New investigations into golden shiner culture

Thomas Kent

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New investigations into golden shiner culture

by

Thomas Emmett Kent

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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
Thomas M. Isenhart
Kenneth Holscher

Iowa State University

Ames, Iowa

2009
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## CHAPTER 2. FEEDING GOLDEN SHINER LARVAE FORMULATED DIETS

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</table>
CHAPTER 1. GENERAL INTRODUCTION

The golden shiner (*Notemigonus crysoleucas*) is a popular baitfish used by anglers that can also be used as a forage fish for other fish. The bright, flashing appearance of this fish has made it the most popular baitfish with fishermen (Dobie et al. 1956; Giudice et al. 1981). Golden shiners are a highly valued baitfish because they have a rapid rate of growth (Flickinger 1971) and in Minnesota they can reach a size for northern pike (*Esox lucius*) bait in the fall of its first year (Dobie et al. 1956). In the northern states, where pond construction is expensive, wild golden shiners are often harvested from natural earthen ponds. With the rapid destruction of natural water areas by pollution and careless construction practices, the attractiveness of using human-made ponds to culture baitfish has increased to meet shortages within the year (Scott and Crossman 1998).

Golden shiners belong to the carp and minnow family Cyprinidae. Golden shiners can survive in a wide variety of habitats and thrive in clear ponds with dense beds of submerged vegetation (Lazur and Chapman 1996). A wide range of water temperatures can be tolerated by golden shiners; their preferred range is 17.2-23.9 °C. They can survive in water as cold as 2 °C, and high mortalities can result if fish are exposed to temperatures above 33.9 °C with upper lethal temperatures near 37.8 °C (Stone et al. 1997). Spawning temperatures and time vary with location. In southern states, this species becomes sexually mature at 1 year at a length of 64.0 mm (Huner and Dupree 1984). Lazur and Chapman (1996) state that most golden shiners attain sexual maturity during their first or second year of life; however, some are known to spawn at 7-8 months of age. Spawning usually commences when water temperatures reach 20 °C (Scott and Crossman 1998), but golden shiners have been observed spawning at water temperatures of 12.8 to 18.3 °C following a
period of warmer weather, indicating that once fish start spawning water temperature is not as critical a factor (Stone et al. 1997). Golden shiners are also relatively tolerant of low oxygen levels (0.2 to 0.3 mg/l).

Light conditions can also play an important role in biological functions, namely spawning periodicity. Light intensity does not seem to play as significant of a role as does light duration. A photoperiod of 15 to 16 hours seems to stimulate spawning (De Vlaming 1975; Rowan and Stone 1996).

Baitfish propagation dates back to the 1920-30s in the East and Midwest, and has been a significant aquaculture industry in the Southeast United States for many years (Flickinger 1971). In the United States the baitfish industry is one of the leading aquaculture industries, ranking third in dollar value (Pounds et al. 1991), with golden shiners leading in sales of baitfish (U.S. Department of Agriculture 2007). The North Central Region (NCR) ranks second only to the Southern Region in cultured baitfish production (U.S. Department of Agriculture 2007). Currently, about two-thirds of the baitfish sold in the NCR come from the wild (Stone et al. 2005). The three primary baitfish species cultured in the NCR in rank order are the fathead minnow (*Pimephales promelas*), the white sucker (*Catostomus commersonii*), and the golden shiner (Gunderson and Tucker 2000). The golden shiner ranked among the top three baitfish sold in four of six states (Illinois, Michigan, Minnesota, Ohio, South Dakota, and Wisconsin) surveyed in the NCR (Meronek et al. 1997).

There are numerous reasons for golden shiner shortages in the NCR, with their popularity as a baitfish being the principle cause of these shortages. Shortages of golden shiners in the summer also reflect transportation problems; many wholesale dealers stop hauling golden shiners from Arkansas, state with largest baitfish industry, because of high
mortality rates associated with handling them during periods of warm water (Gunderson and Tucker 2000). In warm weather, the golden shiner is very delicate and is hard to keep alive (Dobie et al. 1956), so extreme care should be taken when handling during hot weather (Guidice et al. 1981).

There has also been increasing restriction on wild harvest of baitfish, further increasing shortages in the NCR. Wild baitfish producers increasingly experience problems accessing traditional harvest areas because of user conflicts and private land ownership. The spread of exotic species, e.g. zebra mussel (*Dreissena polymorpha*) and Eurasian watermilfoil (*Myriophyllum spicatum L.*), and subsequent regulations limiting baitfish harvest in infested areas, designed to prevent their spread, have further reduced wild baitfish availability to the baitfish market. In addition, some management agencies have applied or are considering harvest restrictions on important baitfish production areas (Gunderson and Tucker 2000). These additional restrictions are in response to increasing concerns regarding the environmental impacts of stocking or harvesting baitfish on duck and game fish populations.

The main biological obstacle to regional production is the limited culture season in the NCR. The culture season is shorter in the NCR (120-150 d) than it is in Arkansas (180 d), the leading state for baitfish production. Culture of goldfish and golden shiners in the southern part of the NCR is limited, but is similar to the methods used in Arkansas (Gunderson and Tucker 2000). In culturing golden shiners or goldfish in the northern part of the NCR, brood fish are stocked around the first of May with spawning taking place soon thereafter. Growth of golden shiners to market size (~86 mm) in the northern part of the NCR nearly always takes more than one growing season (Gunderson and Tucker 2000). A
Michigan study indicated that these fish will not reach 76 mm in length until their second summer (Cooper 1936). One method to address this issue is to provide newly hatched golden shiner fry earlier in the spring, but to date there is simply little information that is available to regional culturists to guide them in out-of-season hatchery operations, e.g., feeds and feeding protocols.

In addition to baitfish markets being driven by different species, they are highly seasonal in nature. In the spring, small (40-60 mm) baitfish are the preferred bait for many crappie (*Pomoxis spp.*) fishermen, while in the summer, largemouth bass (*Micropterus salmoides*) fishermen use medium-sized minnows (80-100 mm), and large minnows or goldfish (*Carassius auratus* [100-130 mm]) are used for trotline fishing. Even larger baitfish (130+ mm) are used when fishing for bass and striped bass (*Morone saxatilis*) in the autumn months (Stone et al. 2005).

To obtain a market-size golden shiner there are both extensive and intensive culture methods. In extensive hatchery operations, fry remain in the same pond with brood fish until harvest time (Dobie et al. 1956). Intensive culture ponds are operated on the principle that greater production can be obtained if the brood fish are maintained in a pond with ideal spawning conditions and the fry or eggs are transferred to culture ponds that have been fertilized, whereby desired invertebrate prey is better managed for use by the fry. Either the egg transfer method or the fry transfer method can be used for intensive culture practices (Stone et al. 1997).

Although it is possible to culture baitfish to marketable size (86 mm) in Minnesota by November of the first year, yields are often low, e.g., only 143 kg/ha were harvested in one study (Mittelmark et al. 1993; Gunderson and Tucker 2000). Generally, little care is
given during the summer months and fish are typically raised on natural pond fertility alone in Minnesota (Engle and Stone 2007).

Culturists can now spawn golden shiners earlier in the season with light and temperature control which would then allow fry to be available earlier in the NCR (De Vlaming 1975; Rowan and Stone 1996). However, a culturist must still feed the fry whether it is pond or tank culture, because suitable natural feed, e.g., zooplankton prey are simply not present in adequate numbers in ponds due to cool temperatures or are difficult to culture in indoor tanks. Thus, a commercial diet needs to be used to feed these fry. The protein requirements for a golden shiner are 40-50% for fry and 28-32% for larger fish (Stone et al. 2005). Effects of feed form (Gatlin and Phillips 1988) and feeding rates (Stone et al. 1993; Rowan and Stone 1995) on golden shiners have been studied, but to date a commercial feed for newly hatched golden shiner fry is still not available.

Golden shiners are omnivorous and will eat any plant and animal life that is small enough for its mouth (Guidice et al. 1981), but zooplankton are more important as food for golden shiners than phytoplankton (Carlander 1969). Ludwig (1989) documented reduced numbers of copepods in ponds with golden shiners as compared to ponds without fish, even when fed a complete diet at 3% body weight/d, confirming the importance of natural food. In general, fry must have adequate zooplankton populations to survive, or at least to be healthy and grow rapidly. Most fry are not particular about the types of zooplankton they will eat, but the animals must be small enough for the fry to ingest. For species with extremely small fish fry, such as sunshine bass (*Morone chrysops x M. saxatilis*) or white bass (*M. chrysops*), small rotifers may be the only zooplankton small enough to eat (Ludwig 1999). For larger fry, small rotifers may not provide enough nutrients to warrant their use.
due to the effort expended to obtain them. Copepod nauplii, newly hatched copepods, are also important first foods for larval fish (Ludwig 1999).

