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.

LITERATURE CITED

Best, C.D. 1981. Initiation of artificial feeding and the control of sex differentiation in yellow perch (*Perca flavescens*). M.S. Thesis, University of Wisconsin, Madison. 121 pp.

Brett, J.R. 1979. Environmental factors in growth. *In:* W.S. Hoar, D.J. Randall, and J.R. Brett, Ed's. Fish Physiology. Vol. 8. Academic Press, New York, NY. pp 599-677.

Brewin, M.K., L.L. Stebbins & J.S. Nelson. 1995. Differential losses of Floy anchor tags between male and female brown trout. North Amer. J. Fish. Mgmt. 15: 881-884.

Bryan, R.D. & J.J. Ney. 1994. Visible implant tag retention by and effects on condition of a stream population of brook trout. North Amer. J. Fish. Mgmt. 14: 216-219.

Carlander, K.D. 1950. Handbook of Freshwater Fisheries Biology. Wm. C.Brown, Dubuque, Iowa. 281 pp.

Cody, R.P. 1985. Applied Statistics and the SAS Programming Language. Elsevier Science Publishing Co., Inc. New York, NY. 187 pp.

Craig, J. 1987. The Biology of Perch and Related Species. Beckenham, Great Britain: Croom Helm Ltd. 333 pp.

Doyle, R. W. and Talbot, A.J. 1988. Repeatability of relative size-specific growth in tilapia. *In:* R.S.V. Pullin, T. Bhukaswan, K. Tonguthai and J.L. Maclean, Ed's, The Second Internationals Symposium on Tilaopia in Aquaculute. ICLARM Conference Proceedings 15, Department of Fisheries, Bangkok, Thailand, and International Center for Living Aquatic Resources Management, Manila, Philippines, pp. 451-456.

Dunham, R.A. and R.O. Smitherman. 1983. Response to selection and realized heritability for body weight in threee strains of channel catfish, *Ictalurus punctatus,* grown in earthen ponds. Aquaculture 33:89-96.

Eguia, M.R.R. and R.V. Eguia. 1997. Use of "internal reference" technique in comparing genetic strains of red tilapia. *In*: K. Fitzsimmons, Ed. Proceedings from the fourth international syposium on tilapia in aquaculture. Orlando, FL.

Eknath, A.E., M.M. Tayamen, M.S. Palada-de Vera, J.C. Danting, R.A. Reyes, E.E. Dionisio, J.B. Capili, H.L. Bolivar, T.A. Abella, A.V. Circa, H.B. Bentsen, B. Gjerde, T. Gjedrem and R.S.V. Pullin. 1993. Genetic improvement of farmed tilapias: the growth performance of eight strains of *Oreochromis niloticus* tested in different farm environments. Aquaculture 111: 171-188.

Fontaine, P., L. Tamazouzt, and V. Capdeville. 1996. Growth of the Eurasian perch (*Perca fluviatilis*) reared in floating cages and in water recirculated system: first results. J. Appl. Ichthyol. 12, 181-184.

Goudie, C.A., B.A. Simco, K.B. Davis and G.J. Carmichael. 1994. Growth of channel catfish in mixed sex and monosex pond culture. Aquaculture 128: 97-104.

Gunnes, K. 1976. Effects of size grading young Atlantic salmon (*Salmo salar*) on subsequent growth. Aquaculture 9: 381-386.

Hagen, N.T. 1996. Tagging sea urchins: a new technique for individual identification. Aquaculture 139: 271-284.

Harvey, W.D. and D.L. Campbell. 1989. Retention of passive interated transponder tags in largemouth bass brood fish. The Progressive Fish-Culturist 51: 164-166.

Heidinger, R.C. and T.B. Kayes. 1993. Yellow Perch. *In*: R.R. Stickney (Ed.), Culture of Non-salmonid Freshwater Fishes. CRC Press, Inc., Boca Raton, FL. 215-229 pp.

Hopkins, K. 1992. Reporting fish growth: a review of the basics. Journal of the World Aquaculture Society 23(3): 173-179.

Huh, H.T., H.E. Calbert, and D.A. Stuiber. 1976. Effects of temperature and light on growth of yellow perch and walleye using formulated feed. Trans. Am. Fish. Soc., 105, 254.

Jacobs, J.M., S. Lindell, W. Van Heukelem, E.M. Halleman and R.M. Harrell. 1999. Strain evaluation of striped bass under controlled conditions. Aquaculture 173: 171-177.

Jenkins, W.E. and T.I.J. Smith. 1990. Use of PIT tags to individually identify striped bass and red drum brood stocks. Am. Fish. Soc. Symp. 7: 341-345.

