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Effects of feeding strategies on growth performance of F1 Gulf coast Striped Bass (*Morone saxatilis*) strains in recirculating aquaculture systems

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Abstract

As feed is a major cost in finfish aquaculture, considerable economic advantages can be gained by optimizing feeding efficiency. In the present study, the effects of reducing feeding frequency were evaluated in Gulf strain Striped Bass *Morone saxatilis* raised in recirculating systems. Juvenile Striped Bass (~170 g) were raised for 84 days at 21 °C and fed three or five times weekly at 3% body weight (% BW) or three, five, and seven times weekly at 2% BW. In another experiment, subadult fish (~720 g) raised at 15 °C for 84 days, were fed three or five times weekly at 2% BW. In all experiments, feeding frequency did not affect growth rates or efficiency and fish fed less frequently consumed more feed per feeding, but typically had reduced feed consumption over the length of the experiment. These results indicate labor and feed costs may be reduced by limiting the feeding frequency of Striped Bass in recirculating systems.

Introduction

The commercial success of any cultured fish species depends on optimizing many environmental and nutritional variables. Since feed costs are the greatest reoccurring operational expense in recirculating aquaculture enterprises (De Silva et al. 1995; Salgado-Ismodes et al. 2020), it is critical to optimize feeding strategies to maximize growth and feed conversion, minimize size heterogeneity, limit feed waste and maintain water quality (Bolliet et al. 2001; Craig et al. 2017). Feed intake, digestibility and feed conversion ratios (FCRs) depend on many factors including diet specifications (Glencross et al. 2007) and feeding method (Cho and Bureau 2001). Optimizing species and age-dependent feeding frequencies can be a simple and effective cost-cutting measure for any aquaculture operation.

Numerous studies have focused on optimizing the number of daily feedings of fish during the larval and early juvenile stages. Many of these studies found improved growth with multiple feedings per day (Liu and Liao 1999, Biswas et al. 2010, Tian et al. 2015) but in others, growth was similar with either one or multiple daily feedings (Busti et al. 2020). In larger juveniles, different feeding regimes involving skipping one or more feeding days per week, were examined for their effects on feed intake and growth variables (Gilannejad et al. 2019; Liu et al. 2022). In some species, restricted feeding days did not diminish growth compared to daily feeding, especially during the colder winter months (Schnaittacher et al. 2005). This strategy may reduce operational expenses by reducing associated labor and feed costs. With long-term feed depredation (weeks), many, but not all fish species demonstrate compensatory growth ("catch up growth") in which a period of accelerated growth occurs upon resumed feeding, relative to continuously fed cohorts (Ali et al. 2003; Peres et al. 2011; Won and Borski 2013). Hybridization of Striped Bass with other *Morone* species, particularly the stenohaline freshwater White Bass *Morone chrysops*, has been conducted since the 1960s, largely because hybrids demonstrated superior growth, disease resistance, and tolerance to higher water temperatures when grown in freshwater ponds (Harrell, 1997). The hybrid Striped Bass (hybrid) industry is currently fourth in value among United States finfish species, behind Channel Catfish *Ictalurus* *punctatus*, Atlantic Salmon *Salmo salar*, and Rainbow Trout *Oncorhynchus mykiss* and they are also cultured in several other countries (NOAA 2020). Recently, however, there has been considerable interest shown in culturing purebred Striped Bass rather than hybrids, as they are preferred in some lucrative ethnic markets, seafood restaurants and sushi bars, and can be grown in “open” systems (e.g., coastal areas) without the risk of genetic contamination of wild stocks. Many studies have investigated the nutritional requirements and husbandry of hybrids (Nematipour et al. 1992; Liu and Liao 1999; Turano et al. 2008), but relatively few have focused on purebreds during juvenile “grow-out”.

Recently, we observed disparate growth of purebred Striped Bass raised at two research facilities employing different feeding strategies (twice daily as a % BW ration, six days a week and once daily to apparent satiation, five days a week; Kenter et al. 2018). The purpose of the current studies was to evaluate the growth performance, feed consumption, and FCRs of sub-adult, Gulf of Mexico strain Striped Bass grown in recirculating systems with simulated autumn (20-21°C) and winter (15-16°C) temperatures. The fish used in these experiments (~170 g; 720 g) were larger than those typically used in many hybrid Striped Bass grow out studies because, Striped Bass are usually grown to a larger size (~1.5-2.5 kg; Anderson et al. 2021) for the fillet market and we wanted to examine the possible effects of reduced feeding frequency during high-consumption, grow-out phases.

