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Effect of initial size on subsequent growth and carcass characteristics of divergently selected channel catfish *

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Summary. Two experiments were conducted simultaneously to determine (1) if fast-growing fingerlings of channel catfish, *Ictalurus punctatus,* could be identified by simple visual selection of body size and (2) if initial size advantages influenced subsequent growth and carcass traits of divergently selected channel catfish. Exp. 1 included large (L), medium (M), and small (S) fingerling sizes from each of the control (C), selected upward (+) and selected downward (–) lines for body weight. Exp. 2 included all fingerlings of the same size (25 ± 5 g) from the 3 lines. Catfish from the L size-class, within each full-sib family in each line, were consistently heavier and longer than M and S size-classes throughout the 53-week experimental period. Fingerlings from the M size-class were also superior in growth to those from the S size-class. Catfish from the + line exceeded those from the C and – lines in body weight and total length at the conclusion of Exp. 1 but not in Exp. 2. This was attributed to the selection of equal size fingerlings in Exp. 2 which may have excluded fingerlings with the best growth potential from the + body weight line. Results of the two experiments combined indicated that one generation of divergent selection has created genetic differences among lines of channel catfish.

Key words: Channel catfish – Divergent selection – Raceway performance – Size variation – Fingerling growth

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Introduction

Fingerling size in channel catfish is strongly influenced by environmental factors, and variation in size among individuals of the same age may be genetically controlled (Bondari 1983 b).

Improving growth rate through genetic manipulation will require minimization of the environmental variability. Moav and Wohlfarth (1974) proposed multiple rearing and communal stocking techniques for carp breeding. These techniques have limited applications and require a knowledge of initial size influences and compensatory growth.

One of the problems concerning growth comparisons of fish from the same population but from different genetic lines is their unequal initial size (weight and length). Fish which are heavier at the start of a test may be at an advantage in subsequent growth rates over the lighter fish. Mean growth rates can be adjusted statistically for differences in initial size (Snedecor and Cochran 1967) but the procedure will require individual measurements and identification of the experimental fish. Obviously, this is easier done in farm animals than aquatic species. Heat branding of fish (Joyce and El-Ibiary 1977) for individual identification will require several extra marks on each fish and because of the stress involved and limited branding space, it may not always be feasible in fingerling studies. Heat branding can, however, be conveniently used to identify the individual fish by genetic line or the size-class.

A short-term performance test to periodically examine the effectiveness of selection and the level of genetic diversity within fish families (family refers to a group of full-sib progeny hatched from a single egg mass) also depends on the influence of initial size on subsequent fish growth. This becomes very important since catfish breeding is a slow process with a generation interval of 3 years, almost as long as that in cattle (Smitherman et al. 1978). Two approaches were followed in this study to deal with initial size variation: (1) the progeny of a single spawn were sub-divided into three different size-classes to determine the effect of initial size on subsequent growth and (2) fingerlings of approximately equal size from different genetic lines were selected to remove variation in initial size. The study also examined the importance of within family selection which should be applicable to other fish species.

Experiment 1 was conducted to determine if initially selected smaller catfish remain smaller than their larger siblings or they possess the ability to compensate in growth at a later age. Effectiveness of divergent selection in causing size variation in channel catfish was to be tested in Experiment 2. Specifically, Experiment 2 was designed to examine if initially selected catfish of equal size from C, +, and – lines diverge in body size at a later age or the initial weight is the major factor involved in determining subsequent gains. Body size variation observed after removal of initial size effect in Experiment 2 will be regarded as a direct response to genetic alterations of divergently selected lines. Size-class variation observed within full-sib families in Experiment 1, however, are due both to genetic and environmental causes. About one-half of the within family differences, observed as size-class variation, could be attributed to genetic causes.