Kapuscinski, A.R., M. Hove, W. Senanan and L.M. Miller. 1996. Selective breeding of walleye: building block for closed-system aquaculture. *In:* R.C. Summerfelt, Ed. Walleye Culture Manual. NCRAC Culture Series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames.

Leach, G.C. 1928. Propagation and distribution of food fishes. Fiscal year 1927, Report to the U.S. Commissioner of Fisheries, U.S. Government Printing Office, Washington D.C. pp 683-736.

Mair, G.C. and D.C. Little. 1991. Population control in farmed tilapias. NAGA, The ICLARM Quarterly 14(3): 8-13.

Malison, J.A. 1985. Growth promotion and the influence of sex steroids on sexually related dimorphic growth and differentiation of yellow perch (*Perca flavescens*). Ph.D. Thesis, University of Wisconsin-Madison. 153 pp.

Malison, J.A., C.D. Best, T.B. Kays, C.H. Amundson, and B.C. Wentworth. 1985. Hormonal growth promotion and evidence for a size-related difference in response to estradiol-17β in yellow perch (*Perca flavescens*). Can. J. Fish Aquat. Sci. 42, 1627-1633.

Malison, J. A., T.B. Kayes, C.D. Best, C.H Amundson, and B.C. Wentworth. 1986. Sexual differentiation and use of hormones to control sex in yellow perch (*Perca flavescens*). Can. J. Fish. Aquat. Sci. 43:26-35.

Malison, J.A., T.B. Kays, B.C. Wentworth, and C.H. Amundson. 1988. Growth and feeding responses of male versus female yellow perch (*Perca flavescens*) treated with estradiol-17β. Can. J. Fish Aquat. Sci. 45, 1942-1948.

Malison, J.A., and M.A.R. Garcia-Abiado. 1996. Sex control and ploidy manipulations in yellow perch (*Perca flavescens*) and walleye (*Stizostedion vireum*). J. Appl. Ichthyology 12: 189-194.

Malison, J.A. 1999. A white paper on the status and needs of yellow perch aquaculture in the North Central Region.[Online]. Available: http://ag.ansc.purdue.edu/aquacic/ncrac/wpapers/ypwhite.html

Manci, W.E. and J.T. Quigley. 1981. Determination of operating parameter values for water reuse aquaculture. Bio-Engineering Symposium for Fish Culture (FCS Publ. 1): 97-103.

McGinty, A.S. 1985. Effects of size at stocking on competition and growth of all-male tilapia hybrids. J. World Mariculture Society 16: 52-56.

Melard C., P. Kestemont, and J.C. Grignard. 1995. Intensive ongrowing of juvenile perch (*Perca fluviatilis*): zootechnical parameters and growth. *In:* Kestemont and Dabrowski (Ed's), Workshop on Aquaculture of Percids: Short Communications. Presses Universitaires de Namur, Namur, Belgium, 25-26.

Melard, C., P. Kestemont, and J.C. Grignard. 1996a. Intensive culture of juvenile and adult Eurasian perch (*P. fluviatilis*): effect of major biotic and abiotic factors on growth. J. Appl. Ichthyology. 12: 175-180.

Melard, C.P., E. Baras, L.M. Kestemont, and P. Kestemont. 1996b. Relationships between stocking density, growth, cannibalism and survival rate in intensively cultured larvae and juveniles of perch (*Perca fluviatilis*). Ann. Zool. Fennici 33:643-651.

Moore, A. 1992. Passive integrated transponder tagging of channel catfish. The Progressive Fish-Culturist 54: 125-127.

Nielsen, L.A. 1992. Internal tags. *In*: Methods of Marking Fish and Shellfish. Spec. Publ., American Fisheries Society, Bethesda, MD, 99. 89-112.

Ombredane, D., J.L. Bagliniere & F. Marchand. 1998. The effects of passive integrated transponder tags on survival and growth of juvenile brown trout (*Salmo trutta* L.) and their use for studying movement in a small river. Hydrobiologia 371/372: 99-106.

Palada-de Vera, M.S. and A. E. Eknath. 1993. Predictability of individual growth rates in tilapia. Aquaculture 111:147-158.

Peterson, N.P., E.F. Prentice & T.P. Auinn. 1994. Comparison of sequential coded wire and passive integrated transponder tags for assessing overwinter growth and survival of juvenile coho salmon. North Amer. J. Fish. Mgmt. 14: 870-873.

Post, G. 1987. Textbook of Fish Health. T.F.H. Publications, Inc. Neptune City, NJ.

