Early Growth and Morphology Among Hybrids of Ictalurid Catfishes

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ABSTRACT. Half-sib ictalurid families were produced when eggs from three channel catfish, *Ictalurus punctatus*, females were fertilized with a mixture of sperm from channel catfish, blue catfish, *I. furcatus*, black bullhead, *Ameiurus melas*, and flathead catfish, *Pylodictis olivaris*. Sperm from all four species successfully fertilized channel catfish eggs, although individual families contained different percentages of the various crosses. The enzyme glucose phosphate isomerase distinguished the different hybrids and parental groups, and confirmed sorting of offspring based on morphology. At 1 month of age, channel catfish ♀ × flathead catfish ♂ hybrids (0.36 ± 0.07 g, mean ± SD) were heavier ($P \leq 0.05$) than channel catfish ♀ × black bullhead ♂ hybrids (0.12 ± 0.03 g), channel catfish

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♀ × blue catfish ♂ hybrids (0.11 ± 0.03 g), and channel catfish (0.10 ± 0.04 g). By 8 months of age, channel catfish ♀ × black bullhead ♂ hybrids (36.4 ± 21.9 g) and channel catfish ♀ × blue catfish ♂ hybrids (34.5 ± 24.2 g) were similar in weight, and each was significantly heavier than channel catfish ♀ × channel catfish ♂ (26.9 ± 16.1 g), while channel catfish ♀ × flathead catfish ♂ hybrids (17.0 ± 6.8 g) weighed the least. Morphometric ratios of channel catfish ♀ × blue catfish ♂ hybrids were intermediate between channel catfish ♀ × channel catfish ♂ and blue catfish for four of 16 features and were similar to either or both of the parental species for 10 others. Ratios for channel catfish ♀ × black bullhead ♂ hybrids were intermediate between channel catfish ♀ × channel catfish ♂ and black bullhead for seven of 16 features. Ratios for channel catfish ♀ × flathead catfish ♂ hybrids were larger than channel catfish ♀ × channel catfish ♂ for eight of 16 features and smaller than channel catfish ♀ × channel catfish ♂ for five of 16 features. All channel catfish ♀ × flathead catfish ♂ hybrid offspring were female, based on examination of the urogenital region or gross appearance of the gonads, while other groups had normal sex ratios. Production of half-sib interspecific hybrid families provides a unique opportunity to evaluate genetic influences on commercially important traits and to evaluate the potential of these ictalurid hybrids in aquaculture.

INTRODUCTION

Production of interspecific hybrids could prove useful in aquaculture, because hybrid vigor and the expression of combined characteristics might result in fish that outperform the species now used in commercial culture. Some diploid hybrids are outstanding sport fish, and triploid hybrids could prevent genetic contamination of native species by unwanted reproduction (Thorgaard 1983, 1986; Thorgaard and Allen 1987). Interspecific hybrids could benefit genetic improvement programs, because they provide genetic markers at the biochemical and molecular levels. Such hybrids could also provide unique information for construction of gene maps and for studies of the influence of heterozygosity on commercial traits, genotype-phenotype interactions, and the regulation of gene expression.

Channel catfish, *Ictalurus punctatus*, have been propagated in federal and state hatcheries since early in this century and have been cultured commercially since about 1960 (Dupree and Huner 1984).

More than 25 interspecific ictalurid hybrids have been produced, dating back to the 1960's (Dupree et al. 1966), but little information is available on direct comparisons of production traits for most of these crosses and their parental stocks (Dupree and Green 1969). The most widely investigated hybrid is between the channel catfish ♀ and blue catfish, *I. furcatus*, ♂. This hybrid is currently regarded as the most suitable for aquaculture because of characteristics such as rapid growth to marketable size (Guidice 1966; Yant et al. 1975), growth uniformity and high dress-out percentage (Brooks et al. 1982b; Dunham et al. 1982), tolerance of low dissolved oxygen (Dunham et al. 1983b), and catchability (Yant et al. 1975; Tave et al. 1981; Dunham et al. 1982, 1986). However, difficulty in obtaining reliable reproduction in ponds between these species (Tave and Smitherman 1982) limits extensive use of this hybrid.

During studies on cryopreservation, morphological and physiological differences were observed among the sperm of ictalurid catfishes, which could affect fertilization rates and the success of hybridization studies. This study evaluated the ability of a mixture of sperm from two congeneric species (channel catfish and blue catfish) and two species of different genera, black bullhead, *Amieurus melas*, and flathead catfish, *Pylodictis olivaris*, to fertilize channel catfish eggs. Genetic and environmental variation were reduced by production of half-sib families that were raised communally. Percent production of crosses within families, early survival and growth, and morphology of offspring were documented.

MATERIALS AND METHODS

Broodstock

Broodstock were obtained from the following sources in 1989 and maintained in 0.04- or 0.1-ha earthen ponds at the Catfish Genetics Research Unit: 2- to 3-year-old channel catfish from Farm Fish, Inc., Louise, Mississippi; 3- to 4-year-old blue catfish from South Fresh Farms, Itta Bena, Mississippi; black bullhead (age unknown) from Spirit Lake State Fish Hatchery, Spirit Lake, Iowa. Flathead catfish (age unknown) were obtained in the fall of 1990 from the Mississippi River near Greenville, Mississippi. Channel catfish, blue catfish, and black bullhead broodstocks were fed floating pellets (32% protein) at 2-3% of their body weight every other day from approximately May through October and were fed sinking pellets (25% protein) twice weekly during the winter. Flathead catfish were provided a forage base of golden shiner, *Notemigonus crysoleucas*, and green sunfish, *Lepomis cyanellus*.

