Aquaculture Research with Striped Bass and Its Hybrids in South Carolina[1]

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Abstract: There is growing interest in the United States to develop fish farming operations using striped bass (*Morone saxatilis*) and or its hybrids. In South Carolina an aquaculture model was developed to allow production of pan-size (300–450 g) striped and white bass hybrids within a year. Brood fish are grown in captivity, matured, and spawned out-of-season using controlled environment systems. Small juveniles are produced early in indoor intensive nursery systems for stocking of grow-out facilities at the onset of suitable outdoor rearing conditions. Testing of model components indicated that cultured striped bass can be conditioned to spawn out-of-season and that the striped bass and white bass hybrids appear well suited for aquaculture development.

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Striped bass and striped bass x white bass (*M. chrysops*) hybrids (original and reciprocal crosses) are popular recreational fish throughout the United States. Since 1964, these fish have been stocked in 456 reservoirs which encompass 57% of the total reservoir area in the United States (Stevens 1984). The striped bass is also an important commercial species especially from North Carolina to Massachusetts. However, landings since 1973 have substantially declined and various management regulations including fishing moratoriums, closed seasons, closed areas, gear restrictions, etc. are being implemented in an attempt to conserve and enhance native fisheries.

Striped bass are well known in the market place and command high prices

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which vary seasonally and by size of fish. Prices for wild fish range from about $3.85 to $8.80/kg with striped bass filets selling for $18.20/kg in certain outlets in Virginia in 1983 (Sport Fish. Inst. 1984). Cultured striped bass have been sold live for $13.20/kg in kosher markets in New York and for the same price in oriental markets in California (Swartz 1984). In Florida, test marketing studies with white bass x striped bass hybrids suggest a market price of $6.60–$8.80/kg (Ednoff 1984, S. Harris, Harris Consulting Inc., Fla., pers. commun. 1985).

Most of the culture activities with striped bass and its hybrids have focused on developing spawning techniques for wild caught fish and for the production of fingerlings in ponds for stocking of recreational waters (Stevens 1966, Tatum et al. 1966, Bayless 1972, Bishop 1975, Bonn et al. 1976, Parker and Geiger 1984). More recently, a number of studies have investigated the potential feasibility of producing striped bass and its hybrids as food fish (Powell 1973; Valenti et al. 1976; Wawronowicz and Lewis 1979; Williams et al. 1981; Kerby et al. 1983*a, b;* Woods et al. 1983; Carlberg et al. 1984, Collins et al. 1984, Smith et al. 1985). Such studies have helped identify suitable techniques and systems for culture of these fish. However, additional information is still required to provide an adequate base for development of an aquaculture industry.

Since 1977, South Carolina has conducted research focused on determining the aquaculture potential of striped bass and its hybrids. Initial efforts examined rearing striped bass and striped bass x white bass hybrids in estuarine net-pens (Williams et al. 1981). As a result of this work, a production model was developed to grow pan-size fish (300–450 g) within 1 year (Smith and Jenkins 1985). This model has 4 components: controlled rearing and spawning of domesticated broodstock, hatchery production of fry, development and utilization of indoor intensive nursery systems, and rearing of fish to market size in production facilities.

This manuscript provides an overview of the results of our aquaculture studies with striped bass and its hybrids to test the production model. Additionally, current status and potential of bass culture in the United States is discussed.

Methods

Development and Description of Model

Striped bass and its white bass hybrids are typically produced from wild brood stock captured during their natural spawning season (late March to early May in South Carolina). In the case of striped bass, fertilized eggs are obtained by injection of human chorionic gonadotropin (HCG) into ripe fish and then either allowing the brood fish to tank spawn or through the manual stripping and mixing of gametes. Hybrids are produced only through the later technique. Eggs are incubated in indoor hatchery systems while the fry are normally stocked in earthen ponds which have been fertilized to induce phytoplankton and zooplankton blooms. Approximately 30 to 40 days later, the zooplankton has been essentially depleted and the ponds are drained and the small juveniles harvested. These juveniles are then used for stocking of recreational waters or for production of larger juveniles. As a consequence of this dependence on wild brood fish, small juveniles for stocking grow-out systems are not available until June/July. Because of this delayed availability of seed stock, the production of pan-size fish cannot be accomplished before the onset of low water temperatures in South Carolina. Thus, overwintering is required with final grow-out obtained during the following spring/summer. This rearing cycle was dramatically demonstrated in net-pen trials conducted during 1977 to 1980 in South Carolina (Williams et al. 1981). Here, fish grew rapidly until December when temperatures declined to 10° C. Average water temperature remained at this level until April at which time water temperature increased and fish growth resumed. Under this production sequence, almost 1 year was required to grow pan-size fish.