Inconsistent fry survival following their transfer to ponds limits production of healthy market-size golden shiner. One possible reason for this variable survival may be their initial diet as it plays a key role in normal growth, survival, and development of fish fry (Lochmann et al. 2004). Golden shiner fry stocked into fertilized ponds derive much of their nourishment from zooplankton, which is rich in protein and micronutrients. The relative composition of cladocerans and copepods are about 71% protein and 19% lipids (Vijverberg and Frank 1976). Even though there have been numerous studies on fertilization of ponds with organic and inorganic fertilizers for other species, i.e. walleye (Sander vitreus) and striped bass, there appears to be a limited amount of relevant information specific to golden shiner culture. A main question is whether golden shiners can be cultured successfully with just formulated fish diets without a detailed pond fertilization program.

Organic fertilizers, e.g. cottonseed and alfalfa meals, are normally used in golden shiner nursery ponds in combination with inorganic fertilizers, but prepared feeds are added to increase yields substantially (Stone et al. 1997; Lochmann et al. 2004). Given this information, there is a need for refinement of pond fertilization regimes (type and amounts) for golden shiner culture in all regions, but with particular emphasis to the NCR with respect to the shorter culture season as well as cooler water temperatures.

The importance of fertilizers for enhancing pond production in modern fish culture is indisputable (Lannan et al. 1986). The reasoning behind fertilization of production ponds is the same as fertilization of terrestrial crops and grasses – to increase primary production by addition of nutrients which, in turn, allows for increased production of livestock (Mischke
1999). The resulting increased phytoplankton populations then cause the water to become a more intense green coloration that is often referred to as a ‘bloom’. Of all aquatic ecosystems, fertilized hatchery ponds are the most dynamic and challenging to manage for consistent production. Anderson and Tave (1993) state that management success and effectiveness are influenced by important decisions:

- What kinds or sources of nutrients should be purchased?
- When should pond filling be started, i.e., how much time and water are needed before fish are stocked?
- What density and age of fish should be stocked?
- How can a satisfactory quality of fish larvae and environmental variables be achieved so that larvae survive stocking and initiate normal feeding and growth?
- Has the initial survival and growth been satisfactory, or should the pond be drawn down and restocked?
- What kind and how much fertilizer should be added to a given pond today?

The estimation of required nutrients for a pond fertilization program depends on the pond’s morphology, hydrology, bottom materials, and water quality; on the type of fish cultured; and on the type of fertilizer employed (Lannan et al. 1986). Application rates and frequencies can vary greatly depending on region and natural productivity of the pond; set rates are difficult to recommend for a specific taxa (Morris and Mischke 1999). Common application rates of alfalfa hay or pellets in drainable ponds in the NCR are 561-1680 kg/ha applied in 3-5 portions over the 4-6 week culture period (168-336 kg/week) (Harding et al. 1992). Harding et al. (1992) state that fertilizer applications in walleye culture ponds (in
contrast to some fertilizer regimes used in Southern areas) are not determined by water temperature. If the culturist waits for the water temperature to reach 21.1 degrees C, as recommended in the southern region, the walleye culture season could be over before fertilization takes place.

All fertilizers may be classified as either inorganic or organic. Inorganic fertilizers are nutrients in simple inorganic compound form whose primary components contain at least one of the following: nitrogen, phosphorus, and/or potassium (N-P-K). Organic fertilizers are animal manures and plant wastes containing 40-50 percent carbon by dry weight. Unlike chemical fertilizers, these materials usually have a low N-P-K-content and must therefore be used in large quantities (Lannan et al. 1986).

Both inorganic and organic fertilizers have been used in production ponds. Inorganic fertilizers provide rapid doses of nitrogen and phosphorus, which then stimulates the autotrophic food chain (Geiger 1983; Clouse 1991; Mischke 1999). Organic fertilizers stimulate the heterotrophic food web generating a larger decomposer community, which can be directly used by zooplankton as a food source and, at the same time, provide a slow release of inorganic nutrients to algae. Organic fertilizers are thought of as stimulating the food web rather than the food chain because they supply the inorganic release of nutrients for use by the phytoplankton and directly supply nutrients for bacteria, fungi, and protozoans. Information varies widely on the use of no fertilization, organic fertilization, inorganic fertilization, or the combination of organic and inorganic fertilization (Morris and Mischke 1999).

Regardless of the type of fertilizer used, nitrogen and phosphorus nutrients are most important to aquatic systems with a nitrate:total phosphorus ratio of 7:1 having the most
favorable results in fish production in recent regional investigations on walleye culture (Mischke 1999). Repeated applications of fertilizer are often used to promote the continued production of natural food that is then preyed upon by cultured fishes. There are many advantages and disadvantages to both fertilizers. Some of the things to consider when choosing inorganic or organic fertilizers are quality of fertilizer based on N-P-K content, source of food for direct consumption by fish and other fish food organisms, cost per unit N-P-K nutrient, and many others (Lannan et al. 1986). To date, there has not been a detailed analysis of pond fertilization regimes specific to golden shiner culture.

The goal of this study was to investigate and improve golden shiner aquaculture in the NCR. Specific objectives were: 1) determine the best commercial diets for producing age-0 fish beyond the initial 14-d culture period in indoor tanks and 2) determine the efficacy of a detailed fertilization program on pond production of golden shiners.

**Thesis Organization**

This thesis contains two chapters, each consisting of a manuscript to be submitted to an appropriate journal. Both chapters will be submitted to the North American Journal of Aquaculture with the following authorship: Thomas E. Kent, Joseph E. Morris, and Richard C. Clayton. Each chapter is formatted according to the journal instructions, except where thesis requirements conflict.

In addition to the two chapters, this thesis contains General Introduction and General Conclusion sections. Both sections were formatted according to the instructions for the North American Journal of Aquaculture.
References


Engle, C. and N. Stone. 2007. Industry Profile: The Aquaculture of Baitfish. Department of Agricultural Economics, Mississippi State University, Mississippi State, MS.


Rowan, M., and N. Stone. 1996. Off-season spawning of golden shiners. The
Progressive Fish Culturist 58:62-64.


CHAPTER 2. FEEDING GOLDEN SHINER LARVAE FORMULATED DIETS

A paper to be submitted to North American Journal of Aquaculture

Thomas E. Kent, Joseph E. Morris, and Richard C. Clayton

Abstract

Survival of golden shiner *Notemigonous crysoleucas* larvae fed nine different formulated diets was evaluated in 2007 and 2008. Fry (1-d post hatch) were stocked equally into indoor tanks and then pair-wise comparisons were ran to evaluate differences in survival among different prepared foods in 14-d culture trials. In 2007 six diets were evaluated and in 2008 three more diets were evaluated against the best performing diet from the 2007 trials. Stocking rates ranged from 8-40 fry/L. In 2007, only the Zeigler™ AP100 trial resulted in any survival of fry. That diet was then used in 2008 as the control for additional pair-wise comparisons. Results from the 2008 culture season showed Zeigler™ AP100 again yielded the best survival; mean survival ranged from 1-28%, while the other three diets had mean survival that ranged from 4-6%. Results from this study show that more effort needs to be directed toward developing a more nutritionally complete diet for golden shiners. In addition, there is need to refine better culture techniques for growth and survival in indoor tank systems. Better feeds and improved culture methods are also needed to support the growth of the golden shiner industry in indoor systems.

Introduction

The golden shiner, *Notemigonous crysoleucas*, is the most common of the four major cultured baitfish species in the U.S. Although, currently about two-thirds of the baitfish sold in the North Central Region (NCR) come from the wild (Stone et al. 2005), wild baitfish producers face increasingly difficult problems accessing traditional harvest areas because of
user conflicts and private land ownership. The spread of exotic species, e.g. zebra mussel 
(*Dreissena polymorpha*) and Eurasian watermilfoil (*Myriophyllum spicatum L.*), and 
subsequent regulations limiting baitfish harvest in infested areas, designed to prevent their 
spread, have further reduced wild baitfish production. Factors limiting the economic 
viability of baitfish culture in the NCR include extreme variability in climate, limited water 
and land resources (some areas), restrictive regulations, variable market demands across the 
region, and other factors (Gunderson and Tucker 2000). Also, since the original October 
2006 USDA-APHIS VHS ruling that limited the interstate transport of specific fish, there has 
been an increased demand for regionally reared baitfish in the NCR.

Commercial baitfish producers in the southern USA predominantly use egg- or fry-
transfer methods for stocking their production ponds in the spring (Brown and Gratzek 1980; 
transfer methods do, unfortunately, involve moving hundreds of egg-laden mats to rearing 
ponds. The result of these movements often result in less than 40 percent hatch with the rest 
lost to fungus, predators and low dissolved oxygen.

Baitfish producers across the NCR most consistently requested aquaculture research 
for the golden shiner (Gunderson and Tucker 2000). Even though many cultured golden 
shiners are brought into the region from Arkansas, shortages warrant investigations to 
increase golden shiner production in this region. The main obstacles to local production are 
the limited pond culture growing season and the unavailability of golden shiner fry early 
enough in the year to reach market size in one growing season in outdoor ponds (Gunderson 
and Tucker 2000). Although the established baitfish industry is based on pond culture, 
attempts are being made to raise baitfish in closed indoor systems (Gunderson and Tucker}
2000; Stone et al. 2005). Stone et al. (1998) state that tank spawning and hatching is now practiced by a major goldfish (*Carassius auratus*) producer, and has great potential for golden shiner producers. Tank culture of golden shiners is a relatively new technology that is rapidly evolving and improving. It is theoretically possible to produce large numbers of fish indoors with a limited number of broodstock because of their high fecundity (Jenkins and Burkhead 1994).