Prentice, E.F., T.A. Flagg & C.S. McCutcheon, 1990. Feasibility of using implantable passive integrated transponder (PIT) tags in salmonids. Am. Fish. Soc. Symp. 7: 317-322.

Purdom, C.E. 1986. Genetic techniques for control of sexuality in fish farming. Fish Physiol. Biochem. 2(1-4): 3-8.

Russo, R.C. and R.V. Thurston. 1977. The acute toxicity of nitrite to fishes. *In:* R.A. Tubb, Ed. Recent Developments in Fish Toxicology. National Environmental Research Service, Ecological Research Series EPA-600/3-77-085. U.S. Environmental Protection Agency, Washington, D.C. pp 118-131.

SAS. 1985. User's Guide: Statistics. SAS Institute Inc., Cary, NC, USA.

Schott, E.F., T.B. Kays, and H.E. Calbert. 1978. Comparative growth of male versus female yellow perch fingerlings under controlled environmental conditions. *In:* Selected Coolwater Fishes of North America, Special Publ. No. 11, Kendall, R.L., Ed., American Fisheries Society, Washington D.C. pp 181-186.

Schumann, G.O. 1963. Artificial light to attract young perch: a new method of augmenting the food supply of predacious fish fry in hatcheries. Progressive Fish-Culturist 25: 171-174.

Scott, W.B. and E.J. Crossman. 1973. Freshwater Fishes of Canada. Fish. Res. Bd. Can. Bull., 184 pp.

Tave, D. 1993. Genetics for Fish Hatchery Managers. Second Edition. Van Norstrand Reinhold, New York. 415 pp.

Umino, T., M. Otsu and M. Takaba. 1993. Some characteristics of runty fish appearing in seed production of red sea bream. Nippon Suisan Gakkaishi 59(6): 925-928.

Wallace, J.C. and A.G. Kolbeinshavn. 1988. The effect of size grading on subsequent growth in fingerling Arctic char, *Salvelinus alpinus* L. Aquaculture 73(1-4): 97-100.

Wedemeyer, G.A. 1996. Physiology of Fish in Intensive Culture Systems. Northwest Biological Science Center. National Biological Service. U.S. Department of the Interior. Chapman and Hall, New York, NY. 232 pp.

Wickins, J.F. 1987. Effects of size, culling and social history on growth of cultured elvers, *Anguilla anguilla* L. Journal of Fish Biology 31:71-82.

Withler, R.E., T.D. Beacham, I.I. Solar and E.M. Donaldson. 1995. Freshwater growth, smolting, and marine survival and growth of diploid and triploid coho salmon (*Oncorhynchus kisutch*). Aquaculture 136: 91-107.

