COMPARATIVE GROWTH OF ALL-FEMALE VERSUS MIXED SEX YELLOW PERCH (*Perca flavescens*) IN RECIRCULATING AQUACULTURE SYSTEMS

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ABSTRACT

Nine, production-scale, recirculating aquaculture systems were utilized to compare the growth parameters between all-female and mixed sex yellow perch stocks. Each system was stocked with 455 fish m^{-3} and contained one of three different biofilter types: a rotating biological contactor, a trickling filter or a bead filter. The all-female fingerlings (S1) used were originally derived from Lake Mendota, Wisconsin. The mixed-sex fingerlings (S2) used were originally derived from Lake Erie. Temperature and photoperiod (23^{o}C, 16H-L) were maintained at levels for optimal growth.

Absolute growth rates ranged from 0.27-0.48 g/day. Mean final density within treatments was 42.8 kg/m^3 and ranged from 37.2-50.2 kg/m^3. The main effect of stock did not have a significant effect on growth ($p > .1$). All-female treatments exhibited more uniform growth. The main effect of filter type did have a significant effect on fish growth ($p < .01$), with fish in tanks containing trickling filters exhibiting significantly higher growth. Total feed conversion averaged 1.61 across all treatments and ranged from 1.38-1.78. S1 treatments consumed a significantly higher percent body weight per day than S2 treatments ($p < .05$).

Analysis of PIT tagged individuals revealed that the mean relative growth rate was significantly higher in S2 individuals (513.9%) compared to S1 individuals (315.3%:

$p < .01$). S2 females (597.8%) grew 1.9 times faster than S1 females (315.3%: $p < .01$). Within S2 individuals, females (597.8%) grew 1.5 times faster than males (395.2%: $p < .05$). For all individuals, 33.6% of the variation in final weight was explained by the variation in initial weight. Differences in the geographic strain or culture history of these stocks may have had a larger overall effect on growth than sexual classification (all-female or mixed sex).

Dress percentage of skin-on butterfly fillets was examined in 20 individuals per stock and in six groups of 20 individuals per stock. Within S2 individuals, 73.7% were female. Mean fillet yield was significantly greater in S1 individuals (47.6%) compared to S2 individuals (43.0%: $p < .01$). Mean GSI in S1 individuals (1.01%) was significantly higher than S2 individuals (0.54%: $p < .05$). Within S2 individuals, mean GSI was significantly higher in females (0.70%) when compared to males (0.08%: $p < .05$). Fillet yield was significantly greater in S1 groups (47.2%) compared to S2 groups (44.9%: $p < .01$). Within each stock fillet yield increased with size.

The difference in fillet yield demonstrated between these stocks may be a result of differences in strain of origin. The identification of superior yellow perch strains or strain crosses with regard to growth rate and fillet percentage is of considerable importance to the industry.

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CHAPTER 1

REVIEW OF YELLOW PERCH (*Perca flavescens*) CULTURE.

TAXONOMIC CLASSIFICATION

The yellow perch (*Perca flavescens*, Mitchell) is classified in the family Percidae, subfamily Percinae, and tribe Percini (Nelson, 1994). Percidae is the second most diverse family of North American freshwater fishes and includes darters, perches, walleye, and sauger. The native range of yellow perch includes the Atlantic, Arctic, Great Lakes, and Mississippi River basins from Nova Scotia and Quebec west to the Northwest Territories and south to Ohio, Illinois, and Nebraska. In the Atlantic drainage, the native range extends south to the Santee River in South Carolina and has been widely introduced elsewhere in the United States (Page and Burr, 1991).

"Historically, the North American yellow perch (*Perca flavescens*) and the Eurasian perch (*Perca fluviatilis*) were considered distinct species. A study by Stetovidov and Dorofeeva (1963) concluded that there was a single, circumpolar species with three subspecies. That taxonomic status was accepted by some North American authors (Scott and Crossman 1967; McPhail and Lindsey 1970), but not by others (Robins 1991). Collette and Banarescu (1977) found that the predorsal bone in the *Perca flavescens* extends between the first and second neural spine while it is anterior of the first neural spine in *Perca fluviatilis*, that morphological difference clearly separates the two species."(Heidinger and Kays, 1993)

Thorpe (1977), however, concluded that the two species are biologically equivalent, and as a result of this, both species will be considered in this literature review.

YELLOW PERCH MARKETS

In the upper Midwest, Friday night fish fries are a long-standing social institution. Historical abundance of the Great Lakes yellow perch made the mild tasting, and relatively inexpensive perch a particular favorite at these weekly affairs (Lesser and Vilstrup, 1978). A serious decline in the Great Lakes fishery began in the early 1970s and has never reversed itself (Riepe, 1998). Commercial perch landings in the Great Lakes peaked at 16.3 million kg in 1969, but dropped to 4.7 million kg in 1976. Traditionally, Lake Erie (85%) and Lake Michigan (12%) accounted for most of the total commercial catch of yellow perch (Lesser and Vilstrup, 1978). However, commercial harvest has been completely banned in Lake Michigan since 1996. In Lake Erie, there are no signs that the yellow perch fishery will be restored to levels experienced in the late 1980s (Ontario Ministry of Natural Resources, 1996).

Declines in the catch of Great Lakes yellow perch have led to high prices for perch fillets. In 1996, wholesale fillet prices varied in the $13 to $17 per kg range (Reipe, 1998), and retail fillet prices have risen to more than $24 per kg (NCRAC, 1996). Wholesale prices for yellow perch in the round range from $2.30-3.00/lb ($5.07-6.61/kg: Malison, 1999c). Despite elevated prices, consumer preference for yellow perch persists and has resulted in yellow perch becoming one of the focal points of aquaculture research in the Great Lakes region of the United States (Brown et al., 1996).

An emerging yellow perch aquaculture industry presently contributes less than 90,720 kg per year. One large food distributor (Great Lakes Marketing, Inc., Waukesha, WI) believes the existing market could readily absorb 23-45 million kg per year (Malison, 1999c). Because of the limited supply, yellow perch is often replaced with imported products. This includes the Eurasian perch (*Perca fluviatilis*) and pike-perch (*Stizostedion lucioperca*) from Europe, walleye

(*S. vitreum*) and sauger (*S. canadense*). Frequently, these alternative products are illegally sold as yellow perch (Malison, 1999b).

Traditionally, Wisconsin has consumed 9 to 11 million kg of yellow perch per year, accounting for 75% of the annual U.S. yellow perch harvest (Calbert and Huh, 1976). A survey of states in the North Central region found that over two-thirds (70%) of responding restaurants that sold yellow perch were located within 50 miles of the Great Lakes (Riepe, 1998).

Several recent studies suggest a potentially large market for farm-raised yellow perch. In a survey of wholesale and retail fish buyers, 72.1% rated farm-raised fish as "somewhat better or superior" versus wild caught fish. The high rating of cultured fish was due to its increased availability, size uniformity, freshness and quality. A vast majority (80.6%) of the buyers indicated they would increase their utilization of farm-raised fish in the future (Hushak, 1993). Aquaculture products may also have a marketing advantage over wild caught products as a result of concerns about microcontaminants in wild fish (Malison, 1999a). Another survey found that, although less than 10% of the restaurants in the North Central region indicated they were purchasing farm-raised yellow perch, over half (56%) reported interest in doing so (Reipe, 1998). Thus, yellow perch was identified as a species with a high potential for aquaculture development based on market presence and buyer demand
(Hushak, 1993).

Industry research has shown that frozen yellow perch fillets are an acceptable product form for the restaurant market. Restaurants prefer fresh (44%) and frozen (51%) fillets about equally when price and supply are not an issue. When yellow perch is actually purchased, however, about two-thirds (65%) of the restaurants purchase frozen fillets (Riepe, 1998). Yellow perch fillets are low in fat (0.8%) and phospolipids (Kinsella et al., 1977). These attributes result

in yellow perch having a long shelf life, resistance to freezer damage, and minimal problems with off-flavor and cooking (Malison, 1999b). The number of production and marketing options broadens considerably once the burden of supplying fresh products is eliminated. Production facilities targeting the restaurant market no longer need to be in close proximity to the Great Lakes. Wherever conditions are most conducive to cost-effective production, yellow perch can be reared and shipped as a frozen product (Riepe, 1998). Accordingly, interest in yellow perch aquaculture has spread from the Midwest throughout much of the United States.

While frozen yellow perch fillets are an acceptable product form for restaurants, other research indicates that this is not the case for perch bought for in-home preparation and consumption (Wesson et al., 1979). Among other species, this study compared fresh yellow perch fillets to that of frozen Eurasian perch fillets imported from Holland. The fresh yellow perch was distinctly less oxidized in flavor, and markedly less dry and tough in texture than the frozen Holland perch product. In-home consumer preference data showed a significant preference for fresh perch, where 85% of the respondents reported a willingness to buy fresh yellow perch compared to 50% reporting a willingness to buy frozen perch (Wesson et al., 1979).

Lindsay (1980) compared fresh cultured yellow perch to fresh wild caught yellow perch. This study found that aquacultured perch fillets were whiter than wild caught perch fillets, and significantly more firm than wild caught perch when prepared as deep-fried fillets. Aquacultured and wild caught perch were equally preferred when environmentally induced off-flavors were absent (Lindsay, 1980). A series of organoleptic evaluations at Purdue University found that cultured yellow perch consistently received the highest preference score when compared to wild caught yellow perch, catfish, walleye, and trout in Indiana, Wisconsin, Illinois, and Kentucky (Cox, 1995).

Fresh yellow perch cultured under controlled environmental conditions commands a higher market price than wild caught perch. This is mainly due to increased fillet yields over wild fish, through the elimination of a 6% loss to freezer shrinkage, and the size uniformity available in cultured fish (Lesser and Vilstrup, 1978). Farm-raised yellow perch have a typical fillet yield of 45%, and average 5% higher yield than wild caught butterfly fillets (Heidinger and Kays, 1993). Restaurant managers prefer standardized portion sizes. Size uniformity of fillets is difficult to achieve with wild caught fish, but aquaculturists have the ability to offer standardized sizes which adds value to their product.

Utilizing fresh perch also reduces the need for frozen storage and eliminates costs of carrying a large inventory. Using costs for the 1975-76 period, the benefits for farm-fresh yellow perch added up to a 47.4 cents per kg price advantage over wild caught fish (Lesser and Vilstrup, 1978). The average 1996/1997 price of fresh fillets ($16.42/kg) purchased by restaurants in the North Central Region was higher than the average price of frozen fillets ($15.19/kg: Reipe, 1998). The premium price that fresh yellow perch demand has unfortunately resulted in previously frozen product being illegally sold as fresh (Malison, 1999a).

YELLOW PERCH CULTURE

Growth & Culture

The current market size for yellow perch is 115-150g, or around 20 cm length (Bennett Fish Inc., Loraine, OH). Calculations from data presented by Carlander (1950) indicate that the mean growth rate of natural populations in North America would produce a 20.4 cm yellow perch after 4 years of life. In southern Wisconsin ponds, approximately 30% of females can reach market size in two growing seasons (Malison, 1999a). Under optimum rearing conditions

of 21°C with 16-h light, fed 3 to 4% of body weight daily, Calbert and Huh (1976) predicted that 1.0-1.5 g yellow perch will reach market size in 9 to 11 months. Preliminary research demonstrated that at 20 to 24°C, perch grew at 0.8 to 1.1 cm per month and had monthly feed conversion ratios from 1.3 to 3.5 (Starr, 1991).

Biologically, the yellow perch is well suited for commercial aquaculture. Yellow perch show little aggressive or cannibalistic behavior, readily accept formulated diets, and are highly tolerant of crowding and other conditions associated with intensive culture (Heidinger and Kayes, 1986).

Problems

Several problem areas have been identified in yellow perch aquaculture, which have impeded the growth of this industry. The yellow perch is a relatively small fish, and even though it can be marketed as small as 115g, it may go through its rapid growth phase before it reaches a harvestable size (Heidinger and Kays, 1993). The yellow perch has a relatively slow growth rate compared to other aquacultured species (Malison, 1999b). The industry advisory council of the North Central Regional Aquaculture Center (NCRAC) has identified the lack of reliable methods of producing perch fingerlings habituated to formulated feeds as a major constraint that presently limits perch aquaculture (NCRAC, 1998). A lack of even the basic understanding of the nutritional needs of yellow perch also may be impeding commercial development (Brown et al., 1996).

Another key problem inhibiting the commercial aquaculture of yellow perch is the growth heterogeneity between male and female perch. Male perch grow much more slowly than females (Schott et al., 1978; Malison et al., 1985; 1986; Malison and Garcia-Abiado, 1996) and

female perch reach larger ultimate sizes than males (Leach, 1928; Carlander, 1950; Scott and Crossman, 1973). This sexual dimorphic growth pattern is evident in yellow perch as small as 8-12 g in total weight and 90-120 mm in total length (Schott et al., 1978; Malison et al., 1986). Body weight can range from 7 to 89 g for 7-month-old fish, with a mean of 25.9g (Melard et al., 1996a). It has been suggested that growth heterogeneity is a result of sexual growth dimorphism, genetic variability, and social behavior (Craig, 1987; Melard et al., 1995).

Le Cren (1958) suggested that the onset of sexually dimorphic growth in Eurasian perch is closely associated with the onset of sexual maturity. Schott (1980) however, demonstrated that sex-related size dimorphism can develop in yellow perch under artificial conditions within the first year of life, in fish that were clearly not mature.

Body size in yellow perch, rather than environmental cues or age, may be the major factor controlling the onset of differential growth between the sexes. Two lines of evidence presented by Schott (1980) support this hypothesis. First, the size variations noted developed under artificial conditions among fish that had never experienced a full annual cycle of photoperiod and temperature fluctuation. Second, rapidly growing fish exhibited size dimorphism at an earlier age than slower growing individuals, indicating a size rather than age threshold.

Female growth in Eurasian perch has been reported as 1.5-1.7 times faster than male growth (Melard et al., 1996a) and by the time female yellow perch reach a size of 100-120g they commonly are 25-50% larger than males (Malison, 1985). Females consume greater amounts of food and convert food more efficiently than males (Malison et al., 1988). Perhaps androgens (male hormones) retard and estrogens (female hormones) accelerate the growth of yellow perch (Schott et al., 1978). Since the difference in growth rate expresses itself long before the fish

reach marketable size (Best, 1981; Malison et al., 1986), methods of producing monosex female populations of yellow perch may substantially increase production in commercial aquaculture.

Sexual development poses a second problem in yellow perch aquaculture. During this time energy and growth are redirected from somatic elements into gonadal development, and overall growth may be reduced (Ihssen et al., 1990; Mair, 1993). After females reach sexual maturity, approximately 87% of their energy is devoted to egg production under natural conditions (Miller, 1995). Sexual maturation not only reduces somatic growth, but it may markedly reduce the fillet yield, as ovaries may account for up to 35% of the total weight of the fish (Malison and Garcia-Abiado, 1996). Accordingly, methods that sterilize or retard gonadal development in yellow perch also may benefit the aquaculture industry.

Production Data

Though aquaculture often has not been economically feasible due to high per unit costs of feed and technology, advances in fish nutrition and recirculating systems have increased yields. Aquaculture technology is pushing production costs down while fish and seafood prices are going up (Hushak, 1993). Numerous scientific and commercial ventures have demonstrated the technical feasibility of raising a wide variety of aquaculture species in recirculating systems (Broussard and Simco, 1976; Bovendeur et al., 1987; Nunley, 1992). The enhanced quality control offered by recirculating systems, combined with an inherent reduction in water usage and environmental impact, makes it a viable choice for the future of the aquaculture industry (Loyless and Malone, 1997).