Methods

Fish Acquisition and pre-experimentation grow out- Gulf coast Striped Bass were bred in captivity during their respective spawning seasons at the Welaka National Fish Hatchery

(Welaka, FL; FL strain) and Possum Kingdom Fish Hatchery (Graford, TX; TX strain). Fry were produced from wild-caught broodstock and stocked into fertilized earthen ponds until fingerlings (< 2 g) could be seined and shipped to the Ritzman Aquaculture Laboratory (University of New Hampshire (UNH), Durham, NH, USA). The fish were cultured by strain for ~10-16 months, in 1500 L grow-out tanks (20-21°C, 5 ppt salinity and 12:12 photoperiod), incorporated into recirculating systems (RAS) equipped with screen filters, bead filters, biological filters, protein skimmers, ultraviolet sterilizers and temperature control. During this pre-experimentation "grow out," the fish were fed (Skretting, Europa; St. Andrew, NS, Canada; 50% minimum (min.) crude protein and 18% min. crude fat) to apparent satiation twice daily. All experiments were conducted in accordance with UNH Institutional Animal Care and Use Committee guidelines.

Simulated Autumn feeding trial- Two, 12-week feeding trials were conducted at 20-21 °C in the UNH Aquaculture Research Center in separate indoor, recirculating systems comprised of six 1500 L tanks and nine 750 L tanks equipped with the RAS components described above. Each 750 L tank received 16 fish/tank (FL strain; 176.4 ± 33.1 g) and randomly assigned to an experimental treatment of a 2% BW ration offered twice daily on three, five or seven days a week. The second trial investigated a 3% BW ration offered twice daily on three or five days a week using the six-tank system stocked with 30 fish/tank (TX strain; 169.0 ± 29.5 g). Feeding schedules are shown in Table 1. Fish were hand fed (Skretting, Europa) twice daily during respective experimental treatments until the prescribed (% BW) rations were consumed or fish appeared satiated (i.e. pellets hit the tank bottom). Total consumption was recorded daily to compare feed consumption and calculate FCRs. All fish were weighed during stocking and again at 30-day intervals until completion of the 12-week trial.

Simulated Winter feeding trial- A third trial was conducted at 15-16 °C in the six-tank system described above. Each tank received 23 fish/tank (FL strain; 729.2 ± 114.2 g) and was randomly assigned to an experimental treatment of a 2% BW ration, offered twice daily, on three or five days a week (Table 1). Feed consumption and measurements were conducted as previously described until the end of the 12-week trial.

Table 1

Weekly feeding frequency treatments applied in both Autumn and Winter trials. F signified fed, "- " indicates unfed.

Feeding frequencies							
	Mon	**Tues**	**Wed**	**Thurs**	**Fri**	**Sat**	**Sun**
3x	**F**	**-**	**F**	**-**	**F**	**-**	**-**
5x	**F**	**F**	**-**	**F**	**F**	**F**	**-**
7x	**F**	**F**	**F**	**F**	**F**	**F**	**F**

Statistical analysis- Comparisons between mean growth rates and feed efficiency metrics between or among feeding regimes were performed using a Student's t-test. A one-way analysis of variance (ANOVA) was used to test among variables when fish were offered feed on three, five, or seven days/week. Normality was confirmed using the Shapiro–Wilk test. Tukey's pairwise comparison was applied if ANOVA output indicated a significant difference ($P < 0.05$) among means. Analyses were performed in JMP Pro (16).

The following formulas were used for growth and feed calculations:

Absolute Growth Rate (AGR)= (Wf-Wi)/T, where T is time in days and Wf and Wi are final and initial fish weights, respectively.

Feed Conversion Ratio (FCR) = (feed intake/n)/(Wf-Wi), where n is the number of fish in a given tank and Wf and Wi are final and initial fish weights, respectively.

%BW= (feed intake/W)*100, where W is mean fish weight at a given sampling

Results

Autumn feeding trial- Mean final weight, growth rate, and FCR were similar among and between treatments in the 2% BW and 3% BW trials respectively at 20-21 °C (Table 2). In both experiments, the tanks fed three times a week had greater, more consistent, daily consumption rates compared to the increased frequency treatments (Table 2; $P < 0.0001$ and 0.0039, respectively), which often failed to finish their prescribed daily rations. This trend shifted, however, when feeding behavior was compared across longer periods of time. Overall, tanks fed three times a week consumed less than the other treatments in both studies when measured weekly (Table 2; $P < 0.0001$ and 0.0277, respectively) and for the entirety of the trial (Table 2; $P = 0.0009$ and 0.0414, respectively). One fish died during the final month of the 2% BW trial but the mortality was not considered to be associated with an experimental feeding strategy.

