JOURNAL OF THE
WORLD AQUACULTURE SOCIETY

Vol. 37, No. 4
December, 2006

Effect of Feeding Frequency on Feed Consumption, Growth, and Feed Efficiency in Aquarium-reared Norris and NWAC103 Channel Catfish (*Ictalurus punctatus*)*

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Abstract.—A 6-wk feeding study was conducted to determine the effect of feeding frequency on growth rate of juvenile Norris and NWAC103 channel catfish, *Ictalurus punctatus,* reared under laboratory conditions. Four replicate groups of Norris and NWAC103 catfish (average weight of 4.0 ± 0.2 g/fish, SEM) were fed to visual satiety at different feeding frequencies (one, two, or three times daily). The percent of total daily food consumed for Norris catfish fed three times daily (0800, 1200, and 1600 h) was 44.4, 27.7, and 27.9%, respectively, while NWAC103 catfish consumed 42.9, 26.7, and 30.4%, respectively. Specific growth rate and feed intake were higher in fish fed three times daily compared to fish fed once and twice daily for both strains. Feed efficiency was reduced in NWAC103 fed three times daily compared to fish fed once or twice, while feed efficiency was similar among the Norris treatments. Gastrointestinal (GI) tract index ([weight of GI tract/weight of fish] × 100) decreased in NWAC103 catfish as feeding frequency increased, while a similar nonsignificant trend was also observed in Norris catfish. The results of this study demonstrate that aquarium-reared Norris and NWAC103 catfish fed three times a day consume more feed and gain more weight than catfish fed once or twice a day. The observed decrease in the GI index as a result of feeding more frequently demonstrates that the size of the GI tract increases, relative to body weight, when catfish are fed only once a day. Under laboratory conditions, the number of times a day the fish are fed should be considered when trying to maximize growth of NWAC103 and Norris strains of catfish.

Fish growth is influenced by feed availability and intake, genetics, fish age and size, environment, and nutrition. Of these factors, feed intake is perhaps the principal factor affecting growth rate of fish (Li et al. 2004). Many studies have compared growth rates of the NWAC103 to different strains of channel catfish, *Ictalurus punctatus*, such as Mississippi ''normal'' and Norris catfish and have found that the NWAC103 channel catfish exhibits superior growth characteristics (Silverstein et al. 1999; Wolters et al. 2000; Li et al. 2001; Jackson et al. 2003; Bosworth et al. 2004). In general, studies find that the NWAC103 consumes more feed and grows faster. It has been suggested that the faster growth of the NWAC103 strain of channel catfish is as a result of their ability to consume more feed (Li et al. 2001). Furthermore, there may be a genetic component to their ability to consume more feed (Silverstein et al. 2001).

Laboratory studies with channel catfish have shown that feeding frequency affects growth performance of these fish. Andrews and Page (1975) fed catfish (mean initial weight of 53 g/fish) 1, 2, 4, and 8 times daily, and even 24 times daily to apparent satiation. Their results showed that weight gain was substantially reduced in fish fed once daily compared to feeding two or more times daily. In addition, feed conversion was not affected by frequency of feeding. The results of that study suggested that feeding two times daily to satiation was sufficient for maximal growth. However, their study did not examine feeding three times daily (Andrews and Page 1975). In addition, the strain of catfish used in the study was not described.

Increasing catfish growth is a primary goal of our broodstock management program at the National Warmwater Aquaculture Center (NWAC)

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in Stoneville, Mississippi, USA. The NWAC103 line of catfish as described by Wolters et al. (2000) was under selective breeding at the NWAC for two generations prior to releasing it in 2001. There is no information available concerning the effect of feeding frequency on growth rate of Norris or NWAC103 catfish reared under laboratory conditions. The ability to maximize growth is important to our selective breeding program. Initial growth performance evaluations are currently conducted under laboratory conditions because of the large numbers of families that are evaluated each year. Because growth is correlated to food intake (Silverstein et al. 1999) and it is not clear how many daily feedings are necessary to maximize growth rate, the present study aimed to examine the effects of feeding frequency on growth performance of juvenile NWAC103 channel catfish and compare these effects to those of a fish that consumes considerably less feed, the Norris strain of catfish.