There is very little published data available on the production requirements of yellow perch in recirculating aquaculture systems (NCRAC, 1998). Kocurek (1979) completed part of

her thesis work on raising yellow perch in recirculating systems. Two rearing tanks, each containing 8,500 liters, were used in this study. Each system was stocked with 1,050 fingerlings, which were raised for 12 months on a trout diet. After 5 months of growth, the fish in both units were divided into 2 groups on the basis of size, with each group occupying 3,180 liters. In both systems, the fastest growing groups reached market size within 12 months. Mean absolute growth rates over the entire experiment were between 0.29-0.41g/day, with 12.7-40.5% mortality (Kocurek, 1979). This was the first such study to demonstrate the technical feasibility of raising yellow perch to market size within a recirculating system.

Preliminary studies have been conducted on Eurasian perch reared in recirculating systems and in floating cages. For 8 weeks, 22-25g perch were reared in both of these systems on an artificial trout diet. Four trials were conducted in each system, with two replicated feeding treatments of 2 and 4% body weight per day. The specific growth rates (1.1-1.4% day^{-1}) were similar for both culture systems (Fontaine et al., 1996).

Starting from 1 g weaned juveniles, intensive rearing of Eurasian perch resulted in a 50% survival rate and favors growth heterogeneity. Despite some individual fish (10-15%) showing a high growth potential, the perch is generally a slow-growing fish even in optimal rearing conditions (average weight = 120 g in 1 year) (Melard et al., 1996a). In intensive rearing systems (50 kg m^{-3}), 44-day old weaned larvae reached an average body weight of 130-150 g after 1 year of rearing (Melard et al., 1995). Market size was reached about 3 months earlier by faster growing fish, thus allowing a better sharing of the production over the annual cycle, depending on market demand.

In other Eurasian perch experiments (stocking biomass from 30-60 kg m^{-3}), the market size of 120-140g was reached after 1 year by only half of the fish, of which 80% were females.

These fish were started from eggs and were fed optimum rations (see description in "Feeding"). At 23^{o}C, Eurasian perch reached the minimum market size with a specific growth rate (SGR = $(LnW_2\text{-}LnW_1)t^{-1}$) around .086% day $^{-1}$ (1.2g day^{-1} in 140g fish) (Melard et al., 1996b).

These results, though preliminary, demonstrated the feasibility of raising both yellow and Eurasian perch in recirculating aquaculture systems using artificial feed. Growth and productivity in intensive perch rearing may be improved substantially through techniques such as the selection of fast-growing strains, selection of fast-growing individuals as broodstock, all-female or sterile triploid fish production (Melard et al., 1995; Melard et al., 1996a). Scientific experiments have not proven these assertions.

Temperature and Photoperiod

In growth experiments, temperature and photoperiod must be carefully controlled, since these factors can greatly influence yellow perch growth (Huh et al., 1976). The optimum temperature for rearing and feeding larval yellow perch is between 20.0 ^{o}C and 23.9 ^{o}C (Heidinger and Kays, 1993). According to McCormick (1974; 1976) the optimum temperature for feeding and rearing juvenile perch is 23.9 to 27.8 ^{o}C. This is slightly higher than the 20-24 ^{o}C range found by Huh (1975). The upper incipient lethal temperature reported for juveniles is 29.1 ^{o}C, and for adults is 33 ^{o}C (Hokanson, 1977).

In Eurasian perch, maximum growth rates (0.06 to 1.80g fish^{-1} d^{-1} for 1 to 300 g fish) were observed at 23 ^{o}C. Rearing at higher (27 ^{o}C) or lower temperatures (11-20 ^{o}C) resulted in lower growth rates. Perch reared at 20 ^{o}C showed a 20% lower growth compared to fish of the same body weight (100g) at 23 ^{o}C (Melard et al., 1995).

Maintaining constant temperatures not only optimizes growth, but also functions to inhibit the sexual maturation in females (Melard et al., 1995; 1996a). Reproductive development in both of these species can have a significant negative impact on somatic growth and fillet yield (Malison and Garcia-Abiado, 1996). According to Hokanson (1977), yellow perch from Minnesota require a minimum chill period of 160 d at 10 ^{o}C or less to obtain 100% female spawning participation. Southern strains of yellow perch may require a shorter chill period at slightly warmer temperatures (Kolkovski and Dabrowski, 1998). Just prior to spawning, the gonadosomatic index (GSI) of mature females may reach 35% (Malison and Garcia-Abiado, 1996), while the GSI of male yellow perch ranges from 8 to 15% (Lagler et al., 1962; Brazo et al., 1975).

In addition to temperature, photoperiod appears to have a significant influence on the growth rate in yellow perch (Huh, 1975; Huh et al., 1976). Growth of perch reared at the same temperature, but with a shorter photoperiod (8 h-L) was only about one-third that of fish exposed to photoperiods of 16 or 20 h light (Huh et al., 1976). Apart from temperature, ration size and size of fish, light is probably the most important factor governing metabolic activity, feeding, and growth (Ryder, 1977).

Grading

Growth heterogeneity constitutes a major constraint in perch culture. Several studies have examined the effect of grading on overall productivity by sorting a population into three non-overlapping, weight-related groups (Melard et al., 1995; 1996b). The grading resulted in similar mean specific growth rates between the three groups, with the emergence of fast growing fish in each group. After 200 days of growth, the heterogeneity was so high in each group that

the weight distributions overlapped by more than 60%. Overall, the grading processes caused the productivity to be 5-6% lower than in non-sorted populations of the same origin and body weight (Melard et al., 1995; 1996b).

Stocking Density

Growth patterns are strongly influenced by stocking density in perch populations (Melard et al., 1996b). High stocking densities often inhibit territorial and agonistic tendencies that potentially limit access to food (Melard et al., 1995). In a 74-day rearing experiment with Eurasian perch, coefficients of variation of fish body weight decreased from 98.4 to 57.9% with increasing density (Melard et al., 1996b). A positive relationship between density and growth was evident until fish reached 15-20 g body weight. In larger individuals, growth rate decreased with increasing stocking densities. Final stocking biomass ranged from 24 to 35 kgm^{-3}. Intensive rearing offsets a reduction in individual growth by achieving a higher productivity. Survival was independent of stocking density and averaged 85% (Melard et al., 1995; 1996a). These experiments support the significance of high density rearing for the culture of juvenile perch, since the maximum growth and minimum size heterogeneity were achieved at the highest stocking densities (1430 and 2380 fish m^{-2} respectively) (Melard et al., 1996b).

Habituation

Under current production schemes, yellow perch fingerlings are produced primarily in ponds. Intensive rearing of larval perch is difficult because the fry are very small at hatch, from 4-7 mm total length (Mansueti, 1964; Ney, 1978), and existing dry or semi-moist diets yield poor

survival (Brown and Dabrowski, 1995). Larvae often are placed into fertilized culture ponds where they feed on rotifers and other small zooplankton (West and Leonard, 1978).

Young perch are positively phototaxic (Schumann, 1963) and pond harvest can be accomplished at night with the aid of a light and lift net. Manci et al. (1983) successfully removed 61% (23,000) of the fingerlings from a 0.08 ha pond using this method. The size of perch that were attracted to the light ranged from 8-50mm.

Fingerlings that have been trained to accept artificial diets can be placed in ponds or tanks and raised to marketable size. Significant components of feed-training fingerlings include: concentrating the fingerlings, removing the natural food source, elevating the temperature to ensure an aggressive feeding response, feeding frequently, and grading fingerlings to reduce cannibalism (Heidinger and Kays, 1993).

Survival is directly related to fingerling size at the beginning of the training period. Less than 50% of larvae smaller than 16 mm can be expected to survive, while 80% of larvae 18 mm long and 98% of those longer than 31 mm have been shown to survive (Best, 1981). Both growth and survival can be maximized by relocating, size-grading, and introducing prepared feeds soon after perch larvae reach 20 mm. In one experiment on yellow perch, the growth of early-trained (ET) perch was compared to late-trained (LT) perch, those trained three weeks later (Best, 1981). Results indicated that even though ET fish were initially significantly smaller in length and weight ($P < 0.001$), after 45 days ET fish were significantly longer ($P < 0.001$) and heavier ($P < 0.001$) than LT tankmates (Best, 1981).

There has been some success reported for rearing perch larvae on live zooplankton. According to Hale and Carlson (1972), 250 planktonic organisms per larval yellow perch are required daily to obtain 50% survival during the first three weeks of feeding. Those authors

recommended feeding at least four times daily using dark-bottomed tanks. Other researchers have successfully reared larval perch in intensive culture tanks using green-water systems with survival as high as 60-80% after 30-45 days (Brown and Dabrowski, 1995).

Feeding

The effect of feeding frequency (1, 3, and 6 feedings/day) on growth has been examined in 30g juvenile Eurasian perch (Melard et al., 1995). At a daily ration of 2% body weight, the highest growth rate was obtained when fish were fed three times a day. A daily ration of 2% body weight corresponded to a feeding level between what was calculated to be the optimum ration and the maximum ration. The maintenance (R_{maint}), optimum (R_{opt}), and maximum (R_{max}) daily food rations were estimated for 1-300g perch reared at 23^{o}C at stocking densities of 20-50 kg m^{-3}as follows: $R_{maint} = 1.09w^{-0.23}$, $R_{opt}=3.30\ w^{-0.24}$, and $R_{max} = 7.60\ w^{-0.31}$ (Melard et al., 1995), where **w** represents the average weight in grams, and **R** is equal to the ration in body weight per day.

The maximum daily ration provided feed conversion ratios from 1.1 to 2.0 in fish ranging from 1 to 150g and up to 3.0 in 300 g fish. The corresponding FCRs for R_{opt} were 1.0, 1.7 and 2.0 (Melard et al., 1996a). The person administering feed may empirically adjust food rations based on apparent food consumption at the population level. This would allow adjustment for differences in survival and growth patterns, and also avoids water quality degradation resulting from overfeeding.

OBJECTIVES

Past research has demonstrated that female perch grow faster and ultimately larger than males, both in the wild and in culture conditions. Currently, all-female perch stocks are available for commercial aquaculture producers. Although these stocks seem to have the potential to increase aquaculture production, scientific research has not confirmed this hypothesis. Against this background, the objectives of this study were: (1) to compare production parameters between all-female and mixed-sex yellow perch stocks in production-scale grow-out trials, (2) to track and compare individual growth between and within stocks and assess the implications towards maximizing production through early selection upon the production stock, and (3) to compare fillet yields between stocks under controlled environmental conditions and evaluate the possible effect of gonadal development on fillet yield.

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CHAPTER 2

COMPARISON OF GROWTH, FEED CONSUMPTION, FEED CONVERSION AND HARVEST DATA OF ALL-FEMALE AND MIXED-SEX YELLOW PERCH (*Perca flavescens*) IN RECIRCULATING AQUACULTURE SYSTEMS.

INTRODUCTION

A key problem inhibiting the commercial aquaculture of yellow perch is the growth heterogeneity between male and female perch. Male perch grow much more slowly than females (Schott et al, 1978; Malison et al., 1985; 1986; Malison and Garcia-Abiado, 1996), and female perch reach larger ultimate sizes than males (Leach, 1928; Carlander, 1950; Scott and Crossman, 1973). This sexual dimorphic growth pattern is evident in yellow perch as small as 8-12 g in total weight and 90-120 mm in total length (Schott et al., 1978; Malison et al., 1986). Body weight can range from 7 to 89 g for 7-month-old fish, with a mean of 25.9g (Melard et al., 1996a). It has been suggested that growth heterogeneity is a result of sexual growth dimorphism, genetic variability, and social behavior (Craig, 1987; Melard et al., 1995).

Female growth in Eurasian perch has been reported as 1.5-1.7 times faster than male growth (Melard et al., 1996a) and by the time female yellow perch reach a size of 100-120g they commonly are 25-50% larger than males (Malison, 1985). Females consume greater amounts of food and convert food more efficiently than males (Malison et al., 1988). It has been suggested androgens (male hormones) retard and estrogens (female hormones) accelerate the growth of yellow perch (Schott, 1978). Since the difference in growth rate expresses itself long before the fish reach marketable size (Best, 1981; Malison et al., 1986), methods of producing monosex

female populations of yellow perch may substantially increase production in commercial aquaculture.

Female yellow perch are homogametic (i.e. XX in an XY sex-determining system). Three methods of producing monosex female yellow perch populations include: (1) gynogenesis; (2) direct estrogen treatment of juveniles; and (3) indirect use of hormones (Malison and Garcia-Abiado, 1996).

Gynogenesis

In gynogenetic fish, both sets of chromosomes are maternally derived. In species with the XY sex-determining system, all gynogens will be females. Gynogens are produced by fertilizing normal eggs with sperm that has been inactivated followed by either a physical or chemical shock timed to disrupt either the second meiotic division (meiotic gynogens) or the first mitotic division (mitotic gynogens), thereby restoring the normal diploid state (Tave, 1996).

Gynogenesis may not be the best available method for producing monosex female yellow perch for aquaculture. Mitotic gynogens are expected to be homozygous at all loci and have inbreeding of 100% (Tave, 1996), impacting viability and performance directly. In several fish species, increased homozygosity has been shown to have a negative affect on the performance of gynogens (Purdom, 1986). Also, the survival and growth of mitotic and meiotic gynogens may be negatively affected as a result of the use of heat or hydrostatic pressure shocks (Malison and Garcia-Abiado, 1996).

Direct Estrogen Treatment of Juveniles

Perch are gonochoristic, meaning that the undifferentiated gonads of juveniles undergo direct transition into either ovaries or testes, and no intersex or hermaphroditic stage occurs (Best, 1981). The most efficient method of administering steroids is by dietary supplement. Administering estradiol-17β at 15-120 mg/kg diet for 84 days induced complete germ cell sex inversion in male yellow perch. This was completed in age zero yellow perch at a total length of 20-35mm (Malison and Garcia-Abiado, 1996).

Throughout the United States and Europe, strict government regulations and consumer concerns prevent the indiscriminate use of hormones in animals destined for human consumption. For this reason, direct estrogen treatment is not the best option in the production of monosex female yellow perch for the aquaculture industry. Tilapia, however, that have been directly treated with 17α-methyltestosterone (MT) to produce monosex male populations have been successfully marketed in many countries (Mair and Little, 1991).

Indirect Use of Hormones

In production of all-female yellow perch, the induction of partial rather than complete sex inversion is advantageous because of the ease of identification between genetic males and genetic females, once the fish reach sexual maturity. Genetic males have paired gonads while genetic females have a single gonad. Treatment of yellow perch initially 20-35mm TL with MT at 1.5-60 mg/kg diet for 84 days induced spermatogenesis and the formation of ovotestes in genetic females (Malison and Garcia-Abiado, 1986). Sperm collected from masculinized females was then used to fertilize normal eggs, resulting in offspring that were 100% females.

Under the current regulations, the indirect use of hormones may be the best method for producing monosex female populations of yellow perch. With this method, fish destined for human consumption are never treated with hormones. Also, females produced by this technique are unlikely to exhibit the impaired performance common in gynogens. Finally this method is inherently 100% effective when properly applied. The only drawback to this technique is the lag time required for treated broodstock to reach sexual maturity which may range from 2 to 4 years (Malison and Garcia-Abiado, 1996).

INDIVIDUAL GROWTH

Passive Integrated Transponder (PIT) tags have proven to be a valuable tool to track individual growth and movement in several fish species (Prentice et al., 1990; Withler et al., 1995; Ombredane et al., 1998). A PIT tag is a glass-encapsulated, physiologically neutral, internal marking device (Nielsen, 1992). The tag consists of a 2.1mm x 12mm rounded cylindrical glass capsule containing a copper wire antenna and an electronic microchip programmed with a unique identification code (Hagen, 1996). The tag has no internal power source; however, the small microchip transmits its identification code when excited by a hand-held detector (Moore, 1992).