Winter feeding trial – Mean final weight, growth rate, and FCR were again similar between feeding frequencies using larger fish in 15-16 °C (Table 3). Additionally, daily consumption was greater in tanks offered feed three times (~1.5% BW) a week compared to five (~1.0% BW, Table 3; $P < 0.0005$). When consumption behavior was compared across longer time periods, however, no differences were observed weekly ($P = 0.062$) or during the entirety of the trial ($P = 0.2806$). Again, one fish died during the final month in a 3x tank but the mortality was not considered to be associated with an experimental feeding strategy.

Table 2

Average initial and final weights (g), AGR, FCR, daily consumption (% BW), weekly consumption (g), and total consumption (kg) of juvenile fish offered 2 or 3% BW rations in 20-21 °C recirculating systems. All values are expressed as Mean ± SD. Values followed by a letter denote a significant difference among feeding strategies in the 2% BW trial (One-way ANOVA and Tukey's; $P > 0.05$) or between strategies in the 3% BW trial (Students T-test; $P > 0.05$).

2% BW				**3% BW**	
	3x	**5x**	**7x**	**3x**	**5x**
Initial Weight (g)	**179.8 ± 31.3**	**178.9 ± 36.5**	**170.5 ± 31.6**	**170.1 ± 28.2**	**167.9 ± 30.7**
Final Weight (g)	**297.7 ± 59.4**	**311.5 ± 80.9**	**318.8 ± 81.7**	**387.9 ± 63.7**	**420.4 ± 83.3**
AGR	**1.37 ± 0.34**	**1.52 ± 0.18**	**1.71 ± 0.31**	**2.59 ± 0.66**	**3.01 ± 0.46**
FCR	**1.35 ± 0.22**	**1.54 ± 0.13**	**1.43 ± 0.17**	**1.12 ± 0.10**	**1.16 ± 0.10**
% BW/feed day	**1.95 ± 0.07^{A}**	**1.52 ± 0.38^{B}**	**1.18 ± 0.39^{B}**	**2.94 ± 0.09^{A}**	**2.14 ± 0.60^{B}**
Weekly consumption (g)	**199.8 ± 29.4^{B}**	**262.5 ± 28.4^{A}**	**278.9 ± 34.9^{A}**	**605.9 ± 141.6^{B}**	**737.0 ± 64.3^{A}**
Total consumption (kg)	**2.44 ± 32.60^{B}**	**3.21 ± 253.2^{A}**	**3.36 ± 107.7^{A}**	**7.20 ± 88.60^{B}**	**8.69 ± 561.44^{B}**

Table 3

Average initial and final weights (g), AGR, FCR, daily consumption (% BW), weekly consumption (g), and total consumption (kg) of subadult fish offered a 2% BW rations in 15-16 °C recirculating systems. All values are expressed as Mean ± SD. Values followed by a letter denotes a significant difference between strategies (Students T-test; P > 0.05).

2% BW		
	3x	**5x**
Initial Weight	**720.5 ± 125.7**	**737.8 ± 102.8**
Final Weight	**993.0 ± 165.5**	**1022.6 ± 153.1**
AGR	**2.98 ± 0.77**	**3.10 ± 0.80**
FCR	**1.83 ± 0.36**	**1.96 ± 0.36**
% BW/feed day	**1.51 ± 0.26^{A}**	**1.01 ± 0.22^{B}**
Weekly consumption (g)	**846.6 ± 102.8**	**974.2 ± 158.4**
Total consumption (kg)	**10.9 ± 0.48**	**12.4 ± 1.7**