Sperm Preparation

A male of each species was anesthetized with 0.02% tricaine methane sulphonate (MS-222), and testes were removed surgically. Sperm cells were released into 10 ml Hanks' Balanced Saline Solution (HBSS) using a glass tissue grinder, and the final volume was adjusted to 50 ml HBSS:1 g testis. The solution was swirled gently to ensure complete suspension of sperm, and particulate material was allowed to settle for 5 minutes. The supernatant was collected and stored at 4°C. Sperm density (cells/ml) was estimated using a Coulter Multisizer[1] (Coulter Electronics, Hialeah, Florida), and percent motility (defined as sperm actively swimming in a rapid forward motion) in each solution was estimated using a light microscope with dark field illumination. Sperm from all four species were combined so that each male contributed about 8.75 million sperm/ml to a solution that contained a total of about 35 million sperm/ml.

Induced Spawning and Fertilization

Female and male channel catfish were paired in 80-L glass-front aquaria supplied with aerated, flow-through well water (26 ± 1°C). Females received intraperitoneal injections of human chorionic gonadotrophin (1,100 IU/kg) on alternate days; males received a single injection (550 IU/kg). Fish in aquaria were monitored for spawning behavior and the presence of eggs. After release of 50-100 ml of eggs (1,750-3,300 eggs), females were removed and anesthetized in MS-222. Eggs were stripped for up to 5 minutes by gentle application of pressure to the abdomen. Incompletely ovu-

1. Reference to trade names or manufacturers does not imply endorsement of commercial products by the U. S. Government.

lated females were returned to aquaria for 30-60 minutes and were then stripped again. This procedure was repeated until all eggs were obtained or until blockage prevented further stripping. Eggs were stripped into plastic bowls (coated with silicone grease to prevent adhesion) containing 100 ml of water; about 10 ml of the sperm mixture was added continually while eggs were stripped. Eggs were allowed to water harden for 10 minutes and the number estimated volumetrically (30-33 eggs/ml). Multiple egg masses from the same female were pooled. Half-sib families, each containing the channel catfish cross (channel catfish ♀ × channel catfish ♂) and three hybrid crosses (channel catfish ♀ × black bullhead ♂; channel catfish ♀ × blue catfish ♂; channel catfish ♀ × flathead catfish ♂), were produced from three female channel catfish.

Egg masses from each female were raised separately. Fry were offered a trout starter diet (sizes 00 and 1; 50% protein) delivered every 30 minutes by automatic feeders for a total ration of 20-25% body weight/day for 21 days. Individual families were then stocked into 160-L tanks at a density of 500 fish/tank. Fry were offered (2-3 times/day) appropriate-sized sinking pellets of trout diet at 20% body weight/day for 52 days, and were fed floating pellets (35-45% protein) at 5-15% of body weight/day for the remainder of the study.

Survival, Growth, and Morphology

Eggs were sampled 24-48 hours after fertilization, and the percentage of embryos at the neurula stage was determined to estimate percent fertilization. Survival was estimated at 21 days of age by extrapolating the weight of three samples of 25 fish/family to the total weight of fish in each family. At 4 and 8 months of age, all fish in each family were sorted visually into the four crosses and counted, and 25 fish from each cross were measured for weight and length.

Percent composition of each cross within families was estimated at 1 month of age, based on electrophoretic analysis of a random sample of 50-100 fry. Fry were weighed to the nearest 0.01 g and prepared for analysis according to methods described by Liu et al. (1992). More than 20 enzymes representing 27 loci were evaluated to identify differences in allozyme phenotypes (unpublished data).

At 4 and 8 months of age, percent composition was based on sampling the entire population. Electrophoretic analysis on a sample of 15 fish/cross was used to confirm visual sorting at 4 months; no confirmation was conducted on 8-month-old fish.

Morphological features were examined at 4 months of age on 15 fish of each cross (from a single family raised in a single tank) and on related and similarly aged black bullhead and blue catfish; flathead catfish were unavailable. Morphometric measurements (Figure 1) were made on the left side of the fish to the nearest 0.1 mm. Measurements were standardized for differences in fish size by calculating ratios relative to total, standard, or head length. Ratios for hybrids were reported as equal, intermediate, greater than, or less than ratios of parental species. Sex, swim bladder shape, and premaxillary toothpatch extensions were observed in necropsied fish from each cross and from laboratory stocks of blue catfish and black bullhead.

Statistical Analyses

All fish from each cross were used to calculate average weight and evaluate mean differences. Ratios of linear measurements among the parental species and the hybrid were compared for channel catfish ♀ × black bullhead ♂ hybrids and channel catfish ♀ × blue catfish ♂ hybrids; channel catfish ♀ × channel catfish ♂ and hybrids of channel catfish ♀ × flathead catfish ♂ were compared directly. Data were analyzed by the General Linear Models procedure using SAS/PC (SAS Institute, Inc. 1988). Significantly different means ($P \leq 0.05$) were identified by Tukey's HSD Studentized range test.

RESULTS

Glucose phosphate isomerase (GPI) unequivocally distinguished hybrids and parental groups (Figure 2) both at 1 and at 4 months of age. Migration of GPI-B was slower in channel catfish than in blue catfish, and different migration rates for GPI-1 and GPI-2 distinguished flathead catfish from black bullhead. Hybrids exhibited codominant expression of both parental allozymes.

FIGURE 1. Morphological measurements and features examined (n = 15 per group) in 4-month-old ictalurid catfish. **A** = lateral view: 1) total length (TL); 2) fork length (FL); 3) standard length (SL); 4) distance from tip of snout to origin of anal fin (IA); 5) distance from tip of snout to origin of dorsal fin (ID); 6) head length (HL); 7) distance from posterior edge of orbit to posterior margin of operculum (EO); 8) pupil diameter (PD); 9) orbit diameter (ED); 10) length of inner (BBI) and outer (BBO) ventral barbels; 11) distance from origin of dorsal fin to origin of anal fin (IDIA); 12) length of anal fin base (AL); 13) length of caudal peduncle (CP); 14) presence or absence of spots; 15) anal fin ray count. **B** = dorsal view of head: 16) distance between nares (DBN); 17) distance between pupils (DBE); 18) distance between opercula (DBO). **C** = ventral view of upper jaw: 19) presence or absence of rearward extension of premaxillary tooth patch. Observations were made on the left side, where applicable.

