Habituation and diet comparison between two types of percid fish

by

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CHAPTER 1. GENERAL INTRODUCTION

Introduction

Walleye (*Sander vitreus*) and yellow perch (*Perca flavescens*) are actively pursued by anglers for sport and food. Walleye (WYE) "is considered to be one of the best eating (sic) of all freshwater fish" (Carmichael et al. 1991) and has a favorable name recognition in stores (Summerfelt 1996a). Yellow perch (YP) "is a highly valued food fish because it has white, flaky flesh that is popular with consumers; this species has been most associated with the traditional Friday-night fish fries" (Hart et al. 2006). Both species are potential aquaculture species for the food fish market in the United States (U.S.).

Walleye fry and fingerling culture started in the mid 1900s and continues today (Summerfelt 1996a). Walleye have been raised in stocking programs as a sport fish within many states and have been stocked into many lakes across the U.S. Conover (1986) reported that in 1983-1984, state, federal and provincial fisheries management agencies in the U.S. stocked more than one billion fry and fingerlings. Although there has been an extensive number of walleye fry and fingerlings produced, information on the culture of advanced size walleye that approach food size is more limited.

Having been stated, there is more information on walleye culture than is available on yellow perch food fish culture. Yellow perch culture information dates back to the mid-1970s when Wisconsin Sea Grant published a yellow perch culture guide (Hart et al. 2006). More recent yellow perch culture publications include Hinshaw (1985) and Hart et al, (2006); nonetheless there is limited practical culture information on yellow perch culture.

In the upper Midwest, the demand for WYE for stocking and food fish, and YP for food fish has been increasing rapidly, but the supply from natural sources has been declining and will not meet increased demand. Commercial harvest of WYE from the Great Lakes and Mississippi River has dropped significantly since the mid 1980s (Summerfelt 1996a). Hart et al. (2006) stated the traditional supply of food size YP has been through commercial harvests from the Great Lakes but supply from natural sources has declined while demand has increased. Because of low supplies and high demand, WYE and YP have gained additional interest as aquaculture species (Summerfelt 1996a; Hart et al. 2006).

Walleye and YP belong to the Percidae family one of the largest groups of North American freshwater fishes. Both species have similar life habits and culture conditions and both accept commercial feeds and are relatively tolerant of intensive culture conditions (Summerfelt 1996b; Hart et al. 2006). Both WYE and YP have similar requirements when it comes to temperature (21 - 24°C), nutrients (40-50% protein), light (low light intensity <10 lux), acceptable water quality (Piper et al. 1982), and tolerance of handling stress.

Hart et al. (2006) and Summerfelt (2005, 2000, 1996b) have published extensive literature reviews on many of the cultural practices for each species. One obvious difference between the two species is that they have different growth rates. There can also be differences in growth rates within a species based on gender. Hart et al. (2006) reported that male YP mature in year 1 or 2 and female perch mature in year 2 or 3. Once perch reach maturity, grow rate slows and they expend energy to develop gamete production (i.e., larger yellow perch at the end of year one are probably females).

A "food size fish" is the size a fish needs to be when it is filleted for a commercial market weight. In the USA, there is a commercial market for WYE at a size of 170-227g skin-on fillet (Summerfelt and Summerfelt 1996). This requires a WYE to be grown to a size larger than 568 g (Summerfelt and Summerfelt 1996).

The minimum size limit for commercial harvest of YP has traditionally been 150 mm or 151 g; however, farmed raised fish are often processed at smaller sizes (Hart et al. 2006). To obtain a food size fish that meets these fillet size categories, a culture period of >12 months is needed for both species. However, if growth rates were compared side-by-side, the walleye should reach the market weight for YP in about 1/3 the time even though the market weight of WYE is thee times the size of YP. If WYE were marketed at a weight similar to YP, they should reach that weight in a shorter period of time reducing overall culture costs, allowing for faster turn around time within a facility.

To obtain a food fish from either species, there are three phases of growth that must take place; fry culture (Summerfelt 1996c; Moodie and Mathias 1996; Moore 1996), habituation to formulated feed (Malison and Held 1996; Nagel 1996; Bristow 1996), and the grow-out phase (Summerfelt and Summerfelt 1996; Held and Malison 1996; Flickinger 1996). One way to produce fry is through pond production. Pond culture of WYE has been described by Summerfelt 2005. Here fry can begin feeding on zooplankton in the water and begin to grow. After they reach a certain size (usually a 30-45 d culture period), the fish are harvested from the pond and placed into tanks to begin the habituation process.

The habituation process is the interval when fish are trained to formulated feed. There have been many studies conducted to evaluate feed and environmental conditions to train the fish to formulated feed (Summerfelt 1996; Hart et al. 2006), but turbid water has not been evaluated. The addition of turbidity in WYE fry culture has shown to have significant effects during the first feeding stage (Bristow et al. 1992; Bristow and Summerfelt 1994). Bristow et al. (1992) noted that a high contrast between feed and the culture water enhanced walleye fry survival. Culture tank visibility may also play a large factor in habituation success for WYE and YP. With YP, Hinshaw (1985) found that a high contrast between feed and tank wall supported the best survival for YP (light level at 205 lux, black tank wall).

Several projects have shown that turbidity level within a culture tank affects distribution of WYE within the tank (Corazza and Nickum 1981; Bristow et al. 1992). One way to alter visibility properties within a tank is with the use of clay slurry (Bristow and Summerfelt 1994). Addition of the clay turns the water a milky-gray color and scatters the light throughout the tank (Bristow et al. 1992). When the brownish-orange colored feed is dropped into the water, there is a greater contrast than when the feed is dropped into clear water.

The combination of pond culture of fry to fingerlings followed by habituation to formulated feed provides an opportunity to culture these fish to larger sizes. Food fish sales in the United States are growing. The U.S. Department of Agriculture’s National

Agriculture Statistics Service (NASS) reported that the U.S. aquaculture industry has grown by 11.7% over the last 7 years (NASS 2006) to $1.1 billion dollars in sales. In 2005, 62% of the values were of food fish (catfish *Ictalurus punctatus*; hybrid striped bass *Morone chrysops* x *M. saxatilis*; tilapia *Oreochromis spp*.; and salmonids *Oncorhynchus spp*.).

One issue with advance fish production is the cost of the feed; fish feed (for food size fish) represents 30-60% of production costs (Stickney 1994; Goddard 1996). Cost-effective, species-compatible, life-stage feeds are needed for fry, fingerling and ultimately food size fish. Typically, fish feeds are formulated for use by one or only a few fish species and for specific life-stage requirements; e.g., starter, growout, and broodstock feeds. The products provided by most feed manufacturers — Nelson & Sons, Inc (Murray, Utah), ARKAT Nutrition Inc. (Dumas, Arkansas), Zeigler Bros, Inc. (Gardners, Pennsylvania), and Rangen Inc. (Buhl, Idaho) — are mostly for trout and related salmonids, channel catfish, and hybrid striped bass. This does not mean that these diets will not work for other species, however, they are not necessarily formulated for other fish species (these manufactures make other types of feed than those listed here and the mention of their names does not imply endorsement). With a major portion of the market share going to only a few food fish, research is needed for diets of emerging species of food fish such as WYE and YP.

Diet consideration and evaluation for WYE production has been an area of interest for many years. In the 1970s, the U.S. Fish and Wildlife Service developed the first open-formula diets labeled the W-series (Beyerle 1975; Colesante 1982). The W-series diet has further evolved from a starter diet to a grower diet (Stettner et al. 1992; Kuipers and Summerfelt 1994; Summerfelt and Clayton 2007). To date, the walleye grower formulation (Barrows and Lellis 1996) is the only commercial manufactured diet for walleye (Nelson and Sons, Inc., Murray, Utah). The current version of this WYE diet is labeled WG 9206 (hereafter referred to as WG). Since this diet has been commercially available for years, it has become the industry standard for fingerling WYE culture to which new experimental diets can be compared.

One consideration that must be made with fish feed is source of the ingredients (feedstuffs). In the past, fish components (meal and oil) from wild stock (menhaden *Brevoortia spp*.) were used as dietary ingredients for manufactured feeds for salmonids and other species. In most aquaculture feeds, fish meals may constitute up to 60% of the total diet (Goddard 1996). If the source of this feed ingredient (wild fish) declines in the future, a replacement to this feed component needs to be found that is readily available and cost effective. Kelly et al. (2002) noted that fish meal is relatively expensive and is becoming less available, especially after El Niño years.

Plant proteins have been intensively studied as alternatives to fish meal. For example, soybean meal can be used in trout feeds with up to 25% replacement of fish meal if it is enriched with methionine (Pillay and Kutty 2005). Flax and soy oils have been used as a replacement for fish oil in open-formula diets for WYE (Summerfelt and Clayton 2007).