To avoid this requirement of overwintering to produce market size fish as well as to ensure availability of small juveniles, a production model was developed for use in South Carolina and other temperate areas (Smith and Jenkins 1985). The model consists of 4 production components or phases: 1) the brood stock phase—domesticated adult fish are matured for spawning under controlled environmental conditions; 2) the hatchery phase—brood fish are artificially spawned and fry produced; 3) the nursery phase—newly hatched fry are reared to small juveniles in intensive culture systems; and, 4) the grow out phase—small juveniles are reared to market size (Fig. 1). On an annual basis, the hatchery would operate during January/February; the nursery from February/March to April, and grow-out from April to November/December (Fig. 1). As adults would be maintained and conditioned throughout the year, the brood stock phase would be continuous.

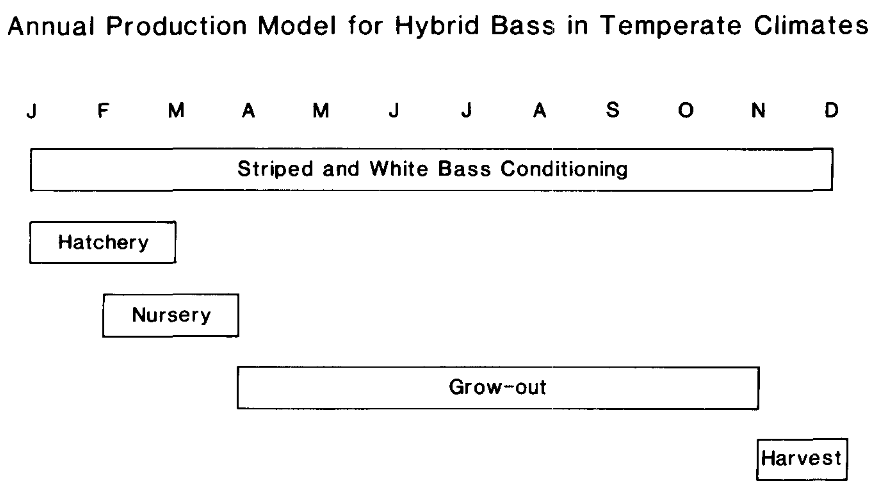

Figure 1. An annual production model for growing pan-size striped bass × white bass hybrids in South Carolina and other temperate areas.

Model Component: Broodstock Phase

Development of controlled indoor maturation systems for striped bass and white bass have not been attempted previously but manipulation of photoperiod and temperature have been successfully employed to control maturation and spawning of some marine fishes including pompano (*Trachinotus carolinus*) and red drum (*Sciaenops ocellata*) (Hoff et al. 1976, 1978; Roberts et al. 1978). Following this approach, we constructed a controlled environment system which utilized recirculated water and which allowed manipulation of temperature and photoperiod (Smith and Jenkins 1984). With this indoor maturation system, striped bass x white bass hybrids were conditioned and manually spawned to produce F_2 hybrids ($F_1 \times F_1$ hybrid) in 1983 and 1984 (Smith and Jenkins 1984). In 1985, trials were initiated in February using striped bass which were 35 months old and had been cultured in brackish water (15 ppt), and wild-caught mature white bass which had been cultured in fresh water for 6 months. Conditioning involved a slight modification and shifting of the normal outdoor temperate and photoperiod cycle by 3 months (Fig. 2).