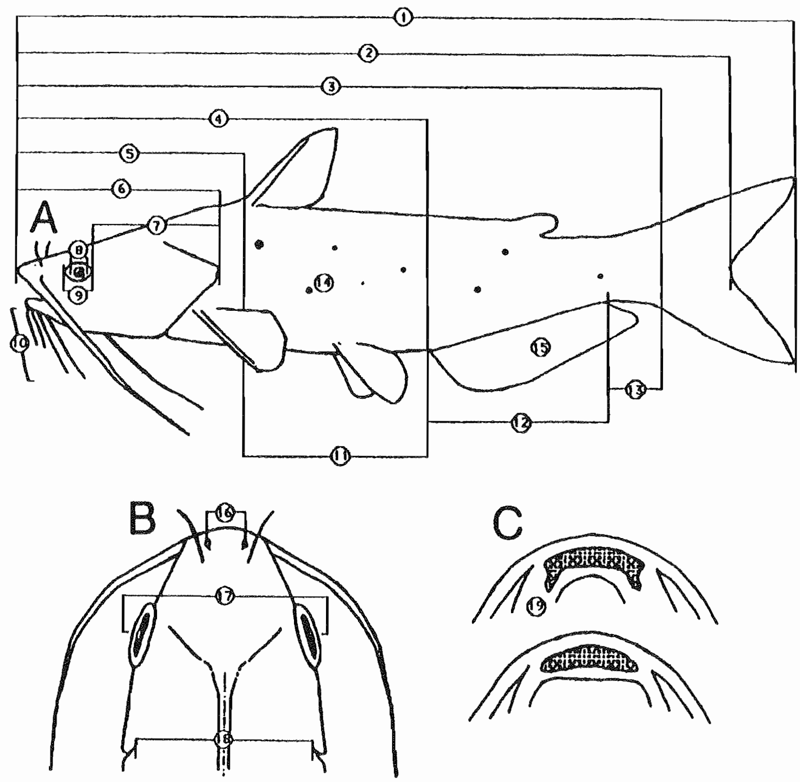
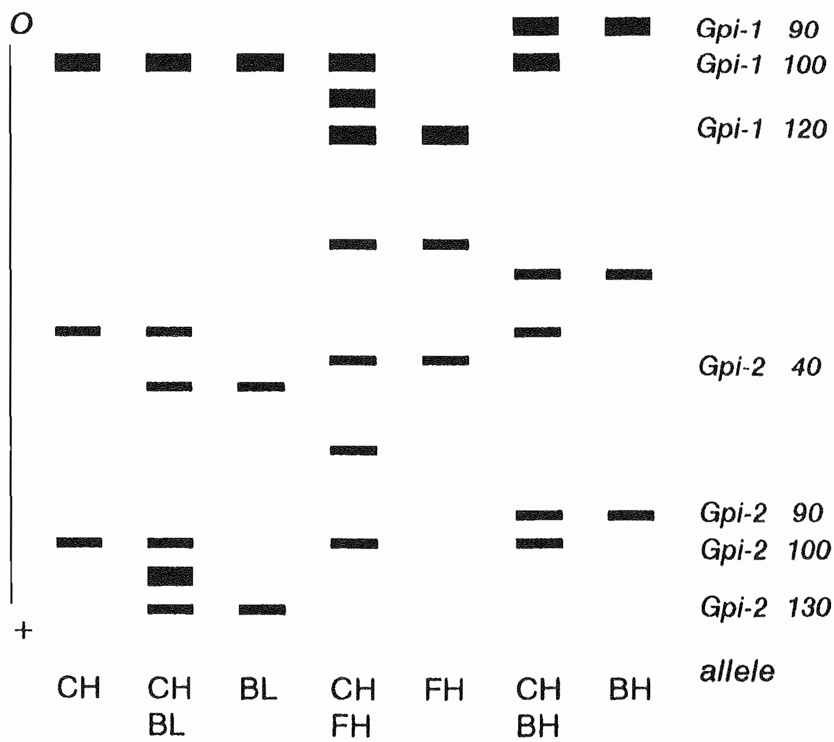


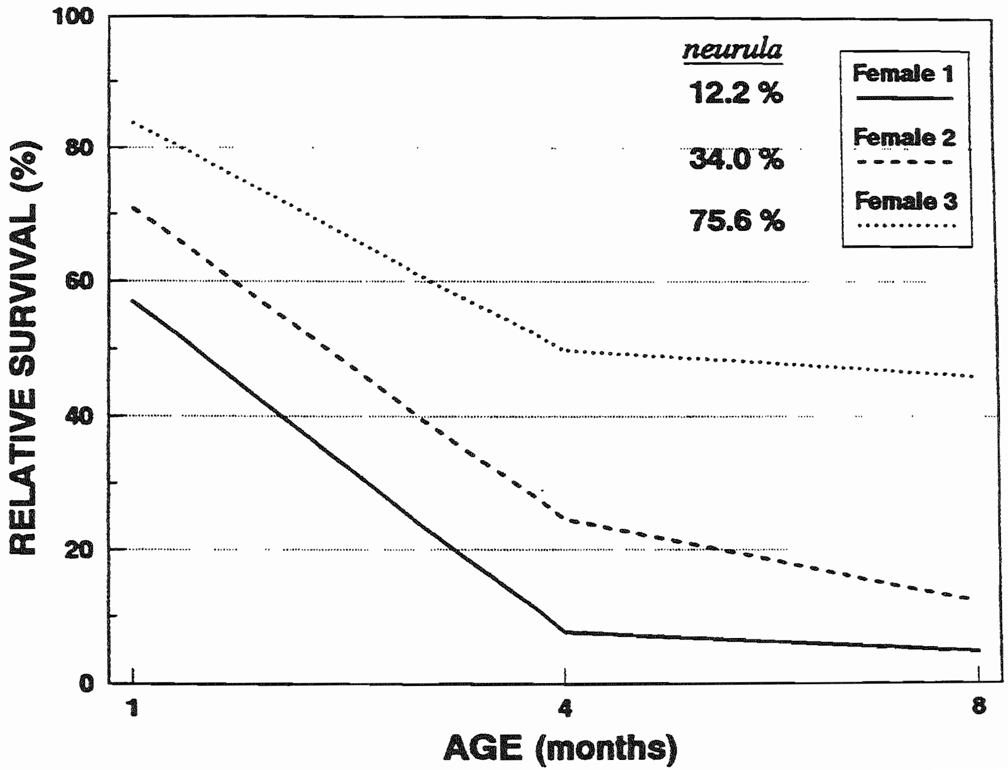
FIGURE 2. Electrophoretic phenotypes of glucose phosphate isomerase (GPI) for channel catfish (CH), blue catfish (BL), flathead catfish (FL), black bullhead (BH) and channel catfish ♀ × blue catfish ♂ hybrids (CH BL), channel catfish ♀ × flathead catfish ♂ hybrids (CH FH), and channel catfish ♀ × black bullhead ♂ hybrids (CH BH). Polarity is represented by "o" and "+."