Retention of PIT tags has been over 95% in several experiments (Harvey and Campbell, 1989; Prentice et al., 1990; Moore, 1992) and reported studies of PIT tags have shown no effect on growth or survival (Jenkins and Smith, 1990; Peterson et al., 1994; Withler et al., 1995; Ombredane et al., 1998). The biggest disadvantage of PIT tags is their cost (Nielsen, 1992). Less expensive tag alternatives, including visible implant tags and T-bar anchor tags, have shown unacceptable retention rates. Bryan and Ney (1994) obtained a retention rate of about

50% using visible implant tags on brown trout, and Brewin et al. (1995) found retention rates of 85.0% and 55.7% for female and male brown trout using T-bar anchor tags.

In aquaculture applications, PIT tags have mainly been used to identify valuable brood fish (Harvey and Campbell, 1989; Jenkins and Smith, 1990). PIT tags may also function in tracking individual growth within high-density rearing conditions. This would provide valuable growth data free from the possible bias associated with sub-sampling populations to monitor growth. Data obtained from specific individuals permits the comparison of growth between males and females within or between treatments. Comparing individual growth between sexes or stocks would have important applications to aquaculture management decisions including size-grading (Gunnes, 1976), culling of individuals (Wickins, 1987), and genetic selection programs (Dunham and Smitherman, 1983).

OBJECTIVES

Currently, all-female perch stocks are available for commercial aquaculture producers. Although these stocks seem to have the potential to increase aquaculture production, scientific research has not confirmed this hypothesis. The objectives of this study were to: (1) compare growth, feed consumption, feed conversion, survival, and harvest data between all-female and mixed-sex yellow perch stocks in production-scale grow-out trials, (2) compare growth between male and female individuals within a mixed-sex fish stock and between female individuals between stocks, and (3) determine the predictability of individual growth rates in yellow perch and assess the implications toward aquaculture management decisions.

METHODS

RAS Design

Nine production scale, recirculating aquaculture systems, located at the Virginia Polytechnic Institute and State University Aquaculture Research Facility, Blacksburg, VA, were utilized in this study. Each independent system had the following identical components: an 8,330 liter rectangular, fiberglass culture tank (6.1m x 1.5m x 1.2m), a rotating drum filter for solids removal (mesh = 120 microns), a U-tube aeration system (0.32m diam. X 13.6m d), and 3, one-horse power pumps (with two pumps leading to the biofilter and one pump leading to the U-tube). Each system contained one of three different biofilter types: a rotating biological contactor (RBC: Figure 2.1), a trickling filter (Figure 2.2), or a bead filter (Figure 2.3). Total surface area, specific surface area, mean flow rate and turnover time are listed for each filter in Table 2.1. Each biofilter type was utilized on three of the nine systems.

Stocking

A high stocking rate (455 fish m^{-3}) was selected for this trial. Each of the nine recirculating systems was stocked with approximately 3,800 perch fingerlings estimated by weight. Four of the tanks were stocked with all-female fingerlings averaging 4.4g (Coolwater Farms, L.L.C., Cambridge, WI). The all-female stock (hereafter referred to as "S1") was produced through the indirect use of hormones, and was originally derived from Lake Mendota, Wisconsin. Examination of 75 S1 individuals confirmed that 100% were female. The remaining five tanks were stocked with mixed-sex fingerlings averaging 5.6g (BPM Inc., Leetonia, OH). The mixed-sex stock (hereafter referred to as "S2") was originally derived from Lake Erie. Examination of 129 S2 individuals confirmed equal sex ratios (65 females: 64 males). The two

groups of fish were arbitrarily assigned to the nine systems on the basis of biofilter type, making sure both groups were represented in each of the three biofilters (see Table 2.7 for experimental design). All fish were acclimated to experimental conditions for approximately 50 days before the growth study began.

Environmental Conditions

Temperature was maintained as close as possible to the optimum growing temperature of 23^{o}C (+/- 2^{o}) (Melard et al., 1995). Water temperature was maintained by regulating the ambient air temperature. During cold weather, heat was supplied through four propane heaters in the building, while an exhaust fan aided in lowering the temperature in warm-weather seasons.

Photoperiod was maintained at the optimum growth conditions of 16-hour light, 8-hour dark cycle (Huh et al., 1976). Sunset and sunrise were simulated utilizing a motorized rheostat, which utilized a 45-minute transition period from full light to full dark conditions and vice versa.

Feed Training

Although both stocks of fish were purchased as "feed trained" fingerlings, all fish were further conditioned to accept an identical high protein, floating diet composed of a minimum of 42% crude protein, 12% fat, 3% crude fiber and a maximum of 13% moisture (Rangen Feeds, Inc., Buhl, ID). Freeze dried krill (Argent Chemical Laboratory, Redmond, WA) was initially added to the feed to stimulate feed acceptance. Young perch are positively phototaxic (Schumann, 1963) and a submerged 35 watt light (modified Starfire II, Brinkmann Corporation, Dallas, TX) was placed in each tank to assist in feed training. Each light was positioned approximately 11 cm below the surface and was supported by a styrofoam float (441 cm^2). All

lights were simultaneously activated just prior to feeding and were turned off approximately 5 minutes after the last feed was administered. Light intensity was adjusted gradually and was controlled by a common rheostat. Emaciated fish that failed to accept the commercial diet were removed and replaced.

Feeding

Feed was administered by hand twice or three times daily. All tanks were fed to satiation at each feeding to allow for differences in survival and growth at the population level between the nine systems. Only small amounts were fed at any one time to eliminate excess feed and to prevent water quality degradation by uneaten feed. Total feed (g) administered in each system was monitored and recorded. Small amounts of food occasionally remained uneaten. This occurred infrequently, and these amounts were not corrected for. Due to the relatively slow growth exhibited by yellow perch, feed consumption and feed conversion estimates were compared between six, 48-day intervals throughout the experiment. Feed consumption was expressed as percent body weight consumed per day and was calculated as [(average daily feed ration/ average total biomass) x 100]. Days where no feed was administered were not included in the calculation. Feed was withheld from all tanks on sampling days. Feed conversion was calculated as dry weight feed consumed divided by wet weight of fish gain.

Sampling

The growth trial was initiated with the measurement of an arbitrary sample of 60 yellow perch (1.6% of the population) from each tank. A crowding device was used to bring together all of the fish in one end of the tank where a sample of fish was netted and transferred into an 880

liter holding tank. The holding tank contained approximately 70 mg/l of the anesthetic MS-222, tricaine methanosulfate (Western Chemical Inc., Ferndale, WA) and 4,000 mg/l of NaCl. Wet weight to the nearest 0.1g and total length to the nearest millimeter were recorded for each fish. An arbitrary sample of 60 (1.6%), 120 (3.2%), or 380 (10%) fish out of each system was measured and weighed approximately once every 28 days thereafter. By allowing four weeks between samples, handling stress was minimized while still allowing accurate monitoring of growth.

Tagged Individuals

PIT tags (Biomark Inc., Boise, ID) were used to track individual growth of yellow perch in recirculating aquaculture systems. In this experiment, a total of 180 yellow perch were individually tagged, with thirty individuals tagged in six separate systems, representing both of the stocks (S1 and S2) in each of three biofilter types (bead, RBC, & trickle). Individuals to be tagged were selected through arbitrary samples from appropriate tanks 56 days into the main growth experiment. A modified syringe with a 12-gauge hypodermic needle was used for tag insertion (Hagen, 1996). Tags were implanted into the body cavity just off the mid-ventral line, posterior of the pectoral fins, and directed toward the anterior of the fish. Measurements recorded included initial length to the nearest millimeter and initial total weight to the nearest 0.1 gram.

Since tagged individuals represented less than one percent (0.79%) of the tank population, recovery during monthly samples was highly unlikely. Therefore, tagged individuals were recovered at the termination of the experiment, when all of the systems were completely harvested. Several hand-held interrogators were used to detect and recover tagged individuals

after 236 days of growth. Upon recovery, final length to the nearest mm and final weight to the nearest 0.1g were recorded. All tags were later removed from these individuals, at which point the gonads were examined for determination of sex.

The relative growth rate of tagged individuals was calculated as:

$$[(W_t - W_i)/W_i \times 100]$$

where W_t is the final weight and W_i is the initial weight. Relative growth rates are reported as a percent increase in weight and allow the comparison of treatments with different initial sizes (Hopkins, 1992).

Water Quality

Water quality parameters that were measured included total ammonia (TAN), un-ionized ammonia, nitrite, nitrate, pH, dissolved oxygen, and alkalinity. Dissolved oxygen and temperature in each system were measured daily with a portable oxygen meter (YSI Co., Yellow Springs, OH). Daily measurements of pH and total ammonia nitrogen (TAN) were made with a pH pen and a spectrophotometer, respectively (Hach Co., Loveland, CO). Weekly measurements were recorded for nitrite and nitrate (spectrophotometer; Hach Co.) and of alkalinity (titration method; Hach Co.).

Fresh water was added daily to each system in order to replace the loss to evaporation, splash out, and solids removal. Around 5% of the tank volume was replaced with fresh water in each system on a daily basis. If water quality became degraded in a particular system, a larger amount of fresh water was added to maintain proper growing conditions. In these cases, water volume replaced in the system was measured and recorded on an individual system basis.

Harvest Data

After 292 days of growth, all tanks were completely harvested. All fish from each tank were sorted according to size. Fish 115g or larger were considered harvestable size. All fish from each tank were weighted in groups of 30 fish at a time. Immediately after sorting, the combined weights of 30 individuals (either undersized or harvestable sized) fish were collectively weighed to the nearest 5 grams. Other harvest data determined for each tank included: total number of fish recovered, percent harvestable versus undersized fish, overall average weight, and average weight of undersized versus harvest-sized fish in each tank.

Statistical Analysis

Linear regression was utilized to compare weight against time in each tank, where the slope of the regression line equals the absolute growth rate in g/d (Hopkins, 1992). To account for differences in initial weight, fixed intercepts were assigned according to stock means. Main effects of stock and filter type on absolute growth, and interaction between these variables were examined using a regression analysis model incorporating fixed intercepts by stock (IML procedure: SAS, 1985). Analysis of variance was used to compare water quality between filters utilizing tank x filter as an error term (GML procedure: SAS, 1985). Comparisons between feed conversion and feed consumption were made by two-way ANOVA, utilizing tank x (stock x filter) as an error term (GML procedure: SAS, 1985). Average group weights (harvestable and undersized) were compared between stocks at harvest using Student's T-test.

Within tagged individuals, Student's T-test was used to compare mean initial weight, mean final weight, and mean relative growth rate between stocks, between sexes within the mixed-sex stock and between females from both stocks. Predictability of individual growth rate

by stock and sex was determined by Pearson correlation analysis between initial body weight and final weight at harvest.

RESULTS

Water Quality

Means and standard errors for water quality variables for each 28-day period are presented in Table 2.2 and Table 2.3. Mean water quality values of the 7 systems remaining in production over the entire study are plotted in Figures 2.4-2.6. Means, standard errors and ranges for water quality variables over the entire 292-day experiment are presented in Table 2.4. Of the water quality variables measured, only pH and unionized ammonia differed between systems with different filters ($p < .05$).

Growth, Feed Consumption, FCR, and Harvest Data

Tank #3 (S1, RBC) experienced complete mortality early in the experiment due to a pipe rupture, and was excluded from all analysis reported in this study. Severe mortality (> 60%) occurred in tank #8 (S1, bead) due to an unknown cause, and was included in all analyses through day 196. The remaining seven tanks averaged 93.5% survival over the entire experiment (Table 2.5).

Means, standard errors, and ranges for total weight at each sample period are presented in Table 2.6. Absolute growth rates from regression analysis model ($r^2 = 0.97$) ranged from 0.27-0.48 g/day and are listed in Table 2.7. Growth contrasts between stock and filter type are summarized in Table 2.8. The main effect of stock did not have a significant effect on growth ($p > 0.1$). The main effect of filter type did have a significant effect on fish growth, with fish in

tanks containing trickling filters (Tank #2, #4, & #7) exhibiting significantly higher growth than in tanks containing either RBCs (Tank #6 & #9) or bead filters (Tank #1 & #5)($p < 0.01$). Growth between tanks containing RBCs and bead filters was not significantly different ($p > 0.1$).

In treatments containing RBCs and trickling filters, growth between stocks was significantly different ($p < 0.01$). There was no significant difference in growth between stocks in treatments containing bead filters ($p > 0.1$).

Tank #4 and #7 (both S2, trickle) were contrasted because they represent a replicated treatment. Growth between these two tanks was significantly different ($p < 0.01$). Growth between tank #1 and #5 (both S2, bead), was not significantly different ($p > 0.1$)

Mean final density within treatments was 42.8 kg/m^3 and ranged from 37.2-50.2 kg/m^3. Total feed conversion averaged 1.61 across all treatments and ranged from 1.38-1.78. Initial and final total biomass and density, total feed conversion, and survival are summarized in Table 2.5. Feed consumption as percent body weight per day is listed in Table 2.9. S1 treatments consumed a significantly higher percent body weight than S2 treatments ($p < 0.05$). Feed consumption was not significantly affected by filter type ($p > 0.1$). Feed conversion results are summarized in Table 2.10. There were no significant differences in feed conversion or total amount fed between any treatments
($p > 0.1$).

Data obtained during final tank harvests is listed in Table 2.11. Mean weight of undersized fish was significantly heavier in S1 treatments (89.9g) compared to S2 treatments (71.4g: $p < .01$). Mean weight of harvest-sized fish was significantly heavier in S2 treatments (167.9g) compared to S1 treatments (135.3g: $p < .01$).

INDIVIDUAL RESULTS

Recovery of Tagged Individuals

Tagged individuals in system #8 (S1, Bead) were excluded from this analysis as a result of high mortality due to an unknown cause. 120 of the remaining 150 (80%) tagged individuals were recovered. 4 of the 120 (3.3%) tagged individuals were recovered as mortalitites.

Results Between All Individuals by Stock

Mean initial weight of S1 individuals (28.4g, SE= 1.74, n= 46) was significantly heavier than the mean of S2 individuals (22.3g, SE= 1.41, n= 70: $p < .01$). Mean final weight was not significantly different between S1 (112.5g, SE = 7.33) and S2 individuals (122.1g, SE= 5.94: $p > 0.1$). The mean relative growth rate was significantly higher in S2 individuals (513.9%, SE=28.0) compared to S1 (315.3%, SE= 34.5: $p < .01$).

Results Between Females by Stock

There was no significant difference between mean initial weight of S2 female individuals (24.6g, SE=1.93, n=41) compared to S1 individuals (28.4g, SE=1.83, n=46: $p > 0.1$). Female S2 individuals (143.6g, SE=6.97) had a significantly heavier mean final weight compared to the S1 individuals (112.5g, SE=6.58: $p < .01$). The mean relative growth rate was significantly higher in female S2 individuals (597.8%, SE=36.2) compared to the S1 individuals (315.3%, SE=34.5: $p < .01$).

Results Between Male And Female Individuals Within A Mixed-Sex Stock

Mean initial weight of male (19.1g, SE= 2.5, n=29) individuals was not significantly different from female (24.6g, SE = 2.1, n=41) individuals ($p > 0.05$). Females had a significantly higher mean final weight (143.6g, SE=8.6) than males (91.9g, SE=10.2: $p < .01$). Mean relative growth rate was significantly higher in females (597.8%, SE =42.0) compared to males (395.2%, SE= 49.9: $p < .05$).