Materials and Methods

Source of Fish

Fish used in this study were from the Norris and NWAC103 strains. The Norris strain originated from the Norris Fish Farm in Arkansas (Dunham and Smitherman, 1984), while the NWAC103 strain originated from broodstock maintained at the USDA/ARS Catfish Genetics Research Unit in Stoneville, Mississippi, USA. Fish from both strains were placed into two 76-L aquariums (one aquarium/strain) for 2 wk prior to distribution into treatment aquariums. Norris and NWAC103 (average weight of 4.0 ± 0.2 g/fish, SEM) channel catfish were randomly stocked into twenty-four 76-L aquariums (10 fish/tank) and allowed to acclimate (fed once daily at 0800 h) for 12 d. There were no statistical differences in initial weight of fish between strains ($P = 0.091$). The aquariums were supplied with flow-through well water (0.5 L/min) and continuous aeration. Water temperature averaged 25.8 ± 0.2 C, and a diel light : dark cycle was set at 14 h:10 h. Four replicate groups of fish were fed to visual satiety at different feeding frequencies (one, two, or three times daily) for 6 wk for each strain of channel catfish. Visual satiety was achieved by feeding all the feed the fish would consume in 20–30 min. Feeding times for the treatments were as follows: once daily – 0800 h, twice daily – 0800 and 1200 h, and three times daily – 0800, 1200, and 1600 h. Fish in all treatments were offered a commercial (36% crude protein) 1.0-mm floating catfish diet (Melick Aquafeed, Catawissa, PA, USA), and the amount of feed consumed was recorded at each feeding. Feed was withheld 24 h prior to handling fish.

At the beginning of the study, fish in each tank ($n = 10$) were anesthetized with 0.1 g/L tricainemethane sulfonate (MS-222; Argent Chemical Laboratories, Redmond, WA, USA) and weighed collectively ($n = 10$/tank). Aquariums were cleaned biweekly throughout the study. At the end of the 6-wk study, fish were weighed as a group as described above. Individual weights, lengths, and weights of the gastrointestinal (GI) tract were collected from four fish from each tank. No mortalities were observed throughout the study.

Data were subjected to two-way ANOVA and the Fisher's protected least significant difference procedure with Statistical Analysis System version 9.1 software. Tank served as the experimental unit for each variable measured. A significance level of $P < 0.05$ was used.

Results

No interactions were observed between fish strain and feeding frequency for specific growth rate (SGR), GI tract index, condition factor (CF), or feed conversion ratio (FCR). However, there was a significant interaction ($P = 0.032$) in feed intake between fish strain and feeding frequency (Table 1). Feed intake was greater for NWAC103 and Norris fish fed three times daily, whereas there were no differences in feed intake for NWAC103 and Norris fish fed once or twice daily.

SGR was similar in NWAC103 fed once and twice daily but increased ($P = 0.027$) in fish fed three times daily (Table 1). In Norris catfish, SGR was higher ($P = 0.015$) in fish fed three times daily than in fish fed once a day but was not different among fish fed twice daily. There

TABLE 1. *Mean SGR, feed intake, FCR, GI tract index, and CF of NWAC103 and Norris channel catfish fed one, two, and three times daily for 6 wk.*

Strain	Feeding frequency	SGR[1]	Feed intake[2] (g/fish)	FCR[3]	GI index[4]	CF[5]
NWAC103	1×	4.1^{z}	20.8^{z}	1.01^{z}	3.63^{z}	0.78
	2×	4.2^{z}	25.9^{z}	1.00^{z}	3.30^{y}	0.79
	3×	4.7^{y}	34.6^{y}	1.06^{y}	3.00^{x}	0.83
Norris	1×	3.1^{z}	9.8^{z}	1.01^{z}	3.63	0.72
	2×	3.4^{yz}	10.4^{z}	0.98^{z}	3.43	0.69
	3×	3.7^{y}	14.3^{y}	1.01^{z}	3.30	0.71
SEM[6]		0.06	0.68	0.007	0.05	0.006
ANOVA: P values						
Strain		<0.001	<0.001	0.139	0.118	<0.001
Feeding frequency		<0.001	<0.001	0.026	0.001	0.103
Interaction		0.636	0.032	0.318	0.381	0.132

Within columns, values with different letters are different ($P < 0.05$) within strain for each level of feeding frequency.

[1] Specific growth rates (SGR) were calculated from the formula $(\ln [BW_2] - \ln [BW_1]/[T - t]) \times 100$, where BW_1 and BW_2 are initial and final weights (g), respectively, and T and t are initial and final times (d), respectively.

[2] Feed intake represents the average amount of food (g) consumed per fish.

[3] Feed conversion ratios (FCR) were calculated as ingested food (g)/weight gain (g).

[4] Gastrointestinal (GI) index was calculated as weight of GI tract (g)/weight of fish (g) × 100.

[5] Condition factor (CF) was calculated as weight of fish (g)/length^3 × 100.

[6] SEM is the pooled standard error of the mean.

was a significant effect of strain on SGR ($P < 0.001$). NWAC103 fish exhibited a higher SGR in fish fed once, twice, and three times daily compared to Norris fish.