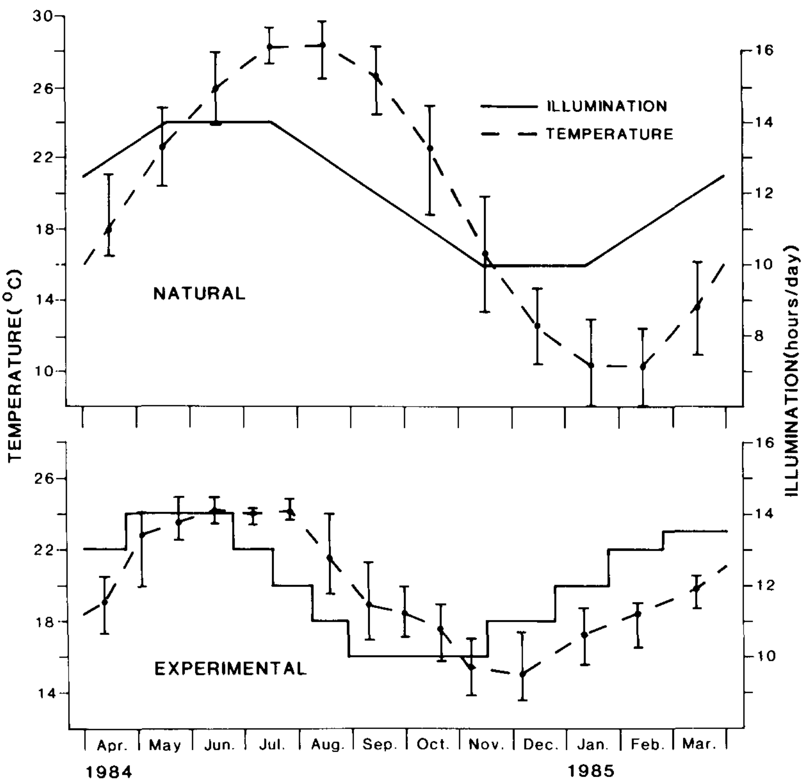

Figure 2. Photoperiod and temperature regimes used to condition striped bass for spawning in 1985. Top: 10-year average conditions in Charleston, S.C.

Striped bass males were mature at age 2 and were running ripe again at 3 years of age in this system. However, only a few females were sufficiently mature (egg diameter ≥750 microns) to attempt spawning at this time. In order to reduce handling stress, tank spawning techniques developed by Bishop (1975) were attempted with these cultured striped bass. Three trials were run, each pairing 1 female and 2 males in 1.8-m diameter tanks. All striped bass were injected with HCG at a rate of 330 I.U./kg of body weight.

In addition to attempts to produce striped bass out-of-season, several spawning trials were also undertaken to produce striped bass hybrids using white bass and white perch (*Morone americana*). Cultured striped bass males and wild caught white bass and white perch females, which had been tank matured during the previous 4–6 months, were used in the studies. All fish were injected once intramuscularly with HCG at a rate of 330 I.U./kg for the striped bass males and 660 I.U./kg for white perch and white bass females. Fish were examined 24–48 hours post-injection to determine time of ovulation. Production of hybrids was attempted through manual stripping and mixing of gametes from the different species.

Model Component: Hatchery Phase

The procedures employed in the hatchery phase were typical of those developed by other workers to culture striped bass (Bayless 1972, Bonn et al. 1976). As discussed previously, mature fish were induced to ovulate using HCG. Striped bass were allowed to tank spawn while eggs and sperm were stripped and mixed to produce hybrids. Eggs were incubated in McDonald hatching jars using standard procedures.

Model Component: Nursery Phase

The nursery phase, conducted in indoor tank systems, was characterized by high population densities, frequent feeding of artificial feeds, daily tank management, and utilization of recirculated brackish water (~5–10 ppt). Such systems are in contrast to typical outdoor pond nursery systems containing fresh water. In the indoor nursery, cylindrical tanks (1.8-m diameter × 74-cm deep) connected to recirculated water systems were used. Tank water exchange rate varied from 10–20 times/day and temperature was maintained at 24°–28° C. *Artemia* nauplii were provided at a density of ~10/ml as the initial food. Several days after initiation of feeding, supplementation with artificial diets (flake diets, soft-moist crumbles, dry rations, etc.) was initiated at frequent intervals (5–10 minutes). Approximately 3 weeks after hatching, the amount of *Artemia* was substantially reduced while the amount of soft-moist and dry rations was greatly increased.