Predictability of Individual Growth

Pearson correlation coefficients between body weight at day 56 and final body weight at day 292 are presented in Table 2.12. In all cases, correlation coefficients were significantly different from zero ($p < .01$). Only positive correlations were observed.

DISCUSSION

There was considerable more difficulty in feed training the all-female yellow perch fingerlings to a floating diet. Although these fish were purchased as "feed trained" fingerlings, they had been originally trained on a sinking diet using a modified pond culture method (Malison, 1999). A significant component of feed training fingerlings is to remove the natural food source (Heidinger and Kays, 1993). Attempting to feed train fingerlings in ponds does not allow for removal of natural food sources. Perhaps the sinking diet or feed training technique used by the producers of the all-female stock contributed to the failure of 1,864 fish (10.9%) to habituate well to tank culture conditions. Mixed-sex fingerlings were originally feed trained by tandem pond-tank culture (Malison, 1999) utilizing a floating diet. 100% of these fingerlings habituated to tank culture conditions.

Based on the water quality data examined here, this research was unable to identify a mechanism that resulted in the superior growth performance exhibited in fish in treatments utilizing trickling filters. Although specific tolerance limits of yellow perch to nitrite (NO_2-N) and nitrate (NO_3-N) are not known (Malison, 1999), these parameters along with temperature and dissolved oxygen were not significantly different between filter types. The 96-h LC_{50} of nitrite is about 13 mg/l (NO_2-N) for channel catfish and 0.3 mg/l for rainbow trout (Russo and Thurston, 1977). Nitrate is commonly considered to be essentially nontoxic to fish (Wedemeyer, 1996).

While both pH and unionized ammonia (NH_3-N) were significantly different by filter type, they were both well within what is considered acceptable levels for most freshwater fish (Piper et al., 1982; Post, 1987). Calculated least square means for pH and NH_3-N were RBC (7.22, .0062 mg/l), trickle (7.41, .0087 mg/l), and bead (7.12, .0063mg/l). Perch develop normally above pH 5.5 (Craig, 1987). Fontaine et al. (1996) reported a pH range of 6.5-7.4 while rearing Eurasian perch in recirculating systems. Based on a 120-day toxicity experiment on yellow perch, Manci and Quigley (1981) suggested operating within 0.50 mg/l NH_3-N. The water quality analysis completed in this experiment was unable to identify a definite mechanism that resulted in increased growth in trickle filter treatments. Analysis of more specific water quality variables related to biofilter performance measured in conjunction with this research by is currently under way.

The results of this study do not support assertions by Malison and Garcia-Abiado (1996) and Melard et al. (1996a) of superior growth rates in all-female yellow perch fish stocks. Due to the presence of males in the mixed-sex stock (S2), individuals from the all-female stock (S1) were expected to grow at an overall faster rate than S2 individuals (Schott et al., 1978; Malison

et al., 1985; 1986; Malison and Garcia-Abiado, 1996). The current research indicated that there were no significant differences in growth between treatments based on the main effect of stock. Possible inherent growth differences originating from differences in geographic strain or culture history (see description below) between these two stocks may have effected these contrasts.

Only 2,407 fish were recovered from tank #7 (S2, trickle). After accounting for mortality, this represents 34.2% fewer individuals than the target stocking rate of 3,800 fish. It is highly unlikely that this discrepancy could be attributed to undetected mortality, rather it is more likely a result of a stocking error or cannibalism. Fish were initially stocked into each tank in groups averaging 400-450 fish per bucket. At this rate, approximately 3 buckets would account for this difference. Heidinger and Kayes (1986) reported that yellow perch show little aggressive or cannibalistic behavior. Malison (1999), however, reported that there is significant cannibalism in pond culture of yellow perch fingerlings, where the number declines by approximately 50% between July and October. Starting with 45-day old juvenile perch, mortality rates of up to 7.1% were attributed to cannibalism despite actively removing potential cannibals (Melard et al., 1996b). The accelerated growth in tank #7 may be attributed to one of these scenarios.

The observation that #7 either was under-stocked or experienced a high incidence of cannibalism has important implications on the growth contrasts. Growth rates within trickle filter treatments were significantly different between stocks ($p < .01$). The same contrast without #7 produces results that are no longer significant ($p > .1$). Similarly it may also explain why growth in replicated treatments (Tank #4 – Tank #7: S2, trickle) were shown to be significantly different. It is important to note that main effects of stock were not significant regardless of the inclusion or exclusion of #7.

There was an unexpected difference in growth by stock within RBC treatments (Tank #6 & Tank #9). Due to its location, Tank #9 (S2, RBC) consistently received the most human disturbance. Perch feeding behavior is readily disturbed by human activity and movement (Malison et al., 1988). A visual barrier was installed to reduce the effect of human disturbance on the fish in tank #9. Relatively higher human disturbance likely contributed to decreased growth in #9. Additionally, an estimated 4,500 fish were initially stocked based on fish recovered at harvest and known mortality. This was the highest estimated stocking density, which may have also contributed the significant contrast between stocks within RBC treatments.

All-female (S1) stocks consumed significantly more food on a per weight basis, with the highest consumption occurring during the second 48-day period (Table 2.9). This is in agreement with previous research (Malison et al., 1988). In the current study, S1 stocks did not exhibit superior feed conversion as previously reported (Malison et al., 1988).

All-female harvest data emphasizes the relative uniformity in growth of this stock. Mean undersized (89.9g) weight was much closer to the mean harvest weight (135.3g) for all-females than the same comparison in mixed sex (71.4g, 167.9g). Growth uniformity reduces the grading requirements and also may eliminate incidence of cannibalism.

Although tag loss can not be discounted, frequent failure of several hand-held detectors probably resulted in the failure to recover 20% of tagged individuals. Each fish was individually scanned, well within the maximum detectable distance of 7.6 cm for hand-held detectors (Nielsen, 1992). Tag detection may have been affected by the inability of the scanning equipment to detect tags that were perpendicular to the reading device (Hagen, 1996).

The effect filter type had on growth in tagged individuals could not be statistically analyzed. Based on analysis of treatment means in the overall growth study, individual fish in

trickle filter treatments may have exhibited higher growth over fish in other treatments. 19 of 46 S1 individuals (41.3%) and 28 of 71 S2 individuals (39.4%) were raised in trickle filter treatments. The effect filter type had on growth of tagged individuals was minimized due to the similarity of the proportion of individuals from trickle filter treatments between stocks.

Due to the presence of males in the mixed-sex stock (S2), individuals from the all-female stock (S1) were expected to grow at an overall faster rate than S2 individuals (Schott et al., 1978; Malison et al., 1985; 1986; Malison and Garcia-Abiado, 1996). The current research indicated that the S2 individuals grew 1.6 times faster than S1 individuals. Higher relative growth rates in S2 were exhibited despite the effect of 29 male individuals (41.4%). To eliminate the effect that males had on the mean relative growth of S2 individuals, a comparison was made between only females from both stocks. This analysis indicated that S2 females grew almost 1.9 times faster than S1 females.

S2 females may have exhibited higher relative growth rates over S1 females as a result of: (1) intraspecific social competition, (2) the influence of male tankmates, (3) the original geographic location or strain, or (4) differences in culture history between stocks.

Malison et al. (1988) compared growth of male and female individuals in treatments that were either reared together or separately. Females gained more weight than males in all treatments, and weight gain was not significantly different between females grown together with males or separately. These researchers concluded that sexually related dimorphic growth in perch is not a result of intraspecific competition between the sexes, but a function of estrogen-enhanced feed consumption and conversion in females (Malison et al., 1988) and androgen-inhibited growth in males (Malison et al., 1985). However, sexually related dimorphic growth in yellow perch is a complex process that may involve several hormones (Malison et al., 1988).

Intraspecific competition between the sexes was not a factor in sexually related dimorphic growth in relatively small (final weight 23.3-37.3g) yellow perch (Malison et al., 1988). However, the current study raised fish to a much larger final size (mean = 118.3g for all tagged fish), more representative of commercial yellow perch producers. Variation in size appeared early in this experiment and became more pronounced with age. As the size dissimilarity increases, it is likely that size hierarchies are established and competition for food is increased, resulting in larger fish affecting subordinates, who may not feed even if the food is available (Umino et al., 1993). Perhaps the growth advantage in small female yellow perch (Malison et al., 1988) manifests into a social hierarchy as fish approach a market size, in which the larger fish (predominantly female) become the dominant fish. In this study, it is possible that a restricted food supply (0.76% = estimated mean body weight consumed per day over last 48 days), aided in the formation of social hierarchies and possibly contributed to higher growth in S2 females (Brett, 1979). Relatively more uniform growth may have prevented similar interactions in S1 treatments.

Goudie et al. (1994) found that male channel catfish (*Ictalurus punctatus*) exhibited faster growth than females whether in mixed sex or monosex ponds. The difficulty of external sex identification resulted in 5 of the 6 monosex treatments (all-female or all-male) having small percentages of the opposite sex. The only monosex female pond to be completely void of males exhibited higher growth than females in ponds with as low as 1 and 2% males. This observation suggested that a small number of males may somehow inhibit female growth, possibly as a result of pheromones (Goudie et al., 1994).

Food consumption in blue tilapia (*Oreochromis aureus*) may be affected by pheromones. Females failed to feed when males were absent but resumed food consumption once males were

added to water circulating through the aquaria (Goudie et al., 1994). It is possible that the presence of males in S2 treatments positively influenced female tankmates in a similar manner.

The differences seen in growth between S1 and S2 may also be a result of their original geographic strain, although further research is warranted in this area. There is currently no published evidence that identifies geographic yellow perch strains that exhibit superior growth under aquaculture conditions (Malison, 1999). Unpublished research indicates differences in growth exist between Lake Mendota (Wisconsin), Green Bay (Wisconsin), North Carolina, and Nebraska strains of yellow perch reared at 16, 22, and 28^{o}C (Paul Brown, Purdue University, personal communication). Preliminary research on striped bass (*Morone saxatilis*), suggest differences in growth exist between several geographically isolated populations along the East Coast (Jacobs et al., 1999). Differences in growth performance have been documented in several strains of tilapia (Eknath et al., 1993; M.R.R. Eguia and R.V. Eguia, 1997). Additionally, different strains may naturally perform better in different aquaculture systems (Kapuscinski et al., 1996).

Differences observed in growth between S1 and S2 may be attributed to differences in the culture history between these stocks. Fingerlings from the S1 stock were produced by stocking fry into ponds that had been hatched through exposure to physical agitation. S2 fingerlings were produced by placing fertilized egg-ribbons into ponds prior to hatch. Both stocks were purchased as "feed-trained" fingerlings. S1 fingerlings were trained on a sinking diet using a modified pond culture method, while S2 fingerlings were originally trained on a floating diet by the tandem pond-tank culture method (Malison, 1999). As a result of the feed training method used by the producers of S2 fingerlings, these fish were already habituated to tank culture conditions when purchased. This may have initially given the S2 individuals a slight growth

advantage over S1 individuals. However, it is important to remember that all fish were acclimated to culture conditions for at least 50 days before the growth study began, thus minimizing this advantage in the actual study.

The original producer of the S2 fish claims to have practiced genetic selection on their stock of yellow perch for 9-10 generations (Marty Domer, Domer's Fish Hatchery, Inc., personal communication). Producers of the S1 fish claim to have practiced genetic selection on their stock of yellow perch for 3-4 generations (Jeff Malison, Coolwater Farms, L.L.C., personal communication). Scientific studies on the heritability of growth-related traits have not been conducted on yellow perch. In the closely related walleye, extremely high heritabilities of weight under intensive conditions at 247 and 270-days were found (h^2= 0.93 & 0.90 respectively: Kapuscinski et al., 1996). If heritabilities for growth-related traits are similarly high in yellow perch, a selective breeding program has the potential to improve growth with high rates of gain per generation. It is important to note that heritabilities of growth in fish vary under different rearing temperatures and under different rearing conditions or facilities (Tave, 1993). Therefore, fish that have undergone selective breeding for improved growth under pond culture conditions may not perform similarly when raised in recirculating aquaculture systems.

Within S2 individuals, females grew 1.5 times faster than male individuals. This is similar to previous research that has demonstrated female growth in Eurasian perch as 1.5-1.7 times faster than male growth (Melard et al., 1996a).

It is a widely held assumption that fish with initially slow growth may remain small for life (a "runt"). As a result, sizes grading of fish and culling of runts are routine practices in fish culture. These practices continue despite the fact that several studies on grading have shown little or no effect on the subsequent growth of fish (Gunnes, 1976; McGinty, 1985; Wallace and

Kolbeinshavn, 1988; Melard et al., 1995; 1996b). Culling of small individuals is not justified unless there is a high correlation between initial stocking weight and harvest weight (Palada-de Vara and Eknath, 1993).

This study found significant correlations in yellow perch between body weight when initially tagged (day 56) to body weight at harvest (day 292) in all groups analyzed. Significance in Pearson correlation analysis is not the same as being important or strong (Cody, 1985). Mean initial and final weights for all tagged individuals were 24.7g and 118.3g respectively. Individual results are plotted in Figure 2.7. For all individuals, 33.6% of the variation in final weight was explained by the variation in initial weight. Based on these results, culling of small yellow perch may or may not be a justifiable management decision. Production managers must base the decision to cull small individuals on factors of production specific to their facility. This would include the availability and price of fingerlings, production costs, and production capacity.

A similar study on individually tagged tilapia (*Oreochromis niloticus*) reared in ponds revealed that growth performance was unaffected by initial size differences (Palada-de Vara and Eknath, 1993). In almost all cases, correlation coefficients were not significantly different from zero, and both positive and negative correlations were observed. Correlations were highest when body weights of males and females were greater than 33g and 25g respectively. Low or negative correlations in tilapia may be a result of compensatory growth, maturation and environmental limitations (Doyle and Talbot, 1988).

Sexually-related dimorphic growth is evident in yellow perch as small as 8-12 g in total weight and 90-120 mm in total length (Schott et al., 1978; Malison et al., 1986). Fish in this study had a mean initial weight of 24.7g and averaged 125.3mm in total length. This research has shown that the growth performance of yellow perch within the size range and conditions

investigated here, are only partially attributed (33.6%) to initial size differences. These results suggest that culling of small yellow perch of similar sizes used in this study, may not be a justifiable management decision. Further investigations with the ability to correlate different initial weights and ages over more frequent time intervals are warranted in yellow perch.

SUMMARY

The results of this study confirm previous research by other authors in that female yellow perch grow faster than male yellow perch within mixed-sex stocks. This study failed to document superior growth rates in all-female stocks over mixed-sex stocks. It appears that differences in the geographic strain or culture history of these stocks may have had a larger overall effect on growth than sexual classification (all-female or mixed sex). However, all-female treatments did exhibit higher feed consumption and relatively more uniform growth, possibly reducing grading requirements and cannibalism in production facilities. Future research efforts should focus on identification of strains with superior growth rates in recirculating systems, followed by within strain comparisons of all-female versus mixed-sex stocks.

Fish in treatments utilizing trickling filters exhibited superior growth performance. Analysis of the water quality parameters examined here did not clearly identify the parameter(s) that resulted in the enhanced growth of fish in trickling filter treatments. Perhaps slight differences in one or more water quality parameters or feed conversion efficiency contributed to the enhanced growth in these treatments.

Culling of small yellow perch of similar sizes used in this study, may or may not be a justifiable management decision. Further investigations with the ability to correlate different initial weights and ages over more frequent time intervals are warranted in yellow perch.

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TABLE 2.1. Total surface area, specific surface area, flow rate and turnover rate for the three biofilter types.