Development to the neurula stage in different half-sib families ranged from 12.2 to 75.6% (Figure 3), and subsequent survival through 8 months (relative to the number at the neurula stage) ranged from 4.7 to 45.9%. Progeny of female 3 had the highest percentage of development to neurulation and the highest survival throughout the study.

Sperm from all four species fertilized eggs of channel catfish; however, families contained variable percentages of the different crosses, and the percentages changed with time. Percentages of fish

FIGURE 3. Percent survival (relative to number at the neurula stage) among three half-sib families of channel catfish ♀ × channel catfish, blue catfish, black bullhead, and flathead catfish ♂.



present at 1 month were: channel catfish ♀ × channel catfish ♂–54-70%; channel catfish ♀ × blue catfish ♂ hybrids–26-38%; channel catfish ♀ × black bullhead ♂ hybrids–0-5%; channel catfish ♀ × flathead catfish ♂ hybrids–3-8% (Figure 4). Percentages of channel catfish ♀ × channel catfish ♂ and channel catfish ♀ × blue catfish ♂ hybrids were still predominant at 8 months, but the proportion of channel catfish ♀ × channel catfish ♂ were lower compared to earlier samples. Channel catfish ♀ × flathead catfish ♂ hybrids were present at 1 month for female 1, but were not observed in subsequent sampling, and channel catfish ♀ × black bullhead ♂ hybrids were present at 4 and 8 months of age for females 1 and 3, but were not observed in initial samples.

After one month, channel catfish ♀ × flathead catfish ♂ hybrids had a greater weight (mean ± SD) (0.36 ± 0.07 g) than channel catfish ♀ × black bullhead ♂ hybrids (0.12 ± 0.03 g), channel catfish ♀ × blue catfish ♂ hybrids (0.11 ± 0.03 g), and channel catfish ♀ × channel catfish ♂ (0.10 ± 0.04 g) (Figure 5). By 8 months, channel catfish ♀ × black bullhead ♂ hybrids and channel catfish ♀ × blue catfish ♂ hybrids were significantly larger than channel catfish ♀ × channel catfish ♂, while channel catfish ♀ × flathead catfish ♂ hybrids were smallest. Total and standard lengths followed essentially the same patterns as weight.

Progeny resulting from the different crosses exhibited characteristics of each of the parents to varying degrees. Channel catfish ♀ × blue catfish ♂ hybrids were deep-bodied, blue in color, and about 50% of the fish had spots (Figure 6a). Anal fin ray counts (28.7 ± 1.3, mean ± SD) of this hybrid were different from channel catfish (24.8 ± 2.0) and blue catfish (30.6 ± 1.3). Morphometric ratios of channel catfish ♀ × blue catfish ♂ hybrids were intermediate between channel catfish and blue catfish for four of 16 features, were similar to channel catfish for four features, and similar to blue catfish for three features (Figure 7a). Eye and pupil diameters of hybrids were larger than those of each parental group. Swim bladders of hybrids resembled blue catfish in that a constriction was present, but the posterior chamber was much reduced, and the overall appearance was intermediate between parental species (Figure 8).

Channel catfish ♀ × black bullhead ♂ hybrids were robust, gray-

FIGURE 4. Percent composition of genetic groups within three half-sib families of channel catfish ♀ × channel catfish, blue catfish, black bullhead, and flathead catfish ♂. Numbers of fish are in parentheses.