Out-of-season spawning has been the principal research focus in tank culture of golden shiners. Temperature and photoperiod are known to control gonadal activity in many species of fish (Lam 1983; Hontela and Stacey 1990; Rowan and Stone 1996). De Vlaming (1975) found that 15.5 h of light and 8.5 h of darkness and a temperature of 25 °C induced gonadal maturation in golden shiners. Spawning usually commences when water temperatures reach 20 °C (Scott and Crossman 1998); however, golden shiners have been observed spawning at water temperatures of 12.8 to 18.3 °C following a period of warmer weather, indicating that once fish start spawning, water temperature is not as critical a factor (Stone et al. 1997). Therefore, spawning tank water temperatures should be in the range of 21.7 °C to 25 °C (Stone et al. 1998).

Growth of golden shiners to market size (~86 mm) in the northern part of the NCR nearly always takes more than one growing season. A Michigan study indicated that these fish will not reach 76 mm in length until their second summer (Cooper 1936). One method to address this issue is to provide newly hatched golden shiner fry earlier in the spring, but to date there is simply little information that is available to regional culturists to guide them in out-of-season hatchery operations, e.g., feeds and feeding protocols. The purpose of this study was to use out-of-season spawning to obtain golden shiner fry, culture the fry
intensively for 30 d, and then stock them into earthen culture ponds for advanced growth. The specific objectives were to stock larval fry into tanks and subsequently feed them commercial diets and compare the survival of the fry using the different diets in a 14-d culture trial.

Methods

Golden Shiner fry were obtained from broodstock exposed to increased photoperiod (16 h light/8 h dark) and water temperature (22 °C) to stimulate gonadal maturation over a 2-week period. The broodstock then spawned in tanks on spawning mats placed for 24 hours at the Iowa State University Aquaculture Research Facility (ARF) in 2007 and 2008. In 2007, eggs were collected from March 22 to April 10. Eggs were collected from April 7 to May 23 in 2008. Broodstock used in 2007 were obtained from University of Arkansas-Pine Bluff in November 2006. Broodstock used in 2008 were fry retained from a pond fertilization project during 2007.

Eggs were removed from mats by submerging the mats in a 1.5% sodium sulfite solution for 2 min (Stone et al. 1998). The eggs were then placed into 6-L McDonald-type hatching jars where they hatched in approximately 2 d. The number of newly hatched fry were determined by volumetric displacement and subsequently stocked evenly (8-40 fry/L) into 100-L black fiberglass tanks at random. Each pair-wise comparison used three tanks per diet, with the exception of one comparison in 2007 when six tanks were used per diet. All tanks had in-tank lighting on 24-h/d and water flow was 3 Lpm with a temperature of 22 °C.

Fry were fed at a rate of 5 g/1,000 fry, similar to that used by Summerfelt (1996) for walleye; auger feeders distributed feed every 20 min for 22 h/d with the exception of one diet (dried plankton) that was hand fed twice per day in 2008. All diets were within the
acceptable size range for golden shiner larvae consumption (150-700 μm). However, the smaller food sizes allow for easier consumption because the fry don’t need to nibble on the pellet as is the case with larger food sizes (Rowan and Stone 1995). Six commercial diets were compared for their effect on fish survival (Table 1). In addition to the commercial diets, a proprietary diet manufactured in Minnesota, a dried plankton diet from Mississippi State University, and a krill diet were also tested. The best performing diet in 2007 was used as a control in the 2008 comparisons. Each feeding trial was conducted for 14 d post hatch (dph) and at the end of the test all surviving fry were enumerated. A statistical analysis software package (SAS Institute, Cary, North Carolina) was used to evaluate results using an ANOVA procedure with a p-value of 0.1 considered significant.

Table 1. Diet information (protein and lipid levels) for commercial diets tested in feeding trials at the Iowa State University Aquaculture Research Facility in 2007 and 2008.

<table>
<thead>
<tr>
<th>Commercial Diet</th>
<th>Manufacturer</th>
<th>Protein</th>
<th>Lipids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Otohime B1 200-360 µ</td>
<td>Otohime larval foods, Japan</td>
<td>50%</td>
<td>10%</td>
</tr>
<tr>
<td>Otohime B2 360-620 µ</td>
<td>Otohime larval foods, Japan</td>
<td>50%</td>
<td>10%</td>
</tr>
<tr>
<td>Skretting Nutra HP 300 µ</td>
<td>Skretting fish foods, Vancouver, BC, Canada</td>
<td>50%</td>
<td>17%</td>
</tr>
<tr>
<td>Skretting Gemma 300 µ</td>
<td>Skretting fish foods, Vancouver, BC, Canada</td>
<td>52%</td>
<td>17%</td>
</tr>
<tr>
<td>Zeigler AP100 150-250 µ</td>
<td>Zeigler Bros., Inc., Gardners, PA</td>
<td>50%</td>
<td>12%</td>
</tr>
<tr>
<td>Silver Cup Soft Moist 440-590 µ</td>
<td>Nelson and Sons, Inc., Murray, UT</td>
<td>44%</td>
<td>15%</td>
</tr>
</tbody>
</table>
Results

In 2007 there were five pair-wise comparisons in which six commercial diets were compared for their effects on fry survival to 14 dph. Of those six diets, only one diet (Zeigler™ AP100) had any fry survival through the culture period (Table 2).

Since the Zeigler™ AP100 was the only diet that produced any positive results it then served as the control for the 2008 tank culture season. In 2008, three more diets were evaluated in pair-wise comparisons against Zeigler™ AP100. In the first comparison, fish in the Zeigler™ AP100 trial had a mean survival of 1% ± 0.3 compared with a diet manufactured in Minnesota which had a mean survival of 4% ± 2.0 (Table 3). In the second comparison, the Zeigler™ AP100 treatment had a mean survival of 28% ± 11.7 compared with a Silver Cup™ soft moist diet (krill based) with a mean survival of 4% ± 1.8 (Table 3). In the third comparison, the Zeigler™ AP100 treatment had a mean survival of 8% ± 1.2 compared with a dried plankton diet which had a mean survival of 6% ± 0.5 (Table 3). The only comparison that was significant (P≤0.1) was the Zeigler™ AP100 vs. Silver Cup™ soft moist diet in the second culture season.
Table 2. Mean survival (%) ± SE for each commercial diet in the pair wise comparisons.
Diets fed to golden shiner larvae in 2007 at the Iowa State University Aquaculture Research Facility.

<table>
<thead>
<tr>
<th>Formulated diet</th>
<th>N</th>
<th>Mean(%) ± SE</th>
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<tbody>
<tr>
<td>Otohime B1</td>
<td>3</td>
<td>0 ± 0</td>
</tr>
<tr>
<td>Skretting Nutra HP</td>
<td></td>
<td>0 ± 0</td>
</tr>
<tr>
<td>Otohime B1</td>
<td>3</td>
<td>0 ± 0</td>
</tr>
<tr>
<td>Skretting Gemma</td>
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<td>0 ± 0</td>
</tr>
<tr>
<td>Otohime B1</td>
<td>3</td>
<td>0 ± 0</td>
</tr>
<tr>
<td>Otohime B2</td>
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<td>0 ± 0</td>
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<tr>
<td>Otohime B1</td>
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<tr>
<td>Zeigler AP100</td>
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<td>6 ± 2.2</td>
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<td>Zeigler AP100</td>
<td>6</td>
<td>8 ± 2.2</td>
</tr>
<tr>
<td>Krill</td>
<td></td>
<td>0 ± 0</td>
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Table 3. Mean survival (%) ± SE, and P-value for each diet in the pair-wise comparisons of diets fed to golden shiner larvae in 2008 at the Iowa State University Aquaculture Research Facility.

<table>
<thead>
<tr>
<th>Formulated diet</th>
<th>N</th>
<th>Mean(%) ± SE</th>
<th>P-value</th>
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<tbody>
<tr>
<td>Minnesota diet&lt;br&gt;Zeigler AP100</td>
<td>3</td>
<td>4 ± 2.0 1 ± 0.3</td>
<td>0.51</td>
</tr>
<tr>
<td>Silver Cup soft moist&lt;br&gt;Zeigler AP100</td>
<td>3</td>
<td>4 ± 1.8 28 ± 11.7</td>
<td>0.09</td>
</tr>
<tr>
<td>Dried plankton&lt;br&gt;Mississippi State University&lt;br&gt;Zeigler AP100</td>
<td>3</td>
<td>6 ± 0.5 8 ± 1.2</td>
<td>0.26</td>
</tr>
</tbody>
</table>

**Discussion**

Golden shiners readily accept prepared feeds (Stone et al. 1997) and moderate survival can be obtained for a short period, i.e. 7 d. However, beyond that time period fry survival is poor when reared in tanks (Rowan and Stone 1995). Unfed golden shiner fry held at 25-26 °C die within 6-7 d after hatching. The amount of days of survival after hatch for unfed fry could be increased at cooler water temperatures. We found that fry consumed feeds that were offered to them, but there was limited movement of the diet to the lower digestive tract. We also noted moderate survival to 7 dph, but survival started to decrease substantially around 10 dph.