Objectives

The comparison of the growth of these WYE and YP during the habituation process has not been reported. Nor has there been much work on the soy-oil diet that has been developed by Summerfelt and Clayton (2007). The objective of one of the two studies in this thesis is to compare the affect of turbid water and clear water culture conditions during the habituation process of pond-run WYE and YP fingerlings. The objective of the second study is to continue the evaluation of a soy-oil open-formula diet for juvenile walleye. Experiments will assist in enhancing culture of these species as a food fish source. This project will undertake this comparison using best information known to date about the culture of both species under separate culture situations.

Thesis Organization

This thesis has been organized with two manuscripts that have been submitted to the North American Journal of Aquaculture for publication in 2007. Chapter 2 contains the manuscript submitted for publication on the habituation performance of two percids to commercial feed under turbid culture conditions. Chapter 3 contains the manuscript submitted for publication on the evaluation of soy-oil open-formula diet for juvenile walleye.

References

Barrows, F.T., and W.A. Lellis. 1996. Diet and nutrition. Pages 315-321 *in* R.C. Summerfelt, editor. Walleye culture manual. NCRAC culture series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Beyerle, G. G. 1975. Summary of attempts to raise walleye fry and fingerlings on artificial diets, with suggestions on needed research and procedures to be used in future tests. The Progressive Fish-Culturist 37:103–105.

Bristow, B.T., R.C. Summerfelt., and R.D. Clayton. 1992. Comparative performance of intensively cultured larval walleye in clear, turbid, and colored water. The Progressive Fish-Culturist 58:1-10.

Bristow, B.T., and R.C. Summerfelt. 1994. Performance of larval walleye cultured intensively in clear and turbid water. Journal of the World Aquaculture Society 25:454-464.

Bristow, B.T. 1996. Extensive-intensive production of advanced fingerling walleye at the Spirit Lake State Fish Hatchery. Pages 209-212 *in* R.C. Summerfelt, editor. Walleye culture manual. NCRAC culture series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Carmichael, G., M. Ring, and J. McCraren. 1991. Sea fare cookbook. Random House, New York.

Colesante, R. T. 1982. 1982 walleye culture. U.S. Fish and Wildlife Service, Diet Testing Development Center, Spearfish, South Dakota.

Conover, M.C. 1986. Stocking cool-water species to meet management needs. Pages 31-39 *in* R.H. Shroud, editor. Fish culture in fisheries management. Fish Culture Section and Fisheries Management Section of the American Fisheries Society, Bethesda, Maryland.

Corazza, L., and J.G. Nickum. 1981. Possible effects of phototactic behavior on initial feeding of walleye larvae. Pages 48-52 *in* L.J. Allen and E.C. Kinney, editors. Proceedings of the bio-engineering symposium for fish culture. American Fisheries Society, Fish Culture Section, Bethesda, Maryland.

Flickinger, S.A. 1996. Production of food fish. Pages 233-235 *in* R.C. Summerfelt, editor. Walleye culture manual. NCRAC culture series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Goddard, S. 1996. Feed management in intensive aquaculture. Chapman and Hall, New York.

Hart, S.D., D.L. Garling, and J. A. Malison. 2006. Yellow Perch (Perca flavescens) culture guide. NCRAC culture series 103. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Held, J.A., and J.A. Malison. 1996. Culture of walleye to food size. Pages 231-232 *in* R.C. Summerfelt, editor. Walleye culture manual. NCRAC culture series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Hinshaw, J.M. 1985. Effects of illumination and prey contrast on survival and growth of larval yellow perch (*Perca flavescens*). Transactions of the American Fisheries Society 114:540-545.

Kelly, A.M., C.C. Kohler, and C.E. Ayala. 2002. Menhaden meal in practical diets for channel catfish fry and fingerlings reared in intensive systems. North American Journal of Aquaculture 64:290-293.

Kuipers, K. L., and R. C. Summerfelt. 1994. Converting pond-reared walleye fingerlings to formulated feeds: Effects of diet, temperature, and stocking density. Journal of Applied Aquaculture 4:31-57.

Malison, J.A., and J.A. Held. 1996. Habituating pond-reared fingerlings to formulated feed. Pages 199-204 in R.C. Summerfelt, editor. Walleye culture manual. NCRAC culture series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Moodie, G.E.E., and J.A. Mathias. 1996. Intensive culture of larval walleye on formulated food. Pages 187-190 in R.C. Summerfelt, editor. Walleye culture manual. NCRAC culture series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Moore, A.A. 1996. Intensive culture of walleye fry on formulated feed. Pages 195-197 in R.C. Summerfelt, editor. Walleye culture manual. NCRAC culture series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Nagel, T. 1996. Intensive culture of fingerling walleye on formulated feeds. Pages 205-207 in R.C. Summerfelt, editor. Walleye culture manual. NCRAC culture series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Pillay, T.V.R., and M.N. Kutty. 2005. Aquaculture principles and practices. Second edition. Blackwell Publishing, Oxford, England.

Piper, R.G., I.B. McElwain, L.E. Orme, J.P. McCraren, L.G. Fowler, and J.R. Leonard. 1982. Fish hatchery management. U.S. Fish and Wildlife Service, Washington, DC.

Stettner, C.R, R. C. Summerfelt, and K. L. Kuipers. 1992. Evaluation of commercial feeds for rearing advanced fingerling walleye. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 46: 402-412.

Stickney, R.R. 1994. Principles of aquaculture. John Wiley & Sons, Inc. New York, New York.

Summerfelt, R.C. 2005. The culture of walleye. American Fisheries Society Symposium 46:373-412.

Summerfelt, R.C. 2000. Walleye culture. Pages 970-985 in R.R. Stickney, editor. Encyclopedia of aquaculture. John Wiley & Sons, Inc., New York.

Summerfelt, R.C. 1996a. Introduction. Pages 1-10 in R.C. Summerfelt, editor. Walleye culture manual. NCRAC culture series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Summerfelt, R.C. 1996b. Walleye culture manual. NCRAC culture series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Summerfelt, R.C. 1996c. Intensive culture of walleye fry. Pages 161-185 in R.C. Summerfelt, editor. Walleye culture manual. NCRAC culture series 101. North

Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Summerfelt, S.T., and R.C. Summerfelt. 1996. Aquaculture of walleye as a food fish. Pages 215-230 in Summerfelt, editor. Walleye culture manual. NCRAC culture series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Summerfelt, R.C., and R.D. Clayton. 2007. Evaluation of open-formula grower diets for juvenile walleyes. North American Journal of Aquaculture 69:53-58.

University of Wisconsin Sea Grant College Program. 1975. Aquaculture: raising perch for the midwest market. University of Wisconsin Sea Grant College Program Advisory Report No. 13. University of Wisconsin Sea Grant College, Madison.

CHAPTER 2. HABITUATION PERFORMANCE OF TWO PERCIDS TO FORMULATED FEED UNDER TURBID CULTURE CONDITIONS

A paper submitted to North American Journal of Aquaculture

Richard D. Clayton and Joseph E. Morris

Abstract

Advanced fingerling walleye (*Sander vitreus*) or yellow perch (*Perca flavescens*) are produced by habituating pond-reared fingerlings to commercial feed. Success of the habituation process depends on many variables, e.g., light source, light duration, temperature, feed, stocking density, and size at harvest. Among these, diet contrast/visibility is an important variable for habituation success. The objective of this study was to compare the effect of turbid water (≥ 100 NTU) and clear water culture conditions during the habituation process for these two species. In 2005 and 2006, twelve 150-L black-cuboidal tanks with in-tank lighting were stocked at a rate of 2 g/L (initial weight; walleye 1.47 g, yellow perch 0.65 g and 0.36g in the second year) with half of the tanks receiving turbidity (clay slurry) and cultured for 28-d. All fish were fed EPAC CW diet every 5 min during a 16-hour daylight interval at 10% body weight/d. In 2005, walleye in the clear treatment had higher survival 83 ± 1.99%, (P=0.014) than the turbid treatment 57 ± 5.97%. The yellow perch in 2005 exhibited opposite survival results; turbid treatment (79 ± 2.1%), clear treatment (54 ± 9.2%, P>0.05). In 2006, there were no significant differences (63-69%) in yellow perch survival between clear and turbid water culture. Differences in yellow perch survival between years may have been due to age and size at stocking at initiation of the habituation phase. These results demonstrate that the addition of clay may enhance the contrast of the feed and thus improving the habituation process for yellow perch.