Materials and methods

Experiment 1

Fingerlings used in this experiment were the first generation progeny of single-pair mated, channel catfish, *Ictalurus punctatus*. The 5-year old parental brood had undergone one generation of upward (+) or downward (–) selection for 40-week body weight. An unselected control line (C) was also propagated simultaneously with the other two lines to determine selection response in the two directions. Stock history and facilities used have been described by Bondari (1980, 1983a). Each line was represented by two full-sib families randomly selected from among 9, 6, and 12 families in C, +, and – lines, respectively. Each full-sib family was randomly reduced to 100 sibling fish at 16 weeks of age. Each set of siblings was raised in a 122-cm diameter tank.

At 40 weeks of age, each full-sib family was visually divided into three size-classes by selecting 20 of the largest (L), 20 of the smallest (S) and a random sample of 20 from the remaining fish in each tank (medium = M). Each fish was weighed to the nearest g, measured for total length to the nearest mm, heat-branded, and then placed in a recirculating raceway system described by Chesness et al. (1976). Sixty unsexed full-sib fingerlings from each of the three lines (C, +, and –) were placed in the first segment of the raceway (replicate 1) and the remaining half (180 fingerlings) in the second segment of the same raceway system (replicate 2). Designs of the two experiments are given in Table 1.

Water was pumped from a 2-ha storage reservoir to the first segment of an earthen channel divided into four segments and flowed by gravity back to the reservoir after passing through the three other segments. The water inflow was aerated by a riser pipe as it entered the first segment and was reaerated by a vertical drop of 46 cm between the two segments. Each segment was 30.5 × 8.5 m with a concrete head-wall in between and contained approximately 125 m^3 of water. All fish were sexed, weighed, measured for total length, and rebranded at 10, 23 and 53 weeks after the experiment began.

Experiment 2

Base population, number of families/line and replication, rearing technique, branding, etc. in this experiment were identical to those of Exp. 1. The sibling progeny were, however, not of three different size-classes in this experiment. Twenty full-sib fingerlings of approximately equal size were assorted randomly from each of the six families (two families per +, –, or C line) for this experiment (Table 1). Families were randomly selected from among 7, 4, and 10 full-sib families in C, +, and – lines, respectively. A range of 25 ± 5 g for body weight was established from results of preliminary analysis of the data obtained from the unselected base population (mean ± 1 SD) and served as the basis for the selection of all 120 fingerlings for this experiment. After branding, the 40-week old unsexed catfish for this experiment were also placed in the two raceway segments used for Exp. 1. As shown in Table 1, sibling fish from each of the three lines were represented in each raceway segment (60 fish/replicate).

The fish used in these two experiments came from the base population described by El-Ibiary et al. (1977) and Bondari (1983a). They were reared in indoor tanks supplied with aerated well water (22 ± 0.5 °C) during the 40-week post-hatching period. Well water was heated to 27 ± 1 °C for the first 16 weeks to promote growth. The fish were fed a commercial feed 3–5 times a day while in indoor tanks and 1–2 times a day in outdoor raceways. All fish were processed at the end of the experiment (93 weeks of age) and head weight and cleaned weight (head-less carcass weight) were determined to the nearest g. Head percentage and dressing percentage were

Table 1. Experimental design-number of fish in each size-class, family, line, experiment (Exp.), and raceway segment

Experiment	Line[b]	Family no.	Fish size[a]			
			L	M	S	Same
	1st segment of the raceway (replication 1)					
1	C	81	20	20	20	
	+	9	20	20	20	
	–	6	20	20	20	
2	C	88				20
	+	18-1				20
	–	54				20
	2nd segment of the raceway (replication 2)					
1	C	83	20	20	20	
	+	18-2	20	20	20	
	–	31	20	20	20	
2	C	89				20
	+	42				20
	–	33				20

[a] L, M, and S represent large, medium, and small size fish, respectively (Exp. 1). All the fish from 3 lines in Exp. 2 were initially the same size

[b] C, +, and – represent first generation fish from control, selected upward, and selected downward lines, respectively. Selection of the parental fish was for 40-week body weight

Table 2. Least-squares means by size-class (L, M, and S) and line (as described in Table 1) for body weight (g) and total length (mm) of channel catfish in Exp. 1