Starter feeds are normally higher in protein than grower feeds and tend to be more complete in nutrients, especially vitamins (Gray 1988). There are no diets available that are specific for golden shiner culture. Stone et al. (2005) state that golden shiner fry are usually held in tanks 1 or 2 dph until free swimming and that prepared feeds alone are probably not sufficient to sustain newly hatched cyprinid fry. Natural food plays an important role in the
diet of baitfish and research has shown that golden shiners will continue to feed on zooplankton and other natural foods even when a complete diet is fed in ponds (Stone et al. 1997). Digestion of proteins during the early stages in many fish species is characterized by a limited production of digestive enzymes by the pancreas and by an unusual pinocytic intracellular digestion. This requires a source of easily digestible nutrients, which are found in natural zooplankton that contain high concentrations of digestive enzymes, free amino acids, and soluble proteins (Dabrowski and Glogowski 1977). However, there has been little work done specific to golden shiners on how natural foods increase survival beyond 14 dph.

The issue to successfully culture fish larvae that have extremely small mouth gapes is often difficult to address in both marine and freshwater fish culture. Total replacement of live prey is still impossible in marine fish. Sea bass (Centropristis striata) larvae fed formulated diets exclusively from first feeding (0.3 mg larval wet weight), or even from their 2nd week of life onwards, exhibited low survival and poor growth (Le Ruyet et al. 2007). Similar to marine fish, freshwater fish culturists have similar culture concerns. For instance, Brown et al. (2007) states that yellow perch (Perca flavescens) are small at hatching (4–7 mm total length) and are difficult to feed due to their small mouth gape. Zooplankton cultures remain the only viable means of mass propagation, but larvae can be trained to accept formulated feeds in ponds at the age of 30–45 d (Brown et al. 2007).

Beyond merely prey items, physical effects of the culture system also affect fry survival. For instance, Downing and Litvak (2004) state that larval haddock (Melanogrammus aeglefinus) survival was greater in white versus black tanks. Growth of haddock larvae was also impaired in black tanks and the low light reflection may have
prevented the larvae from consuming sufficient food to support growth and survival.

Conclusions garnered from this study indicate that there is a need for dark conditions to allow for inactivity and digestion for this species. In a similar study of Eurasian perch larvae (*Perca fluviatilis* L.), light grey walls produced the best survival and light grey and white walls produced the best growth in weight and length (Tamazouzt et al. 2000). In our studies we used black tanks and light was on for 24 h/d; this may need to be investigated further to see if this culture method could improve growth and survival of the golden shiner fry.

Although live feeds such as brine shrimp (*Artemia*) are often used for newly hatched fry of other species, baitfish producers would probably be reluctant to consider cultured live prey because of the cost and labor requirements (Rowan and Stone 1995), as well as the fact that brine shrimp are simply too large to be consumed by newly hatched golden shiners. In a study conducted on American shad (*Alosa sapidissima*) fed artemia nauplii and dry diet supplements, it was apparent that dry prepared feeds (particularly the Zeigler™ AP100 diet) offered in combination with artemia nauplii enhanced survival, although the reasons for this were not clear. It did appear, however, that particle size of the AP100 diet had an influence as the prepared diet was initially smaller in size than the artemia nauplii (Wiggins et al. 1986). Zeigler™ AP100 is also considered a partial replacement for artemia. Given this information, it is obvious that more research needs to be done to develop a more nutritionally complete diet that supports growth and survival, especially at the onset of exogenous feeding. Also, given the little information on tank culture of golden shiner larval fry we believe that there are many unanswered questions on the best culture methods outside of feeding and feeding practices, such as tank color, light duration and intensity, water flow, and many others.
Acknowledgements

The North Central Regional Aquaculture Program, under grant number 2005-38500-15847, supported this study. We sincerely thank all the undergraduate research assistants who worked on this project to help with all daily activities involved.

References


Gunderson, J.L., and P. Tucker. 2000. A white paper on the status and needs of
baitfish aquaculture in the north central region. NCRAC. Michigan State University,
East Lansing, Michigan.

Scott, and T. J. Lam, editors. Reproductive seasonality in teleosts: environmental
Influences. CRC Press, Boca Raton, Florida.

Fisheries Society, Bethesda, Maryland.

Lam, T. J. 1983. Environmental influences on gonadal activity in fish. Pages 65-116 in
W. S. Hoar, D.J. Randall, and E. M. Donaldson, editors. Fish physiology.

feeding: formulated diets or live prey? Journal of the World Aquaculture Society
24:211-224.

and subsequent fry survival in rearing ponds. Progressive Fish-Culturist 51:229-231.

The Progressive Fish Culturist 57:242-244.

Rowan, M., and N. Stone. 1996. Off-season spawning of golden shiners. The
Progressive Fish Culturist 58:62-64.

Publications, Oakville, Ontario, Canada.


CHAPTER 3. POND CULTURE OF GOLDEN SHINERS

A paper to be submitted to North American Journal of Aquiculture

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Abstract

Organic fertilizer was compared to a mix of organic and inorganic fertilizers for the culture of golden shiners (*Notemigonus crysoleucas*) in 0.08-ha earthen culture ponds in 2007. Age-1 broodstock were stocked (51.6 kg/ha) on May 1, 2007 and all ponds were harvested October 29-November 1, 2007. Organic fertilization consisted of one application of soybean meal at a rate of 9.1 kg/pond/week followed by weekly applications at a rate of 4.5 kg/pond/week for 5 weeks. Nitrogen (36-0-0) fertilizer was used for 4 weeks to adjust nitrate-nitrogen to total phosphorus ratios (NO3-N:TP) to 7:1 on the mixed fertilizer treatment. Water temperature, DO, and pH were all within acceptable ranges for golden shiner pond culture. Nitrite levels were low in both treatments throughout the culture period. Ammonia-nitrogen (TAN) had the largest difference between treatments with the mixed fertilization treatment having elevated TAN levels compared to the organic fertilizer only treatment. Golden shiner fry collected at harvest in the organic only fertilization treatment averaged 71.2 mm ± 8.8 in length while those harvested in the mixed fertilization treatment averaged 82.2 mm ± 4.0. Golden shiner fry in the organic only treatment averaged 4.6 g ± 2.6 in weight while the fry in the mixed fertilization treatment averaged 4.9 g ± 0.8. Total production from this experiment was 537 kg/ha ± 148.7 in the organic only treatment and 548 kg/ha ± 63.5 in the mixed fertilization treatment; total age-0 golden shiner fry numbers harvested averaged 326,215/ha ± 186192 in the organic only treatment and 115,972/ha ± 20764 in the mixed fertilization treatment. The average length, weight, and production
(weight and numbers/ha) were all found to be not significant (P<0.1). Diet selection was evaluated by examination of contents of fish stomachs and *Chydorus* and cyclopoids were the preferred prey species in both treatments.

**Introduction**

Baitfish propagation started in the East and Midwest in the 1920-30s and has been a major agribusiness in the Southeast United States for many years (Flickinger 1971). In the United States, the baitfish industry is one of the leading aquaculture industries, ranking third in dollar value (Pounds et al. 1991), with golden shiners (*Notemigonus crysoleucas*) leading the sales of baitfish (U.S. Department of Agriculture 2007). The North Central Region (NCR) was second only to the Southern Region in cultured baitfish production (U.S. Department of Agriculture 2007). Currently, about two-thirds of the baitfish sold in the North Central Region come from the wild (Stone et al. 2005). The three primary baitfish species cultured in the NCR are fathead minnows (*Pimephales promelas*), white suckers (*Catostomus commersonii*), and golden shiners (Gunderson and Tucker 2000). The golden shiner ranked among the top three baitfish sold in four of six states (Illinois, Michigan, Minnesota, Ohio, South Dakota, and Wisconsin) surveyed in the NCR (Meronek et al. 1997).

To obtain a market-size golden shiner there are both extensive and intensive culture methods used in hatcheries. In an extensive hatchery, fry remain in the same pond with the brood fish until harvest time (Dobie et al. 1956). Intensive culture ponds are operated on the principle that greater production can be obtained if the brood fish are maintained in a pond with ideal spawning conditions and the fry or eggs transferred to growing ponds. Either method can be used for intensive culture practices (Stone et al. 1997).
It is possible to culture baitfish to marketable size (86 mm) in Minnesota by November of the first year, but yields are often low (Mittelmark et al. 1993). Culturists can now spawn golden shiners earlier in the NCR culture season with light and temperature manipulations (De Vlaming 1975; Rowan and Stone 1996). However, even with this new information a culturist must still feed fry whether it is pond or tank culture. Feed may be in the form of live feed, e.g., microcrustacea, or a prepared diet.