Feed intake was higher ($P < 0.01$) in fish fed three times daily compared to fish fed once and twice daily for both strains of fish. FCR was reduced ($P = 0.049$) in NWAC103 fed three times daily compared to fish fed once or twice daily, while FCR was similar ($P = 0.301$) among the Norris treatments. The GI tract index decreased ($P = 0.003$) in NWAC103 catfish fed twice and three times daily compared to those fed once a day, while a similar, but nonsignificant, trend was observed among the Norris treatments. No differences in CF were observed as a result of feeding multiple times a day for either strain of fish.

For both Norris and NWAC103 catfish, the greatest amount of food consumed in all treatments was at the 0800 h feeding (Table 2). Norris and NWAC103 catfish fed twice daily consumed approximately 62 and 38%, respectively, of the total food consumed at 0800 and 1200 h, respectively. Norris catfish fed three times daily consumed 44.4, 27.7, and 27.9%, respectively, at 0800, 1200, and 1600 h, while NWAC103 catfish consumed 42.9, 26.7, and 30.4%, respectively. There were no differences ($P = 0.265$) between strains for percent consumed.

Discussion

The present 6-wk feeding study demonstrates that both NWAC103 and Norris juvenile channel catfish fed three times a day will gain more weight than catfish fed once or twice a day. Weight gain in NWAC103 fish fed three times a day was 52% greater compared to fish fed only once a day. Similarly, Norris fish fed three times a day gained 23% more weight than fish fed only once a day. There was no difference in weight gain between fish fed once or twice a day in NWAC103 and Norris catfish.

Andrews and Page (1975) showed that weight gain was reduced in catfish fed once a day and was not enhanced by feeding four or more times a day. The data showed that optimal growth was obtained from groups of fish fed to satiation two times per day. However, in their study, the fish fed twice a day were fed at 0800 and 1630 h (Andrews and Page 1975). The fish in the present study were fed at 0800 and 1200 h. The difference in the amount of time between feedings may explain the difference between our study and the study of Andrews and Page (1975).

TABLE 2. *Percent of total daily food consumed at each feeding in NWAC103 and Norris channel catfish fed one, two, and three times daily for 6 wk.*

Strain[1]	Feeding frequency	0800 h	1200 h	1600 h	SEM[2]
NWAC103	1×	100.0[3]	Not fed[4]	Not fed	
	2×	61.2[y]	38.8[z]	Not fed	0.008
	3×	42.8[y]	30.7[z]	26.5[z]	0.005
	1×	100.0	Not fed	Not fed	
	2×	61.8[y]	38.2[z]	Not fed	0.008
Norris	3×	43.5[y]	28.5[z]	28.0[z]	0.005

Within rows, values with different letters are different ($P < 0.001$) within strain for feeding frequency. No significant interaction was detected.

[1] NWAC103 and Norris catfish were fed once, twice, and three times a day (0800, 1200, and 1600 h).

[2] SEM is the pooled standard error of the mean.

[3] Percent of the total food that was consumed at each feeding.

[4] Not fed at this time.

Perhaps the fish in the present study would have consumed more feed and gained more weight if they would have been fed at 0800 and 1630 h.

We observed that the greatest amount of feed consumed in all treatments was at the 0800 h feeding and that the amount consumed decreased at the subsequent feeding (1200 h). However, fish in both strains consumed approximately the same amount of food at the 1600 h feeding compared to the 1200 h feeding. Similarly, Andrews and Page (1975) found that catfish fed in the morning consumed the most feed and the amount of feed decreased at each subsequent 3-h interval.

More recent laboratory studies demonstrate that feeding a fixed ration divided into two or three feedings daily does not affect growth or feed consumption of catfish compared to fish fed only once daily (Noeske-Hallin et al. 1985; Jarboe and Grant 1996). The discrepancy between results from these studies may have resulted from differences in environmental conditions or strains of fish. Catfish were maintained in closed recirculating raceways in the study of Jarboe and Grant (1996), while no information was provided on whether similar strains of catfish were used in the other studies.

It has been demonstrated that the amount of food a fish consumes is dependent on stomach fullness, and intervals between feedings are a function of the rate of emptying (Grove and Crawford 1980; Grove et al. 1985). The results of the current study and the study of Andrews and Page (1975) suggest that feeding frequency in catfish may also be related to stomach size. It has been suggested for winter flounder, *Pseudopleuronectes americanus*, that the amount of food consumed at a second feeding is equivalent to the amount of food already digested (Huebner and Langton 1982). Perhaps gut fill is one of the factors that limits how much a fish will eat at each subsequent feeding. This would explain why the fish consumed more food during the morning feeding (following an overnight fast) and less feed after the morning feeding.

