrier to allow for more even distribution of the smaller diet. The goal was to feed 0.681 kg per day. From the aforementioned ratio, 0.454 kg of Lancy CW 4/6 was fed, which was the small food that the fish could theoretically consume, and 0.227 kg of Lancy CW 8/12 was added as the carrier. Feed was periodically mixed at a 1:9 ratio with a blaze orange fluorescent dye (Day-Glo Color Corporation, Cleveland, OH) to allow for subsequent identification using an ultra-violet light (Morris and D’Abramo 1990).

Fry traps were set periodically for the feeding events (Summerfelt et al. 1996). On 22 May 2003 light traps were set and retrieved the morning of 23 May 2003. Fish caught in traps were taken back to the hatchery building and separated from the large amounts of zooplankton. Fish were taken to a dark room and examined with a ultra-violet light to determine if they had eaten the treated feed.

**Sampling methods**

Incoming water was filtered with a 75-µm Saran sock for 2 hours at the start of pond filling on 20 April 2003. The samples were preserved in 10% formalin and analyzed in the
lab. Water sampling began 21 April 2003. Water samples were collected twice a week (Monday and Thursdays) using a tube sampler to sample the water column. Pond-side water quality testing included pH, temperature, and Secchi disk readings. A YSI Model 60 pH meter (Yellow Springs, Ohio) was used to record pH and temperature. Standards were used weekly to calibrate the pH meter. Water chemistry was conducted using a Hach DR/2010 spectrophotometer (Hach, Loveland, Colorado). Variables analyzed include ammonia-nitrogen (NH$_3$-N), nitrite-nitrogen (NO$_2$-N), nitrate-nitrogen (NO$_3$-N), total phosphorus (TP), and bi-weekly alkalinity and hardness.

Morning (0600h) and afternoon (1500h) temperature and dissolved oxygen levels at the bottom, middle, and top of the ponds were taken twice per week (Tuesdays and Fridays) with a YSI Model 55 Oxygen Meter (Yellow Springs, Ohio).

Water samples for chlorophyll a were collected twice a week (Mondays and Thursdays). Samples of 300-ml were filtered through 47mm glass Microfibre filters using a vacuum pump (Barnant Company, Barrington, Illinois). The filters were frozen and stored in darkness until analysis. Chlorophyll a and phaeophytin levels were analyzed using the procedures described by APHA et al. (1998).

Zooplankton samples were taken twice weekly (Mondays and Thursdays) with oblique tows of an 80-µ Wisconsin net (Wildco Company, Saginaw, WI) and preserved with a chilled formalin/sucrose solution (APHA et al. 1998). Specimens were counted and identified on site using Pennak (1989).

Benthos was sampled using Hester-Dendy slides (Hester and Dendy 1962). Six sets of eight slides were placed into each pond at a depth of 0.3 m. One sampler was retrieved each week (Fridays). Samples were preserved in 10% buffered formalin. Samplers were scraped later and organisms identified to family using Merritt and Cummins (1996). Chironomids were further identified to genus. Since dry weight of Diptera is linearly related
to the width of the head capsule (Smock 1980), we measured chironomids at the middle of the season and at harvest, and used Smock’s regression equation to determine biomass.

Benthic samples were also taken using an inverted bucket. One bucket was placed in the shallow end of each pond one day before harvest. After the ponds were drained, the contents under the buckets were collected and preserved in 10% buffered formalin. Samples were analyzed later, and the area of the bucket was calculated to determine organisms per m².

After the ponds were drained, the benthos was also sampled using an invertebrate net. The net was placed on the plastic lining, and a sweep was taken in each pond. The contents of the net were preserved in 10% formalin, and analyzed later.

Aquatic insect adults were sampled with emergence traps. One trap was placed at the water surface in the shallow end of each pond. Traps were emptied once a week (Fridays). Samples were preserved in chilled formalin/sucrose solution (APHA et al. 1998) and were later identified using Merritt and Cummins (1996).

Fingerlings were harvested 5-6 June 2003. Ponds were drained and fish collected in the catch basin at the end of the pond. Samples of 100 fish from each pond were taken and mean weights and lengths were recorded. Percent survival was calculated, as well as number of fish harvested. Biomass was calculated as kg of fish/ha, and relative weight was calculated using the equation formulated by Flammang et al. (1999). Fish samples were also preserved for stomach content analysis.

The pools were sampled weekly (Fridays) for water chemistry (ammonia-nitrogen (NH₃-N), nitrite-nitrogen (NO₂-N), nitrate-nitrogen (NO₃-N), total phosphorus (TP), pH, and temperature). Two Hester-Dendy samplers were placed in each pool; one sampler was removed half way through the culture period and the other was removed at time of fish harvest. The pools were fertilized at the rate of 112 kg/ha alfalfa pellets per week. Twice during the culture season, the pools were ranked visually by abundance of aquatic invertebrates. At harvest, the pools were disassembled and all contents were removed and
preserved in 10% formalin. Samples were analyzed later; the pool contents were counted and identified to family.