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

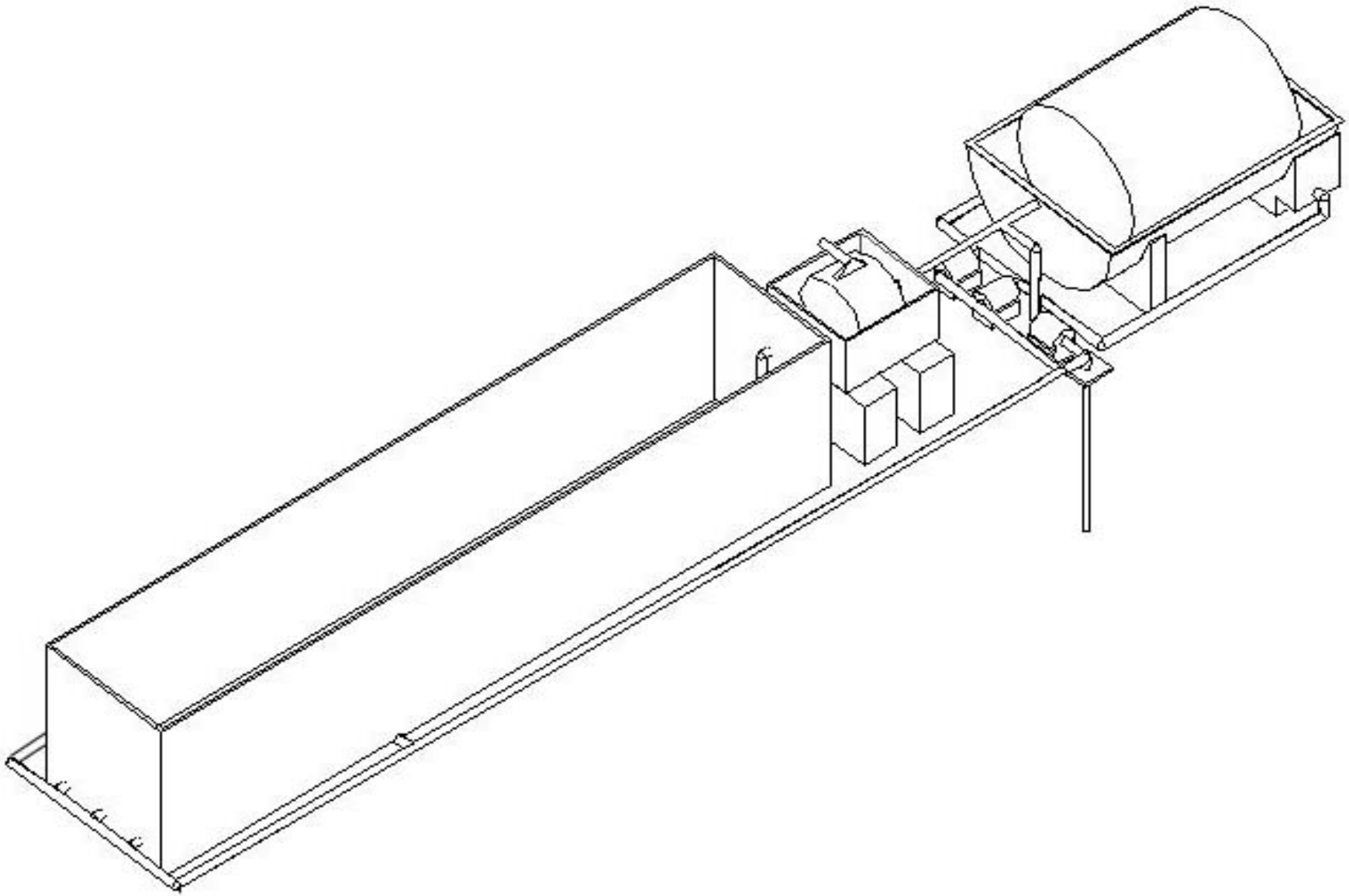

Figure 2.1. Schematic diagram of recirculating aquaculture system in RBC filter treatments.