Line[f]	Body weight					Total length				
	L	M	S	$\bar{Y}$	SE	L	M	S	$\bar{Y}$	SE
	Initial (age = 40 weeks)									
+	49^{a}	26^{b}	16^{c}	30^{d}	1.1	187^{a}	155^{b}	133^{c}	157^{d}	1.9
C	43^{a}	27^{b}	15^{c}	28^{d}	1.1	176^{a}	154^{b}	129^{c}	153^{d}	1.9
−	39^{a}	20^{b}	9^{c}	23^{e}	1.1	178^{a}	145^{b}	112^{c}	145^{e}	1.9
$\bar{X}$	44^{a}	24^{b}	13^{c}			180^{a}	152^{b}	125^{c}		
SE	1.0	1.0	1.0			1.7	1.7	1.7		
	After 10 weeks (age = 50 weeks)									
+	120^{a}	93^{b}	69^{c}	93^{d}	3.6	251^{a}	230^{b}	210^{c}	230^{d}	2.7
C	101^{a}	81^{b}	52^{c}	77^{e}	3.8	236^{a}	220^{b}	192^{c}	215^{e}	2.8
−	112^{a}	74^{b}	50^{c}	80^{e}	2.6	245^{a}	217^{b}	192^{c}	219^{e}	1.9
$\bar{X}$	112^{a}	83	56^{c}			245^{a}	222^{b}	198^{c}		
SE	3.2	3.1	3.4			2.4	2.3	2.5		
	After 23 weeks (age = 63 weeks)									
+	497^{a}	419^{b}	313^{c}	410^{d}	14.6	378^{a}	354^{b}	324^{c}	352^{d}	4.2
C	444^{a}	401^{b}	254^{c}	381^{d,e}	16.4	360^{a}	352^{a}	308^{b}	344^{d}	4.7
−	458^{a}	352^{b}	296^{c}	375^{e}	12.4	372^{a}	338^{b}	318^{c}	344^{d}	3.6
$\bar{X}$	476^{a}	399^{b}	291^{c}			372^{a}	350^{b}	318^{c}		
SE	13.8	13.9	16.0			3.9	4.0	4.6		
	After 53 weeks (age = 93 weeks)									
+	729^{a}	627^{b}	485^{c}	603^{d}	21.2	418^{a}	398^{b}	370^{c}	394^{d}	4.5
C	600^{a}	602^{a}	451^{b}	547^{e}	17.9	387^{a}	389^{a}	363^{b}	379^{e}	5.2
−	704^{a}	496^{b}	398^{c}	548^{e}	24.9	421^{a}	387^{b}	353^{c}	390^{d,e}	3.8
$\bar{X}$	687^{a}	573^{b}	440^{c}			411^{a}	391^{b}	362^{c}		
SE	20.8	20.9	22.6			4.4	4.4	4.8		

[a, b, c] Size-class means within a row with different letters differ ($P<0.05$)
[d, e] Line means within a column with different letters differ ($P<0.05$)
[f] $\bar{y}$ and $\bar{x}$ represent pooled line and pooled size-class means, respectively. SE indicates standard error of $\bar{x}$ or $\bar{y}$ means

also determined as head weight × 100/body weight and carcass weight × 100/body weight, respectively.

Statistical analysis

The General Linear Model (GLM) of the Statistical Analysis System computer package (SAS 1982) was used to analyze the data. The statistical model used for Exp. 1 included effects of replicate, line, size-class and sex. All possible two-way interactions of line, size-class, and sex were also included in the model. In addition, data from each line were analyzed separately by including replicate, size-class, sex and size-class × sex interaction in the model. The model used for Exp. 2 included replicate, line, sex, and line × sex interaction. Analysis of initial data (40 weeks old) did not include sex or sex related interactions. A complete fixed effects model was assumed so error mean squares were used to test the significance of main effects and remaining interactions in both experiments. Mean comparisons for significant line or size-class effects were also performed by the SAS computer package. Further analysis included effects of age of fish, replication within age, size-class, line, and all possible interactions between age, size-class and line. Replication within age mean square was used to test the age effect and error mean square for the remaining effects. Chi-square test was employed to determine the size-class, line, or sex effect on fish mortality.