Data analysis

Treatment differences were analyzed using JMP 5.0 (SAS Institute, Cary, North Carolina) to determine significant differences in water chemistry parameters, zooplankton, benthic, and adult aquatic insect populations, as well as fish production parameters. Overall differences between treatments were analyzed via repeated measures, and weekly differences between treatments were analyzed with a t-test. Pool data was analyzed using a factorial design. Significance was also set at $P \leq 0.10$.

Results

Water Filters

The volume of incoming water was determined to allow for calculations of total organisms per liter as well as extrapolation to numbers per pond. The saran (75 µ) sock on one pond blew out due to too much water pressure. The filter sock was replaced, and the amount of water filtered was estimated from the flow rate. The organisms in the incoming water samples were predominately bryozoan statoblasts and zooplankton; there were limited macroinvertebrates in the samples. Organisms were enumerated, and the average number of total organisms, excluding bryozoan, was 0.00029 organisms/L ($\pm 0.00007$). The average number of bryozoan statoblasts was 3.97 organisms/L ($\pm 1.31$). Zooplankton were not counted as they were too damaged to identify or quantify.

Water Quality

Ponds in the “feed” treatment had slightly higher values in nearly every parameter examined (Table 3.1). This was especially true toward the end of the culture season when the fish were being fed; the extra incoming nutrients manifested themselves in higher phosphorus and ammonia readings (Figure 3.1 and Table 3.1). There were overall significant differences between treatments. Ponds in the feed treatment had significantly higher NH$_3$-N,
NO₂-N, and NO₃-N. During week 5, there was a significant difference between treatments; the feed treatment had significantly higher NH₃-N, NO₂-N, and TP. There were also significant differences between treatments in weeks 6 and 7; the feed treatments had higher NH₃-N and TP. However, this did not appear to have much effect on the nutrient ratios of the “feed” ponds (Figure 3.2). The dissolved oxygen levels were affected by the incoming nutrients; there were significant differences between treatments during weeks 4 and 6 with the no feed treatments having higher levels of dissolved oxygen. The “feed” ponds did have elevated chlorophyll a levels; again, this could be due to the higher level of incoming nutrients (Figure 3.3). The only significant difference between treatments in chlorophyll a levels was week 7. There were several rain events throughout the culture season, and a week of cool weather impacted some of the primary production and resulted in clearing of ponds (Figure 3.4).

Table 3.1. Means ± SEs (range) of water quality variables in plastic-lined research ponds under two treatments during the 2003 walleye fingerling culture period at Rathbun Fish Culture and Research Facility, Moravia, Iowa.

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<tr>
<th>Variable</th>
<th>Feed</th>
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</thead>
<tbody>
<tr>
<td>Dissolved Oxygen (mg/L)</td>
<td></td>
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</tr>
<tr>
<td>Morning</td>
<td></td>
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</tr>
<tr>
<td>Bottom</td>
<td>5.44 ± 0.79</td>
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<td>(0.1-14.0)</td>
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</tr>
<tr>
<td>Middle</td>
<td>9.21 ± 0.49</td>
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</tr>
<tr>
<td>(3.3-15.0)</td>
<td>(5.0-16.0)</td>
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</tr>
<tr>
<td>Top</td>
<td>9.12 ± 0.43</td>
<td>9.58 ± 0.45</td>
</tr>
<tr>
<td>(3.7-14.2)</td>
<td>(5.1-16.1)</td>
<td></td>
</tr>
<tr>
<td>Afternoon</td>
<td></td>
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</tr>
<tr>
<td>Bottom</td>
<td>8.31 ± 0.78</td>
<td>9.78 ± 0.71</td>
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<tr>
<td>(0.1-14.6)</td>
<td>(1.4-17.3)</td>
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<td>Middle</td>
<td>10.6 ± 0.58</td>
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<td>(3.9-18.0)</td>
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<td>10.8 ± 0.49</td>
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<td>(5.6-14.4)</td>
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Table 3.1. (continued)