Introduction

Fish fry rely on their yolk sac for energy after hatching. Once the yolk sac has been absorbed, and the fish change over to exogenous feed, they enter the first critical culture period (often called the first-feeding stage). During pond-production of percids, this first feeding takes place with natural prey as a food source in the culture pond. Many culture regimes end at this point when the fish are harvested and subsequently stocked as fingerlings. However, to be successful at producing an advanced fingerling walleye (*Sander vitreus*, WYE) or yellow perch (*Perca flavescens*, YP), fish have to be converted over to commercial feeds for further grow-out, hereafter referred to as the habituation phase.

In percids, this phase takes place when pond-run fish are harvested and stocked into tanks for further culture (Malison and Held 1995). Kuipers and Summerfelt (1994) described the habituation process. Moore et al. (1994) further describes this habituation process for WYE using a tandem pond-tank technique.

Malison and Held (1992, 1995), and Kestemont and Mélard (2000) further describe several variables that affect the outcome of the habituation phase, e.g., light source, light duration, temperature, feed, stocking density, and size at harvest (Table 1). These studies, among others, describe culture factors that play a role in the success of the habituation phase.

Walleye and YP are morphologically similar species in the same family (Ney 1978). Walleye hatch at 7.0-9.5 mm and YP hatch at 4.5-7.0 mm; both are photopositive (Ney 1978) at this stage. With these similarities, there are still differences. During their first summer, WYE fingerlings become piscivorous and YP fingerlings continue to eat invertebrates (Ney 1978). Walleye growth is also more temperature dependant while YP growth is more photo-period dependant (Ney 1978).

Another difference is the way that these two percids respond to light. It has been noted that YP feeding activity decreased during the night time hours in contrast to WYE preference for feeding at this same time (Carlander 1997; Post 1990). In addition, WYE were more active during the day when turbidity or cloud cover was present. Ney also noted that El-Zarka (1959) found that turbidity in Lake Huron hindered YP growth in the first year of life. Given these past studies, diet visibility may play a significant role in the habituation success.

Bristow et al. (1992) noted that a high contrast between feed and the culture water enhanced walleye fry survival. Culture tank visibility may also play a large factor in habituation success for WYE and YP. With YP, Hinshaw (1985) found that a high contrast between feed and tank wall supported the best survival for YP (light level at 205 lux, black tank wall).

Several projects have shown that the turbidity level within a culture tank affected the distribution of WYE within the tank (Corazza and Nickum 1981; Bristow et al. 1992). One way to alter the visible properties within a tank is with the use of clay slurry (Bristow and Summerfelt 1994). They describe how turbidity might alter the visible properties of the culture tank. With the addition of clay, the water turns a milky-gray color and scatters light throughout the tank (Bristow et al. 1992). When the brownish-orange colored feed is dropped into the water, there is a greater contrast than when the feed is dropped into clear water.

Since the addition of turbidity in walleye fry culture has shown to have significant effects during the first feeding stage (Bristow et al. 1992; Bristow and Summerfelt 1994), we wanted to investigate if there are similar effects of turbidity during the habituation process (28-d) of two percid species, WYE and YP, during the 2005 and 2006 culture seasons. The objective of this study is to compare the effect of turbid water and clear water culture conditions during the habituation process of pond-run WYE and YP fingerlings.

Methods

Fish.— Pond-run fish were harvested and transported to the Aquatic Research Campus Facility (ACRF) at Iowa State University and were gravimetrically stocked at 2 g/L. For both the 2005 and 2006 culture periods, WYE were obtained from the Iowa Department of Natural Resources Spirit Lake Hatchery. All of the WYE in the second year died on the second day post stocking from an outbreak of *Columnaris*. In 2005, YP were obtained from Shady Lane Fish Farm, Illinois. In 2006 the YP were obtained from Fishberry Fish Farm, Nebraska. Both WYE and YP were 45-79 d of age at the initiation of the experiment (Table 2).

Culture facility and experimental design.— In 2005, twelve 150-L black-cuboidal tanks were stocked at a rate of 2 g/L (300 g/ tank) of WYE (204 fish) or YP (459 fish) with six tanks per species. Flow rates were set at ~ 1.25 Lpm or 0.5 exchanges/h. Fish were cultured in flow-through system with dechlorinated municipal tap water. In 2006, the stand-pipes were cut down to create a tank volume of 100 L. This was due to the smaller fish size that was available and this allowed the stocking weight to be kept the same previous year. Yellow perch were then stocked at the same 2 g/L with a total of 835 fish stocked per tank. Each year, turbidity was maintained ≥ 100 NTU within six tanks (three per species) using the method described by Bristow and Summerfelt (1994). Tank covers were used to limit the light and stress level of the fish in the tank. Tanks were siphoned and cleaned three times/wk.

Water quality.— Dissolved oxygen (DO), turbidity, and temperature were measured daily. Ammonia (TAN), pH, hardness, and alkalinity were measured twice during the experiment (beginning and end). Temperature was measured with a glass thermometer (±0.1 °C). Dissolved oxygen was measured with an oxygen meter (Model #57, Yellow Springs Instrument Company) calibrated by the Winkler method (APHA et al. 1998). Turbidity was measured with a 90° scattered-light turbidimeter (Hach model 2100P, Hach Co., Loveland Colorado). Total alkalinity at pH 4.6 and hardness (ManVer 2 method) were measured by titration in each culture tank (APHA et al. 1998). The Nesslerization method (APHA 1998) was used to measure total ammonia nitrogen (TAN). The pH was measured electrometrically with a standard combination electrode and meter.

Feed and light.— Fish were fed the EPAC CW diet (INVE Aquaculture Inc., Ogden Utah) during a 16-h daylight interval (8-h night period). In-tank lighting was used (Siegwarth and Summerfelt 1992) at a low level <10 LUX measured at the surface of the clear tanks. Fish were initially fed size 6/8 mm diet and then transitioned up to the 8/12 mm and 8/20 mm diet. At the time of this study, the EPAC diet was the most successful diet for walleye habituation (J.A. Johnson, Iowa Department of Natural Resources, personal communication). Feed was dropped into the tank from an automatic auger-type feeder every 5 min during the 16-h light period at 10% body weight/d (bwd) initially.

Twenty-five fish from each tank were weighed weekly. Feeders were then recalibrated to maintain the 10% bwd rate. This feeding rate was probably in excess of satiation and maintenance requirements so as to not limit growth or feed acceptance.

Statistical analysis— A completely randomized experimental design was used. Trials were analyzed with a single factor analysis of variance with treatments represented by turbid or clear water ($P \leq 0.05$). Experimental units, six tanks per species, with three replicates (tanks) per treatment were used. Data were analyzed using StatView, 5.0.1 (SAS Institute Inc., North Carolina). All values reported are means ± standard error. Survival (%), normalized biomass index (NBI, unit less), and specific growth rates (SGR, %/d) were calculated. NBI was first described by Conklin et al (1975) as a method to illustrate growth responses with variable survival. Specific growth rate (SGR), where $SGR = [(LnWt_{t2} - LnWt_{t1})/t \text{ (days)}] \times 100$ and NBI (Normalized biomass index) = $[(Wt_{t2}*$ # harvested)-$(Wt_{t1}*$# stocked)]/#stocked were calculated.

Results and Discussion

Water quality.— For both years, all other parameters pH, TAN, nitrite, and nitrate showed small variation but were within an acceptable range for fish culture (Colt and Tomasso 2001). Water quality parameters in 2005 for WYE were similar for treatments (Table 3). The average temperature of 20.5 ± 0.01 °C which was close to the 22 °C optimum level for walleye as reported by Smith and Koenst (1975). Mean DO was 7.1 ± 0.12 mg/L for the clear treatment and 7.3 ± 0.05 mg/L for the turbid treatment. Turbidity, 110.9 ± 4.45 NTU, for the turbid treatment and 0 NTU for the clear water treatment, was obviously significantly different ($P<0.001$).

Water quality for YP in 2005 was similar to that of WYE (Table 3). Temperature averaged 20.5 ± 0.01 °C for both treatments. Dissolved oxygen was 7.2 ± 0.06 mg/L and 6.9 ± 0.15 mg/L for the clear and turbid treatments, respectively. Turbidity was the only different variable between the two treatments, 102.9 ± 7.1 NTU for the turbid treatment and 0 NTU for the clear water treatment ($P<0.001$).

In 2006, the YP water quality parameters were similar to those in 2005 (Table 3). Temperature averaged 20.7 ± 0.01 °C for both treatments. Dissolved oxygen was 6.8 ±

0.14 mg/L and 6.8 ± 0.12 mg/L for the clear and turbid treatments, respectively. Turbidity was the only significantly different variable between the two treatments.