The protein requirements for a golden shiner are 40-50% for fry and 28-32% for larger fish (Stone et al. 2005), but a specific diet for baitfish has yet to be developed. However, effects of feed form (Gatlin and Phillips 1988) and feeding rates (Stone et al. 1993; Rowan and Stone 1995) on golden shiners have been studied. Results indicate that golden shiners consume close to 3% of body weight at one time, but take longer to satiate than channel catfish (Ictalurus punctatus). Feeding rates range from 6-11 kg/ha/d (Stone et al. 2005) to 44.8-56 kg/ha/d (Lazur and Chapman 1996). This range has regional variation. Ludwig (1989) documented reduced numbers of copepods in ponds with golden shiners compared to ponds without fish, even when fish were fed a complete diet at 3% body weight/d, confirming the importance of natural food. Golden shiners are omnivorous and will eat any plant and animal life that is small enough for its mouth (Guidice et al. 1983), but zooplankton was found to be more important as food of golden shiners than phytoplankton (Carlander 1969).

Inconsistent fry survival following their transfer to ponds limits production of healthy market-size golden shiner. One possible reason for this variable survival may be their initial diet. Diet plays a key role in normal growth, survival, and development of fish fry (Lochmann et al. 2004); golden shiner fry stocked into fertilized ponds derive much of their
nourishment from zooplankton, which is rich in protein and micronutrients. The relative composition of cladocerans and copepods are about 71% protein and 19% lipids (Vijverberg and Frank 1976). Stone et al. (1997) reported that a combination of fertilizers are normally used on fry nursery ponds and that while pond fertilization remains a common practice, use of prepared feeds, e.g. trout (Salmo spp.) and channel catfish diets, increases yields of golden shiners (Stone et al. 1997; Lochmann et al. 2004). Even with this information it seems apparent that more work needs to be done to find more efficient ways to produce market-size golden shiners by their first year in the NCR.

The importance of fertilizers for enhancing pond production in modern fish culture is indisputable (Lannan et al. 1986). The reasoning behind fertilization of production ponds is the same as fertilization of terrestrial crops and grasses – to increase primary production by addition of nutrients which, in turn, allows for increased production of livestock (Geiger 1983; Boyd 1990; Clouse 1991; Mischke 1999). All fertilizers may be classified as either inorganic or organic. Inorganic fertilizers are nutrients in simple inorganic compound form whose primary components contain at least one of the following: nitrogen, phosphorus, and/or potassium (N-P-K). Organic fertilizers include animal manures and plant wastes containing 40-50 percent carbon by dry weight. Unlike chemical fertilizers, these materials usually have a low N-P-K-content and must therefore be used in large quantities (Lannan et al. 1986) which then can cause depressed dissolved oxygen levels resulting from their decomposition.

Both organic and inorganic fertilizers have been used in culture ponds. Organic fertilizers stimulate the heterotrophic food web generating a larger decomposer community, which can be directly used by zooplankton as a food source and, at the same time, provide a
slow release of inorganic nutrients to algae. Organic fertilizers are thought of as stimulating the food web rather than the food chain because they supply the inorganic release of nutrients for use by the phytoplankton and directly supply nutrients for bacteria, fungi, and protozoans (Mischke 1999). Inorganic fertilizers provide rapid doses of nitrogen and phosphorus, which then stimulates the autotrophic food chain. Regardless of the type of fertilizer used, nitrogen and phosphorus components are most important to the aquatic systems.

To date, there has not been a detailed analysis of pond fertilization regimes specific to golden shiner culture. The purpose of this study was to use two different fertilization regimes, organic only vs. a mix of organic and inorganic fertilizers, to evaluate growth and production of fry in earthen ponds and to evaluate diet selection of fry. The first objective was to determine if there is a difference in growth (total length (mm) and weight (g)) and production (total weight and numbers) based on fertilization regime. The second objective was to determine diet selection of the golden shiner young of year fish.

**Methods**

This study was conducted at the Iowa State University (ISU) Horticulture Station, Ames, Iowa, in May-October 2007. Six 0.08-ha earthen ponds were used to compare the effects of the two pond fertilization regimes on overall fish production. The ponds are rectangular in shape and are 2.44-m deep on the deepest end for possible overwintering of fish species. The ponds were filled with water from an 18-m well that produces about 189 L/min of water 2-weeks prior to the May 1, 2007 stocking date.

Age-1 fish were obtained from University of Arkansas-Pine Bluff in November 2006. Ponds were stocked on May 1, 2007 with broodfish (age-1) at 51.6 kg/ha and allowed to spawn. Artificial spawning mats (18.3 m x 45.7 cm) were placed in each pond to give the
fish substrate to spawn on. Since some of these broodfish were involved in an out-of-season spawning experiment in tanks earlier in the season, they were randomly mixed and stocked into the ponds to limit the effects of the earlier experiment.

The initial application of fertilizer was soybean meal applied to all ponds on May 9, 2007 at a rate of 112 kg/ha, followed by weekly applications of 56 kg/ha for a total of 190.9 kg applied during the culture season. Three of the ponds were selected at random to receive urea nitrogen (36-0-0), hereafter referred to as inorganic, applications to achieve a total nitrate-nitrogen:total phosphorus ratio of 7:1, a ratio previously identified as being the most beneficial to walleye production by Mischke (1999). The inorganic regime was managed during the initial 30-d culture period and was applied four times for a total of 199.2 kg/ha of fertilizer. The organic fertilization regime was continued throughout the culture season as long as water quality was maintained, e.g., total ammonia nitrogen below 1 mg/L and DO levels above 4 mg/L.

In all ponds fish were also fed a supplemental commercial trout diet (Nelson and Sons, Inc., Murray, Utah). Adults were fed at 5% body weight (bw) 3X per week (3.5 mm, 32% protein). Once eggs hatched and fry first appeared, approximately 4 weeks after broodstock were stocked, a smaller salmon fry diet (Nelson and Sons, Inc., Murray, Utah [mash, #0, #1, #2, 52% protein]) was applied 3X per week. The feeding rate was 8.4 kg/ha at a minimum and was increased to 22.4 kg/ha as zooplankton numbers decreased in the pond based on low numbers of organisms (<200/ml). The increase in feeding rate was the same for all ponds and a total of 73.4 kg of broodstock diet and fry diet combined was fed to each pond over the culture period.
Water samples were collected using a tube sampler (~1-m long) to sample the water column. A Hach model HQ40D meter (Hach Chemical Company, Loveland, Colorado) was used to record temperature, dissolved oxygen (DO), and pH ~2 h after sunrise. During the first 30-d culture period, weekly water chemistry included temperature, DO, pH, ammonia-nitrogen (NH$_3$-N; TAN), nitrite-nitrogen (NO$_2$-N), NO$_3$-N, total phosphorus (TP) and everything except temperature, DO, and pH were measured with a HACH DR 3000 spectrophotometer (HACH Chemical Company, Loveland, Colorado). Thereafter, there were weekly recordings for water temperature, pH, DO, and ammonia-nitrogen (NH$_3$-N). Following the initial 30-d culture period there were bi-weekly readings for nitrite-nitrogen (NO$_2$-N), NO$_3$-N, and total phosphorus. All meter readings and water collected for analysis were done ~2 h after sunrise.

Chlorophyll $a$ and phaeophytin levels were analyzed using the procedures described by APHA et al. (1998). 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.

Zooplankton samples were taken weekly using an 80-µ Wisconsin net (Wildco Company, Saginaw, Wisconsin) and preserved with a 4% buffered formalin (APHA et al. 1998). A sample consisted of three oblique tows/pond; one tow midway along the long axis of the pond on each side and one tow from the deep end of the pond. Specimens were later identified and enumerated using Pennak (1989). As previously indicated, these values were used to guide feeding rates in the ponds based on the trend of declining numbers of organisms.
Starting 3 weeks post stocking, benthic samples were collected using an Eckman Dredge (225 cm²) from two, randomly selected locations per pond – one sample collected midway along the long axis of the pond and one at the shallow end. The two samples from each pond were combined and rinsed through a No. 30 sieve (APHA 1998). The samples were then preserved with 4% buffered formalin and organisms later identified and enumerated using Pennak (1989). There were 18 samples collected during the culture period beginning on May 25 and ending October 12.

Fish samples were collected on June 18, July 25, and at harvest (October 29-November 1, 2007) and measured for total length (TL) and weight (Wt). Fish were then returned to the laboratory where stomachs were removed and prey organisms counted and identified. Fish collected on the first two sample dates were collected using a 9.1-m long seine (0.8-mm) immediately after they were fed a diet marked with a fluorescent dye. An orange fluorescent pigment (Day-Glo Fluorescent Pigment, AX-8878, blaze orange, Day-Glo Color Corporation, Cleveland, Ohio) was mixed at a 1:9 ratio (weight:weight) with a starter mash diet. This allowed for easy visual evidence of commercial diet in the gut (Morris et al. 1990). Fish collected at harvest were collected by using a seine with 4.7-mm mesh.