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<td>Temperature (° C)</td>
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<tr>
<td>Morning</td>
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<td></td>
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</tr>
<tr>
<td>Bottom</td>
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<td>17.7 ± 0.47</td>
<td>17.6 ± 0.46</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(14.3-22.6)</td>
<td>(14.1-22.6)</td>
</tr>
<tr>
<td>Middle</td>
<td></td>
<td>18.1 ± 0.47</td>
<td>18.0 ± 0.45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(14.1-23.0)</td>
<td>(14.4-22.9)</td>
</tr>
<tr>
<td>Top</td>
<td></td>
<td>18.2 ± 0.46</td>
<td>18.0 ± 0.45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(14.2-23.0)</td>
<td>(14.4-22.8)</td>
</tr>
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<td>Afternoon</td>
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<td></td>
</tr>
<tr>
<td>Bottom</td>
<td></td>
<td>18.2 ± 0.60</td>
<td>18.3 ± 0.58</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(11.7-23.6)</td>
<td>(12.3-23.2)</td>
</tr>
<tr>
<td>Middle</td>
<td></td>
<td>19.4 ± 0.63</td>
<td>19.3 ± 0.61</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(11.7-24.6)</td>
<td>(12.3-24.2)</td>
</tr>
<tr>
<td>Top</td>
<td></td>
<td>20.4 ± 0.71</td>
<td>20.2 ± 0.70</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(11.7-26.2)</td>
<td>(12.1-26.2)</td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td>8.04 ± 0.21</td>
<td>8.11 ± 0.19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(5.65-9.40)</td>
<td>(5.93-9.42)</td>
</tr>
<tr>
<td>Top</td>
<td></td>
<td>8.21 ± 0.20</td>
<td>8.24 ± 0.18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(5.90-9.46)</td>
<td>(6.27-9.56)</td>
</tr>
<tr>
<td>Secchi disk (m)</td>
<td></td>
<td>1.01 ± 0.06</td>
<td>1.11 ± 0.07</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.30-1.6)</td>
<td>(0.4-1.7)</td>
</tr>
<tr>
<td>Alkalinity (mg/L)</td>
<td></td>
<td>86.4 ± 1.7</td>
<td>86.9 ± 1.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(71.0-100.0)</td>
<td>(76.0-97.0)</td>
</tr>
<tr>
<td>Hardness (mg/L)</td>
<td></td>
<td>135.3 ± 11.4</td>
<td>132.4 ± 9.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(96.0-225.0)</td>
<td>(102.0-219.0)</td>
</tr>
<tr>
<td>Ammonia (NH3-N; mg/L)</td>
<td></td>
<td>0.26 ± 0.03</td>
<td>0.17 ± 0.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.06-0.82)</td>
<td>(0.03-0.39)</td>
</tr>
<tr>
<td>Nitrite (NO2-N; mg/L)</td>
<td></td>
<td>0.01 ± 0.001</td>
<td>0.009 ± 0.004</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.005-0.018)</td>
<td>(0.005-0.014)</td>
</tr>
<tr>
<td>Nitrate (NO3-N; mg/L)</td>
<td></td>
<td>0.2 ± 0.01</td>
<td>0.2 ± 0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.1-0.4)</td>
<td>(0.1-0.4)</td>
</tr>
<tr>
<td>Total Phosphorus (mg/L)</td>
<td></td>
<td>0.09 ± 0.008</td>
<td>0.08 ± 0.008</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0-0.21)</td>
<td>(0.0-0.28)</td>
</tr>
<tr>
<td>Ratio (NO3-N:TP)</td>
<td></td>
<td>3.2 ± 0.4</td>
<td>4.8 ± 1.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0-10.0)</td>
<td>(0.0-66.7)</td>
</tr>
</tbody>
</table>
Figure 3.1. Means and standard errors of total phosphorus (mg/L) concentrations in plastic-lined walleye culture ponds under two treatment regimes, feed and no feed, during the 2003 fingerling culture season at Rathbun Fish Culture and Research Facility, Moravia, Iowa. Black arrow indicates when fish were stocked. Gray arrow indicates when feeding began.
Figure 3.2. Means and standard errors of ratios of nitrate-nitrogen to total phosphorus (NO₃-N:TP) in plastic-lined walleye culture ponds under two regimes, feed and no feed, during the 2003 fingerling culture season at Rathbun Fish Culture and Research Facility, Moravia, Iowa. Dashed line indicates target ratio of 7:1 NO₃-N:TP. Black arrow indicates fish stocking date, and gray arrow indicates when feeding began.
Figure 3.3. Means and standard errors of chlorophyll a (mg/m³) levels in plastic-lined walleye fingerling culture ponds under two regimes, feed and no feed, during the 2003 walleye fingerling culture period at Rathbun Fish Culture and Research Facility, Moravia, Iowa. Gray arrow indicates when feeding began.
Figure 3.4. Temperature and precipitation during the 2003 walleye culture season at the Rathbun Fish Culture and Research Facility, Moravia, Iowa. Black arrow indicates stocking date, gray arrow indicates when feeding began, and white arrow indicates harvest date. Data obtained from http://cdo.ncdc.noaa.gov/dly/DLY, visited 6 November 2003.
**Zooplankton**

There were no significant differences in zooplankton populations between treatments. Ponds in the “feed” treatment, however, typically contained more zooplankton (Figures 3.5, 3.6, and 3.7). There was a significant difference between treatments in week 5; the feed treatment had significantly more cyclopoids. Toward the end of the culture season, the zooplankton numbers began to decline, most likely due to predation pressure from walleye. We noted that, during the night sampling of fry, there were massive amounts of zooplankton in the traps, to the point where water could not flow out of the trap and fish had to be picked from the zooplankton. However, these large numbers of zooplankton are not reflected in the results, possibly because zooplankton were attracted to the light of the night traps or the heat of the light. It has been documented that zooplankton, specifically cladocerans, move up in the water column at night to be near warmer water (Dodson and Frey 2001).
Figure 3.5. Means and standard errors of *Daphnia* spp. densities in plastic-lined walleye fingerling culture ponds under two regimes, feed and no feed, during the 2003 walleye fingerling culture period at Rathbun Fish Culture and Research Facility, Moravia, Iowa. Black arrow denotes stocking date of walleye. Gray arrow indicates when feeding began.
Figure 3.6. Means and standard errors of calanoid copepod densities in plastic-lined walleye fingerling culture ponds under two regimes, feed and no feed, during the 2003 walleye fingerling culture period at Rathbun Fish Culture and Research Facility, Moravia, Iowa. Black arrow denotes stocking date of walleye. Gray arrow indicates when feeding began.
Figure 3.7. Means and standard errors of cyclopoid copepod densities in plastic-lined walleye fingerling culture ponds under two regimes, feed and no feed, during the 2003 walleye fingerling culture period at Rathbun Fish Culture and Research Facility, Moravia, Iowa. Black arrow denotes stocking date of walleye. Gray arrow indicates when feeding began.
Benthos

