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Domestication and strain evaluation of striped bass (*Morone saxatilis*)

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Abstract

Variation in growth rate within and among geographic strains of striped bass, *Morone saxatilis*, has recently been evaluated by researchers at the University of Maryland. Recent research on strain evaluation of geographical populations of striped bass suggests that Maryland strains may exhibit superior growth rates among those populations examined. In this study, variation in growth rate was evaluated within and among a number of striped bass families originated from Chesapeake Bay, MD, USA, as well as five additional North American, Atlantic coast strains from Nova Scotia, Canada to Florida, USA. All striped bass were maintained in flow-through tank systems receiving ambient Chesapeake Bay water. Significant differences in growth performance among putative genetic stocks within the 1983 year-class F_1 demonstrated among-stock variation that could be exploited in a selective breeding program. Similarly, comparisons of growth performance within and among domesticated F_2 families of the 1992 year-class revealed significant differences among the families, as well as the geographic stocks, suggesting the utility of heritability estimation experiments and a selection program designed to utilize both individual and family selection. Comparisons of growth at age 2 in both length and weight between families of the Maryland strain and families from five other geographical regions revealed significant differences between strains.

Keywords: Bass; Striped bass; Domestication; Strain evaluation

1. Introduction

The striped bass (*Morone saxatilis*) and its hybrids of the family Moronidae (Johnson, 1984) make up one of the fastest growing segments of the U.S. finfish aquaculture industry (Striped Bass Growers Association, 1998). It is also a species that is growing in popularity in Israel, Taiwan and other Pacific-rim nations due to its high

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quality. The industry's growth, however, is limited by the lack of domesticated broodstock and the continued reliance upon wild brood fish for its seedstock. The development of striped bass broodstock, as with any species, involves significant investments of time and capital, but is essential in order to complete the life cycle of this species in captivity and genetically improve this fish for aquaculture. However, in order to domesticate and ultimately selectively breed striped bass in captivity, many genetic, environmental, reproductive and nutritional requirements for the adult fish must be better understood.

A number of recent scientific advancements have been published which will help remove previously perceived obstacles to the development and maintenance of domestic stocks of *Morone* by the industry. The University of Maryland's Crane Aquaculture Facility (CAF) has established a significant population of domestic striped bass broodfish (Woods, 1998; Woods and Sullivan, 1993). The CAF broodstock is the only reported population where multiple generations of domesticated striped bass have been produced and maintained and where selection efforts have been initiated (Harrell, 1997). Nutritional studies of domestic striped bass have been recently published (Harrell and Woods, 1995; Small et al., 2000). Control and understanding of the reproduction of domestic striped bass populations is now better understood than ever before (Hodson and Sullivan, 1993; King et al., 1994; Mylonas et al., 1998; Sullivan et al., 1997; Woods and Sullivan, 1993).

As Sorgeloos (1999) recently suggested, the real challenge for the next decade is to get the aquaculture industries to introduce effective genetic improvement programs using selective breeding, and the first priority is to develop domesticated brood stock. With progress being made to elucidate domestic striped bass biology, coupled with recent evidence that demonstrates genetic differences among geographically separated populations of striped bass (Laughlin and Turner, 1996; Leclerc et al., 1996; Wirgin et al., 1989, 1997; Roy et al., 2000), and demonstrated differences in growth rate among strains of striped bass under controlled environmental conditions (Jacobs et al., 1999), this effort was undertaken to quantify the variation in growth within and among the various families and geographic strains of F_1 and F_2 generation striped bass currently in existence at the University of Maryland's Crane Aquaculture Facility. Examination of growth rate as a first priority was chosen as reasonable heritabilities can be generated (Tave, 1993), as has been demonstrated for other important aquacultured fish species such as the rainbow trout, *Oncorhynchus mykiss* (Kincaid et al., 1977), carp *Cyprinus carpio* (Moav and Wohlfarth, 1976), channel catfish *Ictalurus punctatus* (Bondari, 1983) and Atlantic salmon (Gjedrem, 1979). In addition, improved growth rate was identified as one of the highest research priorities in a recent survey of striped bass producers (Harrell and Webster, 1997).