Model Component: Grow-Out Phase

Research in South Carolina has focused on comparing the aquaculture characteristics of striped bass and its hybrids to identify fish suitable for commercial culture. For the past several years, these studies have been conducted in indoor culture systems which utilized 1.8-m diameter × 74-cm deep fiberglass tanks connected to

Table 1. Stocking and harvest data for tank grow-out trials with striped bass and its hybrids.

	Stocking Data		Harvest Data			
	Density Fish/m^3	Mean weight (g)	Duration (days)	Survival (%)	Mean weight (g)	Density (kg/m^3)
Study I						
Striped bass	35.3	30.0	219	74.6	592.9	15.6
F_1 hybrid bass (SB X WB)	65.8	46.6	302	78.4	835.4	43.1
Study II						
Striped bass	31.6	4.4	287	95.9	289.3	8.8
F_1 hybrid bass (WB X SB)	31.6	6.4	287	100.0	506.6	16.0
F_2 hybrid bass	31.6	12.8	287	84.2	346.7	9.2
Study III						
F_1 hybrid bass (SB X WB)	31.6	23.3	140	99.1	262.5	8.3
F_1 hybrid bass (SB X WP)	31.6	21.5	140	99.1	175.6	5.5

heated 24°–28° C recirculated brackish water (mean salinity = 7.0 ppt, range 0.0 to 15.0 ppt). Three studies have been conducted. In study 1, striped bass and the striped bass x white bass hybrids were reared at different densities (35.3 vs. 65.8 fish/m^3, respectively) (Table 1). During this study, treatments were not replicated and fish were not sampled at regular intervals (Smith et al. 1985). The second study compared striped bass, white bass x striped bass hybrids, and F_2 hybrids (F_1 striped bass/white bass × F_1 striped bass/white bass) at the same density (32 fish/m^3) (Table 1). In this study, treatments were replicated and fish were sampled at 4-week intervals. The third study was also replicated and the fish routinely sampled. In this case, striped bass x white bass hybrids and striped bass x white perch hybrids were reared under the same conditions as in study 2 (stocking density 32 fish/m^3, fed commercial trout feed, sampled at 4-week intervals, etc.).

Results and Discussion

Brood Stock Phase

Results of the 3 trials conducted in late January/early February 1985, to develop and demonstrate out-of-season spawning techniques for cultured striped bass were highly encouraging. In the first trial, egg development progressed normally but approximately 5 hours before estimated time of ovulation the female developed a severe hemorrhagic condition posteriorly ("red tail disease") and died. Eggs matured normally in the second trial but clogged the standpipe screen when spawned, resulting in the tank overflowing. Upon inspection of the tank several hours later some eggs were observed but none hatched. More than 66,000 overripe eggs were manually expressed while checking this female. In the last trial, the female required a second dose of HCG (330 I.U./kg) 42.5 hours after the first dose. Subsequently, eggs were ovulated and expelled into the water where they were fertilized by the males. Eggs were allowed to hatch in the spawning tank. Sampling of the tank after 43 hours indicated that at least several thousand fry had already hatched and that many of the remaining eggs were degenerating. The fry appeared normal and grew during the following week until poor water quality conditions resulted in the loss of all fry.

The mixed spawning responses which we had observed with the striped bass do occur on occasion in large-scale hatchery operations (D. Bishop, Tenn. Wildl. Resour. Agency, pers. commun., 1985, T. Curtis, S.C. Wildl. and Mar. Resour. Dep., pers. commun., 1985). It seemed that at least part of our difficulty was related to the size and age of the females which we attempted to spawn. Most state and federal hatcheries rarely collect or attempt to spawn 3-year-old females as they are usually considered too small and immature for spawning purposes.