We found that there was limited diversity in the benthic community. It is estimated that 90% of our samples consisted of chironomids, specifically, *Chironomus*. There were no significant overall differences in chironomids between treatments sampled with Hester-Dendy samplers; however the “feed” treatment had more organisms per sample once feeding commenced (Figure 3.8). There was a significant difference between treatments during week 3; the feed treatments had significantly more chironomids. There were no significant differences in biomass between treatments. The numbers in the Hester-Dendy samplers decreased over time, indicating possible predation by fish. There were no significant differences in chironomids between treatments sampled both with the bucket and sweep-net samplers (Figures 3.9 and 3.10). The overall greatest abundance was found in the sweep-net samples.
Figure 3.8. Means and standard errors of chironomid densities in plastic-lined walleye fingerling culture ponds under two regimes, feed and no feed, sampled with Hester-Dendy samplers, during the 2003 walleye fingerling culture period at Rathbun Fish Culture and Research Facility, Moravia, Iowa. Black arrow denotes stocking date; Gray arrow indicates when feeding began.
Figure 3.9. Means and standard errors of chironomid densities in plastic-lined walleye fingerling culture ponds under two regimes, feed and no feed, sampled by bucket sampler during the 2003 walleye fingerling culture period at Rathbun Fish Culture and Research Facility, Moravia, Iowa.
Figure 3.10. Means and standard errors of chironomid densities in plastic-lined walleye fingerling culture ponds under two regimes, feed and no feed, sampled by sweep net during the 2003 walleye fingerling culture period at Rathbun Fish Culture and Research Facility, Moravia, Iowa.
Emerging Adults

The emerging adults were determined to be chironomids. There was no significant overall difference between treatments in the emerging adults (Figure 3.11). However, there were significant differences between treatments during weeks 4 and 6. During week 4, the no feed treatment had significantly more emerging chironomid adults, whereas in week 6 the feed treatment had significantly more emerging chironomids. In general, the number of adults emerging peaked mid-May and declined steadily thereafter. The treatment that had more larval chironomid (Feed) did not have more emerging adults.

Figure 3.11. Means and standard errors of total emerging adult chironomids from walleye fish culture ponds under two different regimes, feed and no feed, during the 2003 walleye culture season at Rathbun Fish Culture and Research Facility, Moravia, Iowa. Gray arrow indicates when feeding began.
Walleye Stomachs and Feeding

The feed treatments received a total of 8.853kg of fish food per pond. Because protein breaks down into nitrogenous compounds, it contributes to the overall nitrogen parameters. From the feed composition data, it was determined that 58% of the feed was crude protein, and 1.2% was phosphorus.

Periodically, during feeding events, light fry traps were set to capture young fish. The feed was dyed with florescent dye that could be illuminated with a black light. None of the walleye captured during these sampling events had any formulated feed in their stomachs.

The fish stomach contents were also analyzed (Figure 3.12). Two weeks before harvest, the most common food item in stomachs was zooplankton, specifically copepods. At time of harvest, the most common food item found in stomachs was chironomid larvae as well as zooplankton copepods. There was a small number of fish (4 out of 90 sampled, or approximately 4%) that had formulated feed in their stomachs at harvest. It is unclear whether the zooplankton ate the dyed feed, and the fish in turn ate the zooplankton; it appeared that the dyed food was in the zooplankton. Allan (1976) states that copepods, because of their raptorial eating habits, are known to seek out larger particles of food. Therefore, the larger particles that they were eating at this time could have been the formulated feed. There were a few grains of food not associated with the zooplankton; however, no fish sampled had exclusively formulated feed in their stomachs. All fish that had consumed formulated feed also consumed natural prey. There were also many fish that had empty stomachs at time of harvest. Forty-seven percent of the feed treatment fish had empty stomachs at harvest, and 70% of the no feed treatment fish had empty stomachs. There were no significant differences between treatments. This would indicate that the fish were starving at time of harvest, but they were not hungry enough to begin feeding on each other, since no walleye were found in any stomach samples.
Figure 3.12. Stomach contents, as percent occurrence, in walleye at the Rathbun Fish Culture and Research Facility, Moravia, Iowa, during the 2003 culture season.