2. Materials and methods

Captive (F_1) and domestic (F_2–F_4) striped bass have been successfully produced from 1983 through the present at the CAF. The striped bass domestication program was initiated in 1983 by spawning wild fish collected from three areas of the Maryland portion of Chesapeake Bay: the Chesapeake and Delaware Canal area (C and D), the Choptank River, and the Nanticoke River. These spawns gave rise to an F_1 progeny of mixed family groups for each of the three stocks. Striped bass broodstock were reared in 6-m diameter, flow-through tanks systems receiving ambient light and oligohaline water from Chesapeake Bay (Maryland, USA), located immediately adjacent to the University of Maryland aquaculture laboratory, the Crane Aquaculture Facility (CAF). All broodstock were fed a commercial salmon formulation (Zeigler Brothers). Progeny groups for a given year-class produced from Maryland strain CAF striped bass broodstock that were induced to spawn were raised separately until approximately 90 days of age. The last three digits of the alphanumeric passive integrated transponder (PIT) tag that identifies the Maryland strain female spawned to produce a progeny group was used to name the family. Larvae were initially fed enriched brine shrimp nauplii until metamorphosis was complete, 1 month after hatch. Three weeks after hatch, the artemia nauplii were supplemented with a commercially available salmon crumble (Zeigler Brothers). After 3 months, they were large enough to receive a PIT tag subcutaneously and were placed into a common 6-m diameter tank for growout to maturity. Neither progeny group numbers nor biomass were equalized before communal rearing. Sample lengths and weights of each group were recorded annually. Geographic stocks are referred to by their place of origin and if their origin was outside of the Maryland Chesapeake Bay region, they were transported to the CAF between 60 and 90 days of age, prior to receiving the PIT tag and being placed into the communal rearing tank. Additional detailed information regarding the reproduction, propagation and husbandry methods for these domesticated striped bass is provided in previously published articles (Woods et al., 1990; Woods and Sullivan, 1993; Woods et al., 1992; Sullivan et al., 1997). Effects of stock, family and gender were evaluated on the original CAF founder stock, F_1 generation striped bass of the 1983 year-class, using a SAS mixed analysis of variance (ANOVA) model (SAS/STAT, 1996). Best linear unbiased predictions (BLUP) were used to compare relative merit among and between domesticated (F_2) Maryland striped bass families of the 1992 year-class for weight-at-age. Family, family $\times$ gender and residual effects were defined as random and gender effect was defined as fixed. BLUP

Table 1
Mean weight-at-age for stocks of 1983 year-class, Maryland strain F_1 striped bass derived from founders collected from three areas of Chesapeake Bay

Age and stock	*n*	Weight (kg)
Age 2		
Choptank River	29	1.03 (0.17)[a]
C and D Canal	13	0.87 (0.14)[b]
Nanticoke River	6	0.81 (0.22)[b]
Age 3		
Choptank River	22	1.71 (0.17)[a]
C and D Canal	12	1.29 (0.19)[b]
Nanticoke River	6	1.16 (0.22)[c]

Standard errors are shown in parenthesis. *n* is the number of individual growth records used in the analysis. Means within columns with a superscript letter in common are not significantly different ($P < 0.05$).

predictions are estimates of performance of the individual family progeny groups expressed as deviations from the mean of all families of each gender as described by Littell et al. (1996). Growth at age 2 of individuals from these same 1992 year-class, F_2 Maryland strain striped bass families was compared to that of individuals from five additional families of different geographic origin (Nova Scotia, Canada; New York, USA; North Carolina, USA, South Carolina, USA; and Florida, USA) using a SAS random ANOVA procedure (SAS/STAT, 1996). Families had to have at least 50 individuals per family to have survived to market size (age 2) to be considered eligible for statistical comparison. Differences in means were determined using a SAS Least Square Means (LSM) procedure (SAS/STAT, 1996).

3. Results

At ages 2 and 3, the Choptank River striped bass were significantly heavier (ANOVA, $P < 0.01$) than both the C and D and Nanticoke River striped bass (Table 1).