Growth.— In 2005, the WYE in the clear treatment had significantly higher survival (P=0.014), 83 ± 2.0% compared to 57 ± 6.0% for the turbid treatment (Table 2). However, there was a significant difference in fish size at the end of the 28 d culture period. The WYE in the turbid treatment were 6.2 mm longer and 7.84 g heavier than those in the clear treatment (P<0.05, Table 2). The normalized biomass index for each treatment was calculated and analyzed and there was no significant difference. The clear treatment had a slightly higher NBI value (3.76 ± 0.043) than the turbid treatment (3.02 ± 0.523) (P=0.231, Table 3).

In 2005, YP reared in turbid water had a substantially higher survival rate 79 ± 2.1% (P=0.054) than those reared in the clear treatment 54 ± 9.2% (Table 2). With a mean final length of 63.4 ± 2.08 mm for the clear treatment and 64.1 ± 0.43 mm for those YP in the turbid treatment, there was no difference in length. The same held true for the final individual mean weights, 3.5 ± 0.26 g for the clear treatment and 3.6 ± 0.01 g for those in the turbid treatment. However, the turbid treatment fish (2.19 ± 0.079) had a significantly higher (P=0.006) NBI than the clear treatment (1.17 ± 0.176).

During the 2006 YP experiment, no significant differences were found in survival or growth. Fish in the clear treatment had a slightly higher survival than the turbid treatment, 69 ± 2.57 % versus 63 ± 2.66% although not significant (P=0.190). The NBI results were also not significantly different, turbid treatment 0.70 ± 0.214, clear treatment 0.90 ± 0.026 (P=0.414).

Summary.— With the objective to compare the effects of turbid water and clear water culture conditions during the habituation phase, we found that use of clay in culture tanks could enhance the contrast of the feed as related to the culture environment. One might surmise that in tanks with turbid water and in-tank lighting, the water column is filled with light. The light, leaving the source is reflected and bounced throughout the water column creating a brighter environment for fish. In a clear-water tank, the light reflects off of the tank side walls, thus having a darker environment. The clear water treatment is a better culture environment for the WYE, which prefer darker culture conditions. In contrast, the turbid water creates a brighter and more favorable environment for the YP. However, the differences in YP survival between years may have been due to the age and size of the YP when they started the habituation phase.

Stress during the harvest and habituation stocking may also have played a role in success. Yellow perch in 2005 were hauled for 11 h, and in 2006 they were hauled for 9 h. In contrast, the WYE were transported for only 2-3 h, which might have resulted in lower stress than what the YP endured.

Implementing these results into the culture practices of habituating WYE in clear water and YP in turbid water will allow for increased success in producing advanced fingerlings. With these results, it appears that these two percid species have inverse visual requirements at this life stage. The addition of turbidity may help the success of YP culture, but will hinder the success of WYE culture.

Ideally, the same age of fish and similar transport time should have been used for this experiment. Additionally, the difference in contrast between the tank wall colors, feed color, and water clarity should be further evaluated, e.g., a comparison should be done with WYE in turbid water with overhead lights and in-tank lights.

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Table 1. Optimum culture conditions for fingerling walleye (WYE) and yellow perch (YP).

Parameter	Species	Optimum	Reference
Light source	WYE	In tank	Siegwarth and Summerfelt 1992
	YP	In tank	Malison and Held 1992
Photo period	WYE	18-h	Kuipers and Summerfelt 1994
	YP	16-h	Huh et al. 1976
Temperature	WYE	22 °C 25.3 °C	Ney 1978, Smith and Koenst 1975, Cai and Summerfelt 1992
	YP	22 °C	Huh et al. 1976, Ney 1978
Feed	WYE	Varies with size and temp	
	YP	?	Not published
Habituation Stocking (g/L)	WYE	1.25-2.92	Kuipers and Summerfelt 1994
	YP	0.65	Malison and Held 1992
Size at pond harvest	WYE	2.54-7.62 cm	Malison and Held 1995
	YP	16.9 mm	Malison and Held 1992
Turbidity	WYE	?	Not published
	YP	?	Not published

Table 2. Normalized biomass (NBI), specific growth rate (SGR), survival, length, and weight for the 2005 and 2006 walleye (WYE) and yellow perch (YP) 28-d habituation period (mean ± SE).

Species	Treatment	Age at stocking (d)	Survival (%)	Initial length (mm)	Final length (mm)	Initial weight (g)	Final weight (g)	NBI	SGR (%/d)
<u>2005</u>									
	Clear	60	83 ± 2.0	59.8	90.3 ± 0.63	1.47	6.27 ± 0.11	3.76 ± 0.043	5.18 ± 0.062
WYE	Turbid	60	57 ± 6.0	59.8	96.5 ± 1.64	1.47	7.84 ± 0.32	3.02 ± 0.523	5.97 ± 0.146
	P-value		0.014		0.025		0.010	0.231	0.007
	Clear	79	54 ± 9.24	40.9	63.4 ± 2.08	0.65	3.5 ± 0.28	1.17 ± 0.176	5.93 ± 0.298
YP	Turbid	79	79 ± 2.15	40.9	64.1 ± 0.43	0.65	3.6 ± 0.01	2.19 ± 0.079	6.07 ± 0.006
	P-value		0.054		0.756		0.689	0.006	0.650
<u>2006</u>									
	Clear	45	69 ± 2.57	33.1	52.2 ± 0.55	0.36	1.83 ± 0.04	0.90 ± 0.026	5.81 ± 0.08
YP	Turbid	45	63 ± 2.66	33.1	51.7 ± 0.41	0.36	1.67 ± 0.30	0.70 ± 0.214	5.35 ± 0.721
	P-value		0.190		0.503		0.617	0.414	0.556

Table 3. Water quality (mean ± SE) over the 28-d habituation period for walleye (Wye) and yellow perch (YP) in 2005 and 2006 (TAN = total ammonia nitrogen).

	2005						2006		
	Walleye			Yellow Perch			Yellow Perch		
Parameter	Clear	Turbid	P	Clear	Turbid	P	Clear	Turbid	P
Temperature (°C)	20.5 ± 0.01	20.5 ± 0.01	-	20.5 ± 0.01	20.5 ± 0.01	-	20.7 ± 0.0	20.7 ± 0.0	-
Dissolved oxygen (mg/L)	7.1± 0.12	7.3 ± 0.05	0.143	7.2± 0.06	6.9± 0.15	0.167	6.8± 0.14	6.8 ± 0.12	0.753
Turbidity (NTU)	0	110.9 ± 4.46	<0.001	0	102.9 ± 7.10	<0.001	0	147.6 ± 17.56	<0.001
pH	7.55 ± 0.02	7.61 ± 0.01	0.065	7.54 ± 0.03	7.58 ± 0.01	0.316	7.35 ± 0.02	7.32 ± 0.06	0.652
TAN (mg/L)	0.48 ± 0.01	0.51 ± 0.05	0.574	0.533 ± 0.02	0.623 ± 0.03	0.085	0.267 ± 0.04	0.255 ± 0.03	0.843
Alkalinity (mg/L)	-	-		-	-		24.83 ± 0.60	24.0 ± 1.15	0.557
Hardness (mg/L)	-	-		-	-		169.8 ± 0.44	171.0 ± 0.58	0.184
Nitrite (mg/L)	0.02 ± 0.00	0.02 ± 0.01	0.766	0.023 ± 0.00	0.024 ± 0.01	0.893	0.095 ± 0.01	0.097 ± 0.01	0.897
Nitrate (mg/L)	0.40 ± 0.06	0.47 ± 0.03	0.374	0.43 ± 0.03	0.50 ± 0.0	0.116	0.35 ± 0.05	0.40 ± 0.09	0.435

References

APHA (American Public Health Association), American Water Works Association, and Water Pollution Control Federation. 1998. Standard methods for the examination of water and wastewater, 20th edition. APHA, Washington, D.C.

Bristow, B.T., R.C. Summerfelt., and R.D. Clayton. 1992. Comparative performance of intensively cultured larval walleye in clear, turbid, and colored water. The Progressive Fish-Culturist 58:1-10.

Bristow, B.T., and R.C. Summerfelt. 1994. Performance of larval walleye cultured intensively in clear and turbid water. Journal of the World Aquaculture Society 25:454-464.

Cai, Y. and R.C. Summerfelt. 1992. Effects of temperature and size on oxygen consumption and ammonia excretion by walleye. Aquaculture 104:127-138.

Carlander, K.D. 1997. Handbook of freshwater fishery biology. Iowa State University Press, Ames, Iowa.

Colt, J. E., and J. R. Tomasso. 2001. Hatchery water supply and treatment. Pages 91-186 *in* G. A. Wedemeyer, editor. Fish hatchery management, second edition. American Fisheries Society, Bethesda, Maryland.

Conklin, D.E., K. Devers and R.A. Shleser. 1975. Initial development of artificial diets for the lobster (*Homarus americanus*). Proceedings of the World Mariculture Society 237-248.