Results and discussion

Experiment 1

Fish from the L size-class were significantly ($P<0.05$) heavier and longer than those from M and S size-classes at the beginning and throughout the 53-week experimental period (Table 2). Fish from the M size-class were initially heavier and longer than those from the S size-class and maintained their superiority during the experiment. These results were consistent for each line and also when averaged over the three lines (Table 2). Thus, regardless of parental selection, those

Table 3. Effect of size-class and line on growth, survial, and carcass traits of channel catfish in Exp. 1 (SE indicates standard error of the least-squares means)

Age (weeks)	Size-class						Line (as described in Table 1)					
	Large		Medium		Small		+		C		−	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
	Average weekly weight gain (g)											
40–50	6.8^{a}	0.5	5.8^{a}	0.5	4.2^{b}	0.5	6.5^{a}	0.5	4.9^{b}	0.5	5.5^{ab}	0.5
50–63	28.1^{a}	1.5	24.5^{a}	1.5	17.7^{b}	1.5	25.3^{a}	1.5	22.6^{a}	1.5	22.5^{a}	1.5
63–93	7.0^{a}	0.9	6.0^{ab}	0.9	5.2^{b}	0.9	7.3^{a}	1.0	5.5^{a}	1.0	5.4^{a}	1.0
40–93	12.1^{a}	0.8	10.5^{a}	0.8	8.1^{b}	0.8	11.6^{a}	0.8	9.6^{b}	0.8	9.6^{b}	0.8
	Average weekly length increase (mm)											
40–50	6.4^{a}	0.4	7.1^{a}	0.4	7.2^{a}	0.4	7.3^{a}	0.4	6.2^{a}	0.4	7.2^{a}	0.4
50–63	9.9^{a}	0.3	9.8^{a}	0.3	9.1^{b}	0.3	9.5^{a}	0.3	9.6^{a}	0.3	9.7^{a}	0.3
63–93	1.3^{a}	0.2	1.4^{a}	0.2	1.5^{a}	0.2	1.5^{a}	0.2	1.2^{a}	0.2	1.4^{a}	0.2
40–93	4.3^{a}	0.2	4.5^{a}	0.2	4.4^{a}	0.2	4.6^{a}	0.2	4.2^{a}	0.2	4.6^{a}	0.2
	Survival (%)											
40–50	68		70		55		65		53		75	
50–63	88		89		94		92		86		91	
63–93	97		99		100		97		98		100	
	No. of fish											
93	69		74		62		70		53		82	
	Head weight (g)											
93	159^{a}	5.0	134^{b}	5.1	105^{c}	5.5	142^{a}	5.1	128^{b}	6.0	4.3	
	Head weight as % of body weight											
93	23.2^{a}	0.3	23.4^{a}	0.3	24.0^{a}	0.4	23.2^{a}	0.3	23.6^{a}	0.3	23.5^{a}	0.2
	Carcass weight (g)											
93	410^{a}	13.8	342^{b}	13.8	266^{c}	14.9	362^{a}	13.0	325^{b}	14.4	331^{b}	11.8
	Dressing (%)											
93	59.6^{a}	0.6	59.6^{a}	0.6	60.0^{a}	0.7	59.9^{a}	0.6	59.3^{a}	0.7	60.0^{a}	0.5

$^{a, b, c}$ Size-class or line means within a row with different letters differ ($P<0.05$)

catfish that achieved a greater size at an early growth stage were capable of maintaining that advantage during their subsequent growth periods. In economic terms, catfish growers can anticipate that larger fingerlings continue to grow more rapidly and reach harvestable size in a shorter time period than do smaller size fingerlings. These results are in agreement with previous results reported by Bondari (1983b) and as was recommended then, smaller fingerlings within each full-sib family should be eliminated by within-family selection prior to stocking.