**Walleye Production**

Walleye production parameters between treatments were similar; there were no significant differences between treatments (Table 3.2). The relative weight index, used as an index for fish body condition, was first introduced by Wege and Anderson (1978) for largemouth bass. Since then, it has been developed for many other fish species, including walleye (Piper et al. 1982). The relative weights are based on a scale of 100, in which a value of 100 indicates good fish health; scores below and above this level reflect.
respectively, fish being robust or thin. In this case, the low relative weights for this culture season indicate that fish were thin; this is probably reflective of the limited prey base for these fish towards the end of the culture season. The IDNR’s production goal of survival was met; however, the desired final weight of the fish was not.

Table 3.2. Mean (±SE) length, weight, survival, biomass, and relative weight of walleyes cultured in plastic-lined research ponds fertilized under two regimes during the 2003 walleye fingerling culture season at the Rathbun Fish Culture and Research Facility, Moravia, Iowa.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Final length (mm)</th>
<th>Final weight (g)</th>
<th>Survival (%)</th>
<th>Fish Biomass (kg/ha)</th>
<th>Relative weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed</td>
<td>42.2 (2.13)</td>
<td>0.436 (0.1958)</td>
<td>80.7 (2.12)</td>
<td>122.7 (12.0)</td>
<td>78.4 (3.76)</td>
</tr>
<tr>
<td>No Feed</td>
<td>39.8 (0.46)</td>
<td>0.482 (0.0189)</td>
<td>82.5 (0.46)</td>
<td>98.6 (5.3)</td>
<td>78.9 (1.05)</td>
</tr>
</tbody>
</table>

Pools

The microcosms had similar water quality; there were no significant differences between the treatments overall (Table 3.3). There was a significant difference between treatments during weeks 3 and 5; the unfiltered unscreened treatment had significantly higher nitrite levels. During week 5 the not filtered unscreened treatment also had significantly higher ammonia. There were no significant differences between benthos sampled by Hester-Dendy samplers (Figure 3.13). Furthermore, there were no significant differences in numbers of benthic invertebrates between treatments (filtered vs. unfiltered, and screened vs. unscreened) from the Hester-Dendy samplers. Chironomids were first observed in the pool areas 2 weeks after they were filled. From observations made on 20 May 2003, the pools with the most chironomids were the unscreened pools. However, on 28 May 2003, the pool
that had the most chironomids was a pool that was screened, but not filtered. From the analysis of the pool contents, we found that there was a significant difference between the screened and unscreened pools in terms of total organisms/m² at the completion of this study. The unscreened pools had significantly more organisms than the screened pools. However, there was no significant difference between the filtered and unfiltered pools in terms of organisms found in pool contents.

Table 3.3. Means ± SEs (range) of water quality variables in plastic microcosms under 4 treatments during the 2003 walleye fingerling culture period at Rathbun Fish Culture and Research Facility, Moravia, Iowa. Treatment abbreviations: FS Filtered and Screened, FNS Filtered and Not Screened, NFS Not Filtered and Screened, and NFNS Not Filtered and Not Screened.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Treatment</th>
<th>FS</th>
<th>FNS</th>
<th>NFS</th>
<th>NFNS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia (NH3-N; mg/L)</td>
<td></td>
<td>0.22 ± 0.03</td>
<td>0.24 ± 0.04</td>
<td>0.19 ± 0.02</td>
<td>0.25 ± 0.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.1-0.41)</td>
<td>(0.09-0.35)</td>
<td>(0.08-0.27)</td>
<td>(0.10-0.39)</td>
</tr>
<tr>
<td>Nitrite (NO2-N; mg/L)</td>
<td></td>
<td>0.012 ± 0.001</td>
<td>0.013 ± 0.001</td>
<td>0.011 ± 0.001</td>
<td>0.014 ± 0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.007-0.015)</td>
<td>(0.006-0.017)</td>
<td>(0.006-0.016)</td>
<td>(0.008-0.021)</td>
</tr>
<tr>
<td>Nitrate (NO3-N; mg/L)</td>
<td></td>
<td>0.3 ± 0.03</td>
<td>0.4 ± 0.06</td>
<td>0.3 ± 0.03</td>
<td>0.4 ± 0.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.2-0.5)</td>
<td>(0.2-0.7)</td>
<td>(0.2-0.5)</td>
<td>(0.3-0.6)</td>
</tr>
<tr>
<td>Total Phosphorus (mg/L)</td>
<td></td>
<td>0.16 ± 0.02</td>
<td>0.14 ± 0.02</td>
<td>0.13 ± 0.01</td>
<td>0.14 ± 0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.08-0.24)</td>
<td>(0.05-0.21)</td>
<td>(0.09-0.18)</td>
<td>(0.09-0.21)</td>
</tr>
<tr>
<td>Ratio (NO3-N:TP)</td>
<td></td>
<td>2.2 ± 0.2</td>
<td>3.1 ± 0.34</td>
<td>2.5 ± 0.26</td>
<td>3.1 ± 0.30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1.25-2.94)</td>
<td>(1.8-4.6)</td>
<td>(1.7-3.8)</td>
<td>(1.8-5.0)</td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td>7.50 ± 0.23</td>
<td>7.84 ± 0.14</td>
<td>7.83 ± 0.12</td>
<td>7.91 ± 0.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(5.81-8.10)</td>
<td>(7.37-8.60)</td>
<td>(7.39-8.30)</td>
<td>(7.41-8.50)</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td></td>
<td>17.7 ± 0.54</td>
<td>18.0 ± 0.52</td>
<td>17.7 ± 0.46</td>
<td>18.2 ± 0.56</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(15.7-19.7)</td>
<td>(16.3-20.0)</td>
<td>(16.1-19.5)</td>
<td>(16.3-21.0)</td>
</tr>
</tbody>
</table>
Figure 3.13. Means and standard errors of benthic invertebrate densities in plastic microcosms sampled with Hester-Dendy samplers during the 2003 walleye fingerling culture period at Rathbun Fish Culture and Research Facility, Moravia, Iowa.
Discussion