Discussion

Fish growth and metabolism are influenced by many factors including feed consumption, water temperature, stocking density, fish size and feeding regimes (Craig et al. 2017). In the present experiments conducted with the smaller fish (~170 g) at simulated Autumn temperature (21°C) weight gain among fish and FCRs were similar irrespective of feeding frequency, but fish fed less frequently consumed more feed per feeding. Several studies have been conducted in which juvenile and sub-adult fish were fed during the weekdays only, as a labor-saving measure. The results of these studies have been conflicting with similar, impaired, and improved growth reported (Nikki et al. 2004; Tasbozan et al. 2016; Tunçelli and Pirhonen 2021). For instance, Tunçelli and Pirhonen (2021) found greater overall feed intake and specific growth rates and lower FCR in juvenile rainbow trout (30 and 48 g) fed every day compared to those fed five days in succession. These results differed from those of Nikki et al. (2004) also working with juvenile rainbow trout of similar size, who found fish starved for 2 days exhibited hyperphagia and grew at the same rate as those fish fed daily. Taşbozan et al. (2016) working with smaller rainbow trout (8.5 g), in contrast, found growth rates of fish starved on weekends exceeded those of continuously fed fish, but did not demonstrate hyperphagy. Similarly disparate results were also observed in studies with non-salmonids that omitted weekend feedings. For instance, similar growth rates were found in European whitefish *Coregonus lavaretus* and Matrinxã *Brycon amazonicus* (Känkänen and Pirhonen 2009; Urbinati et al. 2014) fed five or seven consecutive days but growth of fingerling dusky grouper *Epinephelus marginatus* and Pirapitinga *Piaractus brachypomus* were significantly reduced by two-day starvation periods (Favero et al. 2021; Spandri et al. 2021). Differences in the length of the experiments, size of the experimental cohorts and daily feeding frequency may have contributed to the observed differences. Our results, however, indicate under the recirculating conditions in which the fish were raised, labor and feed expenses can be reduced by feeding Striped Bass thrice per week, compared to five days per week or daily.

Recommended feeding frequencies vary with fish species and size. Generally, larval and small juvenile fish need to be fed more frequently than older juveniles or broodstock to meet their high energy demands and growth rates decrease as fish get larger (Imslamd and Jonassen 2001; Craig et al. 2017). In the present study, Striped Bass were fed on a percent body weight basis, rather than to apparent satiation, to avoid inter-investigator variation among feedings. Piper et al. (1982) recommended feeding rates of 2% BW a day for Striped Bass 27.2 g or larger raised at 21°C and Hung et al. (1993) found optimal feeding rates of 1.0-1.5% BW for Striped Bass fingerlings (38 g) raised at 19 °C. In the simulated autumn experiments, fish fed more frequently consumed less per daily feeding than those fed less frequently and did not consume the entire, allotted portion (i.e. 2 or 3% BW). The growth performance of the Striped Bass used in these studies was similar to comparative size Striped Bass previously cultured under identical experimental conditions and fed seven days a week (Kenter et al. 2018). Larger juveniles, as used in the current studies, have previously been shown in other species to be more resistant to conditions of feed restriction, than smaller fish, because they have greater stores of body energy such as glycogen, lipids and proteins (Favero et al. 2021).

In ectothermic fishes, temperature sets the rates of most biochemical reactions and physiological processes and has therefore been labelled the abiotic master factor (Brett 1971; Jobling 1996). Cooler temperatures may reduce growth rates and energy reserves by decreasing feed consumption, reducing digestion rates, increasing gut transit time and lowering gastrointestinal evacuation rates (Miegel et al. 2010). Greatest feeding efficiency and growth rates of juvenile Striped Bass occurred at 24 °C but feeding continues at much lower temperatures (Cox and Coutant 1981). The growth rates of the larger fish raised at 15 °C and fed three or five times weekly were similar to each other and to smaller fish raised at 21 °C, but their FCRs were higher. This may be a reflection of the greater fish size, lower temperature, or both. Although the fish fed three times a week reared at a lower temperature consumed greater amounts of feed per feeding than those fed five times a week, their weekly and total feed consumption was similar, unlike the smaller fish raised at 21 °C. As a trend in lower weekly consumption ($P = 0.06$) and growth was observed in fish fed three times a week, longer term experiments are warranted with different size Striped Bass to determine if feeding efficiency can be improved by further reducing feeding frequency or portion sizes during winter conditions. It should also be determined if suboptimal feeding regimes in larger juveniles results in nutrient partitioning towards somatic vs. visceral growth as observed with smaller Striped Bass (Hung et al. 1993)

In conclusion, reducing feeding frequency did not affect the growth of Striped Bass cultured at simulated autumn or winter temperatures. Striped Bass fed less frequently consumed more feed per feeding but less over the total duration of each experiment, except at lower temperatures. These results indicate labor, and feed costs, can be reduced by optimizing the feeding frequency of Striped Bass in recirculating systems or during different seasons in extensive culture systems (ponds, net-pens).

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