Biofilter	Total S.A. (m^2)	Specific S.A. (m^2/m^3)	Flow Rate (gpm)	Turnover Rate (per hour)
Bead	1,044	2,757	71.94	1.57
RBC	325	28	91.57	2.03
Trickle	465	1,681	84.81	2.24

TABLE 2.2. Means and standard errors for pH, temperature, and dissolved oxygen for each 28-day period.

	Tank #1		Tank #2		Tank #4		Tank #5		Tank #6		Tank #7		Tank #8		Tank #9	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Period	pH		pH		pH		pH		pH		pH		pH		pH	
1	7.42	0.025	7.74	0.025	7.70	0.022	7.30	0.030	7.55	0.030	7.89	0.026	7.33	0.030	7.52	0.023
2	7.24	0.022	7.64	0.032	7.63	0.023	7.19	0.033	7.40	0.025	7.89	0.027	7.07	0.028	7.56	0.020
3	7.10	0.039	7.33	0.039	7.62	0.049	6.99	0.037	7.14	0.041	7.70	0.042	6.89	0.039	7.42	0.043
4	6.99	0.034	7.14	0.040	7.25	0.033	6.89	0.045	7.04	0.028	7.54	0.032	6.97	0.046	7.18	0.032
5	7.08	0.028	7.18	0.035	7.21	0.039	7.04	0.026	7.14	0.033	7.40	0.047	7.20	0.027	7.11	0.036
6	7.06	0.025	7.15	0.034	7.22	0.040	6.95	0.030	7.06	0.031	7.42	0.043	7.14	0.034	7.03	0.030
7	7.10	0.021	7.13	0.041	7.25	0.044	7.08	0.038	7.14	0.028	7.44	0.054	7.35	0.034	7.06	0.033
8	7.04	0.037	7.43	0.040	7.17	0.039	6.99	0.052	7.17	0.035	7.37	0.058	N/A	N/A	7.11	0.034
9	7.16	0.033	7.28	0.038	7.16	0.038	7.16	0.021	7.23	0.025	7.45	0.046	N/A	N/A	7.10	0.037
10	7.22	0.050	7.33	0.041	7.16	0.031	7.16	0.025	7.26	0.038	7.60	0.033	N/A	N/A	7.22	0.039
Period	Temperature		Temperature		Temperature		Temperature		Temperature		Temperature		Temperature		Temperature	
1	22.9	0.16	22.69	0.171	22.5	0.17	22.45	0.186	21.8	0.19	21.76	0.212	21.9	0.19	21.1	0.19
2	22.9	0.11	23.02	0.101	22.6	0.10	22.30	0.284	21.5	0.16	22.11	0.087	21.8	0.11	21.0	0.08
3	22.9	0.12	22.95	0.130	22.4	0.13	22.59	0.118	21.7	0.15	22.12	0.100	21.9	0.19	21.2	0.13
4	22.8	0.16	23.04	0.138	22.7	0.14	22.86	0.141	22.1	0.17	22.10	0.143	22.2	0.15	21.3	0.19
5	23.7	0.13	23.62	0.139	23.3	0.15	23.41	0.152	22.7	0.17	22.45	0.162	22.4	0.21	21.8	0.20
6	23.4	0.18	23.36	0.159	22.8	0.20	22.72	0.521	22.6	0.17	22.24	0.192	22.2	0.20	22.0	0.20
7	23.5	0.23	23.25	0.247	23.1	0.18	23.36	0.165	23.0	0.18	22.43	0.186	21.9	0.89	22.7	0.18
8	24.3	0.11	23.80	0.161	24.0	0.15	24.29	0.114	23.6	0.12	23.19	0.129	N/A	N/A	23.1	0.14
9	24.1	0.19	24.40	0.108	24.1	0.23	24.23	0.233	24.1	0.16	23.71	0.147	N/A	N/A	23.6	0.19
10	23.4	0.19	23.22	0.173	23.1	0.18	23.38	0.176	22.9	0.14	22.56	0.139	N/A	N/A	22.7	0.15
Period	Dissolved O_2		Dissolved O_2		Dissolved O_2		Dissolved O_2		Dissolved O_2		Dissolved O_2		Dissolved O_2		Dissolved O_2	
1	9.2	0.35	9.02	0.17	9.0	0.11	9.87	0.20	8.8	0.20	9.51	0.29	9.3	0.29	9.2	0.19
2	7.8	0.36	7.91	0.11	8.9	0.11	8.90	0.30	9.5	0.24	9.94	0.11	8.9	0.20	8.8	0.37
3	8.9	0.33	8.50	0.18	8.8	0.10	8.59	0.24	8.9	0.30	9.34	0.17	9.4	0.36	8.7	0.20
4	9.3	0.42	9.49	0.31	9.6	0.26	9.78	0.44	10.0	0.44	8.97	0.14	9.2	0.31	8.8	0.31
5	8.0	0.30	8.98	0.21	8.8	0.18	8.21	0.27	8.5	0.33	8.54	0.13	9.1	0.40	8.9	0.43
6	8.8	0.23	9.48	0.20	9.0	0.24	11.00	0.60	9.4	0.30	8.94	0.32	10.0	0.36	9.5	0.39
7	9.9	0.28	9.36	0.22	10.0	0.18	9.78	0.31	10.0	0.28	10.39	0.15	10.3	0.21	10.2	0.38
8	10.1	0.29	9.35	0.18	9.0	0.22	9.49	0.30	10.2	0.28	8.92	0.25	N/A	N/A	10.3	0.45
9	9.9	0.29	9.50	0.21	10.4	0.37	10.15	0.34	10.1	0.34	8.38	0.23	N/A	N/A	10.1	0.40
10	10.5	0.32	11.08	0.21	10.1	0.51	10.61	0.27	10.4	0.37	10.08	0.21	N/A	N/A	10.9	0.25

TABLE 2.3. Means and standard errors for NH_3, NO_2-N and NO_3-N for each 28-day period.

	Tank #1		Tank #2		Tank #4		Tank #5		Tank #6		Tank #7		Tank #8		Tank #9	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Period	NH_3		NH_3		NH_3		NH_3		NH_3		NH_3		NH_3		NH_3	
1	.0038	.0002	.0081	.0005	.0073	.0004	.0033	.0003	.0071	.0005	.0088	.0007	.0043	.0002	.0042	.0003
2	.0037	.0002	.0093	.0006	.0070	.0004	.0031	.0003	.0051	.0003	.0085	.0005	.0034	.0002	.0053	.0003
3	.0037	.0002	.0075	.0005	.0092	.0009	.0030	.0002	.0052	.0003	.0089	.0007	.0036	.0002	.0059	.0005
4	.0049	.0004	.0072	.0006	.0074	.0005	.0044	.0005	.0052	.0003	.0079	.0005	.0055	.0005	.0056	.0004
5	.0076	.0005	.0082	.0006	.0094	.0007	.0064	.0003	.0062	.0005	.0075	.0006	.0080	.0005	.0046	.0003
6	.0069	.0005	.0076	.0006	.0091	.0007	.0053	.0004	.0059	.0005	.0100	.0009	.0082	.0006	.0046	.0003
7	.0062	.0005	.0068	.0005	.0089	.0006	.0077	.0005	.0057	.0004	.0089	.0007	.0083	.0008	.0059	.0004
8	.0077	.0007	.0112	.0009	.0083	.0006	.0062	.0005	.0062	.0004	.0079	.0007	N/A	N/A	.0069	.0006
9	.0094	.0007	.0093	.0008	.0094	.0005	.0102	.0003	.0086	.0004	.0111	.0009	N/A	N/A	.0092	.0007
10	.0100	.0008	.0076	.0005	.0077	.0006	.0077	.0003	.0079	.0006	.0133	.0010	N/A	N/A	.0095	.0007
Period	NO_2-N		NO_2-N		NO_2-N		NO_2-N		NO_2-N		NO_2-N		NO_2-N		NO_2-N	
1	0.28	0.04	0.14	0.01	0.08	0.01	0.33	0.03	0.47	0.04	0.04	0.01	0.52	0.04	0.24	0.02
2	0.19	0.02	0.16	0.02	0.09	0.01	0.17	0.01	0.58	0.04	0.03	0.01	0.49	0.03	0.08	0.00
3	0.25	0.02	0.38	0.05	0.19	0.06	0.20	0.02	1.06	0.11	0.09	0.01	0.67	0.16	0.11	0.01
4	0.06	0.07	0.46	0.04	0.42	0.08	0.33	0.04	0.67	0.09	0.13	0.05	0.52	0.04	0.31	0.04
5	0.80	0.07	0.42	0.05	0.68	0.09	0.59	0.02	0.32	0.04	0.21	0.09	0.34	0.04	0.39	0.09
6	0.66	0.06	0.42	0.04	1.05	0.32	0.49	0.07	0.28	0.04	0.08	0.01	0.26	0.02	0.38	0.06
7	0.61	0.09	0.54	0.09	0.37	0.04	0.50	0.05	0.34	0.08	0.09	0.02	0.20	0.03	0.05	0.10
8	0.57	0.06	0.37	0.04	1.02	0.15	0.44	0.04	0.30	0.03	0.15	0.03	N/A	N/A	0.61	0.08
9	0.63	0.12	0.32	0.04	0.82	0.15	0.59	0.11	0.26	0.03	0.29	0.06	N/A	N/A	0.58	0.10
10	0.61	0.11	0.34	0.03	0.80	0.15	0.53	0.11	0.40	0.07	0.17	0.05	N/A	N/A	0.54	0.06
Period	NO_3-N		NO_3-N		NO_3-N		NO_3-N		NO_3-N		NO_3-N		NO_3-N		NO_3-N	
1	10.4	1.5	12.0	2.2	15.2	1.5	11.2	1.1	10.8	2.2	14.2	0.5	11.4	2.4	10.8	1.4
2	16.5	0.5	26.5	3.5	23.0	4.0	8.0	0.0	18.0	1.0	18.0	1.0	20.0	0.0	16.0	2.0
3	21.3	2.1	31.0	1.7	24.8	2.5	19.3	1.2	16.3	0.9	17.8	1.1	22.3	3.5	16.3	0.8
4	36.6	4.3	53.8	5.8	58.4	9.7	33.3	6.9	38.8	5.8	35.0	6.9	39.8	7.0	34.6	5.2
5	62.7	4.4	61.1	4.5	90.7	12.5	62.1	5.4	50.7	4.6	57.1	6.0	40.3	3.5	45.6	3.6
6	74.1	6.8	68.9	6.6	98.3	8.6	72.6	7.7	69.1	6.6	71.5	7.9	48.5	7.1	70.8	7.1
7	84.2	8.1	95.3	5.0	107.1	5.8	95.5	4.3	84.3	4.5	106.2	5.0	42.4	3.4	103.5	3.3
8	87.0	5.0	65.7	4.7	87.9	6.2	83.8	4.8	79.1	3.8	75.0	5.5	N/A	N/A	90.4	4.6
9	58.8	4.3	81.9	3.3	75.5	4.6	68.2	4.1	84.7	4.2	85.6	3.7	N/A	N/A	88.6	6.0
10	65.9	5.3	76.2	7.2	55.8	3.2	71.3	4.4	79.6	4.5	80.8	4.7	N/A	N/A	89.8	5.5

TABLE 2.4. Mean water quality values, standard deviations, standard errors, and ranges over the entire study. Data for tank #8 is included through day 196.

		Tank							
		1	**2**	**4**	**5**	**6**	**7**	**8**	**9**
	Mean	23.35	23.30	23.06	23.21	22.57	22.44	22.16	22.03
	Std Dev	0.990	0.938	1.014	1.056	1.129	0.963	0.927	1.223
Temp	**SE**	0.059	0.056	0.060	0.062	0.067	0.057	0.067	0.072
	Min	19.4	19.4	19.5	19.6	18.9	18.9	18.4	18.1
	Max	25.8	25.5	25.8	25.8	25.3	24.9	24.4	25.0
	Mean	7.15	7.34	7.32	7.07	7.21	7.57	7.14	7.23
	Std Dev	0.203	0.273	0.291	0.210	0.218	0.281	0.240	0.251
pH	**SE**	0.012	0.016	0.017	0.013	0.013	0.017	0.017	0.015
	Min	6.54	6.66	6.42	6.16	6.58	6.67	6.41	6.55
	Max	7.70	8.00	8.01	7.71	8.00	8.10	7.70	7.80
	Mean	9.42	9.37	9.45	9.66	9.70	9.40	9.445	9.66
	Std Dev	1.714	1.375	1.388	1.781	1.781	1.296	1.637	2.014
DO	**SE**	0.102	0.082	0.083	0.106	0.106	0.077	0.119	0.119
	Min	4.3	6.7	6.6	4.7	4.5	5.5	6.1	5.0
	Max	15.3	15.3	15.5	16.3	15.3	13.6	15.4	16.5
	Mean	0.0064	0.0083	0.0083	0.0058	0.0062	0.0093	0.0057	0.0062
	Std Dev	0.0034	0.0033	0.0032	0.0030	0.0024	0.0040	0.0031	0.0029
NH_3	**SE**	0.0002	0.0002	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002
	Min	0.0014	0.0018	0.0017	0.0009	0.0014	0.0017	0.0012	0.0017
	Max	0.0184	0.0209	0.0190	0.0191	0.0180	0.0315	0.0187	0.0206
	Mean	0.511	0.347	0.538	0.407	0.474	0.125	0.440	0.370
	Std Dev	0.327	0.203	0.569	0.252	0.328	0.155	0.287	0.292
NO_2	**SE**	0.027	0.017	0.047	0.021	0.027	0.013	0.029	0.024
	Min	0.063	0.058	0.014	0.047	0.078	0.010	0.078	0.054
	Max	1.680	1.630	3.820	1.650	1.800	0.880	2.620	1.610
	Mean	63.96	68.76	75.95	67.32	66.68	70.70	37.85	74.39
	Std Dev	29.53	27.62	33.46	28.98	27.64	31.88	19.04	33.41
NO_3	**SE**	2.98	2.78	3.38	2.93	2.75	3.22	2.57	3.37
	Min	8.0	7.0	13.0	8.0	6.0	13.0	5.00	7.0
	Max	130.0	128.0	157.0	126.0	113.0	140.0	105.0	137.0

TABLE 2.5. Total biomass, density, feed conversion and survival for each tank.

	Total Biomass (kg)		Density (kg/m^3)		Feed	Percent
Tank	Initial	Final	Initial	Final	Conversion	Survival
1	28.79	310.95	3.44	37.19	1.72	91.0
2	24.79	334.14	2.97	39.97	1.65	90.2
4	41.36	419.77	4.95	50.21	1.64	92.7
5	36.33	330.29	4.35	39.51	1.78	95.0
6	23.79	340.97	2.85	40.79	1.53	94.2
7	22.96	363.85	2.75	43.52	1.38	96.5
9	36.67	406.63	4.39	48.64	1.55	94.7

TABLE 2.6. Means, standard errors, and ranges for total weight at each sample period.