Concurrent with the tank spawning trials with striped bass, we also attempted to produce hybrids "out-of-season." As our cultured male striped bass were running ripe, we used female white bass and female white perch to make crosses. Several trials were attempted to produce both types of hybrids using female bass which had been held for 4–5 months in outdoor culture tanks. White bass x striped bass and white perch x striped bass larvae were produced but in many cases complete ovulation did not occur. We concluded that part of the problem was our lack of familiarity in staging and handling these fish and that we may have prematurely attempted to manually strip eggs.

The findings of these studies suggest that our controlled maturation approach using environmental manipulation appears satisfactory. In the case of striped bass, this is the first reported case of this species being cultured from eggs and then being spawned out-of-season using artificial conditioning techniques. Presently, these striped bass as well as others are being conditioned for spawning in January–February 1986. Additionally, white bass adults which have been in captivity for more than a year are being concomitantly conditioned so that striped bass/white bass hybrids can also be produced at this time.

Nursery Phase

Indoor nursery systems have a number of desirable characteristics. First, there is a greatly reduced requirement for land as the fish are reared at high population densities. Second, the culturist can exert substantial control over water quality, disease, feed availability and quality, and thereby provide more optimum rearing conditions. Third, the culturist can visually see the fish and thus is aware of their general health, growth rate, and population size. In recent years, advances in diets, feed delivery systems, water management, and culture techniques have resulted in the attainment of survival rates in intensive nursery systems which are comparable to those obtained in extensive pond systems (Lewis and Heidinger 1981, Kerby et al. 1983*a*, Smith and Jenkins 1985). Studies with striped bass x white hybrids conducted during 1985 resulted in tank population densities ranging from 4,100 to 4,900 fish/m^3 after 31 days.

From an aquaculture standpoint, intensive nursery systems are especially important in temperate climates. In our case, the controlled out-of-season spawning of brood stock results in the production of fry when outdoor temperatures are not suitable for pond stocking of fry. Thus, indoor systems are required. Further, fish reared in such systems are already conditioned to accept artificial rations and can survive the crowded rearing conditions typical of aquaculture operations.

Indoor nursery systems do have certain constraints. Fish are reared at high population densities and no wild food supplementation exists, therefore, the culturist must provide feed of suitable size, quantity, and quality on a nearly continuous basis. Also, water systems tend to be complex and incorporate various equipment to aerate, circulate, and filter the culture media. In some systems, complete water sterilization is also attempted. Aggressive interactions among fish are often observed in intensive nursery systems and cannibalism can be responsible for substantial mortality losses (Rhodes and Merriner 1973, McIlwain 1976, Bonn et al. 1976, Lewis and Heidinger 1981, Braid and Shell 1981, Smith and Jenkins 1984). The severity of this problem can be reduced by frequent feeding of acceptable and nutritious feeds, reduced population densities, and size grading of fish as soon as feasible.

Grow-Out Phase

The highest costs in the annual production model occur during the production phase. Here, large facilities are required, and feed and labor costs are substantial. Thus, it is especially important to identify suitable culture sites, systems, feeds, management practices, marketing approaches, and type of fish for the production phase. A variety of culture systems have been examined which range from net-pens, tanks, and ponds, with water sources varying from fresh water wells and power plants to estuarine coastal waters (Powell 1973, Valenti et al. 1976, Wawronowicz and Lewis 1979, Williams et al. 1981, Kerby et al. 1983*b*, Woods et al. 1983, Collins et al. 1984). For the most part, striped bass and its white bass hybrids have been successfully reared in these systems and water types, at least on a research or pilot scale. Commercial rations formulated specifically for striped bass are not available; however, trout and salmon rations have been fed successfully with feed conversions obtained in the range of 1.3 to 2.4 (Powell 1973, Collins et al. 1984, Carlberg et al. 1984, Smith and Jenkins 1985).