Corazza, L., and J.G. Nickum. 1981. Possible effects of phototactic behavior on initial feeding of walleye larvae. Pages 48-52 *in* L.J. Allen and E.C. Kinney, editors. Proceedings of the bio-engineering symposium for fish culture. American Fisheries Society, Fish Culture Section, Bethesda, Maryland.

El-Zarka, S.E.D. 1959. Fluctuations in the population of yellow perch, *Perca flavescens* (Mitchell) in Saginaw Bay, Lake Huron. U.S. Fish and Wildlife Services Bulletin 59:365-415.

Hinshaw, J.M. 1985. Effects of illumination and prey contrast on survival and growth of larval yellow perch (*Perca flavescens*). Transactions of the American Fisheries Society 114:540-545.

Huh, H.T., H.E. Calbert, and D.A. Stuiber. 1976. Effects of temperature and light on growth of yellow perch and walleye using formulated feed. Transactions of the American Fisheries 105:254-258.

Kestemont, P. and C. Mélard. 2000. Chapter 11-aquaculture. Pages 191-224 *in* J.F. Craig, editor. Percid Fishes Systematics, Ecology and Exploitation. Blackwell Scientific Publisher, London, England.

Kuipers, K. L., and R. C. Summerfelt. 1994. Converting pond-reared walleye fingerlings to formulated feeds: Effects of diet, temperature, and stocking density. Journal of Applied Aquaculture 4:31-57.

Malison, J. A., and J. A. Held. 1992. Effects of fish size at harvest, initial stocking density and tank lighting conditions on the habituation of pond-reared yellow perch (*Perca flavescens*) to intensive culture conditions. Aquaculture 104:67-78.

Malison, J. A., and J. A. Held. 1995. Habituating pond-reared fingerlings to formulated feed. Pages 199-204 *in* R. C. Summerfelt, editor. Walleye culture manual. NCRAC Culture Series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Moore, A., M.A. Prange, R.C. Summerfelt, and R.P. Bushman. 1994. Evaluation of tank shape and a surface spray for intensive culture of larval walleyes fed formulated feed. The Progressive Fish-Culturist 56:l00-11

Ney, J.J. 1978. A synoptic review of yellow perch and walleye biology. American Fisheries Society Special Publication 11:1-12.

Post, J.R. 1990. Metabolic allometry of larval and juvenile yellow perch (*Perca flavescens*); in situ estimates and bioenergetic models. Canadian Journal of Fisheries and Aquatic Sciences 47:554-560.

Siegwarth, G. L., and R. C. Summerfelt. 1992. Light and temperature effects on performance of walleye and hybrid walleye fingerlings reared intensively. The Progressive Fish-Culturist 54:49-53.

Smith, L.L., Jr., and W. M. Koenst. 1975. Temperature effects on eggs and fry of percoid fishes. U.S. Environmental Protection Agency Ecological Research Series EPA-660/3-75-017, Corvallis, Oregon.

CHAPTER 3. COMPARISON OF SOY AND FISH OIL IN PRACTICAL GROWOUT DIETS FOR WALLEYE

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Abstract

A feeding trial was conducted to compare growth and other performance variables of feed-trained juvenile walleye fed an open-formula diet with 10% soy oil (SOY) replacement for 11.75% menhaden oil in the commercially manufactured walleye grower diet (WG). The SOY diet was formulated to be identical to the WG formulation; feed-grade ingredients contained about 46% crude protein and gross energy (SOY 1,121 J/g and WG 1,192 J/g). Fish were stocked into triplicate-1,000-L tanks and cultured for 63 d. Fish were fed 7% body weight/d during a 16-hr light period with intank lighting. Juvenile walleye were 157-d old, 124 ± 1.0 mm in total length and 24.4 ± 0.71 g at the start of the trial. The relative growth rate (%) for both treatments was > 100% over the 63-d culture period. We observed no significant differences in specific growth rate, survival, final mean lengths, or weights between treatments. Soy oil, at 10%, was a suitable replacement for nearly 12% fish oil in a feed for the growout phase of walleye culture. In 2007, the cost of menhaden oil in the WG formulation was 1.6 times greater ($0.39/lb) than soy oil ($0.29/lb) based in the percent of oils used in the diets.

Introduction

The U.S. Department of Agriculture's National Agriculture Statistics Service (NASS) reported that the U.S. aquaculture industry has grown by 11.7% over the last 7 years (NASS 2006) to $1.1 billion dollars in sales. In 2005, 62% of the values were of food fish (catfish *Ictalurus punctatus*; hybrid striped bass *Morone chrysops* x *M. saxatilis*; tilapia *Oreochromis spp*.; and salmon *Oncorhynchus spp*.). Fish feed represents 30-60% of production costs for food fish (Stickney 1994; Goddard 1996).

Cost-effective, species-compatible, life-stage feeds are needed for fry, fingerling and ultimately food size fish. Typically, fish feeds are formulated for use by one or only a few fish species and for specific life-stage requirements; e.g., starter, growout, and broodstock feeds. The products provided by most feed manufacturers — Nelson & Sons, Inc (Murray, Utah), ARKAT Nutrition Inc. (Dumas, Arkansas), Zeigler Bros, Inc. (Gardners, Pennsylvania), and Rangen Inc. (Buhl, Idaho) — are mostly for trout and related salmonids, channel catfish, and hybrid striped bass. This does not mean that these diets will not work for other species, however, they are not necessarily formulated for other fish species (these manufactures make other types of feed than those listed here and the mention of their names does not imply endorsement). With major portion of the market share going to only a few food fish, research is needed for diets of emerging species of food fish; i.e., walleye *Sander vitreus*.

Diet consideration and evaluation for walleye (WYE) production has been an area of interest for many years. In the 1970s, the U.S. Fish and Wildlife Service developed the first W-series open-formula diets (Beyerle 1975; Colesante 1982). The W-series diet has further evolved from a starter diet to a grower diet (Stettner et al. 1992; Kuipers and Summerfelt 1994; Summerfelt and Clayton 2007). To date, the walleye grower formulation (Barrows and Lellis 1996) is the only commercial manufactured diet for walleye (Nelson and Sons, Inc., Murray, Utah). The current version of this WYE diet is labeled WG 9206 (hereafter referred to as WG). Since this diet has been commercially available for years, it has become the industry standard for fingerling WYE culture with which researchers have a base diet to compare new experimental diets with. It is used by the Iowa Department of Natural Resources (IDNR) for production of advanced walleye fingerlings (C. Clouse, IDNR, personal communication).

One consideration that must be made with fish feed is source of the ingredients (feedstuffs). In the past, fish components (meal and oil) from wild stock (menhaden *Brevoortia spp*.) were used as dietary ingredients for manufactured feeds for salmonids and other species. In most aquaculture feeds, fish meals may constitute up to 60% of the total diet (Goddard 1996). If the source of this feed ingredient (wild fish) declines in the future, a replacement to this feed component needs to be found that is readily available and cost effective. Kelly et al. (2002) noted that fish meal is relatively expensive and is becoming less readily available, especially after El Niño years.

Plant proteins have been intensively studied as alternatives to fish meal; e.g., soybean meal can be used in trout feeds with up to 25% replacement of fish meal if it is enriched with methionine (Pillay and Kutty 2005). Some plant oils have been used as a replacement for fish oil in open-formula diets for WYE (Summerfelt and Clayton 2007). The present study was undertaken to compare growth and other performance variables of feed-trained juvenile walleye fed an open-formula diet with 10% soy oil (SOY) replacement for 11.75% menhaden oil in the commercially manufactured walleye grower diet (WG).

Methods

Experimental design and statistical analysis. — The experiment was a single-factor (feed type) analysis with soy oil diet (SOY) and walleye grower diet (WG) the treatments. Experimental units were three replicates (tanks) per treatment. Data were analyzed using StatView 5.0.1 (SAS Institute Inc., North Carolina). All values reported are means ± standard error. Survival (%), normalized biomass index (NBI, unit less), and specific growth rates (SGR, %/d) were calculated. NBI was first described by Conklin et al (1975) to illustrate growth responses with variable survival: NBI (normalized biomass index) = [(Wtt2* # harvested)-(Wtt1*# stocked)]/#stocked. Specific growth rate (SGR) = [(LnWtt2-LnWtt1)/t (days)] x 100.

Fish. —On September 29, 2006, after a 4-week acclimation interval following transport of the fish from the IDNR Rathbun Fish Hatchery, fish were stocked at a rate of 5.1 g/L (5,100 g/ tank) of WYE (209 fish) into each culture tank, which were randomly assigned to treatments. Walleye (157-d old) averaged 124 ± 1.0 mm in total length and weighed 24.4 ± 0.71 g at stocking (Table 1). The fish were cultured for 63 d.