Diet selection was analyzed by the Strauss electivity index (Strauss 1979) to evaluate which organism was selected for, or not selected for. This was done by subtracting the proportion of the organism available in the pond from the proportion of the organism in the fish stomach. This index has a value from -1 to 1, with -1 being not preferred and 1 being a preferred item.
Data Analyses

The two objectives were evaluated with a completely random design (P= 0.1). Growth and fish production were analyzed by a single factor analysis of variance with treatments represented by the organic fertilizer and mixed fertilizer regimes (SAS Institute, Cary, North Carolina). Individual ponds were used as experimental units. Growth (length and weight), production, and diet were assessed after the grow-out phase to November 1, 2008. Pond water quality, zooplankton samples, benthic samples, and chlorophyll $a$ samples were analyzed by the proc mixed procedure to produce a repeated measures analysis of variance.

Results

Fish Production—Golden shiner fry collected at harvest in the organic only fertilization treatment averaged 71.2 mm ± 8.8 in total length and 4.6 g ± 2.6 in weight, while those harvested in the mixed fertilization treatment averaged 82.2 mm ± 4.0 in total length and 4.9 g ± 0.8 in weight (Figures 1 and 2).

The average total golden shiner fry weight harvested from the treatment ponds was 537 kg/ha ± 148.7 in the organic treatment and 548 kg/ha ± 63.5 in the mixed fertilization treatment (Figure 3). Total fry numbers harvested averaged 326,215/ha ± 186192 in the organic only treatment and 115,972/ha ± 20764 in the mixed fertilization treatment (Figure 4). The average length, weight, and production (total weight and numbers/ha) were all found to be not significant (P≤0.1).
Figure 1. Mean total length (mm) ± SE of age-0 golden shiner harvested October 29-
November 1, 2007 at the Iowa State University Pond Aquaculture Research Facility, Ames, Iowa.
Figure 2. Mean weight (g) ± SE of age-0 golden shiner harvested October 29-November 1, 2007 at the Iowa State University Pond Aquaculture Research Facility, Ames, Iowa.
Figure 3. Average total production (kg/ha) ± SE of age-0 golden shiner harvested October 29-November 1, 2007 at the Iowa State University Pond Aquaculture Research Facility, Ames, Iowa.
Figure 4. Average total fry numbers/ha ± SE of age-0 golden shiner harvested October 29-November 1, 2007 at the Iowa State University Pond Aquaculture Research Facility, Ames, Iowa.

Water Quality—Water quality was tested throughout the culture season and of all the parameters tested only TAN, pH, DO, and unionized ammonia nitrogen were found to have significant treatment differences. TAN, pH, DO and unionized ammonia nitrogen were greatest in the mixed fertilization treatment from the middle of June to the end of July. Unionized ammonia in the organic only treatment ranged from 0.01-0.16 mg/L and 0-0.33 mg/L in the mixed fertilization treatment (Figure 8). There was a date effect due to the additional inorganic fertilizer added to the mixed fertilization ponds. After all fertilization (inorganic and organic) was ceased due to high TAN levels in the mixed fertilization ponds, DO, TAN, and pH levels decreased to similar levels regardless of treatment the remainder of
the culture season (Figures 5, 6, 7). The average values for all other water quality parameters tested were not significant (Table 1).

Figure 5. Mean dissolved oxygen (DO) ± SE tested in ponds fertilized with organic only and a mixed fertilizer treatment during the 2007 golden shiner culture season at the Iowa State University Pond Aquaculture Research Facility, Ames, Iowa.
Figure 6. Mean pH ± SE tested in ponds fertilized with organic only and a mixed fertilizer treatment during the 2007 golden shiner culture season at the Iowa State University Pond Aquaculture Research Facility, Ames, Iowa.
Figure 7. Mean total ammonia nitrogen (TAN) ± SE tested in ponds fertilized with organic only and a mixed fertilizer treatment during the 2007 golden shiner culture season at the Iowa State University Pond Aquaculture Research Facility, Ames, Iowa.
Figure 8. Mean unionized ammonia nitrogen ± SE tested in ponds fertilized with organic only and a mixed fertilizer treatment during the 2007 golden shiner culture season at the Iowa State University Pond Aquaculture Research Facility, Ames, Iowa. Line indicates level of concern.
Table 1. Mean values ± SE by treatment for water quality parameters tested in ponds fertilized with organic only and a mixed fertilizer treatment during the 2007 golden shiner culture season at the Iowa State University Pond Aquaculture Research Facility, Ames, Iowa.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Temp (°C) ± SE</th>
<th>DO (mg/L) ± SE</th>
<th>pH ± SE</th>
<th>TAN (mg/L) ± SE</th>
<th>Nitrite (mg/L) ± SE</th>
<th>Nitrate (mg/L) ± SE</th>
<th>Total Phosphorus (TP) (mg/L) ± SE</th>
<th>Unionized ammonia (mg/L) ± SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic only</td>
<td>23.1 ± 0.39</td>
<td>7.8 ± 0.32</td>
<td>8.4 ± 0.13</td>
<td>0.21 ± 0.02</td>
<td>0.01 ± 0.00</td>
<td>0.34 ± 0.03</td>
<td>0.11 ± 0.01</td>
<td>0.04 ± 0.01</td>
</tr>
<tr>
<td>Mixed fertilization</td>
<td>23.5 ± 0.39</td>
<td>8.5 ± 0.30</td>
<td>8.6 ± 0.07</td>
<td>0.37 ± 0.05</td>
<td>0.02 ± 0.00</td>
<td>0.34 ± 0.02</td>
<td>0.10 ± 0.01</td>
<td>0.10 ± 0.02</td>
</tr>
</tbody>
</table>

Chlorophyll $a$ and phaeophytin were analyzed throughout the culture season, but both were found to be not statistically significant. The mean values for chlorophyll $a$ were 18.6 ± 6.7 for organic only and 16.5 ± 4.5 for organic/inorganic. The mean values for phaeophytin were 24.1 ± 11.5 for organic only and 15.8 ± 5.4 for organic/inorganic.

*Macroinvertebrate data*-Benthic samples taken through the culture period were analyzed and almost all samples contained primarily Chironomidae (chironomids). Other benthics that were found in samples were Oligochaetae, Chaoboridae, Coleoptera, Hemiptera, Ephemeroptera, Leptophlebiidae, Zygoptera, Anisoptera, and Amphipoda, with
very few found in any of the samples. Chironomid larvae averaged 686.4/m² for organic only and 588.5/m² for mixed fertilization (Figures 9 and 10); there were no significant treatment differences. No other benthic species averaged over five organisms/m².

Figure 9. Mean number ± SE of chironomidae/m² in ponds fertilized with organic and a mixed fertilizer treatment during the 2007 golden shiner culture season at the Iowa State University Pond Aquaculture Facility, Ames, Iowa.
Figure 10. Mean chironomidae ± SE/m²/treatment/date in ponds fertilized with organic and a mixed fertilizer treatment during the 2007 golden shiner fingerling culture season at the Iowa State University Pond Aquaculture Facility, Ames, Iowa.

Most zooplankton categories were not significantly different in the two treatments with the exception of Ceriodaphnia and most rotifer genera. When all rotifer genera were combined there was a significant difference (P<0.1) between the two fertilizer treatments with a larger number of rotifers in the mixed fertilization treatment. Cladoceran abundance ranged from 0.6 to 49.5/m³ for organic only and 0.37 to 124.8/m³ for mixed fertilization on average throughout the culture season. The most abundant cladocerans were Bosmina, Chydorus, and Daphnia for both treatment types (Figures 11, 12, 13). Copepod abundance ranged from 4.3 to 8746/m³ for organic only and 5.1 to 13311.0/m³ for mixed fertilization. Calanoida, Cyclopoids, and nauplii were all abundant in both treatments with nauplii being
the most abundant in both treatments (Figures 14, 15, 16). Of the rotifers, *Brachionus* and *Keratella* dominated the population in both treatments (Figures 17 and 18).

![Graph showing Bosmina spp. densities over time with dates from May 1 to November 1, 2007. Graph includes data for Organic only and Mixed fertilization treatments. Arrow indicates initiation of fry feeding.](image)

**Figure 11.** *Bosmina* spp. densities in golden shiner culture ponds fertilized with organic and a mixed fertilization treatment during the 2007 golden shiner culture period at the Iowa State University Pond Aquaculture Research Facility, Ames, Iowa. Arrow indicates initiation of fry feeding.
Figure 12. *Chydorus* spp. densities in golden shiner culture ponds fertilized with organic and a mixed fertilization treatment during the 2007 golden shiner culture period at the Iowa State University Pond Aquaculture Research Facility, Ames, Iowa. Arrow indicates initiation of fry feeding.
Figure 13. *Daphnia* spp. densities in golden shiner culture ponds fertilized with organic and a mixed fertilization treatment during the 2007 golden shiner culture period at the Iowa State University Pond Aquaculture Research Facility, Ames, Iowa. Arrow indicates initiation of fry feeding.
Figure 14. Calanoida densities in golden shiner culture ponds fertilized with organic and a mixed fertilization treatment during the 2007 golden shiner culture period at the Iowa State University Pond Aquaculture Research Facility, Ames, Iowa. Arrow indicates initiation of fry feeding.
Figure 15. Cyclopoida densities in golden shiner culture ponds fertilized with organic and a mixed fertilization treatment during the 2007 golden shiner culture period at the Iowa State University Pond Aquaculture Research Facility, Ames, Iowa. Arrow indicates initiation of fry feeding.
Figure 16. Copepoda nauplii densities in golden shiner culture ponds fertilized with organic and a mixed fertilization treatments during the 2007 golden shiner culture period at the Iowa State University Pond Aquaculture Research Facility, Ames, Iowa. Arrow indicates initiation of fry feeding.
Figure 17. *Brachionus* spp. densities in golden shiner culture ponds fertilized with organic and a mixed fertilization treatment during the 2007 golden shiner culture period at the Iowa State University Pond Aquaculture Research Facility, Ames, Iowa. Arrow indicates initiation of fry feeding.
Figure 18. *Keratella* spp. densities in golden shiner culture ponds fertilized with organic and a mixed fertilization treatment during the 2007 golden shiner culture period at the Iowa State University Pond Aquaculture Research Facility, Ames, Iowa. Arrow indicates initiation of fry feeding.