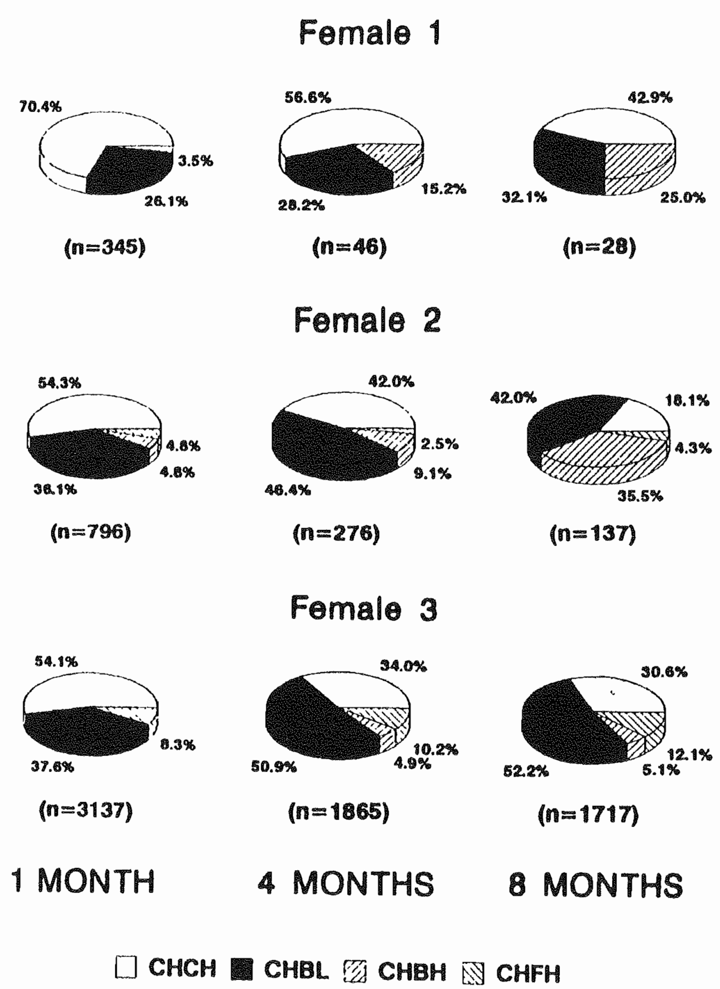


FIGURE 5. Weight of three half-sib families of channel catfish ♀ × males of channel catfish, blue catfish, black bullhead, and flathead catfish: CH × CH = channel catfish ♀ × channel catfish ♂; CH × BL = channel catfish ♀ × blue catfish ♂; CH × BH = channel catfish ♀ × black bullhead ♂; CH × FH = channel catfish ♀ × flathead catfish ♂. Values for each group were combined across the three half-sib families (n = 25/group/family). Groups sharing letters were not significantly different within each age group (ANOVA followed by Tukey's HSD Studentized range test; $P \leq 0.05$).

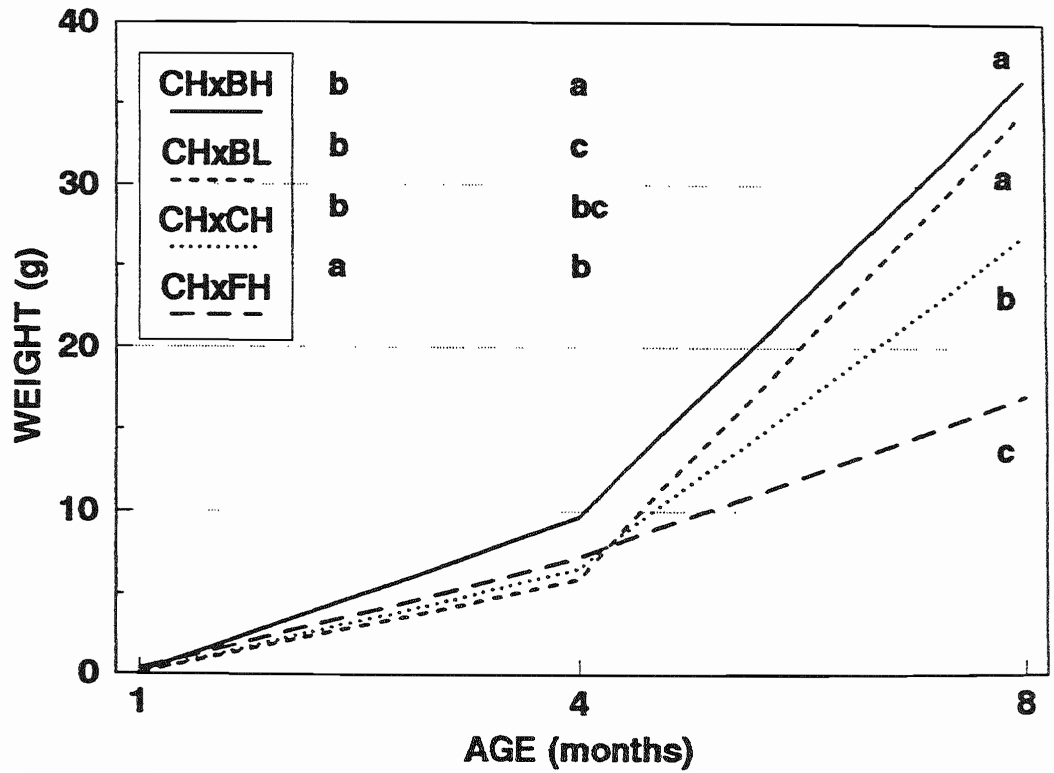


FIGURE 6. Photographs of parental species and hybrids of ictalurid catfish. **A** = channel catfish ♀ × channel catfish ♂ (CH × CH); and channel catfish ♀ × blue catfish ♂ (CH × BL); blue catfish ♀ × blue catfish ♂ (BL × BL). **B** = channel catfish ♀ × channel catfish ♂ (CH × CH); channel catfish ♀ × black bullhead ♂ (CH × BH); black bullhead ♀ × black bullhead ♂ (BH × BH). **C** = channel catfish ♀ × channel catfish ♂ (CH × CH); channel catfish ♀ × flathead catfish ♂ (CH × FH). Channel catfish ♀ × channel catfish ♂, channel catfish ♀ × blue catfish ♂, channel catfish ♀ × black bullhead ♂, and channel catfish ♀ × flathead catfish ♂ were siblings raised in tanks, and blue catfish and black bullhead were from related and similarly-aged laboratory stocks raised in ponds; flathead catfish were not available.