	Tank #1				Tank #2				Tank #4				Tank #5			
Day	Weight (g)	SE	Min	Max	Weight (g)	SE	Min	Max	Weight (g)	SE	Min	Max	Weight (g)	SE	Min	Max
1	7.97	0.37	4.4	20.1	7.31	0.33	3.0	15.6	10.74	0.64	4.5	22.2	9.66	0.54	4.4	23.0
30	15.79	1.29	7.6	60.5	16.86	0.65	5.0	35.0	16.03	0.91	6.5	41.4	17.07	1.14	6.2	37.9
57	19.80	1.28	5.7	82.2	26.66	0.76	4.3	49.7	21.16	1.13	4.0	88.6	18.55	0.89	5.6	65.4
85	28.39	1.56	8.1	99.2	45.78	1.35	13.9	97.6	33.77	1.99	6.7	93.3	30.88	1.63	7.4	98.0
113	40.56	2.77	8.1	156.4	61.76	1.74	22.7	112.7	42.41	2.29	8.0	123.4	42.14	2.46	7.7	131.6
144	51.34	3.14	10.4	195.2	68.23	1.92	20.2	139.3	70.77	4.16	12.7	194.1	53.20	2.92	12.8	158.7
169	66.44	3.84	10.6	248.5	79.36	2.23	29.1	161.3	80.24	4.53	11.4	259.1	68.66	3.21	15.5	181.0
197	75.02	4.62	9.9	259.6	83.82	22.05	33.9	143.9	97.66	5.36	16.4	245.8	66.89	3.32	9.7	192.2
225	73.58	4.21	12.9	275.4	87.05	2.55	29.9	191.4	94.76	4.83	13.7	257.9	86.86	4.80	15.2	312.0
255	82.89	2.38	13.4	308.3	101.82	1.37	26.2	192.5	116.27	2.97	17.2	300.1	88.18	2.26	11.1	284.5
282	96.09	2.63	13.1	284.4	106.95	1.40	35.1	212.6	112.16	2.87	15.9	335.0	97.71	2.58	13.0	319.3

	Tank #6				Tank #7				Tank #8				Tank #9			
Day	Weight (g)	SE	Min	Max	Weight (g)	SE	Min	Max	Weight (g)	SE	Min	Max	Weight (g)	SE	Min	Max
1	6.88	0.28	3.0	15.4	9.23	0.55	3.6	25.1	7.33	0.31	3.4	14.6	8.18	0.45	4.1	24.0
30	15.18	0.56	8.1	25.5	19.61	1.90	5.3	71.2	14.94	0.53	7.7	25.0	12.46	0.60	5.3	30.5
57	23.64	0.80	8.0	53.7	23.28	1.70	5.3	99.2	23.94	1.09	5.3	69.4	12.83	0.48	5.7	28.0
85	37.34	1.17	9.6	69.9	35.69	2.19	7.4	154.4	31.92	0.99	9.2	76.2	20.16	1.21	6.3	109.1
113	50.97	1.61	13.8	95.3	55.64	3.38	9.6	191.4	38.88	1.25	10.1	86.9	28.33	1.88	5.7	133.1
144	62.77	1.83	23.7	105.5	72.51	5.01	9.6	281.7	49.03	1.50	13.1	108.9	42.65	2.63	8.7	143.8
169	72.72	1.89	26.6	146.7	91.39	5.69	13.7	298.6	52.37	1.49	20.0	122.4	53.53	3.40	9.4	182.3
197	66.89	3.32	9.7	192.2	93.92	5.42	13.3	265.1	N/A	N/A	N/A	N/A	59.58	3.40	9.1	165.8
225	88.59	2.27	37.0	175.1	113.29	6.04	21.0	324.1	N/A	N/A	N/A	N/A	70.65	3.98	13.3	230.9
255	94.55	1.31	39.2	220.0	155.65	4.25	15.5	438.6	N/A	N/A	N/A	N/A	87.43	2.64	11.0	280.5
282	105.19	1.46	26.4	239.4	147.70	4.17	14.6	477.8	N/A	N/A	N/A	N/A	88.16	2.51	15.2	342.9

TABLE 2.7 Absolute growth rates (slope) and fixed intercepts by stock from regression analysis.

Tank #	Stock	Biofilter	Intercept	Slope
1	Mixed-Sex	Bead	9.1560	0.2977
2	All-Female	Trickle	7.1733	0.3721
3	All-Female	RBC	7.1733	N/A
4	Mixed-Sex	Trickle	9.1560	0.3859
5	Mixed-Sex	Bead	9.1560	0.3066
6	All-Female	RBC	7.1733	0.3453
7	Mixed-Sex	Trickle	9.1560	0.4801
8	All-Female	Bead	7.1733	0.2797
9	Mixed-Sex	RBC	9.1560	0.2714

TABLE 2.8. Growth contrasts between stock, filter type, and interactions. Contrasts #8 & #9 were between replicated treatments.

	Contrast	p-value
1	RBC-Trickle	0.0000
2	RBC-Bead	0.2667
3	Trickle-Bead	0.0000
4	S1-S2	0.1425
5	S1-S2 (RBC)	0.0000
6	S1-S2 (Trickle)	0.0000
7	S1-S2 (Bead)	0.3886
8	Tank #4 - Tank #7	0.0000
9	Tank #1 - Tank #5	0.5573
10	S1-S2 (Trickle)(w/o #7)	0.365

TABLE 2.9. Average percent daily body weight consumed per period. Values are for 48 day periods.

	Tank								Period
Period	#1	#2	#4	#5	#6	#7	#8	#9	Average
1	1.28	1.70	1.24	1.24	1.76	1.42	1.92	1.02	1.45
2	1.61	2.93	1.25	1.65	2.59	1.56	2.29	1.30	1.90
3	1.45	1.60	1.43	1.47	1.49	1.31	1.25	1.25	1.41
4	1.18	1.03	1.07	1.25	0.97	1.22	N/A	1.47	1.17
5	0.92	0.79	0.74	1.02	0.78	0.97	N/A	1.03	0.89
6	0.91	0.70	0.73	0.77	0.67	0.62	N/A	0.90	0.76

TABLE 2.10. Average feed conversion per period. Values are for 48 day periods.

	Tank								Period
Period	#1	#2	#4	#5	#6	#7	#8	#9	Average
1	0.67	0.71	0.57	0.64	0.75	0.58	0.91	0.56	0.67
2	1.16	1.81	1.10	1.18	1.59	0.96	1.55	0.98	1.29
3	1.69	1.65	1.89	1.69	1.60	1.39	1.26	1.48	1.58
4	1.89	1.62	1.97	2.08	1.50	1.91	N/A	2.50	1.92
5	1.72	1.42	1.51	1.93	1.42	1.75	N/A	1.98	1.67
6	2.32	1.69	1.70	1.92	1.65	1.49	N/A	2.30	1.87

TABLE 2.11. Summary of data obtained from final harvest of each tank.

Observation	#1	#2	#4	#5	#6	#7	#9
Number of Fish Recovered	3292	3063	3581	3575	3260	2407	4261
Mean Weight (g)	94.5	109.1	117.2	92.4	104.6	151.2	95.4
Mean Wt of Harvestable Fish (g)	152.4	136.6	169.6	151.8	132.7	193.9	156.5
Mean Wt of Undersized Fish (g)	70.6	90.8	79.2	70.1	88.9	70.6	68.9
% Harvestable	29.2	39.9	42.1	27.3	35.7	65.3	30.3

TABLE 2.12. Pearson correlation coefficients between initial and final weight over 236 days of growth.

Group Examined	N	r	r^2	P-Value
All Individuals	116	0.579	0.336	0.0001
All-Females	46	0.435	0.189	0.0025
Mixed-Sex (M-S)	70	0.661	0.437	0.0001
Females in M-S	41	0.673	0.454	0.0001
Males in M-S	29	0.615	0.378	0.0004

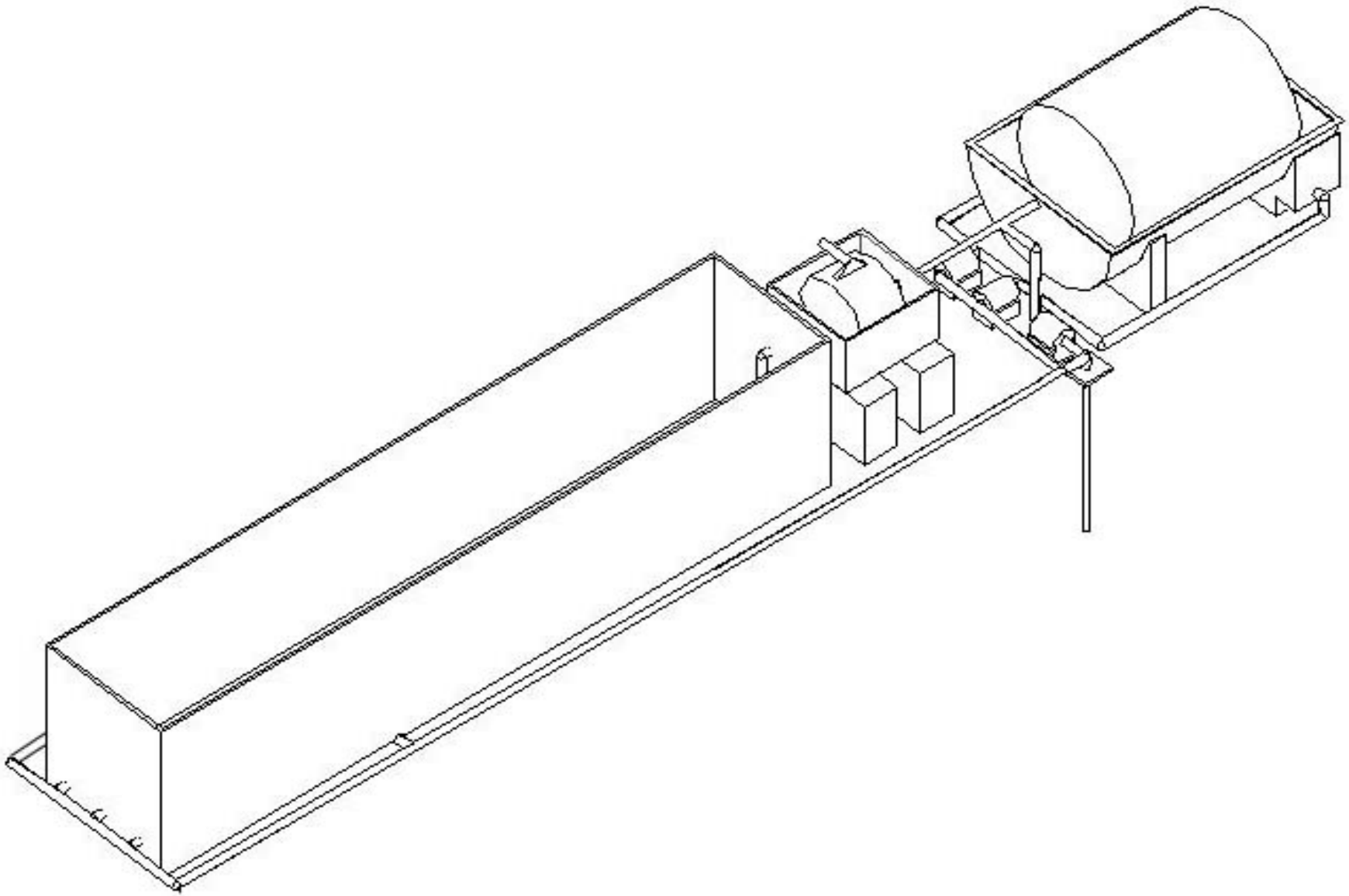

Figure 2.1. Schematic diagram of recirculating aquaculture system in RBC filter treatments.

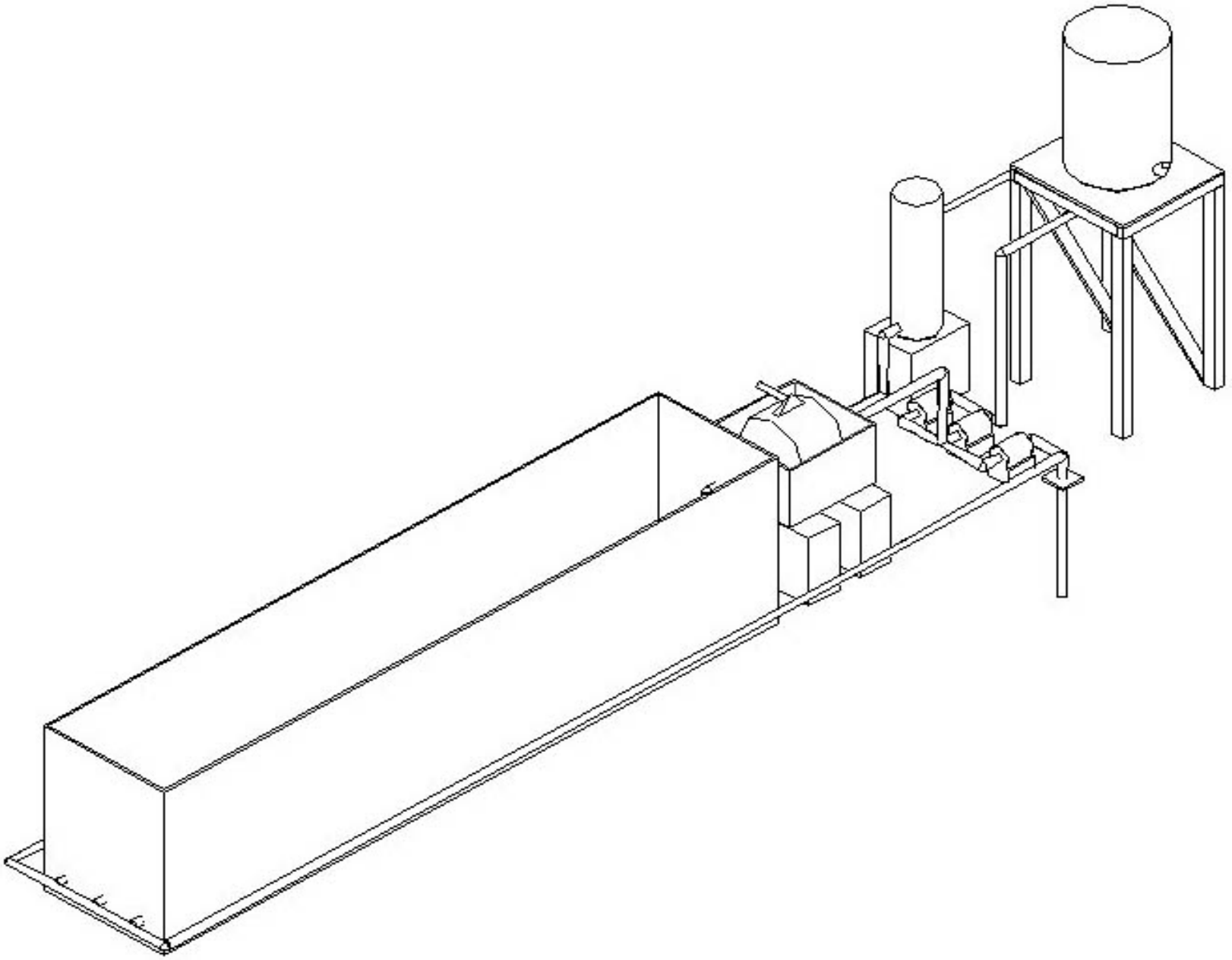

Figure 2.2. Schematic diagram of recirculating aquaculture system in trickle filter treatments.