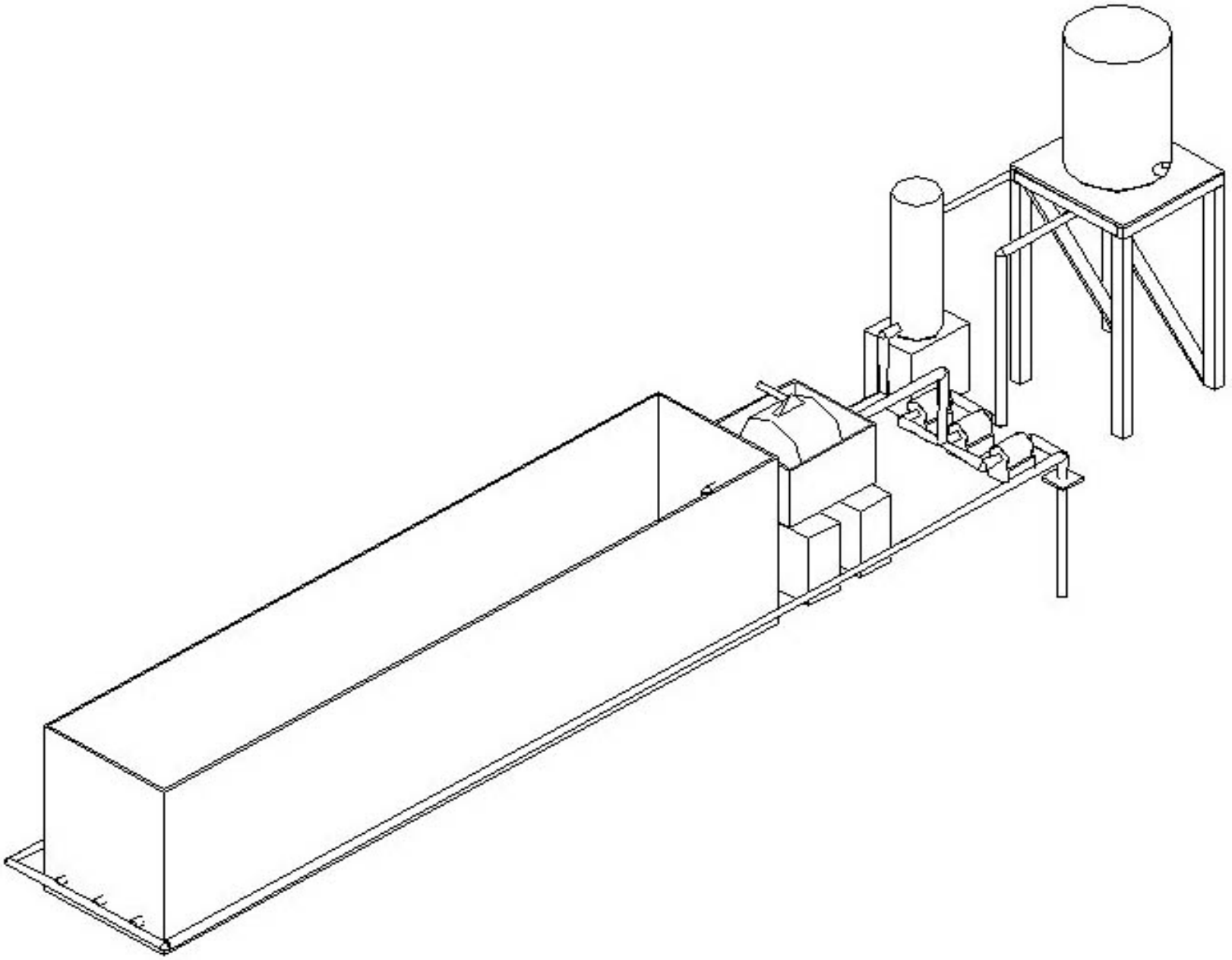

Figure 2.2. Schematic diagram of recirculating aquaculture system in trickle filter treatments.