Table 2
Best linear unbiased prediction (BLUP) rankings of relative merit of weight-at-age among 1992 year-class Maryland strain F_2 families of striped bass. Standard errors shown in parenthesis. *n* is the number of individual growth records used in the analysis

Family	Females		Males	
	n	Weight (kg)	*n*	Weight (kg)
Age 2				
F12	35	+0.16 (0.035)	33	+0.16 (0.036)
26F	31	+0.02 (0.036)	21	+0.04 (0.036)
322	9	+0.01 (0.039)	10	+0.06 (0.038)
E01	59	+0.01 (0.035)	31	−0.01 (0.036)
E76	31	−0.05 (0.036)	13	−0.08 (0.037)
15A	20	−0.06 (0.036)	19	−0.04 (0.037)
95A	17	−0.09 (0.037)	13	−0.13 (0.038)
Age 3				
F12	57	+0.16 (0.035)	45	+0.14 (0.035)
26F	30	+0.01 (0.036)	21	+0.04 (0.037)
322	9	+0.02 (0.039)	9	+0.06 (0.039)
E01	59	+0.03 (0.035)	31	0.00 (0.036)
E76	30	−0.05 (0.036)	13	−0.09 (0.038)
15A	20	−0.06 (0.037)	19	−0.03 (0.037)
95A	16	−0.11 (0.037)	13	−0.13 (0.036)
Age 4				
F12	64	+0.52 (0.13)	64	+0.23 (0.13)
26F	31	+0.30 (0.14)	21	+0.27 (0.14)
322	9	+0.03 (0.15)	10	+0.25 (0.15)
E01	59	−0.06 (0.13)	31	−0.14 (0.13)
E76	31	−0.20 (0.13)	13	−0.33 (0.15)
15A	20	−0.23 (0.14)	19	+0.05 (0.14)
95A	17	−0.37 (0.14)	13	−0.35 (0.15)

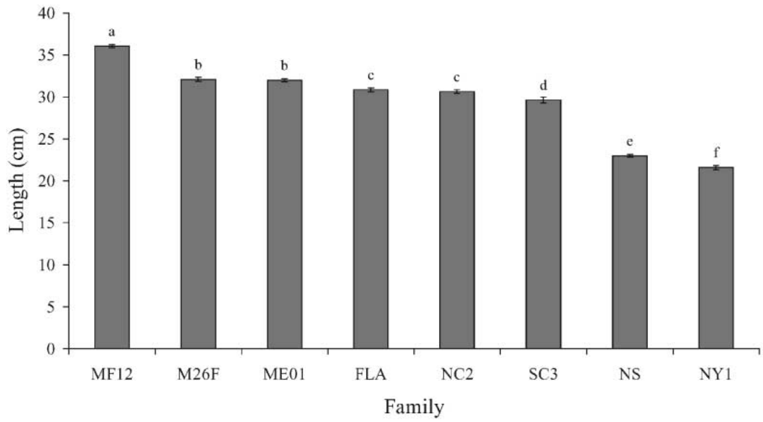

Fig. 1. Total length of 2-year-old individuals from 1992 year-class, full-sibling families of striped bass. Values are means ± S.D. from a minimum of 50 striped bass. Different superscript letters above each bar denote statistically significant differences between means at $P < 0.05$. The key of geographic strains: M = Maryland, FL = Florida, NC = North Carolina, SC = South Carolina, NS = Nova Scotia, Canada and NY = New York. All Maryland families are F_2 generation families and all non-Maryland strains are F_1 generation.

At age 3, the Choptank River striped bass were heavier than the C and D fish (ANOVA, $P < 0.001$), which in turn were also significantly (ANOVA, $P < 0.001$) heavier than the Nanticoke River fish (Table 1). Growth data for this initial year-class showed significant differences in growth performance among genetic stocks known to be distinct on the