Culture Facility. — Six, 1,000-L black-circular tanks with three tanks per diet treatment were used. The black tank color has been found to improve survival and growth compared with blue-colored tanks because walleye prefer a darker environment (Harder and Summerfelt 1996). Fish were cultured in flow-through, single-pass system with flow rates at ca. 16 Lpm or 1.0 exchanges/h. Tanks were covered and provided with in-tank light (16 hr light:8 hr dark). Tanks were siphoned and cleaned 3x/wk.

Feeds and feeding. — The diets were manufactured from the WG-9206 formula of Barrows and Lellis (1996). The SOY diet was manufactured by Kansas State University (Adam Fahrenholz, Department of Grain Science and Industry, Manhattan) and the commercial diet by Nelson and Sons, Inc., Murray, Utah. The SOY diet contained 10% soy oil and no fish oil, whereas the WG diet contained 11.75% fish oil. Fish were fed at a rate of 7% body weight/d (bwd). Fish were mass-weighed three times during the experiment and those weights were then used to calibrate the feeders. The feeder calibrations were checked weekly. Fish were fed every 5 min over a 16-hr light period (8-hr dark).

Water quality. — Dissolved oxygen (DO) and temperature (°C) were monitored daily. Ammonia (TAN), pH, hardness, nitrite, nitrate, and alkalinity were measured four times during the experiment. Dissolved oxygen was measured with a meter (Model #57, Yellow Springs Instrument Company) calibrated by the Winkler method (APHA et al. 1998). A glass thermometer was used to measure temperature (±0.1 °C). Total alkalinity at pH 4.6 and hardness (ManVer 2 method) were measured by titration in each culture tank (APHA et al. 1998). The Nesslerization method (APHA 1998) was used to measure total ammonia nitrogen (TAN). The pH was measured electrometrically with a standard combination electrode and meter.

Samples. — Feed and fish were sampled for proximate analysis. Feed samples were taken before the trial was started and fish were sampled from the population before the experiment was stocked to obtain a baseline analysis. Upon completion of the 63-d feeding trial, two fish from each tank (six tanks) were sampled and then pooled by treatment for proximate analyses. Proximate composition all these feed and fish samples was conducted by a commercial laboratory (Minnesota Valley Testing Laboratories, Inc., New Ulm, Minnesota).

Results and Discussion

There were no differences in water quality between treatments. Temperature averaged 20.8 ± 0.04 °C for both treatments. Dissolved oxygen ranged from 6.4 ± 0.09 mg/L for the

SOY treatment and 6.7 ± 0.09 mg/L for the WG treatments (P = 0.120). Total ammonia nitrogen averaged 0.19-0.17 mg/L; SOY and WG respectively at a pH of 7.9 for the SOY and 8.1 for the WG. All of the parameters were within optimum culture conditions for fish growth (Colt and Tomasso 2001).

The relative growth rate (%) for both treatments was > 100% over the 63-d culture period; SOY 116.2 ± 5.62%, WG 124.5 ± 16.58% with no significant difference between the treatments (P = 0.660, Table 1). There were also no differences in specific growth rate (SGR) for the two treatments (SOY 1.22 ± 0.04 %/d, WG 1.27 ± 0.12 %/d, P = 0.689). Likewise, differences in survival were not significant (P=0.478). The NBI analysis, which normalizes growth with variable survival, was not different between treatments (P=0.528).

All measures of growth rate in the present study were higher than those found by Summerfelt and Clayton (2007) for SOY and WG diets, even though fish density in the present study was 5.1 g/L compared with the 0.7 g/L from Summerfelt and Clayton experiment (2007). Increased densities are needed to allow for more cost-effective culture operations. Beyond improved production efficiency, increased fish density may also directly improve individual fish feeding performance. For instance, Pitcher and Parrish (1993) described how fish monitor each other's behavior, and feeding activity in one fish stimulates the feeding response in other fish among the group. Jørgensen et al., (1993) noted that artic char *Salvelinus alpinus* had faster growth at higher than lower density.

There were minor differences in proximate composition of the diets (Table 2). The SOY diet had slightly higher moisture content (10.35%) than the WG diet (8.02%). The gross energy of both diets was similar, SOY had 1,121 J/g and the WG had 1,192 J/g. These values were similar to those in the Summerfelt and Clayton (2007) experiment where WG diet's gross energy was 1,258J/g and the SOY diet had 1,114J/g. Proximate analysis of whole fish (as received basis) was similar between SOY and WG, except for slightly higher crude fat and energy content in the SOY treatment (Table 3). There was substantial difference in crude fat between the pre-stocking and treatment groups.

Replacement of fish oil with plant derived oils in fish feeds are equally as effective as replacing fish meals with plant derived meals (Trushenski et al. 2006). The soy oil was a successful replacement for the fish oil in walleye fingerling diets. Soy oil, at 10%, was a suitable replacement for nearly 12% fish oil in a feed for the growout phase of walleye culture. In 2007, the cost of menhaden oil ($0.39/lb) in the WG formulation was 1.6 times greater than soy oil ($0.29/lb) based in the percent of the oils used in the diets. Thus, soy oil as a replacement for fish oil is a more economical formulation. Further research is needed to determine the influence of soy oil on fatty acid composition of fish fillets as it is known that substitution of canola oil for menhaden oil significantly influenced the fatty acid composition of fillets and livers of hybrid striped bass (Wonnacott 2004). Similar research is needed for other emerging aquaculture species, e.g., yellow perch *Perca flavescens*.

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Table 1. Normalized biomass (NBI), specific growth rate (SGR), survival, length, relative weight, and weight of walleye for the 63-d culture interval using two feed types (mean ± SE) soy-oil diet (SOY) and a commercial diet (WG). Relative growth rate (%) is calculated as percent of initial weight.

	SOY	WG	P-value
Survival (%)	76 ± 10.2	67 ± 5.5	0.478
Initial length (mm)	123.9	123.9	-
Final length (mm)	174.1 ± 0.41	176.5 ± 3.88	0.567
Initial weight (g)	23.4	23.4	-
Final weight (g)	52.7 ± 1.37	54.7 ± 4.04	0.660
Relative (%)	116.2 ± 5.62	124.5 ± 16.58	0.660
NBI	15.4 ± 4.49	12.0 ± 2.28	0.528
SGR (%/d)	1.22 ± 0.04	1.27 ± 0.12	0.689

Table 2. Proximate analysis (as received) of feed after a 63-d feeding trial with an open-formula, soy-oil diet (SOY) and a commercial diet (WG).

Variable	WG	Soy
Moisture (%)	8.02	10.35
Dry Matter (%)	91.98	89.65
Ash (%)	10.13	10.75
Crude Fat, Acid Hydrolysis (%)	17.88	14.20
Fiber, crude (%)	1.03	1.26
Crude Protein, N X 6.25 (%)	46.6	46.0
Phosphorus (%)	1.59	1.66
Gross Energy (J/g)	1,192	1,121

Table 3. Proximate analysis (as received) of fish before (pre-stocking) and after a 63-d feeding trial with walleye grower formulas fed either 10% soy-oil (SOY) or 11.75% menhaden oil.

Variable	Before	Soy oil	Menhaden oil
Moisture (%)	74.36	73.23	73.56
Dry Matter (%)	25.64	26.77	26.44
Ash (%)	4.14	3.37	5.00
Crude Fat, Ethyl Ether (%)	1.74	3.32	3.11
Crude Protein, N X 6.25 (%)	18.50	17.50	18.20
Phosphorus (%)	0.78	0.57	0.73
Gross Energy (J/g)	1177	1428	1252

References

APHA (American Public Health Association), American Water Works Association, and Water Pollution Control Federation. 1998. Standard methods for the examination of water and wastewater, 20th edition. APHA, Washington, D.C.

Beyerle, G. G. 1975. Summary of attempts to raise walleye fry and fingerlings on artificial diets, with suggestions on needed research and procedures to be used in future tests. The Progressive Fish-Culturist 37:103–105.

Colesante, R. T. 1982. 1982 walleye culture. U.S. Fish and Wildlife Service, Diet Testing Development Center, Spearfish, South Dakota.

Colt, J. E., and J. R. Tomasso. 2001. Hatchery water supply and treatment. Pages 91-186 in G. A. Wedemeyer, editor. Fish hatchery management, second edition. American Fisheries Society, Bethesda, Maryland.

Conklin, D.E., K. Devers and R.A. Shleser. 1975. Initial development of artificial diets for the lobster (Homarus americanus). Proceedings of the World Mariculture Society 237-248.

Goddard, S. 1996. Feed management in intensive aquaculture. Chapman and Hall, New York.