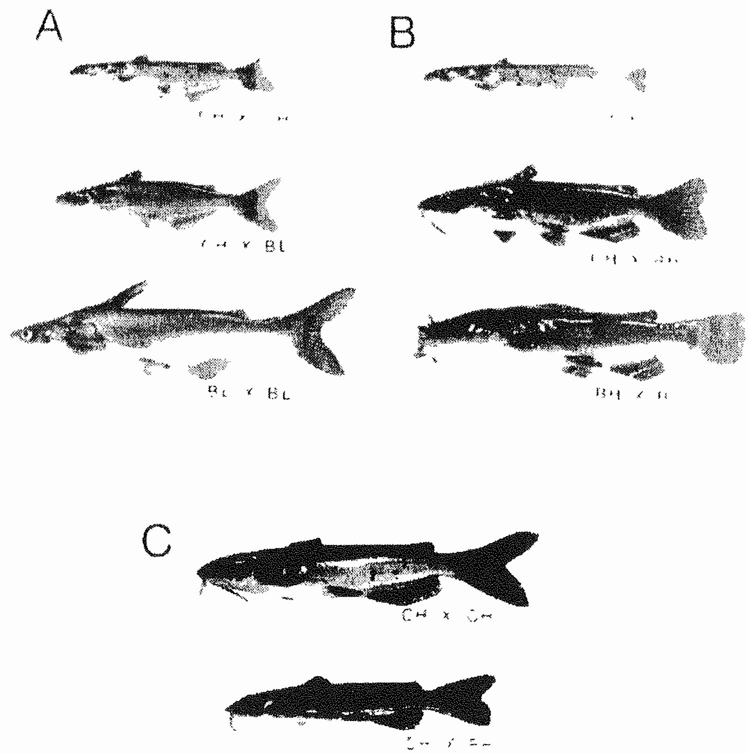


FIGURE 7. Ratios of morphological features (abbreviations given in Figure 1) relative to total length (TL), standard length (SL), or head length (HL) measured on 4-month old channel catfish (CH), blue catfish (BL), black bullhead (BH), channel catfish ♀ × blue catfish ♂ hybrids (CHBL), channel catfish ♀ × black bullhead ♂ hybrids (CHBH), channel catfish ♀ × flathead catfish ♂ hybrids (CHFH). Flathead catfish of similar age were not available. Significant subsets (ANOVA followed by Tukey's HSD Studentized range test; $P < 0.05$) among crosses were classified as equal, intermediate, greater than, or less than either or both parental species.

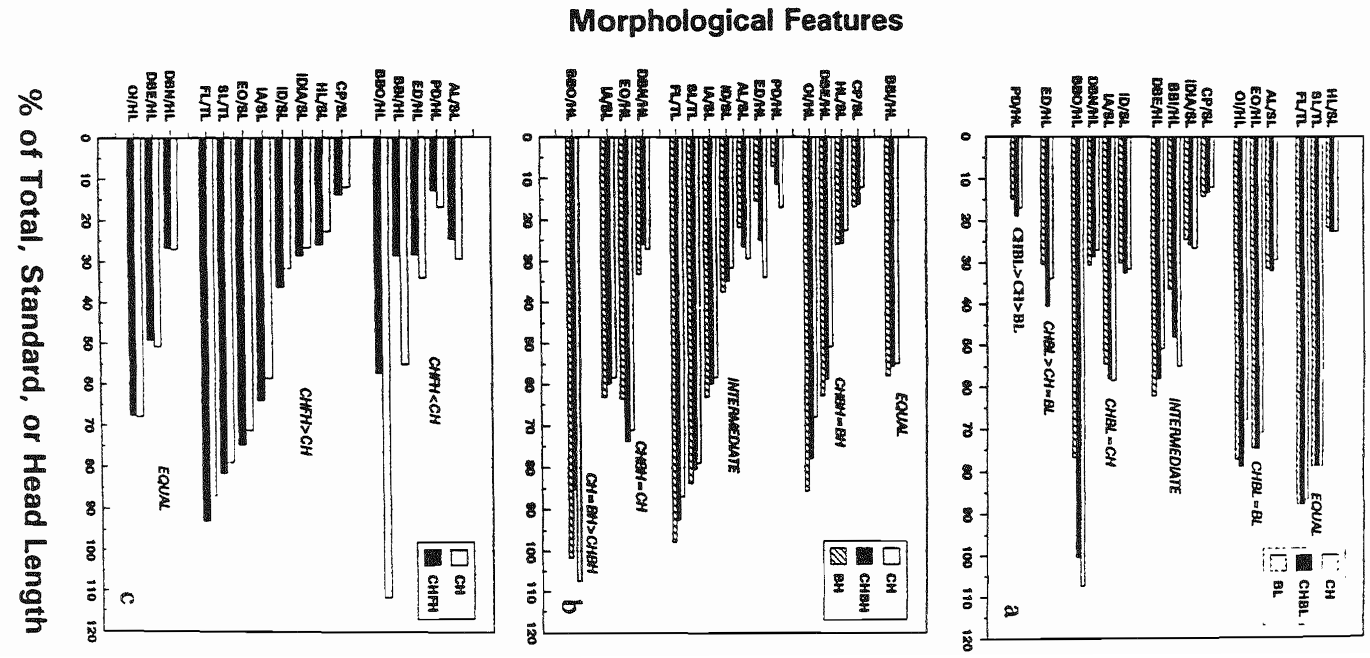
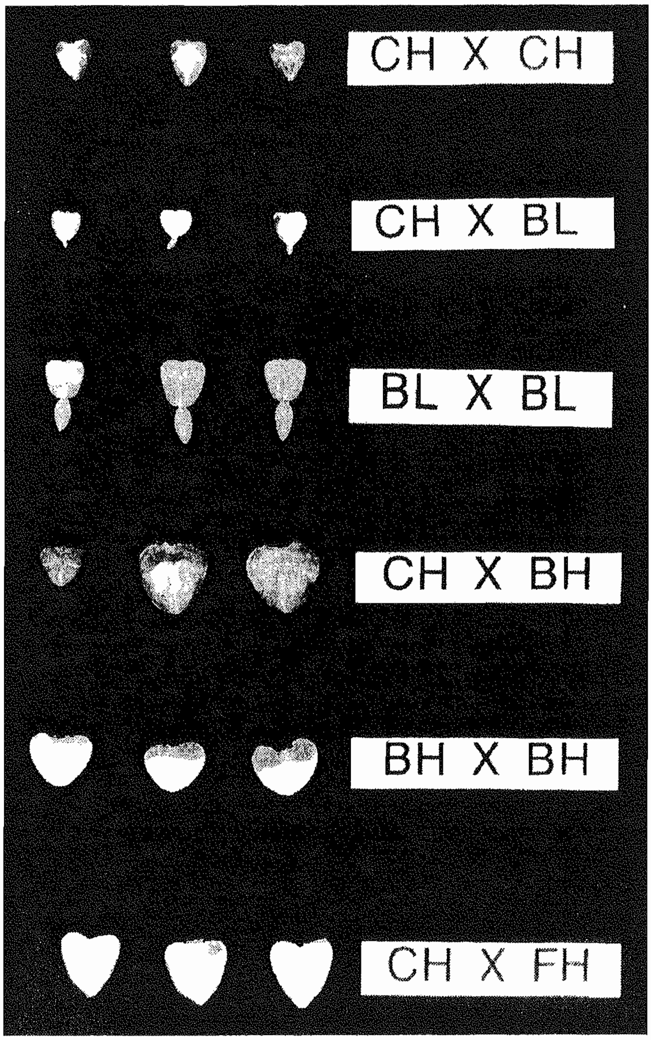