*Stomach analyses*-The organisms that were preferred by fish collected on 6/18/07 in the organic only treatment were *Chydorus* and cyclopoids, with electivity indexes of 0.41 and 0.31, respectively. These two prey items, along with *Keratella*, also appeared in more fish stomachs than any other species (Figures 19 and 20). In the mixed fertilization treatment cyclopoids were the preferred species with an index of 0.36. *Alona* was moderately preyed upon in the mixed fertilization treatment with a Strauss index of 0.17. *Keratella* were also abundant in the stomachs of fish in the mixed treatment, but they were also abundant in the environment and actually had a Strauss index of -0.09 (Figure 19). Cyclopoids, *Chydorus*,...
and *Keratella* by far had the highest % occurrence in fish stomachs in this treatment on this sample date (Figure 20). *Keratella* (0.28 Strauss index) was the most preferred item eaten in the samples pulled on 7/25/07 in the organic only treatment, while *Keratella* (0.27 Strauss index) and cyclopoids (0.44 Strauss index) were preferred in the mixed fertilization treatment (Figure 19).

In the organic only treatment cyclopoids, nauplii, *Brachionus*, and *Keratella* were evenly split in % occurrence, while in the mixed fertilization treatment cyclopoids and *Keratella* occurred in more fish stomachs at a rate of 29% and 19%, respectively (Figure 20). This sample date, however, had a small sample size due to the movement of the fry to deeper water which we could not sample, with the exception of one pond in the organic only treatment. The samples taken at harvest show similar results as the 6/18/07 sample date, with *Chydorus*, cyclopoids, and *Keratella* occurring in more stomachs than any other organisms in both treatments (Figure 20).

Fish stomachs were also analyzed for presence of a formulated diet on the 6/18 and 7/25 sample dates. In the organic only treatment, 77 % of stomachs collected on 6/18 had formulated diet. In a similar fashion, 76% of fish collected from the mixed fertilization treatment had the marked diet. Fish in the organic only treatment had 88% presence of food as compared with 95% of the fish in the mixed fertilization treatment on 7/25.
Figure 19. Percent number in age-0 golden shiner stomachs from culture ponds fertilized with organic and a mixed fertilization treatment during the 2007 golden shiner fingerling culture period at the Iowa State University Pond Aquaculture Research Facility, Ames, Iowa.

Figure 20. Percent occurrence in age-0 golden shiner stomachs from culture ponds fertilized with organic and a mixed fertilization treatment during the 2007 golden shiner fingerling culture period at the Iowa State University Pond Aquaculture Research Facility, Ames, Iowa.
Discussion

The stocking rate, ca. 52 kg/ha, of broodstock used in our study may have been a factor in our production. Stone et al. (1997) states golden shiner broodstock should be stocked at 22.4-44.8 kg/ha when broodstock are reared in the same pond as the larvae. This may have affected some of our production as the larger number of broodstock in our ponds may have preyed upon both eggs and young. Also, since hatching and growth occur in the same pond, parasites and disease easily spread from adults to the young (Stone et al. 1997).

Production using this method is highly variable, ranging from 112.1-560.4 kg/ha of fry due to these problems (Stone et al. 1997). Our golden shiner fry production from this experiment in total weight ranged from 239.7-690.2 kg/ha in organic only treatment and 429.1-646.2 kg/ha in the mixed fertilization treatment. Production was highly variable in the organic only treatment due to a very low number of fish in one of the three ponds and a large number of fish, about half the total number harvested in both treatments, in one of the three ponds. This resulted in very few large golden shiner fingerlings in one pond and a large number of undersized fish in another pond.

Contrary to the Cooper (1936) study, which states that shiners in Michigan will not reach 76 mm until their second summer, we were able to nearly reach that size in one growing season in the organic only treatment and exceeded that length in the mixed fertilization treatment. This shows that either of the fertilization regimes used in this study could be successful in the NCR. However, the organic only treatment might be preferred given the decreased effort needed in applying it compared to the detailed water analyses needed for the mixed treatment.
Although it is possible to culture baitfish to marketable size (86 mm) in Minnesota by November of the first year, yields are often low; only 143 kg/ha were harvested (Mittelmark et al. 1993; Gunderson and Tucker 2000). In our study we nearly reached that size in one growing season, but we had much better yields overall than that study. Again, the use of a pond fertilization program appears to be beneficial in improving golden shiner culture production in this region.

Based on visual observation of the large variation in size and number in two ponds of the organic only treatment, it may have been beneficial to move some of the excess fingerlings into alternate ponds that had a limited number of fry present. This would have allowed more growth through decreased fry stocking densities. However, even with the high variation within the organic only treatment there was still not a significant difference in total weight harvested, total fish harvested, average length, or average weight between the two treatments.

The main difference in pond water quality in this study was with total ammonia nitrogen (TAN). Ponds in the mixed fertilization treatment received an additional amount of nitrogen inorganic fertilizer that served to increase ammonia levels; all ponds received the same amount of soybean meal. This is best illustrated because once fertilization was stopped TAN levels dropped to the organic only treatment levels and then both treatments tracked closely the rest of the culture season. This was not really of concern though since golden shiners are highly tolerable of questionable water quality and are not affected by ammonia until levels reach 2 mg/L (Stone et al. 1997), which was never obtained in this study.

In contrast to TAN levels, there was some concern regarding unionized ammonia levels. Sensitivity of fish to ammonia varies between species and age/size of fish. Lethal
level (acutely toxic concentrates that are predicted to kill 50% of the population over 4 d) is ca. 1.0 mg/L unionized ammonia. However, growth of silver perch (*Bidyanus bidyanus*) was reduced when concentrations were above 0.36 mg/L unionized ammonia over 3 weeks (Barker et al. 2002). In a study of unionized ammonia effects on fathead minnows, it was estimated that the threshold concentration, based on survival, growth, and reproductive success, was 0.27 mg/L unionized ammonia. However, based on the histological damage caused by the higher levels this threshold was estimated to be closer to 0.15 mg/L (Thurston et al. 1986). Ludwig et al. (2007) found that ponds fertilized only with organic fertilizer had lower TAN and unionized ammonia levels, but they did not have a significantly lower crop of zooplankton than ponds that received more nutrient input, i.e. mixed fertilization. This information shows that fish production may have been affected by unionized ammonia levels as it not only has effects on survival, but also on further growth and reproductive success. Given this information, it may be beneficial to fertilize using only organic fertilizers whereby pH, TAN, and unionized ammonia levels are moderated. The result will then be to increase survival and growth while also still maintaining a good standing crop of zooplankton.

Even though *Keratella* were abundant in the ponds it didn’t seem to be the prey that was selected for as overall the golden shiner fry appeared to target larger prey items, e.g., cyclopooids. The consumption of larger prey will result in more energy and protein for a given amount of effort. Hatch (1988) stated that golden shiners do shift from small prey items to larger prey items as they mature. The first shift is from predominantly algae and rotifers to an epiphytic cladoceran diet. The second change is from an epiphytic cladoceran diet to a predominant planktonic cladoceran diet. This shift occurs due to the increase in mouth gape and an enlargement of the digestive tract. This was observed in the fish stomach
samples in this study in which the smaller fish mainly ate *Keratella*, but as the fish began to grow they focused on *Chydorus* and cyclopoids.

It was also noted that very few benthics, i.e. chironomids, were observed in the fish stomachs in this study. Ludwig (1989) found that ponds stocked with golden shiners had significantly fewer copepods but more rotifers than fishless ponds, which is similar to the findings in this study in which cyclopoids and *Chydorus* tended to be the prey more selected for. However, cyclopoids are known to prey upon freshwater fish larvae. Frimpong and Lochmann (2005) found that cyclopoids at a density of 500/L showed significant mortality among larval fish of small sizes. Fish that reach a larger size has a decreased risk of predation. Golden shiners larger than 5 mm total length that are stocked in ponds with fewer than 500 cyclopoids/L would experience little predation.