Macroinvertebrates, especially chironomids (Order Diptera), are important in the diet of many fish (Crowder and Cooper 1982; Fox 1989; Culver and Geddes 1993; Summerfelt et al. 1993; Flowers 1996; Mischke 1999). In earthen production ponds, the determination of their origin as well as their subsequent management is not as critical given the fact that these invertebrates are able to live and survive between culture seasons in bottom sediments.

The incoming water was therefore filtered to determine the possibility of chironomid colonization via the water supply. We found that very few chironomids came in with the water supply, suggesting that overland oviposition via adults was the mechanism for colonizing ponds. Bryozoan statoblasts were the most common organism in the incoming water; bryozoans commonly occupy incoming water pipelines (Wood 2001). In spite of their abundance, bryozoans are not significant to fish culture, because fish do not eat them.

The use of fish feed did impair pond water quality. The ponds in the “feed” treatment typically had lower dissolved oxygen, and higher nutrient loads as indicated by high levels of NH3-N, NO2-N, and NO3-N. This is mostly likely attributed to the incoming nutrients associated with the fish feed, since feeding fish in an aquaculture setting tends to increase nutrients in the water and can lead to water quality problems (Huner and Dupree 1984; Barrows and Hardy 2001). These increased nutrient levels led to an increase in the amount of primary production, which resulted in increased chlorophyll a levels as well as decreased Secchi disk readings. Because fish were not consuming the feed, it sank to the bottom of the ponds and began to decompose, thereby dropping the oxygen levels. This indicates that possibly the feeding rate was too high, since much of the feed was being wasted, leading to water quality issues. The feed had such an affect on the water quality, especially the dissolved oxygen that concern for the health and survival of fish led to feed being withheld later in the season.
Zooplankton abundance appeared to be affected by the addition of feed. Populations, especially of copepods, appeared to respond to the feed. This may be due to the raptorial nature of copepods, as described by Allan (1976), in that they were actively seeking out organic matter, in this case the formulated feed, to consume. In general, all ponds had sufficient zooplankton numbers to support fish growth (Hoxmeier et al. 2003). However, zooplankton numbers started to decline toward the end of the culture season, most likely due to fish predation.

The benthic numbers were substantially higher in 2003 compared to 2002. There was also significantly more chironomid biomass in 2003 than in 2002. Most likely this is due to seasonal variability and not treatment effects, but it is still an important note. Fox (1989) and Fox et al. (1989) both found dry chironomid biomass in their studies of earthen ponds to average approximately 7 g/m² and be as high as 20 g/m². We found the chironomid biomass of the plastic-lined ponds to range from 3.88 to 8.52 g/m². This difference can be attributed to the lack of sediments (habitat) for chironomids in plastic-lined ponds. Even though there were no significant differences between treatments in benthic abundance, the overall abundance was greater than found in the 2002 culture season. This increase in numbers allowed for a more productive harvest, in terms of larger, healthier fish. However, once the fish were old enough to prey predominately on benthic invertebrates, the numbers started to decline as in 2002.

Overall, the sweep-net samples had the most benthic organisms. This may be because samples were taken from the bottom of the pond upon being drained and fish harvested. The ponds are steeply sloped at this facility, and when they are drained, the water pulls the “sediment” with it, creating a slurry of remaining fertilizer, allochthonous materials, and benthic organisms. This slurry typically ends up on the flat part of the ponds, from which the sweep sample was taken.
Emerging adults were sampled, and consistent with the benthos samples, there were no significant differences between treatments. The peak of the adult emergence was mid-May, and dropped off thereafter.

Studies in striped bass (Morone saxatilis) culture indicate that it is important to start supplemental feeding of larval fish as soon as they are stocked (Fitzmayer et al. 1986; Morris 1989). In our study there was an abundance of natural food for walleye, so it was unlikely that walleye would choose instead the formulated feed. Parker and Geiger (1984) suggested that, for striped bass, feeding be supplemented when fish have depleted their natural food base. This in fact was the case, as there were few pellets found in walleye stomachs; natural food (mostly chironomids) was found. Fish that were sampled earlier in the culture season had mainly zooplankton in their stomachs. Other studies on walleye culture found a similar situation where walleye fingerlings typically consume zooplankton first as a natural food item, and later switch to macroinvertebrates such as chironomid larvae (Fox 1989; Barrows and Hardy 2001; Summerfelt et al. 1993). We found that this switch in diet occurred in the fourth week of culture. Therefore, the use of formulated feed might be best when the natural food base is depleted.