FIGURE 8. Swim bladders of channel catfish (CH), blue catfish (BL), black bullhead (BH), channel catfish ♀ × blue catfish ♂ hybrids (CH × BL), channel catfish ♀ × black bullhead ♂ hybrids (CH × BH), and channel catfish ♀ × flathead catfish ♂ hybrids (CH × FH). Swim bladders were obtained from 4-month-old sibling channel catfish ♀ × channel catfish ♂, channel catfish ♀ × blue catfish ♂ hybrids, channel catfish ♀ × black bullhead ♂ hybrids, and channel catfish ♀ × flathead catfish ♂ hybrids raised in tanks, and blue catfish and black bullhead from related and similarly-aged laboratory stocks raised in ponds; swim bladders from flathead catfish were not available.

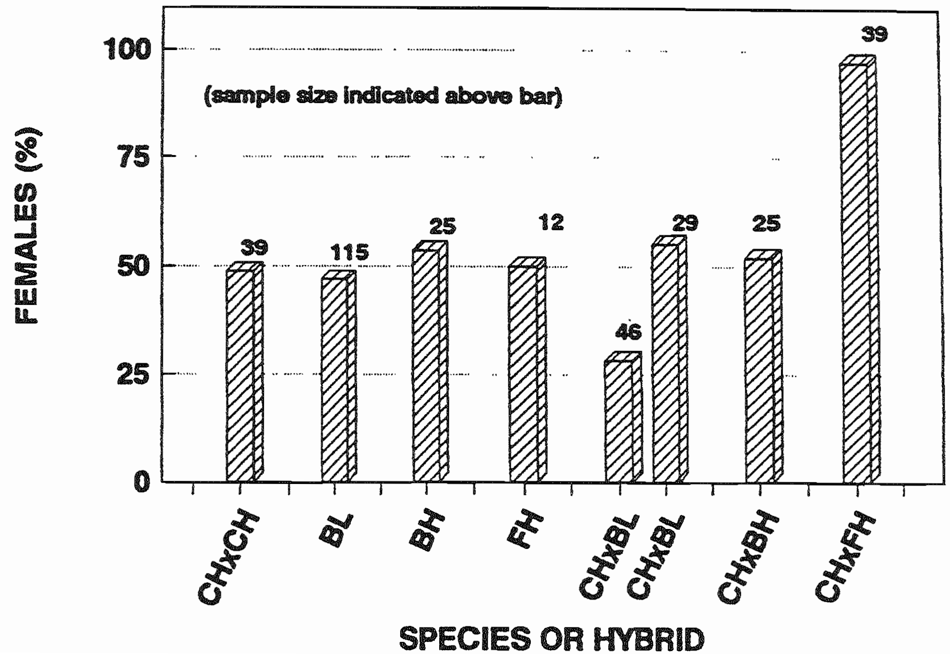


ish-brown to gold in color, and only one of 15 fish had spots (Figure 6b). The number of rays in the anal fin (21.8 ± 0.7) was intermediate between channel catfish (24.8 ± 2.0) and black bullhead (18.8 ± 0.6). Channel catfish ♀ × black bullhead ♂ hybrids were intermediate between channel catfish and black bullhead for seven of 16 features, were similar to channel catfish for three features, and were similar to black bullhead for four features (Figure 7b). The distance between the eyes of channel catfish ♀ × black bullhead ♂ hybrids resembled that of black bullhead, but the distance between the nares resembled that of channel catfish. Inner barbels of this hybrid were equal in length to those of the parental species, but outer barbels were shorter than those of both parental species. Swim bladder shape of channel catfish ♀ × black bullhead ♂ hybrids was similar to the heart-shaped swim bladders of channel catfish and black bullhead (Figure 8).

Channel catfish ♀ × flathead catfish ♂ hybrids were elongated and shallow-bodied, black to gold in color with a mottled appearance, and about 50% of the fish had spots (Figure 6c). All channel catfish ♀ × flathead catfish ♂ hybrids had rearward extensions of the premaxillary toothpatch, but these were reduced in size compared to those seen in adult flathead catfish. Anal fin ray counts of channel catfish ♀ × flathead catfish ♂ hybrids (20.1 ± 0.9) were intermediate between channel catfish (24.8 ± 2.0) and fin ray counts reported for flathead catfish (14-17; Cross 1967). Channel catfish ♀ × flathead catfish ♂ hybrids were longer than channel catfish for eight of 16 features, most linear measurements of the head were shorter than those of channel catfish, and all three head width measurements were similar to those of channel catfish (Figure 7c). Swim bladder shape of channel catfish ♀ × flathead catfish ♂ hybrids was similar to that of channel catfish (Figure 8) and adult flathead catfish observed in the laboratory.

The channel catfish ♀ × channel catfish ♂ cross, laboratory stocks of the other parental species, and channel catfish ♀ × black bullhead ♂ hybrids had sex ratios that were not different from 1:1 (Figure 9). Significantly fewer females were observed in channel catfish ♀ × blue catfish ♂ progeny from female 2, but half-sib channel catfish ♀ × blue catfish ♂ hybrids from female 3 had a

FIGURE 9. Sex ratios of channel catfish (CH × CH), blue catfish (BL), black bullhead (BH), flathead catfish (FH), channel catfish ♀ × blue catfish ♂ hybrids (CH × BL), channel catfish ♀ × black bullhead ♂ hybrids (CH × BH), and channel catfish ♀ × flathead catfish ♂ hybrids (CH × FH). Channel catfish ♀ × channel catfish ♂, channel catfish ♀ × blue catfish ♂ hybrids, channel catfish ♀ × black bullhead ♂ hybrids, and channel catfish ♀ × flathead catfish ♂ hybrids were 4-month-old siblings; blue catfish and black bullhead were from related and similarly-aged laboratory stocks; flathead catfish were wild-caught adults. Sex was identified by observation of gonads in necropsied fish or by examination of the urogenital papilla.



normal sex ratio. Channel catfish ♀ × flathead catfish ♂ hybrids appeared to be all females.