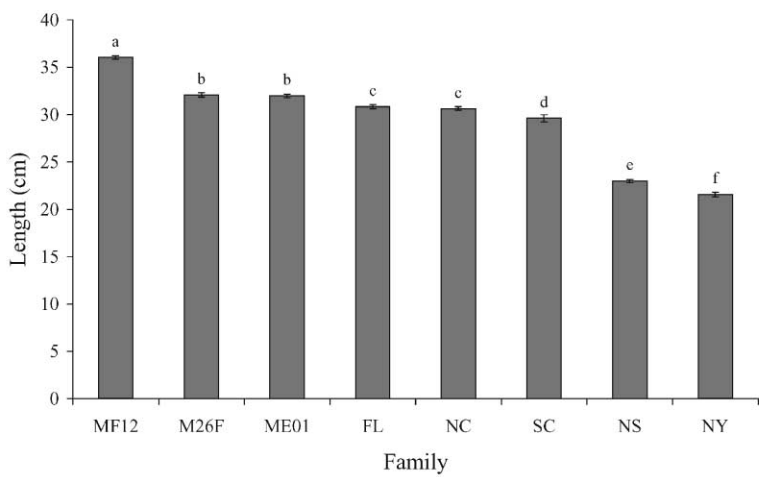

Fig. 2. Weight of 2-year-old individuals from 1992 year-class, full-sibling families of striped bass. Values are means ± S.D. from a minimum of 50 striped bass. Different superscript letters above each bar denote statistically significant differences between means at $P < 0.05$. The key of geographic strains: M = Maryland, FL = Florida, NC = North Carolina, SC = South Carolina, NS = Nova Scotia, Canada and NY = New York. All Maryland families are F_2 generation families and all non-Maryland strains are F_1 generation.

basis of isozyme characterization and originating from three distinct areas of Chesapeake Bay (Morgan et al., 1973). The 1992 year-class analysis includes the seven F_2 families produced with weight data at ages 2, 3 and 4 years (Table 2). Analysis of weight indicated significant effects of family at all three ages. The effect of gender was significant for weight at ages 2 and 4. In addition, there was a significant gender × family interaction for weight at age 4. As striped bass are usually marketed after 2 growing seasons, analysis using BLUP focused on the weight at age 2 to rank the 1992 year-class families. Weight at age 2 within the fastest growing Maryland family, F12, ranged from 374 to 774 g, with a mean of 493 ($\pm$36) g. When striped bass growth in length, after 2 years at the CAF, was compared between individuals from six geographic strains, significant differences were observed. Maryland strains were found to be significantly (ANOVA, $P < 0.05$) longer than all other strains (Fig. 1). Similarly, when growth in weight at market size was analyzed, two of the three Maryland strains were found to be significantly (ANOVA, $P < 0.05$) heavier than all other geographic strains. The remaining Maryland strain (EO1) was significantly heavier than all but the Florida strain (Fig. 2).

4. Discussion and conclusions

One of the main objectives of this study was to determine if significant variation existed among geographic strains as well as within families of domesticated Maryland strain striped bass that could be exploited for genetic improvement of growth performance. Strain differences for growth rate have been described for several species of fish and it has been suggested that where discrete natural populations exist for any species, they could serve as resources for growth rate assessment and use in aquaculture (Purdom, 1993). Moav et al. (1964, 1975) found clear differences in growth between strains of Israeli carp and those from Europe and Asia. Similarly, analysis of strains of rainbow trout from different regions of Great Britain demonstrated very large differences in growth rate and these differences were genetic in that successive generations exhibited a continuity of the trait (Purdom, 1993). Evidence of exploitable variation in growth rate of striped bass, based on ANOVA and BLUP tests of significance in these studies suggest that useful variation does exist between geographic stocks and within specific families. Similar results for striped bass examined at another University of Maryland laboratory were recently published by Jacobs et al. (1999), who reported significant differences in both survival and growth among stocks and families of striped bass cultured under controlled conditions of recirculating aquaculture systems for approximately 6 months. They also reported that among geographic strains, Maryland and Florida strains grew significantly better than the New York and South Carolina strains evaluated, which is consistent with our findings at market size, or 2 years of age. Best linear unbiased predictions of family merit demonstrated that there was significant variation among and within striped bass families produced at the CAF. Significant differences in growth performance among stocks grown in ambient flow-through conditions, supports the findings of Jacobs et al. (1999) who tested many of the same strains under controlled recirculating aquaculture system conditions. These studies suggest the utility of further genetic evaluations, i.e. progeny-based performance evaluations under controlled environmental conditions, with greater numbers of families representing each geographical strain, followed by selective breeding of high performance stocks. Differences in performance both among and within families suggests the utility of heritability estimation, which if attractively high, could be followed by individual and/or family selection. Finally, although growth is but one trait of immediate importance to the industry, superior performance appears to reside within the Maryland strain. In addition to Maryland strain progeny, cross-breeding experiments between Maryland and Florida strains also appears to have potential especially if survivorship and tolerance to stressful conditions associated with aquaculture could be demonstrated.

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