Total feed intake was higher in fish fed three times daily compared to fish fed once and twice daily for both strains of fish. It is interesting to note that NWAC103 catfish fed once a day consumed approximately 47% more feed than Norris catfish fed only once a day. When NWAC103 catfish were fed twice and three times a day, they consumed 40 and 41%, respectively, more feed than Norris catfish fed twice and three times a day. Other studies have also shown that NWAC103 catfish consume considerably more feed than Norris catfish (Silverstein et al. 1999; Wolters et al. 2000; Li et al. 2001; Jackson et al. 2003; Bosworth et al. 2004; Peterson et al. 2004). In a study comparing the growth rates of NWAC103 and Norris catfish (mean initial weight of ~34 g), Peterson et al. (2004) demonstrated that NWAC103 catfish consumed 36% more feed and gained 44% more weight than Norris catfish during a 9-wk study. This study is the first to show that as feeding frequency is increased to twice and three times daily, the percentage increase in food consumed between

NWAC103 and Norris catfish remains about the same.

Feed intake was affected by fish strain, feeding frequency, and their interaction in the present study. For both the NWAC103 and the Norris fish, feed intake was greater for fish fed three times daily compared to fish fed once or twice daily. However, the NWAC103 fish consumed significantly more feed at all three feeding levels compared to the Norris strain. The interaction observed between fish strain and frequency level may be a cumulative effect of the NWAC103 fish consuming more feed. The NWAC103 fish consumed more feed when fed once a day compared to the Norris fish, and the differences in feed consumption between strains increased as the number of feedings increased, resulting in the strain × frequency interaction.

Andrews and Page (1975) showed that FCR for channel catfish was not affected by frequency of feeding. For the Norris strain, we also found that FCR was not affected by feeding frequency. However, for the NWAC103 strain, we observed that FCR was increased in fish fed three times daily. The biological significance of the increase in FCR in NWAC103 catfish fed three times a day is not clear. An FCR of 1.01 in catfish fed once a day and an FCR of 1.06 in catfish fed three times a day may not be biologically significant.

The GI tract index decreased in NWAC103 catfish fed twice and three times daily, respectively, compared to fish fed only once a day, and a similar trend was observed among the Norris treatments. Diet-induced changes in GI morphology are well documented in fish (Kapoor et al. 1975; Buddington et al. 1997), with nutrient-dilute diets tending to induce enlargement of the intestine and hypertrophy of the stomach. The ability to enlarge the GI tract after feeding foods of low nutrient density may represent a suite of adaptations that enable fish to maintain rates of nutrient and energy intake (Rozin and Mayer 1961; Grove et al. 1978). Similarly, reducing feeding frequency results in an increase in meal size, which is presumably brought about by an increase in gastric capacity or hypertrophy of gut tissues (Jobling 1982). Jobling (1982) demonstrated that plaice *Pleuronectes platessa* fed every other day developed larger stomachs than those fed more frequently. Perhaps the change in size of the GI tract in catfish fed multiple times a day is a response to regulate digestive functions such as enzyme profile and secretion or nutrient transport and absorption (Buddington et al. 1997). The observed change in the size of the GI tract as a result of feeding frequency in catfish warrants further investigation.

In the current study, there was growth advantage from feeding three times a day at 0800, 1200, and 1600 h compared to feeding at only 0800 or 0800 and 1200 h in a laboratory environment. However, it was labor intensive to feed the fish three times a day. Furthermore, feeding more than twice a day in a pond environment would also be labor intensive and not practical under most farm management settings. Recently, Li et al. (2005) showed that there were few, if any, advantages to feeding catfish (food fish) in grow-out ponds more than once daily to apparent satiation. The use of an automatic feeder may provide an alternative method of delivering feed to aquarium-reared catfish when increased growth is desired.

Using rainbow trout as a model, Hardy (1998) suggested that a relationship exists among feeding level, growth rate, and feed efficiency, with the maximum feed efficiency occurring at a feeding rate above maintenance feeding level but below the maximum feeding level. Similarly in catfish, Li et al. (2004) evaluated the relationship among feed intake, growth rate, and FCR. The results of their study showed that weight gain increased as feed intake increased (Li et al. 2004). In addition, Li et al. (2004) demonstrated that FCR improved as feeding rate increased and peaked at feeding rates of approximately 90 and 100% satiation. This study also shows that weight gain increases as food intake increases and at some point a plateau is reached for FCR.

In conclusion, juvenile aquarium-reared Norris and NWAC103 catfish fed three times a day at 0800, 1200, and 1600 h consume more feed and gain more weight than catfish fed once a day at 0800 h or twice a day at 0800 and 1200 h. Feeding catfish three times a day is impractical under most management practices

except with the use of an automatic feeder. Feeding Norris and NWAC103 catfish once daily to apparent satiation is acceptable to achieve good growth and feed efficiency.

Acknowledgments

The authors wish to thank the assistance of Ms. Monica Loden and Mr. Jimmy Warren of the USDA/ARS Catfish Genetics Research Unit for their efforts in feeding the fish. The authors also wish to thank Dr. Chris Murdock for his efforts in sample collection.

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