Recent research in South Carolina has focused on comparing the aquaculture characteristics of striped bass and its hybrids to identify fish best suited for commercial culture. Comparisons have been made in indoor culture systems which utilize 1.8-m diameter tanks connected to recirculating brackish water systems. In the first study (Study I), striped bass and the striped bass x white bass hybrids were reared at different densities (35.3 vs. 65.8 fish/m^3) and stocked at different sizes (30.0 vs. 46.6 g, respectively). Results indicated that survival rates were comparable (74.6% vs. 78.4%) after 219 days and that growth was rapid. Additionally, in spite of the higher stocking density, the striped bass × white bass hybrids grew as rapidly as the striped bass (Smith et al. 1985). After 219 days the striped bass had grown to a mean size of 592.9 g while the striped bass × white bass hybrids grew to a mean size of 835.4 after 302 days (Table 1). Another study (Study II) compared the striped bass, white bass × striped bass hybrids, and F_2 hybrids ($F_1 \times F_1$ striped bass/white bass). Results of this 280-day study indicated that the striped bass and the white bass/striped bass hybrids exhibited excellent survival rates (average, 97.8%) and that the white bass/striped bass hybrids grew substantially faster than the striped bass and the F_2 hybrids (Table 1) (Smith et al. 1985). Recently, a 140-day study (Study III) compared growth and survival of striped bass × white bass hybrids and striped bass × white perch hybrids reared under the same conditions as fish in Study II (Table 1). Both hybrids had excellent survival rates (average 99.1%) but the striped bass × white bass hybrids demonstrated more rapid growth and a higher standing crop at harvest (Table 1).

Aquaculture Outlook

These results in addition to those obtained elsewhere indicate that the striped bass × white bass hybrids (original and reciprocal crosses) are well suited for aquaculture development (Williams et al. 1981; Kerby et al. 1983*a, b;* Woods et al. 1983; Smith et al. 1985). These fish exhibit "hybrid vigor" at least for the first 1–2 years and can be reared under a wide variety of environmental conditions. The current decline in fishery landings coupled with the market demand for striped bass should encourage the aquaculture production of striped bass and its white bass hybrids. This conclusion was supported in a recent issue of the Wall Street Digest where financial analysts included the aquaculture of striped bass in their top 10 recommended investments at this time (Anon. 1985).

At present, there are constraints to development of aquaculture with striped bass and its hybrids. The supply of juveniles for stocking grow-out systems is limited and often unpredictable. State and federal hatcheries will not provide these fish to commercial operations and the few private hatcheries which do offer fish for sale, base their operations on collection of ripe fish from wild spawning populations. As a result, cost of small juveniles is often high and the supply not regularly available. Development of systems and techniques for producing domesticated brood stock which can be conditioned to spawn at a predetermined time should be useful in alleviating some of the uncertainty in seed stock availability and cost.

Utilization of intensive nursery systems for producing small juveniles is increasing and this trend is expected to continue. When coupled with out-of-season spawning of adults, such systems can result in early availability of small juveniles and full utilization of the outdoor grow-out season. From a planning perspective, intensive nursery systems are highly desirable as population size can be estimated continuously rather than only at harvest as is the case with pond systems.

Production characteristics of striped bass and white bass hybrids reared under strictly comparable culture conditions in a variety of systems is not currently available. However, available information suggests that pan-size fish can be produced from small juveniles at commercially attractive levels in about 8 months under optimal rearing conditions (Smith and Jenkins 1985, Smith et al. 1985).

In addition to the biological issues, legal and marketing considerations must also be considered in evaluating the aquaculture potential of striped bass and hybrid bass culture. Current restrictions on the harvesting and sale of native striped bass in certain states can be expanded to include cultured fish and thus prevent aquaculture development. Additionally, certain states list the striped bass and its hybrids as game fish and thus exclude them from commercialization. To resolve these issues, an educational effort should be directed towards fishery managers, state legislators, and policy makers. The production of cultured food fish should not be viewed in an adversary role but rather should be considered as a means of relieving some of the pressure on native stocks and as a means of reducing the dependence of the United States on foreign fishery product imports. Through the cooperation of state and federal agencies with the private sector; striped bass and hybrid bass aquaculture could become a significant industry in the United States within the next 5 to 10 years.

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