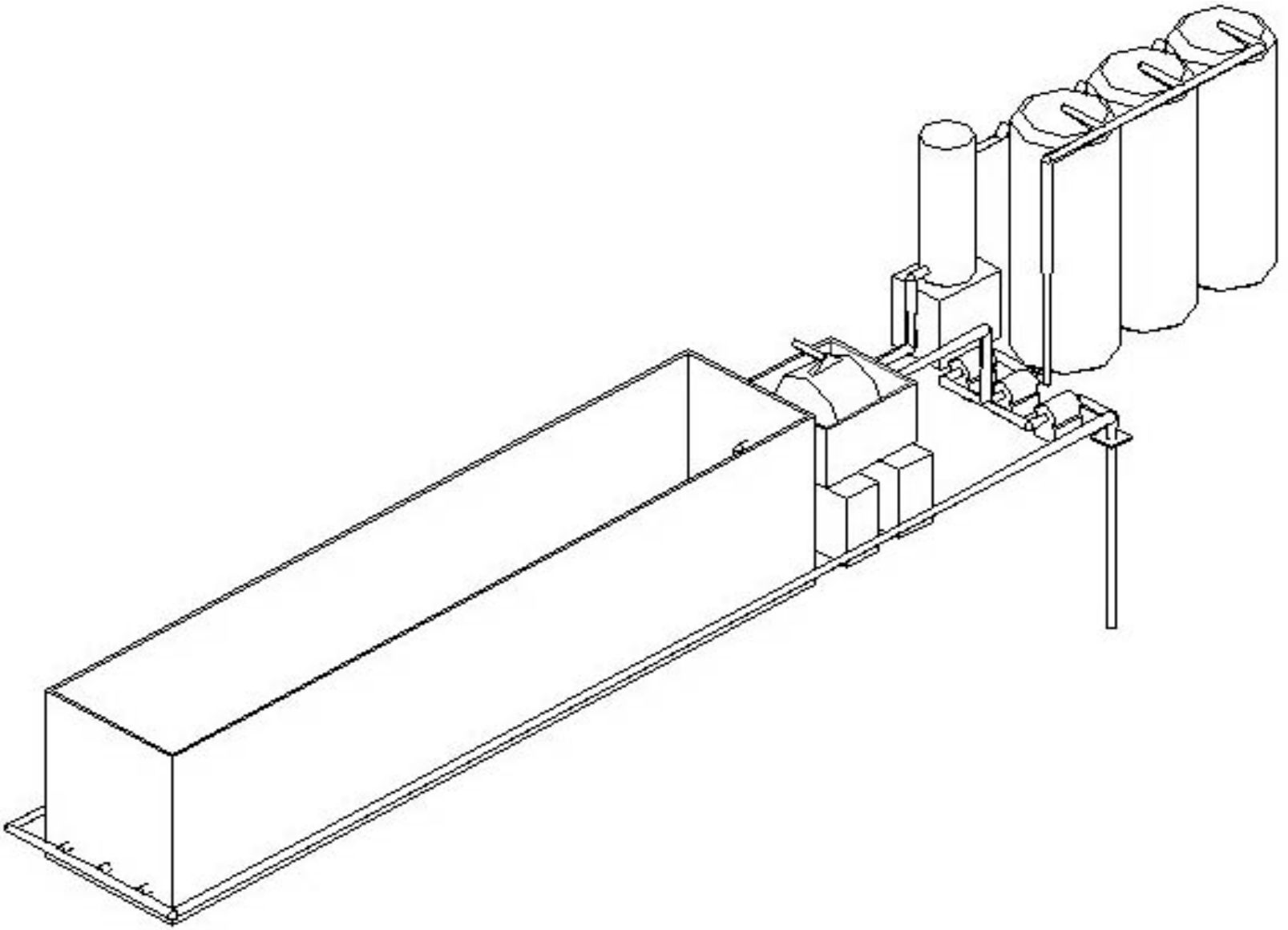

Figure 2.3. Schematic diagram of recirculating aquaculture system in bead filter treatments.

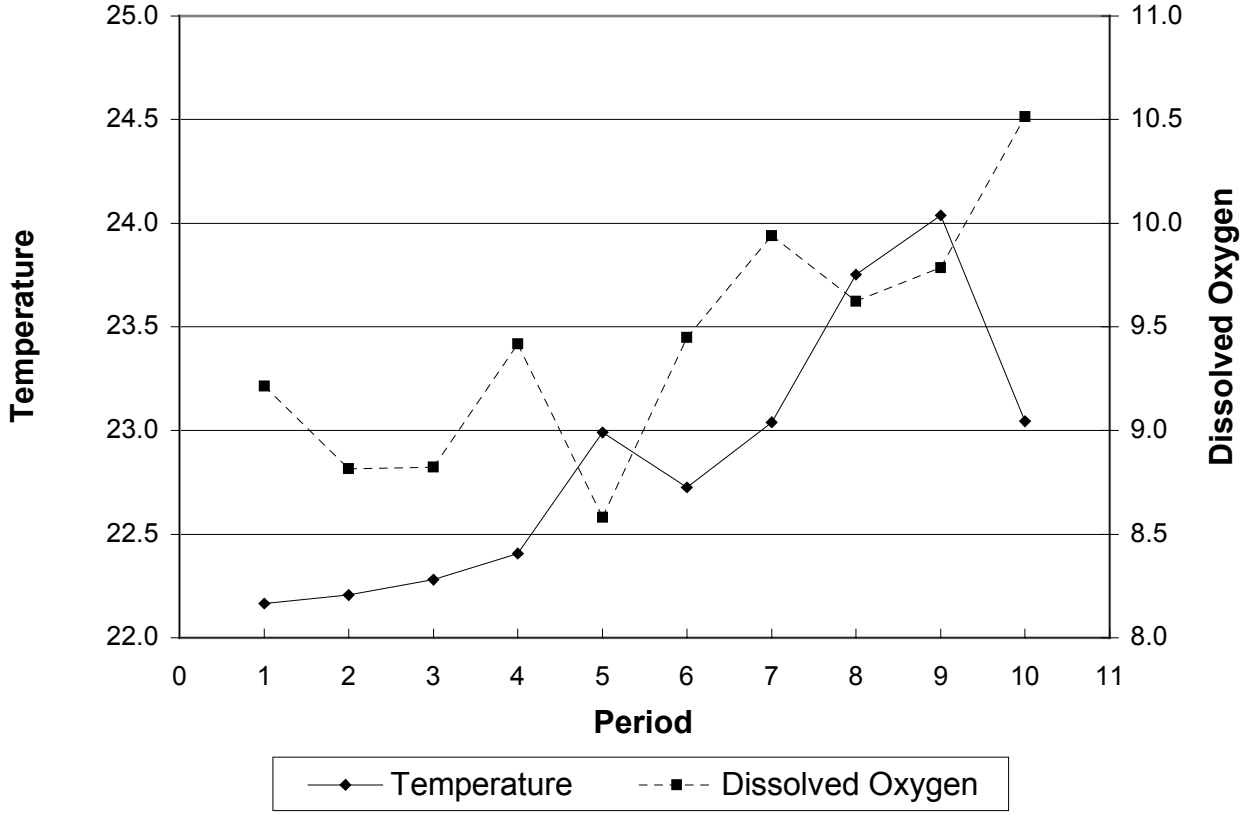

FIGURE 2.4. Mean temperature and dissolved oxygen values of the 7 systems remaining in production over the entire study. Values plotted are 28-day means.

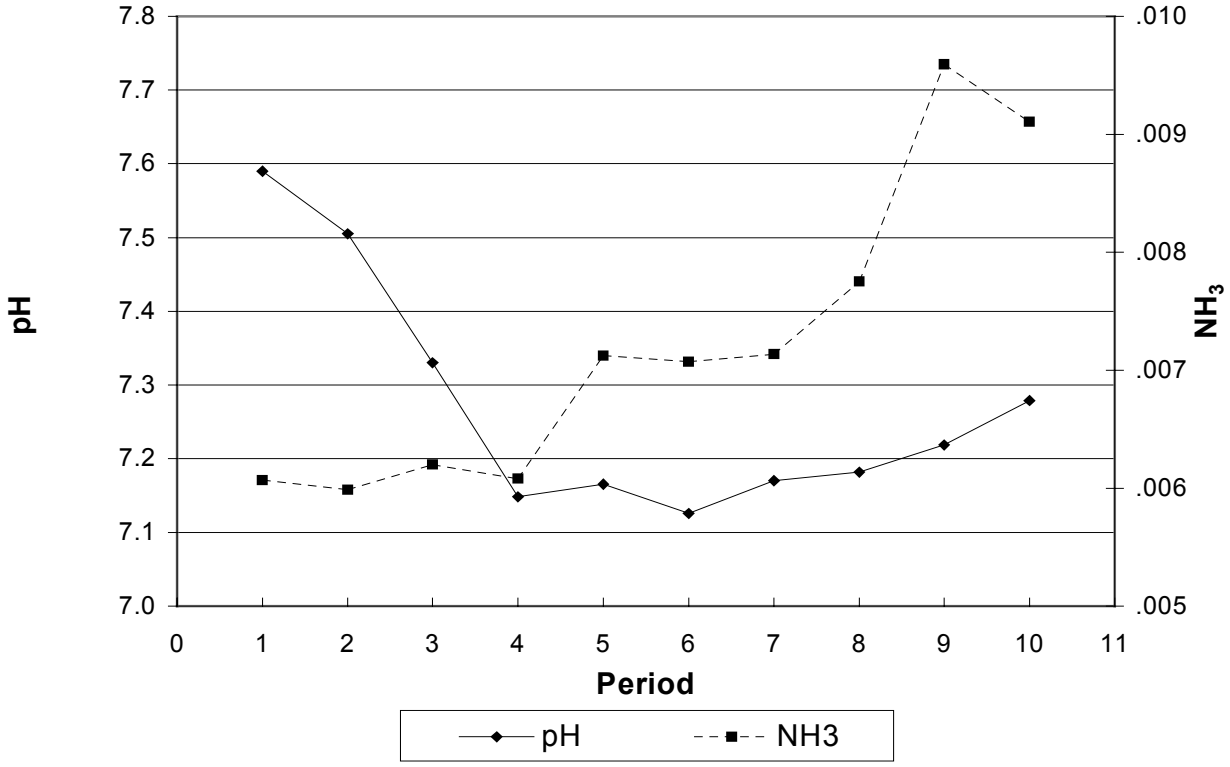

FIGURE 2.5. Mean pH and NH_3 values of the 7 systems remaining in production over the entire study. Values plotted are 28-day means.

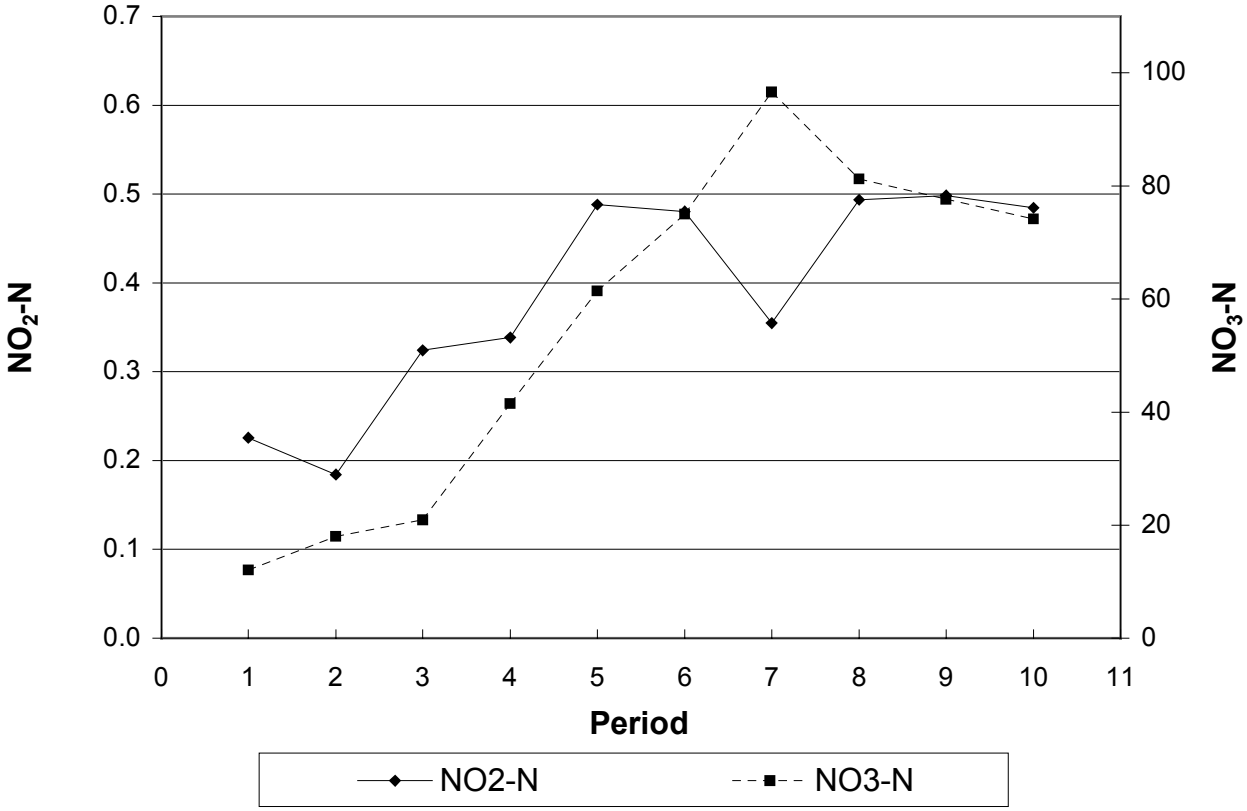

FIGURE 2.6. Mean nitrite (NO_2-N) and nitrate (NO_3-N) values of the 7 systems remaining in production over the entire study. Values plotted are 28-day means.

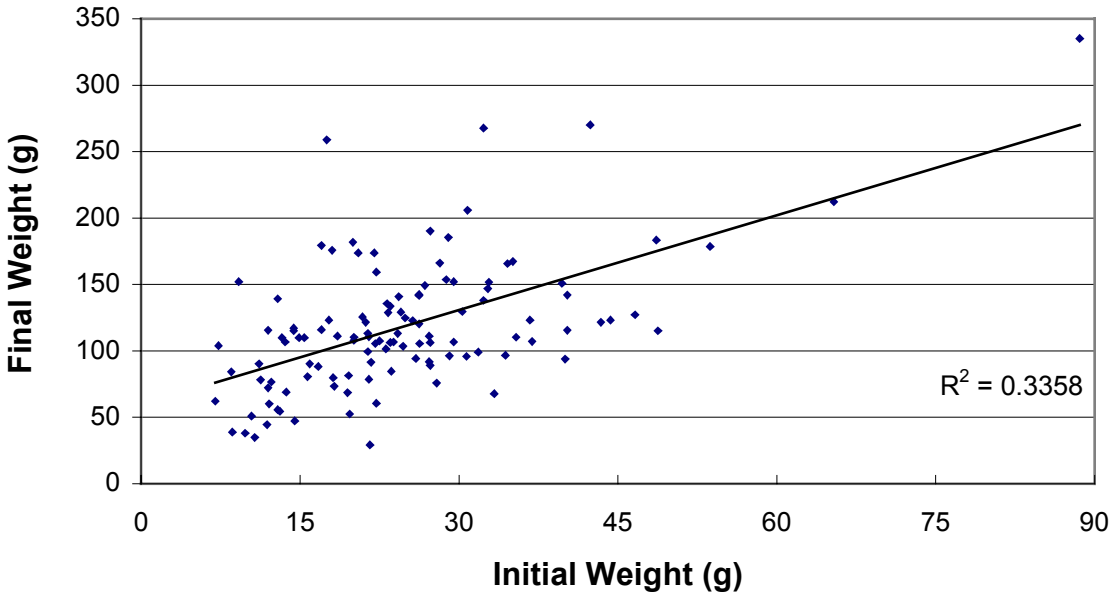

FIGURE 2.7. Initial versus final weight in all tagged individuals.

CHAPTER 3

COMPARISON OF FILLET YIELD AND GONADOSOMATIC INDEX (GSI) BETWEEN ALL-FEMALE AND MIXED SEX YELLOW PERCH (*Perca flavescens*) STOCKS.