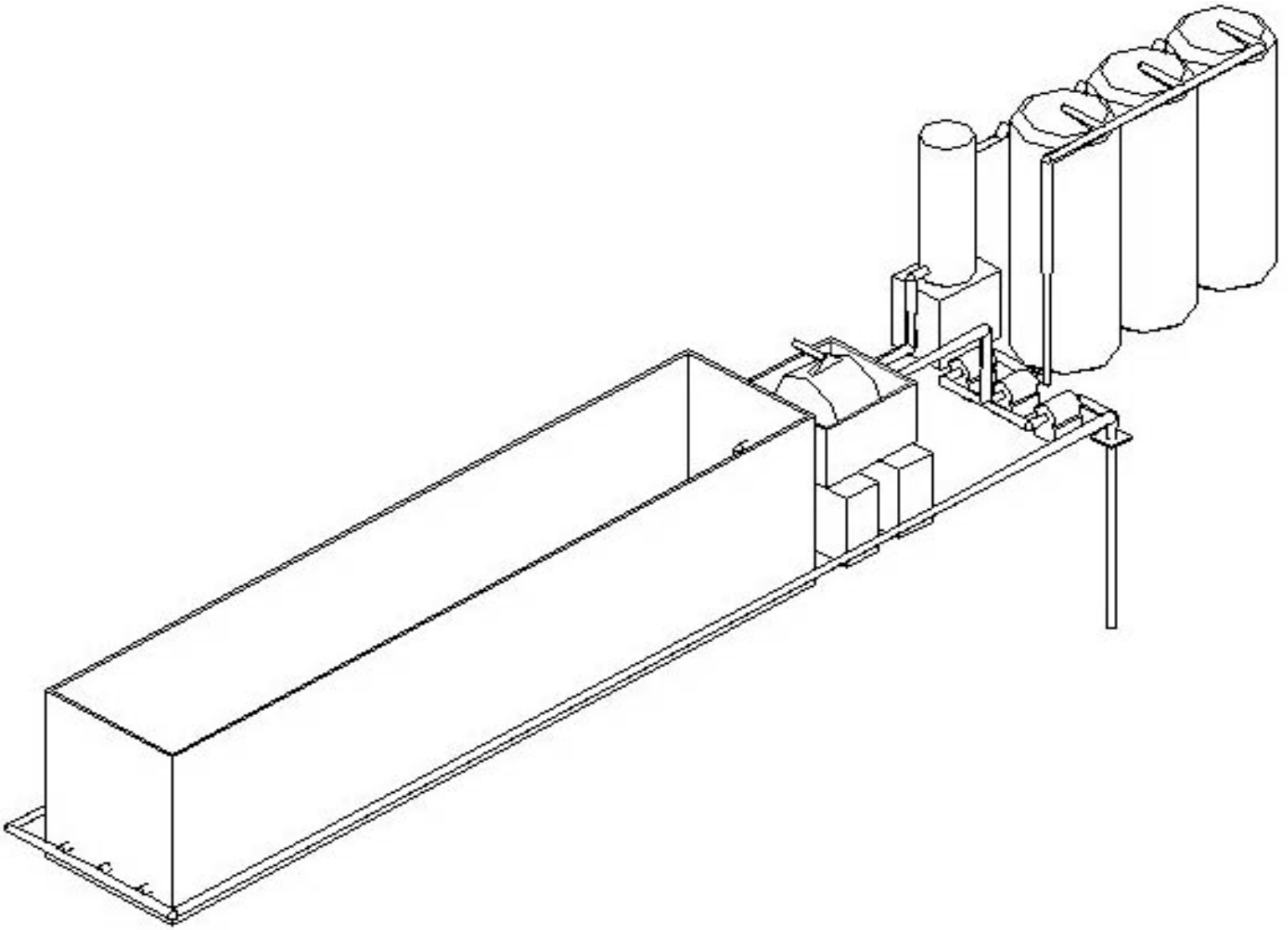

Figure 2.3. Schematic diagram of recirculating aquaculture system in bead filter treatments.

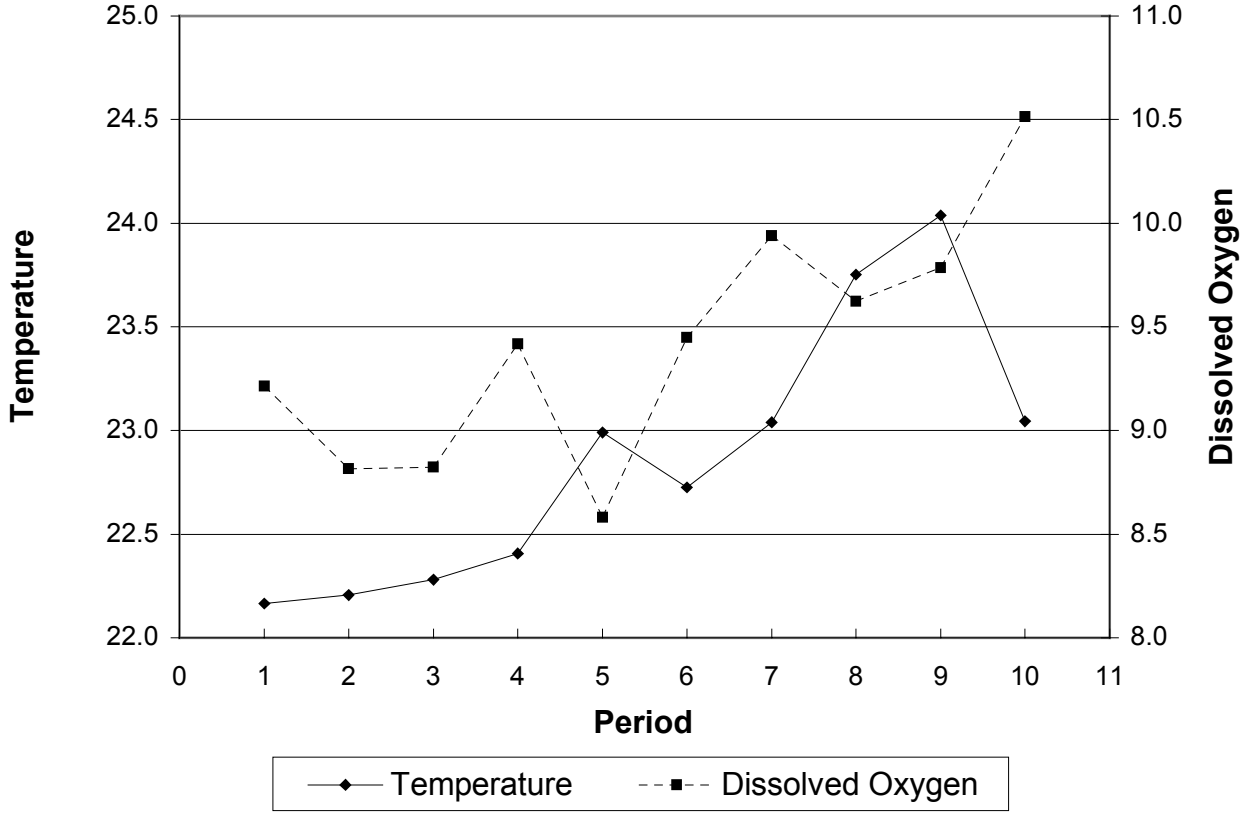

FIGURE 2.4. Mean temperature and dissolved oxygen values of the 7 systems remaining in production over the entire study. Values plotted are 28-day means.