The overall production numbers (survival, final lengths and weights) were up from 2002, and the production goals set by the IDNR were met for this project. The success in this venture is due, in part, to the abundance of natural prey found in ponds. Since there was an increase in the amount of food available, fish were able to grow bigger and have better survival rates.

The pools allowed for a better determination of sources of invertebrates, in particular chironomid larvae, into these plastic-lined culture ponds. Pools were set up next to the ponds to mirror to some extent the pond environment. The first chironomid larvae appeared 2 weeks after filling the ponds, in accordance with (Swink and Novotny 1985) who stated that it took 14 days for Diptera (Chironomidae) to colonize open water, and Matena (1990) who
found larvae in newly filled ponds after 11 days. The filtered vs. unfiltered water yielded no significant differences in invertebrate numbers, each treatment had a few organisms. However, the screened vs. unscreened treatments were significantly different; the unscreened pools had significantly more organisms. This would indicate that the colonization of small bodies of water by chironomid larvae must occur over land, as suggested by Armitage et al. (1995). This would also explain why there were so few chironomid larvae coming in with the water, yet the ponds became heavily populated with them as the culture season progressed.

This study suggests that the feeding of larval walleye in plastic-lined culture ponds is not necessary, especially when there is an abundance of natural prey. The pool study suggests that the method of colonization of chironomids in the culture ponds is occurring by adults flying in overland.

Acknowledgements

We would like to thank the Iowa Department of Natural Resources for funding the project. We thank Andy Fowler, Lisa Kaatz, Ryan Olive, Natasha Schuchmann, and Jason Palmer for their technical support and assistance. We also thank the staff at the Rathbun Fish Culture and Research Facility for their technical support.

Literature Cited


CHAPTER 4. GENERAL CONCLUSIONS

General Discussion

2002

The fertilization of ponds for the management of zooplankton in fish culture ponds has been well studied (Geiger 1983a; Geiger 1983b; Geiger et al. 1985; Fox 1989; Geiger and Turner 1990; Summerfelt et al. 1993; Flowers 1996). However, most studies have occurred in earthen ponds. There are few studies on the effects of fertilization for plastic-lined ponds, and again, most have focused on zooplankton management. This study was intended to look at the effects of fertilization, specifically organic fertilizers, on the benthic community in plastic-lined fish culture ponds. We found that ponds treated with organic fertilizers had more benthic invertebrates, specifically chironomids, and therefore could support a healthier fish community, as seen in the significant differences in weight, length and biomass in walleye harvested from these ponds.

Overall, the water chemistry was affected by the increased nutrients of the organic fertilization treatment. Nitrogen and phosphorus levels were elevated, as were chlorophyll a levels whilst dissolved oxygen levels decreased as primary production increased. These water quality issues were expected, especially the decreased dissolved oxygen, since it can be associated with the use of organic fertilizers (Johnson and Schlosser 1991). With the increase of primary production, the more productive ponds were able to support greater zooplankton biomass.

There were no significant differences in zooplankton or benthic numbers; however, the organic treatment typically increased numbers of invertebrates. There was greater biomass of chironomids in the organic/inorganic treatment during week 4. This can be explained by the greater numbers of chironomids found in this treatment, rather than increased weight, since both treatments had similar average weights. Fox (1989) and Fox et
al. (1989) both found dry chironomid biomass in their studies of earthen ponds to average approximately 7g/m$^2$ and be as high as 20g/m$^2$. We found the chironomid biomass of the plastic-lined ponds to range from 0.34 to 1.58 g/m$^2$. This difference can be attributed to the lack of sediments (habitat) for chironomids in plastic-lined ponds. At harvest, it was noted that there was much more detritus in the organic ponds, potentially acting as substrate and food source for benthic organisms, however, overall sediments are lacking compared to earthen ponds. Subsequently, the final production numbers revealed larger fish in the organically treated ponds. Because only differences in production parameters were significant, we are unable to say whether it is due to the increase in abundance of natural prey or coincidental.

Nevertheless, these results suggest that organic fertilizer was an important aspect in culturing fingerling walleye in plastic-lined ponds at Rathbun Fish Culture and Research Facility. Further work would be helpful in determining a more concrete relationship between organic fertilizer and benthic invertebrate abundance.

**2003 Feed study**

The Iowa Department of Natural Resources has a walleye-stock program in which 203mm walleye are stocked into state lakes. To obtain these large walleye fingerlings, biologists with the Rathbun Fish Culture and Research Facility have undertaken a production protocol that involves pond culture for the first 30-40 days of production and subsequent indoor training period. The majority of fish losses come from when the walleye are brought indoors and feed trained or switched over to formulated feed from the natural food in the ponds. The idea behind this year's study was to introduce formulated feed to the fingerlings before they were brought indoors whereby mortality rates are depressed.