DISCUSSION

Offspring from males of all four species were represented in each of the families produced, indicating successful interspecific fertilization of channel catfish eggs. Therefore, gamete incompatibility cannot account for the failure of catfishes to hybridize readily in nature or in commercial culture. Crosses between the two species of the genus *Ictalurus* had the highest production of offspring, while intergeneric crosses accounted for less than 25% of the fish produced. Differences in activation and rate and duration of sperm motility among species could account for some of the variation observed in composition of offspring: channel catfish and blue catfish had 60-70% motility; black bullhead had <5% motility; flathead catfish had about 20% motility, but activation was slower than in other species. Differential survival among the crosses contributed to changes in the percentages observed over time. However, some differences in percentages among sample periods can be attributed to sampling error at 1 month of age, which omitted the channel catfish ♀ × black bullhead ♂ hybrids that were observed in subsequent samples. Additionally, channel catfish ♀ × flathead catfish ♂ hybrids were either sampled completely at 1 month or had poor viability, as they were not observed in subsequent samples.

Successful induction of spawning and resultant offspring production varies among females of channel catfish (Dupree and Huner 1984; Goudie et al. 1992) and remains an impediment to rigorous evaluation of hybridization efforts and genetic improvement programs in general (Bondari 1990). Poor survival of some hybrid groups could have suggested incompatibility within the hybrid genome; however, maternal factors adversely affected survival in this study. Sources of variation among females include genetic and physiological mechanisms and culture conditions. More information is needed on the reproductive biology and control of maturation and spawning of channel catfish to predict and control this variation among females.

Obvious differences in growth patterns were observed among the crosses produced in these families. For example, channel catfish ♀ × blue catfish ♂ hybrids had slow early growth but rapidly caught up to the channel catfish ♀ × black bullhead ♂ hybrid toward the end of the study. In contrast, channel catfish ♀ × flathead catfish ♂ hybrids exhibited the fastest early growth, but by 8 months had the poorest growth. Nutritional deficiencies for this hybrid cannot be ruled out, as flathead catfish are known to be carnivorous (Cross 1967); in this study they received only pelleted diets specifically prepared for channel catfish. Piscivorous activity by channel catfish ♀ × flathead catfish ♂ hybrids were not observed in this study. Observations on growth of these crosses must be considered preliminary, however, as they were made on fish raised in tanks, and growth could be different in other environments.

Morphological features of hybrids are generally intermediate between those of the parental species, although traits can be similar to either or outside the ranges of the parental groups (Chevassus 1983). Paternal predominance has been reported in channel catfish ♀ × blue catfish ♂ hybrids for external appearance, swim bladder shape, and anal fin ray counts (Dunham et al. 1982), and uniformity of growth and morphometry (Brooks et al. 1982b). However, in a related study, Dunham et al. (1983a) reported a number of features of the channel catfish ♀ × blue catfish ♂ hybrid that were intermediate to the parental species. Morphological characteristics observed in this study were predominantly intermediate for all the hybrid crosses compared to the parental species. It should be noted that these observations were made on young fish, and morphology could change considerably with further growth and sexual maturation.

Abnormalities of the caudal fin occurred in nearly all the channel catfish ♀ × channel catfish ♂ and channel catfish ♀ × blue catfish ♂ hybrids in one family but were not observed in channel catfish ♀ × black bullhead ♂ hybrids and channel catfish ♀ × flathead catfish ♂ hybrids raised in the same tank. Caudal fin abnormalities could not be attributed to genetic causes in studies of channel catfish (Dunham et al. 1991), but could be due to environmental perturbations (e.g., high temperatures or low dissolved oxygen) during critical developmental stages. Various hybrids may be differentially susceptible to factors that cause fin abnormalities, but the relative roles of genetics and environment have not been established.

The 1:1 sex ratios of parental species and most of the hybrids reported in this study were the same as sex ratios observed in commercial stocks of channel catfish and blue catfish (Brooks et al. 1982a), flathead catfish (Turner and Summerfelt 1971), and hybrids of channel catfish and blue catfish (LeGrande et al. 1984). However, limited information on sex ratios of ictalurids is available and aberrant sex ratios may occur; for example, matings between white catfish, *A. catus*, ♀ × blue catfish ♂ reportedly produced all-female offspring (R.A. Dunham, Auburn University, Alabama, pers. comm.). Observation of all-female offspring in channel catfish ♀ × flathead catfish ♂ hybrids in the present study is tentative because sex was not confirmed by histological examination. Additionally, hybrids may mature at an older age than channel catfish, and identification of sex may be restricted by the lack of gonadal differentiation in 4-month-old hybrids. Alternatively, limited development of distinct gonads may reflect sterility in this hybrid.

Although many hybrids among ictalurid catfishes were produced in the 1960's, additional analyses, including evaluation of different strains, documentation through marketable size and sexual maturation, and influences of female variability on offspring viability, would be informative. Production of families of half-sib interspecific hybrids provides unique opportunities to complement earlier research, evaluate genetic influences on development, growth, and morphology, and estimate heritability for variance components for commercially-important traits. Exploitation of specific characteristics of hybrids would be useful for a genetics selection program. As an example, incorporation of the desirable characteristics of black bullhead catfish for early rapid growth and ability to tolerate poor water quality and low dissolved oxygen, combined with the many desirable production traits of channel catfish and blue catfish, could produce an improved fish for commercial culture.

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