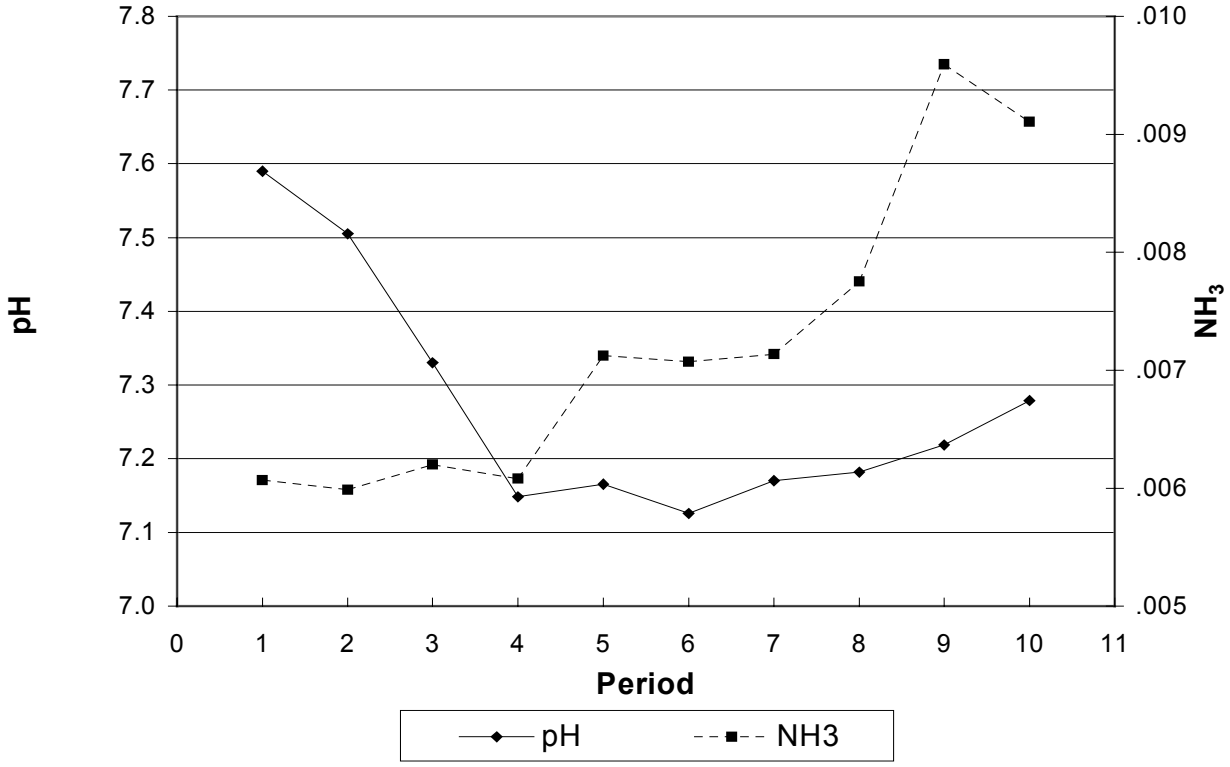

FIGURE 2.5. Mean pH and NH_3 values of the 7 systems remaining in production over the entire study. Values plotted are 28-day means.