In nature, newly hatched golden shiner fry are found along the shore in shallow water. As they grow they congregate in schools, and over time, move into deeper water (Stone et al. 2002). This movement would explain why few benthic organisms were found in the stomachs of the fish since benthic invertebrates are near shore. The benthic organisms may also be too large for the larval fry to consume, which may explain why it was so hard to sample any fish with a beach seine on our second sample date.

In summary, it is possible to reach a market size in one growing season with either fertilization treatment. It is still possible to also have harvest yields within normal values no matter what fertilization regime is used even though it is highly variable using the extensive method of culture. It would probably be advised to transfer eggs or fry from the ponds to ensure better survival, growth, and yields with less variability. This study also showed that even though fish were fed a prepared diet they still searched for natural prey. It is also to be
noted that as fry begin to get larger they search for larger prey even though smaller prey may be more abundant.

Implications for future research should include continued refinement of pond fertilization practices specific to golden shiners, increased sampling of larval fish earlier in the culture season to measure the importance of rotifers and smaller invertebrates to fish survival, and the use of alternative sources of nitrogen, e.g., NaNO₃, in place of urea that was used in this study.

The role of the prepared diets in ponds also need further investigating as their influence on the organic loading in these ponds. For instance, in the absence of these diets would it be possible to obtain similar production levels using an appropriate pond fertilization program whereby the invertebrate prey base is maximized? Sampling protocols should focus on zooplankton measurements, but not benthics as they were not utilized by golden shiner larvae in this study.

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References


and practices for aquaculture and fisheries research. NSW Fisheries Animal Care and Ethics Committee, Nelson Bay, Australia.


CHAPTER 4. GENERAL CONCLUSIONS

Baitfish propagation dates back to the 1920-30s in the East and Midwest and has been a significant aquaculture industry in the Southeast United States for many years (Flickinger 1971). In the United States, the baitfish industry is one of the leading aquaculture industries, ranking third in dollar value (Pounds et al. 1991), with golden shiners leading the sales of baitfish (U.S. Department of Agriculture 2007). The North Central Region (NCR) was second only to the Southern Region in cultured baitfish production (U.S. Department of Agriculture 2007). The three primary baitfish species cultured in the NCR in rank order are the fathead minnow (*Pimephales promelas*), the white sucker (*Catostomus commersonii*), and the golden shiner (Gunderson and Tucker 2000). The golden shiner ranked among the top three baitfish sold in four of six states (Illinois, Michigan, Minnesota, Ohio, South Dakota, and Wisconsin) surveyed in the NCR (Meronek et al. 1997).

There are numerous reasons for the golden shiner shortages in the NCR with their popularity as a baitfish being the principle cause of these shortages. The main obstacle to regional production is the limited culture season in this region. The culture season is shorter in the NCR (120-150 d) than it is in Arkansas (180 d), the leading state for baitfish production. The potential role of using out-of-season spawning techniques to culture fish earlier in the season, as well as the efficacious use of a detailed pond fertilization regimes, are two techniques that can be used to address the limited culture season in this region. The objectives were: 1) determine the best commercial diets for producing age-0 fish beyond the initial 14-d culture period in indoor tanks, and 2) determine the efficacy of a detailed fertilization program on pond production.
In 2007 there were five pair-wise comparisons in tanks in which six commercial diets were compared for their effects on fry survival to 14-d post hatch. Of those six diets only one diet (Zeigler™ AP100) had any survival through the 14-d culture period. Since the Zeigler™ AP100 was the only diet that produced any positive results it was carried over to the 2008 tank culture season as the control. In 2008, three more diets were compared in pair wise comparisons using Zeigler™ AP100 as the control. In the first comparison, the Zeigler™ AP100 had a mean survival of 1% ± 0.3 compared with a diet manufactured in Minnesota which had a mean survival of 4% ± 2.0. In the second comparison, the Zeigler™ AP100 had a mean survival of 28% ± 11.7 compared with a Silver Cup soft moist diet that was krill based which had a mean survival of 4% ± 1.8. In the third comparison, the Zeigler™ AP100 had a mean survival of 8% ± 1.2 compared with a dried plankton diet which had a mean survival of 6% ± 0.5. The only comparison that was significant (P=0.1) was the Zeigler™ AP100 vs. Silver Cup soft moist diet.

Beyond merely prey items, physical effects of the culture system also affect fry survival. For instance, Downing and Litvak (2004) state that larval haddock (Melanogrammus aeglefinus) survival was greater in white versus black tanks. Growth of haddock larvae was also impaired in black tanks and the low light reflection may have prevented the larvae from consuming sufficient food to support growth and survival. In a similar study of Eurasin perch larvae (Perca fluviatilis L.) light grey walls produced the best survival and light grey and white walls produced the best growth in weight and length (Tamazouzt et al. 2000). In my study I used black tanks, and light was on for 24 h/d; this may need to be investigated further to see if this culture method could improve growth and survival of the golden shiner fry.
Although live feeds such as brine shrimp are often used for newly hatched fry of other species, baitfish producers would probably be reluctant to consider cultured live prey because of the cost and labor requirements (Rowan and Stone 1995). Given this information it is obvious that more research needs to be done to develop a more nutritionally complete diet that supports growth and survival during the entire culture period. Also, given the little information on tank culture of golden shiner larval fry I believe that there are many unanswered questions on the best culture methods outside of feeding and feeding practices such as tank color, light duration and intensity, water flow, and many others.

In the second objective, I investigated the role of detailed fertilization regimes on fish production and fry diet selection. Golden shiner fry collected at harvest in the organic only fertilization treatment averaged 71.2 mm ± 8.8 in length while those harvested in the mixed fertilization treatment averaged 82.2 mm ± 4.0. Golden shiner fry in the organic only treatment averaged 4.6 g ± 2.6 in weight while the fry in the mixed fertilization treatment averaged 4.9 g ± 0.8. The production from this experiment was 537 kg/ha ± 148.7 in the organic only treatment and 548 kg/ha ± 63.5 in the mixed fertilization treatment; Total age-0 golden shiner fry numbers harvested averaged 326215/ha ± 186192.9 in the organic only treatment and 115972/ha ± 20764.1 in the mixed fertilization treatment. The average length, weight, and production (weight and numbers/ha) were all found to be not significant (P≤0.1).

Stone et al. (1997) states that the broodstock stocking rate should be 22.4-44.8 kg/ha using the extensive culture method. The stocking rate I used, 51.8-53.5 kg/ha, may have affected some of our numbers; excessive number of broodstock in the wild spawn method sometimes results in broodstock preying on eggs and young. Also, since hatching and growth occur in the same pond, parasites and disease easily spread from adults to the young
(Stone et al. 1997). These variables do result in highly variable production values in the wild culture method, 112.1-560.4 kg/ha.

My production from this experiment ranged from 239.7-690.2 kg/ha in the organic only treatment and 429.1-646.2 kg/ha in the mixed fertilization treatment. The production was highly variable in the organic only treatment due to a very low number of fish in one of the three ponds. The numbers of fish in the ponds are also highly variable especially when leaving the fry in the ponds with the broodstock due to the problems previously discussed. This was also seen in this study, especially in the organic only treatment, because there was a large number of fish in one of the ponds, but they were extremely undersized due to the large number of fish in one pond.

The preferred organisms to be eaten were *Chydorus* and cyclopoids no matter the treatment. *Cyclopoids* and *Chydorus* also appeared in more fish stomachs than any other species. *Keratella* was also abundant in the stomachs of fish in the mixed fertilization treatment, but they were also very abundant in the environment. The samples taken at harvest time showed similar results as the earlier sample dates, with *Chydorus* and *Cyclopoids* occurring in more stomachs than any other organisms in both treatments.

Even though *Keratella* were abundant in the ponds it didn’t seem to be the prey that was selected for. Overall, golden shiner fry appeared to target larger prey items. Hatch (1988) stated that golden shiners do have a shift from small prey items to larger prey items that have greater energy and protein. The first shift is from predominantly algae and rotifers to an epiphytic cladoceran diet. The second change is from an epiphytic cladoceran diet to a predominant planktonic cladoceran diet. This shift occurs due to the increase in mouth gape and an enlargement of the digestive tract. This was observed in the fish stomach samples in
this study in which the smaller fish mainly ate keratella, but as the fish began to grow they focused on *Chydorus* and cyclopoids. It was also noted that very few benthics were consumed in the fish stomachs in this study. In nature, newly hatched golden shiner fry are found along the shore in shallow water. As they grow they congregate in schools, and over time, move into deeper water (Stone et al. 2002). This would explain why few benthic organisms were found in the stomachs of the fish. This may also explain why it was so hard to sample any fish with a beach seine on my second sample date.

In summary, it is possible to reach a market size in one growing season with either fertilization treatment. It is still possible to also have harvest yields within normal values no matter what fertilization regime is used even though it is highly variable using the extensive method of culture. It would probably be advised to transfer eggs or fry from the ponds to ensure better survival, growth, and yields with less variability. This study also showed that even though fish were fed a prepared diet they still searched for natural prey. It is also noted that as the fry begin to get larger they search for larger prey even though smaller prey may be more abundant.

**References**


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