Harder, T., and R. C. Summerfelt. 1996. Effects of tank color and size on the success of training walleye fingerlings to formulated feed. Pages 631-636 in G. S. Libey and M. B. Timmons, editors. Successes and failures in commercial recirculating aquaculture. Northeast Regional Agricultural Engineering Service (NRAES) 98(2).

Jørgensen, E.H., J.S. Christiansen, and M. Jobling. 1993. Effects of stocking densities on food intake, growth performance, and oxygen consumption in Artic charr (Salvelinus alpinus). Aquaculture 110:191-204.

Kelly, A.M., C.C. Kohler, and C.E. Ayala. 2002. Menhaden meal in practical diets for channel catfish fry and fingerlings reared in intensive systems. North American Journal of Aquaculture 64:290-293.

Kuipers, K. L., and R. C. Summerfelt. 1994. Converting pond-reared walleye fingerlings to formulated feeds: Effects of diet, temperature, and stocking density. Journal of Applied Aquaculture 4:31-57.

NASS (National Agriculture Statistics Service). 2006. 2002 Census of Aquaculture (2005) 3: Special Studies Part 2. Washington D.C.

Pillay, T.V.R., and M.N. Kutty. 2005. Aquaculture principles and practices. Second edition. Blackwell Publishing, Oxford, England.

Pitcher, T.J., and J.K. Parrish. 1993. Functions of schooling behavior in fishes. Pages 363-440 in T. J. Pitcher, editor. The behavior of teleost fishes. Chapman and Hall, New York.

Stickney, R.R. 1994. Principles of aquaculture. John Wiley & Sons, Inc. New York, New York.

Stettner, C.R, R. C. Summerfelt, and K. L. Kuipers. 1992. Evaluation of commercial feeds for rearing advanced fingerling walleye. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 46: 402-412.

Summerfelt, R.C., and R.D. Clayton. 2007. Evaluation of open-formula grower diets for juvenile walleyes. North American Journal of Aquaculture 69:53-58.

Trushenski, J. T., C. S. Kasper, and C. C. Kohler. 2006. Challenges and opportunities in finfish nutrition. North American Journal of Aquaculture 68:122-140.

Wonnacott, E. J., R. L. Lane, and C. C. Kohler. 2004. Influence of dietary replacement of menhaden oil with canola oil on fatty acid composition of sunshine bass. North American Journal of Aquaculture 66:243–250.

CHAPTER 4. GENERAL CONCLUSION

General Discussion

In the Midwest, fish culturists are still seeking suitable aquaculture species for the region's climate conditions e.g., cool water. Possible species include members of the percid family. Walleye (*Sander vitreous,* WYE) "is considered to be one of the best eating (sic) of all freshwater fish" (Carmichael et al. 1991) and has a favorable name recognition in stores (Summerfelt 1996a). Yellow perch (*Perca flavescens,* YP) "is a highly valued food fish because it has white, flaky flesh that is popular with consumers; this species has been most associated with the traditional Friday-night fish fries" (Hart et al. 2006). With statements like these, it is easy to see why both percid species are under consideration as potential aquaculture species for the food fish market in the United States (U.S.).

To successfully produce WYE or YP for food fish production, the fish must first survive three phases of growth; fry culture (Moodie and Mathias 1996; Moore 1996; Summerfelt 1996c), habituation to formulated feed (Bristow 1996; Malison and Held 1996; Nagel 1996), and the grow-out phase to food fish (Held and Malison 1996; Flickinger 1996; Summerfelt and Summerfelt 1996). One way to produce fry is through pond production, where fry begin feeding on natural prey zooplankton. After they reach a certain size (usually a 30-45d culture period), the fish are then harvested from the pond and placed into tanks to begin the habituation process.

Fingerling habituation.— In this phase, fish must adapt to a commercial diet. There have been many studies conducted as to the optimal conditions to train the fish to formulated feed (Summerfelt 1996b; Hart et al. 2006) with varying degrees of success. One of those conditions that have not been evaluated is the use of turbidity. The addition of turbidity in WYE fry culture has shown to have significant effects during the first feeding stage (Bristow et al. 1992; Bristow and Summerfelt 1994). Bristow et al. (1992) noted that a high contrast between feed and the culture water played enhanced walleye fry survival. Culture tank visibility may also play a large factor in habituation success for

WYE and YP. With YP, Hinshaw (1985) found that a high contrast between feed color and tank wall color supported the best survival for YP (light level at 205 lux, black tank wall).

Several projects have shown that the turbidity level within a culture tank affect the distribution of WYE within the tank (Corazza and Nickum 1981; Bristow et al. 1992). One way to alter the visible properties within a tank is with the use of clay slurry (Bristow and Summerfelt 1994). The authors describe how turbidity might alter the visible properties of the culture tank. With the addition of the clay, the water turns a milky-gray color and scatters the light throughout the tank (Bristow et al. 1992). When the brownish-orange colored feed is dropped into the water, there is a greater contrast than when the feed is dropped into clear water.

The objective of the habituation study was to compare the affect of turbid water and clear water culture conditions during the habituation process of pond-run walleye and yellow perch. All water quality parameters, through-out the habituation experiments, showed small variation but were within an acceptable range for fish culture (Colt and Tomasso 2001); turbidity levels were obviously different. Walleye were exposed to 111 NTU in the turbid treatment and 0 NTU for the clear water treatment. The YP turbidity treatment averaged 103 NTU for the turbid treatment and 0 NTU for the clear water treatment.

The WYE in 2005 in the clear treatment had significantly higher survival rates than those in the turbid treatment. However, with this increase in survival, there was then a significant difference in fish size at the end of the 28-d culture period. With this increased survival, final lengths and weights were higher in the turbid treatments. Both of these differences were probably due to the difference in stocking density at the end of the habituation period

The YP in 2005, exhibited opposite results. Yellow perch in the turbid treatment had higher survival rates than those reared in the clear treatment. However, with the YP, there were no differences in length and weight. During the 2006 YP experiment, there were no significant differences found.

We found that by using clay in culture tanks, we are able to enhance the feed contrast to the culture environment thereby altering WYE and YP survival during the habituation phase. One might surmise that in tanks with turbid water and in-tank lighting, the water column is filled with light. The light, leaving the source is reflected and bounced throughout the water column creating a brighter environment for fish. In a clear-water tank, the light reflects off of the tank side walls, thus having a darker environment. The clear water treatment is then an improved culture environment for the WYE, which prefer darker culture conditions. In contrast, the turbid water creates a brighter and more favorable environment for the YP. However, the differences in YP survival between years may have been due to the age and size of the YP when they started the habituation phase. Also, stress during the harvest and habituation stocking may have influenced these results.

Implementing these results into the culture practices of habituating WYE in clear water and YP in turbid water will allow for increased success in producing advanced fingerlings. With these results, it appears that these two percid species have inverse visual requirements at this life stage.

Soy-oil diet.— Cost-effective, species-compatible, life-stage feeds are needed for all phases of fish culture. Typically, fish feeds are formulated for use by one or only a few fish species and for specific life-stage requirements, e.g., starter, growout, and broodstock feeds. Most commercial feeds are manufactured for trout and related salmonids, channel catfish, and hybrid striped bass. This does not mean that these diets will not work for other species; however, they are not necessarily formulated for other fish. With the major portion of the market share going to only a few species of food fish, research is needed for diets of emerging species of food fish, i.e., WYE.

Diet consideration and evaluation for WYE production has been an area of interest for many years. In the 1970s, the U.S. Fish and Wildlife Service developed the first W-series open-formula diets (Beyerle 1975; Colesante 1982). The W-series diet has further evolved from a starter diet to a grower diet (Stettner et al. 1992; Kuipers and Summerfelt 1994; Summerfelt and Clayton 2007). To date, the walleye grower formulation (Barrows and Lellis

1996) is the only commercial manufactured diet for walleye (Nelson and Sons, Inc., Murray, Utah). The current version of this WYE diet is labeled WG 9206 (hereafter referred to as WG). Since this diet has been commercially available for years, it has become the industry standard for fingerling WYE culture with which researchers have a base diet to compare new experimental diets with.

One consideration that must be made with fish feed is source of the ingredients (feedstuffs). In the past, fish components (meal and oil) from wild stock (menhaden *Brevoortia* spp.) were used as dietary ingredients for manufactured feeds for salmonids and other species. In most aquaculture feeds, fish meals may constitute up to 60% of the total diet (Goddard 1996). If the source of this feed ingredient (wild fish) declines in the future, a replacement to this feed component needs to be found that is readily available and cost effective. Kelly et al. (2002) noted that fish meal is relatively expensive and is becoming less readily available, especially after El Niño years.