Catfish from the + line were 30% heavier and 9% longer than those from the − line at the onset of the experiment, but were not significantly heavier or longer than unselected control fish (Table 2). At the conclusion of the test, however, the + catfish were significantly heavier than both control and − lines which were not significantly different from one another. The + catfish were also longer ($P<0.05$) than control but comparable in total length to the − line catfish.

Average weekly weight gain was significantly influenced by the size-class effect at all ages but the weekly increase in total length was not size-class related (Table 3). Except for the age 50–63 interval, weekly weight gain of catfish from the S size-class was significantly ($P<0.05$) less than that of the M size-class. Catfish from L and M size-classes, however, did not differ significantly in weekly weight gain or length increase. These results indicated that initially selected smaller catfish were not able to compensate in growth at a later age and that larger fish remained larger because of their initial size advantages. Regression of final body weight (93 weeks old) on initial body weight (40 weeks old) indicated that an increase of one g in initial weight was associated with an increase of 7.9 g in final weight. An increase of one mm in initial total length corresponded with an increase of 0.9 mm in final total length. These results confirm that as recommended by Bondari (1983b), selective breeding of channel catfish for improved growth rate should include full-sib fingerlings from L and some from M size-classes. The S size-class fingerlings should be eliminated.

Analysis of the averages of weekly gain shown in Table 3 indicate an effective upward trend for the + line catfish as compared to the unselected control line. No such trend is evident for the weekly length increase since the overall 40–93 week increases do not differ among lines. Also, no effective downward trend was observed for either weekly weight gain or length increase of the – line catfish.

Catfish from the three size-classes differed significantly ($P<0.05$) in head weight and cleaned carcass weight. Larger fish possessed larger heads and produced heavier carcasses than did smaller fish but when these traits were expressed as percentages of body weight, no significant differences were observed among the three size-classes (Table 3). These results indicate that increased body size in channel catfish is associated with head enlargement and heavier carcasses, but relative carcass composition is not altered by the size increase. Correlation coefficients between final body weight and head weight and between body weight and carcass weight were 0.95 and 0.96, respectively. Head weight and carcass weight were also correlated significantly ($r=0.92$).

Head and clean carcass of the – and C line fish were similar in weight but both lines weighed significantly ($P<0.05$) less than those of the + line fish (Table 3). No significant difference in head percent or dressing percent existed among three lines.

This experiment was not designed to evaluate differences between +, –, and C lines since only one family from a population of families was included in each replicate and since only selected and not random members of each family were included in the experiment. These results, however, indicate that one generation of divergent selection has created genetic variability among lines. In a previous study, Bondari (1983a) reported a 20% increase in 40-week body weight of the upwardly selected catfish over the randombred control. Based on Bondari (1983a) body weight decrease in the downward direction was about equal (20%) to body weight increase in the upward direction. No other studies on divergent selection of channel catfish have been reported to compare the results.

Table 4. Least-squares means and standard errors of the means (SE) for growth, survival, and carcass characteristics of channel catfish in Exp. 2

Age (weeks)	Line (as described in Table 1)					
	+		C		–	
	Mean	SE	Mean	SE	Mean	SE
	Body weight (g)					
40	25[a]	0.7	25[a]	0.7	25[a]	0.7
50	75[a]	4.4	82[a]	4.6	71[a]	4.7
63	413[a]	20.5	455[a]	22.8	305[b]	26.4
93	584[ab]	31.5	656[a]	32.2	516[b]	35.5
	Average weekly weight gain (g)					
40–50	5.4[a]	0.3	5.6[a]	0.3	4.5[a]	0.3
50–63	26.1[a]	1.9	28.4[a]	1.9	19.2[b]	1.9
63–93	6.6[a]	0.4	6.6[a]	0.4	5.9[a]	0.4
40–93	11.2[a]	0.3	11.8[a]	0.3	8.9[b]	0.3
	Total length (mm)					
40	152[a]	1.3	150[a]	1.3	153[a]	1.3
50	216[a]	3.4	224[a]	3.5	216[a]	3.6
63	352[a]	5.3	361[a]	5.9	322[b]	6.9
93	387[ab]	6.6	404[a]	6.7	382[b]	7.4
	Average weekly length increase (mm)					
40–50	6.7[a]	0.4	7.3[a]	0.4	6.2[a]	0.4
50–63	10.4[a]	0.6	10.6[a]	0.6	8.6[a]	0.6
63–93	1.4[a]	0.2	1.4[a]	0.2	1.7[a]	0.2
40–93	4.6[a]	0.1	4.8[a]	0.1	4.2[b]	0.1
	Survival (%)					
40–50	75		78		68	
50–63	100		71		93	
63–93	100		100		92	
	Head weight (g)					
93	138[ab]	7.8	150[a]	7.9	122[b]	8.8
	Head weight as % of body weight					
93	23.5[a]	0.5	22.9[a]	0.5	23.7[a]	0.5
	Carcass weight (g)					
93	342[b]	19.6	400[a]	20.0	312[b]	22.1
	Dressing (%)					
93	59.4[a]	0.7	61.0[a]	0.7	60.5	0.8