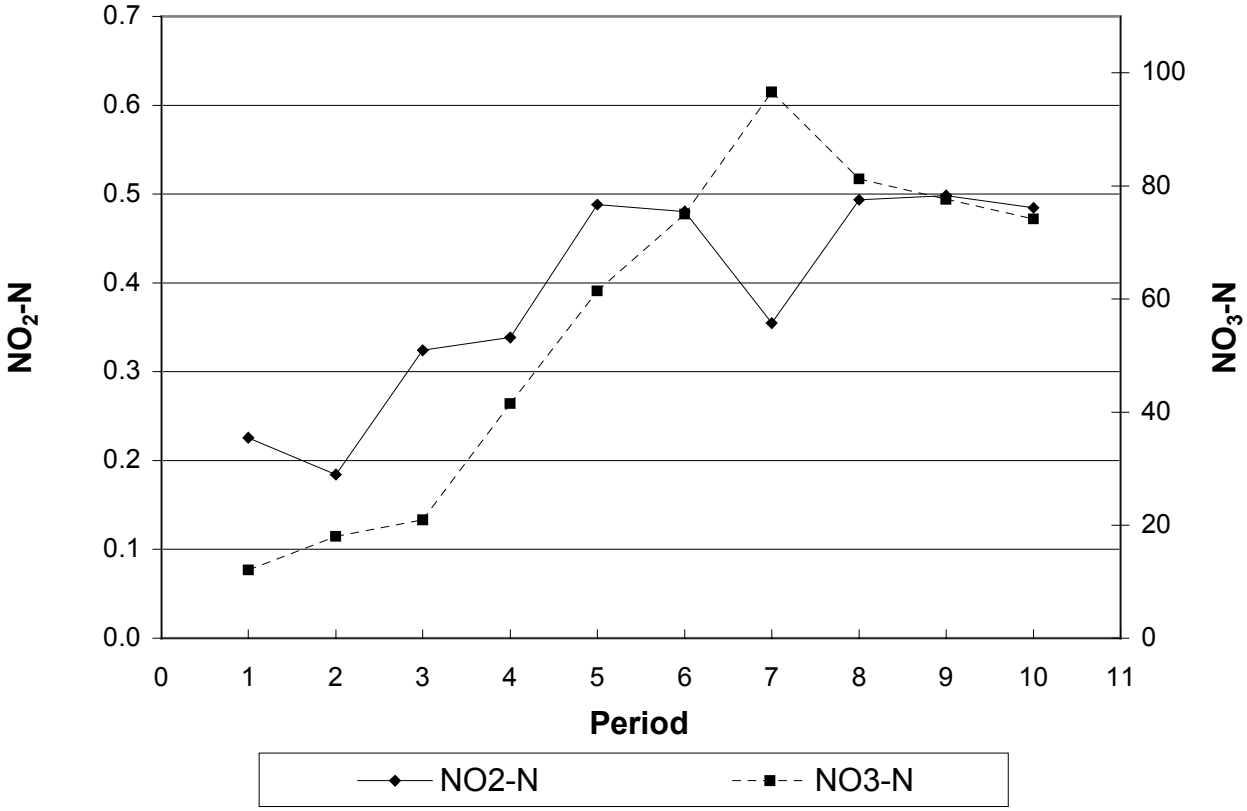

FIGURE 2.6. Mean nitrite (NO_2-N) and nitrate (NO_3-N) values of the 7 systems remaining in production over the entire study. Values plotted are 28-day means.

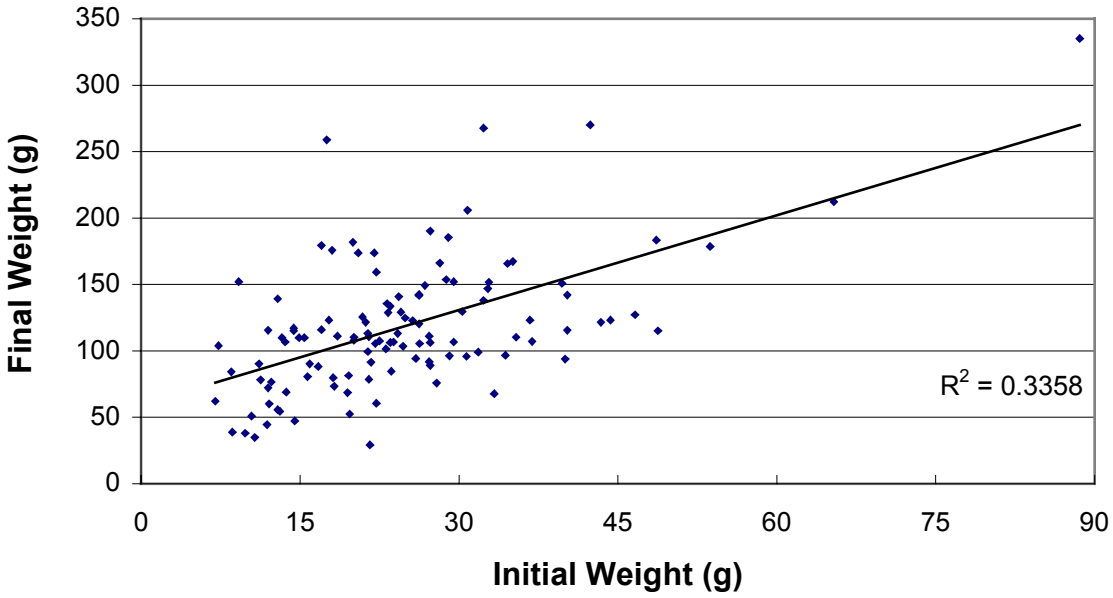

FIGURE 2.7. Initial versus final weight in all tagged individuals.