INTRODUCTION

Sound marketing data is critical for business planning, capital acquisition, and the ultimate success of potential aquaculture ventures. The yellow perch market demands a skin-on butterfly fillet (Mike Libbin, Paragon Processing, Inc.; Chris Bennett, Bennett Fish, Inc., personal communications). In a 1996/97 survey, the vast majority (95%) of restaurant managers indicated that fillets were the preferred product form for yellow perch. Less processed products available include whole fresh (in the round) or whole frozen perch (Riepe, 1998). Yellow perch fillets are low in fat (0.8%) and phospolipids (Kinsella et al., 1977). These attributes result in yellow perch having a long shelf life, resistance to freezer damage, and minimal problems with off-flavor and cooking (Malison, 1999b). Restaurants prefer fresh (44%) and frozen (51%) fillets about equally when price and supply are not an issue. When yellow perch is actually purchased, however, about two-thirds (65%) of the restaurants purchase frozen fillets (Riepe, 1998).

The processing of yellow perch is expensive compared to other fish species, with total processing costs averaging $0.50-1.00/lb ($1.10-2.20/kg) or more for fillets (Malison, 1999). The butterfly fillet is a relatively difficult cut and requires skilled processors (for technique see Virginia Seagrant, 1999). At the present time, machine filleting results in an unacceptable loss of yield. Because of their small size, most yellow perch are scaled by machine and filleted by hand (Malison, 1999).

Due to the consumer preference for filleted yellow perch, maximizing fillet yields is a high priority for both producers and processors of aquacultured yellow perch. Selection among and within breeds and breed crosses has been used to improve carcass traits of livestock (Johansson and Rendell, 1968), and similar approaches may be useful for improving fillet yield in yellow perch. The identification of techniques or stocks that result in increased fillet yield will add to the total production and profitability of the industry.

OBJECTIVES

The objectives of this study were to: (1) compare the fillet yield of market-sized yellow perch between all-female and mixed-sex fish stocks, (2) compare the gonadosomatic index (GSI) in individual fish between these stocks and assess its possible affect on fillet yield, and (3) compare fillet yield and GSI between male and female individuals within a mixed-sex fish stock and between female individuals by stock.

METHODS

Fish used in this study were reared in recirculating aquaculture systems at the Aquaculture Research Facility, Virginia Polytechnic Institute and State University, Blacksburg, VA. Two distinct stocks of yellow perch were utilized in this study. The all-female stock (S1) was originally derived from Lake Mendota, Wisconsin (Coolwater Farms, Cambridge, WI). The mixed-sex stock (S2) was originally derived from Lake Erie (BPM Inc., Leetonia, OH). Yellow perch were selected from harvest-sized fish at the end of a 292-day growth period. Prior to selection, fish from both stocks were sorted according to size. Fish with total weights of at least 115g were considered of harvestable size. The harvest-sized fish from each stock were

transferred from grow-out tanks (S1 n = 2, S2 n = 5) used in the study into one tank for each stock. After the fish were sorted, they were held without food for 96 hours, and then transferred on ice to the processing facility.

Processing measurements were conducted at a facility experienced in processing 113,000 kg of yellow perch annually (Bennett Fish, Inc., Loraine, OH). All fish were scaled using a full scaling machine (Fishmore, Windsor, Canada). A skilled processor then filleted perch by hand. To eliminate differences in individual fillet efficiency and technique, the same person cut all of the fish used in this study.

Measurements on individual fish included total weight before scaling and weight of butterfly fillet, both measured to the nearest 0.1 g. Individual fillet yield (S1 n= 18, S2 n = 19) was calculated as the weight of fillet over the total weight of fish prior to scaling. The carcasses of the fish examined for individual fillet yield were retained for recovery of gonads. The gonads were later removed and weighed to the nearest 0.001g. This data was used to determine the sex ratio in the mixed-sex stock, and to calculate and compare the GSI: [(weight of gonads/ total weight of fish)*100] in both stocks. Total weight, fillet yield, and GSI were also compared between male and female individuals from S2, as well as between S1 and S2 females.

Six groups of 20 individuals each (n = 120 individuals per stock) were also examined for fillet yield. Group measurements taken included total combined weight of the 20 fish prior to scaling and the combined weight of the 20 butterfly fillets. Group fish and fillet weights were measured to the nearest 0.005 lb (2.27 g).

Student's T-test was used to compare individual total weight, fillet yield, and GSI between stocks, between sexes within S2, and between S1 and S2 females. Group fillet yield and average total weight by group were also compared using T-tests between stocks.

RESULTS

Group results by stock

Mean total weight in S2 (154.8g, SE=1.64) groups were significantly heavier than S1 (135.5g, SE=1.64) groups ($p < .01$). Fillet yield was significantly greater in S1 (47.2%, SE=0.25) groups compared to S2 (44.9%, SE=0.25) groups ($p < .01$).

Individual results by stock

Mean total weight in S2 (201.1g, SE= 11.3) individuals were significantly heavier than S1 (146.1g, SE= 11.7) individuals ($p < 0.05$). Mean fillet yield was significantly greater in S1 (47.6%, SE= 0.52) individuals compared to S2 (43.0%, SE=0.51) individuals ($p < .01$). Mean GSI in S1 (1.01%, SE=0.15) individuals was significantly higher than S2 (0.54%, SE=0.14) individuals.

Individual results by sex within a mixed sex stock

Examination of the gonads revealed that 14 of the 19 fish in S2 were female (73.7%), while only 5 of the individuals were male (26.3%). There were no significant differences between the mean weight of males (189.9g, SE=29.6) versus females (205.2g, SE=17.7). Mean GSI was significantly higher in females (0.70%, SE=0.10) when compared to males (0.08%, SE=0.17: $p < 0.05$). There was no significant difference between fillet yield by sex ($p > 0.1$).

Individual results between females by stock

Mean weight in female S2 individuals (205.2g, SE= 13.2, n=18) was significantly greater than female S1 individuals (146.1g, SE= 11.7, n=14) ($p < 0.05$). Fillet yield was significantly

greater in S1 (47.6%, SE= 0.52) individuals compared to female individuals from the S2 stock (42.7%, SE=0.59) ($p<.01$). GSI in female individuals was not different between stocks ($p > 0.1$).

Effect of fish size on fillet yield

Within each stock fillet yield in yellow perch increased slightly with size (see Figure 3.1 & 3.2). Although this is not a strong relationship ($r^2 = 0.45$ in S1 individuals, $r^2 = 0.28$ in S2 groups), small increases in fillet yield may be achieved by rearing yellow perch to a larger size.

DISCUSSION

The reported range in fillet yields for wild and cultured perch is 34-48% (Malison, 1999b). The results of this study are similar to those found by Heidinger and Kays (1993), who reported an average fillet yield of 45% for farm-raised yellow perch. Cultured yellow perch yield 4-5% more in fillet percentage than wild caught perch (Calbert and Huh, 1976; Lesser and Viltrup, 1978; Heidinger and Kays, 1993). Yellow perch have relatively high fillet yields when compared to tilapia, 25.4% for fish averaging 585g, and channel catfish, 30.9% for fish averaging 610g (Clement et al., 1994). This is partially due to increased yields found in skin-on butterfly fillets. Processing percentage between skin-on and skin-off walleye fillets can differ by as much as 8.4% (Summerfelt et al., 1996).

Lindsay (1980) reported fillet yields ranging from 42.5-43.5% for aquacultured perch averaging 150g. Wild caught perch (175-200g) had similar yields. It was concluded that the similarity in yields between these wild and cultured fish was mainly due to the larger size of the wild fish, as fillet yield generally increased with fish size (Lindsay, 1980). Fillet yield increased with size in both palmetto bass and paradise bass (Bosworth et al., 1998), as did dressing yield in

channel catfish (Lovell and Li, 1992). In walleye, processing percentage did not increase with fish weight (Summerfelt et al., 1996).

In the current study, fillet yield in yellow perch increased slightly with size (see Figure 3.1 & 3.2). Although this is not a strong relationship ($r^2 = 0.45$ in S1 individuals, $r^2 = 0.28$ in S2 groups), small increases in fillet yield may be achieved by rearing yellow perch to a larger size. Revenues generated from higher yields would have to out-weight the production costs of rearing fish to a larger size.

Surprisingly, individuals and groups from the S1 stock had significantly higher fillet yields despite having a significantly smaller mean weight and significantly larger GSI. Perch can sexually mature before they reach a harvestable size, and sexual maturation may significantly reduce their growth rate and fillet yield (Schott, 1980). Fully developed yellow perch ovaries may result in GSI values of up to 35% (Malison and Garcia-Abiado, 1996) resulting in 10-25% reduction in fillet yield (Malison, 1999). However, GSI values in this study were extremely low due to the constant photoperiod and temperature maintained throughout the experiment, and had minimal effect on fillet yield.

The difference in fillet yield demonstrated between these stocks may be a result of differences in strain of origin. Significant differences in percentage of fillet between different strains and crossbreds have been demonstrated in rainbow trout (Hörstgen-Schwark et al., 1986). Differences in carcass yield have also been identified among strains of Atlantic salmon (Gjerde and Gjedrem, 1984) and channel catfish (Smitherman et al., 1983), and fillet yield also may differ among geographic strains of yellow perch (Mike Libbin, Paragon Processing, Inc.; Chris Bennett, Bennett Fish, Inc., personal communications). When compared to purebred walleye, processing yield was not improved in hybrid walleye (Summerfelt et al., 1996).

The strength of comparisons between male and female individuals within the S2 stock was hampered by the unequal sex ratio (73.7% female). These results are similar to those obtained by Melard et al. (1996) who found that 80% of the harvestable fish were female after one year in intensive culture conditions. Even though GSI was significantly higher in female individuals, the gonads in both sexes accounted for less than 1% of the total body weight and minimized the effect of sex on fillet percentage. Sexual maturation is inhibited in female perch under constant culture conditions above 18^{o}C (Melard et al., 1996) and this investigation indicates that it may have the same effect in male yellow perch. Processing percentages for skinless fillets between male and female walleye raised under intensive conditions were not significantly different (Summerfelt et al., 1996). Other research has shown that dress percentage in rainbow trout and gutted body weight in Atlantic salmon are both significantly influenced by sex (Gjerde and Gjedrem, 1984).

To eliminate the possible effect of sex on fillet yield, only female individuals were compared between stocks. Despite the fact that S2 individuals were significantly heavier, mean GSI values were similar between individuals of both stocks. Again S1 individuals exhibited superior fillet percentages and emphasizes the possible affect that strain may have on fillet yield in yellow perch.

Given the high value of yellow perch, even small increases in fillet yield would result in substantial increases in income for producers and processors. The results of this study indicate that selecting superior strains of yellow perch may increase fillet yields by as much as 4.6%. Using an average price of fresh fillets of $7.45 per pound (Riepe, 1998), understanding strain-specific yields can produce and additional income of $34,270 per 100,000 pounds of rounds

produced. Conversely, a 10% reduction in fillet percentage has been shown to raise production costs by more than 5% in Argentinian hake (Crupkin et al., 1996).

SUMMARY

This study shows that exposing yellow perch to constant photoperiod and temperature conditions minimizes gonadal development. GSI values in this study were extremely low and had minimal effect on fillet yield. This results in high fillet percentages averaging 44.9-47.2%. Selecting superior strains of yellow perch may increase fillet yields by as much as 4.6%. The identification of superior yellow perch strains or strain crosses with regard to fillet percentage is of considerable importance to the industry. Harvesting yellow perch at larger sizes also appears to slightly increase yields regardless of strain.

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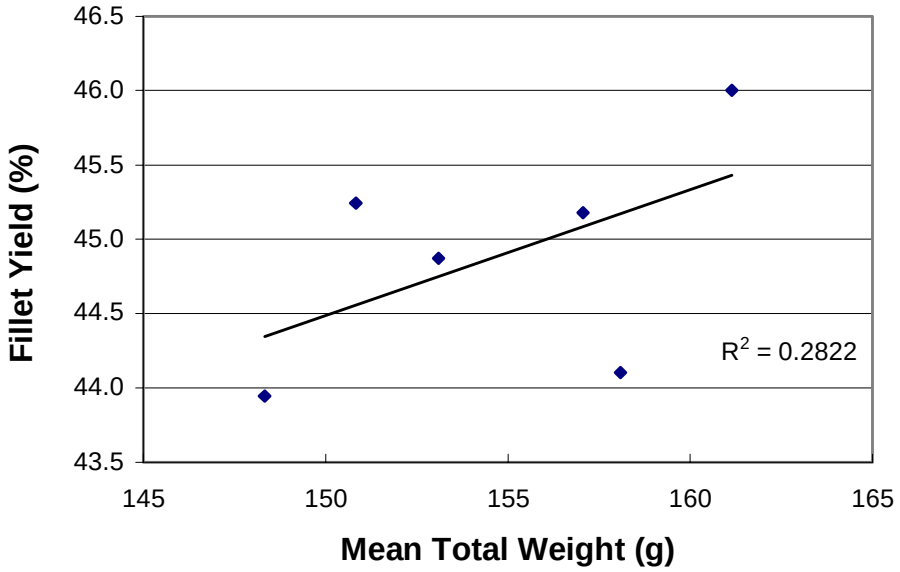

Figure 3.1. Mean total weight versus fillet yield in mixed-sex groups.

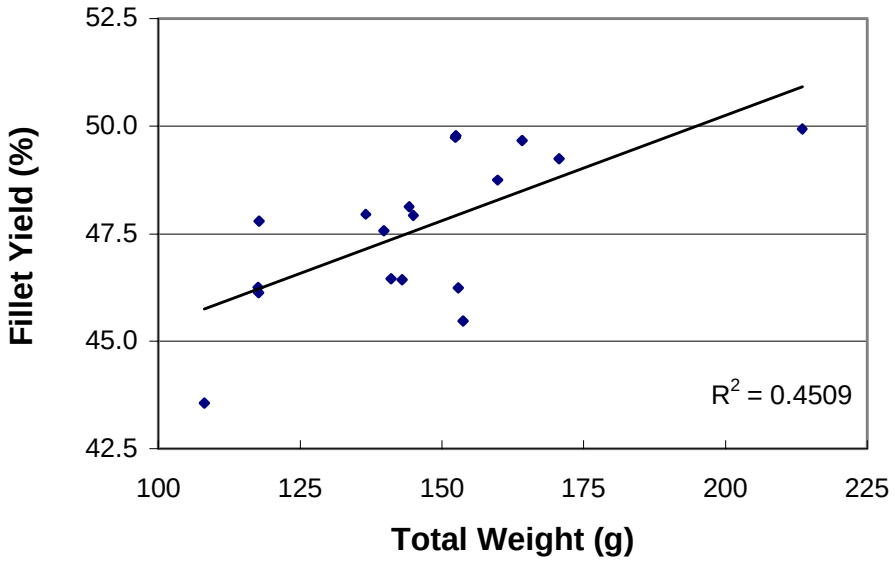

Figure 3.2. Total weight versus fillet yield in all-female individuals.

VITA

Mark H. Schmitz was born in Sheboygan, Wisconsin on October 15, 1973 to James H. Schmitz and Nancy J. (Doegnitz) Schmitz. He was raised in Silver Creek, Wisconsin and graduated from Sheboygan Area Lutheran High School in 1992. He then attended the College of Natural Resources at the University of Wisconsin in Stevens Point. During the summers of 1993-1995, Mark worked for the Wisconsin Department of Natural Resources on a fish management crew in Plymouth, Wisconsin. Mark was employed as an aquaculture technician at Alpine Farms in Sheboygan Falls, Wisconsin during the summer of 1996. Mark received a Bachelor of Science degree, with a double major in Biology and in Water Resources with an emphasis in Fisheries in December of 1996.

Mark began a research assistantship at the Virginia Polytechnic Institute and State University in July of 1997 under the direction of Dr. George S. Libey. He was engaged to Katherine A. Leibham on August 22, 1998. Mark completed his Master of Science degree in May of 1999.