All ponds were fertilized with organic and inorganic fertilizers. The fish in the fed treatment were given 0.454kg/day of Lansy CW 4/6 (INVE, Salt Lake City, Utah). We
found however, that the feed added nutrients and specifically increased ammonia-nitrogen and total phosphorus. We also found the dissolved oxygen dropped over the culture period as more food was added, and several times, feed was withheld because of dangerously low oxygen levels.

The benthic numbers were substantially higher in 2003 compared to 2002. There was also significantly more chironomid biomass in 2003 than in 2002. Most likely this is due to seasonal variability and not treatment effects, but it is still an important note. Fox (1989) and Fox et al. (1989) both found dry chironomid biomass in their studies of earthen ponds to average approximately 7g/m² and be as high as 20g/m². We found the chironomid biomass of the plastic-lined ponds to range from 3.88 to 8.52 g/m².

Overall, there was an abundance of natural food, both zooplankton and benthic invertebrates. Because there was so much natural prey, the likelihood of fish choosing formulated feed over natural food was negligible. In fact, there were very few fish with formulated feed in their stomachs, and these food particles typically were associated with zooplankton. This pattern could change if culture ponds were lacking a natural food base. Walleye fingerlings, if deprived of natural food, may in fact consume formulated feed in the ponds.

**Pool study**

Fish are known to alter the distribution and abundance of their prey, including benthic invertebrates (Gilinsky 1984, Macchiusi and Baker 1992, Svensson et al. 1999). However, other studies have shown that fish may have no effect on the benthic community (Thorp and Bergey 1981, Hanson and Legget 1986). For this reason, we used small pools that mimicked culture ponds, but were free of predation pressure on the benthic community. This project also allowed us to determine the mode of colonization and approximate colonization time through our two treatments: screened, unscreened and filtered, unfiltered.
We found that pools in the unscreened treatment had significantly more chironomids than the others. This led us to believe that the majority of the chironomids colonized the ponds over land. There was no significant difference between filtered and unfiltered water. It was noted the first chironomid larvae appeared 2 weeks after filling.

Final Conclusions & Future Considerations

The plastic-lined ponds at the Rathbun Fish Culture and Research Facility can be heavily influenced by outside events, not only by what is coming in over land, but by the water supply and the reservoir from which it comes. From the filtered water of 2003, we found that zooplankton and benthic invertebrates come in with the Lake Rathbun water supply, albeit in limited numbers. From the pool study, we found that chironomid adults flying in overland were colonizing the pools. Because pools were placed next to the ponds, it can be assumed that the chironomids also were colonizing the ponds. This is a safe assumption because the abundance in the numbers of chironomids does not correlate with the number of larva coming in with the water supply. Therefore, we believe that much of the chironomid colonization of the culture ponds occurred from adults flying overland and depositing eggs on the water surface.

These two studies represent the final years of the fertilization study for walleye culture in plastic-lined ponds funded by the Iowa Department of Natural Resources. Rogge (2002), in the first year of study, examined the role of fertilizers in general (none, inorganic, organic) to the importance of walleye culture in plastic-lined ponds. In the second year of study, organic fertilizer was compared to a mix of inorganic and organic. In 2002, we compared inorganic fertilizer to a mix of organic and inorganic fertilizer, followed by a year study of use of supplemental feeding. From these studies, we have concluded that organic fertilizers are important in the culture of walleye in plastic-lined ponds. The years that organic fertilizers were used, there was more prey available, both zooplankton and benthic invertebrates, to the young fish. However, we noted in each year of the study that nitrogen
was limiting, and that more inorganic nitrogen was added to adjust to the targeted ratios. Alfalfa pellets were the organic fertilizer used throughout the study; however, alfalfa pellets tend to add only a minimal amount of nitrogen to the ponds. Soybean meal, another organic fertilizer, is known to have higher amounts of nitrogen compared to alfalfa pellets (7% for soybean oil meal vs. 2% for alfalfa hay (Snow 1957)). Clouse (1991) stated that soybean meal is 44% protein, and alfalfa meal is 18% protein. Therefore, it may be advantageous to use soybean meal in place of alfalfa pellets as the organic fertilizer in the future.

As stated earlier, walleye fingerlings may consume formulated feed, if the natural prey base is unavailable. In such a case it would be important to feed. However, if one is managing for zooplankton and benthic invertebrates with the application of organic fertilizers and can sustain a natural prey base, formulated feed is not needed for the culture of walleye in plastic-lined fish culture ponds. Furthermore, there are still questions as to the timeline of when food should be added. We noted some fish eating the formulated feed; the zooplankton population was depleted at this time, and the benthic numbers were beginning to decline, however, there was some remnant of the natural food base. It is unclear if we would have had better success getting the walleye on formulated feed if we had waited longer to harvest them, thus giving the natural food base more time to decline. However, this was not a feasible option since we did not want to allow cannibalism in our culture ponds.

In conclusion, for the culture of fingerling walleye in plastic-lined ponds, we recommend managing for a natural prey base of zooplankton and benthic invertebrates with the use of organic fertilizers, and monitoring water quality parameters, such as ammonia nitrogen, total phosphorus, dissolved oxygen, temperature and pH. The application of supplemental commercial fish diets might be useful when the natural food base in the ponds becomes depressed.
Literature Cited


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