[a, b] Line means within a row with different letters differ ($P<0.05$)

Survival during 10–23 and 23–53 weeks of the experimental period was not size or line dependent (Table 3). Mortality during the first 10 weeks in the open raceway system was relatively high and was mainly caused by predators (snakes and birds). Smaller fish were apparently easier prey for these predators. Branding and handling of fish also caused mortality.

Male catfish were significantly ($P < 0.05$) heavier (612 vs. 521 g) and longer (396 vs. 379 mm) with larger head (153 vs. 112 g) and heavier carcass (370 vs. 308 g) than female catfish at the conclusion of the test. No significant sex × size-class or sex × line interaction was observed indicating that size or line differences are real and the response does not depend on sex of the fish.

Age of fish significantly ($P < 0.01$) influenced body weight and total length of channel catfish. Age × size-class interaction was significant ($P < 0.05$) for body weight but not total length. These results indicated that effects of age and size class on body weight are not additive and that age must be considered in comparisons of fish weight from various size-classes. No significant age × line interaction was observed.

Experiment 2

This experiment began with fingerlings of equal size from +, –, and C lines. The fish remained not significantly different in body weight, total length, weekly weight gain, or weekly length increase 10 weeks after the experiment began (Table 4). Divergence, however, occurred 23 weeks after the onset of the experiment since catfish from the + and C lines were comparable to one another but both were superior in weight and length to the – catfish. Catfish from + and C lines remained similar in size at the conclusion of the test but the – fish were also comparable in weight and length to the + fish (Table 4). The control fish were, however, superior to the – fish in weight, length, and overall weekly increases in both traits at the end of the experiment. Head weight and carcass weight differed significantly among lines, but no differences in head percent or dressing percent were observed (Table 4).

These results differed from those observed in Exp. 1 when size-classes were established for each line. Selection of equal size fingerlings for this experiment eliminated larger fingerlings from the + line along with the smaller fingerlings from the – line and to a lesser extent from the C line. Elimination of catfish with best genetic potential for growth from the + line caused the remaining smaller fish from this line to be comparable in weight and length to the larger fish from C and – lines at the end of the test. The fact that fish from the C line were significantly ($P < 0.05$) heavier and longer than those from the – line and that overall weekly gains of both + and C lines were greater than the – line indicates that one generation of divergent selection has been effective in creating genetic variability among lines as was concluded in Exp. 1. Studies of this sort have not been conducted with channel catfish to compare the results.

Male catfish were 22.4% heavier (644 vs. 526 g) and 7.4% longer (405 vs. 377 mm) than female catfish at the end of the experiment. They also possessed larger head (161 vs. 112 g) and heavier carcass (394 vs. 308) than female catfish. Sex × line interaction was not significant and percent survival was not line dependent, as in Exp. 1. Age of fish and age × line interaction influenced both body weight and total length significantly ($P < 0.05$). This interaction was not important in Exp. 1 which shows another difference between the outcome of the two experiments.

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