Plant proteins have been intensively studied as alternatives to fish meal. For example, soybean meal can be used in trout feeds with up to 25% replacement of fish meal if it is enriched with methionine (Pillay and Kutty 2005). Some plant oils have been used as a replacement for fish oil in open-formula diets for WYE (Summerfelt and Clayton 2007). The objective of my feed experiment was to continue the evaluation of a soy-oil open-formula diet for juvenile walleye. The WG diet and the soy-oil diet (SOY), used by Summerfelt and Clayton (2007), were used for this experiment.

As with the habituation experiment, all of the parameters were within optimum culture conditions for fish growth (Colt and Tomasso 2001). The relative growth rate (%) for both treatments was > 100% over the 63-d culture period with no significant differences. There were also no differences in specific growth rate or survival.

All measures of growth rate in the present study were higher than those found by Summerfelt and Clayton (2007) for SOY and WG diets, even though fish density in the present study was 5.1 g/L compared with the 0.7 g/L from Summerfelt and Clayton experiment (2007). Increased densities are needed to allow for more cost-effective culture operations.

Beyond improved production efficiency, increased fish density may also directly improve individual fish feeding performance. For instance, Pitcher and Parrish (1993) described how fish monitor each other's behavior, and feeding activity in one fish stimulates the feeding response in other fish among the group. Jørgensen et al. (1993) noted that artic char *Salvelinus alpinus* had faster growth at the relatively higher stocking densities.

There were only minor differences in proximate composition of the diets. The gross energy of both diets was similar to each other as well as diets used by Summerfelt and Clayton (2007). Proximate analysis of whole fish (as received basis) was similar between SOY and WG, except for slightly higher crude fat and energy content in the SOY treatment.

Replacement of fish oil with plant-derived oils in fish feeds are equally as important as replacing fish meals with plant-derived meals (Trushenski et al. 2006). The soy oil was a successful replacement for the fish oil in walleye fingerling diets. Soy oil, at 10%, was a suitable replacement for nearly 12% fish oil in a feed for the growout phase of walleye culture. In 2007, the cost of menhaden oil ($0.86/kg) in the WG formulation was 1.3 times greater than soy oil ($0.64/kg) based in the percent of the oils used in the diets. Thus, soy oil as a replacement for fish oil is a more economical formulation for percid culture.

Recommendations for Future Research

One recommendation for the future is to reduce stress levels. Stress during the harvest and habituation stocking may have played a role in the success of the experiment. Yellow perch in 2005 were hauled for 11 h, and in 2006 they were hauled for 9 h. In contrast, the WYE were transported for only 2-3 h, which probably resulted in lower stress than what the YP endured. Additionally, the difference in contrast between the tank wall colors, feed color, and water clarity should be further evaluated, e.g., a comparison should be done with WYE in turbid water with overhead lights and in-tank lights.

With the soy-oil diet, further research is needed to determine the influence of soy oil on fatty acid composition of fish fillets. Similar research is needed for other emerging aquaculture species.

References

Barrows, F.T., and W.A. Lellis. 1996. Diet and nutrition. Pages 315-321 *in* R.C. Summerfelt, editor. Walleye culture manual. NCRAC culture series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Beyerle, G. G. 1975. Summary of attempts to raise walleye fry and fingerlings on artificial diets, with suggestions on needed research and procedures to be used in future tests. The Progressive Fish-Culturist 37:103–105.

Bristow, B.T. 1996. Extensive-intensive production of advanced fingerling walleye at the Spirit Lake State Fish Hatchery. Pages 209-212 *in* R.C. Summerfelt, editor. Walleye culture manual. NCRAC culture series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Bristow, B.T., and R.C. Summerfelt. 1994. Performance of larval walleye cultured intensively in clear and turbid water. Journal of the World Aquaculture Society 25:454-464.

Bristow, B.T., R.C. Summerfelt., and R.D. Clayton. 1992. Comparative performance of intensively cultured larval walleye in clear, turbid, and colored water. The Progressive Fish-Culturist 58:1-10.

Carmichael, G., M. Ring, and J. McCraren. 1991. Sea fare cookbook. Random House, New York.

Colesante, R. T. 1982. 1982 walleye culture. U.S. Fish and Wildlife Service, Diet Testing Development Center, Spearfish, South Dakota.

Colt, J. E., and J. R. Tomasso. 2001. Hatchery water supply and treatment. Pages 91-186 *in* G. A. Wedemeyer, editor. Fish hatchery management, second edition. American Fisheries Society, Bethesda, Maryland.

Corazza, L., and J.G. Nickum. 1981. Possible effects of phototactic behavior on initial feeding of walleye larvae. Pages 48-52 *in* L.J. Allen and E.C. Kinney, editors. Proceedings of the bio-engineering symposium for fish culture. American Fisheries Society, Fish Culture Section, Bethesda, Maryland.

Flickinger, S.A. 1996. Production of food fish. Pages 233-235 *in* R.C. Summerfelt, editor. Walleye culture manual. NCRAC culture series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Goddard, S. 1996. Feed management in intensive aquaculture. Chapman and Hall, New York.

Hart, S.D., D.L. Garling, and J. A. Malison. 2006. Yellow Perch (*Perca flavescens*) culture guide. NCRAC culture series 103. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Held, J.A., and J.A. Malison. 1996. Culture of walleye to food size. Pages 231-232 *in* R.C. Summerfelt, editor. Walleye culture manual. NCRAC culture series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Hinshaw, J.M. 1985. Effects of illumination and prey contrast on survival and growth of larval yellow perch (*Perca flavescens*). Transactions of the American Fisheries Society 114:540-545.

Jørgensen, E.H., J.S. Christiansen, and M. Jobling. 1993. Effects of stocking densities on food intake, growth performance, and oxygen consumption in Artic charr (Salvelinus alpinus). Aquaculture 110:191-204.

Kelly, A.M., C.C. Kohler, and C.E. Ayala. 2002. Menhaden meal in practical diets for channel catfish fry and fingerlings reared in intensive systems. North American Journal of Aquaculture 64:290-293.

Kuipers, K. L., and R. C. Summerfelt. 1994. Converting pond-reared walleye fingerlings to formulated feeds: Effects of diet, temperature, and stocking density. Journal of Applied Aquaculture 4:31-57.

Malison, J.A., and J.A. Held. 1996. Habituating pond-reared fingerlings to formulated feed. Pages 199-204 in R.C. Summerfelt, editor. Walleye culture manual. NCRAC culture series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Moodie, G.E.E., and J.A. Mathias. 1996. Intensive culture of larval walleye on formulated food. Pages 187-190 in R.C. Summerfelt, editor. Walleye culture manual. NCRAC culture series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Moore, A.A. 1996. Intensive culture of walleye fry on formulated feed. Pages 195-197 in R.C. Summerfelt, editor. Walleye culture manual. NCRAC culture series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Nagel, T. 1996. Intensive culture of fingerling walleye on formulated feeds. Pages 205-207 in R.C. Summerfelt, editor. Walleye culture manual. NCRAC culture series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Ney, J.J. 1978. A synoptic review of yellow perch and walleye biology. American Fisheries Society Special Publication 11:1-12.

Pillay, T.V.R., and M.N. Kutty. 2005. Aquaculture principles and practices. Second edition. Blackwell Publishing, Oxford, England.

Pitcher, T.J., and J.K. Parrish. 1993. Functions of schooling behavior in fishes. Pages 363-440 in T. J. Pitcher, editor. The behavior of teleost fishes. Chapman and Hall, New York.

Stettner, C.R, R. C. Summerfelt, and K. L. Kuipers. 1992. Evaluation of commercial feeds for rearing advanced fingerling walleye. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 46: 402-412.

Summerfelt, R.C. 1996a. Introduction. Pages 1-10 in R.C. Summerfelt, editor. Walleye culture manual. NCRAC culture series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Summerfelt, R.C. 1996b. Walleye culture manual. NCRAC culture series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Summerfelt, R.C. 1996c. Intensive culture of walleye fry. Pages 161-185 in R.C. Summerfelt, editor. Walleye culture manual. NCRAC culture series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Summerfelt, R.C., and R.D. Clayton. 2007. Evaluation of open-formula grower diets for juvenile walleyes. North American Journal of Aquaculture 69:53-58.

Summerfelt, S.T., and R.C. Summerfelt. 1996. Aquaculture of walleye as a food fish. Pages 215-230 in Summerfelt, editor. Walleye culture manual. NCRAC culture series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Trushenski, J. T., C. S. Kasper, and C. C. Kohler. 2006. Challenges and opportunities in finfish nutrition. North American Journal of Aquaculture 68:122-140.

Wonnacott, E. J., R. L. Lane, and C. C. Kohler. 2004. Influence of dietary replacement of menhaden oil with canola oil on fatty acid composition of sunshine bass. North American Journal of Aquaculture 66:243–250.

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